

Master Thesis

Revealing the Technical Secrets of the 40 Most Used Passenger Aircraft with Reverse Engineering

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Abstract

Purpose – To provide the aeronautical community with harmonized parameters of the most used passenger jets with more than 50 seats taken from a wide selection of publically available data sources. In addition, the three most important hidden (or secret) parameters are added: maximum lift coefficient (for landing and take-off), maximum glide ratio, and Specific Fuel Consumption (SFC).

Approach – The Excel-based tool "Passenger Jet Reverse Engineering" was used to reveal the secret parameters of each aircraft. Using the program's verification tool, the numbers obtained from reverse engineering could be compared to eliminate modeling insufficiencies until only a relatively small deviation was left.

Findings – The most used 47 aircraft (with first flight between 1979 and 2017) account already for more than 90% of all aircraft in service or on order based on numbers from 2017. Then 43 aircraft were evaluated. Maximum lift coefficients were obtained between 2.0 and 3.8 of which only 75% is used on average for take-off. The maximum glide ratio varied between 14 and 22. It increased with 0.11 per year (based on the new or the derivative aircraft's date of first flight). Reverse engineering revealed SFC between 11 mg/Ns and 19 mg/Ns.

Research limitations – Reverse engineering in aircraft design is based on preliminary sizing methods, which include statistical values e.g. for some of the mission segment fuel fractions.

Practical implications – Statistical trends can now be obtained to the benefit of preliminary aircraft design calculations.

Social implications – The discussion about aviation implications is facilitated as secret numbers have come to light.

Originality – Reverse engineering has not been applied to such a large number of passenger aircraft before.



DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

Revealing the Technical Secrets of the 40 Most Used Passenger Aircraft with Reverse Engineering

Task for a Master Thesis

Background

In aircraft design at the Hamburg University of Applied Sciences, an aircraft had to be redesigned in every exam for almost 20 years. To set the examination, manual reverse engineering was necessary to reveal the unknown (secret) technology parameters. These parameters are in particular: the lift coefficient during landing and take-off, the maximum glide ratio, and the specific fuel consumption in cruise. In the frame of a thesis entitled "Reverse Engineering of Passenger Jet Classified Parameters" an Excel-based tool "Passenger Jet Reverse Engineering" (PJRE) was created and 9 different conventional and unconventional aircraft were examined. In another thesis "Case Studies for Reverse Engineering in Passenger Aircraft Design" the previously developed tool was used for 8 new case studies.

Task

Task is the application of PJRE to about 40 most used passenger aircraft in order to cover 90% of the aircraft in service or on order. PJRE should be used to reveal the mentioned parameters kept otherwise secret. The objective is to provide the aviation community with a reliable catalogue of aircraft parameters and general information. The values determined with PJRE have to be checked for plausibility. These points should be taken into account:

- Consideration of a wide range of sources for the reliable selection of input parameters.
- Brief introduction to preliminary sizing.
- Brief introduction to reverse engineering.
- Brief description of PJRE and the method.
- Aviation market research of the most used passenger aircraft.
- Presentation of the passenger aircraft individually.
- Presentation of the results of reverse engineering.
- Discussion of the results and extraction of conclussions.

The report has to be written in English based on German or international standards on report writing.

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List of Symbols

A Aspect ratio

 A_{eff} Effective aspect ratio

a Speed of sound

 B_s Breguet factor, distance B_t Breguet factor, time

b Wing span C_D Drag coefficient

 $C_{D,i}$ Induced drag coefficient $C_{D,0}$ Drag coefficient at zero lift

 C_L Lift coefficient

 $(C_{L,max})_{base}$ Maximum lift coefficient of the base of an airfoil

 $C_{L,MAX,TO}$ Maximum lift coefficient for take-off $C_{L,MAX,L}$ Maximum lift coefficient for landing $C_{L,md}$ Lift coefficient for minimum drag c_{MAC} Mean aerodynamic chord length

 $\overline{c_f}$ Skin friction factor

 c_t Tip chord c_r Root chord

E Aerodynamic efficiency

e Oswald's span efficiency factor

g Gravitational acceleration (9.81 m/s^2)

h Altitude

 k_{APP} Factor for approach

 k_E Factor for aerodynamic efficiency

 $k_{e,NP}$ Factor span efficiency for non-planar configurations

 $k_{e,WL}$ Factor span efficiency for winglet

 k_L Factor for landing k_{TO} Factor for take-off

L Temperature lapse rate (0,0065 K/m)

M Mach number

Molar mass of dry air (0,0289644 kg/mol)

 $M_{\rm ff}$ Mission fuel fraction

m Mass

m Fuel mass flow

 m_{MI}/m_{MTO} Relative maximum landing mass

 m/S_W Wing loading

 n_E Number of engines

p Local atmospheric pressure

 p_0 Standard atmospheric pressure at SL (101325 Pa)

q Dynamic pressure

R Range

R Universal gass constant (8,31447 J/mol/K)

Re Reynolds number

SFC Specific fuel comsumption

 S_{ref} Reference area S_W Wing area S_{wet} Wetted area S Distance / length S_{LFL} Landing field length

 S_{TOFL} Take-off field length / reference field length

T Thrust

 T_0 Standard temperature at SL (288,15 K)

 $T/(m \cdot g)$ Thrust-to-weight ratio

t Time

t Airfoil thickness t/c Relative thickness

V Volume V Speed

 V_{APP} Approach speed

 V_{md} Speed for minimum drag

 V_S Stall speed

 V_1 Take-off decision speed V_2 Take-off safety speed

 $x_{(y_c),max}$ Position of maximum camber $x_{t,max}$ Position of maximum thickness

 $(y_c)_{max}/c$ Camber

Greek Symbols

 ΔX (DELTA) Additional value Δx (DELTA) Correction term

 Δy Leading edge sharpness parameter γ (gamma) Ratio for air specific heat (1,4)

 γ_{CLB} (gamma) Climb gradient

 γ_{MA} (gamma) Missed approach climb gradient

 η (eta) Efficiency Λ (LAMBDA) Sweep angle

 λ (lambda) Taper

 μ (mu) Bypass ratio

 μ (mu) Dynamic viscosity

 φ (phi) Sweep angle

 π (pi) 3,141592653589793...

 ρ (rho) Density

 σ (sigma) Relative air density

Subscripts

25 25% Chord

CLB Climb
CR Cruise
DES Descend
E Engine
F Fuel
f flap

H.L. Hinge line
L Landing

LE Leading edge

LFL Landing field length MA Missed approach

MAC Mean Aerodynamic Chord

ML Maximum Landing
MTO Maximum Take-Off

max Maximum

OE Operating empty

PL Payload
RES Reserve
s Slat
TO Take-off

TOEF Take-off field length

W Wing

List of Abbreviations

AAC Aircraft Approach Category

ADG Aircraft Design Group

ARC Aerodrome Reference Code

BAe British Aerospace
BWB Blended Wing Body
CAD Computer-aided Design
CEO Current Engine Option

CFR Code of Federal Regulations
CG Certification Specification

DATCOM Data Compendium

EASA European Aviation Safety Agency FAA Federal Aviation Administration

FAR Federal Aviation Regulations (certification specs)

FL Flight level

HAW Hochschule für Angewandte Wischenschaften ICAO International Civil Aviation Organization

ISA International Standard Atmosphere

LR Long range

MA Missed Approach
MD McDonnell Douglas

MTOW Maximum Take-Off Weight MZFW Maximum Zero Fuel Weight

NACA National Advisory Committee for Aeronautics

NEO New Engine Option
OAPR Overall Pressure Ratio

PAX Passenger

PW Pratt & Whitney

SFC Specific Fuel Comsumption

SI International System (Système Internationale)

SL Sea Level SR Short Range

SUGAR Subsonic Ultra Green Aircraft Research

RE Reverse Engineering

TET Turbine Entry Temperature

ULR Ultra-Long Range

USA United States of America
USAF United States Air Force
VELA Very Efficient Large Aircraft

LAMEA Latin America, Middle East and Africa

List of Definitions

Camber

"Camber (noun) is the degree to which an aircraft wing or other aerofoil curves up from its front edge and down again to its back edge." (Allen 2006)

Comprehensive

"Comprehensive (adj) means covering completely or broadly." (Allen 2006)

Circuitous

"Circuitous (adj) indirect in route or method; roundabout." (Allen 2006)

Drag

"Drag (noun) is the retarding force acting on a body, e.g. an aircraft, moving through air, water or other fluid, parallel and opposite to the direction of motion." (Allen 2006)

Flap

"Flap (noun) is a movable control surface on an aircraft wing for increasing lift during take-off or drag during landing." (Allen 2006)

Lift

"Lift (noun) is the component of the aerodynamic force acting on an aircraft or wing that is perpendicular to the relative wind and usu constitutes the upward force opposing the pull of gravity." (Allen 2006)

Loiter

"Loiter (adj intrans) is to remain in an area for no obious reason." (Allen 2006)

Matching chart

A matching chart shows the two-dimensional relation between the wing loading and the thrust-to-weight ratio for landing, take-off, second segment, cruise and missed approach.

Slat

"Slat (noun) is a control surface along the leading edge of a wing that can be extended forward to create a gap (slot) to improve airflow." (Allen 2006)

Turbofan

"Turbofan (noun) is a jet engine with a turbofan. It refers to the fan that is directly connected to and driven by a turbine and is used to supply air for cooling, ventiliation or combustion." (Allen 2006)

Verification

"Verification (noun) is the act or instance of verifying." (Allen 2006)

Verify

"Verify (verb trans) to ascertain the truth, accuracy, or reality of something." (Allen 2006)

1 Introduction

1.1 Motivation

For competitive reasons manufacturers try to protect their product design with its inherent parameters. This is done to protect company know-how and to maintain a possible design advantage with respect to competing products. This principle is followed not only in case of military aircraft, but also for civil passenger jets. Parameters like maximum take-off mass are known as part of the certification process. Further parameters may be given, because they are uncritical or needed for aircraft operation. Other parameters like aerodynamic efficiency or engine efficiency are classified information. It would be beneficial to know such parameters to do own flight performance calculations or even redo a preliminary sizing of the aircraft under investigation. This can be done out of interest, educational exercise or for a more in depth case study. Knowing classified parameters would enable a comparison of various similar contemporary aircraft or to investigate the evolution of aircraft with their parameters throughout aviation history. Reverse Engineering is a legal possibility to acquire the knowledge withheld.

Reverse engineering, also called back engineering, is the process by which a man-made object is deconstructed to reveal its designs, architecture, code or to extract knowledge from the object. This process is carried out with the objective of obtaining information or a design from a product, in order to determine what its components are and how they interact with each other and what was the manufacturing process. Reverse engineering was born during the Second World War, when enemy armies seized war supplies such as airplanes or other war machinery to improve theirs through exhaustive analysis.

There are many reasons for performing reverse engineering in various fields. Although reverse engineering has its origins in the analysis of hardware for commercial or military advantage, the reverse engineering process, as such, is not concerned with creating a copy or changing the artifact in some way; it is only an analysis in order to deduce design features from products with little or no additional knowledge about the procedures involved in their original production. In some cases, the goal of the reverse engineering process can simply be a redocumentation of legacy systems. Even when the reverse-engineered product is that of a competitor, the goal may not be to copy them, but to perform competitor analysis.

Software reverse engineering can help to improve the understanding of the underlying source code for the maintenance and improvement of the software, relevant information can be extracted in order to make a decision for software development and graphical representations of the code can provide alternate views regarding the source code, which can help to detect and fix a software bug or vulnerability. Frequently, as some software develops, its design information and improvements are often lost over time, but this lost information can usually be recovered with reverse engineering.

The reverse engineering application never changes the functionality of the product that is the object of the application, but rather allows to obtain products that indicate how it has been built. Its realization allows to obtain the following benefits:

- Reduce the complexity of the system: trying to understand the system facilitates its maintenance, and the existing complexity decreases.
- Generate different alternatives: from the starting point of the process, mainly source code, graphic representations are generated, which facilitates their understanding.
- Recover and/or update lost information (changes that were not documented at the time): in the evolution of the system, changes are made that are not usually updated in the representations of the highest level of abstraction, for which recovery is used of design.
- Detect side effects: changes that can be made to a system can lead to unwanted effects; This series of anomalies can be detected by reverse engineering.
- Facilitate reuse: through reverse engineering, possible reuse components of existing systems can be detected, increasing productivity and reducing maintenance costs and risks.

1.2 Definitions

'Revealing the Technical Secrets of the 40 Most Used Passenger Aircraft with Reverse Engineering' is the title of this thesis. In this section, every term will be defined, using two descriptive English dictionaries; **Longman 2009** and **Allen 2006**.

Reveal

The term *reveal* is defined as follows (according to **Longman 2009**):

re veal (verb [transitive]): to make known something that was previously secret or unknown.

The plain meaning of this word serves exactly for the purpose of this title since we are about to calculate parameters that otherwise would remain unknown.

Technical

According to **Longman 2009**, the term *technical* is defined as follows:

tech ·ni ·cal (adjective): connected with knowledge of how machines work.

The word has several meanings but the first one is the one that concers us since it is related to *machines*, given that the data that is going to be used and revealed is related to aircraft.

Secrets

According to **Longman 2009**, the term *secret* is defined as follows:

se-cret (adjective): known about by only a few people and kept hidden from others.

In the context of this thesis, the few people that know the secrets would be the manufacturers, who will keep the parameters hidden from their competitors in order safeguard their interests.

Used

The present tense of the verb *to use* is defined by **Longman 2009** as follows:

Use (verb[transitive]): if you use a particular tool, method, service, ability etc, you do something with that tool, by means of that method etc, for a particular purpose

In this case, the thing, tool or service that is used for a particular purpose is the aircraft. Particulary, the most used passenger aircraft will be studied throughout this thesis.

Passenger

The term *passenger* is defined as follows according to **Longman 2009**:

A pas·sen·ger (noun) is a person who travels in any vehicle (boat, aeroplane, car, etc.) but who is not the driver or anyone working there.

A similar definition is provided by **Allen 2006**:

A passenger (noun) is somebody who travels in, but does not operate, a public or private conveyance.

In the context of this thesis, both meanings of *passenger* can be taken literally. The focus lies on passenger aeroplanes only. This excludes cargo flights and military operations.

Aircraft

The term *aircraft* is defined as follows according to **Longman 2009**:

air-craft (noun [countable]): a plane or other vehicle that can fly

This simple definition is enough to assure that aircrafts are going to be measured and weighted, specifically passenger airplanes.

Reverse

The term *reverse* is defined as follows (according to **Longman 2009**):

Reverse (verb trans) is to change something, such as a decision, judgment or process so that it is the opposite of what it was before.

In this thesis, reverse has the meaning to change a calculation method in a way that the inputs become the outputs. Aircraft technology requires a big amount of parameters, therefore the term reverse cannot be taken literally in its meaning. Not every input becomes an output and vice versa. In this thesis, the reversing is done by aiming on specific parameters which has to become an output. All the other parameters are unchanged in there meaning and thus remain inputs.

Engineering

According to Allen 2006, the definition of the term *engineering* is as follows:

En·gi·neer·ing (noun) the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to human beings in machines, structures, pro-cesses, etc.

This definition corresponds with the context of *engineering* in this thesis. Science and mathematics that are used, are the main tool for designing an aeroplane. The engineering in this thesis is pure theoretical engineering.

1.3 Objective of the Thesis

The main objective of this thesis is to provide the aviation community with a reliable catalogue of aircraft parameters and general information. The determination of the secret parameters opens up a multitude of possibilities as they are essential and fundamental basic values for many calculations in aircraft technology. In order for this catalogue to be competent and appealing to the community members, it must cover the vast majority of aircraft models and manufacturers. Here is where the first question arises: How many aircraft models it is necessary to study to cover a fairly broad spectrum of the market? Not only that but, which are the currently most sold and delivered commercial airplanes?

The answer comes from doing research on the sales of every aircraft ever manufacture. **DVB 2018** provides useful information about this field of study, describing the position of almost every commercial airplane in the aviation market, analysing how was its market impact and comparing it with its direct competitors. According to the aircrafts' sales, a ranking of the most used commercial airplanes can be elaborated and it turned out that, in order to cover the 90% of the current in service aircraft, just the first 40 aircraft must be taken into account.

The aim of this work is to determine the secret parameters of these 40 conventional passenger aircraft using the PJRE tool. In addition, it should be checked how reliable the results of the

tool are by comparing them with results from the verification calculation. The secret parameters are estimated with certain methods in order to do the verification. The maximum lift coefficient for take-off and landing is calculated taking into account the aerodynamics of the high-lift contribution. Here, formulas according to **Bhatia 2010** are used. The verification uses an estimation method from **Scholz 2017a** for the maximum aerodynamic efficiency. The specific fuel consumption is calculated according to **Scholz 2016**. All these methods for verifying the secret parameters are also integrated in the PJRE tool. In other words, the tool delivers results for the secret parameters from the reverse engineering calculation as well as from the verification calculation.

Finally, an attempt on extracting some interesting conclusions and patterns has been made. Taking into account parameters like the first flight of each aircraft or its range, it would be interesting to find a logical evolution on the behavior of the revealed secret parameters such as the increase of the specific fuel consumption with range or the increase of the aerodynamic efficienty with the date of the first flight.

1.4 Literature Review

The most important source is the Master's thesis **De Grave 2017** as well as the Master's thesis **Cheema 2019**. The focus of these master's thesis is a detailed description and use of the PJRE tool. All important information on the structure and use of the tool was taken from these works. In the master's thesis, the formulas for the secret parameters are also derived using the reverse engineering method. In addition, 9 different conventional and unconventional aircraft have already been examined in **De Grave 2017** master's thesis and 8 conventional aircraft in the case of **Cheema 2019** master's thesis.

Fort the aviation market research, **DVB 2018** is the main source. It provides useful information about every commercial aircraft, wheather if it is a passenger aircraft or a freighter. For each airplane, a detailed description of its position in the aviation market is provided, as well as relevant sales information, such as the in service and on order number of aircrafts of each model, which is key to carry out the research of the most commercial aircraft. Further information is also available such us the number of operators, the first flight, the class, the seat capacity, the range and the engine option, which will be useful to decide the engine thrust when searching the public parameters of each aircraft.

The books Jane's 2007, Jane's 2008, Roux 2007a and Roux 2007b were used to research the input parameters for the PJRE tool. Besides these books, the aircraft characteristic for airport planning (Boeing 2020, Airbus 2020, Bombardier 2020, Embraer 2020 and ATR 2020) proved to be reliable and updated sources of information, as well as the website for the book Civil Jet Aircraft Design by L. Jenkinson, P. Simkin and D. Rhodes (Jenkinson 2019a and Jenkinson 2019b) which contains information about all required input parameters. Detailed

and reliable data can be obtained from these sources. In this thesis, the remaining sources for researching the input parameters are listed again.

The lecture script according to **Scholz 2015** is used again and again in various places throughout the work. Most of the information from this script is used for preliminary sizing of an aircraft, along with **Loftin 1980** which uses the same five subsections: landing, take-off, missed approach, second segment and cruise.

1.5 Structure of the Work

This thesis has associated published data in Harvard Dataverse and is divided into the following sections:

- Chapter 2 explains the state of the art. As such, the current situation of the topic that is going to be discuss and analyzed is described. The specific content of this chapter summerize the previous work of **De Grave 2017** and **Cheema 2020**.
- Chapter 3 explains how to carry out one of the most important tasks: the data research. So as to the collected information to be as detailed and reliable as possible, some useful piece of advise regarding sources of information (such as Jane's 2007, Roux 2007 or Jenkinson 2019) is given.
- Chapter 4 makes an overview on the aviation market, explaining trends and focusing deeper in the commercial aviation market. In addition, a more comprehensive study of the commercial aircraft sales relying on **DVB 2018** is carried out in order to unravel which are the most used passenger aircraft.
- **Chapter 5** explains the most important part of this thesis. Every aircraft that is object of this study is analyzed individually regarding its position in the aviation market, the sales and their competitors. Finally, the parameters that are necessary to run the Excel-based tool are shown and the secret parameters are revealed.
- Chapter 6 discusses the reliability and accuracy of the results obtained with the Excelbased tool and attempts to extract useful conclusions based on the evolution of the secret parameters in chronological order, looking for trends and patterns graphically.
- Appendix A shows the results of the program 1.RevEng_737-800.xlms shows the results of the program 2.RevEng_A320-200.xlsm shows the results of the program 3.RevEng_A320-200Neo.xlsm

Appendix D shows the results of the program 4.RevEng 737-8.xlsm shows the results of the program 5.RevEng A321-200.xlsm Appendix E shows the results of the program 6.RevEng A321-200 Neo.xlsm Appendix F Appendix G shows the results of the program 7.RevEng A319-100.xlsm Appendix H shows the results of the program 8.RevEng 737-700.xlsm shows the results of the program 9.RevEng 777-300ER.xlsm Appendix I shows the results of the program 10.RevEng A330-300.xlsm Appendix J Appendix K shows the results of the program 11.RevEng 787-9.xlsm shows the results of the program 12.RevEng A350-900.xlsm Appendix L shows the results of the program 13.RevEng A330-200.xlsm Appendix M Appendix N shows the results of the program 14.RevEng 190.xlsm shows the results of the program 15.RevEng 175.xlsm Appendix O Appendix P shows the results of the program 17.RevEng 737-900ER.xlsm shows the results of the program 18.RevEng CRJ200.xlsm Appendix Q shows the results of the program 19.RevEng 767-300.xlsm Appendix R hows the results of the program 20.RevEng CRJ900.xlsm Appendix S s shows the results of the program 21.RevEng ERJ-145.xlsm Appendix T Appendix U shows the results of the program 22.RevEng 787-8.xlsm shows the results of the program 23.RevEng 777-200ER.xlsm Appendix V Appendix W shows the results of the program 24.RevEng MD-83.xlsm Appendix X shows the results of the program 25.RevEng 757-200.xlsm shows the results of the program 26.RevEng A380-800.xlsm Appendix Y Appendix Z shows the results of the program 28.RevEng CRJ700.xlsm Appendix AA shows the results of the program 29.RevEng C919.xlsm Appendix AB shows the results of the program 33.RevEng MRJ90.xlsm **Appendix AC** shows the results of the program 35.RevEng 737-300.xlsm shows the results of the program 36.RevEng A350-1000.xlsm **Appendix AD** Appendix AE shows the results of the program 39.RevEng CS300.xlsm Appendix AF shows the results of the program 40.RevEng 767-300F.xlsm Appendix AG shows the results of the program 41.RevEng ARJ21-700.xlsm **Appendix AH** shows the results of the program 42.RevEng ARJ21-900.xlsm shows the results of the program 43.RevEng 787-10.xlsm **Appendix AI** Appendix AJ shows the results of the program 44.RevEng 747-400.xlsm shows the results of the program 45.RevEng 737-500.xlsm Appendix AK Appendix AL shows the results of the program 46.RevEng 777F.xlsm **Appendix AM** shows the results of the program 47.RevEng 195.xlsm shows the results of the program 48.RevEng 717-200.xlsm Appendix AN **Appendix AO** shows the results of the program 49.RevEng 737-400.xlsm shows the results of the program 50.RevEng A300.xlsm Appendix AP Appendix AQ shows the results of the program 51.RevEng 747-8.xlsm

2 State of the Art

The Excel-based tool "Passenger Jet Reverse Engineering" (PJRE) for determining the secret parameters is based on the reverse engineering method. More precisely, theoretical reverse engineering was used to develop formulas for the secret parameters. For this, well-known formulas from the dimensioning of aircraft from the aircraft design subject were used. The basic knowledge of aircraft design will be explained very briefly in this thesis. If necessary, the lecture notes **Scholz 2015** are recommended. The work by **De Grave 2017** also summarizes the most important components of the lecture on the subject of dimensioning.

2.1 Aircraft Preliminary Sizing

The aircraft development consists of several phases: project phase, definition phase and development phase. The project phase consists of the dimensioning and design activities. This means that, among other things, market analysis is carried out, configurations are found and engines are selected.

The most important design parameters are determined in the dimensioning of the aircraft. These include the take-off mass, the fuel mass, the operating empty mass, the wing area and the take-off thrust. The configuration and geometry are defined in the draft.

Requirements and design parameters are parameters of aircraft design. The requirements for payload, Mach number, range, landing and take-off distance as well as the climb gradient in the 2nd segment and missed approach must be given at least at the beginning of the aircraft design.

Furthermore, boundary conditions, which are derived from approval regulations and technology limits, must be observed. Since this study focuses only on jet powered aircrafts, two distinctions are made in the regulations which an aeroplane has to meet to obtain a certification. For light jets (weights less than 12 500 lb or 5700 kg) FAR Part 23 or CS-23 applies to obtain a certification. For large jet powered aeroplanes FAR Part 25 or CS-25 is applied. The EASA-CS-25 is applied in this case because the emphasis is placed on large aeroplanes. The EASA developed the Certification Specification (CS) which are quite similar to the FAR, the rules developed by the Federal Aviation Administration (FAA, United States of America).

The preliminary sizing consists out of five different parts: landing, take-off, second segment, missed approach and cruise. For each of them, certain input values are necessary and the aircraft design parameters are the output.

The method to find the thrust-to-weight ratio and the wing loading for every section will be briefly explaned, according to **Scholz 2015** and **Loftin 1980**. In the end, the relation between the thrust-to-weight ratio and the wing loading of every part will be plotted in a 'matching chart'. This chart makes it possible to visualise the design point. In the end, the aircraft design parameters are calculated according to the design point.

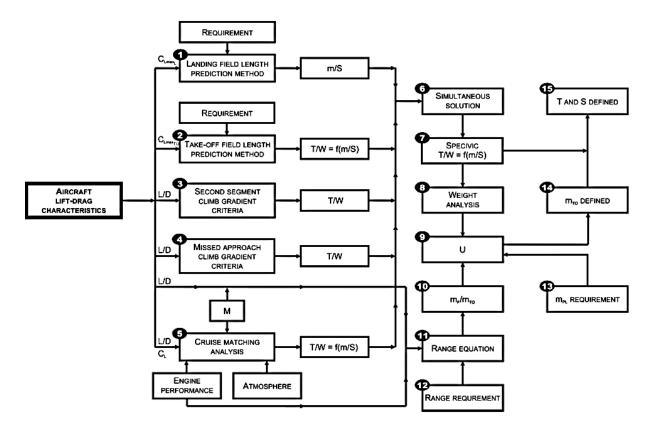


Figure 2. 1 Aircraft-sizing flow diagram for preliminary sizing for jet powered aircraft (Scholz 2015 based on Loftin 1980)

The aircraft preliminary sizing is widely explained in detail in **De Grave 2017**. Each one of the parts is analyzed and provided with the necessary equations to explain mathematically the aircraft sizing that will be submitted to the reverse process in the next section in order to turn the process around and develop the Excel-based tool.

2.2 Reverse Engineering

Common specifications for commercial aeroplanes are easily to find, but there are a few exceptions. These exceptions are called "the companies' secrets". These parameters are not released by the design company because that way everybody could produce duplicates of the design and all the investments of research, work and money could be abused by third parties. But there is a way to find these parameters. By uniting the knowledge of preliminary sizing and reverse engineering, a good approximation of these parameters can be made. These parameters are the maximum lift coefficient for landing and take-off, the maximum aerodynamic efficiency and the specific fuel consumption.

The aim is to dissect a designed aeroplane using reverse engineering. By doing this, specific parameters are revealed which, in most designs, are concealed by the designing company. Since this case is a study, guided by the Hochschule für Angewandte Wissenschaften Hamburg, an exception on intellectual ownership is applicable. This means that it is not necessary to ask the owners of the copyright for permission to reproduce or publicly share the protected information.

The reverse engineering starts with the research of the product. The next step is the build-up of the black box which consists out of the inputs and outputs of the product without knowing the mutual relation. To find the internal relations between the inputs and outputs, a function analysis is performed. This results in functions that are determined by input-output-relations and contraints. Eventually the black-box is transformed into a white-box.

Therefore, to perform a reverse engineering process, a knowledge of several engineering areas is required. The entire process starts with the understanding of the product, how the separate parts work together. What is their function? What is their mutual interaction? Thereafter the reverse process starts, which requires skills in problem solving. In the end, the product is theoretically reverse engineered and the inputs and outputs are determined in a way that the product can satisfy the requirements of the customer.

Prescreening and Black-box

The theoretical reverse engineering starts with the prescreening of the product. Therefore, a product must be chosen, in this case a certain airplane is selected. To determine the reverse engineering parameters from the selected airplane, it is important that the common specifications of the concerned aeroplane are known. Therefore, it is prescreened by doing research on information about the airplane specifications. To perform a successful reverse engineering, it is important that the following specifications for jet powered aeroplanes are known from the prescreening:

Parameter	Symbol	Units
PAX		
_anding field length (ISA)	C	m
Approach speed	S _{LFL} V _{APP}	m/s
• •		
Take-off field length (ISA)	S _{TOFL}	m
Range (max payload)	R	km
Cruise Mach number	M _{CR}	
Cruise speed	V _{CR}	m/s
Cruise altitude	h _{CR}	m
A.C.		2
Ving area	S _W	m²
Ving span	b _W	m
Aspect ratio	A	
Maximum take-off mass	m _{MTO}	kg
Payload mass	m _{PL}	kg
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	3
Maximum landing mass	m _{ML}	kg
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	9
Operating empty mass	m _{OE}	kg
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}	··9
Maximum zero fuel mass	m _{MZF}	kg
Ving loading	m _{MTO} /S _W	kg/m²
wing loading	TIMIO/OW	Kg/III
Number of engines	n _E	
Engine type		
Take-off thrust for one engine	T _{TO,one engine}	kN
Total take-off thrust	T _{TO}	kN
Thrust to weight ratio	$T_{TO}/(m_{MTO}^*g)$	$T_{TO}/(m_{MTO}*g)$
Bypass ratio	μ	
Overall pressure ratio	OAPR	
Specific fuel comsumption (dry)	SFC (dry)	kg/N s
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s
Available fuel volume	V	m³
rvanabie luei volullie	V _{fuel,available}	III-
Sweep angle	ф ₂₅	۰
Mean aerodynamic chord	C _{MAC}	m
Position of maximum camber	X _{(y_c),max}	%с
Camber	(y _c) _{max} /c	%с
Position of maximum thickness	X _{t,max}	%с
Relative thickness	t/c	%
Tanor	λ	

λ

Taper

Once the prescreening is done, the next step is to build-up the black-box. The outputs are the reverse engineering results; maximum lift coefficient for landing and take-off, maximum aerodynamic efficiency and the specific fuel consumption. The inputs are the aeroplanes specifications shown in Table 2.1. To make things easier, subfunctions are implemented on; landing, take-off and cruise. The subfunction cruise consists out of two additional subfunctions, because it contains relations for two outputs that are determined a different way. As a result, the Figure 2.2 shows the final black-box for the reverse engineering process for jet powered aeroplanes.

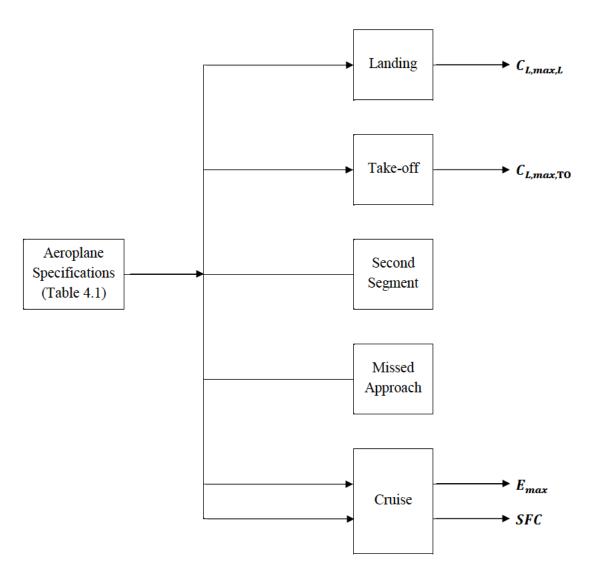


Figure 2. 2 Black-box for jet powered aircraft (**De Grave 2017**)

Functional Analysis

Every function and subfunction is built. The entire black-box can be replaced by a white-box. Figure 2.3 represents the entire reverse engineering process. The inputs are the values found with the prescreening. The outputs are the reverse engineering values. And the mutual relation is shown by the equations between brackets. The process to reverse engineer an aeroplane consists of out of four subfunctions; landing, take-off and two times climb. Each subfunctions require certain inputs.

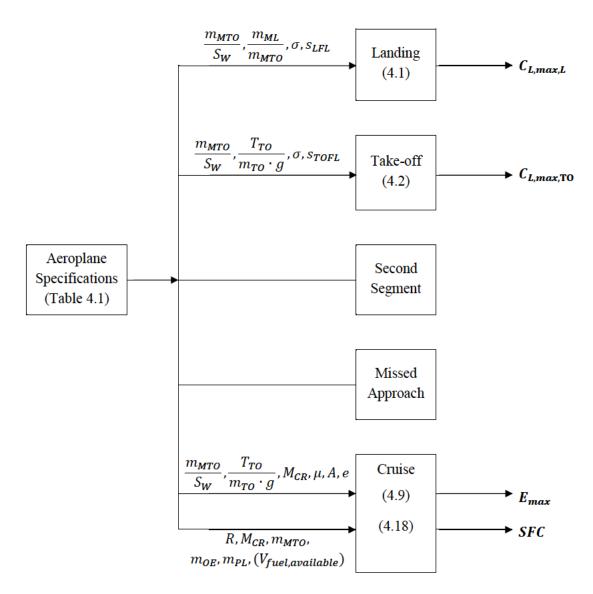


Figure 2. 3 Complete white-box for jet powered aeroplanes (De Grave 2017)

In order to carry out the complete white-box, smaller white-boxes had to be built first along with the equations that allow the user to extract the outputs by introducing the inputs. The following equations according to **De Grave 2017** were determined for the individual secret parameters:

Maximum Lift Coefficient for Landing

$$C_{L,max,L} = \frac{\frac{m_{MTO}}{S_W} \frac{m_{ML}}{m_{MTO}}}{k_L \sigma s_{LFL}}$$
(2.1)

With $k_L = 107 \ kg/m^3$

Maximum Lift Coefficient for Take-off

$$C_{L,max,TO} = \frac{k_{TO}}{\sigma} \frac{m_{MTO}}{S_{TOFL}} \left(\frac{T_{TO}}{m_{MTO}}g\right)^{-1}$$
(2.2)

With $k_{TO} = 2{,}34 \, m^3/kg$

Maximum Aerodynamic Efficiency

$$\frac{2 \cdot \frac{T_{TO}}{m_{MTO} \cdot g}}{\frac{1}{\left(\frac{V}{V_{md}}\right)^{2}} \cdot \left[E_{max}^{1,19} \cdot (0,0576\mu - 1.76) \cdot \left(\frac{4 \cdot g \cdot \frac{m_{MTO}}{S_{W}} \cdot \left(\frac{V}{V_{md}}\right)^{2}}{\pi \cdot A \cdot e \cdot M^{2} \cdot \gamma \cdot p_{0}}\right)^{\frac{1}{5.258}}\right]$$

$$\frac{2 \cdot \frac{T_{TO}}{m_{MTO} \cdot g}}{\frac{1}{\left(\frac{V}{V_{md}}\right)^{2}} \cdot \left(-E_{max}\right) \cdot (0,0328\mu - 1,05) + 1 = 0$$
(2.3)

Specific Fuel Consumption (according to operating empty mass and the payload mass)

$$E \cdot ln \left(\frac{1 - \frac{V_{fuel,available} \cdot \rho_{fuel}}{m_{MTO}}}{M_{ff,TO} \cdot M_{ff,CLB}^2 \cdot M_{ff,DES} \cdot M_{ff,L} \cdot M_{ff,engine \, start} \cdot M_{ff,taxi}} \right)$$

$$g \cdot \left(\frac{R + s_{RES}}{V_{CR}} + t_{loiter} \right)$$
(2.4)

Specific Fuel Consumption (according to available fuel volume)

$$SFC = -\frac{E \cdot ln \left(\frac{\frac{m_{PL}}{m_{MTO}} + \frac{m_{OE}}{m_{MTO}}}{M_{ff,TO} \cdot M_{ff,CLB}^2 \cdot M_{ff,DES} \cdot M_{ff,L}}\right)}{g \cdot \left(\frac{R + s_{RES}}{V_{CR}} + t_{loiter}\right)}$$
(2.5)

Now that all the reverse engineering values are theoretically discovered, it can be applied to a model. If the user is interested in studying how the individual White boxes were developed and which are the equations of each part of the reverse engineering, **De Grave 2017** carries out a comprehensive study in this topic. However, this is not the aim of this thesis, but to continue building over this previous work.

2.3 The Tool

The tool is based on the dimensioning method according to Loftin 1980. By using the reverse engineering method, the design parameters take-off mass, fuel mass, operating empty mass, wing area, take-off thrust and others are assumed to be known, in order to infer the secret parameters. The PJRE tool is an Excel file that consists of a total of 10 tabs. This chapter briefly describes each of the eight tabs according to **De Grave 2017**. A detailed description of the tabs contained in the tool can be found in the **De Grave 2017** master's thesis.

2.3.1 Data

The "Data" tab contains technical and empirical data. The tool takes information from this tab in order to verify the secret parameters. This data is also used when input parameters are specified by the user as "Unknown".

The "Data" tab consists of the following sections:

- SKYbrary
- Airfoil
- High lift systems
- Winglets
- Conversions

SKYbrary

The tool uses an upper and lower limit for the input parameters wingspan, safety take-off distance and approach speed, if these are specified as unknown. This upper and lower limit is obtained by using the information provided by "SKYbrary". In certain cases, the user has to enter the aircraft category in "SKYbrary". To do this, the aircraft category must be selected in the Aircraft Design Group (ADG), ICAO Aerodrome Reference Code and Aircraft Approach Category (AAC) classes. Limits for the wingspan are determined by selection in the Aircraft

Design Group and ICAO Aerodrome Reference Code classes. The ICAO Aerodrome Reference Code also provides limits to the safety start distance. The tool draws limits on approach speed from the Aircraft Approach Category class. In the subsection of "SKYbrary", auxiliary tables are given so that the user knows which number or letter that is appropriate for the aircraft under investigation must be selected for the respective class.

AIRCRAFT			2. ICAO	3.	3. AAC C	
A320-200			4 C			
No conflict between ADG and ICAO	Specification limits					
		LL	UL	Unit		
	Wing span		24	36 m		
	Tail Height		9,1	13,7 m		
	OMGW span		6	9 m		
	S _{TOFL}		1800	3000 m		
	V _{APP}		121	140 kt		

Figure 2. 4 Screenshot: Reverse Engineering.xlsm – _Data – _SKYbrary

<u>Airfoil</u>

The "Airfoil" section contains airfoil data that the tool uses to verify the maximum lift coefficient for take-off and landing. For example, it contains data on which airfoil type contains which ratio of leading edge sharpness and the relative thickness $\Delta y / (t / c)$. The data listed in the "Airfoil" section contain fixed values and equations. The equations are based on **Bhatia 2010**. In this work, every diagram is plotted and approached by equations. These equations are used in the Excel file in order to get the correct data. The airfoil data is used in the '4) Verification' tab. The master thesis **De Grave 2017** explains in detail which equations are used and how Excel uses and processes this information.

Table 2. 2 Δ*y*-parameter for known NACA airfoils (determined from **DATCOM 1978**)

Airfoil type	Δy/(t/c)
Use own type & values	0
NACA 4 digit	26,0
NACA 5 digit	26,0
NACA 63 series	22,0
NACA 64 series	21,3
NACA 65 series	19,3
NACA 66 series	18,3

High-lift Systems

By referring to the information from the "High-lift systems" section, the tool integrates the influence of the high lift systems on the leading and trailing edges on the maximum lift coefficient for take-off and landing. In this way, the theoretical aerodynamic calculation of the maximum lift coefficient for take-off and landing is guaranteed.

 Table 2. 3
 Flap characteristics (Stinton 1983)

Description	Profile	Increase of lift coefficient
0,3c Nose flap deflected 30° - 40°	Ø	62%
Fixed slat forming a slot		37%
Handley Page automatic slat	g	43%
0,1c Kruger flap	8	46%

 Table 2. 4
 Slat characteristics (Stinton 1983)

Description	Profile	Increase of lift coefficient
0,3c Plain flap deflected 45°		51%
0,3c Single slotted flap deflected 45°		53%
Double slotted flap ²		98%
0,3c Split flap deflected 45°		67%
0,3c Split (Zap) flap hinged at 0,8c - deflected 45°		75%
0,3c Split (Zap) flap hinged at 0,9c - deflected 45°		80%
0,3c Fowler flap deflected 40°		119%
0,4c Fowler flap deflected 40°		140%

Winglets

The section "Winglets" provides information to carry out the verification for the maximum aerodynamic efficiency. This influences the effective aspect ratio. Different winglet types are listed with the associated $ke_{,NP}$ value, which the user can select during verification for the maximum glide ratio. For the maximum aerodynamic efficiency, the verification uses an estimation method from **Scholz 2017a**.

Table 2. 5 Span efficiency for various optimally loaded non-planar configurations (h/b = 0,2) (**Kroo 2005**)

Non-plan	ar configuration	k _{e,NP}
V-wing		1,03
Diamond wing	<>>	1,05
X-flat wing	><	1,32
X-wing	$>\!\!<$	1,33
Double wing		1,36
H-wing		1,38
End plate $(k_{WL} = 2,13)$		1,41
Quasi-closed C-wing		1,45
Box wing		1,46

Conversions

In the section "Conversions" some conversions of sizes are listed. In order for the tool to run correctly, the input parameters must be entered in the correct units. The user can use these conversion data to convert the input parameters into the correct units.

2.3.2 Instructions

This tab is a guide and describes, among other things, what must be observed if some input parameters are specified as unknown. The tab also summarizes what needs to be entered in the respective tabs and which tabs do not have to be filled out. In any case, the user should read these instructions through before using the tool.

2.3.3 Data Collection

This table can be used by the user to create an overview of the input parameters and the associated sources. Some sources are entered on the top line of the diagram and others can be added. The left column contains the input parameters that are required for using the tool.

Nothing needs to be entered in the fields with an error message, as these values are calculated by the tool. This "Data Collection" table can be of use to other users. If another user uses the tool for the same aircraft but has different values, he can understand the cause of the deviation by looking at this table.

Data Collec	ction		737-300		1		2		3	4	5	6	7	8	9
				Source:	Aircraft characteristic	s for airport planning	Jane		Jenkinson	Engine	Scholz	Paul Müller	Elodie Pouv	Data collection	Webs
Parameter	Symbol	Units	Chosen value		A	В	Basic	LR	Jenkinson	Engine	Scholz			Data collection	webs
PAX			149		128-13	34-149	128-1	49	149-128			149	149-128		
Landing field length	SLFL	m	1433		14	60	143	3	1396			1433	1396	1400	
Approach speed	VAPP	m/s	69.45			00	69.4		68.42			69.44		66.877778	
Temperature above ISA (288,15K)	ΔTL	K	0		()	0		0,12			00,11		00,011110	
Relative density	s		1				Ĭ		Ů						
·															
Take-off field length	STOFL	m	1940		2980	2225	228		1939				1939	1600	2300
Temperature above ISA (288,15K)	ΔT_{TO}	K	0		0	0	15		0						
Relative density	S		_												
Range (max payload)	R	km	1464		35	50	420	4	2922			4204	1464		4204
Cruise Mach number	McR		0,745				0,74	5		0,8			0,74	0,745	0,745
Wing area	Sw	m²	105,4				105,		91,04			105,4			
Wing span	b _W	m	28,88		28,88	-31,22	28,8		28,9			28,88		28,9	28,88
Aspect ratio	A		7,9				7,9		9,1740993			7,9	9,16		9,11
Maximum take-off mass	m _{MTO}	kg	58967		56472-58967	63276	56470	62820	56470			56470	56473	56470	62820
Payload mass	m _{PL}	kg	16148		16148	15404			16030				16148		
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		1			0.24344143			0.2838675				0.286		
Maximum landing mass	m _{ML}	kg	51710		51710	52889	51720	52890				51720			51700
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	ng	0		01110	0.83584613	01120	02000	0.9157075			01120	01710		01700
Operating empty mass	m _{OE}	kg	31869		31479	32904	32704	33266					31480		32700
Mass ratio, operating empty - take-of		ng	0.000		01470	0.52000759	02704	00200	0.5643528				0.557		OLIOC
Wing loading	m _{MTO} /S _W	kg/m²	535.6			0,02000.00	535.6	595.8					620		
Maximum zero fuel mass	m _{MZF}	kg	47627		47627	49714	47625	49715					47628		48410
maximum zoro raor maco	TIMZF	ng	47027		41021	40714	47020	40710	47000				47020		40410
Number of engines	n _E		2						2				2	2	2
Engine type	CFM56-3		CFM56-3B1		CFM56-3B1	CFM56-3B2	CFM56-	3C-1	CFM56-3-B1	CFM56-3B1			CFM56-3B1	CFM56-3B1	
Take-off thrust for one engine	T _{TO,one engine}	kN	88,964			97,7942	89-97	7,9	89	88,96444			88,964	90	90
Total take-off thrust	T _{TO}	kN													
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	0,32						0,3213166				0,32		
Bypass ratio	и		6							6			6		
Specific Fuel Comsumption (dry)	SFC (dry)	kg/N s	1,08E-05							1,0754E-05			1,08E-05		
Specific Fuel Comsumption (cruise)	SFC (cruise	kg/N s	1,89E-05							1,8876E-05			1,89E-05		
Available fuel volume	V _{fuel,available}	m³	20,102		20,102	23.827	20,104-2	23 83	20,105-23,170	n			20,102		23,17
Transporter routile	▼ ruer,avariable				20,102	23,021	20,104-2	20,00	20,100-20,170	,			20,102		20,17
Cruise speed	V _{CR}	m/s	220,7						220,7-252,6					220,69667	
Cruise altitude	h _{CR}	m	10668				1019	95	10668-7924,8	10668			10668		
Sweep angle	Ф25	•	25						25				25		25
Mean aerodynamic chord	OMAC	m	3,73						3,73				3,73		
Position of maximum camber	X _{(y c),max}	%c	10						2,10				5,1.0		10
Camber	(y _c) _{nax} /c	%c	0.8												0.8
Position of maximum thickness	X _{t,max}	%c	29.7												29,7
Relative thickness	t/c	%	12.9						12,89				12.9		12,5
Taper	λ		0,24	1					3,73				0.24		. 2.,0
Overall pressure ratio	OAPR		22.6						5,70	22.6			3,24		
Turbine entry temperature	TET	К								22,0					

Figure 2. 5 Screenshot-Data collection

2.3.4 Specifications and Reverse Engineering Results

Almost all of the entries that the user has to make are made in this tab. All of the blue fields printed here in bold must be completed by the user. The bold red fields are results that the tool calculates. Values printed in black are calculated values.

Aeroplane Specifications

The section "Airplane Specifications" starts with the subsection "Data to apply reverse engineering". Here the user enters the input parameters in the blue thick printed fields. If the input parameter "Known" appears next to the input field, this means that this input parameter can also be specified as "Unknown".

Aeroplane Specifications

				LL	UL
Landing field length	Known	S _{LFL}	1646 m		
Approach speed	Known	V_{APP}	72,00 m/s	72,0	72,0
Temperature above ISA (288,15K)		ΔT_L	0 K		
Relative density		σ	1		
Take-off field length	Known	S _{TOFL}	2300 m	2300	2300
Temperature above ISA (288,15K)		ΔT_TO	0 K		
Relative density		σ	1,000		
Range (maximum payload)		R	1998 NM		
Cruise Mach number		M_{CR}	0,785		
Wing area		S _W	125 m²		
Wing span	Known	b_W	34,32 m ²	34,32	34,32
Aspect ratio		Α	9,45		
Maximum take-off mass		m _{MTO}	78245 kg		
Maximum payload mass		m_{PL}	20276 kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,259		
Maximum landing mass		m_{ML}	65315 kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,835		
Operating empty mass		m_{OE}	41145 kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,526		
Wing loading		m_{MTO}/S_W	628,0 kg/m²		
Number of engines		n _E	2		
Take-off thrust for one engine		T _{TO,one engine}	106,757 kN		
Total take-off thrust		T_{TO}	213,514 kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,278		
Bypass ratio		μ	5,3		
Available fuel volume		fuel,available	23,86 m³		

Figure 2. 6 Screenshot: Reverse Engineering.xlsm – _Specs + RE – _Data to apply reverse engineering

In the next subsection "Data to optimize V/Vmd" values for the cruise speed and the cruise altitude are entered. The values for these input parameters are used by the solver in Excel in order to minimize the square sum of the differences in reverse engineering. This is done by optimizing the ratio between speed and speed with minimum resistance V / Vmd. This ratio has a value between 1 and 1.316, which corresponds to the speed at minimum resistance or the maximum cruise speed.

Data to optimize V/V _{md}					
LL UL					
Cruise speed	$V_{\sf CR}$	233 m/s			
Cruise altitude	h _{CR}	11887 m			
Speed ratio	V/V_{md}	1,000 -	1	1,316	

Figure 2. 7 Screenshot: Reverse Engineering.xlsm – _Specs + RE – _Data to optimize V/Vmd

The last subsection is called "Data to execute the verification". Some of the input parameters that are required for the verification of the maximum lift coefficient for take-off and landing are entered here. Further input parameters for the verification must be entered in the "Verification" tab.

Data to execute the verification					
				Range	
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	4,17 m		
Position of maximum camber Camber		x _{(y_c),max} (y _c) _{max} /c	30 %c 4 %c	15 - 50 %c 2 - 6 %c	
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45 %c	
Relative thickness	Known	t/c	12,5 %		
Taper		λ	0,219		

Figure 2. 8 Screenshot: Reverse Engineering.xlsm – _Specs + RE – _Data to execute the verification

Reverse Engineering

First there is the subsection "Reverse engineering & optimization of V/Vmd". Here you can see the deviations between the value entered by the user ("Original Value") and the value calculated by the tool ("RE Value") for the following parameters: safety take-off and landing distance, approach speed, span, and cruising speed and altitude.

In the second subsection, "Results reverse engineering", the results of the secret parameters maximum lift coefficient for take-off and landing, maximum glide ratio and specific fuel consumption are listed. In addition, here is the button which the user presses after the input parameters have been entered in order to run the tool.

Reverse Engineering

Reverse engineering & optimization of V/Vmd					
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S_{LFL}	1646	1646	m	0,00%
Approach speed	V_{APP}	72,00	72,0	m/s	0,00%
Take-off field length	S _{TOFL}	2300	2300	m	0,00%
Span	b_W	34,32	34,32	m	0,00%
Aspect ratio	Α	9,45	9,45		0,00%
Cruise speed	V_{CR}	232,5	232	m/s	-0,3 <mark>6%</mark>
Cruise altitude	h_{CR}	11887	11679	m	-1,75%
Squared Sum Absolute maximum deviation					3,20E-04 1,8%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,98			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,30		Pava	rse Engineering
Maximum aerodynamic efficiency	E _{max}	18,17		Keve	ise Engineening
Specific fuel consumption	SFC	1,54E-05 kg/	/N/s		

Figure 2. 9 Screenshot: Reverse Engineering.xlsm – _Specs + RE – _Reverse Engineering

2.3.5 Maximum Lift Coefficient

The maximum lift coefficient for take-off and landing is calculated in this tab. In addition, individual parameters are calculated for the flight phases take-off, landing, 2nd segment and go-around maneuver, just as they are calculated in the dimensioning of passenger aircraft. With these sizes it is possible to create a design diagram. The draft diagram and the associated table can be found in the tabs "5a) Matching Chart and "5b) Matching Chart-points.

The only input the user has here is the choice of certification basis. Using FAR Part 25 will take the drag of the landing gear into account. JAR-25/CS-25 does the calculations with retracted landing gear and thus no additional drag.

1) Maximum Lift Coefficient for Landing and Take-off

	anding	
Landing field length	S _{LFL}	1646 m
Геmperature above ISA (288,15К)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_APP	1,70 (m/s²) ^{0.8}
Approach speed	V_{APP}	72,00 m/s
Factor, landing	k_L	0,107 kg/m ³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,83
Wing loading at maximum take-off mass	m_{MTO}/S_W	628,0 kg/m ²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,98
Ta	ake-off	
Take-off field length	S _{TOFL}	2300 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,278
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,30
2nd	Segment	
Aspect ratio	Α	9,453
Lift coefficient, take-off	$C_{L,TO}$	1,60
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\DeltaC_D,flap$	0,025
ift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C_D,P	0,045
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	9,54
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,258
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,76
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,033
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Profile drag coefficient	$C_{D,P}$	0,068
Glide ratio in landing configuration	EL	8,11
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,241

Figure 2. 10 Screenshot: Reverse Engineering.xlsm - _1) C_Lmax

2.3.6 Maximum Aerodynamic Efficiency

The maximum aerodynamic efficiency is calculated in this tab. At the top of the subsection "Constant parameters" there are constant parameters that are required for the calculation. There is also a subsection of this type in the "3) SFC" tab. The maximum aerodynamic efficiency can not be calculated directly but has to be solved using a numerical iteration. Therefore, the Newton-Raphson method is applied. In the Excel file, there are ten iterations executed to calculate the maximum aerodynamic efficiency. The iteration converges quickly, thus it is impossible that the amount of iterations is not sufficient. The iteration is found on the bottom of this tab. The eventual value for the maximum aerodynamic efficiency is shown in the red field, represented on the picture below.

2) Maximum Aerodynamic Efficiency

Constant parameters							
Ratio of specific heats, air	γ	1,4					
Earth acceleration	g	9,81	m/s²				
Air pressure, ISA, standard	p_0	101325	Pa				
Oswald eff. factor, clean	е	0,85					
Specifications							
Mach number, cruise	M _{CR}	0,785					
Aspect ratio	A	9,45					
Bypass ratio	μ	5,30					
Wing loading	m_{MTO}/S_W	628	kg/m²				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,278					
Variables							
	V/V_{md}	1,0					
Ca	lculations						
Zero-lift drag coefficient	$C_{D,0}$	0,019					
Lift coefficient at E _{max}	$C_{L,md}$	0,69					
Ratio, lift coefficient	$C_L/C_{L,md}$	1,000					
Lift coefficient, cruise	G_{L}	0,695					
Actual aerodynamic efficiency, cruise	E	18,17					
Max. glide ratio, cruise	E _{max}	18,17					
Newton-Raphson for the maximum lift-to-d	Irag ratio						
Iterations	1	2	3				
f(x)	0,23	-0,01	0,00				
f'(x)	-0,10	-0,11	-0,11				
E_{max}	16	18,26	18,17				

Figure 2. 11 Screenshot: Reverse Engineering.xlsm – _2) E_max

2.3.7 Specific Fuel Comsumption

The specific fuel consumption is calculated in this tab. In the "Mission fuel fraction" subsection, the user must select the type of aircraft and the type of flight. For the aircraft type, the user can choose between "Transport Jet" and "Business Jet". The "Transport Jet" is a passenger aircraft. A "business jet" is a jet that carries a small number of passengers. According to the type of jet, the fuel fractions will modify automatically. It is also possible to fill out own values for a specific mission. Besides this, the user has to give up if it is a domestic flight or an international flight. According to the choice made here, the amount of reserve fuel will modify. To calculate the specific fuel consumption, the payload mass and operating empty mass must be 'known' in the tab 'Specs+RE'. It is important that the payload mass matches with its range. If the maximum range is used to calculate the specific fuel consumption, there is also another way to calculate this using the available fuel volume of the aeroplane.

3) Specific Fuel Consumption

Consta	int parameters	
Ratio of specific heats, air	γ	1,4
Earth acceleration	g	9,81 m/s ²
Air pressure, ISA, standard	\mathbf{p}_0	101325 Pa
Fuel density	$ ho_{fuel}$	800 kg/m ³
Spe	ecifications	
Range	R	1998 NM
Mach number, cruise	M _{CR}	0,785
Bypass ratio	μ	5,30
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,278
Available fuel volume	$V_{ m fuel,available}$	23,86 m³
Maximum take-off mass	m _{MTO}	78245 kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,259
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	0,526
Calcu	ılated values	
Actual aerodynamic efficiency, cruise	E	18,17
Cruise altitude	h _{CR}	11679 m
Cruise speed	V _{CR}	232 m/s
Missio	n fuel fraction	
Type of aeroplane (according to Roskam)	Transport jet	
Fuel-Fraction, engine start	M _{ff,engine}	0,990
Fuel-Fraction, taxi	M _{ff.taxi}	0,990
Fuel-Fraction, take-off	M _{ff.TO}	0,995
Fuel-Fraction, climb		0,980
Fuel-Fraction, dimb	M _{ff,CLB}	
	M _{ff,DES}	0,990
Fuel-Fraction, landing	$M_{ff,L}$	0,992
	Iculations	0.215
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,215
Mission fuel fraction (acc. to PL and OE)	M_ff	0,785
Available fuel mass	F,available	19088 kg
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,244
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,771
Distance to alternate	S _{to alternate}	200 NM
Distance to alternate	S _{to alternate}	370400 m
Choose: FAR Part121-Reserves	domestic	yes
	international	no
Extra-fuel for long range		5%
Extra flight distance	S _{res}	370400 m
Loiter time	t _{loiter}	2700 s
Specific fuel consumption	SFC	1,54E-05 kg/N/s

Figure 2. 12 Screenshot: Reverse Engineering.xlsm - _3) SFC

2.3.8 Verification

The verification is independent of the actual reverse engineering. It serves only as a theoretical check of the reverse engineering results. This provides the user with a verification value and the option to confirm the reverse engineering result. The deviations between the verification values and the reverse engineering results are displayed directly below the results.

Maximum Lift Coefficient for Landing and Take-off

Some of the values required for verification for the maximum lift coefficient for take-off and landing have already been entered in the "Spec + Re" tab in the "Data to execute the verification" subsection. In the subsection "Maximum lift coefficients" the user has to select the profile type in order to calculate the maximum lift coefficient of the wing. After calculating the maximum lift coefficient of the wing, the influence of the high lift systems on the leading and trailing edge on the lift coefficient is calculated. The user has to indicate how many different types of flaps the aircraft has and select the flap types. Furthermore, the span or area of these flaps must be specified. The sweep angle of the hinge line must also be specified for the flaps on the front edge. Finally, the results of the maximum lift coefficient for take-off and landing from the verification and from the reverse engineering are shown below.

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	K _φ	0,87
Flap group A	- Ψ	-,
Double-slotted flap	Δc _{L.max.fA}	1,42
Use flapped span	b W,fA	6,846 m
Percentage of flaps allong the wing	D_ VV ,IA	18%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0.22
Flap group B	△QL,max,fA	0,22
Double-slotted flap	$\Delta c_{L,max,fB}$	1,42
Use flapped span	b W,fB	11,84 m
Percentage of flaps allong the wing		31%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,39
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,61
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	Ψ _{H.L.}	26 °
Slat group A	TH.L.	
0,1c Kruger flap	$\Delta c_{L,max,sA}$	0.66
Use slatted span	b W,sA	4.46 m
Percentage of slats allong the wing	J,u	12%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0.07
Slat group B	L,IIIax,sA	,,,,,
0,3c Nose flap	Δc _{L.max.SB}	0.90
Use slatted span	b W,sB	25.4 m
Percentage of slats allong the wing	5,52	67%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,54
Increase in maximum lift coefficient, slat	ΔC _{L.max.s}	0,61
, , , , , , , , , , , , , , , , , , , ,	— -L,max,s	-,- :
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2.64
RE value maximum lift coefficient, landing	- L,IIIQA,L	2,98
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,04
RE value maximum lift coefficient, take-off	~L,max, ro	2,30
140/		_,

Figure 2. 13 Screenshot: Reverse Engineering.xlsm – _4) Verification – Maximum lift coefficient

Aerodynamic Efficiency

For the verification of the maximum aerodynamic efficiency, the user must select the winglet type. If the aircraft does not have any winglets, the user can select this accordingly. In addition to the winglet type, the winglet height must be specified. The last entry here is the value for the ratio of wetted surface and wing area $S_{\text{wet}}/S_{\text{W}}$.

Aerodynamic efficiency			
eal aircraft average		k_{WL}	2,83
nd plate		$k_{e,WL}$	1,11
pan		b_W	34,32 m
/inglet height		h	2,49 m
spect ratio		Α	9,45
ffective aspect ratio		$A_{\rm eff}$	10,45
fficiency factor, short range		k _E	15,15
elative wetted area		S _{wel} /S _W	6,35
erification value maximum aerodynamic efficiency		E _{max}	19,4
E value maximum aerodynamic efficiency			18,17
E value maximum derecynamic emolency	7%		

Figure 2. 14 Screenshot: Reverse Engineering.xlsm – _4) Verification – Maximum aerodynamic efficiency

Specific Fuel Comsumption

The verification value of the specific fuel consumption is calculated in this tab. The user does not have to enter anything here. However, it is advisable to enter values for the turbine inlet temperature TET and the overall pressure ratio OAPR in order to obtain more reliable and more real values.

Nevertheless, this verification turns out to be inefficient when the value for the input parameter "Take-off thrust for one engine" is below 60 kN.

Cruise Mach number	M_{CR}	0,785
Cruise altitude	h _{CR}	11887 m
By Pass Ratio	μ	5,30
Take-off Thrust (one engine)	T _{TO,one engine}	106,76 kN
Overall Pressure ratio	OAPR	26,00
Turbine entry temperature	TET	1445,06
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	$\eta_{ m ventilator}$	0,86
Compressor efficiency	$\eta_{ m compresor}$	0,86
Turbine efficiency	$\eta_{ m turbine}$	0,90
Nozzle efficiency	η_{nozzle}	0,98
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T _S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,67
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,73
Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Gas generator function	G	2,15
Verification value specific fuel consumption	SFC	0,60 kg/daN/h
Verification value specific fuel consumption	SFC	1,68E-05 kg/N/s
RE value specific fuel consumption	SFC	1,54E-05 kg/N/s

Figure 2. 15 Screenshot: Reverse Engineering.xlsm – _4) Verification – _Specific fuel consumption

2.3.9 Matching Chart

This tab shows the design diagram for the aircraft under studied. Using the dimensioning method, either the wing loading, the thrust-to-weight ratio or the thrust-to-weight ratio is calculated as a function of the wing loading for each flight phase. The results are plotted on the design diagram. The design point indicates the lowest possible thrust / weight ratio with the greatest possible wing loading. However, this design point is not marked in the tool. By looking at the diagram, the user can determine whether everything is correct. Unusual curves are an indication that an error has crept in. The respective points that are shown in this diagram are located in the "5b) Matching Chart points" tab.

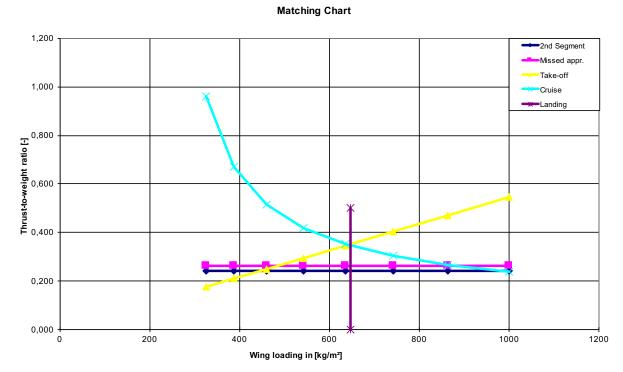


Figure 2. 16 Screenshot: Reverse Engineering.xlsm – _5a) Matching Chart

2.3.10 Instructions for Using the Tool

In this paragraph, the user is told how to work with the program. A brief version of the operating instructions can be found in the Excel file under the tab "Instructions". In order to be user friendly, the program is build-up using colour code and drop down menus. In a few cells, where it is not obvious what to do, additional information is shown when the cell is selected.

In general, the bold blue values represent input. These cells should be filled out by the user. There is no possibility one can make the program unusable by changing these values. Cells with another layout should not be touched unless the user is aware of the consequences and knows how to handle this. Blue values (not bold) are parameters based on experience. Black values are calculated interim or repeated values. The bold red values are the actual results which interest the user. The final colour is light grey, these values can be either parameters that do not apply or upper and lower limits.

Execute the Reverse Engineering

To start the reverse engineering, the user goes to the tab "Specs + RE" and does the necessary research about the aeroplane that has to be reverse engineered. The aeroplane specifications need to be filled out, starting with changing the status of a few parameters to "Known" or "Unknown". If the case occurs that the take-off field length or the wing span is unknown or if both the landing field length and the approach speed are unknown, the user goes to the tab "Data –

SKYbrary" where the aircraft category is filled out, using the drop down menus. Extra attention is required when the numerical classification of the category ICAO Aerodrome Reference Code equals four. When this occurs, the user has to give an upper limit for the take-off field length. The range status should also be adapted. The user gets a drop down menu with the following options for the range: range for maximum payload, range for maximum PAX (number of passengers), maximum range and the possibility to use another range according to the payload range diagram of the aeroplane. The available volume of fuel is only to be filled out when the maximum range is used. Now that every parameter has a status, the user fills out all the values.

Next is the data to optimize V/V_{md} . The actual cruise speed and cruise altitude of the aeroplane is filled out. When one of these parameters is unknown, the user has to fill out an upper and lower limit for this. If necessary, the upper and lower limits for V/V_{md} can be adapted. Initial it is set in a way that the lower limit is the minimum drag speed and the upper limit is the maximum range speed.

The next step is to choose a certification basis in the tab "1) C_Lmax" under the section "Missed Approach". Choosing FAR Part 25 will add profile drag due to the extended landing gear. The other certification basis, JAR-25 or CS -25, does not integrate an additional drag caused by the landing gear.

As a final step, the user goes to the tab "3) SFC". In the section "Mission fuel fraction" there is a drop down menu for the user where one can select if the aeroplane is a transport jet or a bussines jet. According to this choice, the mission fuel fraction will be modified. Since the mission is not standard or the same for every plane, the user can adapt these values without causing any problems in the program. The last input for the user is to assign the type of flight to the aeroplane, wether it is a domestic or international flight. According to this input, the fuel reserves will modify, complying with FAR Part-121-Reserves.

Eventually, the user returns to the tab "Specs + RE" and pushes the "Reverse Engineering" button. The solver in Excel will start and the reverse engineering calculations are made. The results are displayed next to the button.

Execute the Verification

The program is initially not created to perform a verification on the reverse engineering values. It is interesting for the keen user to verify the trustworthiness of the reverse engineering calculations. The reliability of the verification values stands or falls with the accuracy of the aeroplane information.

Start on the tab "Specs + RE" and go to the section "Data to execute the verification". Fill out the bold blue values. If the relative thickness is unknown, Excel will simply calculate the mean

relative thickness using an equation which only depends on the cruise Mach number, detailed explained in **De Grave 2017**.

From here on, everything happens in the tab "4) Verification". In the section "Maximum lift coefficients" the user selects the type of airfoil. If the type is not a standard NACA profile or the user owns more detailed data, it is possible to select "Use own type & values". When this is the case, the user fills out the required information in the tab "Data" section "Airfoil". Once this is done, the amount of flap and slat types are slected. Also the types itself are selected. For the selection of the flap and slat type, the user should consult **Jane's 2008**. Next, the user choses whether the flapped span or flapped area is used to calculate the contribution of the flaps and slats. The area gives a more accurate result but is more time consuming then using the span. When using the span, measure the length of the flaps or slats along the wing (not perpendicular to the symmetric plane). The flapped or slatted span or area is than filled out. For the slats, the sweep angle of the hinge line must be inserted. Besides that, the deviation with the reverse engineering results is calculated and shown graphically directly under the verification values for the maximum lift coefficients.

In the section "Maximum aerodynamic efficiency", the user starts by chosing the type of winglets. For the selection of the winglet type and height, the user should consult **Winglets 1999**, **Winglets 2008** and **Aviation Partners 2020**. Note, if the winglet is an endplate, the user should also fill out the winglet height. Next, the relative wetted area must be filled out. For the calculations of the maximum aerodynamic efficiency, a value is chosen using Figure 2.17. If the aeroplane is not on the picture, a typical value for jet powered passenger aeroplanes is a value between 6,0 and 6,2 or an own estimation can be made too. These inputs result in a verification value for the maximum aerodynamic efficiency which is compared with the value gained with the reverse engineering.

52

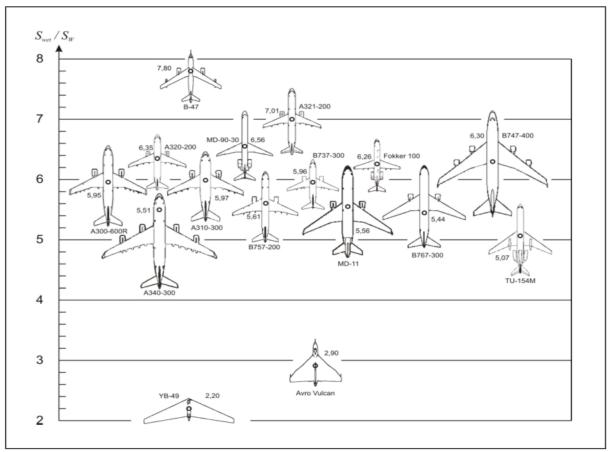


Figure 2. 17 Aircraft plan forms and their relative wetted area S_{wet}/S_w (Raymer 1989)

Finally, the specific fuel consumption is verified. This does not require any input from the operator. Pay attention that the overall pressure ratio (OAPR) or the turbine entry temperature (TET) can deviate a lot from the practical values. They have a big influence on the result of the specific fuel consumption. This can be an explanation if the deviation between the reverse engineered value and the verification value of the specific fuel consumption is big.

3 Data Research

The data research represents a great part of the invested time while doing the Master's thesis. This time might not be reflected in the final result but it is of vital importance if one is to provide with reliability to the final conclusions.

In order to use the tool successfully, it is important to collect reliable input parameters of the aircraft. Searching for the input parameters can be very complex and time-consuming. By narrowing down to reliable sources, the search for the input parameters can be considerably simplified. This section is made to be helpful for the user. It describes how to find a big amount of useful information in a quick and accurate way. The tips and tricks are based on own experience and provide a good basic and support for the user.

To begin, several sources and platforms are mentioned and described using pros and cons concerning accuracy, reliability and integrality. A single source is rarely enough to collect all the information needed to use the tool. It is recommended to look through all of the sources listed below and to write down the respective input parameters. In the end, an overview is shown of a comparison between the different sources.

3.1 Jane's All the World's Aircraft

It is an annual that contains information about all the airships over the years. It was founded by John Fredrick Thomas Jane (1865 - 1916) in 1909. Since then, it has been compiled and edited by many different authors. The aircraft data are detailed, complete and reliable. Because of this, its purchase is very expensive. A disadvantage is that not every airvehicle is contained in one book. The data for older aeroplanes can be found in the old editions but are left out in the new editions, unlike a dictionary. The books contain useful aircraft specifications (regarding the Excel file) such as:

Table 3. 1 Source of information (Jane's 2007 and Jane's 2008) catalogue

Performance	Cruising Mach number
	Take-off field length
	Landing field length
	Range
	Cruise speed
	Cruise altitude
	Approach speed
Weights and loadings	Maximum payload
	Operating empty weight
	Maximum take-off weight
	Waxiinuin take-on weight

	Maximum landing weight
Dimensions	3 view sketch
Power plant	Thrust
	Usable fuel capacity
Wing	Wing span
	Wing area
Flying controls	Leading edge devices
	Trailing edge devices

3.2 Élodie Roux

The first book of Élodie Roux, Avions civils à réaction: plan 3 vues et données caractéristiques (**Roux 2007a**), the user will find the data of nearly 270 civilian airplanes equipped with single or double flow reactors. These are civil transport planes, cargo planes, business planes, etc. Each aircraft is displayed on two pages presenting: a 3-view plan and characteristic data of geometry, mass, propulsion and performance with the Payload/Range diagram. It is a well organized source of information with the only inconvenient that is just written in French.

 Table 3. 2
 Source of information (Roux 2007a) catalogue

	-,
Performance	Cruising Mach number
	Cruising altitude
	Take-off field length
	Landing field length
	Payload-Range diagram
Weights and loadings	Maximum payload
	Operating empty weight
	Maximum take-off weight
	Maximum landing weight
	Maximum zero fuel weight
	Weight ratios
Dimensions	3 view sketch
Power plant	Engine type
	Number of engines
	Thrust
	Usable fuel capacity
	Specific fuel consumption, cruise
	Specific fuel consumption, dry
	Bypass ratio
Wing	Wing span
_	Wing area
	Aspect ratio
	Taper ratio
	Root chord

	Sweep angle at 25% chrod
	Dihedral angle
	Relative thickness
Flying controls	Trailing edge devices

The second book, Turbofan and Turbojet Engines: database handbook (**Roux 2007b**), is a collection of the characteristics of about 1500 turbofan and turbojet engines, with or without afterburner. These engines are implanted on many kinds of aircraft: airliners, freighters, business aircraft, fighters, experimental aircraft, gnopters... In order to facilitate the use of this book, engine characteristics are shown in the same synthetic way: thrust, specific fuel consumption, engine weight, bypass-ratio, overall pressure ratio, turbine entry temperature...

 Table 3. 3
 Source of information (Roux 2007b) catalogue

I able 3. 3	Source of information (Noux 2007)) Catalogue
	Power plant	Engine type
		Turbine Entry Temperature at static sea level
		Cruise thrust (at M _{cr} and h _{cr})
		Static sea level thrust with/without afterburner
		Bypass ratio
		Overall pressure ratio at static sea level
		Overall pressure ratio in cruise
		Specific fuel consumption at static sea level
		Specific fuel consumption in cruise
		Cruise Mach number

3.3 Jenkinson

The third reference is a website on the book 'Civil Jet Aircraft Design' by L. Jenkinson, P. Simkin and D. Rhodes (Jenkinson 2017). The site contains more than only some details about the book, it contains aircraft industry data. This site can be used for both aircraft (Jenkinson 2017a) and engine (Jenkinson 2017b) specifications. The listing of the engine specifications is divided into three stages; take-off, climb and cruise. They are very comprehensive, accurate, user friendly and free. A few disadvantages are that some engine parameters are not expressed in SI-units and thus they need to be converted before one is able to use the values for the program. Besides, the list of different aircraft types is not large. The last disadvantage is that there is no 3 view drawing available, which makes it impossible to scale measure some parameters. The following specifications can be found with this source:

Table 3. 4 Source of information (Jenkinson 2017a) catalogue

Performance	Cruise Mach number
	Cruise altitude
	Cruise speed
	Approach speed

	Take-off field length
	Landing field length
	Payload-Range diagram
Weights and loadings	Maximum payload
	Operating empty weight
	Maximum take-off weight
	Maximum landing weight
	Maximum zero fuel weight
	Weight ratios
Power plant	Engine type
	Number of engines
	Static thrust
	Fuel capacity (Standard or optional)
	Specific fuel consumption
Wing	Wing span
	Wing area
	Aspect ratio
	Taper ratio
	Root chord
	Mean aerodynamic chord
	25% sweep angle
	Relative thickness
	Maximum lift coefficient, landing
	Maximum lift coefficient, take-off
Flying controls	Leading edge devices
	Trailing edge devices

Engine specifications (Jenkinson 2017b)

 Table 3. 5
 Source of information (Jenkinson 2017b) catalogue

•	,
Take-off	Thrust
	Bypass ratio
	Overall pressure ratio
	Specific fuel consumption
Climb	Maximum thrust
Cruise	Altitude
	Mach number
	Thrust
	Specific fuel consumption

3.4 Airport Planning

The next source worthy to consult is the airport planning (Boeing 2020, Airbus 2020, Bombardier 2020, Embraer 2020 and ATR 2020). This is information provided by the aircraft manufacturer and can be found on their own website. It gives a description about every detail

from the aeroplane such as general dimensions, aircraft performance, servicing operations and maintenance preparation. The data provided by this source is integral, quite complete, reliable and for free. The only disadvantage is that the documents contain lots of unnecessary data so that it takes some time to discover the required information. Data that are needed to perform the reverse engineering and that can be found using this source are:

 Table 3. 6
 Source of information (Airport planning) catalogue

	3,
Performance	Take-off field length
	Landing field length
	Payload-Range diagram
	Approach speed
Weights and loadings	Maximum payload
	Operating empty weight
	Maximum take-off weight
	Maximum landing weight
Dimensions	3 view drawing (detailed)
Power plant	Engine type
	Usable fuel capacity

3.5 Engine

Engine 2005 is a presentation of technical information of Civil Turbojet/Turbofan Specifications, sorted by engine manufacturer. It is narrowed to engines information, therefore, it is a reliable site to check the engine options of every aircraft.

 Table 3. 7
 Source of information (Engine 2005) catalogue

Power plant	Engine type
	Thrust (dry)
	Thrust (cruise)
	Bypass ratio
	Overall pressure ratio
	Specific fuel consumption (dry)
	Specific fuel consumption (cruise)
	Mach number
	Cruise altitude

3.6 Data Collection

The last interesting and free source is **SKYbrary 2017a** which contains data of 554 aeroplanes. This source provides data which are not comprehensive in comparison with the required inputs

for the program. When it is consulted by the user for the first time, it is possible that the display of the information is not clear. The following, usefull information, is listed below:

 Table 3. 8
 Source of information (SKYbrary 2017a) catalogue

Performance	Cruise Mach number
	Cruise speed
	Approach speed
	Take-off field length
	Landing field length
	Range
Weights and loadings	Maximum take-off weight
Dimensions	3 view sketch
Power plant	Engine type
	Number of engines
	Thrust
Wing	Span

3.7 Paul Müller

For the verification of the parameters search, it has been also taken into account the Diplomarbeit from Paul Müller, **Müller 1999**, *Anpassung von Statistik-Gleichungen des Flugzeugentwurfs an neue Flugzeugtypen*. In the *Appendix C Verwendete Flugzeugtypen* there is a compilation of several aircraft that provides a fairly wide range of parameters that are useful for the user, belonging to several aircraft types. However, when studying the values more carefully the user realices that these paremeters might be selected from one of the sources explained above.

Table 3. 9 Source of information (Müller 1999) catalogue

,	, 3
Performance	Landing field length
	Approach speed
	Range (maximum Payload)
Weights and loadings	Maximum take-off weight
	Maximum landing weight
Dimensions	3 view sketch
Wing	Span
	Area
	Aspect ratio

The sources mentioned above are only to help the user. If all these sources are consulted and there are still a few parameters missing, that does not mean that they can not be found in another way. It is recommended to take a look on the manufactures platform. This contains lots of thrustworthy information. If by then, the user still has unknown parameters, the last option is

to invoke SKYbrary. This source is free and already integrated in the Excel file. A big disadvantage is that it uses intervals and thus the final value for a certain parameter depends on the solver in Excel and the accuracy from the other specifications. SKYbrary is only an option if the take-off field length, the wing span or when both the landing field length and the approach speed is unknown. Using this method is inadvisable and serves as a last possible solution to perform the reverse engineering.

 Table 3. 10
 Every source of information features

	Jane's	Roux	Jenkinson	Airport	Engine	SKYbrary
Performance						
Cruise Mach number	Х	Х	Х	Х	Х	X
Take-off field length	Х	Х	Х	Х		х
Landing field length	Х	Х	Х	Х		х
Range	х		х			х
Payload-Range diagram		Х		Х		
Cruise speed	Х		Х			Х
Cruise altitude	Х	Х	Х		Х	
Approach speed	Х		Х	Х		х
Weights and loadings						
Maximum take-off weight	Х	Х	Х	Х		х
Maximum payload	Х	Х	Х	Х		
Maximum landing weight	Х	Х	Х	Х		
Operating empty weight	Х	Х	х	Х		
Maximum zero fuel weight	Х	Х	х	Х		
Weight ratios		Х	х			
Power plant						
Number of engines	Х	х	х	Х		х
Thrust	х	Х	х		Х	х
Bypass ratio	Х	х			Х	
Overall pressure ratio		Х			Х	
Fuel capacity	х	Х	х	Х		
Specific fuel consumption		Х			Х	
Wing						
Span	х	x	х	Х		х
Area	х	x	х			
Aspect ratio	х	x	х			
Taper ratio		х	х			
Root chord	Х	х				
Mean aerodynamic chord		Х	х			
Sweep angle at 25% chrod	Х	Х	х			
Dihedral angle	Х	Х				
Relative thickness		Х	х			
Flying controls						
Leading edge devices	х		х			
Trailing edge devices	Х	Х	Х			

Below is shown a table that rates every source of information from 1 to 5 in terms of comprehensiveness of the aircraft/engine types (the source offer a wide range of aircraft/engine types), comprehensiveness of the parameters (the source offers all the parameters that the user is

searching), accuracy (the parameter values are accurate enough), reliability (the parameter values are consistent and match the specifications of the other sources) and its access (the source can be found quickly and for free on the web or, on the contrary, must be searched in a library).

 Table 3. 11
 Ranking of the sources

	Jane's	Roux	Jenkinson	Airport	Engine	SKYbrary
Comprehensiveness aircraft/engine types	5	4	2	4	4	3
Comprehensiveness parameters	4	5	4	3	2	1
Accuracy	5	4	5	5	5	2
Reliability	4	4	3	5	5	2
Free	No	No	Yes	Yes	Yes	Yes

4 Aviation Market

The aviation market is segmented by Type (Commercial Aircraft, Military Aircraft, General Aviation), and Geography. The aviation market is anticipated to show the next behaviors during the forecast period, according to **Aviation Market 2020**:

- Increasing defense expenditure, mostly from the developing countries, may drive the procurement of military aircraft, thereby propelling the growth of the aviation market in the coming years.
- Lower air fares, growing living standards, and a growing middle-class in large, emerging markets, like China and India, are the hmajor contributors to increased air travel.
 This has made the airlines operating in the regions to establish new routes and serve more passengers, by procuring new aircraft, thereby adding more seats.
- Replacement of aging commercial aircraft and the procurement of new generation commercial aircraft are the main factors driving the growth of the market.

4.1 Key Market Trends

The commercial aircraft segment dominates the aviation market, accounting for more than half of the market revenues, as of 2019. The commercial segment is expected to continue to dominate the market during the forecast period, due to the rising demand for new aircraft to cater to the increasing air travel. Additionally, several airlines are replacing their ageing fleet with newer generation fuel-efficient aircraft. The military aircraft segment is anticipated to grow, however, slower than the commercial aircraft segment, as most of the new aircraft order finalizations for the military take few years before getting the final approval for the procurement. The declining military expenditures from some countries also hampered the growth of the military aircraft segment, to some extent.

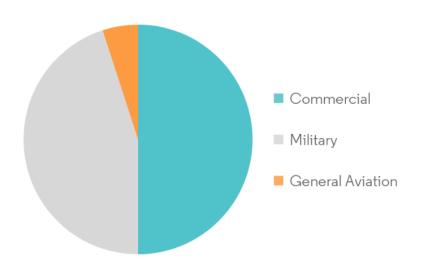


Figure 4. 1 Aviation Market: Revenue (%), by type, Global, 2019 (Aviation Market 2020)

Where is the largest and fastest growing market for the commercial aircraft? North America was the largest region in the global commercial aircraft market, accounting for 60% of the market in 2019. Asia Pacific was the second largest region accounting for 15% of the global commercial aircraft market. Eastern Europe was the smallest region in the global commercial aircraft market.

The market in the Asia-Pacific Region is expected to grow during the Forecast Period (2020-2025). In 2019, North America accounted for the highest market share across all the regions in the world. The revenues from the region are predominantly due to the United States, which has the highest aircraft fleet in the world. North America was followed closely by Asia-Pacifc, in terms of revenue share, in 2019. Revenues from Asia-Pacific are projected to grow with a high growth rate, during the foecast period, as the emerging economies in the region, like India and China, are experiencing a huge surge in their respective aviation markets, due to an increased demand for air travel in the countries.

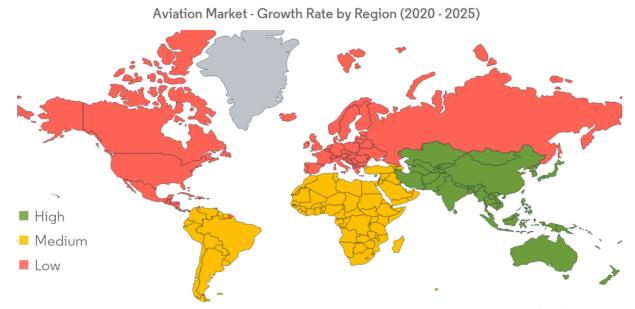


Figure 4. 2 Aviation Market – Growth rate by region (2020-2025) (Aviation Market 2020)

4.2 Commertial Aircraft Market

Commercial aircraft transport passengers and cargo from one location to another. Commercial aviation involves general aviation and scheduled airline services. The world commercial aircraft market is divided by aircraft size, end user, and geographical region. The aircraft sizes could be wide-body, narrow-body, regional, and others (single aisle, feederliner, and short haul). Considering the end users, the market is bifurcated into public and private sector. Based on geography, the market is analyzed across four major regions namely, North America, Europe, Asia-Pacific, and LAMEA.

The forecast for the commercial aircraft market can be summarized as follows, according to **Aviation Market 2020**:

- Increase in number of air passengers: This factor is expected to have high impact on the market growth throughout the forecast. Key players in the market have anticipated significant growth in the number of air passengers by the end of 2034; by then, they aim to enhance their overall air transport services.
- Improvement in commercial aviation network: Increase in passenger security concerns may encourage prominent players to invest significant amount on passenger security enhancement solutions and services, thus, projecting high impact of this factor by the end of 2022.
- Increasing tourism and economic development: It is anticipated that; the global tourism industry will witness significant hike during the forecast period. This is projected to have a high impact on the overall commercial aircraft market by 2022.

- Environment-friendly and fuel-efficient aircraft: To meet the environment compliance by the governments, businesses have started consuming and offering eco-friendly products and services. By 2022, the overall impact of this factor is expected to remain high due to increasing environmental concerns.
- Lack of security and terrorism threats: Significant increase in aviation terrorism has created a negative impact on commercial aircraft market growth. Currently, this factor has high impact in the market and is expected to remain high throughout the forecast period. Major issues include air traffic control error, cabin fire, explosive devices, flight hijacks, lightning, and incompetent pilots.
- Congestion and delay: Currently, congestion and delay have high impact on the market growth. However, introduction of several initiatives by government and aviation service providers to manage air-traffic effectively may reduce the overall impact on the market growth by 2022.

Aircraft fleets in mature markets around the world are aging rapidly and with growing demand from airlines and fleet operators for fuel-efficient aircrafts, manufacturing companies are offering advanced aircrafts for passenger transportation. These advanced aircrafts are equipped with advanced avionics, superior cabin designs and noise reduction capabilities that increase the fuel efficiency and performance of aircrafts. Higher hydraulic operating pressure (5000 psi) systems, variable frequency power generators, Brake to Vacate technology and high-efficiency air filters are new technologies being integrated in aircrafts. Some of the new aircraft offerings include Airbus A320 neo, A330 neo, Boeing's 787, 737 MAX, 777X and Bombardier's C-series.

4.3 Commercial Aircraft Sales

Table 4.1 shows the exact number of sold and delivered in service aircraft according to a model classification, taking into account the backlog for each model as well.

 Table 4. 1
 Commercial aircraft sales (DVB 2018)

	Manufacturer	Aircraft type	Total	,	Manufacturer	Aircraft type	Total
1	Boeing	737-800	4984	51	Boeing	737-400	142
2	Airbus	A320-200	4279	52	Irkut	MS-21-300	142
3	Airbus	A320-200 Neo	3671	53	Sukhoi	SSJ100-95	127
4	Boeing	737-8	2065	54	Boeing	737-400SF	124
5	Airbus	A321-200	1686	55	Boeing	737-9	119
6	Airbus	A321-200 Neo	1355	56	Bombardier	CS100	113
7	Airbus	A319-100	1341	57	Fokker	100	111
8	Boeing	737-700	1026	58	Boeing	737-300SF	109
9	Boeing	777-300ER	813	59	Airbus	A340-300	103
10	Airbus	A330-300	735	60	Airbus	A300-600F	103
11	Boeing	787-9	678	61	Embraer	195-E2	102
12	Airbus	A350-900	625	62	Embraer	175-E2	100
13	Airbus	A330-200	553	63	Boeing	747-8F	88
14	Embraer	190	536	64	McDonnel D.	MD-11BCF	85
15	Embraer	175	529	65	Embraer	190-E2	83
16	ATR	ATR 72-600	527	66	Boeing	757-200PF	79
17	Boeing	737-900ER	508	67	Airbus	A321-200NX	74
18	Bombardier	CRJ100/200/440	499	68	Airbus	A300-600F	68
19	Boeing	767-300/300ER	452	69	Bombardier	CRJ1000NextGe	67
20	Bombardier	CRJ900	438	70	Boeing	737-7	65
21	Embraer	ERJ-145	417	71	McDonnel D.	MD-90-30	64
22	Boeing	787-8	401	72	Boeing	777-200	62
23	Boeing	777-200ER	348	73	Airbus	A340-600	62
24	McDonnel D.	MD-81/82/83/88	345	74	Boeing	767-200SF	59
						767-	
25	Boeing	757-200	333	75	Boeing	300(ER)BCF/SF	56
26	Airbus	A380-800	316	76	Boeing	757-300	55
27	Bombardier	Dash-8 Q400NextGen	301	77	Boeing	777-200LR	54
28	Bombardier	CRJ700	300	78	Airbus	A321-100	54
29	Comac	C919	287	79	Boeing	737-900	52
30	ATR	ATR 72-500	286	80	Boeing	777-8	53
31	Boeing	777-9	263	81	Boeing	737-600	48
32	Boeing	737-10	256	82	Boeing	777-300	48
33	Mitsubishi	MRJ90	233	83	Airbus	A319-100 Neo	47
34	Bombardier	Dash-8 Q400	225	84	Airbus	A318-100	44
35	Boeing	737-300	218	85	Boeing	747-400BCF	43
36	Airbus	A350-1000	212	86	Airbus	A330-200F	41
37	Boeing	737-8-200	210	87	Embraer	ERJ-135	40
38	Boeing	757-200SF	205	88	Boeing	747-81	37
39	Airbus	A330-900 Neo	204	89	Boeing	767-400ER	37
40	Bombardier	CS300	200	90	McDonnel D.	MD-11F	34
41	Boeing	767-300F	190	91	Irkut	MS-21-200	33
42	Comac	ARJ21-700	180	92	Boeing	737-300QC	29
43	Boeing	787-10	168	93	Airbus	A310-200	26
44	Boeing	747-400	165	94	Airbus	A310-300	26
45	Boeing	737-500	162	95	Fokker	70	25
46	Boeing	777 Freighter	160	96	Airbus	A300-600(R)	22
47	Embraer	195	157	97	Boeing	767-200	16
48	Boeing	717-200	154	98	Airbus	A310-200F	16
49	Embraer	170	152	99	Boeing	747-400M Combi	13
50	Boeing	747-400(ER)F	143	100	Bombardier	CRJ100/200PF/SF	10

In order to carry out the research, it has been taken into account the maximum number of manufacturers, aircraft models and types. The objective is to cover the whole commertial market spectrum. To do so, both passenger aircraft and freighters have been included, as well as every engine option, either turbofan or turboprop. Although the Reverse Engineering Excel-based tool PJRE is not design to study turboprop engines, they have been also taken into account so as to increase the research reliability and accuracy.

The following manufacturers take part in the research: Airbus, Boeing, Bombardier, Embraer, McDonnel Douglas, Fokker, Mitsubishi, Sukhoi, Irkut, Comac and ATR. In total, 118 aircraft models have been studied, of which 91 were passenger aircraft and 26 were freighters. In addition, the vast majority had turbofan as engine option and only 4 out of 118 had turboprop as engine option.

If we add up all the sold aircraft, a total of 37753 is given. The aircrafts of the table have already been ranked by their number of sales, being the Boeing 737-800 the most used commertial aircraft, with 4984 aircraft in service, and the Airbus A320-200 the second most used commertial aircraft, with 4279 sold and delivered aircraft. Only these two aircraft models already cover the 25% of the commertial market spectrum.

How many more aircraft models must be taken into account in order to cover the 90% of the market?

The following figure shows the cumulative sum of the most used commercial aircraft, with which a visual interpolation can be carried out in order to unravel the number of aircraft models that will be the object of study. Thank to the graph's shape, one can realize that only less than half of the aircraft models are needed to cover almost all of the commercial market spectrum.

67

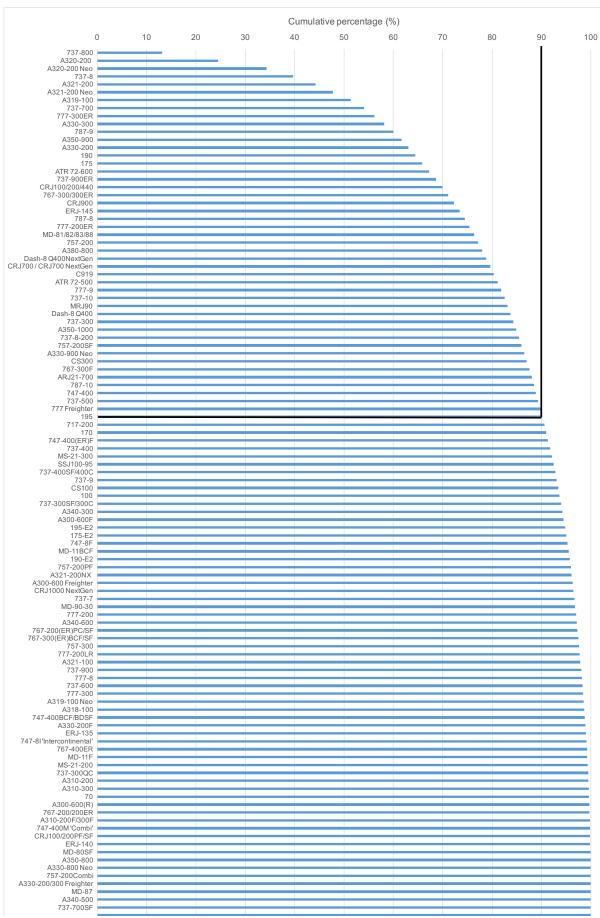


Figure 4. 3 Cummulative sum of most used passenger aircraft

68

Figure 4.4 shows the most used passenger aircraft. These values include both aircraft in service and in backlog. Now that the sales of every aircraft are displayed, it becomes clearer that sales are concentrated in the first aircraft models. These are the Boeing 737-800 and the Airbus A320-200, closely followed by the Airbus A320-200Neo and Boeing 737-8, which are the modern and more efficient versions of the first two aircrafts.

Based on aircraft size, the market is segmented into wide-body, narrow-body, and regional jets. From the ranking, it is evident that the narrow-body segment has the maximum market share aircraft, as they are fuel-efficient and help in reducing the overall cost. This is one of the crucial factors that have increased the adoption of narrow-body aircraft globally. However, the wide-body segment is expected to grow at a rapid rate during the forecast period due to an increase in the number of aircraft delivery via wide-body aircraft, especially in Asia-Pacific.

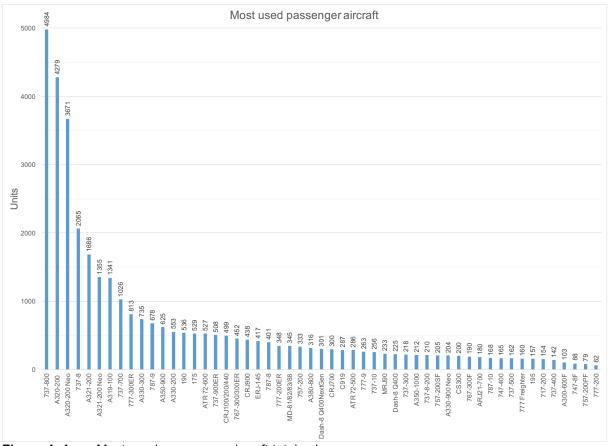


Figure 4. 4 Most used passenger aircraft total sales

5 Aircraft Analysis

5.1 Boeing 737-800

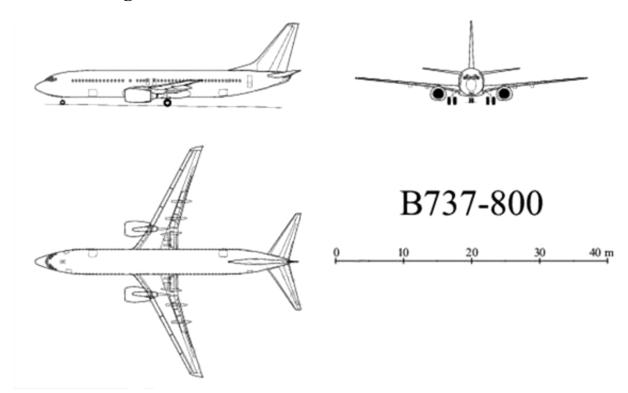


Figure 5. 1 3 view drawing of the Boeing 737-800 (Roux 2007a)

The 737-800 is a medium narrow-bodied jet with capacity for a maximum seating of 189 passengers whose first flight took place on July 31, 1997. It is considered the most liquid commercial aircraft in the market today due to its more than 4450 aircraft in active service, over 500 on order backlog and almost 200 operators. It belongs to the 737NG (Next Generation) family (737-700, 737-800 and 737-900ER). Among the aircraft family, the 737-800 represents the optimum model. It has a slightly longer fuselage than its 737-400 predecessor, increasing the seating capacity and overtaking by two seat-rows the A320, its main competitor, giving it a potential revenue advantage and lower seat-mile costs. Besides, the fact that there is only one engine option (CFM56-7B) generates no engine split as in the A320 market. In order to stimulate sales on the 737, Boeing offered performance upgrades consisting of an improved engine, the CFM56-7BE 'Evolution' engine, aerodynamic refinements, weight schedule improvements, the new Sky Interior, longer maintenance intervals, new space-saving lavatories and/or aggressive pricing, as well as standardize the use of winglets in order to improve in 3-5% the fuel burn. With more than 500 aircraft on order and the introduction of the 737 MAX, Boeing will increase the production of the 737 from 44 aircraft per month to 57 aircraft per month in 2019.

Boeing and Aeronautical Engineers (AEI) also offer freight conversions: AEI launched its 737-800SF (Special Freighter) program on 4 March 2014 while Boeing's 737-800BCF (Boeing

Converted Freighter) program was launched on 24 February 2016, being able to carry up to 23,9t of cargo in up to 6,5 cubic feet on routes of up to 3700km.

Table 5. 1Input values of the Boeing 737-800

Parameter	Symbol	Units	Chosen value
PAX			189
_anding field length (ISA)	S _{LFL}	m	1646
Approach speed	V _{APP}	m/s	72
ake-off field length (ISA)		m	2300
ake-on held length (IOA)	STOFL	""	2300
Range (max payload)	R	km	3700
Cruise Mach number	M _{CR}		0,785
Cruise speed	V _{CR}	m/s	232,5
Cruise altitude	h _{CR}	m	11887
Ving area	Sw	m²	124,6
Ving span	bw	m	34,32
Aspect ratio	A	III	9,45
Aspect ratio	^		9,45
Maximum take-off mass	m _{MTO}	kg	78245
Payload mass	m _{PL}	kg	20276
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,259
Maximum landing mass	m _{ML}	kg	65315
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,835
Operating empty mass	m _{OE}	kg	41145
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,526
Maximum zero fuel mass	m _{MZF}	kg	61690
Ning loading	m _{MTO} /S _W	kg/m²	564,3
Number of engines	n _E		2
Engine type			CFM56-7B24
Take-off thrust for one engine	T _{TO,one engine}	kN	106,757
Total take-off thrust	T _{TO}	kN	213,514
hrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,31
Bypass ratio	μ		5,3
Overall pressure ratio	OAPR		26
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,05E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,78E-05
Available fuel volume	Vertical	m³	26,022
avaliable luci volulile	V _{fuel,available}	III	20,022
Sweep angle	ф ₂₅	۰	25
Mean aerodynamic chord	C _{MAC}	m	4,17
Position of maximum camber	X _{(y_c),max}	%с	30
Camber	(y _c) _{max} /c	%с	4
Position of maximum thickness	X _{t,max}	%с	30
Relative thickness	t/c	%	12,5
Гарег	λ		0,219

 Table 5. 2
 Reverse engineering results of the Boeing 737-800

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,98	-11
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,30	-11
Maximum aerodynamic efficiency	E _{max}	-	18,17	7
Specific fuel consumption	SFC	kg/N/s	1,54E-05	9

5.2 Airbus A320-200

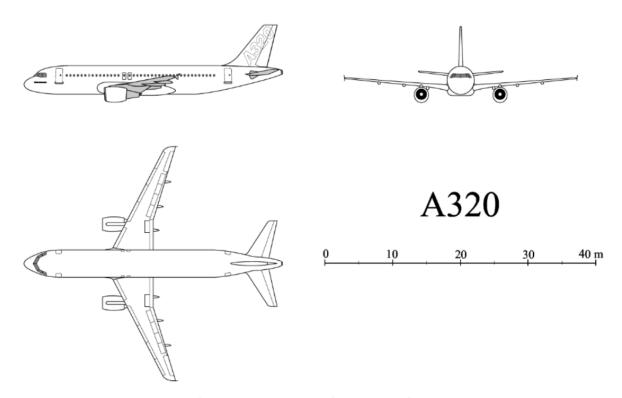


Figure 5. 2 3 view drawing of the Airbus A320-200 (Roux 2007a)

The A320-200 is a medium narrow-bodied jet with capacity for a maximum seating of 180 passengers whose first flight took place on June 27, 1988. It is the reference aircraft of narrow-bodied aircraft family from Airbus and is one of the most successful aircraft regarding sales volume. It had a successful entrance in the low cost market thank to the selection of the A320 by JetBlue in 1999 and was followed by more low cost airline orders, particularly from Asia, which led to a current value of 4048 airplanes in service, 231 on order and 266 operators around the world.

It was originally conceived as a longer range of its A320-100 predecessor, featuring wigtip fences and an increased fuel capacity. Early versions of the A320s were powered by the old V2500-A1 or CFM56-5A, that needed substantially more maintenance which made them much

less attractive. However, modern versions are equipped with either CFM56-5B or IAE V2500-A5. Having split engine options is an advantage for operators during purchase operations and could be a disadvantage to the manufacturer since in theory two sub-fleets could limit remarketing options. Nevertheless, in case of the A320 the two sub-fleets each have enough critical mass to ensure market liquidity. In 2012 Airbus launched the so-called Sharklets (Airbus marketing name for winglets) which has resulted in an improvement of approximately 4% in fuel consumption which in turn improves operational flexibility, that is, an increase of 500kg of payload and 280km of additional range.

Table 5. 3Input values of the Airbus 320-200

Parameter	Symbol	Units	Chosen value
PAX			180
_anding field length (ISA)	S _{LFL}	m	1490
Approach speed	V _{APP}	m/s	70
Γake-off field length (ISA)		m	2180
ake-off field leftgtif (15A)	S _{TOFL}		2100
Range (max payload)	R	km	2870
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	230
Cruise altitude	h _{CR}	m	11278
Ving area	S _w	m²	122,4
			34,1
Ning span	b _W	m	9,4
Aspect ratio	^		9,4
Maximum take-off mass	m _{MTO}	kg	77000
Payload mass	m _{PL}	kg	19000
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	-	0,247
Maximum landing mass	m _{ML}	kg	64500
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,838
Operating empty mass	m _{OE}	kg	42100
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}	· ·	0,547
Maximum zero fuel mass	m _{MZF}	kg	61000
Ving loading	m _{MTO} /S _W	kg/m²	600
3 44 5		, and the second	
Number of engines	n _E		2
Engine type			CFM56-5B4
Take-off thrust for one engine	T _{TO,one engine}	kN	111,2
Total take-off thrust	T _{TO}	kN	222,4
Γhrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,32
Bypass ratio	µ	. (2 0,	6
Overall pressure ratio	OAPR		29,1
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	9,62E-06
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,54E-05
Available fuel volume	V _{fuel,available}	m³	23,86
Sweep angle	ф ₂₅	•	24,967
Mean aerodynamic chord		m	4,2
Position of maximum camber	C _{MAC}	%c	4,2 15
	X _{(y_c),max}		
Camber	(y _c) _{max} /c	%c	1,8
Position of maximum thickness	X _{t,max}	%c	30
Relative thickness	t/c	%	15,2
aper	λ		0,24

 Table 5. 4
 Reverse engineering results of the Airbus 320-200

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,31	-6
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,29	-0
Maximum aerodynamic efficiency	E _{max}	-	16,80	13
Specific fuel consumption	SFC	kg/N/s	1,60E-05	1

5.3 Airbus A320-200Neo



Figure 5. 3 view drawing of the Airbus A320-200Neo (Norebbo 2020)

The A320-200Neo is a medium narrow-bodied jet with capacity for a maximum seating of 189 passengers whose first flight took place on September 25, 2014. In December 2010, Airbus launched the 'New Engine Option' (or "NEO") for the A320 family. Lufthansa was the first airline to be delivered the A320-200Neo and it was followed by more than 4000 aircraft in backlog. This new aircraft type results in an efficiency gain of 10-15% when compared to the standard A320-200. The gain is based on two new features: the new engine option and some aerodynamic and structural adjustments together with new winglets ('Sharklets'). The engine option consists of either the Pratt & Whitney's PW1100G-JM ('Geared Turbo Fan') engines or CFM's new Leap-1A engines, whose larger diameter (higher BPR and heavier) offers a 15% fuel burn advantage.

Table 5. 5Input values of the Airbus 320-200Neo

Parameter	Symbol	Units	Chosen value
PAX			180
Landing field length (ISA)	S _{LFL}	m	1440
Approach speed	V _{APP}	m/s	69
Take-off field length (ISA)	S _{TOFL}	m	1880
Range (max payload)	R	km	4500
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	230
Cruise altitude	h _{CR}	m	11000
Wing area	Sw	m²	
Wing span	b _W	m	35,8
Aspect ratio	Α		
Maximum take-off mass	m _{MTO}	kg	79000
Payload mass	m _{PL}	kg	19250
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,244
Maximum landing mass	m _{ML}	kg	67400
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,853
Operating empty mass	m _{OE}	kg	
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		
Maximum zero fuel mass	m _{MZF}	kg	64300
Wing loading	m _{MTO} /S _W	kg/m²	
Number of engines	n _E		2
Engine type			CFM LEAP-1A
Take-off thrust for one engine	T _{TO,one engine}	kN	136,5
Total take-off thrust	T _{TO}	kN	273
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
Bypass ratio	μ		
Overall pressure ratio	OAPR		40
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	26,73
0	1	•	24.067
Sweep angle	Ф25		24,967
Mean aerodynamic chord	C _{MAC}	m % o	15
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	1,8
Position of maximum thickness	X _{t,max}	%c	30
Relative thickness	t/c	%	15
Taper	λ		

 Table 5. 6
 Reverse engineering results of the Airbus 320-200Neo

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,57	-13
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,28	-13
Maximum aerodynamic efficiency	E _{max}	-	18,01	13
Specific fuel consumption	SFC	kg/N/s	1,36E-05	8

5.4 Boeing 737-8

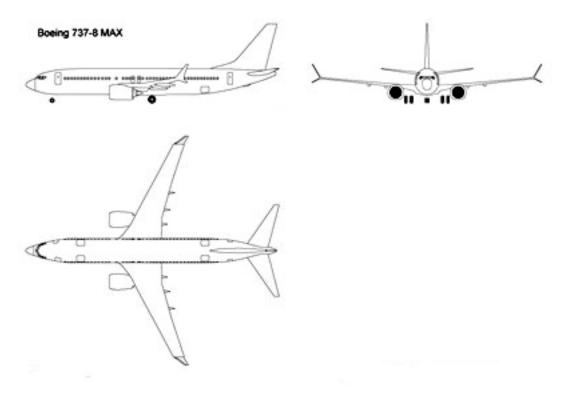


Figure 5. 4 3 view drawing of the Boeing 737-8 (Blueprints 2020)

The 737-8 is a medium narrow-bodied jet with capacity for a maximum seating of 189 passengers whose first flight took place on January 29, 2016. It was Boeing's respond to the introduction of the A320Neo family by Airbus. The 737-8 directly competes against the A320Neo with the 2056 orders that have been placed among 63 operators, making it the most popular 737 MAX variant. There are however many open orders for which the customer has not yet decided for the specific 737 MAX variant. The name "MAX" is used as a marketing term to name the whole family (737-7, 737-8, 737-8-200, 737-9 and 737-10), which was presented in August 2011 as a quick reaction to A320Neo's efficient specifications and high sales figures. Initially Boeing did not change the fuselage length and door configurations of the 737 MAX so the 737-7, 737-8 and 737-9 corresponded to those of the -700, -800 and 900ER members of the 737NG family.

The most important new feature of the 737 MAX was the introduction of the new CFM International LEAP-1B engine which are mounted higher and further forward relative to the 737NG's CFM56 engines and whose new larger fan diameter improves the fuel burn by a claimed 12-14%. The new engine also has external nacelle chevrons similar to those on the 787 and 747-8 which reduce engine noise. The new Leap-1B engine is smaller than either the Leap-1A or the PW1100G engine options available to operators of the new A320neo family. Fuel efficiency is also improved by some aerodynamic modifications on the fuselage (a new tail cone) of the 737 MAX and the introduction of a new winglet design, called the Boeing Advanced Technology ("AT") winglet. Therefore, the range of the 737 MAX has increased by 740-1000km compared to the 737NG.

Table 5. 7Input values of the Boeing 737-8

Parameter	Symbol	Units	Chosen value
PAX			189
Landing field length (ISA)	S _{LFL}	m	1650
Approach speed	V _{APP}	m/s	
Take-off field length (ISA)	S _{TOFL}	m	2540
Range (max payload)	R	km	4630
Cruise Mach number	M _{CR}		0,79
Cruise speed	V _{CR}	m/s	233,89
Cruise altitude	h _{CR}	m	
Wing area	Sw	m²	124,6
Wing span	b _w	m	35,92
Aspect ratio	Α		
Maximum take-off mass	m _{MTO}	kg	82190
Payload mass	m _{PL}	kg	
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		
Maximum landing mass	m _{ML}	kg	69308
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,843
Operating empty mass	m _{OE}	kg	
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		
Maximum zero fuel mass	m _{MZF}	kg	65952
Wing loading	m _{MTO} /S _W	kg/m²	
Number of engines	n _E		2
Engine type			LEAP-1B25
Take-off thrust for one engine	T _{TO,one engine}	kN	130
Total take-off thrust	T _{TO}	kN	260
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
Bypass ratio	μ		
Overall pressure ratio	OAPR		40
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	25,817
Sweep angle	ф ₂₅	0	25
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%c	20,4
Camber	(y _c) _{max} /c	%c	1,5
Position of maximum thickness	X _{t,max}	%c	39,9
Relative thickness	t/c	%	10
Taper	λ		

 Table 5. 8
 Reverse engineering results of the Boeing 737-8

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,15	-8
Maximum lift coefficient, take-off	C _{L,max,TO}	-	1,88	-0
Maximum aerodynamic efficiency	E _{max}	-	17,45	17
Specific fuel consumption	SFC	kg/N/s	1,77E-05	-13

5.5 Airbus A321-200

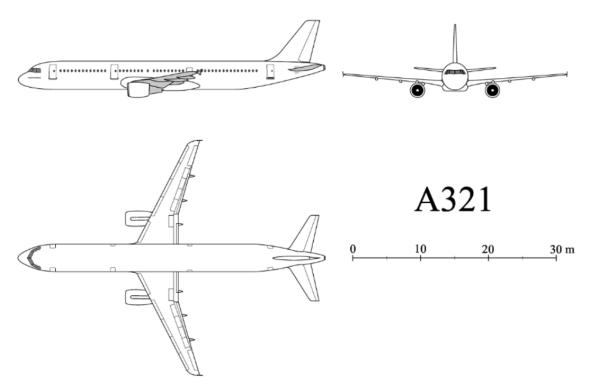


Figure 5. 5 3 view drawing of the Airbus A321-200 (Roux 2007a)

The A321-200 is a large narrow-bodied jet with capacity for a maximum seating of 220 passengers whose first flight took place on March 15, 1997. It is the first direct competitor to the Boeing 757-200. Although A321-200's range is not as high as the 757-200, the A321-200 become a strong competitor on medium routes, such as the US coast-to-coast, taking over the US domestic routes and leaving the 757 only for long distance single aisle routes. With 1443 aircraft in service and 243 on order, in the recent years the A321 sales figures have been rising resulting since 2010 in the outsold of the 319 and the outsold of the A320 in the past two years, making it the second most popular aircraft in the A320 family. With more than 100 operators, the A321-200 has become popular among low-cost carriers (Frontier, Vueling, WizzAir, VietJet, etc).

The A321-200 features structural reinforcements, a higher weight schedule and a provision for two ACTs which gives it its 5560km range when compared to its A321-100 predecesor. From mid-2013 'Sharklets' have been available for new A321s resulting in a fuel burn improvement of approximately 4% and 2550kg more payload which further enhances operational flexibility. Also, Airbus has developed increased cabin enhancements ("ICE") to raise the A320 family's seating capacity through changes to cabin configuration (new rear galley configuration and lavatory design) and the use of slim-line seats. In 2014, the Aviation Authorities reassessed the A320 family exit limit to increase its exit capability, which also contributes to a higher seating capacity on A320 family aircraft. For the A321-200, all these initiatives, in combination with reduced seat pitches, improved the seat count by up to ten additional seats, resulting in a much lower fuel burn per seat.

Table 5. 9Input values of the Airbus 321-200

Parameter	Symbol	Units	Chosen value
PAX			185
London fold longth (ICA)	_		1500
Landing field length (ISA)	S _{LFL}	m /-	1580
Approach speed	V _{APP}	m/s	72
Take-off field length (ISA)	S _{TOFL}	m	2200
Range (max payload)	R	km	3700
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	231
Cruise altitude	h _{CR}	m	11278
Wing area	S _w	m²	122,4
Wing span	bw	m	34,09
Aspect ratio	A		9,4
			-,.
Maximum take-off mass	m _{MTO}	kg	93500
Payload mass	m _{PL}	kg	23000
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	•	0,246
Maximum landing mass	m _{ML}	kg	77800
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	J	0,832
Operating empty mass	m _{OE}	kg	49200
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	•	0,526
Maximum zero fuel mass	m _{MZF}	kg	73800
Wing loading	m _{MTO} /S _W	kg/m²	762,6
Number of engines	n _E		2
Engine type			CFM56-5B3/P
Take-off thrust for one engine	T _{TO,one engine}	kN	142,342
Total take-off thrust	T _{TO}	kN	284,684
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,33
Bypass ratio	μ		5,4
Overall pressure ratio	OAPR		33,7
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	0,0000102
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	26,6
Sweep angle	ф ₂₅	o	24,967
Mean aerodynamic chord	C _{MAC}	m	4,3
Position of maximum camber	X _{(y_c),max}	%c	7,5
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		0,24

 Table 5. 10
 Reverse engineering results of the Airbus 321-200

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,76	-18
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,62	-10
Maximum aerodynamic efficiency	E _{max}	-	15,35	18
Specific fuel consumption	SFC	kg/N/s	1,44E-05	9

5.6 Airbus A321-200Neo

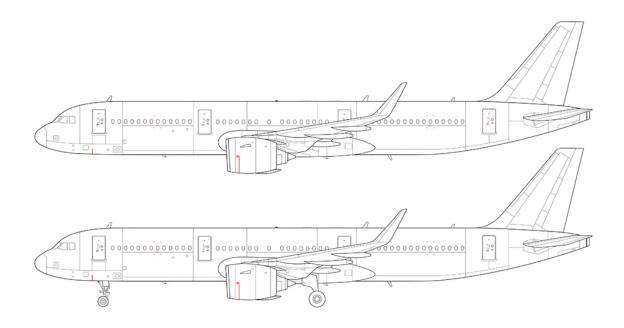


Figure 5. 6 3 view drawing of the Airbus A321-200Neo (Norebbo 2020)

The A321-200Neo is a large narrow-bodied jet with capacity for a maximum seating of 230 passengers whose first flight took place on February 9, 2016. The base-line A320-200Neo entered service in 2016 and the longer A321-200Neo followed in May 2017. The first A321-200N was delivered to Virgin America. With a backlog of more than 1300 aircraft, the A321-200Neo is a very successful programme for Airbus. Boeing tried hard to catch up with the 737-9 and the 737-10, but even if we combine the sales of these Boeing types, Airbus has still sold almost a thousand more A321-200Neo.

Like the A320-200Neo, the A321-200N will either have Pratt & Whitney's PW1100GJM ('Geared Turbo Fan') engines or CFM's new LEAP-1A engines. The larger (higher bypass ratio) and slightly heavier engines reportedly will offer ~15% fuel burn advantage. Together with

some aerodynamic and structural adjustments and the new 'Sharklets' winglets, the anticipated efficiency gain is expected to be 10-15% compared to the preceding A321-200s.

Table 5. 11Input values of the Airbus 321-200Neo

Parameter	Symbol	Units	Chosen value
PAX			202
Landing field length (ISA)	S _{LFL}	m	1700
Approach speed	V _{APP}	m/s	70
Take-off field length (ISA)	S _{TOFL}	m	2300
Range (max payload)	R	km	5600
Cruise Mach number	M _{CR}		0,79
Cruise speed	V _{CR}	m/s	231,5
Cruise altitude	h _{CR}	m	12000
Wing area	S _W	m²	
Wing span	b _w	m	35,8
Aspect ratio	Α		
Maximum take-off mass	m _{MTO}	kg	97000
Payload mass	m _{PL}	kg	24000
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	Ng	0,247
Maximum landing mass	m _{ML}	kg	79200
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	кg	0,816
Operating empty mass		kg	0,010
Mass ratio, operating empty - take-off	m _{OE} m _{OE} /m _{MTO}	Ng	
Maximum zero fuel mass	m _{MZF}	kg	75600
Wing loading	m _{MTO} /S _W	kg/m²	
		-	
Number of engines	n _E		2
Engine type			PW1133G-JM
Take-off thrust for one engine	T _{TO,one engine}	kN	147
Total take-off thrust	T _{TO}	kN	294
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
Bypass ratio	μ		12,5
Overall pressure ratio	OAPR		
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	29,474
Sweep angle	ф ₂₅	o	24,967
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	$\mathbf{x}_{t,max}$	%c	
Relative thickness	t/c	%	
Taper	λ		

 Table 5. 12
 Reverse engineering results of the Airbus 321-200Neo

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	3,46	-10
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,42	-10
Maximum aerodynamic efficiency	E _{max}	-	20,10	3
Specific fuel consumption	SFC	kg/N/s	1,25E-05	17

5.7 Airbus A319-100

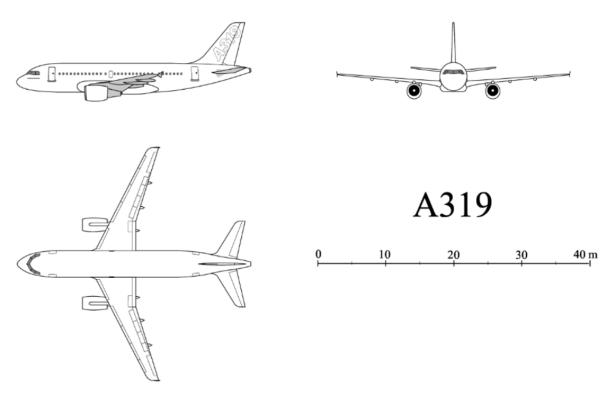


Figure 5. 7 3 view drawing of the Airbus A319-100 (Roux 2007a)

The A319-100 is a moderate size narrow-bodied jet with capacity for a maximum seating of 156 passengers whose first flight took place on August 29, 1995. For a long time, the A319 was the second most popular member of the A320 family, with over 1300 in service aircraft, but, based on the current trend in orders, it has lost this position to the A321. Due to the few on order aircraft (just 25), A319-100's sales have been lagging behind the larger A320 and A321 which have lower seat-mile costs due to their larger seating capacity. The outlook for the A319 is rather unclear. The biggest operator, easyJet has started to gradually phase out the A319 but, on the other hand, low cost carriers such as Allegiant and Volotea are looking for second hand A319s as they transition their fleets from the MD-80 / Boeing 717 to a fleet of Airbus narrow-bodied aircraft.

The A319 is a simple shrink of the baseline A320. Like its main competitor, the 737-700, it is used by a wide range of operators, specifically 131 operators. The increased MTOW options combined with up to two additional fuel tanks give the A319 a relatively long range by single aisle standards. Since 2013 "Sharklets" have been available for the A319s, replacing the original wingtip fences for in-service A320 Family aircraft, resulting in 4.0% fuel burn improvement and 500kg more payload. The Airbus developement of "ICE" (increased cabin enhancements) along with the Aviation Authorities reassessment of the A320 family exit limit to increase the A320 exit capability meant the improvement of the seat count by up to 15 additional seats resulting in lower operating cost per seat. Airbus developed a second over-wing emergency exit option, initially for easyJet, allowing an increase from 145 to 156 passengers.

The A319 is also offered in a low-density long range version for (high) premium services and as an intercontinental corporate jet with up to six additional fuel tanks. There are 65 A319s in service as corporate/private jet/VIP/Head of State aircraft (called the ACJ319).

Table 5. 13Input values of the Airbus 319-100

Parameter	Symbol	Units	Chosen value
PAX			156
Landing field length (ISA)	S _{LFL}	m	1400
Approach speed	V _{APP}	m/s	67
Take-off field length (ISA)	S _{TOFL}	m	1750
Range (max payload)	R	km	4630
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	230
Cruise altitude	h _{CR}	m	11278
Ving area	S _w	m²	122,4
Wing span	b _w	m	34,09
Aspect ratio	Α		9,4
Maximum take-off mass	m _{MTO}	kg	75500
Payload mass	m _{PL}	kg	17900
Mass ratio, payload - take-off	m _{PL/} m _{MTO}	Ng .	0,237
Maximum landing mass	m _{ML}	kg	62500
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	'v9	0,828
Operating empty mass	m _{OE}	kg	41200
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	ng .	0,546
Maximum zero fuel mass	m _{MZF}	kg	58500
Wing loading	m _{MTO} /S _W	kg/m²	616,8
Tring loading	IIIM TO/OW	Ng/III	020,0
Number of engines	n _E		2
Engine type			CFM56-5B6
Take-off thrust for one engine	T _{TO,one engine}	kN	104,5
Fotal take-off thrust	T _{TO}	kN	209
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,32
Bypass ratio	μ	, , , , , , , , , , , , , , , , , , , ,	6,2
Overall pressure ratio	OAPR		24,1
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	9,06E-06
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	•
Available fuel volume	V _{fuel,available}	m³	23,859
Sweep angle	Ф25	•	24,967
Mean aerodynamic chord	C _{MAC}	m	4,2
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	11,8
Taper	λ		0,24

 Table 5. 14
 Reverse engineering results of the Airbus 319-100

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,26	-5
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,33	-5
Maximum aerodynamic efficiency	E _{max}	-	17,65	7
Specific fuel consumption	SFC	kg/N/s	1,62E-05	2

5.8 Boeing 737-700



Figure 5. 8 3 view drawing of the Boeing 737-700 (Roux 2007a)

The 737-700 is a moderate size narrow-bodied jet with capacity for a maximum seating of 149 passengers whose first flight took place on February 9, 1997. As stated before, the 737-700 is part of the 737 New Generation family and it is the successor of the 737-300. This means it offers the new features of the New Generation family keeping the same old fuselage. It had a decent commercial success, with more than 1000 in service aircrafts and a broad operator base consisting of more than 100 operators, with a large fleet, concentrated at large large North American airlines. Besides, Southwest has added in recent years more than 65 737-700s, previously operated by other airlines, to its fleet and 12 more used 737-700s are due to enter the active Southwest fleet in the near future. Its main competitor, the Airbus

A319, is similarly popular and both aircraft seem to have perfectly split the 130-seat market for years.

The 737-700 has benefitted from performance upgrades like the CFM56-7BE 'Evolution' engines, aerodynamic refinements, weight schedule improvements, the new Sky Interior and/or aggressive pricing. Blended Winglets (3-5% fuel burn improvement) are becoming more prevalent (915 in service).

Table 5. 15Input values of the Boeing 737-700

Parameter	Symbol	Units	Chosen value
PAX			149
anding field length (ICA)			1400
anding field length (ISA)	S _{LFL}	m m/s	67
Approach speed	V _{APP}		
ake-off field length (ISA)	S _{TOFL}	m	1800
Range (max payload)	R	km	2852
Cruise Mach number	M _{CR}		0,785
Cruise speed	V _{CR}	m/s	232
Cruise altitude	h _{CR}	m	11887
Ving area	Sw	m²	124,6
Ving span	b _w	m	34,32
Aspect ratio	A		9,45
Acrimum take off mass		l	60.100
Maximum take-off mass	m _{MTO}	kg	69400
Payload mass	m _{PL}	kg	17010
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,245
Maximum landing mass	m _{ML}	kg	58060
lass ratio, landing - take-off	m _{ML/} m _{MTO}		0,837
Operating empty mass	m _{OE}	kg	38147
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,550
Maximum zero fuel mass	m _{MZF}	kg	54658
Ving loading	m _{MTO} /S _W	kg/m²	484
lumber of engines	n _E		2
Engine type			CFM56-7B20
ake-off thrust for one engine	T _{TO,one engine}	kN	91,633
otal take-off thrust	T _{TO}	kN	183,266
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	T _{то} /(m _{мто} *g)	0,31
Bypass ratio	μ	10.(10 3)	5,6
Overall pressure ratio	OAPR		22,7
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,02E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,79E-05
Available fuel volume	V _{fuel,available}	m³	26,022
Sweep angle	ф 25	•	25
Mean aerodynamic chord	C _{MAC}	m	4,17
Position of maximum camber	X _{(y_c),max}	%c	10
Camber	(y _c) _{max} /C	%c	0,8
Zumbol .			•
Position of maximum thickness	V.		/4 /
Position of maximum thickness Relative thickness	X _{t,max}	%c %	29,7 12,5

Table 5. 16Reverse engineering results of the Boeing 737-700

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	3,11	-14
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,44	-14
Maximum aerodynamic efficiency	E _{max}	-	17,99	8
Specific fuel consumption	SFC	kg/N/s	1,72E-05	0

5.9 Boeing 777-300ER

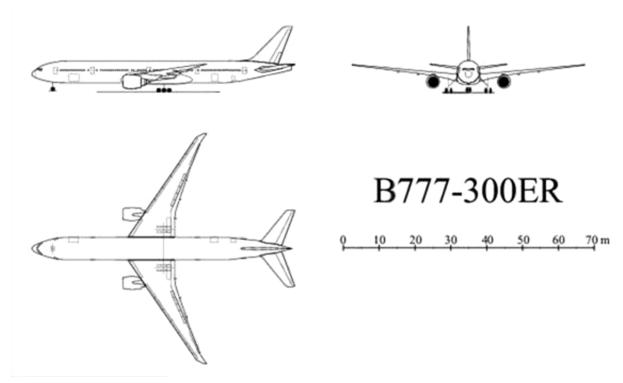


Figure 5. 9 3 view drawing of the Boeing 777-300ER (Roux 2007a)

The 777-300ER is a large wide-bodied jet with capacity for a maximum seating of 396 passengers whose first flight took place on February 24, 2003. It basically consists of the stretched 777-300 fuselage with the larger, stronger wing of the 777-200LR and the GE90 engines as only posible option, which simplifies remarketing. With 745 built and delivered aircraft and 68 on order, the 777-300ER has become the must successful Boeing wide-bodied aircraft. The main reason was the successfully replacement of the 747-100/200/300 and even the 747-400, for this was the main purpose the 777-300ER was conceived for. Therefore, the longer term 747 replacement market and limited competition from Airbus' much less efficient four-engined A340-600 almost gave the 777-300ER a monopoly in its market segment. However, the A350-1000, which entered service in 2017, is to offer a very strong challenge.

To ensure that the current 777-300ER remains competitive in the long range market well after the 777X enters service, Boeing introduced a set of upgrades for the current 777-300ER early 2015. These upgrades include engine and aerodynamic improvements and interior adjustments.

These will result in 2% fuel-burn savings and an increased seating capacity by up to 14 seats that will push the potential fuel-burn savings on a per-seat basis to as much as 5%. Most of the upgrades are retrofitable, and must help Boeing to keep the 777-300ER attractive and pursue new sales of the current generation 777-300ER until the transition to the 777X at the end of this decade. With the coming introduction of the A350-1000 and the 777-9, sales of the 777-300ER have slowed down and its looks like its heydays are over. In the last two years the 777-300ER's backlog has shrunk which has forced Boeing to cut production and with the current order backlog, this new production rate means that Boeing has already sold 90% of the available slots for 2019.

Table 5. 17Input values of the Boeing 777-300ER

Parameter	Symbol	Units	Chosen value
PAX			370
Landing field length (ISA)	S _{LFL}	m	1844
Approach speed	V _{APP}	m/s	77
Take-off field length (ISA)	S _{TOFL}	m	3050
Range (max payload)	R	km	9275
Cruise Mach number	M _{CR}		0,84
Cruise speed	V _{CR}	m/s	252
Cruise altitude	h _{CR}	m	10668
Wing area	Sw	m²	427,8
Wing span	bw	m	64,79
Aspect ratio	A		8,7
Maximum take-off mass	m _{MTO}	kg	351535
Payload mass	m _{PL}	kg	69853
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	9	0,199
Maximum landing mass	m _{ML}	kg	251290
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	3	0,715
Operating empty mass	m _{OE}	kg	167829
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	3	0,477
Maximum zero fuel mass	m _{MZF}	kg	237682
Wing loading	m _{MTO} /S _W	kg/m²	615
Number of engines	n _E		2
Engine type			GE90-115B
Take-off thrust for one engine	T _{TO,one engine}	kN	511,5
Total take-off thrust	T _{TO}	kN	1023
Γhrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,3
Bypass ratio	μ		7,2
Overall pressure ratio	OAPR		42
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	181,283
Sweep angle	ф 25	۰	31,64
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%c	30
Camber	(y _c) _{max} /c	%c	5,9
Position of maximum thickness	X _{t,max}	%c	30
Relative thickness	t/c	%	22
Taper	λ		

 Table 5. 18
 Reverse engineering results of the Boeing 777-300ER

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,98	-11
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,13	-11
Maximum aerodynamic efficiency	E _{max}	-	16,25	27
Specific fuel consumption	SFC	kg/N/s	1,22E-05	22

5.10 Airbus A330-300

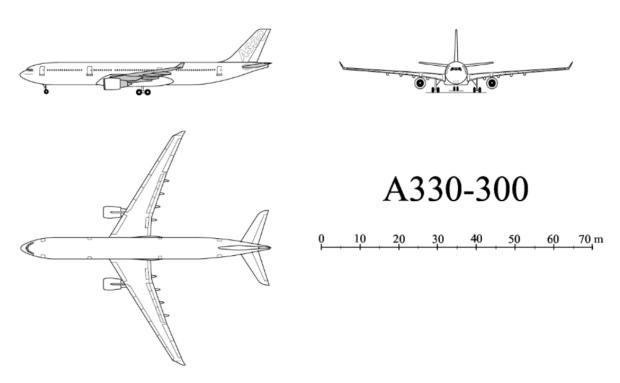


Figure 5. 10 3 view drawing of the Airbus A330-300 (Roux 2007a)

The A330-300 is a large wide-bodied jet with capacity for a maximum seating of 440 passengers whose first flight took place on November 2, 1992. The A330-300 is the twin-engined, medium-range sister of the long-range A340-300, with the same fuselage, wing and cockpit. It can be equipped with engines from all three major engine manufacturers. The Airbus A330-300 entered commercial service in 1994 and was optimized for medium range high-density markets, but continuous improvement on the A330-300 means that it has developed into a very capable and efficient medium to long haul aircraft. Prove of that is its 663 in service aircraft and 72 on order. Because of its lower structural weight (higher efficiency) and greater range capability it enjoys considerably more success than the 777-200.

With 20 year's production and the introduction of new generation competitors as the A350XWB and 787, Airbus has been studying ways to extend the life of the A330. In 2013 Airbus launched a new regional version of the A330-300 with a lower 199t MTOW, de-rated engines, a cockpit optimized for high cycle operations and a high density cabin tailored for shorter ranges (less galleys and crew rest rooms). This makes the A330-300 a relatively low-priced short-haul wide bodied people mover. This version is primarily aimed at markets with large populations and fast growing, concentrated air traffic flows (so mainly SO-Asia and China), and is in fact a kind of a return to the originally A330-300 design and intended role.

Table 5. 19Input values of the Airbus A330-300

Parameter	Symbol	Units	Chosen value
PAX			375
Landing field length (ISA)	S _{LFL}	m	1750
Approach speed	V _{APP}	m/s	70
Take-off field length (ISA)	S _{TOFL}	m	2320
Range (max payload)	R	km	7000
Cruise Mach number	M _{CR}		0,82
Cruise speed	V _{CR}	m/s	
Cruise altitude	h _{CR}	m	11887
Wing area	Sw	m²	361,6
Wing span	b _w	m	60,3
Aspect ratio	A		10,01
Maximum take-off mass	m _{MTO}	kg	242000
Payload mass	m _{PL}	kg	48400
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		0,200
Maximum landing mass	m _{ML}	kg	185000
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,764
Operating empty mass	m _{OE}	kg	124600
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,515
Maximum zero fuel mass	m _{MZF}	kg	173000
Wing loading	m _{MTO} /S _W	kg/m²	633
Number of engines	n _E		2
Engine type			Trent 772-60
Take-off thrust for one engine	T _{TO,one engine}	kN	316,267
Total take-off thrust	T _{TO}	kN	632,534
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,28
Bypass ratio	μ		4,89
Overall pressure ratio	OAPR		36,8
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,60E-05
Available fuel volume	V _{fuel,available}	m³	97,53
Sweep angle	ф ₂₅	0	29,7
Mean aerodynamic chord	C _{MAC}	m	7,28
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	15,3-11,3-10,6
Taper	λ		0,235

 Table 5. 20
 Reverse engineering results of the Airbus 330-300

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,73	1
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,53	•
Maximum aerodynamic efficiency	E _{max}	-	19,19	10
Specific fuel consumption	SFC	kg/N/s	1,55E-05	1

5.11 Boeing 787-9

Boeing 787-9

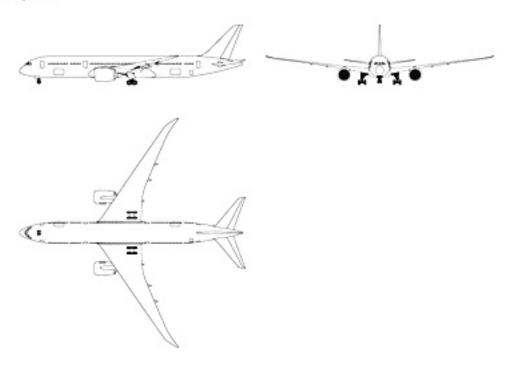


Figure 5. 11 3 view drawing of the Boeing 787-9 (Blueprints 2020)

The 787-9 is a medium wide-bodied jet with capacity for a maximum seating of 420 passengers whose first flight took place, after some design and production difficulties which led to serious delays, on September 17, 2013. However, the 787-9 did not suffer from a difficult entry-into-service with operational reliability problems for the airlines as the 787-8 did. For this reason, customers increasingly see the 787-9 as the preferred variant with better performance. As of summer 2017, with 242 787-9s in active service and 436 787-9s on order, the 787-9 has clearly outsold the 787-8.

In general, the 787 family features many new technologies like a full composite structure including wing and barrel shaped fuselage sections (accommodates 9 abreast seating), new up to

15-20% more efficient and relatively quiet engines, improved aerodynamics and many new electric systems instead of pneumatics/hydraulics.

The 787 family is initially designed to replace the 757- and 767 products but the 787-9 variant is closer to the 777-200ER in terms of payload-range. Compared to the baseline 787-8, the 787-9 has more powerful engines and a stretched fuselage which should enable it to carry some 40 more passengers over an additional 550km range. The A350-800 is expected to be a close competitor but the slightly larger A350-900 could offer competing seat-mile economics as well. Compared to the larger 777-200ER, the 787-9 is expected to bring a 20% relative trip cost improvement which is a 10% improvement in seat mile cost.

Table 5. 21Input values of the Boeing 787-9

Parameter	Symbol	Units	Chosen value
PAX			420
Landing field length (ISA)	S _{LFL}	m	1870
Approach speed	V _{APP}	m/s	
Take-off field length (ISA)	S _{TOFL}	m	3140
Range (max payload)	R	km	9720
Cruise Mach number	M _{CR}		0,85
Cruise speed	V _{CR}	m/s	252
Cruise altitude	h _{CR}	m	
Wing area	Sw	m²	325
Wing span	b _W	m	60,12
Aspect ratio	Α		11,1
Maximum take-off mass	m _{MTO}	kg	254011
Payload mass	m _{PL}	kg	
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		
Maximum landing mass	m _{ML}	kg	192776
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,759
Operating empty mass	m _{OE}	kg	115350
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,454
Maximum zero fuel mass	m _{MZF}	kg	181436
Wing loading	m _{MTO} /S _W	kg/m²	
Number of engines	n _E		2
Engine type			GEnx 72A1
Take-off thrust for one engine	T _{TO,one engine}	kN	235,76
Total take-off thrust	T _{TO}	kN	471,52
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
Bypass ratio	μ		9
Overall pressure ratio	OAPR		46,3
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	126,429
Sweep angle	ф ₂₅	0	32,2
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%с	
Relative thickness	t/c	%	
Taper	λ		

 Table 5. 22
 Reverse engineering results of the Boeing 787-9

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	2,96	3
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,20	3
Maximum aerodynamic efficiency	E _{max}	-	20,08	27
Specific fuel consumption	SFC	kg/N/s	1,23E-05	21

5.12 Airbus A350-900

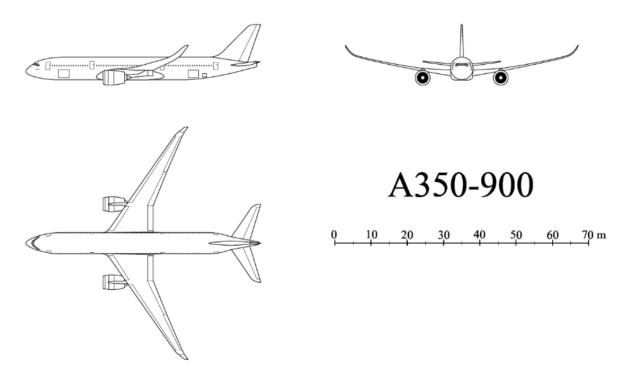


Figure 5. 12 3 view drawing of the Airbus 350-900 (**Roux 2007a**)

The A350-900 is a large wide-bodied jet with capacity for a maximum seating of 315 passengers whose first flight took place on June 14, 2013. The A350 family represents the Airbus' answer to the slightly smaller Boeing 787 family and effectively also competes with the slightly larger Boeing 777 family. It is also considered to be the future twin-engine replacement of the A330/A340 family as well. With 105 A350-900s aircraft in service and 520 on order, it is by far the most popular variant of the A350 family

After its first launch in 2004, the design failed to impress the market and was criticized for being nothing more but an upgraded A330 which wouldn't be able to compete with the Boeing 787. Airbus responded with the redesigned A350 'XWB' (eXtra Wide Body) which featured a wider fuselage, a new (composite) wing, upgraded A380 based systems and an advanced technology cockpit with 6 large LCD screens. The A350-900 is the first and base line A350 model

and features a fuselage which is longer than the A350-800 to accommodate approximately 40 more passengers. In terms of payload-range, the A350-900 is positioned closest to the 777-200ER which has 740km less range and a slightly lower seat capacity. The slightly smaller 787-9 and stretched 787-10 are competitors as well.

Currently around 105 A350-900s have been delivered to various customers and most airlines note that the reliability of the A350 is "over and beyond" expectations. So the entry into service of this new design seems to be without any problems. Something which cannot be said from its production process.

In October 2015 Airbus introduced a new long range version of the A350-900. The A350-900ULR (Ultra Long Range) will feature a higher 278/280t MTOW, a 17% higher usable fuel capacity as well as aerodynamic tweaks to stretch its range to 18000km.

Table 5. 23Input values of the Airbus 350-900

Parameter	Symbol	Units	Chosen value
PAX			315
Landing field length (ISA)	S _{LFL}	m	1960
Approach speed	V _{APP}	m/s	72
Take-off field length (ISA)	S _{TOFL}	m	2830
Range (max payload)	R	km	10000
Cruise Mach number	M _{CR}		0,85
Cruise speed	V _{CR}	m/s	250,5
Cruise altitude	h _{CR}	m	13100
Wing area	Sw	m²	443
Wing span	b _W	m	64,75
Aspect ratio	Α		9,25
Maximum take-off mass	m _{MTO}	kg	265000
Payload mass	m _{PL}	kg	49800
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,188
Maximum landing mass	m _{ML}	kg	202500
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,764
Operating empty mass	moe	kg	130700
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		0,493
Maximum zero fuel mass	m _{MZF}	kg	189500
Wing loading	m _{MTO} /S _W	kg/m²	598
Number of engines	n _E		2
Engine type			Trent XWB-74
Take-off thrust for one engine	T _{TO,one engine}	kN	329
Total take-off thrust	T _{TO}	kN	658
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,25
Bypass ratio	μ		8,9
Overall pressure ratio	OAPR		
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	138
Sweep angle	Ф25	0	35
Mean aerodynamic chord	C _{MAC}	m	8,35
Position of maximum camber	X _{(y_c),max}	%c	15
Camber	(y _c) _{max} /c	%c	1,8
Position of maximum thickness	X _{t,max}	%c	30
Relative thickness	t/c	%	15
Taper	λ		0,113

 Table 5. 24
 Reverse engineering results of the Airbus 350-900

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,23	-4
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	1,74	-4
Maximum aerodynamic efficiency	E _{max}	-	22,02	7
Specific fuel consumption	SFC	kg/N/s	1,54E-05	0

5.13 Airbus A330-200

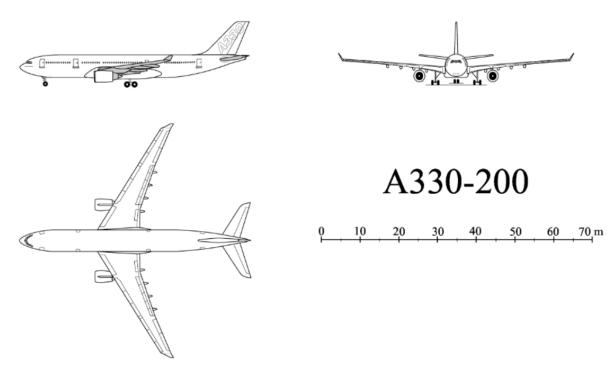


Figure 5. 13 3 view drawing of the Airbus 330-200 (Roux 2007a)

The A330-200 is a medium wide-bodied jet with capacity for a maximum seating of 406 passengers whose first flight took place on August 13, 1997. Iberia and Aerolíneas Argentinas are the first operators of 242t MTOW A330-200s. The 242t MTOW option makes the A330-200 an interesting aircraft for airlines who need the extra performance for hot-and-high operations or who need a suitable aircraft for long range, relatively low demand routes.

The A330-200 is the longer range, shorter fuselage development of the A330-300. Airbus positioned the A330-200 as an efficient, more capable and more comfortable alternative to the Boeing 767-300ER. Due to the initial sales success of the A330-200, with 528 aircraft built and delivered, supported by significant interest from leasing companies, Boeing decided to launch the stretched 767-400ER in 1997. The A330-200s newer technology, superior range capability and crew commonality with the A320 and A340 families made the A330-200 the preferred

choice in its category. The coinciding demise of the 767 drove Boeing to the development of the Sonic Cruiser concept and later the 787 (originally 7E7) which initially claimed performance should be 20-30% more efficient (787-8) than the A330-200. However, the 787's troublesome entry into service (delays) caused strong (interim) demand for the A330 is now also offered at an upgraded 242t MTOW for more payload/range to better compete with the 787.

The continuous improvement to the A330 programme and especially the A330-300 means that the A330-300 has now almost the same range to offer as the A330-200 with far more passenger load. This makes the A330-300 a more efficient aircraft. Since 2009 annual sales of the A330-200 have been less than the A330-300 and by 2013 the A330-200 was finally outsold by the A330-300. The A330-200 backlog is currently 25 aircraft.

Table 5. 25Input values of the Airbus 330-200

Parameter	Symbol	Units	Chosen value
PAX			375
Landing field length (ISA)	S _{LFL}	m	1750
Approach speed	V _{APP}	m/s	70
Take-off field length (ISA)	S _{TOFL}	m	2500
Range (max payload)	R	km	7400
Cruise Mach number	M _{CR}		0,82
Cruise speed	V _{CR}	m/s	241,79
Cruise altitude	h _{CR}	m	11887
Wing area	S _W	m²	361,6
Wing span	b _w	m	60,3
Aspect ratio	Α		10,01
Maximum take-off mass	m _{MTO}	kg	242000
Payload mass	m _{PL}	kg	47400
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		0,196
Maximum landing mass	m _{ML}	kg	180000
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,744
Operating empty mass	m _{OE}	kg	120600
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,498
Maximum zero fuel mass	m _{MZF}	kg	168000
Wing loading	m _{MTO} /S _W	kg/m²	633
Number of engines	n _E		2
Engine type			Trent 772B-60
Take-off thrust for one engine	T _{TO,one engine}	kN	316,279
Total take-off thrust	T _{TO}	kN	632,558
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,28
Bypass ratio	μ		4,89
Overall pressure ratio	OAPR		36,8
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,60E-05
Available fuel volume	V _{fuel,available}	m³	139,09
Sweep angle	ф ₂₅	0	29,7
Mean aerodynamic chord	C _{MAC}	m	7,28
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	15,3-11,3-10,6
Taper	λ		0,235

 Table 5. 26
 Reverse engineering results of the Airbus 330-200

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,66	0
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,35	U
Maximum aerodynamic efficiency	E _{max}	-	19,19	10
Specific fuel consumption	SFC	kg/N/s	1,64E-05	-4

5.14 Embraer 190

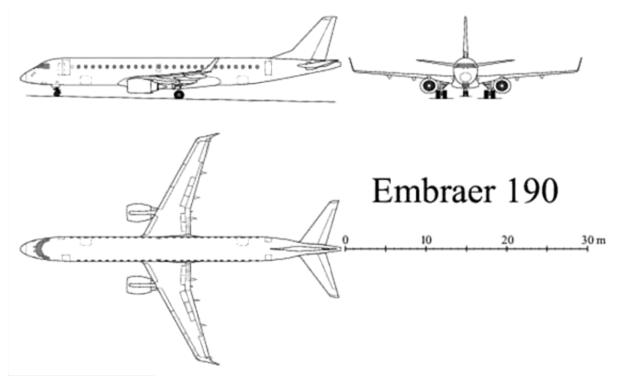


Figure 5. 14 3 view drawing of the Embraer 190 (Roux 2007a)

The Embraer 190 is a large regional jet with capacity for a maximum seating of 114 passengers whose first flight took place on March 12, 2004. It is currently offered in a standard, long and advanced range (STD/LR/AR) variant of which the -AR has become the production standard. The E190 is a stretch of the E170 and has a larger wing and more powerful engines with FADEC technology. It got certified for steep approaches in 2010 and enjoys a reasonable sound operator base (up to 44).

The Embraer 190 was launched by successful US low-cost carrier JetBlue Airways, which meant a significant victory for Embraer, indicating the viability of an E-jet as a low density route and market development aircraft. Apart from the North American market including Air

Canada (45 orders, from which 25 still in service) and American (20, inherited after the US Airways merger) as important customers, significant orders were taken from Latin America, Europe and Asia. There are currently 484 built and delivered aircraft and 52 more on order.

The E190's main competitor is the more efficient but narrower CRJ900/1000 and it is a replacement for the older Fokker F100, BAe146-300 and Avro RJ100. Also, for network operators, the E190 is an alternative for the smallest members of the 737 and A320 families. These offer fleet commonality benefits but are also significantly heavier, have much higher trip costs and are more difficult to fill in low density market. Going forward, the success of the E190 will be challenged by new competitors of which the slightly larger CS100 and slightly smaller MRJ90 will be equipped with considerably more efficient engines. Consequently, Embraer was forced to revamp its E-jet family. Early 2013 Embraer announced an enhanced version of the "1st" generation E-Jet, featuring a redesigned wingtip and two packages of aerodynamic, structural and systems improvements to the wing and the fuselage. The new E190 will not feature the new wingtip, designed exclusively for the E175. All these adjustments will lead to a reduction of fuel consumption by 1-2% on the E190.

Table 5. 27Input values of the Embraer 190

Parameter	Symbol	Units	Chosen value
PAX			106
Landing field length (ISA)	S _{LFL}	m	1323
Approach speed	V _{APP}	m/s	
Take-off field length (ISA)	S _{TOFL}	m	2076
Range (max payload)	R	km	1852
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	236
Cruise altitude	h _{CR}	m	10669
Wing area	Sw	m²	92,53
Wing span	b _W	m	28,72
Aspect ratio	Α		8,92
Maximum take-off mass	m _{MTO}	kg	51800
Payload mass	m _{PL}	kg	12900
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,249
Maximum landing mass	m _{ML}	kg	43000
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,830
Operating empty mass	m _{OE}	kg	27900
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,539
Maximum zero fuel mass	m _{MZF}	kg	40800
Wing loading	m _{MTO} /S _W	kg/m²	516,5
Number of engines	n _E		2
Engine type			CF34-10E5
Take-off thrust for one engine	T _{TO,one engine}	kN	82,292
Total take-off thrust	T _{TO}	kN	164,584
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,35
Bypass ratio	μ		5
Overall pressure ratio	OAPR		29
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,08E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	16,029
Sweep angle	ф ₂₅	0	
Mean aerodynamic chord	C _{MAC}	m	3,68
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	$\mathbf{X}_{t,max}$	%с	
Relative thickness	t/c	%	15,3-11,3-10,6
Taper	λ		

 Table 5. 28
 Reverse engineering results of the Embraer 190

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,28	-12
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	1,95	
Maximum aerodynamic efficiency	E _{max}	-	14,41	29
Specific fuel consumption	SFC	kg/N/s	1,80E-05	-4

5.15 Embraer 175

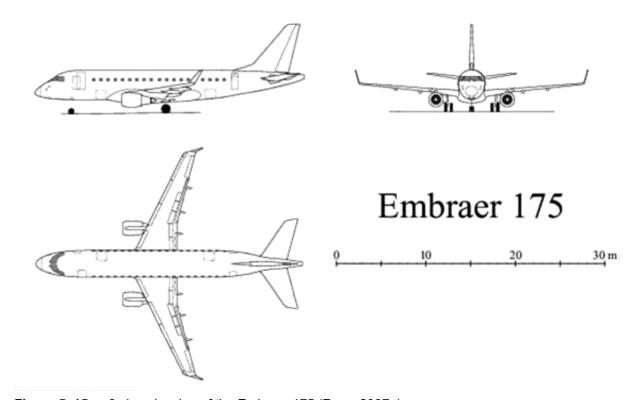


Figure 5. 15 3 view drawing of the Embraer 175 (Roux 2007a)

The Embraer 175 is a medium regional jet with capacity for a maximum seating of 88 passengers whose first flight took place on June 15, 2003. Like the E170, the E175 is offered in a basic, mid and high gross weight version (STD/LR/AR) with increasing range. The Embraer 175 is a two seat row stretch of the E170, resulting in an increased payload (8 more seats) at the cost of reduced range capability. Contrary to the E170 or the E190, the E175 is not certified for steep approaches which exclude it from certain airports like London City.

The scope clause optimized E175 is especially popular in the US and this has resulted in a huge concentration of E175s (80,3%) in the US at Republic Airlines (126 in service / 5 on order), Skywest Airlines (103 in service / 2 on order), Mesa Airlines (54 in service), Compass Airlines

(56 in service), Envoy Air (40 in service / 4 on order), Horizon Air (10 in service / 23 on order). As can be seen from this list, the E175 still has a healthy order backlog.

Like the E170, the main competition comes from the lighter but narrower CRJ700 but also the more efficient 70 seat turboprops (ATR72-500 and Q400) have become increasingly popular due to lower fuel burn, lower noise and fewer emissions. The arrival of a new regional jets such as the Superjet SSJ100, the Bombardier CS100 and Mitsubishi's MRJ70/90, the last two featuring significantly more efficient ultra-high bypass ratio engines, forced Embraer to revamp its E-jet family, announcing an enhanced version of the "1st" generation E-Jet, featuring a redesigned wingtip and two packages of aerodynamic, structural and systems improvements to the wing and the fuselage which led to a reduction of fuel consumption by 5% for the E175. The E175 is the only member of the E-jet family that features the full package of modifications, because: i) it believes the performance improvements will be most pronounced on this variant; ii) the E175 will be the last version of the "E1" family to be replaced by the "E2" and; iii) to strengthen the E175's position as the preferred scope optimized regional jet in North America.

Table 5. 29Input values of the Embraer 175

Parameter	Symbol	Units	Chosen value
PAX			86
Landing field length (ISA)	S _{LFL}	m ,	1294
Approach speed	V _{APP}	m/s	1714
Take-off field length (ISA)	S _{TOFL}	m	1714
Range (max payload)	R	km	1815
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	221,4
Cruise altitude	h _{CR}	m	10668
Ning area	Sw	m²	72,72
Wing span	bw	m	26
Aspect ratio	A	111	9,3
Aspect ratio	Α		3,3
Maximum take-off mass	m _{MTO}	kg	40370
Payload mass	m _{PL}	kg	10200
Mass ratio, payload - take-off	m _{PL/} m _{MTO}	Ng .	0,253
Maximum landing mass	m _{ML}	kg	34100
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	'v9	0,845
Operating empty mass	m _{OE}	kg	21500
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	Ng	0,533
Maximum zero fuel mass	m _{MZF}	kg	31700
Wing loading	m _{MTO} /S _W	kg/m²	515,7
Tring loading	IIIM 1070W	Ng/III	313,7
Number of engines	n _E		2
Engine type			CF34-8E2
Take-off thrust for one engine	T _{TO,one engine}	kN	62,275
Total take-off thrust	T _{TO}	kN	124,55
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,34
Bypass ratio	μ		5
Overall pressure ratio	OAPR		28,5
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,11E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	11,625
Sweep angle	ф 25	٥	
Mean aerodynamic chord	C _{MAC}	m	3,195
Position of maximum camber	X _{(y_c),max}	%c	-,200
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		

 Table 5. 30
 Reverse engineering results of the Embraer 175

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,39	-15
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,41	-15
Maximum aerodynamic efficiency	E _{max}	-	15,02	27
Specific fuel consumption	SFC	kg/N/s	1,94E-05	-6

5.16 Boeing 737-900ER

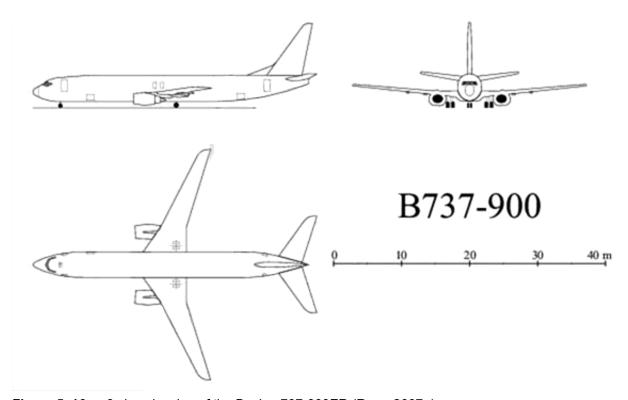


Figure 5. 16 3 view drawing of the Boeing 737-900ER (Roux 2007a)

The 737-900ER is a large narrow-bodied jet with capacity for a maximum seating of 215 passengers whose first flight took place on September 5, 2006. It was developed by Boeing as a solution to the bad outcome that had the 737-900, which was not able to compete effectively with the A321. The 737-900ER offers longer range and more seats. Technically, it features a flat rear pressure bulkhead which enlarges the usable cabin space, a pair of additional "midexit" doors to increase the maximum seat capacity to 215, structural and aerodynamic changes and two optional additional fuel tanks which increase the range to enable it to fly 'coast-to-coast' in the US domestic market

In the first years of service, the 737-900ER fleet was highly concentrated with Lion Air and this somehow contributed to its stigma as a not very liquid, difficult-to-finance asset. Since

2011, things have improved, especially thanks to big orders from United and Delta Air Lines, who saw the aircraft as a more-able replacement for their domestic 757- 200s than the smaller 737-800. With 136 aircraft (all in service), United is the biggest operator of the type, followed by Delta with a fleet of 120 aircraft (83 aircraft in service and 37 on order).

With only 21 operators and its high fleet concentration in North America and Indonesia, it is clear that the 737-900ER does not have the market appeal of its fiercest competitor, the A321-200. On paper, the 737-900ER matches some of the A321-200's key capabilities but, a combination of a late introduction compared to the rest of the 737NG family and a poor field performance in hot/high take-off conditions meant that the aircraft failed to match the A321 for sales volume and particularly for growth of the operator base.

Table 5. 31Input values of the Boeing 737-900

Parameter	Symbol	Units	Chosen value
PAX			215
Landing field length (ISA)	S _{LFL}	m	1660
Approach speed	V _{APP}	m/s	72
Take-off field length (ISA)	S _{TOFL}	m	2600
Range (max payload)	R	km	3120
Cruise Mach number	M _{CR}		0,785
Cruise speed	V _{CR}	m/s	228,61
Cruise altitude	h _{CR}	m	11215
Wing area	Sw	m²	125
Wing span	b _w	m	34,32
Aspect ratio	A		9,4
			٠, .
Maximum take-off mass	m _{MTO}	kg	79015
Payload mass	m _{PL}	kg	17830
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	9	0,226
Maximum landing mass	m _{ML}	kg	66360
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	9	0,840
Operating empty mass	m _{OE}	kg	42493
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	3	0,538
Maximum zero fuel mass	m _{MZF}	kg	62730
Wing loading	m _{MTO} /S _W	kg/m²	595,1
3 444 3		J	
Number of engines	n _E		2
Engine type			CFM56-7B26
Take-off thrust for one engine	T _{TO,one engine}	kN	117,433
Total take-off thrust	T _{TO}	kN	234,866
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,32
Bypass ratio	μ		5,6
Overall pressure ratio	OAPR		27,9
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,08E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	29,663
Sweep angle	Ф25	۰	25,02
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%c	10
Camber	(y _c) _{max} /c	%c	0,8
Position of maximum thickness	X _{t,max}	%c	29,7
Relative thickness	t/c	%	12,5
Taper	λ		0,219

Table 5. 32 Reverse engineering results of the Boeing 737-900

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,99	-12
Maximum lift coefficient, take-off	C _{L,max,TO}	-	1,88	-12
Maximum aerodynamic efficiency	E _{max}	-	16,00	15
Specific fuel consumption	SFC	kg/N/s	1,77E-05	-8

5.17 Bombardier CRJ200

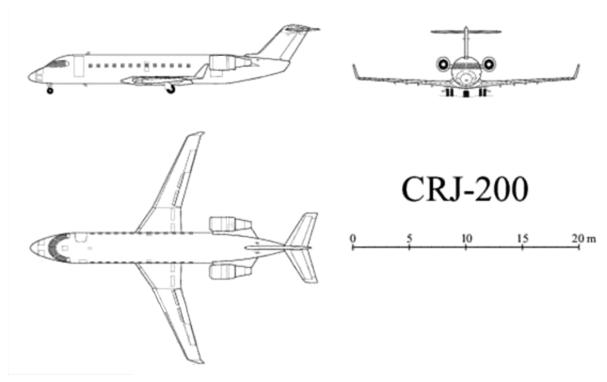


Figure 5. 17 3 view drawing of the Bombardier CRJ200 (Roux 2007a)

The CRJ100 is a small regional jet with capacity for a maximum seating of 50 passengers whose first flight took place on May 10, 1991. The CRJ200 is basically a CRJ100 with improved engines and also exists in -ER and -LR version. It is effectively a stretch of the Bombardier CL-601 Challenger corporate jet.

In the nineties, the 'Canadair Regional Jet' replaced a part of the more fuel-efficient but slower turboprop fleets in hub-spoke networks, but also supplemented mainline narrowbody operations during off-peak hours and developed new thin point-to point routes taking away traffic from competitors ("hub raiding"). Vis-a-vis Embraer's 50 seater jets (ERJs), the Bombardier products had a head start as they were available a couple of years earlier. US mainline pilot unions, who

considered the regional jet a threat, forced limitations (via so-called scope clauses) on the number and size of regional jets to be operated by the US Major carriers via their regional partners. By virtually excluding the use of regional jets larger than 50 seats, the unions created a synthetic market for (sub-optimized) 50-seaters. A few years later, relaxation of the scope clauses led to an oversupply of 50-seaters as airlines switched to the more economical 70-seater regional jets. Many CRJ100/200 ended up in the famous storage areas in the Southwestern US deserts. The CRJ100/200s had some success as a (converted) Corporate/VIP-jet (101 in service / 13 stored), though large concentrations of the passenger fleet remain in the North American regional market.

 Table 5. 33
 Input values of the Bombardier CRJ200

Parameter	Symbol	Units	Chosen value
PAX			50
Landing field length (ISA)	S _{LFL}	m	1478
Approach speed	V _{APP}	m/s	70
Take-off field length (ISA)	S _{TOFL}	m	1768
Range (max payload)	R	km	1064,9
Cruise Mach number	M _{CR}		0,74
Cruise speed	V _{CR}	m/s	225
Cruise altitude	h _{CR}	m	11278
Ving area	Sw	m²	57,07
Ving span	b _w	m	21,21
Aspect ratio	A		7,88
•			,
Maximum take-off mass	m _{MTO}	kg	24041
Payload mass	m _{PL}	kg	6125
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	•	0,255
Maximum landing mass	m _{ML}	kg	21320
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	3	0,887
Operating empty mass	m _{OE}	kg	13835
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	3	0,575
Maximum zero fuel mass	m _{MZF}	kg	19960
Wing loading	m _{MTO} /S _W	kg/m²	424
g	333,110.00		
Number of engines	n _E		2
Engine type	_		CF34-3B1
Take-off thrust for one engine	T _{TO,one engine}	kN	41,012
Total take-off thrust	T _{TO}	kN	82,024
Γhrust to weight ratio	T _{TO} /(m _{MTO} *g)	T _{TO} /(m _{MTO} *g)	0,39
Bypass ratio	μ		6,3
Overall pressure ratio	OAPR		21
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	9,80E-06
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	,
	(5.2.2)		
Available fuel volume	V _{fuel,available}	m³	8,081
Sweep angle	ф ₂₅	۰	24,9
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		0,248

 Table 5. 34
 Reverse engineering results of the Bombarider CRJ200

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,36	-11
Maximum lift coefficient, take-off	C _{L,max,TO}	-	1,60	-11
Maximum aerodynamic efficiency	E _{max}	-	15,17	16
Specific fuel consumption	SFC	kg/N/s	1,77E-05	11

5.18 Boeing 767-300

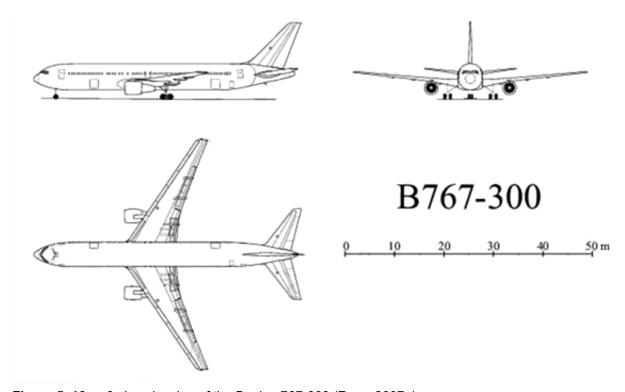


Figure 5. 18 3 view drawing of the Boeing 767-300 (Roux 2007a)

The 767-300 is a medium wide-bodied jet with capacity for a maximum seating of 229 passengers whose first flight took place on January 30, 1986. The basic 767-300 is essentially a 45 seat stretch of the 767-200. Boeing almost simultaneously developed the higher gross weight 767-300ER which has up to 3700km of additional range, a standard lower deck large cargo door and is mostly used on inter-continental routes. The 767-300ER is the most successful member of the 767 family, selling over 500.

However, like the 757, the 767 is technically outdated, a problem that became obvious after the introduction of the A330-200 which is more efficient and more capable. Many airlines therefore replaced their 767-300ERs with the new Airbus products (among others KLM, Air Europa, SAS, and Air France). Although still on offer by Boeing, sales of the 767-300ER have dried

up. The A330-200 still records moderate sales and has already outsold the 767-300ER. It is possible to upgrade the 767-300ER with winglets (4-5% fuel burn improvement) which has been done to 270 aircraft, mostly by the US majors which still operate the majority of the 767-300(ER) fleet. Boeing's 787 will replace a large part of all 767s in the near future. However, the economics of 767-300ER with relative low capital costs but a higher fuel burn work better than those of a fuel efficient, but expensive to acquire 787-8, especially in a low fuel price environment.

Table 5. 35Input values of the Boeing 767-300

Parameter	Symbol	Units	Chosen value
PAX			290
Landing field length (ISA)	S _{LFL}	m	1646
Approach speed	V _{APP}	m/s	74,6
Take-off field length (ISA)	S _{TOFL}	m	2545
Range (max payload)	R	km	3873
Cruise Mach number	M _{CR}		0,8
Cruise speed	V _{CR}	m/s	236,5
Cruise altitude	h _{CR}	m	11887
Wing area	S _w	m²	283,3
Wing span	bw	m	47,57
Aspect ratio	A	•••	7,99
A Special Paris	^		7,55
Maximum take-off mass	m _{MTO}	kg	158758
Payload mass	m _{PL}	kg	39140
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	'\9	0,247
Maximum landing mass	m _{ML}	kg	136078
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	Ng .	0,857
Operating empty mass		kg	84541
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}	kg	0,533
Maximum zero fuel mass		lea.	126099
	m _{MZF}	kg	552
Wing loading	m _{MTO} /S _W	kg/m²	332
Number of engines	n _E		2
Engine type			CF6-80C2B2F
Take-off thrust for one engine	T _{TO,one engine}	kN	231,351
Total take-off thrust	T _{TO}	kN	462,702
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,3
Bypass ratio	μ		5,3
Overall pressure ratio	OAPR		30,4
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	9,00E-06
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,63E-05
(,	(5.5.4)		·
Available fuel volume	V _{fuel,available}	m³	63,216
Sweep angle	ф ₂₅	۰	31,5
Mean aerodynamic chord	-	m	6,98
	C _{MAC}		20
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	1,5
Position of maximum thickness	X _{t,max}	%c	20
Relative thickness	t/c	%	11,5
Taper	λ		0,207

 Table 5. 36
 Reverse engineering results of the Boeing 767-300

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,73	1
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	1,73	•
Maximum aerodynamic efficiency	E _{max}	-	17,44	11
Specific fuel consumption	SFC	kg/N/s	1,52E-05	4

5.19 Bombardier CRJ900

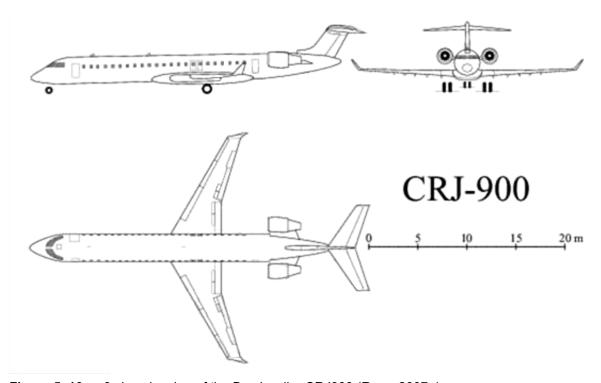


Figure 5. 19 3 view drawing of the Bombardier CRJ900 (Roux 2007a)

The CRJ900 is a large regional jet with capacity for a maximum seating of 90 passengers whose first flight took place on February 21, 2001. The CRJ900 is a further stretch of the already stretched CRJ700 (almost twice the length of the original CL-601 Challenger) with more powerful engines. The aircraft is offered in a standard and high gross weight -ER version, this last one offering 430km additional range. In April 2016 Bombardier introduced an improved cabin for the CRJ900, with larger bins, larger forward toilet and bigger entrance area. These improvements are also available as retrofit for older CRJ900s.

The main competition for the CRJ900 comes from the smaller 78-seat Embraer 175 but primarily the slightly larger 98-seat Embraer 190. In general, the CRJ is slightly more efficient, partly

due to the E-Jets' larger cabin crosssection offering more comfort, which is however appreciated by the passengers, especially on longer routes. Looking forward, Mitsubishi's all new MRJ90 could turn out to be a very efficient, modern technology, competitor as well.

Initially, there was only very limited airline interest, though (in anticipation of) further relaxation of scope clauses, ordering eventually took off. The CRJ900 now also 'benefits' from scope clauses, prohibiting some operators to scale up to larger RJs or even mainline narrowbodies on some routes. The CRJ900(ER) offers the advantage of commonality with the existing fleet of CRJ's. Although not many, the CRJ900 still gets some orders.

 Table 5. 37
 Input values of the Bombardier CRJ900

Parameter	Symbol	Units	Chosen value
PAX			86
Landing field length (ISA)	S _{LFL}	m	1596
Approach speed	V _{APP}	m/s	71,5
Take-off field length (ISA)	S _{TOFL}	m	1878
Range (max payload)	R	km	1828
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	244
Cruise altitude	h _{CR}	m	
Wing area	S _W	m²	68,63
Wing span	bw	m	23,24
Aspect ratio	A		7,87
Maximum take-off mass	m _{MTO}	kg	38329
Payload mass	m _{PL}	kg	10205
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,266
Maximum landing mass	m _{ML}	kg	33340
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,870
Operating empty mass	m _{OE}	kg	21432
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		0,559
Maximum zero fuel mass	m _{MZF}	kg	31751
Wing loading	m _{MTO} /S _W	kg/m²	532
Number of engines	n _E		2
Engine type			CF34-8C5
Take-off thrust for one engine	T _{TO,one engine}	kN	64,499
Total take-off thrust	T _{TO}	kN	128,998
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,36
Bypass ratio	μ		4,9
Overall pressure ratio	OAPR		28,5
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,11E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	10,989
Sweep angle	ф ₂₅	۰	
Mean aerodynamic chord	C _{MAC}	m ov -	
Position of maximum camber	X _{(y_c),max}	%c	
Camber Position of maximum thickness	(y _c) _{max} /c	%c %c	
Relative thickness	X _{t,max}	%c %	
Taper	λ	/0	
Taper	^		

 Table 5. 38
 Reverse engineering results of the Bombardier CRJ900

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,84	-3
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,24	-3
Maximum aerodynamic efficiency	E _{max}	-	15,17	16
Specific fuel consumption	SFC	kg/N/s	1,47E-05	25

5.20 Embraer ERJ-145

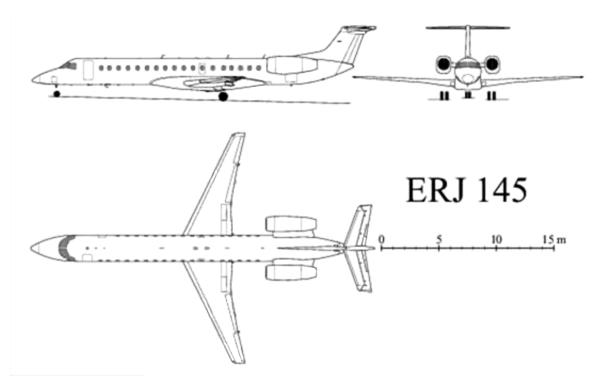


Figure 5. 20 3 view drawing of the Embraer ERJ-145 (Roux 2007a)

The Embraer ERJ-145 is a small regional jet with capacity for a maximum seating of 50 passengers whose first flight took place on August 11, 1995. The ERJ-145 was offered in seven different variants (excluding military and business jets), each tailored to match different range and MTOW requirements for different operators. Embraer has developed the –EU and –EP version of the ERJ-145ER and the LU variant of the ERJ-145LR for (European) airlines which prefer aircraft that fall in lower MTOW fee scales for airports and ATC. For airlines that did need the MTOW capabilities of the –LR, but didn't have a long-range capability requirement, Embraer developed the –MP. Furthermore, it developed the extra-long range –XR for Continental's ExpressJet. The –LR version is by far the preferred variant of the ERJ-145 with 37 operators, a fleet of 226 aircraft in service and 117 aircraft in storage.

The combination of high fleet concentration in the US and the scope clause relaxations to 70+ seats resulted the phase-out of many ERJ-145's. In the secondary market, there is strong competition from the surplus of similar sized CRJ100/200 jets. Although a high level of commonality remains among the different ERJ-145 versions, it turned out that all these different variants further complicate remarketing efforts.

Table 5. 39Input values of the Embraer ERJ 145

Parameter	Symbol	Units	Chosen value
PAX			50
Landing field length (ISA)	S _{LFL}	m	1400
Approach speed	V _{APP}	m/s	65
Take-off field length (ISA)	S _{TOFL}	m	2270
Range (max payload)	R	km	1759
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	231,5
Cruise altitude	h _{CR}	m	11278
Wing area	Sw	m²	51,18
Wing span	b _W	m	20,04
Aspect ratio	Α		7,85
Maximum take-off mass	m _{MTO}	kg	22000
Payload mass	m _{PL}	kg	5153
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,234
Maximum landing mass	m _{ML}	kg	18700
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,850
Operating empty mass	m _{OE}	kg	11947
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,543
Maximum zero fuel mass	m _{MZF}	kg	17100
Wing loading	m _{MTO} /S _W	kg/m²	402,5
Number of engines	n _E		2
Engine type			AE3007A1/1
Take-off thrust for one engine	T _{TO,one engine}	kN	33,717
Total take-off thrust	T _{TO}	kN	67,434
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,33
Bypass ratio	μ		5,3
Overall pressure ratio	OAPR		23
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	5,146
Sweep angle	ф ₂₅	۰	22,7
Mean aerodynamic chord	C _{MAC}	m	3,13
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	$\mathbf{X}_{t,max}$	%c	
Relative thickness	t/c	%	11
Taper	λ		0,254

 Table 5. 40
 Reverse engineering results of the Embraer ERJ-145

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	2,44	-9
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	1,34	-9
Maximum aerodynamic efficiency	E _{max}	-	16,55	2
Specific fuel consumption	SFC	kg/N/s	1,47E-05	66

5.21 Boeing 787-8

Boeing 787-8

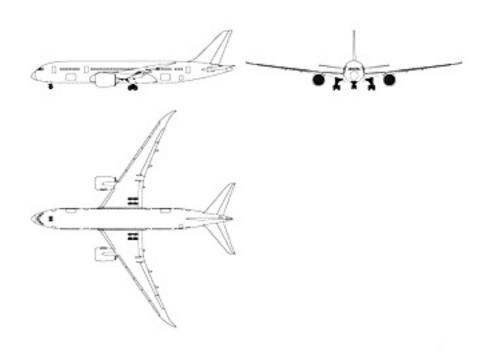


Figure 5. 21 3 view drawing of the Boeing 787-8 (Blueprints 2020)

The 787-8 is a medium wide-bodied jet with capacity for a maximum seating of 440 passengers whose first flight took place on December 15, 2009. The 787 family is initially designed to replace the 757- and 767 products and is the most successful wide-bodied aircraft design ever in terms of aircraft ordered prior to its entry into service. The 787 family features many new technologies like a full composite structure including wing and barrel shaped fuselage sections (accommodates 9 abreast seating), new up to 15-20% more efficient and relatively quiet engines, improved aerodynamics and many new electric systems instead of pneumatics/ hydraulics.

The 787-8 is the 'baseline model' and is optimized for the long-range medium-density markets and would serve as such as a replacement for the 767-300ER and be a new threat to the successful A330-200. Furthermore, its ultra-long-range capability enables it as well to develop new point-to-point routes, as airlines may use it as "pathfinder" to develop routes between city-pairs at long range that have insufficient traffic density to (yet) justify the larger long range aircraft types. Design and production difficulties lead to multiple serious delays of the first delivery. As of summer 2017, more than 330 787-8s have been built and delivered to more than 40 operators.

Table 5. 41Input values of the Boeing 787-8

Parameter	Symbol	Units	Chosen value
PAX			440
Landing field length (ISA)	S _{LFL}	m	1520
Approach speed	V _{APP}	m/s	72
Take-off field length (ISA)	S _{TOFL}	m	3100
Range (max payload)	R	km	10180
Cruise Mach number	M _{CR}		0,85
Cruise speed	V _{CR}	m/s	252
Cruise altitude	h _{CR}	m	
	- Tolk		
Wing area	Sw	m²	325
Wing span	bw	m	60,12
Aspect ratio	A		11,1
·			
Maximum take-off mass	m _{MTO}	kg	227930
Payload mass	m _{PL}	kg	45359
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	•	0,199
Maximum landing mass	m _{ML}	kg	167825
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	· ·	0,736
Operating empty mass	m _{OE}	kg	117480
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	•	0,515
Maximum zero fuel mass	m _{MZF}	kg	161025
Wing loading	m _{MTO} /S _W	kg/m²	
Number of engines	n _E		2
Engine type			GEnx 72A1
Take-off thrust for one engine	T _{TO,one engine}	kN	235,76
Total take-off thrust	T _{TO}	kN	471,52
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
Bypass ratio	μ		9
Overall pressure ratio	OAPR		43,8
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	126,917
Sweep angle	ф ₂₅	٥	32,2
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%с	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		

Table 5. 42 R	Reverse engineering	results of th	e Boeing 787-8
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Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,96	0
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	1,91	U
Maximum aerodynamic efficiency	E _{max}	-	19,73	29
Specific fuel consumption	SFC	kg/N/s	1,16E-05	30

5.22 Boeing 777-200ER

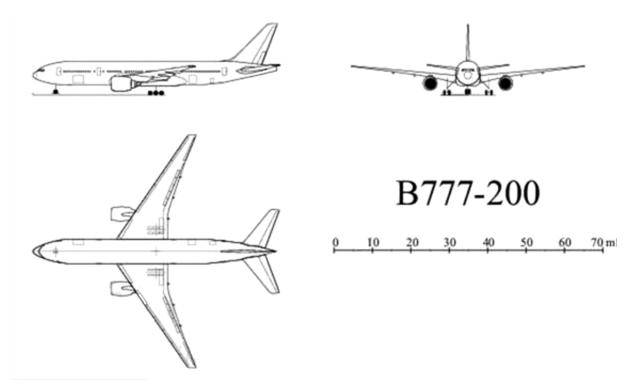


Figure 5. 22 3 view drawing of the Boeing 777-200ER (Roux 2007a)

The 777-200ER is a large wide-bodied jet with capacity for a maximum seating of 440 passengers whose first flight took place on October 7, 1996. The Boeing 777-family was developed to fill the capacity gap between the 767 and 747-400 and to replace older wide bodies as DC-10 and L 1011 Tristar. Especifically, the 777-200ER, also referred to as the 777-200IGW (increased gross weight) or 777B, was developed to replace the DC-10 and L1011 tri-jets on long-haul routes and compete with the four engine A340-300 and the MD-11 tri-jet. The 777-200ER is offered in six different gross weight variants. Its payload/range performance combined with the efficiency of twin-engines made the 777-200ER the fastest selling wide-bodied until the 787 was launched.

In recent years, sales of the 777-200ER have dried up and although the aircraft is still offered by Boeing there are no 777-200ERs on backlog. The 777-200ER has long been one of the most

popular wide-bodied aircraft in the market. But with a new generation aircraft entering service in the coming years and the fact the 777-200ER design is starting to age, many aircraft will be phased out in the coming years. Most 777-200ERs are still in service operated by their original operator. With the new replacement types as the 787-9 and A350-900 now entering service and their deliveries finally getting momentum, it is not expected that market values for 777-200ER aircraft will recover.

Many airlines favour the A330-300 especially the new 240t and 242T MTOW variants or go for the larger 777-300ER variant, which has become the most popular model within the 777-family. In 2013, the 777-200ER was overtaken by the 777-300ER in terms of the number of aircraft produced. It seems that Airbus finally will challenge the 777-200ER's market dominance with the A350-900 design. For operators that don't need the range, the more efficient high gross weight A330-300 (or the future A330-900N) is more attractive.

Table 5. 43Input values of the Boeing 777-200ER

Parameter	Symbol	Units	Chosen value
PAX			440
Landing field length (ISA)	S _{LFL}	m	1585
Approach speed	V _{APP}	m/s	71
Take-off field length (ISA)	S _{TOFL}	m	2135
Range (max payload)	R	km	4820
Cruise Mach number	M _{CR}		0,84
Cruise speed	V _{CR}	m/s	
Cruise altitude	h _{CR}	m	11155
Wing area	Sw	m²	427,8
Wing span	b _w	m	60,93
Aspect ratio	A		8,68
Maximum take-off mass	m _{MTO}	kg	242670
Payload mass	m _{PL}	kg	54635
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		0,225
Maximum landing mass	m _{ML}	kg	200050
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,824
Operating empty mass	m _{OE}	kg	135550
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,559
Maximum zero fuel mass	m _{MZF}	kg	190510
Wing loading	m _{MTO} /S _W	kg/m²	567
Number of engines	n _E		2
Engine type			GE90-85B
Take-off thrust for one engine	T _{TO,one engine}	kN	377
Total take-off thrust	T _{TO}	kN	754
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,32
Bypass ratio	μ		8,4
Overall pressure ratio	OAPR		40
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	9,18E-06
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,47E-05
Available fuel volume	V _{fuel,available}	m³	117,348
Sweep angle	ф ₂₅	•	31,6
Mean aerodynamic chord	C _{MAC}	m	8,75
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%с	
Position of maximum thickness	$\mathbf{X}_{t,max}$	%с	
Relative thickness	t/c	%	14,5-11,1-10,4
Taper	λ		0,149

 Table 5. 44
 Reverse engineering results of the Boeing 777-200

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,76	-11
Maximum lift coefficient, take-off	C _{L,max,TO}	-	1,96	-11
Maximum aerodynamic efficiency	E _{max}	-	17,81	-1
Specific fuel consumption	SFC	kg/N/s	1,26E-05	18

5.23 McDonnel Douglas MD-83

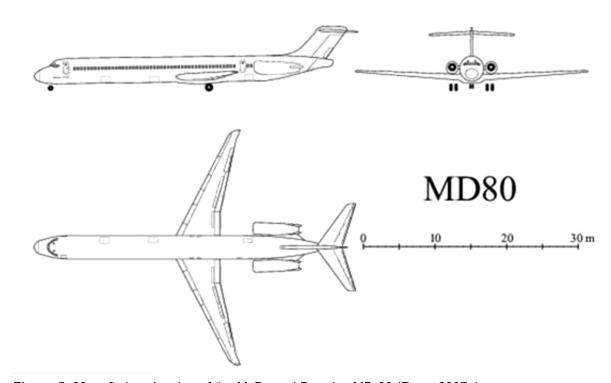


Figure 5. 23 3 view drawing of the McDonnel Douglas MD-83 (Roux 2007a)

The MD-80 family is the generic term for a number of development versions of small regional jets (MD-81/82/83/87/88) with capacity for a maximum seating of 172 passengers based on the Douglas DC-9, initially referred to as DC-9 'Super 80', whose first flight took place on October 19, 1979.

The MD-81 differed from the DC-9-50 by a 14ft fuselage stretch, improved more quiet PW JT8D Series 200 engines and extended wing. The increased payload/range MD-82, the most successful MD-80, is equipped with the higher thrust JT8D-217 engines. The MD-83 incorporated the slightly higher trust JT8D-219 engines and additional fuel tanks which increased its payload/range capability. The MD-88 is similar to the MD-83, but is equipped with the more advance EFIS-cockpit.

As the first Stage III noise compliant single aisle mainline jet, initially the MD-80 was a commercial success. Powered by engines derived from the "old" JT8D, the MD-80 had a head-start over the competition. Once the 737 Classic (-300/-400/-500) - powered by the more advanced all new CFM56 engines – reached the market, the end of the MD-80 came in sight. The arrival of the Airbus A320 family (powered by the CFM56 as well as the new V2500 engine) meant the beginning of the end for the once very successful (McDonnell) Douglas single aisle product range.

 Table 5. 45
 Input values of the McDonnel-Douglas MD-83

Parameter	Symbol	Units	Chosen value
PAX			172
Landing field length (ISA)	S _{LFL}	m	1585
Approach speed	V _{APP}	m/s	71,51
Take-off field length (ISA)	S _{TOFL}	m	2551
Range (max payload)	R	km	3345
Cruise Mach number	M _{CR}		0,76
Cruise speed	V _{CR}	m/s	225
Cruise altitude	h _{CR}	m	10668
Wing area	Sw	m²	112,3
Wing span	b _w	m	32,87
Aspect ratio	Α		9,62
Maximum take off mass		lea.	72575
Maximum take-off mass	m _{MTO}	kg	72575
Payload mass	m _{PL}	kg	18721
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,258
Maximum landing mass	m _{ML}	kg	63276
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,872
Operating empty mass	m _{OE}	kg	35300
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,486
Maximum zero fuel mass	m _{MZF}	kg	55338
Wing loading	m _{MTO} /S _W	kg/m²	646
Number of engines	_		2
Number of engines	n _E		
Engine type	_	1.51	JT8D-219
Take-off thrust for one engine	T _{TO,one engine}	kN	96,526
Total take-off thrust	T _{TO}	kN	193,052
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,27
Bypass ratio	μ		1,8
Overall pressure ratio	OAPR		20,1
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,47E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	2,09E-05
Available fuel volume	V _{fuel,available}	m³	26,426
_			
Sweep angle	ф ₂₅	•	24,5
Mean aerodynamic chord	C _{MAC}	m	4,08
Position of maximum camber	X _{(y_c),max}	%c	82
Camber	(y _c) _{max} /c	%c	2,3
Position of maximum thickness	X _{t,max}	%c	36
Relative thickness	t/c	%	11
Taper	λ		0,195

Table 5. 46 Reverse engineering results of the McDonnel Douglas MD-83

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	3,32	-17
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,26	-17
Maximum aerodynamic efficiency	E _{max}	-	14,76	24
Specific fuel consumption	SFC	kg/N/s	1,67E-05	23

5.24 Boeing 757-200

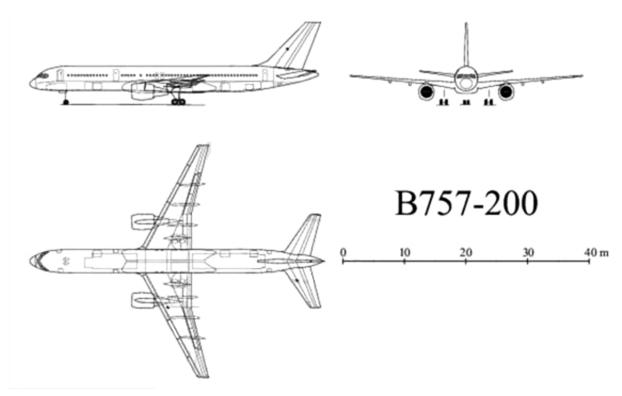


Figure 5. 24 3 view drawing of the Boeing 757-200 (**Roux 2007a**)

The 757-200 is a large narrow-bodied jet with capacity for a maximum seating of 224 passengers whose first flight took place on February 19, 1982. It was developed in conjunction with the wide-bodied 767 programme. As a result, the 757-200 shares some components with the 767 and has a common crew rating. The 757 was designed for trans-continental markets that had outgrown the then-available 727. In its first years of production, the 757 attracted many orders from major carriers and charter airlines alike.

Nevertheless, for the higher frequency mainline operations, legacy carriers and more importantly low cost airlines, mostly selected A320 family or 737NG aircraft, when these aircraft became available on the market. The 757's transcontinental range made the aircraft heavy in comparison to the more modern A320 family and 737NG. The newer A321-200 was lighter, more fuel efficient and also able to fly US coast-to-coast routes. When retrofitted with winglets

(73,3% of pax fleet), the 757-200 became 4-5% more fuel-efficient which opened up a whole new role in low density medium haul (transatlantic) operations. In 2016, Aviation Partners Boeing (APB) introduced the Scimitar Blended Winglets (SBW) for the Boeing 757-200 aircraft which delivered one percent reduction of fuel burn, so were only attractive for aircraft that would remain in service for a longer period of time.

Boeing decided to end the 757 production in 2004. Although the partout phase had already started for older 757s, large fleets of younger 757s remained in passenger service, particularly at some US majors. About 21 percent of the 757-200 fleet is stored today. Some will be converted to freighter, but many will not return to the skies again. With the introduction of even more efficient aircraft with the same seating, payload and range specifications as the 757-200 in the form of the A321Neo and 737-9, the days of the 757-200 as a transcontinental workhorse of the US majors are numbered.

Table 5. 47Input values of the Boeing 757-200

Parameter	Symbol	Units	Chosen value
PAX			224
Landing field length (ISA)	S _{LFL}	m	1550
Approach speed	V _{APP}	m/s	68
Take-off field length (ISA)	S _{TOFL}	m	2225
Range (max payload)	R	km	4440
Cruise Mach number	M _{CR}		0,8
Cruise speed	V _{CR}	m/s	241
Cruise altitude	h _{CR}	m	11795
Wing area	S _W	m²	185,25
Wing span	b _W	m	38,05
Aspect ratio	Α		7,8
Maximum take-off mass	m _{MTO}	kg	115650
Payload mass	m _{PL}	kg	22650
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,196
Maximum landing mass	m _{ML}	kg	89800
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,776
Operating empty mass	m _{OE}	kg	60800
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		0,526
Maximum zero fuel mass	m _{MZF}	kg	83460
Wing loading	m _{MTO} /S _W	kg/m²	538,7
Number of engines	n _E		2
Engine type			RB211-535E4
Take-off thrust for one engine	T _{TO,one engine}	kN	178,5
Total take-off thrust	T _{TO}	kN	357
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,37
Bypass ratio	μ		4,4
Overall pressure ratio	OAPR		25,8
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,72E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,69E-05
Available fuel volume	V _{fuel,available}	m³	42,68
Sweep angle	Ф25	0	25
Mean aerodynamic chord	C _{MAC}	m	5,64
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		0,243

 Table 5. 48
 Reverse engineering results of the Boeing 757-200

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,92	0
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,09	U
Maximum aerodynamic efficiency	E _{max}	-	15,54	15
Specific fuel consumption	SFC	kg/N/s	1,74E-05	-3

5.25 Airbus A380-800

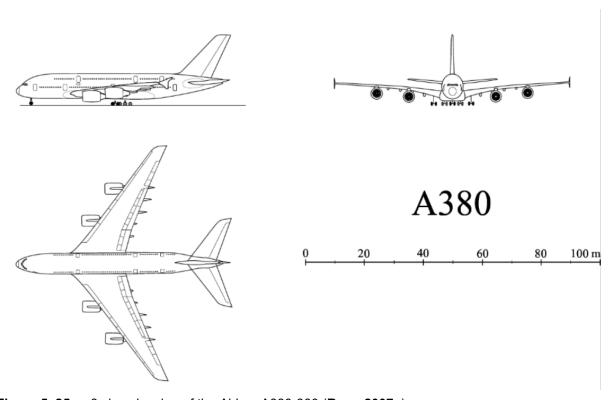


Figure 5. 25 3 view drawing of the Airbus A380-800 (Roux 2007a)

The A380-800 is a very large wide-bodied jet with capacity for a maximum seating of 853 passengers whose first flight took place on April 27, 2005. The double deck A380-800 has been the largest passenger aircraft in production, since it made its first flight in April 2005. According to Airbus, the A380 offers 49% more cabin floor space which results in 26% more seat space than the Boeing 747-400. Also, the A380 is quieter and is claimed to have 1500km more range and 17% better operating economics. The Airbus A380 is offered with a two engine choice. The GP7200 of Engine Alliance and the RR Trent 900. With a market share of 42% for the GP2700 and 49% for the RR Trent, it seems that there is some equilibrium between the two engine manufacturers.

The A380's main competitor is the 747-8I which still will accommodate 58 less seats than A380 but certainly closes in on range and operating economics. It however failed to impress the market so far. Airbus has the opportunity to stretch the current design into an A380-900 to obtain an even larger aircraft with better seat-mile economics, though such stretch seems unlikely in the foreseeable future.

Only 19 different operators have ordered the A380, and its fleet is mainly concentrated with one airline. 45 % of all A380 (in service and on order) are operated or will be operated by Emirates. A380 sales got a highly needed boost in 2013 but since 2013 the order intake of the A380 has again been slow. With this shrinking backlog, Airbus has decided to cut the production from the A380 from twenty-seven aircraft per year to twelve from 2018. Since the very slow order intake for the A380 and some awkward announcements from an Airbus official in 2014 about a possible end of production for the A380 due to the difficulty of turning a profit from the programme, the future of the A380 has been intensely discussed.

Table 5. 49Input values of the A380-800

Parameter	Symbol	Units	Chosen value
PAX			853
Landing field length (ISA)	S _{LFL}	m	2100
Approach speed	V _{APP}	m/s	71
Take-off field length (ISA)	S _{TOFL}	m	2950
Range (max payload)	R	km	12149
Cruise Mach number	M _{CR}		0,85
Cruise speed	V _{CR}	m/s	267,5
Cruise altitude	h _{CR}	m	10668
Wing area	S _W	m²	845,82
Wing span	b _W	m	79,75
Aspect ratio	A		7,52
Maximum take-off mass	m _{MTO}	kg	575000
Payload mass	m _{PL}	kg	83600
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		0,145
Maximum landing mass	m _{ML}	kg	386000
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,671
Operating empty mass	m _{OE}	kg	270015
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,470
Maximum zero fuel mass	m _{MZF}	kg	361000
Wing loading	m _{MTO} /S _W	kg/m²	662
Number of engines	n _E		4
Engine type			Trent 970-84
Take-off thrust for one engine	T _{TO,one engine}	kN	334,282
Total take-off thrust	T _{TO}	kN	1337,128
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,24
Bypass ratio	μ		7,1
Overall pressure ratio	OAPR		45,6
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	324,562
Sweep angle	ф ₂₅	•	35
Mean aerodynamic chord	C _{MAC}	m	12,3
Position of maximum camber	X _{(y_c),max}	%c	81
Camber	(y _c) _{max} /c	%c	2,5
Position of maximum thickness	X _{t,max}	%c	37
Relative thickness	t/c	%	13,4-9,1-9,2
Taper	λ		0,225

 Table 5. 50
 Reverse engineering results of the Airbus 380-800

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,25	-10
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,01	-10
Maximum aerodynamic efficiency	E _{max}	-	18,94	4
Specific fuel consumption	SFC	kg/N/s	1,48E-05	1

5.26 Bombardier CRJ700

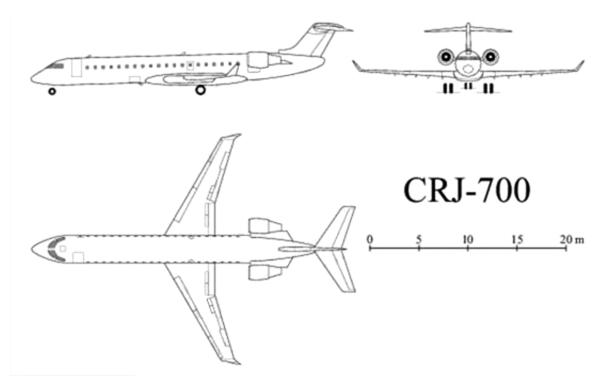


Figure 5. 26 3 view drawing of the Bombardier CRJ700 (Roux 2007a)

The CRJ700 is a medium regional jet with capacity for a maximum seating of 78 passengers whose first flight took place on May 27, 1999. The CRJ700 is a stretched CRJ200 which can accommodate 20 additional passengers. In addition, the CRJ700 includes more powerful engines, a larger wing and tail and a lowered floor and higher cabin windows for increased passenger comfort. The CRJ700 comes in three series: Series 700 for 68 passengers, Series 701 for 70 passengers and Series 702 for 78 passengers. The CRJ 705 is essentially a CRJ900. All series are offered as basic or as a higher gross weight -ER and LR - variant for more range.

Because of the regional jets' dependence on the US market, the success of the CRJ700 was mostly reliant on the relaxation of scope clauses which allowed airlines to replace (a limited number of) 50-seaters on markets that better fit the more efficient 70-seaters. However, further scope clause relaxation could turn the regional operators to the CRJ705/900/1000 and/or

E190/195. Compared to its main Embraer 170 competitor, the CRJ700 benefits from its commonality with the large CRJ-fleet and from lower operating costs. However, the E170 has a larger and more comfortable passenger cabin and has a broader operator base that is much less concentrated to the North American market.

In 2008 the CRJ700 was replaced by the CRJ700 NextGen with an upgraded cabin with larger bins and windows and slightly reduced weights for improved fuel burn. The current order backlog is very limited with just eight aircraft on order. The CRJ700 /CRJ700 NextGen fleet remains very concentrated in the North American market and faces some competition from more efficient larger turboprops as the Dash8-Q400 and ATR72-600. Twelve CRJ700 / CRJ700NextGen are in use as Corporate/VIP aircraft (one stored).

 Table 5. 51
 Input values of the Bombardier CRJ700

Parameter	Symbol	Units	Chosen value
PAX			78
Landing field length (ISA)	S _{LFL}	m	1550
Approach speed	V _{APP}	m/s	69,45
Take-off field length (ISA)	S _{TOFL}	m	1564
Range (max payload)	R	km	1556
Cruise Mach number	M _{CR}		0,77
Cruise speed	V _{CR}	m/s	228
Cruise altitude	h _{CR}	m	
Wing area	S _W	m²	68,63
Wing span	b _W	m	23,24
Aspect ratio	Α		7,87
Maximum take-off mass	m _{MTO}	kg	34019
Payload mass	m _{PL}	kg	8528
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,251
Maximum landing mass	m _{ML}	kg	30390
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,893
Operating empty mass	m _{OE}	kg	19269
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		0,566
Maximum zero fuel mass	m _{MZF}	kg	28259
Wing loading	m _{MTO} /S _W	kg/m²	480,8
Number of engines	n _E		2
Engine type			CF34-8C1
Take-off thrust for one engine	T _{TO,one engine}	kN	61,341
Total take-off thrust	T _{TO}	kN	122,682
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,38
Bypass ratio	μ		4,9
Overall pressure ratio	OAPR		28,5
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,05E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	10,989
Sweep angle	Ф25	0	26,6
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		

 Table 5. 52
 Reverse engineering results of the Bombardier CRJ700

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,67	1
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,02	l
Maximum aerodynamic efficiency	E _{max}	-	13,54	30
Specific fuel consumption	SFC	kg/N/s	1,48E-05	21

5.27 Comac C919

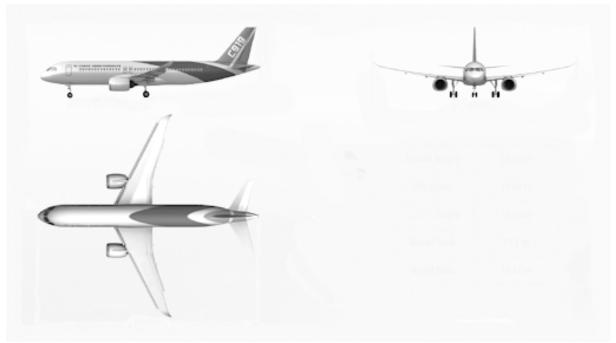


Figure 5. 27 3 view drawing of the Comac C919 (Comac 2018)

The C919 is a medium narrow-bodied jet with capacity for a maximum seating of 168 passengers whose first flight took place on May 5, 2017. In terms of range and PAX capacity, the C919 is very similar to the A320Neo. However, when compared to the A320 family and 737 family, the C919's fuselage is approximately 25cm wider and is able to accommodate an LD3 container in its belly. Initially, the C919 is only offered in one size and features CFM's new Leap-1C engines but this could be complemented with a Chinese domestically developed engine at a later stage as well. The Leap-1C engines are claimed to be up to 15% better than today's standard but A320neo features the same engines and also Pratt & Whitney's PW1000G GTF engines which will probably be equally efficient.

With the C919, Commercial Aircraft Corporation of China (COMAC) makes a serious attempt to break into the Airbus and Boeing hold on the mainline single aisle market. The C919 is designed and built in China with support from reputably western aviation industry suppliers

such as CFMI, Hamilton Sundstrand, Honeywell and GE. Besides the A320Neo the C919 will also compete against the new Boeing 737 Max and Russia's Irkut MS-21. So far 287 C919s have been ordered, mainly by Chinese airlines or leasing companies. It is already clear that the C919s will fulfil a not insignificant part of the aircraft demand in the Chinese market.

It is not yet clear whether this first Chinese commercial mainline aircraft will also be successful abroad. In 2011, Bombardier and COMAC signed an agreement to cooperate in the fields of marketing and support but also collaboration on the complementary C919 and CSeries programmes and future aircraft development was not excluded. It is not totally clear what the partial take-over of the CSeries program by Airbus may mean for the cooperation between Bombardier and COMAC. In 2015 COMAC closed a deal with Boeing to jointly operate a 737 completion centre in China. This agreement already seemed to put stress on the cooperation between Bombardier and COMAC, as engineering experience, certification and after service knowledge can now be obtained by COMAC from the American manufacturer.

Table 5. 53Input values of the Comac C919

DAY		Units	Chosen value
PAX			168
Landing field length (ISA)	S _{LFL}	m	1600
Approach speed	V _{APP}	m/s	69,45
Take-off field length (ISA)		m	2000
rake-off field leftgiff (ISA)	STOFL	III	2000
Range (max payload)	R	km	4075
Cruise Mach number	M _{CR}		0,785
Cruise speed	V _{CR}	m/s	231,5
Cruise altitude	h _{CR}	m	7965
Ving area	Sw	m²	129,15
Wing span	bw		
• .	A	m	35,8
Aspect ratio	A		
Maximum take-off mass	m _{MTO}	kg	77300
Payload mass	m _{PL}	kg	20400
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		0,264
Maximum landing mass	m _{ML}	kg	66682
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,863
Operating empty mass	m _{OE}	kg	42100
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		0,545
Maximum zero fuel mass	m _{MZF}	kg	62679
Wing loading	m _{MTO} /S _W	kg/m²	600
Number of engines	n _E		2
Engine type			CFM LEAP-1C
Take-off thrust for one engine	T _{TO,one engine}	kN	104,384
Γotal take-off thrust	T _{TO}	kN	208,768
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
Bypass ratio	μ		11
Overall pressure ratio	OAPR		
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	24,45
	- Idol,dvallable		27,73
Sweep angle	Ф25	0	
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness Relative thickness	X _{t,max}	%c %	

 Table 5. 54
 Reverse engineering results of the Comac C919

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	3,02	-8
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	1,75	-0
Maximum aerodynamic efficiency	E _{max}	-	17,97	9
Specific fuel consumption	SFC	kg/N/s	1,09E-05	24

5.28 Boeing 777-9

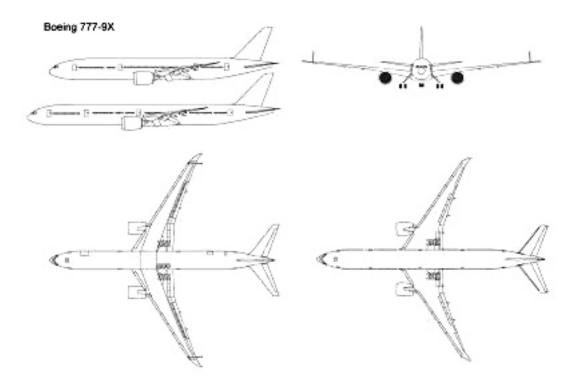


Figure 5. 28 3 view drawing of the Boeing 777-9 (Blueprints 2020)

The 777-9 is a large wide-bodied jet with capacity for a maximum seating of 414 passengers. It is the largest variant of the 777X family and has the program lead with service entry in 2020. It has a stretched fuselage in comparison with the 777-300ER. As of summer 2017, a total of 263 777-9s were ordered by ANA, Cathay, Emirates, Etihad, Lufthansa, Qatar and Singapore Airlines. The new 777X aircraft will feature a new scaled up version of the composite wings used for the smaller 787. Its new wing is the largest wingspan of any twin-engine Boeing aircraft type to date and is going to have a considerably better lift-to-drag ratio being significantly lighter than the wings on the current models. It will be built using carbon-fibre reinforced plastic and will feature folding wingtips to allow the new wing 777 models to operate at airfields without the facilities to handle aircraft with longer wing-spans. Another novelty on the 777X is the advanced aluminium-lithium fuselage which is lighter. In the cabin, Boeing looks to accommodate a more comfortable 10 abreast economy arrangement and nine-abreast premium economy

offering while maintaining the same cross section. Core to the new variants will be a new General Electric GE9X engine, offering the latest generation engine technology. All these improvements will make the 777X 15-20% more efficient than the current 777 variants.

After years of studying, Boeing formally launched the new 777X family at the Dubai Air Show in November 2013. These new 777X family is growth derivative of the current 777 line up and is intended to compete with the new Airbus A350-900/1000. Initially two series of the new 777X were offered, the 777-8X and 777-9X. In November 2015 Boeing formally dropped the "X" suffix for the individual 777X variants, although the combined family however will still be known as 777X. In the summer of 2016, Boeing acknowledged, that a stretch of the 777-9 is technically possible. If pursued, this new 777-10 derivative of the 777X family would give Boeing a very capable two engine competitor to the Airbus A380. Boeing has said it will launch the 777-10 as there is enough customer interest.

Table 5. 55Input values of the Boeing 777-9

Parameter	Symbol	Units	Chosen value
PAX			414
Landing field length (ISA)	S _{LFL}	m	
Approach speed	V _{APP}	m/s	
Take-off field length (ISA)	STOFL	m	
Range (max payload)	R	km	
Cruise Mach number	M _{CR}		
Cruise speed	V _{CR}	m/s	
Cruise altitude	h _{CR}	m	
Wing area	Sw	m²	
Wing span	b _W	m	64,82
Aspect ratio	A		
Maximum take-off mass	m _{MTO}	kg	351534
Payload mass	m _{PL}	kg	
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		
Maximum landing mass	m _{ML}	kg	266258
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,757
Operating empty mass	m _{OE}	kg	188241
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,535
Maximum zero fuel mass	m _{MZF}	kg	254918
Wing loading	m _{MTO} /S _W	kg/m²	
Number of engines	n _E		2
Engine type			GE9X-105B1A
Take-off thrust for one engine	T _{TO,one engine}	kN	466,7465487
Total take-off thrust	T _{TO}	kN	933,4930975
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
Bypass ratio	μ	, , , , , , , , , , , , , , , , , , , ,	
Overall pressure ratio	OAPR		
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	197,977
Sweep angle	ф ₂₅	۰	
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		

5.29 Boeing 737-10

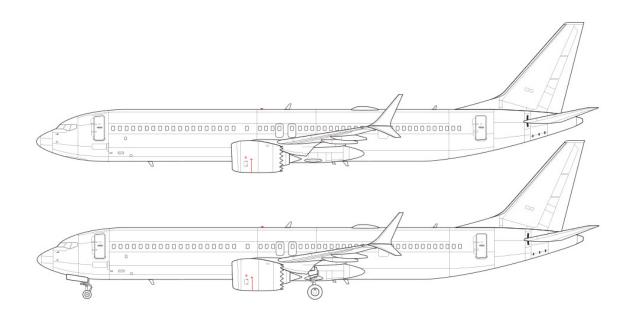


Figure 5. 29 3 view drawing of the Boeing 737-10 (Norebbo 2020)

The 737-10 is a large narrow-bodied jet with capacity for a maximum seating of 230 passengers which was Boeing's respond to two rather disappointing events: the poor sales of the 737-9 and the huge success of the A321neo. The new aircraft, a further two seat rows stretch of the 737-9, is called the 737-10 and was officially launched at the Paris Air Show in June 2017. It features the same "mid-exit" door (for a variable exit-limit rating) but, besides its length there are few other visible differences. Despite the greater clearance, Boeing chose to stick with the Leap-1B engine to minimise development cost and offers a thrust-bump version of the engine for the 737-10, rather than choosing a larger fan engine like the Leap-1A which might provide lower fuel consumption but less commonality. To support the greater passenger capacity, the aircraft will also have an increased MTOW. With 256 orders, the 737-10 had a very successful start and several airlines converted their 737-9 orders into 737-10 orders. For example, United swapped its 100 strong 737-9 order for the 737-10. In total, 214 of the 256 orders were swapped from other MAX variants. Boeing has said the 737-10 is scheduled to enter commercial service in 2020

One of the solutions would be the introduction of an all new design aircraft, dubbed in the media as the New Midsize Aircraft ("NMA"). The NMA is expected to fit between the larger narrow-bodied aircraft like the 737-900ER and smaller wide-bodied aircraft like the 767-200 or 787-8, and might be capable of transporting 220-280 passenger over transatlantic and/or transcontinental distances. The introduction of a possible NMA is a hot topic in the aviation media and at various business conferences. The question is whether this market segment will be big enough to make enough sales for Boeing's business case.

Table 5. 56Input values of the Boeing 737-800

Parameter	Symbol	Units	Chosen value
PAX			230
anding field length (ISA)	S _{LFL}	m	
approach speed	V _{APP}	m/s	
ake-off field length (ISA)	S _{TOFL}	m	
ange (max payload)	R	km	5960
ruise Mach number	M _{CR}		0,79
ruise speed	V _{CR}	m/s	233,89
ruise altitude	h _{CR}	m	
/ing area	Sw	m²	
/ing span	b _W	m	35,92
spect ratio	A		
			00765
laximum take-off mass	m _{MTO}	kg	89765
ayload mass	m _{PL}	kg	
lass ratio, payload - take-off	m _{PL/} m _{MTO}		
aximum landing mass	m _{ML}	kg	75931
ass ratio, landing - take-off	m _{ML/} m _{MTO}		0,846
perating empty mass	m _{OE}	kg	
ass ratio, operating empty - take-off	m _{OE} /m _{MTO}		
aximum zero fuel mass	m _{MZF}	kg	72574
ing loading	m _{MTO} /S _W	kg/m²	
umber of engines	n _E		2
ngine type			
ake-off thrust for one engine	T _{TO,one engine}	kN	
otal take-off thrust	T _{TO}	kN	0
hrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
ypass ratio	μ		
verall pressure ratio	OAPR		
pecific fuel comsumption (dry)	SFC (dry)	kg/N s	
pecific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
vailable fuel volume	V _{fuel,available}	m³	25,817
weep angle	ф 25	۰	
lean aerodynamic chord	C _{MAC}	m	
osition of maximum camber	X _{(y_c),max}	%c	
amber	(y _c) _{max} /c	%c	
osition of maximum thickness	X _{t,max}	%c	
elative thickness	t/c	%	
aper	λ		

5.30 Mitsubishi MRJ90

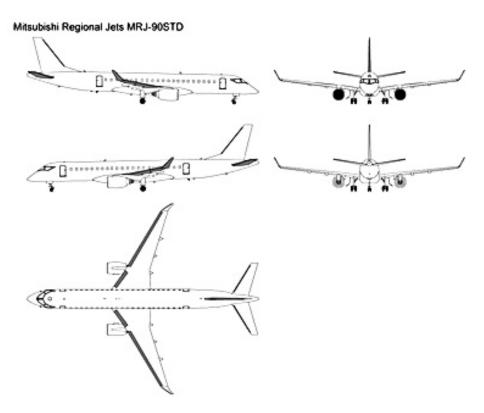


Figure 5. 30 3 view drawing of the Mitsubishi MRJ90 (Blueprints 2020)

The MRJ90 is a large regional jet with capacity for a maximum seating of 96 passengers whose first flight took place on November 11, 2015. The MRJ90 will be the first and base line MRJ model to enter service in mid-2020. It will feature a fuselage which will be longer than the MRJ70 to accommodate approximately 12 more passengers. An important element of the MRJ product will be the PW1217G geared turbo fan engine (GTF) which is claimed to be 15% more fuel efficient, 50% less noisy and up to 40% cheaper to maintain than current technology engines. The MRJ fuselage is of a simple circular cross section with cargo compartment in the back. The MRJ90 will have three variants (STD, -ER and -LR) with the same size but higher MTOWs for increasing range capability

With its Mitsubishi Regional Jet (MRJ) programme, the Mitsubishi Aircraft Corporation aims to set a new standard of regional jets. Its main competitors – the E-Jets -mostly features a double-bubble design with underfloor cargo space. The MRJ90 faces strong competition from the latest versions of the E175, E175-E2, E190, E190-E2 and the CRJ900 which have been dominating the 90-seater market segment for quite some years. Additionally, slightly larger aircraft such as the E195, E195-E2, CRJ1000 and CS100 (using the same engine technology) could turn out to be competitors, especially in a growth market.

The success of the MRJ90 is largely depending on the scope clause dominated US domestic regional market. Generally, more easing of scope clauses could create demand if more 90 seaters would be permitted but if further loosened, larger aircraft become competitors. To date, Mitsubishi Aircraft Corporation is actually quite successful in this market and managed to get two landmark orders for the MRJ90 in the US. Trans States Holdings ordered 50 MRJs (+ 50 options) in 2009 and in 2012 SkyWest Airlines ordered 100 MRJ90s (+ 100 Options).

 Table 5. 57
 Input values of the Mitsubishi MRJ90

Parameter	Symbol	Units	Chosen value
PAX			88
Landing field length (ISA)	S _{LFL}	m	1480
Approach speed	V _{APP}	m/s	70
Take-off field length (ISA)	S _{TOFL}	m	1500
rane on nois iong in (ion)	TIOPE		
Range (max payload)	R	km	1610
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	230
Cruise altitude	h _{CR}	m	11900
Wing area	Sw	m²	86
Wing span	b _w	m	30,9
Aspect ratio	A		
•			
Maximum take-off mass	m _{MTO}	kg	40995
Payload mass	m _{PL}	kg	8976
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		0,219
Maximum landing mass	m _{ML}	kg	38400
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	· ·	0,937
Operating empty mass	m _{OE}	kg	24900
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}	3	0,607
Maximum zero fuel mass	m _{MZF}	kg	36150
Wing loading	m _{MTO} /S _W	kg/m²	
3			
Number of engines	n _E		2
Engine type			PW1217G
Take-off thrust for one engine	T _{TO,one engine}	kN	78,2
Total take-off thrust	T _{TO}	kN	156,4
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,4
Bypass ratio	μ	, , , , , , , , , , , , , , , , , , , ,	8,4
Overall pressure ratio	OAPR		
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	
Sweep angle	ф ₂₅	0	
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		

 Table 5. 58
 Reverse engineering results of the Mitsubishi MRJ90

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,82	1
Maximum lift coefficient, take-off	C _{L,max,TO}	-	1,91	'
Maximum aerodynamic efficiency	E _{max}	-	17,41	19
Specific fuel consumption	SFC	kg/N/s	1,68E-05	-1

5.31 Bombardier DHC-8-401 (Dash-8 Q400)

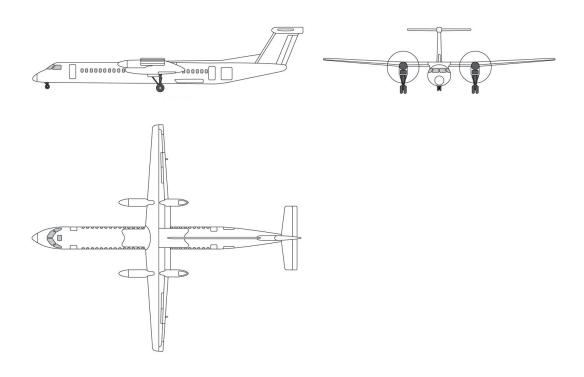


Figure 5. 31 3 view drawing of Bombardier Dash-8 Q400 (Blueprints 2020)

The Dash-8 Q400 is a twin-engined, medium range regional turboprop airliner with capacity for a maximum seating of 82 passengers whose first flight took place on January 31, 1998. The Q400 has a new stretched fuselage compared to the Q300. It has the same nose section and vertical tail as the other Dash-8 family aircraft, but has a new developed horizontal tail. The fuselage's cross section and structure are based on the earlier Dash-8s but with two entry doors at forward and aft ends of the fuselage on the left side. The inner wing section and wing fuselage wing joint are also developed new for the Q400. The outer wing of the Q400 has been strengthened. The Dash-8 Q400 is powered by two FADEC equipped PW150 turboprop engines with six bladed propellers. To improve the passenger's comfort, the Q400 is fitted with Bombardier's

newest systems to reduce noise and vibration to levels comparable with a CRJ. The flightdeck consist of five LCD screens, showing the same information to the pilot as in the earlier versions, so all the Dash-8s have a common type rating.

The –Q400 is the latest and longest member of the Dash-8 family, which besides the –Q400 consists of the original Series 100 (39 seats), the Series 200 (same capacity, more powerful engines) and the Series 300 (a stretched fuselage 50 seater). All models delivered after mid 1996 have cabin noise and vibration suppression systems and are redesignated with the Q(uiet)-prefix. Bombardier stopped production of the Q100 in 2006 and of the Q200 and Q300 in 2009, leaving only the Q400 in production. The Q400 was developed in the late nineties and entered commercial service in 2000. It was developed to meet the requirements of regional airlines for larger aircraft on high density, short-haul routes competing against the faster regional jets.

 Table 5. 59
 Input values of the Bombardier Dash-8 Q400

Parameter	Symbol	Units	Chosen value
PAX			82
Landing field length (ISA)	S _{LFL}	m	1290
Approach speed	V _{APP}	m/s	
Take-off field length (ISA)	S _{TOFL}	m	1300
Range (max payload)	R	km	1390
Cruise Mach number	M _{CR}		0,62
Cruise speed	V _{CR}	m/s	185,2
Cruise altitude	h _{CR}	m	5334
Wing area	Sw	m²	63,08
Wing span	b _w	m	28,42
Aspect ratio	A		12,8
Maximum take-off mass	m	kg	28998
	m _{MTO}	_	8480
Payload mass	m _{PL}	kg	
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	l	0,292 28009
Maximum landing mass	m _{ML}	kg	
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,966
Operating empty mass	m _{OE}	kg	17150
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,591
Maximum zero fuel mass	m _{MZF}	kg	25855
Wing loading	m _{MTO} /S _W	kg/m²	459,7
Number of engines	n _E		2
Engine type			PW150A
Take-off thrust for one engine	T _{TO,one engine}	kN	3781 kW
Total take-off thrust	T _{TO}	kN	7562 kW
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	3,84 kg/kW
Bypass ratio	μ		
Overall pressure ratio	OAPR		
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	6,526
Sweep angle	ф 25	۰	
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	$\mathbf{X}_{t,max}$	%с	
Relative thickness	t/c	%	
Taper	λ		

5.32 Boeing 737-300

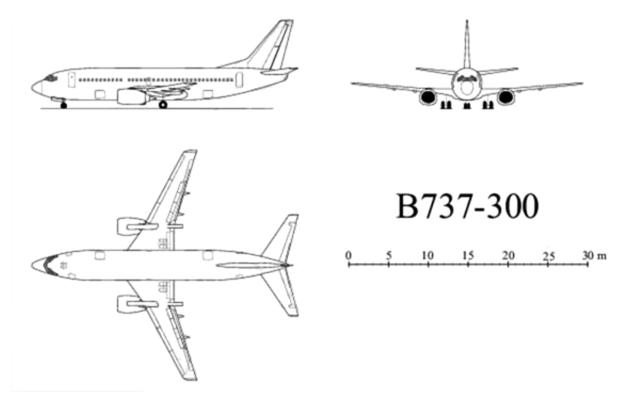


Figure 5. 32 3 view drawing of the Boeing 737-300 (Roux 2007a)

The 737-300 is a moderate size narrow-bodied jet with capacity for a maximum seating of 149 passengers whose first flight took place on February 24, 1984. The 737-300 was the first version of the 737 'Classic' Family and was derived from the 737-200 as a growth replacement. It would become the most successful of the three-version family with over 1,000 delivered from 1984 to 1999. Early built 737 Classics were still equipped with analogue cockpit displays. Digital CRT displays became standard in 1988. The 737 'Classic' is preferred above its MD-80 competitors, mostly due to its cleaner, more economical CFM56 engine versus the older PW JT8D-200.

Compared with its modern competitors (737-700 and A319), the 737-300 is more expensive to maintain, less fuel efficient and offers much less range. With low fuel prices, the 737-300 could still be attractive as its capital costs are minimal and modifications like winglets (145 modified) could improve performance. Nevertheless, many 737-300s were parked during the last economic crisis with only a few coming back when markets recovered, almost all with second tier airlines. More and more phase-outs and part-outs illustrate the type nearing the end of its service life.

As of summer 2017, more than 100 operators still fly with the 737-300, most of them having very small fleets. Southwest Airlines was the exception and was for long time by far the biggest operator with a fleet of 93 737-300 aircraft. However, with the introduction of the 737 Max in its fleet, Southwest accelerated the retirement of its 737-300s and all aircraft were phased out

by 1 October 2017. Cargo conversion programmes are offered for the 737-300 which may extend the operating lives of some suitable 737-300s. Currently around five 737-300s are converted to freighter per year.

Table 5. 60Input values of the Boeing 737-300

Parameter	Symbol	Units	Chosen value
PAX			149
_anding field length (ISA)	S _{LFL}	m	1433
Approach speed	V _{APP}	m/s	69,45
Take-off field length (ISA)			1940
rake-off field length (ISA)	S _{TOFL}	m	1940
Range (max payload)	R	km	1464
Cruise Mach number	M _{CR}		0,745
Cruise speed	V _{CR}	m/s	220,7
Cruise altitude	h _{CR}	m	10668
Ning area	S _w	m²	105,4
	bw		28,88
Ning span	A	m	7,9
Aspect ratio	^		7,9
Maximum take-off mass	m _{MTO}	kg	58967
Payload mass	m _{PL}	kg	16148
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		0,274
Maximum landing mass	m _{ML}	kg	51710
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,877
Operating empty mass	moe	kg	31869
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,540
Maximum zero fuel mass	m _{MZF}	kg	47627
Ving loading	m _{MTO} /S _W	kg/m²	535,6
			_
Number of engines	n _E		2
Engine type	_		CFM56-3B1
Γake-off thrust for one engine	T _{TO,one engine}	kN	88,964
Total take-off thrust	T _{TO}	kN	177,928
Γhrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,32
Bypass ratio	μ		6
Overall pressure ratio	OAPR		22,6
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,08E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,89E-05
Available fuel volume	V _{fuel,available}	m³	20,102
Sweep angle	Ф25	0	25
Mean aerodynamic chord	C _{MAC}	m	3,73
Position of maximum camber	X _{(y_c),max}	%c	10
Camber	(y _c) _{max} /c	%c	0,8
Position of maximum thickness	X _{t,max}	%c	29,7
Relative thickness	t/c	%	12,9
	W U	/0	12,3

 Table 5. 61
 Reverse engineering results of the Boeing 737-300

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,20	-17
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,19	
Maximum aerodynamic efficiency	E _{max}	-	14,84	18
Specific fuel consumption	SFC	kg/N/s	1,78E-05	-6

5.33 Airbus A350-1000

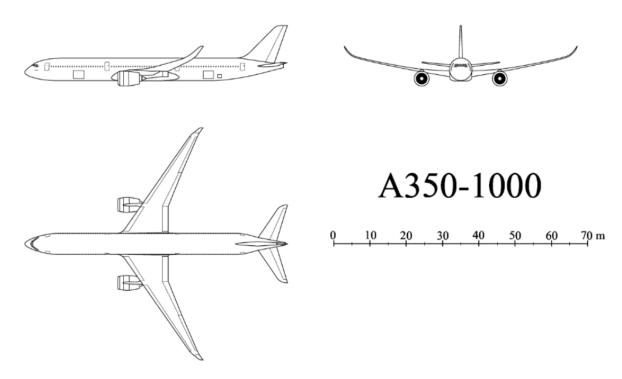


Figure 5. 33 3 view drawing of the Airbus A350-1000 (Roux 2007a)

The A350-1000 is a very large wide-bodied jet with capacity for a maximum seating of 369 passengers whose first flight took place on November 24, 2016. The A350-1000 will be a stretch of the base line -900 to accommodate 40 more seats. In terms of payload/range, the A350-1000 is expected to be a competitor to the 777-300ER which has the same range and 30 more seats. If the Rolls-Royce Trent XWB engines are indeed as efficient and as powerful as planned and the airframe will not be too heavy, the A350-1000 might turn out to be considerably more efficient and a strong contender of the very successful 777-300ER. GE refused to offer GEnx engines for the A350 family as the type poses a threat to exclusively GE powered 777-300ERs. The first aircraft was delivered to launch customer Qatar Airways early 2018.

As stated before, the A350 family could be seen as Airbus' answer to the slightly smaller Boeing 787 family and effectively also competes with the slightly larger Boeing 777 family. In order to be able to compete with the 787, Airbus redesigned the family to the A350'XWB' (eXtra Wide Body) which featured a wider fuselage, a new (composite) wing, upgraded A380 based systems and an advanced technology cockpit with 6 large LCD screens.

So far 212 A350-1000s have been ordered of which 58 were former A350-800 and A350-900 orders. In September 2017 three high profile A350-1000 customers, United, Cathay and LATAM, converted their A350 orders to the smaller A350-900 variant. This meant that the A350-1000 lost 20% of its order backlog. As Airbus didn't lose these customers, as they swapped their orders to the smaller A350-900 variant, it looks like this lesser interest in the A350-1000 is more the result of the trend that Airlines prefer relatively smaller widebodies and the market for twin-engined aircraft in the highest capacity sector has substantially weakened, as also Boeing has difficulties finding new orders for their 777X and 787-10 aircraft.

Table 5. 62Input values of the Airbus 350-1000

Parameter	Symbol	Units	Chosen value
PAX			369
Landing field length (ISA)	S _{LFL}	m	2110
Approach speed	V _{APP}	m/s	75
Take-off field length (ISA)	S _{TOFL}	m	2950
Range (max payload)	R	km	14815
Cruise Mach number	M _{CR}		0,85
Cruise speed	V _{CR}	m/s	250,5
Cruise altitude	h _{CR}	m	12190
Wing area	S _W	m²	443
Wing span	b _w	m	64,75
Aspect ratio	Α		9,25
Maximum take-off mass	m _{MTO}	kg	290000
Payload mass	m _{PL}	kg	67250
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		0,232
Maximum landing mass	m _{ML}	kg	225500
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,778
Operating empty mass	m _{OE}	kg	115700
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,398965517
Maximum zero fuel mass	m _{MZF}	kg	210000
Wing loading	m _{MTO} /S _W	kg/m²	666
Number of engines	n _E		2
Engine type			Trent XWB-74
Take-off thrust for one engine	T _{TO,one engine}	kN	329
Total take-off thrust	T _{TO}	kN	658
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,22
Bypass ratio	μ		8,9
Overall pressure ratio	OAPR		50
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	156
Sweep angle	ф ₂₅	0	35
Mean aerodynamic chord	C _{MAC}	m	8,35
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%с	
Position of maximum thickness	X _{t,max}	%с	
Relative thickness	t/c	%	
Taper	λ		0,113

 Table 5. 63
 Reverse engineering results of the Airbus 350-1000

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	2,36	-4
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,03	-4
Maximum aerodynamic efficiency	E _{max}	-	20,76	9
Specific fuel consumption	SFC	kg/N/s	1,53E-05	-4

5.34 Boeing 737-8-200



Figure 5. 34 3 view drawing of the Boeing 737-8-200 (Norebbo 2020)

The 737-8-200 is a medium narrow-bodied jet with capacity for a maximum seating of 200 passengers. In September 2014 Boeing introduced a new high density variant of the 737 MAX Family, marketed as the 737 MAX 200 but designated the 737-8-200. The 737-8-200 is based on the 737-8 airframe. Modifications to the cabin such as smaller front and rear galleys and the addition of two "mid-exit" doors, installed in the rear fuselage section to meet the FAA evacuation regulations, have made it possible to accommodate up to 200 passengers. The 737-8-200 will have the same MTOW as the 737-8 and will therefore have a shorter range of 5000km. The 737-8-200 is specifically intended for low cost carriers, as Boeing expects that the low cost sector will account for 35% of the single-aisle airline capacity by 2033. With 200 seats, a 737-8-200 will have 5% lower operating costs than the 737-8. Launch customer of the 737-8-200 is Ryanair which ordered 100 aircraft and took options for a 100 more in November 2014. In May 2016, Vietnamese low-cost carrier VietJet Air ordered 100 737-8-200s. A remarkable order as VietJet Air is currently an all Airbus operator with a fleet of 37 Airbus A320Ceo aircraft in

service and 91 A320Neo family aircraft on order. During the Paris Air Show in June 2017, Ryanair ordered an additional 10 737-8-200s.

Table 5. 64Input values of the Boeing 737-8-200

Parameter	Symbol	Units	Chosen value
PAX			200
Landing field length (ISA)	S _{LFL}	m	1650
Approach speed	V _{APP}	m/s	
Take-off field length (ISA)	S _{TOFL}	m	2540
3 (1)	10.2		
Range (max payload)	R	km	4630
Cruise Mach number	M _{CR}		
Cruise speed	V _{CR}	m/s	
Cruise altitude	h _{CR}	m	
Wing area	Sw	m²	
Wing span	b _W	m	35,92
Aspect ratio	Α		
Maximum take-off mass	m _{MTO}	kg	82190
Payload mass	m _{PL}	kg	
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		
Maximum landing mass	m _{ML}	kg	69308
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,843
Operating empty mass	moe	kg	
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		
Maximum zero fuel mass	m _{MZF}	kg	65952
Wing loading	m _{MTO} /S _W	kg/m²	
Number of engines	n _E		2
Engine type			LEAP-1B25
Take-off thrust for one engine	T _{TO,one engine}	kN	
Total take-off thrust	T _{TO}	kN	0
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
Bypass ratio	μ		
Overall pressure ratio	OAPR		
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	25,817
Sweep angle	ф ₂₅	0	
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	$\mathbf{X}_{t,max}$	%с	
Relative thickness	t/c	%	
Taper	λ		

5.35 Airbus A330-900Neo

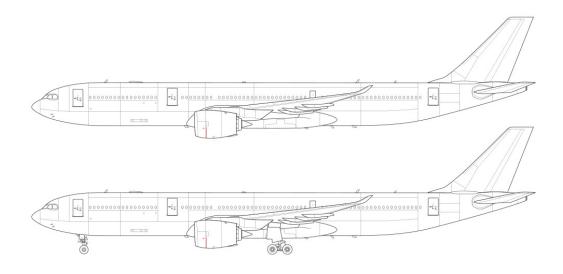


Figure 5. 35 3 view drawing of the Airbus 330-900Neo (Norebbo 2020)

The A330-900Neo is a very large wide-bodied jet with capacity for a maximum seating of 440 passengers whose first flight took place on October 19, 2017. Central to the new A330 concept are the new RR Trent 7000 engines. Contrary to the A330Ceo (current engine option), the A330neo will only have one engine manufacturer. Besides these new engines the A330Neo also features new larger winglets, an increased wingspan and some aerodynamic improvements to the wings and fuselage. The cabin design is also optimised and includes new-design lavatories and crew rests. These increased cabin efficiencies will result in up to ten seats more than in the current A330. All new techniques and improvements contribute to 11% lower trip costs and (thanks to 10 extra seats) 14% lower fuel burn per seat. The A330Neo has more than 95% spare parts commonality with the current generation A330s and both generations have the same type rating. This minimises the entry in service costs for airlines that already operated the A330, as they would not need to spend money on new spares or additional flight crew training. The A330NEO comes in two sizes, the A330-800N and A330-900N. The A330-900N is the larger of the two and will be the successor of the A330-300. With a backlog of 204, the A330-900N is far more popular than the A330-800N, so the main focus of the A330NEO programme will be on the -900N variant.

After months of speculation, Airbus launched the A330NEO (new engine option) at the Farnborough Air show in July 2014. Airbus studied hard to introduce a new version of the A330. The current A330 was still its best-selling wide bodied airliner as it was a relatively inexpensive wide-bodied positioned in the lower half of the Wide-bodied market; it was very well positioned to serve high density routes in the market segment below 7400km. A final reason to be hesitant about a new A330 design was that a more efficient A330Neo might easily steal orders from the

A350 XWB. Current A330 customers such as Delta and AirAsiaX kept pushing Airbus to develop a more efficient version of the A330. The fact was that developing a new version of the A330 would be relatively cheap as Airbus could use the same principles employed to develop the A320neo and benefit from engine technology developed for the A350 XWB, therefore Airbus decided to introduce the A330NEO.

Table 5. 65Input values of the Airbus A330-900Neo

	Symbol	Units	Chosen value
PAX			440
Landing field length (ISA)	S _{LFL}	m	
Approach speed	V _{APP}	m/s	73
Take-off field length (ISA)	S _{TOFL}	m	
Range (max payload)	R	km	
Cruise Mach number	M _{CR}		
Cruise speed	V _{CR}	m/s	154,44
Cruise altitude	h _{CR}	m	
Ning area	Sw	m²	465
Wing span	b _w	m	64
Aspect ratio	A		8,8
Mayingum taka aff maga		le a	247000
Maximum take-off mass	m _{MTO}	kg	247000
Payload mass	m _{PL}	kg	44000
Mass ratio, payload - take-off	m _{PL} /m _{MTO}		0,178
Maximum landing mass	m _{ML}	kg	191000
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,773
Operating empty mass	m _{OE}	kg	132000
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		0,534
Maximum zero fuel mass	m _{MZF}	kg	181000
Wing loading	m _{MTO} /S _W	kg/m²	
Number of engines	n _E		2
Engine type			RR Trent 7000
Take-off thrust for one engine	T _{TO,one engine}	kN	150
Total take-off thrust	T _{TO}	kN	300
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	
Bypass ratio	μ		
Overall pressure ratio	OAPR		
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	139,09
Suva an anala	1	0	
Sweep angle	Φ25		7 27
Mean aerodynamic chord	C _{MAC}	m ov -	7,27
Position of maximum camber	X(y_c),max	%c	
D In	11/1 /0	%c	
Camber	(y _c) _{max} /C		
Camber Position of maximum thickness Relative thickness	X _{t,max} t/c	%c %	

5.36 Bombardier CS300 / Airbus A220

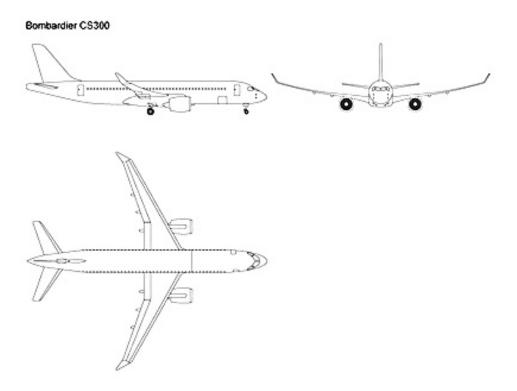


Figure 5. 36 3 view drawing of the Bombardier CS300 / Airbus A220 (Blueprints 2020)

The CS300 is a moderate size narrow-bodied jet with capacity for a maximum seating of 160 passengers whose first flight took place on February 27, 2015. Bombardier's CS300 is a stretch of the CS100 design. The two version together are specifically designed to cover the 100-149 seats market segment between the larger regional jets and the smaller narrowbodies. The CS300 competes with the smaller mainliners like the A318/A319 and 737-600/700. Initially the main technology improvement compared to these types was the Geared Turbofan engine technology, although this advantage was lost, when the Neo and MAX were introduced equally featuring advanced engine technology. The CSeries will be powered by two PW Geared Turbo Fan (GTF) engines which are claimed to be up to 15% more fuel efficient, 50% less noisy and up to 40% cheaper to maintain than today's technology engines. Next to that, the CSeries will feature a fuselage and wing structure of new lightweight (composite) materials, fly-by-wire and a very modern LCD cockpit. A higher MTOW version for extended range (CS300ER) and an eXtra Thrust version for short field length operations (CS300XT) will also be developed. The cabin will accommodate 3+2 abreast seating in economy class and roll-aboard sized overhead bins.

This all should make the CS300 at least 15% more efficient than its competitors today. But Airbus and Boeing have not been idle and the A319Neo and the 737 MAX 7 will come a lot closer to the CS300 performance than today's (NG and ceo) products in terms of efficiency. In March 2013 Bombardier disclosed a high density variant of the CS300, which could accommodate up to 160 seats. By launching the high-density design Bombardier added two extra overwing exit doors and increasing the length of the fuselage as well as of the MTOW. With a seat

capacity of up to 160, the CS300 competes with established names as the Airbus A320neo and Boeing 737-8. So far 200 CS300s have been ordered by eight airlines and three lease companies.

 Table 5. 66
 Input values of the Bombardier CS300 / Airbus A220

Parameter	Symbol	Units	Chosen value
PAX			160
anding field length (ISA)	S _{LFL}	m	1509
approach speed	V _{APP}	m/s	66,1
ake-off field length (ISA)	S _{TOFL}	m	1890
Range (max payload)	R	km	3610
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	230
Cruise altitude	h _{CR}	m	11126
Ving area	Sw	m²	112,3
Ving span	b _w	m	35,1
Aspect ratio	A		10,97
Maximum take-off mass	m _{MTO}	kg	67585
Payload mass	m _{PL}	kg	18711
/ass ratio, payload - take-off	m _{PL} /m _{MTO}	Ng	0,277
Maximum landing mass	m _{ML}	kg	51029
Aass ratio, landing - take-off	m _{ML} /m _{MTO}	kg	0,755
Operating empty mass	m _{OE}	kg	35221
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}	kg	0,521
Maximum zero fuel mass		ka	55792
Ving loading	m _{MZF} m _{MTO} /S _W	kg kg/m²	615
ving loading	III _{MTO} /S _W	kg/III	013
lumber of engines	n _E		2
Engine type			PW1524G
ake-off thrust for one engine	T _{TO,one engine}	kN	103,6
otal take-off thrust	T _{TO}	kN	207,2
hrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,299
Bypass ratio	μ		12
Overall pressure ratio	OAPR		
specific fuel comsumption (dry)	SFC (dry)	kg/N s	0,0000112
specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
vailable fuel volume	V _{fuel,available}	m³	21,805
Swoon angle		0	
Sweep angle	Ф25		
Mean aerodynamic chord Position of maximum camber	CMAC	m %c	
Camber	(y_c),max	%c	
Position of maximum thickness	(y _c) _{max} /c X _{t,max}	%c	
Relative thickness	t/c	%	
aper	λ	70	

 Table 5. 67
 Reverse engineering results of the Bombardier CS300 / Airbus A220

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	2,81	-9
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,28	-9
Maximum aerodynamic efficiency	E _{max}	-	20,98	-2
Specific fuel consumption	SFC	kg/N/s	1,26E-05	20

5.37 Boeing 767-300F

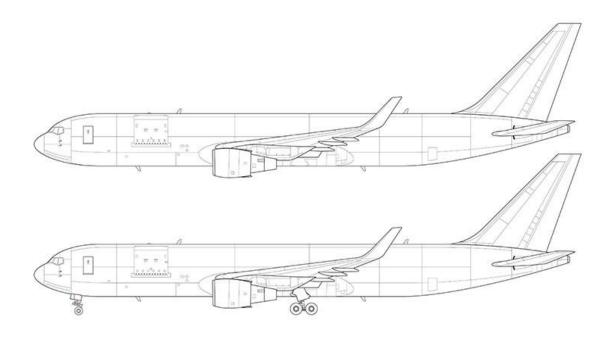


Figure 5. 37 3 view drawing of the Boeing 767-300F (Norebbo 2020)

The 767-300 is a medium size medium range wide-bodied freighter, based on the passenger 767-300ER platform, with capacity for 52480kg payload, whose first flight took place on June 20, 1995. It competes with Airbus' A300-600F and the larger A330-200F which arrived in 2010 but hasn't gained much traction yet. Compared to the 767-300F, the Airbus products have a slightly larger fuselage cross section which enables them to accommodate standard containers in a transverse position. This maximizes volume and avoids costly re-packaging of containerized freight in interline operations. The 767-300F can hold up to 24 standard pallets. However, with customized unit load devices, the 767-300F enjoys a significantly better payload/range capability than the A300-600F.

The biggest user of the 767-300F is currently UPS who operates 59 767-300F aircraft. Besides UPS, there had for a long time not been many orders for the 767-300F and other operators of the type only have a marginal fleet of 4 maximum, with the only exception LAN Cargo which

together with its subsidiaries operated 11 aircraft. The 767-300F got a big boost in December 2011 when FedEx chose the 767-300F as replacement for their MD-10Fs. So far Fedex has ordered 109 767-300Fs. Today the only outstanding orders for the 767 freighter are from Fedex.

Table 5. 68Input values of the Boeing 767-300F

Parameter	Symbol	Units	Chosen value
PAX			
anding field length (ISA)	S _{LFL}	m	1740
Approach speed	V _{APP}	m/s	
Take-off field length (ISA)	S _{TOFL}	m	2926
Range (max payload)	R	km	5556
Cruise Mach number	M _{CR}		0,8
Cruise speed	V _{CR}	m/s	238,33
Cruise altitude	h _{CR}	m	11887
Ving area	Sw	m²	283,3
Ving span	b _w	m	47,57
Aspect ratio	A		7,99
/laximum take-off mass	m _{MTO}	kg	186880
Payload mass	m _{PL}	kg	50800
Aass ratio, payload - take-off	m _{PL} /m _{MTO}	Ng	0,272
Maximum landing mass	m _{ML}	kg	147871
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	Ng .	0,791
Operating empty mass	m _{OE}	kg	85275
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	Ng	0,456
Maximum zero fuel mass	m _{MZF}	kg	140160
Ving loading	m _{MTO} /S _W	kg/m²	653
ving loading	mwio/ew	Kg/III	033
lumber of engines	n _E		2
Engine type			CF6-80C2B7F
ake-off thrust for one engine	T _{TO,one engine}	kN	276,233
otal take-off thrust	T _{TO}	kN	552,466
hrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,3
Bypass ratio	μ		5,3
Overall pressure ratio	OAPR		31,8
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	9,15E-06
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	91,38
Sweep angle	ф ₂₅	٠	31,5
Mean aerodynamic chord	C _{MAC}	m	6,98
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%с	
Position of maximum thickness	X _{t,max}	%с	
Relative thickness	t/c	%	11,5
Гарег	λ		0,207

 Table 5. 69
 Reverse engineering results of the Boeing 767-300F

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,80	-1
Maximum lift coefficient, take-off	C _{L,max,TO}	-	1,75	- 1
Maximum aerodynamic efficiency	E _{max}	-	15,95	15
Specific fuel consumption	SFC	kg/N/s	1,43E-05	9

5.38 Comac ARJ21-700

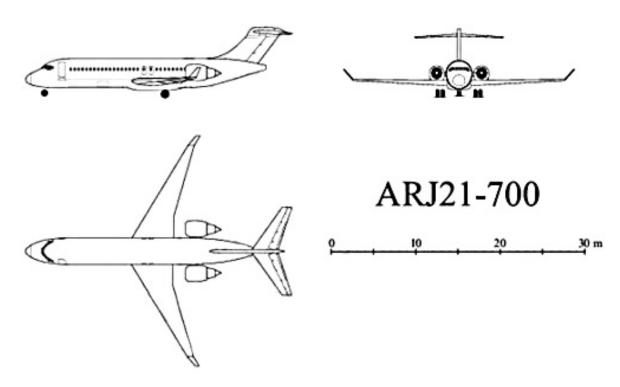


Figure 5. 38 3 view drawing of the Comac ARJ21-700 (Roux 2007a)

The ARJ21-700 is a large regional jet with capacity for a maximum seating of 90 passengers whose first flight took place on November 28, 2008. The ARJ21 regional jet is China's first domestically developed aircraft by government-controlled COMAC. The initial family is planned to consist of two passenger types - the ARJ21-700 and the stretched ARJ21-900. The ARJ21s are primarily aimed at the Chinese domestic regional market. Both versions will have a standard and an extended range (-ER) variant. The design has some exterior resemblance with the DC-9, though features a newly (Antonov) designed wing with winglets and GE's CF34-10 engines which also power the E190/195. Other involvement from western countries is Rockwell Collins avionics and Honeywell's fly bywire systems.

So far, only the smaller ARJ21-700 has been ordered, making a total of 180 ordered aircraft. The great part of the orders come from: Henan Airlines, the largest customer with 50 aircraft on order; launch customer Chengdu Airlines has ordered 30 ARJ21-700s and Hebei Airlines and Shandong Airlines each 10.

The first commercial delivery of the ARJ21-700 slipped several times the manufacturers encountered problems in the development as well in the certification process. Late December 2014, COMAC finished the last functional and reliability tests on one of the prototypes, marking the completion of all test modules required for the ARJ21-700. On 30 December 2014, the Chinese aviation authorities finally issued the type certification for the ARJ21 (initially scheduled for 2007). A major milestone for the commercial aviation sector in China. COMAC worked hard to make all the necessary improvements and on 9 July 2017, more than 2,5 year after the type certification, COMAC received the production certificate for the ARJ21 from the Civil Aviation Administration of China

Table 5. 70Input values of the Comac ARJ21-700

Parameter	Symbol	Units	Chosen value
PAX			90
Landing field length (ISA)	S _{LFL}	m	1550
Approach speed	V _{APP}	m/s	
Take-off field length (ISA)	S _{TOFL}	m	1700
Range (max payload)	R	km	2225
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	230
Cruise altitude	h _{CR}	m	10668
Wing area	S _W	m²	79,86
Wing span	b _W	m	27,29
Aspect ratio	Α		9,32
Maximum take-off mass	m _{MTO}	kg	43500
Payload mass	m _{PL}	kg	8935
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,205
Maximum landing mass	m _{ML}	kg	37665
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,866
Operating empty mass	m _{OE}	kg	24955
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		0,574
Maximum zero fuel mass	m _{MZF}	kg	33890
Wing loading	m _{MTO} /S _W	kg/m²	507,1
Number of engines	n _E		2
Engine type			CF34-10A
Take-off thrust for one engine	T _{TO,one engine}	kN	80,068
Total take-off thrust	T _{TO}	kN	160,136
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,4
Bypass ratio	μ		5
Overall pressure ratio	OAPR		29
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	12,719
Sweep angle	ф ₂₅	•	25
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		

 Table 5. 71
 Reverse engineering results of the Comac ARJ21-700

Secret parameter	Symbol	Units	RE Value	Verification deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	2,84	0
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,35	U
Maximum aerodynamic efficiency	E _{max}	-	14,89	27
Specific fuel consumption	SFC	kg/N/s	1,72E-05	3

5.39 Boeing 787-10

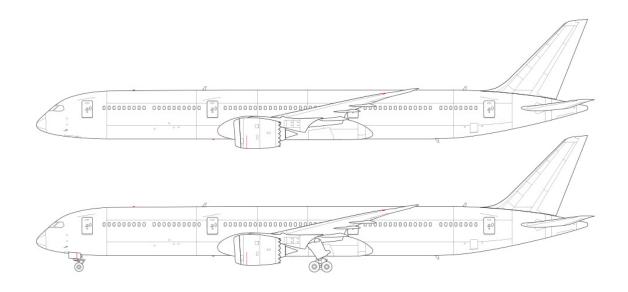


Figure 5. 39 3 view drawing of the Boeing 787-10 (Norebbo 2020)

The 787-10 is a large wide-bodied jet with capacity for a maximum seating of 440 passengers whose first flight took place on March 31, 2017. It has the same wingspan and engines as the 787-9, which indicates that the 787-10 would probably be targeted for thick, medium-long routes such as transpacific or transatlantic. As such, it would be a strong competitor to today's very successful Airbus A330-300 (having slightly more pax and more range) as well as to the Airbus A330-800/900Neo and Airbus A350-800 and -900 which probably will be heavier but probably beat the -10 on range. In general, the 787 family features many new technologies like a full composite structure including wing and barrel shaped fuselage sections (accommodates 9 abreast seating), new up to 15-20% more efficient and relatively quiet engines, improved aerodynamics and many new electric systems instead of pneumatics/hydraulics. A clear advantage for the 787-10 would be that it could benefit from the design, production and operational experience gained with the 787-8 and -9.

Initially the 787-10 was very well received in the market and in the first half year after its introduction at the Paris Air Show 2013, more than 120 aircraft had been ordered. Since then,

the new order intake has been slow with only 48 new 787-10 orders, which in combination with a few order swaps from the 787-9 to 787-10 makes for a total backlog of 168 aircraft.

Table 5. 72Input values of the Boeing 787-10

Parameter	Symbol	Units	Chosen value
PAX			440
_anding field length (ISA)	S _{LFL}	m	1855
Approach speed	V _{APP}	m/s	2000
Take-off field length (ISA)	STOFL	m	2995
rake-off field leftgiff (lozy)	STOFL		2333
Range (max payload)	R	km	7710
Cruise Mach number	M _{CR}		0,85
Cruise speed	V _{CR}	m/s	253,61
Cruise altitude	h _{CR}	m	10700
Ving area	Sw	m²	325
Ving span	b _W	m	60,12
Aspect ratio	A	111	11,1
napoli Tallo	^		11,1
Maximum take-off mass	m _{MTO}	kg	254011
Payload mass	m _{PL}	kg	
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		
Maximum landing mass	m _{ML}	kg	201848
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,795
Operating empty mass	m _{OE}	kg	135500
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}		0,533
Maximum zero fuel mass	m _{MZF}	kg	192776
Wing loading	m _{MTO} /S _W	kg/m²	
Number of auxiliar	_		2
Number of engines	n _E		Genx 72A1
Engine type	_	LAI	
Take-off thrust for one engine	T _{TO,one engine}	kN	340
Total take-off thrust	T _{TO}	kN	680
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	9
Bypass ratio	μ		
Overall pressure ratio	OAPR		53,3
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	138,7
Sweep angle	ф ₂₅	٥	32,2
Mean aerodynamic chord	C _{MAC}	m	,
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	
Taper	λ		

 Table 5. 73
 Reverse engineering results of the Boeing 787-310

3	9	J		
Secret parameter	Symbol	Units	RE Value	Verification

				deviation[%]
Maximum lift coefficient, landing	$C_{L,max,L}$	-	3,13	-6
Maximum lift coefficient, take-off	$C_{L,max,TO}$	-	2,24	-0
Maximum aerodynamic efficiency	E _{max}	-	19,62	9
Specific fuel consumption	SFC	kg/N/s	1,14E-05	31

5.40 Boeing 747-400

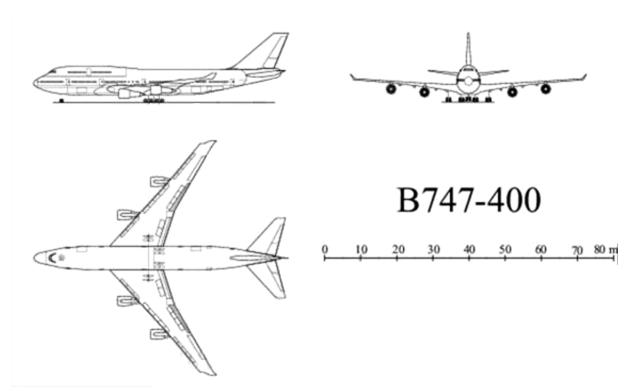


Figure 5. 40 3 view drawing of the Boeing 747-400 (Roux 2007a)

The 747-400 is a large wide-bodied jet with capacity for a maximum seating of 620 passengers whose first flight took place on April 29, 1988. The 747 was the first Wide-bodied in service and remained the largest passenger airliner until the A380 entered into service in 2007. The 747-400 was introduced into service in 1989 and enjoyed a monopoly in the 3-class over 400 seat capacity class for almost 20 years. The introduction of the A340-600 and 777-300ER as well as the A380 served to fragment market demand for the 747-400. Although none of these aircraft exactly matches the capacity of the 747-400, they do offer an alternative option and reduced the market for the new passenger 747-400s. Boeing unsuccessfully tried to re-start demand by offering the extended range 747-400ER which was only sold to Qantas (6). Boeing's 747-400's replacement product is the 747-8I which is the latest 747 derivative. Production of the 747-400 passenger aircraft ended in March 2005 followed by the last -400ERF freighter produced in October 2009. The 2008 economic crisis accelerated the phase out of the passenger 747-400s. By lack of a large secondary market, part out has already become a viable end-of-

life solution for some vintages. 64 747-400s have been permanently withdrawn from used since January 2015. Many of these aircraft have been scrapped.

Once the Queen-of-the-Skies and the flagship of many top-notch airlines, the 747-400 has now the old-age-aircraft stigma and many airlines who once operated large fleets of 747-400s has phased them out or will phase them out in the very near future. Most 747-400 are / will be replaced by Airbus A380s or Boeing 777-300ERs. As the costs of operating a used 747-400 are very high, there is little appetite for used 747-400s. There are 13 747-400s in service as corporate/VIP/government aircraft (one VIP 747-400 stored) and one 747 been converted to water bomber.

Table 5. 74Input values of the Boeing 747-400

Parameter	Symbol	Units	Chosen value
PAX			620
Landing field length (ISA)	S _{LFL}	m	2100
Approach speed	V _{APP}	m/s	75,1
Take-off field length (ISA)	S _{TOFL}	m	3200
Range (max payload)	R	km	10695
Cruise Mach number	M _{CR}		0,85
Cruise speed	V _{CR}	m/s	253
Cruise altitude	h _{CR}	m	10668
Ving area	Sw	m²	541,16
Ving span	b _w	m	64,44
Aspect ratio	A		7,67
Maximum take-off mass	m	ka	396830
	m _{MTO}	kg	63657
Payload mass	m _{PL}	kg	
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	l	0,160
Maximum landing mass	m _{ML}	kg	260362
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	I	0,656
Operating empty mass	m _{OE}	kg	179015
Mass ratio, operating empty - take-off	m _{OE} /m _{MTO}	I	0,451
Maximum zero fuel mass	m _{MZF}	kg	242672
Ning loading	m _{MTO} /S _W	kg/m²	670,5
Number of engines	n _E		4
Engine type			PW4056
Take-off thrust for one engine	T _{TO,one engine}	kN	252
Total take-off thrust	T _{TO}	kN	1008
Γhrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,28
Bypass ratio	μ		4,9
Overall pressure ratio	OAPR		30,2
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	9,06E-06
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	204,333
Sweep angle	ф 25	•	37,5
Mean aerodynamic chord	C _{MAC}	m	9,68
Position of maximum camber	X _{(y_c),max}	%с	15
Camber	(y _c) _{max} /c	%c	1,4
Position of maximum thickness	X _{t,max}	%c	35
Relative thickness	t/c	%	9,4
Гарег	λ	,-	0,278

 Table 5. 75
 Reverse engineering results of the Boeing 747-400

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	2,14	0
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,07	U
Maximum aerodynamic efficiency	E _{max}	-	16,42	18
Specific fuel consumption	SFC	kg/N/s	1,46E-05	15

5.41 Boeing 737-500

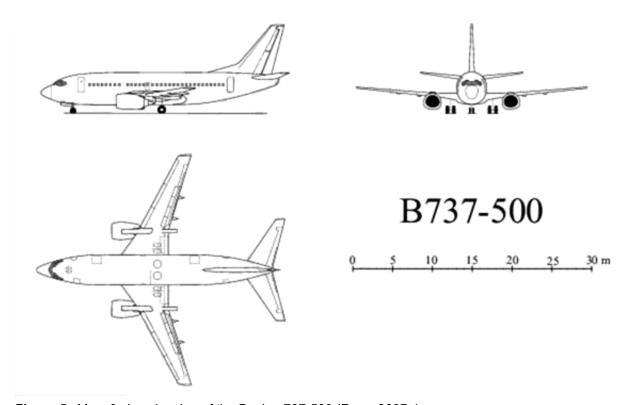


Figure 5. 41 3 view drawing of the Boeing 737-500 (Roux 2007a)

The 737-500 is a small narrow-bodied jet with capacity for a maximum seating of 149 passengers whose first flight took place on June 30, 1989. The -500 is the smallest member of the 737 Classic family with the longest range. It replaced the similar sized 737-200. Commonality with the -300 and -400 and the large US domestic market gave the -500 the upper hand. Additional winglets can improve the aircraft performance. So far about 60 737-500s have been retrofitted with winglets. For high cycled aircraft structural issues will lead to increased maintenance/inspection costs with repairs, possibly further shortening the economic life. Given its small size, there is very little interest in conversion to freighter, so there are no conversion programmes for the 737-500.

Competition came from the less successful A318 and 737-600. In the secondary market, the 737-500 isn't widely accepted as it is relatively heavy and has comparatively high seat-mile costs. Newer competitors like E190/195 and C-Series are much more efficient. In 2015 and 2016, main operators Southwest (25 aircraft) and Lufthansa (33 aircraft) phased out the type. The biggest current operator UTAir (32 aircraft) has already announced that it will phase out the fleet in the near future and the first 10 aircraft will leave the fleet before 2018. Because of its long range the type has been popular in Russia and as of today, Russia is still home to the largest population of 737-500s, with 42 aircraft flying for 4 different commercial operators.

Table 5. 76Input values of the Boeing 737-500

Parameter	Symbol	Units	Chosen value
PAX			149
Landing field length (ISA)	S _{LFL}	m	1362
Approach speed	V _{APP}	m/s	66
Take-off field length (ISA)	S _{TOFL}	m	1832
Range (max payload)	R	km	2519
Cruise Mach number	M _{CR}	KIII	0,745
Cruise speed	V _{CR}	m/s	221
Cruise speed Cruise altitude	h _{CR}	m	10668
Cruise ailliude	IICR	""	10000
Wing area	S _w	m²	91,04
Wing span	b _W	m	28,88
Aspect ratio	A	***	9,16
Aspectiano	^		3,10
Maximum take-off mass	m _{MTO}	kg	52390
Payload mass		kg	15182
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	Ng	0,290
Maximum landing mass		ka	49895
Mass ratio, landing - take-off	m _{ML}	kg	0,952
	m _{ML} /m _{MTO}	lea.	31312
Operating empty mass	m _{OE}	kg	
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	l	0,598 46490
Maximum zero fuel mass	m _{MZF}	kg	575
Wing loading	m _{MTO} /S _W	kg/m²	5/5
Number of engines	n _E		2
Engine type			CFM56-3B1
Take-off thrust for one engine	T _{TO,one engine}	kN	88,964
Total take-off thrust	T _{TO}	kN	177,928
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,35
Bypass ratio	μ	, , , , ,	6
Overall pressure ratio	OAPR		22,6
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,08E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,89E-05
	. ,	-	
Available fuel volume	V _{fuel,available}	m³	20,102
Sweep angle	Ф25	•	25
Mean aerodynamic chord	C _{MAC}	m	3,73
Position of maximum camber	X _{(y_c),max}	%с	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	X _{t,max}	%c	
Relative thickness	t/c	%	12,9
Taper	λ		0,24

 Table 5. 77
 Reverse engineering results of the Boeing 737-500

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,76	-19
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,84	-19
Maximum aerodynamic efficiency	E _{max}	-	15,11	20
Specific fuel consumption	SFC	kg/N/s	1,84E-05	-10

5.42 Boeing 777F

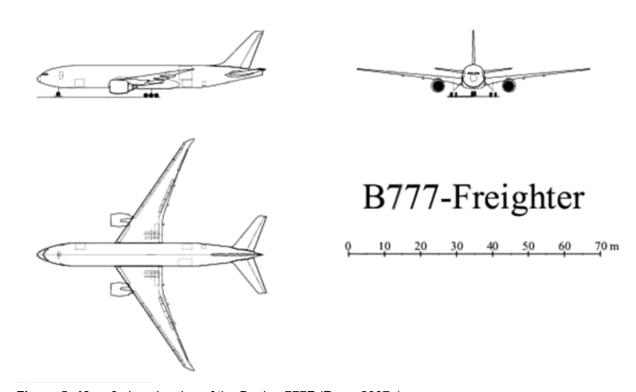


Figure 5. 42 3 view drawing of the Boeing 777F (Roux 2007a)

The 777 Freighter is the world's longest range twin-engine freighter. It is a large size long range wide-bodied freighter with capacity for 102000kg payload, whose first flight took place on July 14, 2008. The 777 Freighter is based on the highly efficient 777-200LR passenger airplane, equipped with a large side cargo door and solely powered by GE90-110/115 engines. The 777 Freighter main deck can accommodate 27 standard pallets. The aircraft is complementary to the significantly larger 747-8F while there seems to be no contemporary competitor until e.g. an A350XWB-900F would be introduced. A 777-8F seems still many years away

The Boeing 777 Freighter was generally seen by the airlines as a potential replacement for the 747-200F/SF and the MD-11F. It offers only slightly less payload than the 747-200F and superior payload capacity compared to the MD-11F but significantly more range than either. From

Boeing's perspective, the discontinuation of the 747-400 Freighter production, left customers to choose between moving up a capacity class to the 747-8F or choosing the slightly smaller payload option offered by the efficient 777 Freighter. With the 777 Freighter and the 747-8F, Boeing has a virtual monopoly in the large, long haul cargo aircraft market for the foreseeable future, as Airbus after the failed attempt of the A380 freighter, does not offer any equally capable freighter.

As the capital investment is significant, the 777 Freighter is mainly operated by larger cargo network operators, integrators and dedicated first tier cargo airlines. Biggest operator is Fedex with 30 aircraft in active service and 10 on order. The 777 Freighter is received very well as it is highly efficient and even opened up new markets and considerably extends the cargo cut off times of suppliers as it doesn't need fuel stops on long range routes.

 Table 5. 78
 Input values of the Boeing 777F

Parameter	Symbol	Units	Chosen value
PAX			
Landing field length (ISA)	S _{LFL}	m	1750
Approach speed	V _{APP}	m/s	72
			3000
Take-off field length (ISA)	S _{TOFL}	m	3000
Range (max payload)	R	km	9050
Cruise Mach number	M _{CR}		0,84
Cruise speed	V _{CR}	m/s	252
Cruise altitude	h _{CR}	m	10668
Wing area	Sw	m²	427,8
Wing span	b _W	m	64,8
Aspect ratio	A	***	04,0
Aspectiatio	^		
Maximum take-off mass	m _{MTO}	kg	347815
Payload mass	m _{PL}	kg	103737
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,298
Maximum landing mass	m _{ML}	kg	260816
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,750
Operating empty mass	m _{OE}	kg	144379
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,415
Maximum zero fuel mass	m _{MZF}	kg	248115
Wing loading	m _{MTO} /S _W	kg/m²	
Niverban of an eigen	_		•
Number of engines	n _E		2
Engine type	_	1.51	GE90-110B1L
Take-off thrust for one engine	T _{TO,one engine}	kN	489
Total take-off thrust	T _{TO}	kN	978
Thrust to weight ratio	T _{то} /(m _{мто} *g)	$T_{TO}/(m_{MTO}*g)$	0,29
Bypass ratio	μ		9
Overall pressure ratio	OAPR		42
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	181,283
Sweep angle	ф 25	۰	31,64
Mean aerodynamic chord	C _{MAC}	m	
Position of maximum camber	X _{(y_c),max}	%с	30
Camber	(y _c) _{max} /c	%с	5,9
Position of maximum thickness	X _{t,max}	%с	30
Relative thickness	t/c	%	22
Taper	λ		

 Table 5. 79
 Reverse engineering results of the Boeing 777F

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,26	-21
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,21	-21
Maximum aerodynamic efficiency	E _{max}	-	18,30	10
Specific fuel consumption	SFC	kg/N/s	1,19E-05	24

5.43 Embraer 195

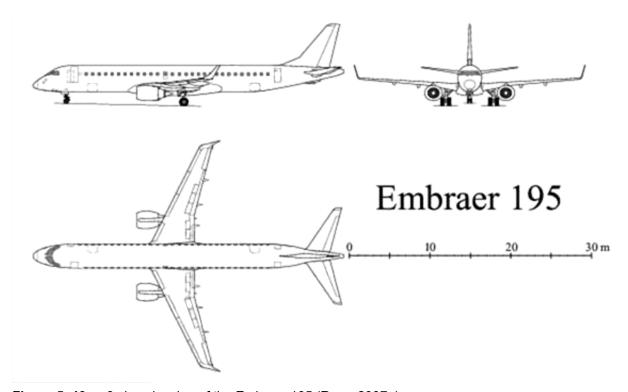


Figure 5. 43 3 view drawing of the Embraer 195 (Roux 2007a)

The Embraer 195 is a large regional jet with capacity for a maximum seating of 118 passengers whose first flight took place on December 7, 2004. The E195 is a further stretch of the E190, giving it an additional 10 seats in single class. This makes it the largest member of the E-jets family with over 85% commonality. Like its smaller family members, the E195 is offered in a standard (-STD), long range (-LR) and advanced range (-AR) version. The -AR has become the production standard and can be downgraded to the -LR or -STD specifications. Early built aircraft which didn't have the -AR structure suffer from a weaker (wing) structure resulting in a lower structural MTOW which limits range. If equipped with more than 100 seats, an additional 3rd cabin crew member is required, which increases costs.

The E195's main competitors are the more efficient but narrower CRJ900/1000 but also its slightly smaller sister the E190. For network operators, the E195 could be a slightly smaller and cheaper (trip cost) alternative for the smallest members of the 737 and A320 narrowbody families but it falls a bit short on range. Going forward, competition will further increase with the arrival of the longer range CS100 which will be equipped with considerably more efficient engines. As a consequence of the increased competition, Embraer was forced to revamp its Ejet family enhancing it to a version of the "1st" generation E-Jet, featuring a redesigned wingtip and two packages of aerodynamic, structural and systems improvements to the wing and the fuselage. The new E195 will not feature the new wingtip, designed exclusively for the E175. All these adjustments will lead to a reduction of fuel consumption by 1-2% on the E190.

Sales success has been fairly limited and is concentrated at Azul (60 aircraft in service) and airlines belonging to the Lufthansa Group (33 aircraft in service and 1 stored). The current backlog for the E195 consist of eight aircraft, seven of them are destined for China's Tianjin Airlines.

Table 5. 80Input values of the Embraer 195

Parameter	Symbol	Units	Chosen value
PAX			118
anding field length (ICA)			1435
Landing field length (ISA)	S _{LFL}	m m/s	1433
Approach speed	V _{APP}	m/s	2251
Take-off field length (ISA)	S _{TOFL}	m	2251
Range (max payload)	R	km	1445
Cruise Mach number	M _{CR}		0,78
Cruise speed	V _{CR}	m/s	247
Cruise altitude	h _{CR}	m	10668
Ning area	Sw	m²	92,53
Ving span	bw	m	28,72
Aspect ratio	A	III	8,92
Aspect ratio	^		8,92
Maximum take-off mass	m _{MTO}	kg	52290
Payload mass	m _{PL}	kg	13530
Mass ratio, payload - take-off	m _{PL} /m _{MTO}	-	0,259
Maximum landing mass	m _{ML}	kg	45000
Mass ratio, landing - take-off	m _{ML} /m _{MTO}	· ·	0,861
Operating empty mass	m _{OE}	kg	28970
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	•	0,554
Maximum zero fuel mass	m _{MZF}	kg	42500
Ving loading	m _{MTO} /S _W	kg/m²	527,3
Number of engines	n _E		2
Engine type			CF34-10E5
Γake-off thrust for one engine	T _{TO,one engine}	kN	82,292
Total take-off thrust	T _{TO}	kN	164,584
Γhrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,34
Bypass ratio	μ		5
Overall pressure ratio	OAPR		29
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,08E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	16,029
Sweep angle	A	0	
Mean aerodynamic chord	ф ₂₅	m	3,68
Position of maximum camber	CMAC	%c	44,2
Camber	X _{(y_c),max}	%c	
Janner	(y _c) _{max} /C	%c	2,7 35
Doubling of manyimarine this low		V/∧ C	35
Position of maximum thickness Relative thickness	X _{t,max}	%	11,8

 Table 5. 81
 Reverse engineering results of the Embraer 195

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,17	-9
Maximum lift coefficient, take-off	C _{L,max,TO}	-	1,83	-9
Maximum aerodynamic efficiency	E _{max}	-	14,41	30
Specific fuel consumption	SFC	kg/N/s	1,70E-05	2

5.44 Boeing 717-200

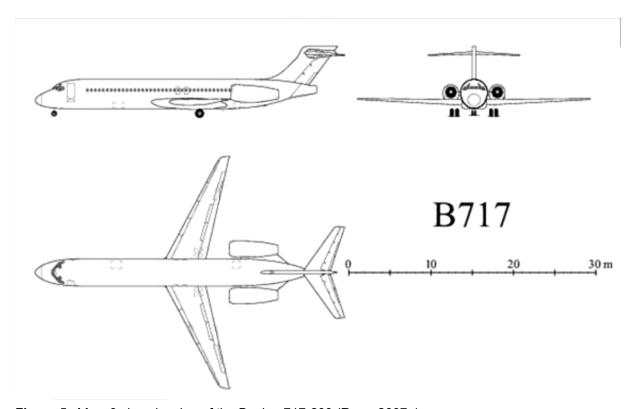


Figure 5. 44 3 view drawing of the Boeing 717-200 (Roux 2007a)

The 717-200 is a small narrow-bodied jet with capacity for a maximum seating of 106 passengers whose first flight took place on September 2, 1998. The Boeing 717 was originally developed by McDonnell Douglas as the MD-95, a 100-seat off-shoot of the MD-90. Development started in 1991 and was targeted at the Northwest Airlines requirement for a DC- 9-30 replacement. The MD-95 was the only former McDonnell-Douglas Corporation commercial passenger aircraft programme retained by Boeing after its take-over of MDC and was subsequently renamed the Boeing 717-200. As such it shared no commonality with other aircraft in production, although Boeing considered both shrink and stretched versions.

As a stand-alone aircraft it didn't have a lot of commercial success and only attracted AirTran Airways as large customer. Production ceased in 2006. Southwest Airlines which acquired

AirTran, sub-leased its inherited 88 strong 717 fleet to Delta Airlines. The first 717 was delivered to Delta in October 2013. By early 2016 the entire AirTran fleet had been transitioned to Delta Air Lines. Delta has also acquired some 717s from other operators and with a current fleet of 91 Boeing 717s in service (58,7% of the current fleet), Delta is by far the biggest operator of the type. The majority of the 717 fleet (98 aircraft) is controlled by the Boeing Capital Corporation. With only five airlines currently operating the Boeing 717, the operator base is very small.

Table 5. 82Input values of the Boeing 717-200

Parameter	Symbol	Units	Chosen value
PAX			106
Landing field length (ISA)	S _{LFL}	m	1450
Approach speed	V _{APP}	m/s	69
Take-off field length (ISA)	S _{TOFL}	m	1677
Range (max payload)	R	km	1375
Cruise Mach number	M _{CR}		0,77
Cruise speed	V _{CR}	m/s	225,3
Cruise altitude	h _{CR}	m	10424
Wing area	Sw	m²	92,97
Wing span	b _W	m	28,45
Aspect ratio	Α		8,71
Maximum take-off mass	m _{MTO}	kg	54900
Payload mass	m _{PL}	kg	14515
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,264
Maximum landing mass	m _{ML}	kg	49898
Mass ratio, landing - take-off	m _{ML/} m _{MTO}		0,909
Operating empty mass	m _{OE}	kg	31071
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,566
Maximum zero fuel mass	m _{MZF}	kg	45586
Wing loading	m _{MTO} /S _W	kg/m²	537
Number of engines	n _E		2
Engine type			BR715A1-30
Take-off thrust for one engine	T _{TO,one engine}	kN	82,292
Total take-off thrust	T _{TO}	kN	164,584
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,34
Bypass ratio	μ		4,7
Overall pressure ratio	OAPR		32,1
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,05E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	
Available fuel volume	V _{fuel,available}	m³	13,905
Sweep angle	ф ₂₅	۰	24,5
Mean aerodynamic chord	C _{MAC}	m	3,88
Position of maximum camber	X _{(y_c),max}	%c	
Camber	(y _c) _{max} /c	%c	
Position of maximum thickness	$\mathbf{X}_{t,max}$	%c	
Relative thickness	t/c	%	11,6
Taper	λ		0,206

 Table 5. 83
 Reverse engineering results of the Boeing 717-200

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,46	-19
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,70	-19
Maximum aerodynamic efficiency	E _{max}	-	14,30	24
Specific fuel consumption	SFC	kg/N/s	1,48E-05	15

5.45 Boeing 737-400

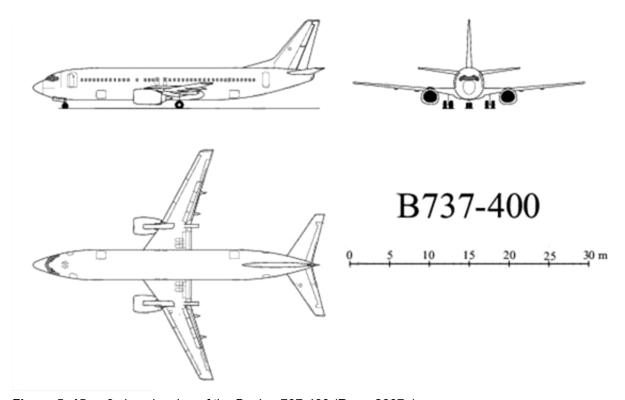


Figure 5. 45 3 view drawing of the Boeing 737-400 (Roux 2007a)

The 737-400 is a small narrow-bodied jet with capacity for a maximum seating of 189 passengers whose first flight took place on February 23, 1988. This stretched version of the 737-300 was Boeing's pretty successful attempt to keep Airbus from having the 150-seat market to itself. The 737-400 enjoyed a good sales performance, especially considering the short eleven-year production cycle. However, it was never to become as successful as the smaller 737-300 and suffered from the simultaneous introduction of the more advanced Airbus A320. Boeing also developed a higher gross weight 737-400 for enhanced payload/range with structural reinforcement of the aircraft. When compared with its modern technology competitors (737-800 and A320), the 737-400 lacks range, is more expensive to maintain and is much less fuel efficient. The 737-400 is the only variant of the classic 737 for which there is no winglet modification

available. The 737-400 is the heaviest of the 737 classics but, has the same wing. As a result, the wing has not enough residual strength to support the winglets.

At low/moderate fuel prices, a 737-400 can be economically viable if purchased at a low price. For high cycled aircraft structural issues will lead to increased maintenance/inspection costs with repairs, possibly shortening the economic life. The 737-400 is still popular with small, cash-strapped airlines who are specialized in charters and wet-lease operations to provide additional capacity during peak season for mainline and first-tier airlines. The low capital cost for the 737-400 permits operators to generate a profit despite low utilisation. As with the smaller -300, cargo conversion programmes are available. As a converted freighter, the 737-400 freighter has become far more popular than its smaller sibling the 737-300 freighter. As of today, ~130 737-400s have been converted, helped by the availability of affordable feedstock aircraft.

Table 5. 84Input values of the Boeing 737-400

Parameter	Symbol	Units	Chosen value
PAX			189
Landing field length (ISA)	S _{LFL}	m	1582
Approach speed	V _{APP}	m/s	71
Take-off field length (ISA)	STOFL	m	2222
Range (max payload)	R	km	3180
Cruise Mach number	M _{CR}		0,745
Cruise speed	V _{CR}	m/s	221,2
Cruise altitude	h _{CR}	m	10668
Wing area	Sw	m²	91,04
Wing span	bw	m	28,88
Aspect ratio	Α		9,16
Maximum take-off mass	m _{MTO}	kg	68040
Payload mass	m _{PL}	kg	18066
Mass ratio, payload - take-off	m _{PL/} m _{MTO}		0,266
Maximum landing mass	m _{ML}	kg	54885
Mass ratio, landing - take-off	m _{ML} /m _{MTO}		0,807
Operating empty mass	moe	kg	33190
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}		0,488
Maximum zero fuel mass	m _{MZF}	kg	51256
Wing loading	m _{MTO} /S _W	kg/m²	690
Number of engines	n _E		2
Engine type			CFM56-3B2
Take-off thrust for one engine	T _{TO,one engine}	kN	97,86
Total take-off thrust	T _{TO}	kN	195,72
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	$T_{TO}/(m_{MTO}*g)$	0,32
Bypass ratio	μ		5,9
Overall pressure ratio	OAPR		24,3
Specific fuel comsumption (dry)	SFC (dry)	kg/N s	1,11E-05
Specific fuel comsumption (cruise)	SFC (cruise)	kg/N s	1,89E-05
	,	_	
Available fuel volume	V _{fuel,available}	m³	20,102
Sweep angle	ф ₂₅	•	25
Mean aerodynamic chord	C _{MAC}	m	3,73
Position of maximum camber	X _{(y_c),max}	%с	20,4
Camber	(y _c) _{max} /c	%с	1,5
Position of maximum thickness	X _{t,max}	%с	39,9
5		%	12.0
Relative thickness	t/c	/0	12,9

 Table 5. 85
 Reverse engineering results of the Boeing 737-400

Secret parameter	Symbol	Units	RE Value	Verification deviation [%]
Maximum lift coefficient, landing	C _{L,max,L}	-	3,56	-10
Maximum lift coefficient, take-off	C _{L,max,TO}	-	2,68	-10
Maximum aerodynamic efficiency	E _{max}	-	15,19	20
Specific fuel consumption	SFC	kg/N/s	1,73E-05	-6

6 Discussion

When comparing the two methods of reverse engineering and verification, it can be seen that the results for the maximum lift coefficient (at landing) are very close to one another, since almost all the deviations values are below 15%, as shown in Figure 6.1 and the deviation average absolute value is 7,7%. From this, it can be concluded that the assumptions for the aerodynamics with regard to some profile values are well suited for the majority of aircraft. This is also a confirmation that the calculation for the lift coefficient from reverse engineering leads to reliable results. It is interesting to notice that almost all the values from the verification are smaller than the values from the reverse engineering. This could be explained through the contribution of the high lift devices, as they may have to be higher in the verification process.

It is important for the user to know that the verification of the maximum lift coefficient for takeoff and landing is difficult to carry out. The reason for this is that information about the aerodynamics of an aircraft is difficult to obtain because that data is classified information. Specifically, the verification method is based on data that contains fixed values and formulas. These
formulas are based on **Bathia 2010** and these values are provided by **DATCOM 1978**, This
method is known for underpredicting the verification values and that may be the reason why
almost all of them turned out to be smaller than the reverse engineering values. As a result,
verification may not be a good reference in every case.

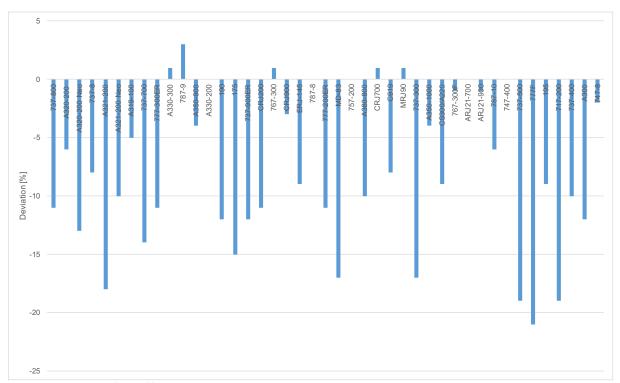


Figure 6. 1 Lift coefficient deviation values

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The results from reverse engineering are also close to the verification values for the results for the specific fuel consumption being the deviation average absolute value just 7,7%. Almost all of them have a deviation below 20%, as shown in Figure 6.2. Although it was found that the fuel mass fractions and the operating empty weight mass fraction have a very large influence on the result, the conservative fuel mass fractions according to **Roskam 1989** give good results. This means that the user must choose the highest maximum take-off weight when searching for the parameters. This way, both the fuel and the operating empty mass fractions will remain as conservative as possible. The user will check that when searching througut the different sources of information, several values for the maximum take-off weight are provided. It is of vital importance that the user selects the highest one if one is to perform the verification process as accurate as possible.

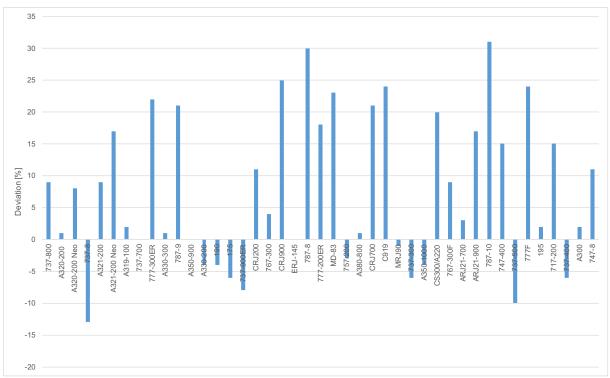


Figure 6. 2 Specific fuel comsumption deviation values

With the maximum aerodynamic efficiency, it can be clearly seen that the results from the verification calculation are greater and that there is a large deviation. The deviation average absolute value of 15,8% is greater than in the other parameters. This pattern can already be seen in the results of the **De Grave 2017** and **Cheema 2019** master's thesis. The results also deviate significantly for aircraft for which a value according to **Raymer 1989** is available for the ratio of wetted surface and wing area S_{WET}/S_W , as this value is often lower than the one used as reference for commertial aircraft, making the deviation even greater. A possible cause is that the k_E value for the various ranges for the verification of the maximum aerodynamic efficiency in cruise is set too high. It cannot be discard that the values from reverse engineering are too low. The tool should therefore be used for an aircraft whose maximum aerodynamic efficiency is known. For this aircraft, the tool should be used to determine the maximum aerodynamic efficiency and then check which result corresponds to the true value of the maximum aerodynamic

efficiency. Only then can it be determined whether the procedure of the tool for determining the maximum aerodynamic efficiency is too imprecise or the k_E value is set too high.

Regarding the values of S_{WET}/S_W and k_E , a further research can be carried out. If the user wishes to select more precise values of these parameters, the Project **Schlüter 2006** can examined, for it provides a wide range of values for different types of commercial aircraft, according to range (short, medium and long) and class (narrow/wide bodied jet).

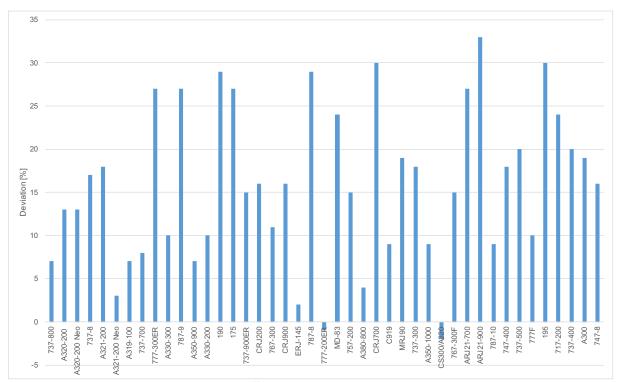


Figure 6. 3 Maximum aerodynamic efficiency deviation values

With regard to the reverse engineering method, the following can still be summarized. By looking at the formulas for the maximum lift coefficient for take-off and landing, it is possible to assess which parameters mainly influence the result. The maximum lift coefficient depends on the requirements of the aircraft. The lift coefficient for landing is determined by the landing field length, the wing loading and the landing mass fraction. The maximum lift coefficient for take-off is determined by the thrust-to-weight ratio and the take-off field length. Short field lengths lead to high lift coefficients.

The formulas for the maximum aerodynamic efficiency and for the specific fuel consumption are more complex than the formulas for the maximum lift coefficient. In addition, more input parameters are required here. The tool uses a numerical iteration for the maximum aerodynamic efficiency. In the case of specific fuel consumption, the tool first calculates other parameters in the formula before calculating the final result. Therefore, it cannot be clearly stated which parameters are decisive for the respective result.

Fort the next conclusions, an attempt on finding useful behaviors and patterns of the obtained parameters has been made. Table 6.1 include all the investigated and reverse engineered aeroplanes in chronological order. This gives an overview of the evolution of certain parameters in aircraft history. The graphs are not always smooth and not every aeroplane seems to fit in the picture. The reason for this is that aircraft are design to fullfil certain requirements. Some aeroplanes are designed for a very specific purpose. This results in deviating parameters. A chronological list of the aeroplanes is shown in Table 6.1.

The chronologically ascending classification according to the year of publication of the aircraft examined in this work gives an overview of the development of a secret parameter. Figure 6.4 analyses the evolution of the maximum aerodynamic efficiency.

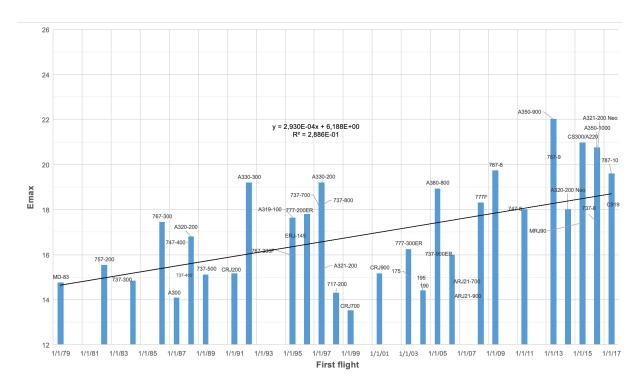


Figure 6. 4 Chronological evolution of E_{max}

Although not in a very smooth way, the graph clearly shows how the maximum aerodynamic efficiency has become higher over time. This shows that the development for more efficient and economical aircraft is proceeding. Especially the most modern aircraft which are equipped with advanced avionics, superior cabin designs and noise reduction capabilities that increase the fuel efficiency and performance of aircrafts. Some of these new aircraft belong to the Airbus Neo (New Engine option) Family, including Airbus A320Neo, A330Neo, the Boeing's NG (New Generation) Family and the MAX Family, including 787, 737 MAX, 777X, and Bombardier's C-series, such as the CS300. All of these aircraft models have a maximum aerodynamic efficiency over 18 and in most of the cases over 20, which is a fairly high value for this parameter, proving the theory that aviation market is focusing on developing more efficient aircraft.

 Table 6. 1
 Aircraft in chronological order

Date of First Flight	Aircraft
19/10/79	MD-83
19/2/82	757-200
24/2/84	737-300
30/1/86	767-300
9/12/87	A300
23/2/88	737-400
29/4/88	747-400
27/6/88	A320-200
30/6/89	737-500
10/5/91	CRJ200
2/11/92	A330-300
20/6/95	767-300F
11/8/95	ERJ-145
29/8/95	A319-100
7/10/96	777-200ER
9/2/97	737-700
15/3/97	A321-200
31/7/97	737-800
13/8/97	A330-200
2/9/98	717-200
27/5/99	CRJ700
21/2/01	CRJ900
24/2/03	777-300ER
15/6/03	175
12/3/04	190
7/12/04	195
27/4/05	A380-800
5/9/06	737-900ER
14/7/08	777F
28/11/08	ARJ21-700
28/11/08	ARJ21-900
15/12/09	787-8
20/3/11	747-8
14/6/13	A350-900
17/9/13	787-9
25/9/14	A320-200 Neo
27/2/15	CS300/A220
11/11/15	MRJ90
29/1/16	737-8
9/2/16	A321-200 Neo
24/11/16	A350-1000
31/3/17	787-10
15/5/17	C919

In addition, a trend line has been calculated in order to study in a more accurate way how much is the maximum aerodynamic efficiency increasing throughout the years:

$$E_{max} = 2,930 \cdot 10^{-4} \ t + 6,188 \tag{6.1}$$

with t = time [days]

This means that, on average, the maximum aerodynamic efficiency increases 4,072E-04 for every temporary unit, being one day one temporary unit. Therefore, the annual increase of the maximum aerodynamic efficiency can be calculated as follows:

$$E_{max} per year = 2,930 \cdot 10^{-4} \frac{1}{day} 365 \frac{day}{year} = 0,106945 \frac{1}{year}$$
 (6.2)

Although almost all the obtained result for maximum aerodynamic efficiency seem consistent, it is important to carry out a critical interpretation of the results. In this case, the diagonal stripe bars display excessively high results. It has been easier to notice these suspicious results thank to visual representation of the Figure 6.4 itself. When analyzing the overall results, it has been considered that these results are not plausible. A good explanation for this behavior is the lack of input parameter information that has been found in this specific aircrafts. The reason why there are so few sources providing this information is that these aircraft belong to a modern family of aircrafts and its information is still incipient.

The engine manufacturers are also responsable for the improvement of the fuel consumption. The first positive influence on the fuel consumption is due to the engines. The engine technology improved and the bypass ratio enlarged, as it can be shown in Figure 6.5.

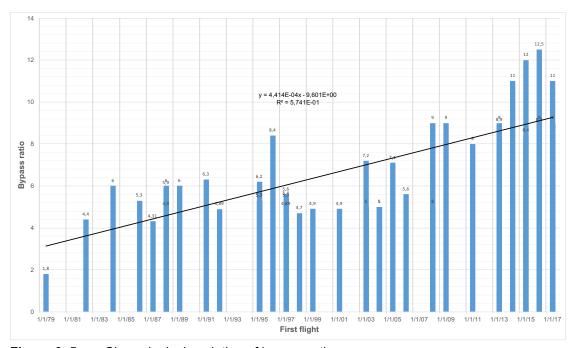


Figure 6. 5 Chronological evolution of bypass ratio

Again, the most modern aircraft offer higher values of bypass ratio. As bypass ratio increases the overall efficiency of the engine increase which is a primary factor that yields lower specific fuel comsumption for the turbofan engine. Additionally, a high bypass ratio engine can produce a greater amount of thrust while consuming the same amount of fuel as a lower bypass ratio engine.

As previously provided in the maximum aerodynamic efficiency section, a trend line for the bypass average evolution has been calculated.

$$\mu = 4{,}414 \cdot 10^{-4} t - 9{,}601 \tag{6.3}$$

with t = time [days]

Applying the same logical procedure as in the case of maximum aerodynamic efficiency, we can calculate the annual bypass ratio increase.

$$\mu \, per \, year = 4,414 \cdot 10^{-4} \, \frac{1}{day} \, 365 \, \frac{day}{year} = 0,161111 \, \frac{1}{year}$$
 (6.4)

In this case, all the results are consistent since they have not been calculated with the Excelbased tool "PJRE", they were input parameters instead. The reason why the bypass ratio has been brought into analysis is to prove and calculate accurately its incremental behavior over the years.

The reader will find useful Table 6.2 and Table 6.4 for they are a display of the overall obtained results organized by aircraft manufacturer and type and by engine manufacturer and type. For the engine specifications (Table 6.4) we look for a reliable relation of the results among the same engine family. There are even cases in which the same engine was used and, therefore, the logical outcome would be that the obtained SFC result was the same. However, although the results are similar in the majority of the cases, this cannot be proven in all of them. Even so, the SFC value that has been calculated is not a purely engine parameter. It has been influenced by all the parameters that served as input in the tool and, therefore, although two different aircraft used the same engine, their mission might be completely different and their SFC would come out differently from reverse engineering.

 Table 6. 2
 Obtained results organized by manufacturer

anufacturer	Aircraft type	Engine type	C _{L,max,L}	C _{L,max,TO}	E _{max}	SFC
Embraer	175	CF34-8E2	3,39	2,41	15,02	1,94E-0
	190	CF34-10E5	3,28	1,95	14,41	1,80E-0
	195	CF34-10E5	3,17	1,83	14,41	1,70E-0
	ERJ-145	AE3007A1/1	2,44	1,34	16,55	1,47E-0
Boeing	717-200	BR715A1-30	3,46	2,70	14,30	1,48E-0
	737-300	CFM56-3B1	3,20	2,19	14,84	1,78E-0
	737-400	CFM56-3B2	3,56	2,68	15,19	1,73E-0
	737-500	CFM56-3B1	3,76	2,84	15,11	1,84E-0
	737-700	CFM56-7B24	3,11	2,44	17,99	1,72E-
	737-8	LEAP-1B25	3,15	1,88	17,45	1,77E-(
	737-800	CFM56-7B24	2,98	2,30	18,17	1,54E-0
	737-900ER	CFM56-7B26	2,99	1,88	16,00	1,77E-(
	747-400	PW4056	2,14	2,07	16,42	1,46E-0
	747-8	Genx-2B67	2,56	2,24	18,03	1,39E-0
	757-200	RB211-535E4	2,92	2,09	15,54	1,74E-0
	767-300	CF6-80C2B2F	2,73	1,73	17,44	1,52E-
	767-300F	CF6-80C2B7F	2,80	1,75	15,95	1,43E-
	777-200ER	GE90-85B	2,76	1,96	17,81	1,26E-
	777-300ER	GE90-115B	2,98	2,13	16,25	1,22E-
	777F	GE90-110B1L	3,26	2,21	18,30	1,19E-
	787-10	Genx 72A1	3,13	2,24	19,62	1,14E-
	787-8	Genx-1B70	2,96	1,91	19,73	1,16E-
	787-9	Genx-1B74	2,96	2,20	20,08	1,23E-
Airbus	A300	CF6-80C2A1	3,28	2,19	14,08	1,51E-
	A319-100	CFM56-5B6	3,26	2,33	17,65	1,62E-
	A320-200	CFM56-5B4	3,31	2,29	16,80	1,60E-
	A320-200 Neo	CFM LEAP-1A	3,57	2,28	18,01	1,36E-
	A321-200	CFM56-5B3/P	3,76	2,62	15,35	1,44E-
	A321-200 Neo	PW1133G-JM	3,46	2,42	20,10	1,25E-
	A330-200	Trent 772B-60	2,66	2,35	19,19	1,64E-
	A330-300	Trent 772-60	2,73	2,53	19,19	1,55E-
	A350-1000	Trent XWB-97	2,36	2,03	20,76	1,53E-0
	A350-900	Trent XWB-83	2,23	1,74	22,02	1,54E-0
	A380-800	Trent 970-84	2,25	2,01	18,94	1,48E-0
Comac	ARJ21-700	CF34-10A	2,84	2,35	14,89	1,72E-0
	ARJ21-900	CF34-10A	2,97	2,41	14,28	1,49E-
	C919	CFM LEAP-1C	3,02	1,75	17,97	1,09E-0
Bombardier	CRJ200	CF34-3B1	2,36	1,60	15,17	1,77E-(
	CRJ700	CF34-8C1	2,67	2,02	13,54	1,48E-0
	CRJ900	CF34-8C5	2,84	2,24	15,17	1,47E-(
Bombardier /Airbus	CS300/A220	PW1525G	2,81	2,28	20,98	1,26E-
IcDonnel D.	MD-83	JT8D-219	3,32	2,26	14,76	1,67E-0
			, -		17,41	1,68E-0

Despite the thorough research that must be done to ensure that all the results are reliable and accurate, there might be cases in which this is not possible. Therefore, an intensive and individual analysis of all the parameters must be carried out to detect unplausible results, either because their values are too high, too low, or simply not consistent.

Table 6.3 provides a deeper study of the average values of maximum aerodynamic efficiency within the same family of aircraft or between aircraft with the same characteristics.

 Table 6. 3
 Comparison of maximum aerodynamic efficiency between Airbus family

Manufacturer	Aircraft type	Engine type	E _{max}	Average	
Bombardier/Airbus	CS300/A220	PW1525G	20,98	20,98	
	A319-100	CFM56-5B6	17,65		
	A320-200	CFM56-5B4	16,80	16,60	
Airbus	A321-200	CFM56-5B3/P	15,35	_	
	A320-200 Neo	CFM LEAP-1A	18,01	10.05	
	A321-200 Neo	PW1133G-JM	20,10	– 19,05	
	A350-1000	Trent XWB-97	20,76	24.20	
	A350-900	Trent XWB-83	22,02	_ 21,39	
	A380-800	Trent 970-84	18,94	18,94	

The first interesting comparison is made between the A320 family and the A320Neo family. The average maximum aerodynamic efficiency of the A320 family is 16,6 and for the A320Neo family it is 19,05. This result is very satisfactory considering that the A320Neo family is more modern than the A320 family besides being the most profitable Airbus family.

The A220 has a maximum aerodynamic efficiency of 20,98 while the A320Neo family has one of 19,05. Overall, they both have the same characteristics, such as a narrow body, payload capacity for approximately 160 passengers and range of approximately 6000 km. Therefore, it is also satisfactory to check that both maximum aerodynamic efficiencies are similar to each other.

Regarding the A350-900/-1000, it is a large wide-bodied jet with an average maximum aerodynamic efficiency of 21,39. The A380-800 is a very large wide-bodied jet with an average maximum aerodynamic efficiency of 18,94. This illustrates that the A350 is a more modern an efficient aircraft compared to the A380, which was built precisely for this purpose, to cover long-haul routes more efficiently than the A380 did.
 Table 6. 4
 Obtained results organized by engine type

Manufacturer	Engine family	Engine type	SFC	Average	μ
General Electric	CF34	CF34-10A	1,72E-05		5
		CF34-10A	1,49E-05	_	5
		CF34-10E5	1,80E-05	_	5
		CF34-10E5	1,70E-05	- - 1,67E-5 –	5
		CF34-3B1	1,77E-05	1,076-5 -	6,3
		CF34-8C1	1,48E-05	_	4,9
		CF34-8C5	1,47E-05	_	4,9
		CF34-8E2	1,94E-05	_	5
	CF6	CF6-80C2A1	1,51E-05		4,31
		CF6-80C2B2F	1,52E-05	1,49E-5	5,3
		CF6-80C2B7F	1,43E-05	_	5,3
	CFM LEAP	CFM LEAP-1A	1,36E-05		11
		CFM LEAP-1B25	1,77E-05	1,4E-5	9
		CFM LEAP-1C	1,09E-05	_	11
	CFM56	CFM56-3B1	1,78E-05		6
		CFM56-3B1	1,84E-05	_	6
		CFM56-3B2	1,73E-05		5,9
		CFM56-5B3/P	1,44E-05		5,4
		CFM56-5B4	1,60E-05	1,67E-5	6
		CFM56-5B6	1,62E-05	_	6,2
		CFM56-7B24	1,72E-05		5,6
		CFM56-7B24	1,54E-05	_	5,3
		CFM56-7B26	1,77E-05	_	5,6
	GE90	GE90-110B1L	1,19E-05		9
		GE90-115B	1,22E-05	1,22E-5	7,2
		GE90-85B	1,26E-05	_	8,4
	GEnx	Genx-1B74	1,23E-05		9
		Genx-1B70	1,16E-05		9
		Genx 72A1	1,14E-05	1,23E-5 –	9
		Genx-2B67	1,39E-05		8
Pratt & Whitney	JT8D	JT8D-219 1,67E-05		1,67E-05	1,8
•	PW1000G	PW1133G-JM	1,25E-05		12,5
		PW1217G	1,68E-05	1,41E-5	8,4
		PW1525G	1,26E-05	- · · -	12
	PW4000	PW4056	1,46E-05	1,46E-05	4,9
Rolls-Royce	AE 3007	AE3007A1/1	1,47E-05	1,47E-05	5,3
Rolls-Royce	BR700	BR715A1-30 1,48E-05		1,48E-05	4,7
	RB211	RB211-535E4 1,74E-05		1,74E-05	4,4
	Trent 700	Trent 772-60	1,55E-05		4,89
		Trent 772B-60	1,64E-05	1,59E-5 —	4,89
	Trent 900	Trent 970-84	1,48E-05	1,48E-5	7,1
	Trent XWB	Trent XWB-83	1 54F-05		8,9
	· - · · · · · · · · · · · · · · · · · ·	Trent XWB-97	1,53E-05	1,54E-5 —	-,-

When checking the results from the engine specifications in Table 6.4 it can be noted that the engines with high bypass ratio are the ones that have revealed less SFC. Besides, these engines usually are the most modern ones and the ones that are used in the most modern aircraft. The engine family CFM LEAP is used in the aircraft families A320Neo, A321Neo, 737 MAX and COMAC C919, and the GEnx family is used in the aircraft Boeing families 747-8 and 787 Dreamliner. One of the results is highlighted in yellow because it is a very high value and, therefore, unreliable.

We notice that the GE90, which is mainly used in the Boeing's 777 family, has a very low SFC. This is not so much due to its BPR, but due to its large size, being that he internal engine efficiencies increase with size.

The CF34 engine family is mainly used in the aircraft families Bombardier Challenger and CRJ, COMAC ARJ21 and Embraer E-Jets, giving a satisfactory SFC average of 1,67E-5 kg/Ns.

The CF6 engine family is used in traditional aircraft families like A300, A310, A330, 747 or 767, providing a satisfactory average SFC of 1,49 kg/Ns but it is gradually being replaced by the newer GEnx family.

7 Summary and Conclusions

This thesis has successfully provided the aeronautical community with useful data. This data consists of the commercial aircraft secrets parameters that the manufacturers do not reveal due to competitive reasons. These parameters are the following: maximum lift coefficient (for landing and take-off), maximum aerodynamic efficiency and Specific Fuel Consumption (SFC). However, this is not the first thesis that manages to provide these secret parameters. On the contrary, there are two previous existing thesis that fulfill this task and explain in detail how this process is exactly carried out. This is the reason why this thesis dedicates the whole state of the art to explain in the briefest, most accurate and understandable way the knowledge that these two thesis brought us. The first one achieved to develop an Excel-based tool with which the user can reveal the secret parameters and the second managed to improve it.

Nevertheless, the virtue of this thesis lies in the intensive study that has been carried out. For the first time, the Excel-based tool "Passenger Jet Reverse Engineering" has been used in a large number of aircraft within the same research. The study of the aviation market has shown that in order to cover the 90% of the total in service or on order aircraft, the first 47 most used passenger aircraft must be selected and studied. These aircraft were selected from a total of 117 aircraft (91 passenger aircraft and 26 freighters), which shows that sales are concentrated in a specific segment of aircraft. This segment is the narrow-body segment which has the maximum market share aircraft, as they are fuel-efficient and help in reducing the overall cost. This is one of the crucial factors that have increased the adoption of narrow-body aircraft globally. In the end, of those 47 aircraft, 4 aircraft had to be discarded due to two reasons: 2 aircraft carried turboprop engines and 2 aircraft did not collected enough data to make the tool work.

One of the most important things when using the tool is to provide it with reliable information, otherwise the obtained results could be useless, even if the verification is performed. The best way to collect reliable information is to look for it in several reliable sources and write down all the values to compare them between each other. This thesis has collected the parameters information from 9 different reliable sources and has selected the most suitable value for each parameter in order to obtain the most accurate results.

Regarding the reverse engineering method, it can be assessed which input parameters are going to have some influence in the output parameters just by looking at the formulas. The maximum lift coefficient depends on the requirements of the aircraft. This means that the lift coefficient for landing is determined by the landing field length, the wing loading and the landing mass fraction, and the maximum lift coefficient for take-off is determined by the thrust-to-weight ratio and the take-off field length. Therefore, short field lengths lead to high lift coefficients. The formulas for the maximum aerodynamic efficiency and for the specific fuel consumption are more complex than the formulas for the maximum lift coefficient and, therefore, it cannot

be clearly stated which parameters are decisive for the respective result, since more input parameters are required here. However, the tool can also be useful to unravel the influence of the input parameters. When the formulas are not clear anymore, the tool can determine whether the input parameters are going to have a direct or indirect proportional influence to the output parameters.

The obtained reverse engineering results have proven to be satisfactory, since every of the three secret parameters from almost every aircraft have not deviated in great quantity from the verification values. For every secret parameter there might be a reason why their values have deviated from the reverse engineering values. In the case of the maximum lift coefficient (at landing), the deviation average absolute value is 7,7% and almost all the values from the verification are smaller than the values from the reverse engineering. In the case of the specific fuel consumption, the deviation average absolute value is 7,7% and it was found that the fuel mass fractions and the operating empty weight mass fraction have a very large influence on the result, which was beneficial to obtain more accurate results. Thirdly, with the maximum aerodynamic efficiency, it can be clearly seen that the deviation average absolute value of 15,8% is greater than in the other parameters, which can be explained by different reasons that must be taken into account for further investigation. These deviations are of vital importance to the research because they allow us to see the flaws of the tool when analyzing such a large number of aircraft and extract statistical data.

Finally, the results have shown that the maximum glide ratio and bypass ratio are continuously increasing as engines and airplanes become more efficient, since the regression line has shown an increase of 0.11 per year in in maximum glide ratio, E_{max} and 0.16 per year in bypass ratio. On average, the next results have been obtained: 2.98 for maximum lift coefficient (for landing), 2.15 for maximum lift coefficient (for take-off), 17 for maximum aerodynamic efficiency and 1,52E-5 kg/Ns for specific fuel consumption.

8 Recommendations

The formulas used for dimensioning an aircraft only apply to jet airliners and business jets. Therefore, the PJRE tool can only be used for this type of aircraft. After implementing the improvements for this tool, a propeller aircraft tool should also be developed in the near future to cover more aircraft

There are a few aircraft that have been analyzed in this thesis in detail, as well as described the same way the rest of the jet aircraft were. However, they could not be included in the Excel tool because of his turboprop nature. These aircraft were the Bombardier DHC-8-401 (Dash-8 Q400) and the ATR 72-600. An interesting improvement could be the possibility of choosing the type of engine of the aircraft.

When searching for the parameters the user must look for the cruise speed. In various sources, the possibility of choosing different speeds is offered. These speeds are usually the following: maximum cruise speed and long range cruise speed. Therefore, it would be interesting to upgrade the tool by integrating a new feature: a function that does the reverse engineering for both speeds, depending on the value for the optimized speed ratio by the program.

The tool provides a good way of comparing aircraft with one another. The tool is also user-friendly and delivers results quickly. Compared to existing methods, most of the necessary input parameters can be found through intensive research and the right selection of sources. It is very important to invest a lot of time in researching the input parameters in order to get good and realistic results.

In the future, little corrections will have to be done so that these deviations are little by little decreasing and the obtained results are increasingly accurate and reliable.

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Appendix A Boeing 737-800

	Units The second secon	Chosen value 189 1646 72 0 2300 0 2700 0,785 124,6 34,32 9,45 78245	Aircraft characteristics for airport planning 160-184 1770 0 2370 33700 34.32-35,79	A 162 72,536667	Jane's B 162-189	Jenkinson 189-160	Engine	Scholz Pa	Paul Müller	Elodie Roux A B 189-162	Data collection	Webs
Symbol Safe	<u>s</u>	2300 0 0 124,6 34,32 9,45 2000 0 0 2 2000 0 0 0 0 0 0 0 0 0 0 0	160-184 1770 0 0 3700 34.32-35,79	72,536		189-160			180			
SiFE VAPP VAPP SiFE SiFE SiPE	90	1646 72 72 0 0 2300 0 0 3700 0,785 124,6 34,32 9,45	1770 0 2370 0 3700 34.32-35,79	72,536					2			
Safe VAPP VAPP Safe	, o	1646 72 0 0 2300 0 0 0,785 124,6 34,32 9,45	1770 0 2370 0 3700 34.32-35,79	72,536								
VAPP VAPP STORIL STORI	9	72 0 0 2300 0 0,785 124,6 34,32 9,45 78245	2370 0 0 3700 34.32-35,79	72,536	46	1600			1600	1600	1600	
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S SW MGR MGR A A A A A A A A A A A A A A A A A A A		3700 3700 0,785 124,6 34,32 9,45 78245	3700	2	2100 2308	3 2316					2300	2400
S MGR MGR MGR SWW DW MGR	5	3700 0,785 124,6 34,32 9,45 78245	3700		15	20						
Sww MGR Sww Maro mate mate mate mate mate mate mate mate	5	3700 0,785 124,6 34,32 9,45 78245	34.32-35.79									
Sw. Sw. Dw. Dw. Dw. Dw. Dw. Dw. Dw. Dw. Dw. D		0,785 124,6 34,32 9,45 78245	34,32-35,79	8	3685 5444				5426	1363		5665
Sw. bw bw A A A A A A A A A A A A A A A A A	_	124,6 34,32 9,45 78245	34,32-35,79		0,785		8,0			62'0	0,785	0,785
bw A A A A A A A A A A A A A A A A A A A		34,32 9,45 78245	34,32-35,79		125	124.6			125	124 6		
MATO MELL MELL MELL MELL MELL MELL MELL MEL		9,45	01,00	78	34 34				34.31	34.32	34.32	35.7
MMTO MPI. MPI. MPI. MMI. MAI. MOE		78245			L	9,4421			9,4	9,45	20,10	9,45
MATO MPL MPL MALIMATO MALIMATO MOE		78245										
MPL MPLMMTO MML MML MALL MOE MOE		2000	70534 78245		70535 79015				78244	70534	70530	79010
MAL/MAITO MAIL/MAITO MOE		20210	20276	21319		14690				20276		
MAIL MAIL/MATO MOE						0,187				0,287		
MML/MMTo Moe		65315	65317	66361 65	65315 66360				65317	65317		66361
\top			0777		-	0,8349527						0,1,1,1
		41145	41413		41145	41480				41413		41413
	/m ²	564.3		ŭ	564 3 632 1	0,53029916				786		
mass mass	1 2	61690	61680	62732 61						900		
Number of engines		2				2				2	2	2
		CFM56-7B24	CFM56-7B24/-7B26/-7B27	CFM56	CFM56	CFM56-7I	CFM56-7B24		J	CFM	327 CFM56-7B	
ne engine T _{TO,one engine}		106,757		115,5714 10	107,6 121,4	107	106,75733			106,757 121,436	117	60,7
						4						121,4
ght ratio		0,31		0,3120514	0,3139717	0,27888615	C				0,35	0,15663
1 0	- 14	5,3					5,3			5,3 4 OFF OF	5,1	
SFC (dry)	kg/N s	1,03E-03					1,047E-U5				00	
Specific Fuel Comsumption (cruise) SFC (cruise kg/N s	s N	1,78E-05					1,774E-05			1,78E-05		
Available fuel volume V _{huel,available} m³	_	26,022	26,022	26	26,025	26,024				26,022		
Cruise speed V _{CR} m/s	_o	232,5				232,53					236,64444	269,167
hcr		11887		1.	11675 10955		10668			11887		12500
Sweep angle \$\displaystyle{\phi}_{25}\$		25				25				25		25,02
namic chord		4,17				4,17				4,17		
per	0	10										10
	0	8,0										0,8
ım thickness	0	29,7										29,7
re thickness t/c		12,5										12,5
		0,219		0,	0,218914186	0,278				0,219		
Overall pressure ratio		56					56					

Aeroplane Specifications

	Data to apply	reverse engineering			
				LL	UL
Landing field length	Known	S _{LFL}	1646 m		
Approach speed	Known	V_{APP}	72,00 m/s	72,0	72,0
Temperature above ISA (288,15K)		ΔT_L	0 K		
Relative density		σ	1		
Take-off field length	Known	S _{TOFL}	2300 m	2300	2300
Temperature above ISA (288,15K)		ΔT_TO	0 K		
Relative density		σ	1,000		
Range (maximum payload)		R	1998 NM		
Cruise Mach number		M_{CR}	0,785		
Wing area		S _W	125 m²		
Wing span	Known	b_W	34,32 m ²	34,32	34,32
Aspect ratio		Α	9,45		
Maximum take-off mass		m _{MTO}	78245 kg		
Maximum payload mass		m_{PL}	20276 kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,259		
Maximum landing mass		m_{ML}	65315 kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,835		
Operating empty mass		m_{OE}	41145 kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,526		
Wing loading		m_{MTO}/S_W	628,0 kg/m²		
Number of engines		n _E	2		
Take-off thrust for one engine		T _{TO,one engine}	106,757 kN		
Total take-off thrust		T _{TO}	213,514 kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,278		
Bypass ratio		μ	5,3		
Available fuel volume		V _{fuel,available}	23,86 m³		

Data	to	optimize	V/V	md
------	----	----------	-----	----

				LL	UL
Cruise speed		V_{CR}	233 m/s		O'L
Cruise altitude		h _{CR}	11887 m		
Speed ratio		V/V _{md}	1,000 -	1	1,316
	Data to exec	ute the verification			
				Rar	nge
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	4,17 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{X}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Known	t/c	12,5 %		
Taper		λ	0,219		

Reverse Engineering

Reverse engineering & optimization of V/Vmo	d
---------------------------------------------	---

oroc engineering	a optimization of th	· iii u		
Quantity	Original value	RE value	Unit	Deviation
S_{LFL}	1646	1646	m	0,00%
V_{APP}	72,00	72,0	m/s	0,00%
S _{TOFL}	2300	2300	m	0,00%
b_W	34,32	34,32	m	0,00%
Α	9,45	9,45		0,00%
V_{CR}	232,5	232	m/s	-0,3 <mark>6%</mark>
h_{CR}	11887	11679	m	-1,75%
				3,20E-04 1,8%
Results rev	erse engineering			
$C_{L,max,L}$	2,98			
$C_{L,max,TO}$	2,30		Reve	erse Engineering
E _{max}	18,17		17646	nse Engineening
SFC	1,54E-05 kg/l	N/s		
	Quantity SLFL VAPP STOFL bW A VCR hCR Results rev CL,max,L CL,max,TO Emax	Quantity Original value SLFL 1646 VAPP 72,00 STOFL 2300 bW 34,32 A 9,45 VCR 232,5 hCR 11887 Results reverse engineering CL,max,L 2,98 CL,max,TO 2,30 Emax 18,17	SLFL 1646 1646 VAPP 72,00 72,0 STOFL 2300 2300 bW 34,32 34,32 A 9,45 9,45 VCR 232,5 232 hCR 11887 11679 Results reverse engineering CL,max,L CL,max,L 2,98 CL,max,TO 2,30 Emax 18,17	Quantity Original value RE value Unit S _{LFL} 1646 1646 m V _{APP} 72,00 72,0 m/s S _{TOFL} 2300 2300 m b _W 34,32 34,32 m A 9,45 9,45 V _{CR} 232,5 232 m/s h _{CR} 11887 11679 m Results reverse engineering C _{L,max,L} 2,98 C _{L,max,TO} 2,30 E _{max} 18,17

1) Maximum Lift Coefficient for Landing and Take-off

	anding	
Landing field length	S _{LFL}	1646 m
Геmperature above ISA (288,15К)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_APP	1,70 (m/s²) ^{0.8}
Approach speed	V_{APP}	72,00 m/s
Factor, landing	k_L	0,107 kg/m ³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,83
Wing loading at maximum take-off mass	m_{MTO}/S_W	628,0 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,98
Ta	ake-off	
Take-off field length	S _{TOFL}	2300 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,278
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,30
2nd	Segment	
Aspect ratio	Α	9,453
Lift coefficient, take-off	$C_{L,TO}$	1,60
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\DeltaC_D,flap$	0,025
ift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C_D,P	0,045
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	9,54
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,258
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,76
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,033
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Profile drag coefficient	$C_{D,P}$	0,068
Glide ratio in landing configuration	EL	8,11
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,241

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,785	
Aspect ratio	A	9,45	
Bypass ratio	μ	5,30	
Wing loading	m_{MTO}/S_W	628 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,278	
	Variables		
	V/V_{md}	1,0	
C	alculations		
Zero-lift drag coefficient	$C_{D,0}$	0,019	
Lift coefficient at E _{max}	$C_{L,md}$	0,69	
Ratio, lift coefficient	$C_L/C_{L,md}$	1,000	
Lift coefficient, cruise	C_L	0,695	
Actual aerodynamic efficiency, cruise	E	18,17	
Max. glide ratio, cruise	E_{max}	18,17	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	1	2	3
f(x)	0,23	-0,01	0,00
f'(x)	-0,10	-0,11	-0,11
E_{max}	16	18,26	18,17

3) Specific Fuel Consumption

Consta	nt parameters	
Ratio of specific heats, air	γ	1,4
Earth acceleration	g	9,81 m/s ²
Air pressure, ISA, standard	p_0	101325 Pa
Fuel density	$ ho_{fuel}$	800 kg/m³
Spe	cifications	
Range	R	1998 NM
Mach number, cruise	M_{CR}	0,785
Bypass ratio	μ	5,30
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,278
Available fuel volume	$V_{fuel,available}$	23,86 m³
Maximum take-off mass	m_{MTO}	78245 kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,259
Mass ratio, operating empty - take-off	$m_{\text{OE}}/m_{\text{MTO}}$	0,526
Calcu	ılated values	
Actual aerodynamic efficiency, cruise	E	18,17
Cruise altitude	h _{CR}	11679 m
Cruise speed	V_{CR}	232 m/s
Missio	n fuel fraction	
Type of aeroplane (according to Roskam)	Transport jet	
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990
Fuel-Fraction, taxi	$M_{\rm ff,taxi}$	0,990
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980
Fuel-Fraction, descent	M _{ff,DES}	0,990
Fuel-Fraction, landing	M _{ff,L}	0,992
Ca	Iculations	
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,215
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,785
Available fuel mass	F,available	19088 kg
Relative fuel mass (acc. to fuel capacity)	m _{F.available} /m _{MTO}	0,244
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,771
(,		2,111
Distance to alternate	S _{to_alternate}	200 NM
Distance to alternate	S _{to_alternate}	370400 m
Choose: FAR Part121-Reserves	domestic	yes
	international	no
Extra-fuel for long range		5%
Extra flight distance	s _{res}	370400 m
Loiter time	t_{loiter}	2700 s
Specific fuel consumption	SFC	1,54E-05 kg/N/s

4) Verification Specifications

Maximum lift coefficients

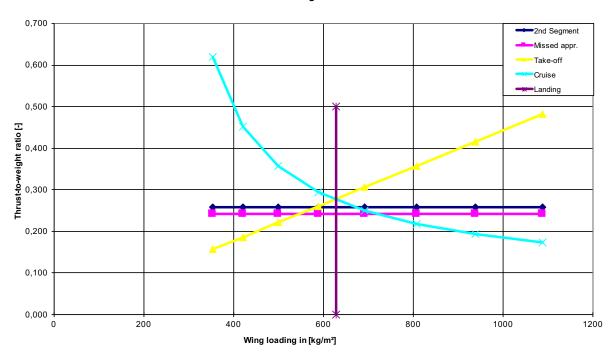
General wing specifications	Airfoil type:	NACA 4 dig
Wing span	b_W	34,32 m
Structural wing span	$b_{W,struct}$	37,87 m
Wing area	S_W	124,6 m ²
Aspect ratio	Α	9,45
Sweep	ϕ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	4,17 m
Position of maximum camber	$\mathbf{x}_{(\mathbf{y_c}),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
Relative thickness	t/c	12,5 %
Taper	λ	0,219
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	72,00 m/s
Mach number, landing	M_APP	0,22
Mach number, cruise	M_{CR}	0,785
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,3 %c
Leading edge sweep	ϕ_{LE}	28,9 °
Reynoldsnumber	Re	2,1E+07
Maximum lift coefficient, base	$c_{L,max,base}$	1,60
Correction term, camber	$\Delta_1 c_{L,max}$	0,12
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,118
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,839
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	$\Delta C_{L,max}$	-0,02
Lift coefficient, wing	C _{L,max}	1,45

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87
Flap group A		
Double-slotted flap	$\Delta c_{L,max,fA}$	1,42
Use flapped span	b_W,fA	6,846 m
Percentage of flaps allong the wing		18%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,22
Flap group B		4.40
Double-slotted flap	Δc _{L,max,fB}	1,42
Use flapped span Percentage of flaps allong the wing	b_W,fB	11,84 m 31%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,39
Increase in maximum lift coefficient, flap		0,61
increase in maximum int coemcient, nap	$\Delta C_{L,max,f}$	0,01
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΦH.L.	26 °
Slat group A		
0,1c Kruger flap	$\Delta c_{L,max,sA}$	0,66
Use slatted span	b_W,sA	4,46 m
Percentage of slats allong the wing		12%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,07
Slat group B		
0,3c Nose flap	Δc _{L,max,SB}	0,90
Use slatted span	b_W,sB	25,4 m
Percentage of slats allong the wing	4.0	67%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,54
Increase in maximum lift coefficient, slat	$\DeltaC_{L,max,s}$	0,61
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,64
RE value maximum lift coefficient, landing		2,98
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,04
RE value maximum lift coefficient, take-off		2,30
-11%	•	
Aerodynamic effi	ciency	
Real aircraft average	k	2,83
_	k _{WL}	1,11
End plate	k _{e,WL}	
Span Winglet height	b _W h	34,32 m 2,49 m
Aspect ratio	A	9,45
Effective aspect ratio	A _{eff}	10,45
Ellocate dopost tallo	, , , , , , , , , , , , , , , , , , ,	10,10
Efficiency factor, short range	k_{E}	15,15
Relative wetted area	S_{wel}/S_W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	19,4
RE value maximum aerodynamic efficiency	− max	18,17
7%		

Specific fuel consumption (Herrmann 2010)

Cruise altitude By Pass Ratio μ 5,30 Take-off Thrust (one engine) μ 5,30 Take-off Thrust (one engine) μ 106,76 kN Overall Pressure ratio μ 106,76 kN Overall Pressure ratio μ 106,76 kN OAPR 26,00 Turbine entry temperature μ 1445,06 Inlet pressure loss μ 1445,06 Inlet efficiency μ 11445,06 Inlet efficiency μ 1145,06 Inlet efficiency μ 1145,06 Inlet μ 1145,06 Inlet efficiency μ 1146,07 Inlet μ 1146,08 Inlet efficiency μ 1146 Inlet μ 1146,08 Inlet efficiency μ 1146 Inlet μ 1147 Inlet μ 1146 Inlet μ 1147 Inlet μ 1146 Inlet μ 1147 Inlet μ 1148 Inlet μ 1149 Inlet μ 1	Cruise Mach number	M_{CR}	0,785
Take-off Thrust (one engine) $T_{TO,one engine}$ $106,76 \text{ kN}$ Overall Pressure ratioOAPR $26,00$ Turbine entry temperatureTET $1445,06$ Inlet pressure loss $\Delta P/P$ 2% Inlet efficiency η_{lnlet} $0,95$ Ventilator efficiency $\eta_{ventilator}$ $0,86$ Compressor efficiency $\eta_{compresor}$ $0,86$ Turbine efficiency $\eta_{hurbine}$ $0,90$ Nozzle efficiency $\eta_{hurbine}$ $0,90$ Temperature at SL T_0 $288,15 \text{ K}$ Temperature lapse rate in troposhpereL $0,0065 \text{ K/m}$ Temperature (ISA) at tropopause T_S $216,65 \text{ K}$ Temperature at cruise altitude $T(H)$ $216,65 \text{ K}$ Dimensionless turbine entry temperature ϕ $6,67$ Ratio of specific heats, air γ $1,40$ Ratio between stagnation point temperature and temperature ψ $1,12$ Temperature function χ $1,73$ Gas generator efficiency η_{gasgen} $0,98$ Gas generator functionSFC $0,60 \text{ kg/daN/h}$ Verification value specific fuel consumptionSFC $0,60 \text{ kg/daN/h}$ Verification value specific fuel consumptionSFC $0,60 \text{ kg/daN/h}$	Cruise altitude	h _{CR}	11887 m
Overall Pressure ratio OAPR 26,00 Turbine entry temperature TET 1445,06 Inlet pressure loss AP/P 2% Inlet efficiency P_{linet} 1,095 Ventilator efficiency P_{linet} 1,095 Ventilator efficiency P_{linet} 1,095 Ventilator efficiency P_{linet} 1,000 Pressor efficiency P_{linet} 1,000 Pressor	By Pass Ratio	μ	5,30
Overall Pressure ratio $OAPR$ 26,00 Turbine entry temperature $OAPR$ 1445,06 Inlet pressure loss OPP 2% Inlet efficiency OPP 2% Inlet efficiency OPP 2% Inlet efficiency OPP 2% Inlet efficiency OPP OPP 2% Inlet efficiency OPP	Take-off Thrust (one engine)	T _{TO,one engine}	106,76 kN
Inlet pressure loss Inlet efficiency Inlet efficiency Ventilator efficiency Ventilator efficiency Ventilator efficiency Ventilator efficiency Turbine efficiency Nozzle efficiency Nozzle efficiency Nozzle efficiency Temperature at SL Temperature at SL Temperature lapse rate in troposhpere L O,0065 K/m Temperature at cruise altitude Tighthamperature at cruise altitude Dimensionless turbine entry temperature ϕ Ratio of specific heats, air Ratio between stagnation point temperature and temperature ϕ Ratio between stagnation point temperature and temperature ϕ Ratio between stagnation point temperature and temperature ϕ ϕ ϕ ϕ ϕ ϕ ϕ ϕ	Overall Pressure ratio		26,00
Inlet efficiency Ventilator efficiency Ventilator efficiency Compressor efficiency Turbine efficiency Nozzle efficiency Nozzle efficiency Nozzle efficiency Temperature at SL Temperature lapse rate in troposhpere Temperature (ISA) at tropopause Temperature at cruise altitude Dimensionless turbine entry temperature ϕ Ratio of specific heats, air Ratio between stagnation point temperature and temperature ϕ Ratio between stagnation point temperature and temperature ϕ Ratio specific heats, air Ratio between stagnation point temperature and temperature ϕ Ratio specific heats, air Ratio between stagnation point temperature and temperature ϕ ϕ ϕ ϕ ϕ ϕ ϕ ϕ	Turbine entry temperature	TET	1445,06
Ventilator efficiency $\eta_{\text{ventilator}}$ $0,86$ Compressor efficiency $\eta_{\text{compresor}}$ $0,86$ Turbine efficiency η_{turbine} $0,90$ Nozzle efficiency η_{nozzle} $0,98$ Temperature at SL T_0 $288,15$ KTemperature lapse rate in troposhpereL $0,0065$ K/mTemperature (ISA) at tropopause T_S $216,65$ KTemperature at cruise altitude $T(H)$ $216,65$ KDimensionless turbine entry temperature ϕ $6,67$ Ratio of specific heats, air γ $1,40$ Ratio between stagnation point temperature and temperature ψ $1,12$ Temperature function χ $1,73$ Gas generator efficiency η_{gasgen} $0,98$ Gas generator function G $2,15$ Verification value specific fuel consumption SFC $0,60$ kg/daN/hVerification value specific fuel consumption SFC $0,60$ kg/daN/h	Inlet pressure loss	ΔΡ/Ρ	2%
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Inlet efficiency	η_{inlet}	0,95
Turbine efficiency $n_{turbine}$ 0,90 Nozzle efficiency n_{hozzle} 0,98 Temperature at SL n_0 288,15 K Temperature lapse rate in troposhpere L 0,0065 K/m Temperature (ISA) at tropopause n_0 216,65 K Temperature at cruise altitude n_0 216,65 K Temperature at cruise altitude n_0 216,65 K Dimensionless turbine entry temperature n_0 6,67 Ratio of specific heats, air n_0 1,40 Ratio between stagnation point temperature and temperature n_0 1,12 Temperature function n_0 2 1,73 Gas generator efficiency n_0 1,73 Gas generator function n_0 3 Gas generator function n_0 5 SFC 0,60 kg/daN/h Verification value specific fuel consumption SFC 1,68E-05 kg/N/s	Ventilator efficiency	η _{ventilator}	0,86
Nozzle efficiency η_{nozzle} 0,98 Temperature at SL T_0 288,15 K Temperature lapse rate in troposhpere L 0,0065 K/m Temperature (ISA) at tropopause T_S 216,65 K Temperature at cruise altitude T_S 216,65 K Dimensionless turbine entry temperature ϕ 6,67 Ratio of specific heats, air ϕ 1,40 Ratio between stagnation point temperature and temperature ϕ 1,12 Temperature function ϕ 1,73 Gas generator efficiency ϕ 0,98 Gas generator function ϕ 2,15 Verification value specific fuel consumption SFC 0,60 kg/daN/h Verification value specific fuel consumption SFC 1,68E-05 kg/N/s	Compressor efficiency	$\eta_{compresor}$	0,86
Temperature at SL T_0 288,15 K Temperature lapse rate in troposhpere L 0,0065 K/m Temperature (ISA) at tropopause T_S 216,65 K Temperature at cruise altitude T_S 216,65 K Dimensionless turbine entry temperature T_S 6,67 Ratio of specific heats, air T_S 1,40 Ratio between stagnation point temperature and temperature T_S 1,12 Temperature function T_S 1,73 Gas generator efficiency T_S 1,73 Gas generator function T_S 1,75 Verification value specific fuel consumption T_S 2,15 Verification value specific fuel consumption T_S 3,60 kg/daN/h Verification value specific fuel consumption T_S 3,60 kg/daN/h	Turbine efficiency	n _{turbine}	0,90
Temperature lapse rate in troposhpere L 0,0065 K/m Temperature (ISA) at tropopause T_S 216,65 K Temperature at cruise altitude $T(H)$ 216,65 K Dimensionless turbine entry temperature ϕ 6,67 Ratio of specific heats, air ϕ 1,40 Ratio between stagnation point temperature and temperature ϕ 1,12 Temperature function ϕ 1,73 Gas generator efficiency ϕ 0,98 Gas generator function ϕ 0,98 Gas generator value specific fuel consumption ϕ SFC 0,60 kg/daN/h Verification value specific fuel consumption ϕ SFC 1,68E-05 kg/N/s	Nozzle efficiency	$\eta_{ m nozzle}$	0,98
Temperature (ISA) at tropopause T_S 216,65 K Temperature at cruise altitude $T(H)$ 216,65 K Dimensionless turbine entry temperature ϕ 6,67 Ratio of specific heats, air γ 1,40 Ratio between stagnation point temperature and temperature ψ 1,12 Temperature function χ 1,73 Gas generator efficiency η_{gasgen} 0,98 Gas generator function η_{gasgen} 0,98 Gas generator value specific fuel consumption η_{gasgen} 0,60 kg/daN/h Verification value specific fuel consumption η_{gasgen} SFC 0,60 kg/daN/h Verification value specific fuel consumption η_{gasgen} 1,68E-05 kg/N/s	Temperature at SL	T_0	288,15 K
Temperature at cruise altitude $T(H)$ 216,65 K Dimensionless turbine entry temperature ϕ 6,67 Ratio of specific heats, air γ 1,40 Ratio between stagnation point temperature and temperature ψ 1,12 Temperature function χ 1,73 Gas generator efficiency η_{gasgen} 0,98 Gas generator function χ 2,15 Verification value specific fuel consumption χ SFC 0,60 kg/daN/h Verification value specific fuel consumption χ 1,68E-05 kg/N/s	Temperature lapse rate in troposhpere	L	0,0065 K/m
Dimensionless turbine entry temperature ϕ 6,67 Ratio of specific heats, air γ 1,40 Ratio between stagnation point temperature and temperature ψ 1,12 Temperature function χ 1,73 Gas generator efficiency η_{gasgen} 0,98 Gas generator function ψ 6,67 ψ 1,12 Temperature function ψ 1,12 Temperature function ψ 1,73 Gas generator efficiency ψ 1,25 ψ 1,58 Gas generator function ψ 2,15 Verification value specific fuel consumption ψ 2,15 Verification value specific fuel consumption ψ 3,68 E-05 kg/N/s	Temperature (ISA) at tropopause	T_{S}	216,65 K
Ratio of specific heats, air γ 1,40 Ratio between stagnation point temperature and temperature υ 1,12 Temperature function χ 1,73 Gas generator efficiency η_{gasgen} 0,98 Gas generator function η_{gasgen} 0,98 Verification value specific fuel consumption SFC 0,60 kg/daN/h Verification value specific fuel consumption SFC 1,68E-05 kg/N/s	Temperature at cruise altitude	T(H)	216,65 K
Ratio between stagnation point temperature and temperature v 1,12 Temperature function v 1,73 Gas generator efficiency v 1,73 Gas generator function v 1,75 Gas generator function v 1,75 Gas generator function v 1,68 E-05 kg/N/s	Dimensionless turbine entry temperature	ф	6,67
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Ratio of specific heats, air	γ	1,40
Gas generator efficiency Gas generator function Quasidation Quasidat	Ratio between stagnation point temperature and temperature	υ	1,12
Gas generator function G 2,15 Verification value specific fuel consumption SFC 0,60 kg/daN/h Verification value specific fuel consumption SFC 1,68E-05 kg/N/s	Temperature function	χ	1,73
Verification value specific fuel consumption SFC 0,60 kg/daN/h Verification value specific fuel consumption SFC 1,68E-05 kg/N/s	Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Verification value specific fuel consumption SFC 1,68E-05 kg/N/s	Gas generator function	G	2,15
	Verification value specific fuel consumption	SFC	0,60 kg/daN/h
RE value specific fuel consumption SFC 1,54E-05 kg/N/s	Verification value specific fuel consumption	SFC	1,68E-05 kg/N/s
9%	·	SFC	1,54E-05 kg/N/s

Matching Chart



Appendix B Airbus A320-200

					-			۷		c	4		5	9	,	×	0
	1			Source:	Aircraft characteristics for airport planning	or airport planning	1000	Jane's	,	Jenkinson	Engine	9	Scholz	Paul Müller E	Paul Müller Elodie Roux Data collection	ata collectior	Webs
PAX	Symbol	Onits	Chosen value		180		pasic 180	Opinon 0		179-150				179 1	179 164-150		
Landing field length	SLFL	٤	1490			1500	0	1490		1440				1470	1440	1440	
Approach speed	V _{APP}	s/m	70			7	70	-		689				70,83		70,48	
Temperature above ISA (288,15K)	ΔT _L	¥	0				0	0		0				0			
Relative density	ø																
Take-off field length	STOFL	ε	2180		1800	2100	0	1960		2180					2180	2190	2090
Temperature above ISA (288,15K)		×	0		0			15		0							
Relative density																	
Range (max payload)	œ	km	2870		3080	4100	0 4800		5185 5639	1180				2200	2870		6100
Cruise Mach number	McR		0,78					0,78			8,0				0,76	0,79	0,78
Wing area	Š	m ₂	122.4					122.4		122.4				122.4	122.44		122.6
Wing span	рм	Ε	34.1		34.1-35.8	5.8		34.09		33.91				33,91	33,91	35.8	34.1
Aspect ratio	⋖		9,4							9,394511				9,4	62'6		
Maximum take-off mass	Ē	5	27000		73500	7800	0 73500	0 75500	27000	73500				73500	73500	73500	73700
Payload mass	ia E	ka s	19000		18100	19400		7							20767		
Mass ratio, payload - take-off	MPL/MMT0	,								0,261088					0,283		
Maximum landing mass	mML	kg	64500		00099	0	64500		00099	64500				64500	64500		
Mass ratio, landing - take-off	MML/MMTO									0,877551							
Operating empty mass	moe	kg	42100					42100		41310					39733		42600
Mass ratio, operating empty - take-off moe/mmro	off moe/mwro														0,541		
Wing loading	m _{MTO} /S _W	kg/m²	009				2,665	9	615,8 628,1	09					009		
Maximum zero fuel mass	MMZF	kg	61000		62500	0	61000		62500	60500					60500		
Nimber of engines	è		2							0						0	0
Engine type	CFM56-5A	CFM56-5A (5%) -5B (55	CFM		CFM56	92		CFM56-5B4/P	34/P	CFM56-5A3		CFM56-5B4			CFM56-5A3 C	CFM56-5A3	•
Take-off thrust for one engine	Tro,one engine	K						120,1		111,2	111,2 117,877883	120,102				118	111,2
Total take-off thrust	T _{TO} KN	Σ	222,4														
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	g)	0,32				0,32705	5 0,31888	88 0,31205	5 0,308445					0,33		
Bypass ratio	1		9 (9 0	7,5			9 6		
Specific Fuel Comsumption (dry)		kg/N s	0								9,339E-06	9,62E-06			9,35E-06		
Specific Fuel Comsumption (cruise)) SFC (cruise kg/N s	e kg/N s	0								1,6867E-05	1,54E-05			1,688E-05		
Available fuel volume	Vfuel, available	E E	23,86		23,859-26,759-29,659	59-29,659		23,86		23,86					23,859		
Cruise speed	V _{CR}	s/m	230					180		230,47-250,53	53					231,5	230
Cruise altitude	hcR	E	11278					11280		11277,6-853	10668	80			11278		11000
Sweep angle	928	•	25							25					25		25
Mean aerodynamic chord	Омас	Ε	4,2							4,288					4,19		
Position of maximum camber	X(y_c),max	%c	15														15
Camber	(yc)max/c	%c	1,8														3,1
Position of maximum thickness	X _{t,max}	%с	30														30
Relative thickness	τζc	%	15,2											_	15,2-11,8-10,8		15
Taper	<		0,24	+						0,24					0,246		
Chorol proced for											× / ′.						

Aeroplane Specifications

Available fuel volume

Data to apply reverse engineering LL UL Landing field length Known **1490** m S_{LFL} 70,00 m/s 70,0 70,0 Approach speed Known V_{APP} Temperature above ISA (288,15K) ΔT_{L} 0 K 1 Relative density Take-off field length Known **2180** m 2180 2180 STOFL Temperature above ISA (288,15K) 0 K ΔT_{TO} 1,000 Relative density R Range (maximum payload) 1550 NM Cruise Mach number 0,78 M_{CR} Wing area 122 m² S_W Wing span Known 34,1 m² 34,1 b_W 34,1 Aspect ratio Α 9,50 Maximum take-off mass **77000** kg m_{MTO} 19000 kg m_{PL} Maximum payload mass Mass ratio, payload - take-off 0,247 m_{PL}/m_{MTO} Maximum landing mass 64500 kg $m_{ML} \\$ Mass ratio, landing - take-off m_{ML}/m_{MTO} 0,838 **42100** kg Operating empty mass m_{OE} Mass ratio, operating empty - take-off 0,547 m_{OE}/m_{MTO} Wing loading 629,1 kg/m² m_{MTO}/S_W Number of engines 2 n_{E} Take-off thrust for one engine T_{TO,one engine} 111,2 kN Total take-off thrust 222,4 kN T_{TO} Thrust to weight ratio 0,294 $T_{TO}/(m_{MTO}*g)$ Bypass ratio 6

fuel, available

23,86 m³

				LL	UL
Cruise speed		V_{CR}	230 m/s		
Cruise altitude		h_{CR}	11278 m		
Speed ratio		V/V_{md}	1,069 -	1	1,316
	Data to execu	ite the verification	1		
				Rar	ige
Sweep angle		φ_{25}	24,967 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		x _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,6 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering &	optimization of V/Vmd
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and an game and g	,			
Quantity	Original value	RE value	Unit	Deviation
S _{LFL}	1490	1490	m	0,00%
V_{APP}	70,00	70,0	m/s	0,00%
s _{TOFL}	2180	2180	m	0,00%
b_W	34,1	34,1	m	0,00%
Α	9,50	9,50		0,00%
V_{CR}	230,0	230	m/s	0,08%
h_{CR}	11278	11278	m	0,00%
				6,90E-07 0,1%
Results rev	erse engineering			
$C_{L,max,L}$	3,31			
$C_{L,max,TO}$	2,29		Boyes	roo Enginooring
E _{max}	16,80		Reve	rse Engineering
SFC	1,60E-05 kg/	/N/s		
	S _{LFL} V _{APP} S _{TOFL} b _W A V _{CR} h _{CR} Results rev C _{L,max,L} C _{L,max,TO} E _{max}	SLFL 1490 VAPP 70,00 STOFL 2180 bW 34,1 A 9,50 VCR 230,0 hCR 11278 Results reverse engineering CL,max,L CL,max,TO 2,29 Emax 16,80	s_LFL 1490 1490 V_APP 70,00 70,0 s_TOFL 2180 2180 b_W 34,1 34,1 A 9,50 9,50 V_CR 230,0 230 h_CR 11278 11278 Results reverse engineering C_L,max,L 3,31 C_L,max,TO 2,29 E_max 16,80	S _{LFL} 1490 1490 m V _{APP} 70,00 70,0 m/s S _{TOFL} 2180 2180 m b _W 34,1 m 34,1 m A 9,50 9,50 V _{CR} 230,0 230 m/s 11278 m N _{CR} 11278 m 11278 m Results reverse engineering C _{L,max,L} C _{L,max,TO} 2,29 E _{max} 16,80 Reve

1) Maximum Lift Coefficient for Landing and Take-off

$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	L	anding	
Relative density σ 1,000 Factor, approach k_{APP} 1,70 $(m/s^3)^{0.5}$ Approach speed V_{APP} 70,00 m/s Factor, landing k_L 0,107 k_g/m^3 70,00 m/s Factor, landing k_L 0,107 k_g/m^3 Mass ratio, landing - take-off m_{Me}/m_{TO} 0,84 Wing loading at maximum take-off mass $m_{Mr}/\sigma/S_W$ 629,1 k_g/m^2 Maximum lift coefficient, landing σ 70,00 m/s 629,1 k_g/m^2 71,000 m/s 71,000 m/s 71,000 m/s 72,100 m/s 72,100 m/s 73,31 m/s 72,100 m/s 73,31 m/s 72,100 m/s 73,31 m/s 73,31 m/s 74,100 m/s 75,100 m/s 75,100 m/s 76,100 m/s 77,100 m/s 76,100 m/s 77,100 m/s	Landing field length	S _{LFL}	1490 m
Factor, approach k _{APP} 1,70 (m/s³) 0.5 Approach speed V _{APP} 70,00 m/s Factor, landing k _L 0,107 kg/m³ Mass ratio, landing - take-off m _{ML} /m _{TO} 0,84 Wing loading at maximum take-off mass m _{MLTO} /Sw 629,1 kg/m² Maximum lift coefficient, landing C _{L,max,L} 3,31 Take-off Take-off (sent) Take-off	Temperature above ISA (288,15K)	ΔT_L	0 K
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Relative density	σ	
Factor, landing k_L 0,107 kg/m³ Mass ratio, landing - take-off m_{ML}/m_{TO} 0,84 Wing loading at maximum take-off mass m_{ML}/m_{TO} 629,1 kg/m² 629,1 kg/m² Maximum lift coefficient, landing m_{ML}/m_{TO} 0 K 629,1 kg/m² m_{ML}/m_{TO} 0 K 7 Take-off field length m_{TO}/m_{TO} 0 K Relative density $m_{TO}/m_{TO}/m_{TO}$ 0 K Relative density $m_{TO}/m_{TO}/m_{TO}/m_{TO}$ 0 R Maximum lift coefficient, take-off $m_{TO}/m_{TO}/m_{TO}/m_{TO}$ 0 R Maximum lift coefficient, take-off $m_{TO}/m_{TO}/m_{TO}/m_{TO}$ 0 R Maximum lift coefficient, take-off $m_{TO}/m_{TO}/m_{TO}/m_{TO}$ 1,59 Lift-independent drag coefficient, clean $m_{TO}/m_{TO}/m_{TO}/m_{TO}$ 0,025 Lift-independent drag coefficient, slats $m_{TO}/m_{TO}/m_{TO}/m_{TO}$ 0,045 Profile drag coefficient, slats $m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_{TO}/m_$	Factor, approach	k_{APP}	1,70 (m/s²) ^{0.5}
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Approach speed	V_{APP}	70,00 m/s
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,84
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Wing loading at maximum take-off mass	m_{MTO}/S_W	629,1 kg/m ²
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Maximum lift coefficient, landing	$C_{L,max,L}$	3,31
Temperatur above ISA (288,15K) ΔT_{TO} 0 K Relative density σ 1,00 Factor k_{TO} 2,34 m³/kg Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,294 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,29 Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,294 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,29 Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,294 Maximum lift coefficient, take-off $T_{CL,TO}$ 1,59 Lift-independent drag coefficient, clean $T_{CD,0}$ (2nd Segment) 0,020 Lift-independent drag coefficient, flaps $T_{CD,0}$ (2nd Segment) 0,020 Lift-independent drag coefficient, slats $T_{CD,0}$ (2nd Segment) 0,020 Lift-independent drag coefficient, slats $T_{CD,0}$ 0,045 Coswald efficiency factor; landing configuration $T_{CD,0}$ 0,045 Coswald efficiency factor; landing configuration $T_{CD,0}$ 0,045 Lift artio in take-off configuration $T_{CD,0}$ 0,045 Climb gradient $T_{CD,0}$ 0,024 Thrust-to-weight ratio $T_{CD,0}$ 0,024 Thrust-to-weight ratio $T_{CD,0}$ 0,043 Lift-independent drag coefficient, clean $T_{CD,0}$ 0,043 Lift-independent drag coefficient, flaps $T_{CD,0}$ 0,043 Lift-independent drag coefficient, slats $T_{CD,0}$ 0,000 Choose: Certification basis $T_{CD,0}$ 0,000 Lift-independent drag coefficient, landing gear $T_{CD,0}$ 0,000 Choose: Certification basis $T_{CD,0}$ 0,007 Lift-independent drag coefficient, landing gear $T_{CD,0}$ 0,007 Climb gradient $T_{CD,0}$ 0,007 Climb gradient $T_{CD,0}$ 0,007 Climb gradient $T_{CD,0}$ 0,001 Climb gradient $T_{CD,0}$ 0,002 Climb gradi	Ta	ake-off	
Relative density σ 1,00 Factor k_{TO} 2,34 m³/kg Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,294 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,29 $\frac{2}{\sqrt{2}}$ Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,29 $\frac{2}{\sqrt{2}}$	Take-off field length	S _{TOFL}	2180 m
Factor k_{TO} 2,34 m³/kg Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,294 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,29 Table Segment Aspect ratio A 9,500 Lift coefficient, take-off $C_{L,TO}$ 1,59 Lift-independent drag coefficient, clean $C_{D,0}$ (2 nd Segment) 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D,flap}$ 0,025 Lift-independent drag coefficient, slats $\Delta C_{D,slat}$ 0,000 Profile drag coefficient $C_{D,P}$ 0,045 Oswald efficiency factor; landing configuration $C_{D,P}$ 0,045 Oswald efficiency factor; landing configuration $C_{D,P}$ 0,045 Oswald efficiency factor; landing configuration $C_{D,P}$ 0,045 Oswald efficiency factor; landing $C_{D,flap}$ 0,024 Thrust-to-weight ratio $C_{D,P}$ 0,024 Thrust-to-weight ratio $C_{D,P}$ 0,024 Thrust-to-weight ratio $C_{D,P}$ 0,024 Missed approach Lift coefficient, landing $C_{D,flap}$ 0,025 Missed approach Lift-independent drag coefficient, clean $C_{D,0}$ (Missed approach) 0,020 Lift-independent drag coefficient, slats $C_{D,flap}$ 0,043 Lift-independent drag coefficient, slats C_{D	Temperatur above ISA (288,15K)	ΔT_TO	0 K
Thrust-to-weight ratio $T_{TO}/(m_{MTC}^*g)$ 0,294 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,29 Thrust-to-weight ratio $C_{L,TO}$ 1,59 Lift-independent drag coefficient, clean $C_{D,0}(2^{nd} \text{ Segment})$ 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D,flap}$ 0,025 Lift-independent drag coefficient, slats $\Delta C_{D,slat}$ 0,000 Profile drag coefficient $C_{D,P}$ 0,045 Oswald efficiency factor; landing configuration $C_{D,P}$ 0,045 Oswald efficiency factor $C_{D,P}$ 0,045 Number of engines $C_{D,P}$ 0,024 Thrust-to-weight ratio $C_{D,P}$ 0,024 Thrust-to-weight ratio $C_{D,P}$ 0,024 Thrust-to-weight ratio $C_{D,P}$ 0,025 Missed approach Lift coefficient, landing $C_{L,L}$ 1,96 Lift-independent drag coefficient, clean $C_{D,0}(M)$ Missed approach) 0,020 Lift-independent drag coefficient, slats $C_{D,flap}$ 0,043 Lift-independent drag coefficient, slats $C_{D,flap}$ 0,043 Lift-independent drag coefficient, slats $C_{D,slat}$ 0,000 Choose: Certification basis $C_{D,flap}$ 0,043 Lift-independent drag coefficient, landing gear $C_{D,pear}$ 0,015 FAR Part 25 yes Lift-independent drag coefficient $C_{D,P}$ 0,078 Glide ratio in landing configuration $C_{D,P}$ 0,078 Glide ratio in landing configuration $C_{D,P}$ 0,078 Climb gradient $C_{D,P}$ 0,078	Relative density	σ	1,00
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Factor	k _{TO}	2,34 m³/kg
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,294
Aspect ratio A 9,500 Lift coefficient, take-off $C_{L,TO}$ 1,59 Lift-independent drag coefficient, clean $C_{D,0}(2^{nd} \operatorname{Segment})$ 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D, flap}$ 0,025 Lift-independent drag coefficient, slats $\Delta C_{D, slat}$ 0,000 Profile drag coefficient $C_{D,P}$ 0,045 Oswald efficiency factor; landing configuration E_{TO} 9,59 Number of engines E_{TO} 9,59 Number of engines E_{TO} 10 0,024 Thrust-to-weight ratio $E_{TO}(m_{MTO}^*g)$ 0,227 $E_{TO}(m_{MTO}^*g)$ 0,257 $E_{TO}(m_{MTO}^*g)$ 0,267 $E_{TO}(m_{MTO}^*g)$ 0,020 Lift-independent drag coefficient, clean $E_{D,0}(Missed \operatorname{approach})$ 0,020 Lift-independent drag coefficient, slats $E_{D,0}(m_{MTO}^*g)$ 0,000 Choose: Certification basis $E_{D,0}(m_{MTO}^*g)$ 0,000 Choose: Certification basis $E_{D,0}(m_{MTO}^*g)$ 0,015 Profile drag coefficient, landing gear $E_{D,P}(m_{MTO}^*g)$ 0,078 Glide ratio in landing configuration $E_{L}(m_{D,P})$ 0,078 Glide ratio in landing configuration $E_{L}(m_{D,P})$ 0,072 Climb gradient $E_{L}(m_{D,P})$ 0,078 Climb gradient $E_{L}(m_{D,P})$ 0,001	Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,29
Aspect ratio A 9,500 Lift coefficient, take-off $C_{L,TO}$ 1,59 Lift-independent drag coefficient, clean $C_{D,0}(2^{nd} \operatorname{Segment})$ 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D, flap}$ 0,025 Lift-independent drag coefficient, slats $\Delta C_{D, slat}$ 0,000 Profile drag coefficient $C_{D,P}$ 0,045 Oswald efficiency factor; landing configuration E_{TO} 9,59 Number of engines E_{TO} 9,59 Number of engines E_{TO} 10 0,024 Thrust-to-weight ratio $E_{TO}(m_{MTO}^*g)$ 0,227 $E_{TO}(m_{MTO}^*g)$ 0,257 $E_{TO}(m_{MTO}^*g)$ 0,267 $E_{TO}(m_{MTO}^*g)$ 0,020 Lift-independent drag coefficient, clean $E_{D,0}(Missed \operatorname{approach})$ 0,020 Lift-independent drag coefficient, slats $E_{D,0}(m_{MTO}^*g)$ 0,000 Choose: Certification basis $E_{D,0}(m_{MTO}^*g)$ 0,000 Choose: Certification basis $E_{D,0}(m_{MTO}^*g)$ 0,015 Profile drag coefficient, landing gear $E_{D,P}(m_{MTO}^*g)$ 0,078 Glide ratio in landing configuration $E_{L}(m_{D,P})$ 0,078 Glide ratio in landing configuration $E_{L}(m_{D,P})$ 0,072 Climb gradient $E_{L}(m_{D,P})$ 0,078 Climb gradient $E_{L}(m_{D,P})$ 0,001	2nd	Segment	
$ \begin{array}{c} \text{Lift-independent drag coefficient, clean} & C_{D,0} (2^{\text{nd}} \text{Segment}) & 0,020 \\ \\ \text{Lift-independent drag coefficient, flaps} & \Delta C_{D, flap} & 0,025 \\ \\ \text{Lift-independent drag coefficient, slats} & \Delta C_{D, slat} & 0,000 \\ \\ \text{Profile drag coefficient} & C_{D,P} & 0,045 \\ \\ \text{Oswald efficiency factor; landing configuration} & e & 0,7 \\ \\ \text{Glide ratio in take-off configuration} & E_{TO} & 9,59 \\ \\ \text{Number of engines} & n_E & 2 \\ \\ \text{Climb gradient} & sin(\gamma) & 0,024 \\ \\ \text{Thrust-to-weight ratio} & T_{TO}/(m_{MTO}*g) & 0,257 \\ \\ \hline & & & & & & & & & & & & & & & & &$			9,500
Lift-independent drag coefficient, flaps $\Delta C_{D,flap}$ 0,025 Lift-independent drag coefficient, slats $\Delta C_{D,slat}$ 0,000 Profile drag coefficient $C_{D,P}$ 0,045 Oswald efficiency factor; landing configuration e 0,7 Glide ratio in take-off configuration E_{TO} 9,59 Number of engines n_E 2 Climb gradient $\sin(\gamma)$ 0,024 Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,257 Missed approach Lift coefficient, landing $C_{L,L}$ 1,96 Lift-independent drag coefficient, clean $C_{D,0}$ (Missed approach) 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D,flap}$ 0,043 Lift-independent drag coefficient, slats $\Delta C_{D,slat}$ 0,000 Choose: Certification basis $JAR-25$ resp. CS-25 no FAR Part 25 yes Lift-independent drag coefficient, landing gear $\Delta C_{D,gear}$ 0,015 Profile drag coefficient $C_{D,P}$ 0,078 Glide ratio in landing configuration E_L 7,50 Climb gradient $\sin(\gamma)$ 0,021	Lift coefficient, take-off	$C_{L,TO}$	1,59
$ \begin{array}{c} \text{Lift-independent drag coefficient, slats} & \Delta C_{D,\text{slat}} & 0,000 \\ \text{Profile drag coefficient} & C_{D,P} & 0,045 \\ \text{Oswald efficiency factor; landing configuration} & e & 0,7 \\ \text{Glide ratio in take-off configuration} & E_{TO} & 9,59 \\ \text{Number of engines} & n_E & 2 \\ \text{Climb gradient} & \sin(\gamma) & 0,024 \\ \text{Thrust-to-weight ratio} & T_{TO}/(m_{\text{MTO}}^*g) & 0,257 \\ \hline & & & & & & & & & & & & & & & & & &$	Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
$ \begin{array}{c} \text{Lift-independent drag coefficient, slats} & \Delta C_{D,\text{slat}} & 0,000 \\ \text{Profile drag coefficient} & C_{D,P} & 0,045 \\ \text{Oswald efficiency factor; landing configuration} & e & 0,7 \\ \text{Glide ratio in take-off configuration} & E_{TO} & 9,59 \\ \text{Number of engines} & n_E & 2 \\ \text{Climb gradient} & \sin(\gamma) & 0,024 \\ \text{Thrust-to-weight ratio} & T_{TO}/(m_{\text{MTO}}^*g) & 0,257 \\ \hline & & & & & & & & & & & & & & & & & &$	Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,025
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Lift-independent drag coefficient, slats		0,000
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Profile drag coefficient	$C_{D,P}$	0,045
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Oswald efficiency factor; landing configuration	е	0,7
Climb gradient $sin(\gamma)$ 0,024 Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,257	Glide ratio in take-off configuration	E _{TO}	9,59
Climb gradient $sin(\gamma)$ 0,024 Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,257	Number of engines	n⊨	2
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$		_	0,024
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	-		0,257
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	Misse	d approach	
Lift-independent drag coefficient, clean $C_{D,0}$ (Missed approach) 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D,flap}$ 0,043 Lift-independent drag coefficient, slats $\Delta C_{D,slat}$ 0,000 Choose: Certification basis JAR-25 resp. CS-25 no FAR Part 25 yes Lift-independent drag coefficient, landing gear $\Delta C_{D,gear}$ 0,015 Profile drag coefficient $C_{D,P}$ 0,078 Glide ratio in landing configuration E_L 7,50 Climb gradient $\sin(\gamma)$ 0,021			1,96
Lift-independent drag coefficient, flaps $\Delta C_{D,flap} = 0,043$ Lift-independent drag coefficient, slats $\Delta C_{D,slat} = 0,000$ Choose: Certification basis $JAR-25 \text{ resp. CS-}25 = 0$ no FAR Part 25 $JAR-25 \text{ resp. CS-}25 = 0,0015$ Profile drag coefficient, landing gear $\Delta C_{D,gear} = 0,015$ Profile drag coefficient $C_{D,P} = 0,078$ Glide ratio in landing configuration $E_L = 0,021$ Climb gradient $Sin(\gamma) = 0,021$			·
Lift-independent drag coefficient, slats $\Delta C_{D,slat} \qquad 0,000$ Choose: Certification basis $JAR-25 \text{ resp. CS-}25 \qquad \text{no}$ FAR Part 25 yes Lift-independent drag coefficient, landing gear $\Delta C_{D,gear} \qquad 0,015$ Profile drag coefficient $C_{D,P} \qquad 0,078$ Glide ratio in landing configuration $E_L \qquad 7,50$ Climb gradient $\sin(\gamma) \qquad 0,021$	-	•	
Choose: Certification basis JAR-25 resp. CS-25 no FAR Part 25 yes Lift-independent drag coefficient, landing gear $\Delta C_{D,gear}$ 0,015 Profile drag coefficient $C_{D,P}$ 0,078 Glide ratio in landing configuration E_L 7,50 Climb gradient $\sin(\gamma)$ 0,021			
Lift-independent drag coefficient, landing gear $\Delta C_{D,gear}$ 0,015 Profile drag coefficient $C_{D,P}$ 0,078 Glide ratio in landing configuration E_L 7,50 Climb gradient $\sin(\gamma)$ 0,021	•		
Profile drag coefficient $C_{D,P}$ 0,078 Glide ratio in landing configuration E_L 7,50 Climb gradient $\sin(\gamma)$ 0,021		FAR Part 25	yes
Glide ratio in landing configuration E_L 7,50 Climb gradient $\sin(\gamma)$ 0,021	Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Climb gradient $\sin(\gamma)$ 0,021	Profile drag coefficient		0,078
	Glide ratio in landing configuration	EL	7,50
	Climb gradient	$sin(\gamma)$	0,021
	Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,259

2) Maximum Aerodynamic Efficiency

Cons	tant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
	pecifications	0.70	
Mach number, cruise	M _{CR}	0,78	
Aspect ratio	Α	9,50	
Bypass ratio	μ	6,00	
Wing loading	m_{MTO}/S_W	629 kg/m²	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,294	
	Variables		
	V/V _{md}	1,1	
	V / V md	1,1	
d	Calculations		
Zero-lift drag coefficient	C _{D,0}	0,022	
Lift coefficient at E _{max}	$C_{L,md}$	0,75	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,876	
Lift coefficient, cruise	C_L	0,661	
Actual aerodynamic efficiency, cruise	E	16,65	
Max. glide ratio, cruise	E _{max}	16,80	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	1	2	3
f(x)	0,09	0,00	0,00
f'(x)	-0,11	-0,12	-0,12
E _{max}	16	16,81	16,80

3) Specific Fuel Consumption

Consta	nt parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Fuel density	$ ho_{fuel}$	800 kg/m³	ł
Spe	cifications		
Range	R	1550 NM	
Mach number, cruise	M_{CR}	0,78	
Bypass ratio	μ	6,00	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,294	
Available fuel volume	$V_{fuel,available}$	23,86 m³	
Maximum take-off mass	m_{MTO}	77000 kg	
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,247	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,547	
Calcu	ılated values		
Actual aerodynamic efficiency, cruise	E	16,65	
Cruise altitude	h _{CR}	11278 m	
Cruise speed	V_{CR}	230 m/s	
Missio	n fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Ca	Iculations		
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,206	_
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,794	
Available fuel mass	m	19088 kg	
Relative fuel mass (acc. to fuel capacity)	F,available	0,248	
	m _{F,available} /m _{MTO}		
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,767	
Distance to alternate	S _{to_alternate}	200 NM	
Distance to alternate	S _{to_alternate}	370400 m	
Choose: FAR Part121-Reserves	domestic	yes	
F	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400 m	
Loiter time	t _{loiter}	2700 s	
Specific fuel consumption	SFC	1,60E-05 kg/N/	s

4) Verification Specifications

Maximum lift coefficients

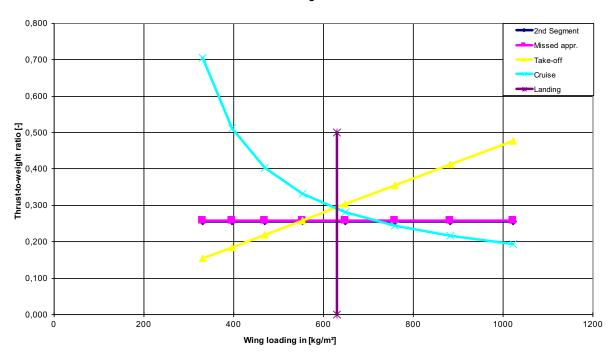
General wing specifications	Airfoil type:		NACA 4 digit
Wing span	b_W	34,1	m
Structural wing span	$b_{W,struct}$	37,62	m
Wing area	S_W	122,4	m²
Aspect ratio	Α	9,50	
Sweep	ϕ_{25}	24,967	0
Mean aerodynamic chord	C _{MAC}	4,2	m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30	%с
Camber	(y _c) _{max} /c	4	%с
Position of maximum thickness	$\mathbf{x}_{t,max}$	30	%с
Relative thickness	t/c	11,6	%
Taper	λ	0,24	
General aircraft specifications			
Temperature above ISA (288,15K)	ΔT_L	0	K
Relative density	σ	1	
Temperature, landing	T_L	273,15	K
Density, air, landing	ρ	1,225	kg/m³
Dynamic viscosity, air	μ	1,72E-05	-
Speed of sound, landing	a_{APP}	331	m/s
Approach speed	V_{APP}	70,00	m/s
Mach number, landing	M_{APP}	0,21	
Mach number, cruise	M_{CR}	0,78	
Calculations maximum clean lift coefficient			
Leading edge sharpness parameter	Δy	3,0	%c
Leading edge sweep	ϕ_{LE}	28,7	•
Reynoldsnumber	Re	2,1E+07	
Maximum lift coefficient, base	$\mathbf{c}_{L,max,base}$	1,58	
Correction term, camber	$\Delta_1 c_{L,max}$	0,18	
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00	
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,083	
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,835	
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80	
Correction term, Mach number	$\Delta C_{L,max}$	-0,01	
Lift coefficient, wing	C _{L,max}	1,45	

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87
Flap group A	•	
0,3c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	1,72
Use flapped span	b_W,fA	26,6 m
Percentage of flaps allong the wing		71%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	1,06
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	1,06
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	$\phi_{H.L.}$	27 °
Slat group A	_	0.00
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	30,82 m
Percentage of slats allong the wing		82%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,66
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing		0%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,00
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,66
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	3,12
RE value maximum lift coefficient, landing		3,31
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,16
RE value maximum lift coefficient, take-off		2,29
-6%		
Aerodynamic eff	iciency	
Real aircraft average	k _{WL}	2,83
End plate	$k_{e,WL}$	1,05
Span	b_W	34,1 m
Winglet height	h	1,1 m
Aspect ratio	Α	9,50
Effective aspect ratio	$A_{\rm eff}$	9,94
Efficiency factor, chart range	k	15 15
Efficiency factor, short range	k _E	15,15
Relative wetted area	S _{wel} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	19,0
RE value maximum aerodynamic efficiency	⊏max	16,80
RE value maximum aerodynamic efficiency		10,00
1376		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,780
Cruise altitude	h _{CR}	11278 m
By Pass Ratio	μ	6,00
Take-off Thrust (one engine)	T _{TO,one engine}	111,20 kN
Overall Pressure ratio	OAPR	29,10
Turbine entry temperature	TET	1448,06
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,94
Ventilator efficiency	$\eta_{ m ventilator}$	0,87
Compressor efficiency	$\eta_{compresor}$	0,86
Turbine efficiency	η_{turbine}	0,90
Nozzle efficiency	$\eta_{ m nozzle}$	0,98
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	φ	6,68
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,82
Gas generator efficiency	$oldsymbol{\eta}_{gasgen}$	0,98
Gas generator function	G	2,14
Verification value specific fuel consumption	SFC	0,58 kg/daN/h
Verification value specific fuel consumption	SFC	1,61E-05 kg/N/s
RE value specific fuel consumption 1%	SFC	1,60E-05 kg/N/s

Matching Chart



Appendix C Airbus A320-200Neo

Data Collection	ction		A320Neo		-	2	3	4	5	9	7	8	6
	4	1 12:45	<u> </u>	conrce:	Aircraft characteristics for airport planning	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Paul Müller∃lodie Roux)ata collection	Webs
PAX	одша	SILIO	Chosen value		WV069 WV069								
Landing field length	SLFL	Ε	1440									1440	
Approach speed	V _{APP}	s/m	69		89							70,48	
Temperature above ISA (288,15K)	ΔΤ _L	~	0										
relative defisity	0												
Take-off field length	STOFL	ε	1880		1880							2190	
Temperature above ISA (288,15K)	ΔΤτο	×											
Relative density	ø												
Range (max payload)	œ	Ē	4500		4500								6300
Cruise Mach number	McR		0,78									0,79	0,78
Wing area	w.	m ₂											
Wing span	ρw	Ε	35,8		35,8							35,8	35,8
Aspect ratio	4												
Maximum take-off mass	DIME.	2	00062		75500 79000							73500	79000
Pavload mass	ē	. A	19250										
Mass ratio, payload - take-off	MPL/MMTO	2	0.243670886										
Maximum landing mass	mML	k	67400		67400 67400								67400
Mass ratio, landing - take-off	MML/MMT0												
Operating empty mass	moe	kg											
Mass ratio, operating empty - take-off moe mon	ff moe/myrro												
Wing loading	MMTo/Sw	kg/m²	0000										04000
Maximum zero idei mass	MMZF	g S	04300		64300								04300
Number of engines	Je		2									2	2
Engine type	CFM LEAF	CFM LEAP-1A (37%), PV	CFIV		LEAP-1A							PW 1100G	LEAP-1A
Take-off thrust for one engine	Tro, one engine KN	Z E	136,5									120	120 104,5-136,5
Total take-off thrust	Tro	Š	273										
Thrust to weight ratio	Tro/(m _{MTo} *g)	(b)											;
Bypass ratio	T (45,0	N/C3	=										-1
Specific Fuel Comsumption (cruise)	SFC (cruise kg/N s	kg/Ns											
		>											
Available fuel volume	Vfuel, available	E B	26,73		23,859-26,759-29,659								26,73
Cruise speed	V _{CR}	s/m	230									231,5	230
Cruise altitude	hcr	٤	11000										11000
Sween andle	ě	۰											
Mean perodynamic chord	420	8											
Position of maximum camber	W. C.	- W	15										15
Camber	(Volume)	2%	. 6										0 00
Position of maximum thickness	Xt,max	%c	30										30
Relative thickness	2/1	%	15										15
Taper	~												
Overall pressure ratio	OAPR			+									
Turbine entry temperature	Ē	~											

Aeroplane Specifications

Available fuel volume

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1440			
Approach speed	Known	V_{APP}	69,00	m/s	69,0	69,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	1880	m	1880	1880
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	2430	NM		
Cruise Mach number		M_{CR}	0,78			
Wing area		S _W	122	m²		
Wing span	Known	b_W	35,8	m²	35,8	35,8
Aspect ratio		Α	10,47			
Maximum take-off mass		m _{MTO}	79000	kg		
Maximum payload mass		m_{PL}	19250	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,244			
Maximum landing mass		m _{ML}	67400	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,853			
Operating empty mass		m_OE	42100	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,533			
Wing loading		m_{MTO}/S_W	645,4	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	136,5	kN		
Total take-off thrust		T _{TO}	273	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}*g)$	0,352			
Bypass ratio		μ	11			

V_{fuel,available}

23,86 m³

Data to optimize V/V _m

				LL	UL
Cruise speed		V_{CR}	230 m/s		
Cruise altitude		h _{CR}	11000 m		
Speed ratio		V/V_{md}	1,096 -	1	1,316
	Data to execu	ite the verification	ı		
				Ran	ige
Sweep angle		ϕ_{25}	24,967 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,6 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering &	optimization of V/Vmd
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Quantity	Original value	RE value	Unit	Deviation
S _{LFL}	1440	1440	m	0,00%
V_{APP}	69,00	69,0	m/s	0,00%
s _{TOFL}	1880	1880	m	0,00%
b_W	35,8	35,8	m	0,00%
Α	10,47	10,47		0,00%
V_{CR}	230,0	230	m/s	0,08%
h_{CR}	11000	11000	m	0,00%
				6,90E-07 0,1%
Results rev	erse engineering			
$C_{L,max,L}$	3,57			
$C_{L,max,TO}$	2,28		Rever	se Engineering
E _{max}	18,01		i (ever	36 Engineening
SFC	1,36E-05 k	g/N/s		
	S _{LFL} V _{APP} S _{TOFL} b _W A V _{CR} h _{CR} Results rev C _{L,max,L} C _{L,max,TO} E _{max}	SLFL 1440 VAPP 69,00 STOFL 1880 bW 35,8 A 10,47 VCR 230,0 hCR 11000 Results reverse engineering CL,max,L 3,57 CL,max,TO 2,28 Emax 18,01	SLFL 1440 1440 VAPP 69,00 69,0 STOFL 1880 1880 bW 35,8 35,8 A 10,47 10,47 VCR 230,0 230 hCR 11000 11000 Results reverse engineering CL,max,L 3,57 CL,max,TO 2,28 Emax 18,01	SLFL 1440 1440 m VAPP 69,00 69,0 m/s STOFL 1880 1880 m bW 35,8 m 35,8 m A 10,47 m/s VCR 230,0 m/s hCR 11000 m Results reverse engineering CL,max,L CL,max,TO CL,max,TO 2,28 Emax 18,01 Rever

1) Maximum Lift Coefficient for Landing and Take-off

L	anding	
Landing field length	S _{LFL}	1440 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	1,70 (m/s²) ^{0.5}
Approach speed	V_{APP}	69,00 m/s
Factor, landing	k_L	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,85
Wing loading at maximum take-off mass	m_{MTO}/S_W	645,4 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,57
т.	ake-off	
Take-off field length	S _{TOFL}	1880 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,352
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,28
2nd	Segment	
Aspect ratio	A	10,471
Lift coefficient, take-off	$C_{L,TO}$	1,58
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,024
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,044
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	10,34
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}*g)$	0,241
Missa	d approach	
Lift coefficient, landing	C _{L,L}	2,11
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,051
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Profile drag coefficient	C_D,P	0,086
Glide ratio in landing configuration	EL	7,55
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,262
	· 10· (· · ·wilo 3/	-,

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sn	ecifications		
Mach number, cruise	M _{CR}	0,78	
Aspect ratio	A	10,47	
Bypass ratio	μ	11,00	
Wing loading	m _{MTO} /S _W	645 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,352	
	Variables		
	V/V _{md}	1,1	
Ci	alculations		
Zero-lift drag coefficient	C _{D,0}	0,022	
Lift coefficient at E _{max}	$C_{L,md}$	0,78	
Ratio, lift coefficient	C _L /C _{L,md}	0,833	
Lift coefficient, cruise	C_L	0,647	
Actual aerodynamic efficiency, cruise	E	17,71	
Max. glide ratio, cruise	E _{max}	18,01	
Newton-Raphson for the maximum lift-to-o	drag ratio		
Iterations	1	2	3
f(x)	0,22	-0,01	0,00
f'(x)	-0,10	-0,11	-0,11
E _{max}	16	18,08	18,01

3) Specific Fuel Consumption

Constant par	ameters	
Ratio of specific heats, air	γ	1,4
Earth acceleration	g	9,81 m/s ²
Air pressure, ISA, standard	p_0	101325 Pa
Fuel density	$ ho_{ m fuel}$	800 kg/m³
Specificat	ions	
Range	R	2430 NM
Mach number, cruise	M _{CR}	0,78
Bypass ratio	μ	11,00
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,352
Available fuel volume	$V_{\text{fuel,available}}$	23,86 m³
Maximum take-off mass	m _{MTO}	79000 kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,244
Mass ratio, operating empty - take-off	$m_{OE/}m_{MTO}$	0,533
Calculated	values	
Actual aerodynamic efficiency, cruise	E	17,71
Cruise altitude	h _{CR}	11000 m
Cruise speed	V _{CR}	230 m/s
5.a.55 speca	-CR	200 11110
Mission fuel		
Type of aeroplane (according to Roskam)	Transport jet	
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990
Fuel-Fraction, taxi	$M_{\rm ff,taxi}$	0,990
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980
Fuel-Fraction, descent	$M_{ff,DES}$	0,990
Fuel-Fraction, landing	$M_{ff,L}$	0,992
Calculati	ons	
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,223
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,777
Available fuel mass	MF,available	19088 kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,242
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,774
Distance to alternate	S _{to_alternate}	200 NM
Distance to alternate	S _{to_alternate}	370400 m
Choose: FAR Part121-Reserves	domestic	yes
	international	no
Extra-fuel for long range		5%
Extra flight distance	S _{res}	370400 m
Loiter time	t _{loiter}	2700 s
Specific fuel consumption	SFC	1,36E-05 kg/N/s

4) Verification Specifications

Maximum lift coefficients

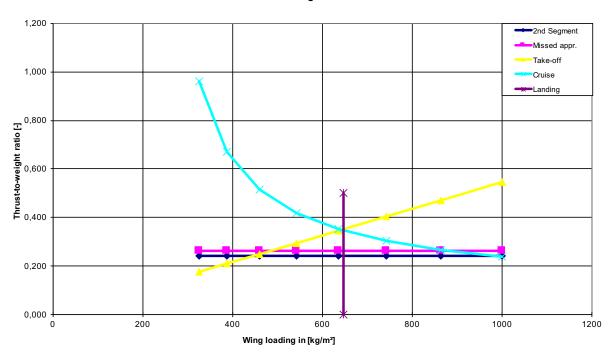
General wing specifications	Airfoil type:	NACA 4 digi
Wing span	b_W	35,8 m
Structural wing span	$b_{W,struct}$	39,49 m
Wing area	S_W	122,4 m ²
Aspect ratio	Α	10,47
Sweep	ϕ_{25}	24,967 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	$\mathbf{x}_{(\mathbf{y}_{\mathbf{c}}),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t.max}$	30 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	69,00 m/s
Mach number, landing	M_{APP}	0,21
Mach number, cruise	M_{CR}	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,0 %c
Leading edge sweep	ϕ_{LE}	28,3 °
Reynoldsnumber	Re	2,1E+07
Maximum lift coefficient, base	$c_{L,max,base}$	1,58
Correction term, camber	$\Delta_1 c_{L,max}$	0,18
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,081
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,833
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	C _{L,max}	1,46

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	K_{φ}	0,87
Flap group A	·	
0,3c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	1,73
Use flapped span	b_W,fA	27,9 m
Percentage of flaps allong the wing		71%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	1,06
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,75
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	\DeltaC_L,max,f	1,06
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	ΨH.L.	27 °
Slat group A	TH.L.	
0,3c Nose flap	Δc _{L.max.sA}	0,90
Use slatted span	b_W,sA	31,5 m
Percentage of slats allong the wing	D_VV,5/\	80%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,64
Slat group B	□ ⊆ ,max,sA	0,04
0,3c Nose flap	$\Delta c_{L,max,SB}$	0.90
Use slatted span	b W,sB	0 m
Percentage of slats allong the wing	0_44,00	0%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,00
Increase in maximum lift coefficient, slat	ΔC _{L,max,s}	0,64
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	3,11
RE value maximum lift coefficient, landing	OL,max,L	3,57
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,98
RE value maximum lift coefficient, take-off	OL,max,TO	2,28
-13%		2,20
Aerodynamic e	fficiency	
	-	
Real aircraft average	k_{WL}	2,83
End plate	$k_{e,WL}$	1,10
Span	b_W	35,8 m
Winglet height	h	2,43 m
Aspect ratio	Α	10,47
Effective aspect ratio	$A_{\rm eff}$	11,50
Efficiency factor, short range	k _E	15,15
Relative wetted area	S _{wel} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	20,4
RE value maximum aerodynamic efficiency	· · · · · ·	18,01
13%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,780
Cruise altitude	h _{CR}	11000 m
By Pass Ratio	μ	11,00
Take-off Thrust (one engine)	T _{TO,one engine}	136,50 kN
Overall Pressure ratio	OAPR	40,00
Turbine entry temperature	TET	1461,39
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,92
Ventilator efficiency	$\eta_{ m ventilator}$	0,89
Compressor efficiency	$\eta_{compresor}$	0,87
Turbine efficiency	$\eta_{ m turbine}$	0,90
Nozzle efficiency	η_{nozzle}	0,99
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,75
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	2,10
Gas generator efficiency	$\eta_{ m gasgen}$	0,97
Gas generator function	G	2,07
Verification value specific fuel consumption	SFC	0,53 kg/daN/h
Verification value specific fuel consumption	SFC	1,46E-05 kg/N/s
RE value specific fuel consumption	SFC	1,36E-05 kg/N/s

Matching Chart



Appendix D Boeing 737-8

Data Collection	ction		737-8		2	3	4	2	9	7	8	6
		:		SOURCE: Aircraft characteristics	Jane's	Jenkinson	Engine	Scholz	Paul Müller Elodie Rous Data collection	die Roud	ata collectior	Webs
Parameter	Symbol	Onits	Chosen value	for airport planning			0					
PAX			189	178-189								175-162
Landing field length	S	8	1650	1650								
Approach speed	V _{APP}	s/m										
Temperature above ISA (288,15K)	ΔT _L	¥	0	0								
Relative density	ø											
Take-off field length	STOFI	2	2540	2540								
Temperature above ISA (288,15K)	ΔΤτο	¥	0	0								
Relative density	ø											
Rence (mex period)	α	E	4630	4630								6704
Cruise Mach number	M _{CR}	Ž	0,79								0,79	0,79
Wing area	Sw	m _z										
Wing span	bw	٤	35,92	35,92							35,9	35,9
Aspect ratio	4											
Manipulation of the contraction	1	3	00700	00100							00101	02404
Maximum take-on mass	ПМТО	₽.	02130	02130							16170	16170
Payload mass	ШЫ	Ď										
Mass ratio, payload - take-off	MPL/MMT0											
Maximum landing mass	m _{ML}	kg	69308	69308								
Mass ratio, landing - take-off	MML/MMTO											
Operating empty mass	Moe	kg										
Mass ratio, operating empty - take-off	ff moe/mmto											
Wing loading	MMTO/Sw	kg/m²	1									
Maximum zero tuel mass	MMZF	Đ	70600	70600								
Ni mbor of oncinos	ś		c								C	0
Number of engines	IIE	70	1 EAD 1025	LEAD 4DOK						=	_	Z 1 E A D 1 D
Engine type	CFM LEAP-1B	2 K	130	LEAF-1B23							130	EAP-15
Tatal talle of the eligilie	TO, one engine KIN	N 3	000								001	
l otal take-off thrust	170	Z ,										
Pyrone rottio	I TOV (ITIMITO 9)	6	đ									a
Specific Firel Comertmetion (dry)	SEC (Apr)	o N/pa	,									0
Specific Fiel Comsumption (criss)		- a										
		2										
Available fuel volume	V _{fuel} , available	m ₃	25,817	25,817								
Cruise speed	VCR	m/s	233.89									233,89
Cruise altitude	hcR	E										
Sweep angle	ф25	۰										
Mean aerodynamic chord	OMAC	Ε										
Position of maximum camber	X(y_c),max	%c	20,4									20,4
Camber	(yc)max/c	%с	1,5									1,5
Position of maximum thickness	Xt,max	%с	39,9									39,9
Relative thickness	t/c	%	10									10
Taper	<											
Overall pressure ratio	OAPR											
Turbine entry temperature	TET	¥										

Aeroplane Specifications

Data to apply reverse engineering

	Data to apply i	everse engineering			
				LL	UL
Landing field length	Known	s_{LFL}	1650 m		
Approach speed	Unknown	V_{APP}	69,00 m/s	69,1	69,1
Temperature above ISA (288,15K)		ΔT_L	0 K		
Relative density		σ	1		
Take-off field length	Known	s _{TOFL}	2540 m	2540	2540
Temperature above ISA (288,15K)		ΔT_TO	0 K		
Relative density		σ	1,000		
Range (maximum payload)		R	2160 NM		
Cruise Mach number		M _{CR}	0,79		
Wing area		S_W	125 m²		
Wing span	Known	b_W	35,92 m ²	35,92	35,92
Aspect ratio		Α	10,36		
Maximum take-off mass		m _{MTO}	82190 kg		
Maximum payload mass		m_PL	20276 kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,247		
Maximum landing mass		m_{ML}	69308 kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,843		
Operating empty mass		m_OE	41145 kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,501		
Wing loading		m_{MTO}/S_W	659,6 kg/m²		
Number of engines		n _E	2		
Take-off thrust for one engine		T _{TO,one engine}	130 kN		
Total take-off thrust		T_TO	260 kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,322		
Bypass ratio		μ	9		
Available fuel volume		V _{fuel,available}	23,86 m³		

Data to optimize V/V _{md}	Data	to	optimize	V/V_{md}
------------------------------------	------	----	----------	------------

	Data to o	P			
				LL	UL
Cruise speed		V_{CR}	234 m/s		
Cruise altitude		h_{CR}	11000 m		
Speed ratio		V/V_{md}	1,108 -	1	1,316
	Data to execu	te the verification			
				Rar	ige
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		X _{(y_c),max}	25 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	40 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,5 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimization of V/Vmd					
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1650	1650	m	0,00%
Approach speed	V_{APP}	Unknown	69,1	m/s	0,00%
Take-off field length	s _{TOFL}	2540	2540	m	0,00%
Span	b_W	35,92	35,92	m	0,00%
Aspect ratio	Α	10,36	10,36		0,00%
Cruise speed	V_{CR}	233,9	233	m/s	-0,31%
Cruise altitude	h_{CR}	11000	10994	m	-0,0 <mark>5%</mark>
Squared Sum Absolute maximum deviation					9,95E-06 0,3%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,15			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,88		Reverse Engineering	
Maximum aerodynamic efficiency	E _{max}	17,45			
Specific fuel consumption	SFC	1,77E-05 kg	J/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

L:	anding	
Landing field length	S _{LFL}	1650 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	1,70 (m/s²) (
Approach speed	V_{APP}	69,13 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,84
Wing loading at maximum take-off mass	m_{MTO}/S_W	659,6 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,15
T:	ake-off	
Take-off field length	S _{TOFL}	2540 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,322
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,88
2nd	Segment	
Aspect ratio	A	10,355
Lift coefficient, take-off	C_L,TO	1,31
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,010
Lift-independent drag coefficient, slats	$\Delta C_D,slat$	0,000
Profile drag coefficient	$C_{D,P}$	0,030
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	12,39
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,209
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,86
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_D,flap$	0,038
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Profile drag coefficient	C_D,P	0,073
Glide ratio in landing configuration	EL	8,25
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,240

2) Maximum Aerodynamic Efficiency

Constant parameters							
Ratio of specific heats, air	γ 1,4						
Earth acceleration	g	9,81 m/s ²					
Air pressure, ISA, standard	p ₀ 101325 Pa						
Oswald eff. factor, clean	е	0,85					
Sp	ecifications						
Mach number, cruise	M _{CR}	0,79					
Aspect ratio	A	10,36					
Bypass ratio	μ 9,00						
Wing loading	m_{MTO}/S_W	660 kg/m²					
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,322					
Variables							
	V/V _{md}	1,1					
C	alculations						
Zero-lift drag coefficient	C _{D,0}	0,023					
Lift coefficient at E _{max}	$C_{L,md}$	0,79					
Ratio, lift coefficient	$C_L/C_{L,md}$	0,814					
Lift coefficient, cruise	CL	0,645					
Actual aerodynamic efficiency, cruise	E	17,09					
Max. glide ratio, cruise	E _{max}	17,45					
Newton-Raphson for the maximum lift-to-drag ratio							
Iterations	1	2	3				
f(x)	0,16	0,00	0,00				
f(x)	-0,11	-0,11	-0,11				
E _{max}	16	17,49	17,45				

3) Specific Fuel Consumption

Consta	nt parameters	
Ratio of specific heats, air	γ	1,4
Earth acceleration	g	9,81 m/s ²
Air pressure, ISA, standard	p_0	101325 Pa
Fuel density	$ ho_{fuel}$	800 kg/m³
Spe	cifications	
Range	R	2160 NM
Mach number, cruise	M_{CR}	0,79
Bypass ratio	μ	9,00
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,322
Available fuel volume	$V_{fuel,available}$	23,86 m³
Maximum take-off mass	m_{MTO}	82190 kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,247
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,501
Calcu	lated values	
Actual aerodynamic efficiency, cruise	E	17,09
Cruise altitude	h _{CR}	10994 m
Cruise speed	V_{CR}	233 m/s
Mission	n fuel fraction	
Type of aeroplane (according to Roskam)	Transport jet	
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990
Fuel-Fraction, take-off	M _{ff,TO}	0,995
Fuel-Fraction, climb	M _{ff,CLB}	0,980
Fuel-Fraction, descent	M _{ff,DES}	0,990
Fuel-Fraction, landing	M _{ff,L}	0,992
Cal	culations	
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,253
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,747
Available fuel mass	MF,available	19088 kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,232
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,783
		3,100
Distance to alternate	S _{to_alternate}	200 NM
Distance to alternate	S _{to_alternate}	370400 m
Choose: FAR Part121-Reserves	domestic	yes
	international	no
Extra-fuel for long range		5%
Extra flight distance	S _{res}	370400 m
Loiter time	t _{loiter}	2700 s
Specific fuel consumption	SFC	1,77E-05 kg/N/

4) Verification Specifications

Maximum lift coefficients

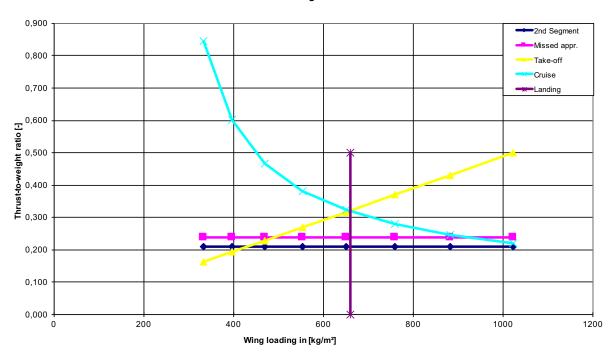
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b_W	35,92 m
Structural wing span	$b_{W,struct}$	39,63 m
Wing area	S_W	124,6 m ²
Aspect ratio	Α	10,36
Sweep	ϕ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	X _{(y_c),max}	25 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t.max}$	39,9 %c
Relative thickness	t/c	11,5 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	69,13 m/s
Mach number, landing	M_{APP}	0,21
Mach number, cruise	M_CR	0,79
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,1 %c
Leading edge sweep	ϕ_{LE}	28,4 °
Reynoldsnumber	Re	2,1E+07
Maximum lift coefficient, base	$\mathbf{c}_{L,max,base}$	1,24
Correction term, camber	$\Delta_1 c_{L,max}$	0,40
Correction term, thickness	$\Delta_2 c_{L,max}$	0,17
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,040
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,851
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,87
Correction term, Mach number	$\Delta C_{L,max}$	-0,02
Lift coefficient, wing	C _{L,max}	1,59

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87
Flap group A		
Double-slotted flap	$\Delta c_{L,max,fA}$	1,56
Use flapped span	b_W,fA	7,18 m
Percentage of flaps allong the wing	**	18%
Increase in maximum lift coefficient, flap group A	$\Delta C_{\!L,max,fA}$	0,25
Flap group B Double-slotted flap	۸۵	1,56
Use flapped span	Δc _{L,max,fB} b_W,fB	12,39 m
Percentage of flaps allong the wing	5_11,15	31%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,42
Increase in maximum lift coefficient, flap	\DeltaC_L,max,f	0,67
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΦH.L.	27 °
Slat group A	TII.L.	
0,1c Kruger flap	$\Delta c_{L,max,sA}$	0,73
Use slatted span	b_W,sA	4,67 m
Percentage of slats allong the wing		12%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,08
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,99
Use slatted span	b_W,sB	26,58 m
Percentage of slats allong the wing	A.C.	67%
Increase in maximum lift coefficient, slat group B Increase in maximum lift coefficient, slat	ΔC _{L,max,sB}	0,59
increase in maximum in coemcient, stat	$\DeltaC_{\!L,max,s}$	0,67
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,90
RE value maximum lift coefficient, landing	OL,max,L	3,15
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,73
RE value maximum lift coefficient, take-off	- L,max, ro	1,88
-8%		
Aerodynamic eff	iciency	
Real aircraft average	k_{WL}	2,83
End plate	k _{e,WL}	1,11
Span	b _W	35,92 m
Winglet height	h	2,7 m
Aspect ratio	Α	10,36
Effective aspect ratio	$A_{\rm eff}$	11,48
Efficiency factor, short range	k _E	15,15
Relative wetted area	S _{wel} /S _W	6,35
Validication value manifestory	-	20.4
Verification value maximum aerodynamic efficiency	E _{max}	20,4 17,45
RE value maximum aerodynamic efficiency		17,45
17.70		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,790
Cruise altitude	h_{CR}	11000 m
By Pass Ratio	μ	9,00
Take-off Thrust (one engine)	T _{TO,one engine}	130,00 kN
Overall Pressure ratio	OAPR	31,70
Turbine entry temperature	TET	1458,46
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,93
Ventilator efficiency	$\eta_{ventilator}$	0,88
Compressor efficiency	$\eta_{compresor}$	0,87
Turbine efficiency	$\eta_{ m turbine}$	0,90
Nozzle efficiency	η_{nozzle}	0,98
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,73
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,89
Gas generator efficiency	$\eta_{ m gasgen}$	0,97
Gas generator function	G	2,16
Verification value specific fuel consumption	SFC	0,55 kg/daN/h
Verification value specific fuel consumption	SFC	1,54E-05 kg/N/s
RE value specific fuel consumption -13%	SFC	1,77E-05 kg/N/s

Matching Chart



Appendix E Airbus A321-200

Particular Par	Data Collection	ction		A321-200		-		2		3	4	5	9	7	8	6
No.	Parameter	Sympo	Units			teristics for airport pla		Jane		enkinson	Engine	Scholz	Paul Müller		Data collection	Webs
No.		6	2	185		185		85-22		0-186			212	199-185		
Note	Landina field lenath	Œ Ø	Ε	1580			700	1577		1580			1587	1580		
No. According to Accode to According to A	Approach speed	V _{APP}	s/m	72			73			71			72,22			
State Stat	Temperature above ISA (288,15K)	ΔT _L	×	0			0	0		0						
No.	Relative density	ø														
No.	Take-off field length	STOFL	Ε	2200	2		500	2330		2000				2000		2180
R R R R R R R R R R	Temperature above ISA (288,15K)	ΔΤτο	¥	0				15		0						
No.	Relative density	s														
Max	Range (max payload)	ď	k	3700	9		1160	5000-5556		3620,66			4600	3621		2600
Sheek min 122.4 min	Cruise Mach number	McR		0,78				0,78			8,0			0,78		0,78
A	Wing area	Š	m²	122,4				122,4		122,4			122,4	126		122,6
March A Part A Part Part A Part P	Wing span	ρw	Ε	34,09		34,1		34,09		33,91			34,09	33,91	35,	34,1
Part kg 23000 22700 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 25000 250000 250000 250000 250000 250000 25000 25000 25000 25000 25000 25000 25000 250	Aspect ratio	ď		9,4						9,3945106			9,4	9,13		
Thinking Fig. Fig	Maximum take-off mass	Мито	kg	93500	83		3500	83000	93900	89000			83000	89000		93500
	Payload mass	ď	kg	23000	22		2000			22780				24500		
Thinking May	Mass ratio, payload - take-off	MPL/MMT0								0,2559551				0,275		
	Maximum landing mass	JWIF		77800	73		2800	73500		73500			73500	75500		
Victor V	Mass ratio, landing - take-off	ПМ І/Мито								0,8258427						
True	Operating empty mass	Moe	¥ d	49200				49200		48000				47000		48500
Transport Tran	Mass ratio, operating empty - take-c	ff moe/mmro	La/m²	762 6				677		0,5393258				0,528		
Trope CFM66-5B3 PG CFM66-5B3 P	Maximum zero fuel mass	NO LINE	N CA	73800	99		3800	69500		71500				71500		73800
Processing Fig. 18 Proces		-IZWIT-	2		3		8		200							
CFMS6-583 CFMS6-583P CF	Number of engines	пE												2	2	2
Trocome No. 142,342 142,342 142,342 142,342 143,342104 142,342 143,342104 142,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 143,342 14	Engine type	CFM56-5E	3 (41%), IAE V			CFM56	Ę.	/156-5B3/P or -:	5B3/2P CF	ပ	-M56-5B3			CFM56-5B3/P	CFM56-5B1	
Tro KN Column Tro KN Column Tro KN Column Tro KN Tro KN Column Tro KN Column Tro KN Column Tro Tro Column Tr	Take-off thrust for one engine	Tro, one engin	KN e	142,342				142,3			142,343104			142,342		133-147
TrO(IMANO 9) U.333 U.320,0050 U.3111 U.320,22815 U.320,005 U.3111 U.320,22815 U.320,000 U.333 U.333 U.330 U.330,000102 U.330,000102 U.331 U.320,000102 U.331 U.320,000102 U.331 U.320,000102 U.331	Total take-off thrust	Tro	₹.	6			-			1						
Note 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100	I hrust to weight ratio	To/(m _{MTO}	(6	0,33			>			_	1			0,33		
Control Cont	Bypass ratio	SEC (dry)		0.0000102							5,4 1 0188F-05			0.0000102		
V _{Cect} annibilities m² 26,6 23,7-26,692-29,684 23,7-26,6-29,684 23,7-26,6 23,7-26,6 23,7-26,6 23,7-26,6 23,7-26,6 23,7-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6 23,1,5-26,6	Specific Fuel Comsumption (cruise)		se kg/N s													
Vor. m/s 231 180 231,5-250,53 11278 231,5 h cer m 11278 11277,6-853 10668 11278 231,5 φ ₂₅ ° 25 25 25 25 ber X _c columar, S _c columar,	Available fuel volume	V _{fuel} , available		26,6	23,7-:	26,692-29,684		23,7-26,6-29,6		,7-26,6				29,5		24,05-30,03
hcg m 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 11278 1127	Cruise speed	V _{CR}	s/m	231				180	23	1,5-250,53					231,5	222,22
φ ₂₅ 25 25 25 Open Control of C	Cruise altitude	hcR	ε	11278					7	277,6-853	10668			11278		
Per X ₀ , c ₁ max %c 4,34 4,34 Nes X ₀ , c ₁ max %c 4,34 7,34 Ness X ₁ max %c 7,24 7,24 No No 0,24 0,239 Nes 33,7 33,7 7,239	Sweep angle	4 25	0	25						25				25		25
Net X _{(V, c), max} %c No %c %c No %c %c No %c %c No No 0,24 OAPR 33,7 0 TET K 33,7	Mean aerodynamic chord	QMAC	Ε	4,3						4,288				4,34		
(y _c) _{max} /c %c %c	Position of maximum camber	X _{(y_c),max}	%c													
нея X _{fmax} % bc % 0,24 A 0,24 33,7 TFT K 33,7	Camber	(yc)max/c	%с													
Vc % A 0,24 OAPR 33,7 TET K	Position of maximum thickness	X _{t,max}	%с													
λ 0,24 0,24 33,7 0,24 33,7 TET K	Relative thickness	t/c	%													
DAPR 33,7	Taper	٧ (0,24			-		+	0,24	1			0,239		
_	Overall pressure ratio	CAPK		33,/			-		+		33,7					

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1580	m		
Approach speed	Known	V_{APP}	72,00	m/s	72,0	72,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	2200	m	2200	2200
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	1955	NM		
Cruise Mach number		M _{CR}	0,78			
Wing area		S_W	122	m²		
Wing span	Known	b_W	34,09	m²	34,09	34,09
Aspect ratio		Α	9,49			
Maximum take-off mass		m _{MTO}	93500	kg		
Maximum payload mass		m_PL	23000	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,246			
Maximum landing mass		m_ML	77800	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,832			
Operating empty mass		m_OE	49200	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,526			
Wing loading		m_{MTO}/S_W	763,9	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	142,342	kN		
Total take-off thrust		T _{TO}	284,684	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,310			
Bypass ratio		μ	5,4			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to e	ptimize	V/V_{md}
------	------	---------	------------

			LL	UL
	V_{CR}	231 m/s		
	h_{CR}	11278 m		
	V/V_{md}	1,014 -	1	1,316
Data to execu	ite the verification	1		
			Ran	ge
	ϕ_{25}	24,967 °		
	C _{MAC}	4,3 m		
	X _{(y_c),max}	30 %c	15 - 50	%с
	(y _c) _{max} /c	4 %c	2 - 6	%с
	$x_{t,max}$	30 %c	30 - 45	%с
Unknown	t/c	11,6 %		
	λ	0,24		
		$\begin{array}{c} V_{CR} \\ h_{CR} \\ V/V_{md} \end{array}$ Data to execute the verification $\begin{array}{c} \phi_{25} \\ c_{MAC} \\ x_{(y_{c}),max} \\ (y_{c})_{max}/c \\ x_{t,max} \\ \end{array}$ Unknown t/c	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$

Reverse Engineering

Reverse eng	ineering &	& optimiz	zation of	f V/Vi	md
-------------	------------	-----------	-----------	--------	----

	erse engineering	a optimization of v	/ VIIIu		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1580	1580	m	0,00%
Approach speed	V_{APP}	72,00	72,0	m/s	0,00%
Take-off field length	s _{TOFL}	2200	2200	m	0,00%
Span	b_W	34,09	34,09	m	0,00%
Aspect ratio	Α	9,49	9,49		0,00%
Cruise speed	V_{CR}	231,0	230	m/s	-0,35%
Cruise altitude	h_{CR}	11278	11278	m	0,00%
Squared Sum Absolute maximum deviation					1,23E-05 0,4%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,76			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,62		Povo	roo Engineering
Maximum aerodynamic efficiency	E _{max}	15,35		Reve	rse Engineering
Specific fuel consumption	SFC	1,44E-05 kg	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Landi	ing	
Landing field length	S _{LFL}	1580 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	72,00 m/s
Factor, landing	k_L	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,83
Wing loading at maximum take-off mass	m_{MTO}/S_W	763,9 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,76
Take-	off	
Take-off field length	S _{TOFL}	2200 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,310
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,62
2nd Seg	ıment	
Aspect ratio	A	9,495
Lift coefficient, take-off	$C_{L,TO}$	1,82
Lift-independent drag coefficient, clean	C _{D.0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,036
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C _{D,P}	0,056
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	8,49
Number of oppings	n	2
Number of engines Climb gradient	n _E sin(γ)	0,024
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,024
Thrust to Weight ratio	TIO/(IIIMIO 9)	0,204
Missed ap	-	2.22
Lift coefficient, landing	C _{L,L}	2,22
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,056
Lift-independent drag coefficient, slats Choose: Certification basis	$\Delta C_{D,slat}$	0,000
Choose. Certification basis	JAR-25 resp. CS-25 FAR Part 25	no yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C _{D,P}	0,091
Glide ratio in landing configuration	E _L	6,78
22 . and in landing configuration	~.	0,10
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,281

2) Maximum Aerodynamic Efficiency

Consta	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sne	ecifications		
Mach number, cruise	M _{CR}	0,78	
Aspect ratio	A	9,49	
Bypass ratio	μ	5,40	
Wing loading	m _{MTO} /S _W	764 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,310	
	/ariables		
	V/V _{md}	1,0	
Ca	alculations		
Zero-lift drag coefficient	C _{D,0}	0,027	
Lift coefficient at E _{max}	$C_{L,md}$	0,83	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,972	
Lift coefficient, cruise	C_L	0,803	
Actual aerodynamic efficiency, cruise	E	15,34	
Max. glide ratio, cruise	E _{max}	15,35	
N (B) () () () () ()			
Newton-Raphson for the maximum lift-to-c	drag ratio	0	0
Iterations	-0,09	0,00	0,00
f(x) f'(x)	-0,09	-0,13	-0,13
E _{max}	16	15,36	15,35
<u></u> max	10	10,00	10,00

3) Specific Fuel Consumption

Constant	t parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	•	m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Speci	fications		
Range	R	1955	NM
Mach number, cruise	M_{CR}	0,78	
Bypass ratio	μ	5,40	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,310	
Available fuel volume	$V_{fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	93500	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,246	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,526	
Calcula	ited values		
Actual aerodynamic efficiency, cruise	E	15,34	
Cruise altitude	h_{CR}	11278	
Cruise speed	V _{CR}	230	m/s
Mission	fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	M _{ff.taxi}	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
· ·	·	,,,,,	
Mission fuel fraction (acc. to PL and OE)	ulations	0,228	
•	m _E /m _{MTO}		
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,772	
Available fuel mass	M _{F,available}	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,204	
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,812	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,44E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

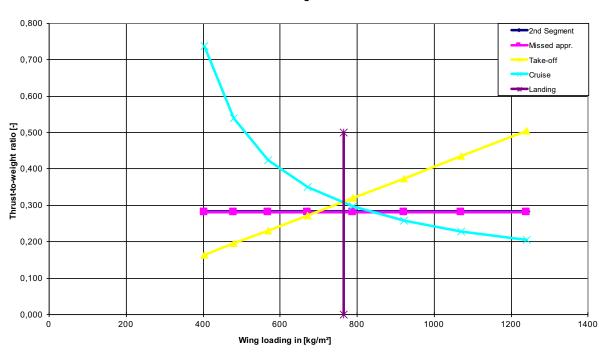
General wing specifications	Airfoil type:	NACA 4 dig
Wing span	b_W	34,09 m
Structural wing span	$b_{W,struct}$	37,60 m
Wing area	S_W	122,4 m ²
Aspect ratio	Α	9,49
Sweep	φ_{25}	24,967 °
Mean aerodynamic chord	c _{MAC}	4,3 m
Position of maximum camber	$\mathbf{x}_{(\mathbf{y}_{\mathbf{c}}),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t,max}$	30 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	72,00 m/s
Mach number, landing	M_APP	0,22
Mach number, cruise	M_{CR}	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,0 %c
Leading edge sweep	ϕ_{LE}	28,7 °
Reynoldsnumber	Re	2,2E+07
Maximum lift coefficient, base	C _{L,max,base}	1,58
Correction term, camber	$\Delta_1 c_{L,max}$	0,18
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,090
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,842
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	$\Delta C_{L,max}$	-0,02
Lift coefficient, wing	C _{L,max}	1,45

Calculations increase of lift coefficient due to flaps			1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87	
Flap group A	·		
0,3c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	1,72	
Use flapped span	b_W,fA	26,59	m
Percentage of flaps allong the wing		71%	
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	1,06	
Flap group B	, . ,		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74	
Use flapped span	b_W,fB	0	m
Percentage of flaps allong the wing		0%	
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00	
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	1,06	
	— - <u>L</u> ,IIIdX,I	,,,,	
Calculations increase of lift coefficient due to slats			1 slat type
Sweep angle of the hinge line	$\phi_{H.L.}$	27	•
Slat group A			
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90	
Use slatted span	b_W,sA	30	m
Percentage of slats allong the wing		80%	
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,64	
Slat group B	E,mov,ov t		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0.90	
Use slatted span	b W,sB	,	m
Percentage of slats allong the wing		0%	
Increase in maximum lift coefficient, slat group B	$\DeltaC_L.max.sB$	0.00	
Increase in maximum lift coefficient, slat	ΔC _{L,max,s}	0,64	
Wing	0	2.40	
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	3,10	
RE value maximum lift coefficient, landing	•	3,76	
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,16	
RE value maximum lift coefficient, take-off		2,62	
- 16%			
Aerodynamic e	fficiency		
Real aircraft average	k_{WL}	2,83	
End plate	$k_{e,WL}$	1,05	
Span	b _W	34,09	m
Winglet height	h	1,1	m
Aspect ratio	Α	9,49	
Effective aspect ratio	A_{eff}	9,93	
Efficiency factor, short range	k _E	15,15	
Relative wetted area	S _{wet} /S _W	7,01	
Verification value maximum aerodynamic efficiency	E _{max}	18,0	
RE value maximum aerodynamic efficiency		15,35	
18%			

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,780
Cruise altitude	h _{CR}	11278 m
By Pass Ratio	μ	5,40
Take-off Thrust (one engine)	T _{TO,one engine}	142,34 kN
Overall Pressure ratio	OAPR	33,70
Turbine entry temperature	TET	1463,80
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	\mathbf{n}_{inlet}	0,95
Ventilator efficiency	$\eta_{ventilator}$	0,88
Compressor efficiency	$\eta_{ m compresor}$	0,86
Turbine efficiency	$\eta_{ m turbine}$	0,90
Nozzle efficiency	η _{nozzle}	0,99
Temperature at SL	T ₀	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T _S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,76
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,94
Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Gas generator function	G	2,14
Verification value specific fuel consumption	SFC	0,56 kg/daN/h
Verification value specific fuel consumption	SFC	1,57E-05 kg/N/s
RE value specific fuel consumption	SFC	1,44E-05 kg/N/s
9%		

Matching Chart



Appendix F Airbus A321-200 Neo

Data Collection	ction		A321Neo	-	2	3	4	2	9	7	8	6
d		41-11		SOURCE: Aircraft characteristics	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Paul MüllerElodie RouyData collectior	Webs
Parameter	Symbol	Units	Chosen value	ror airport planning								
XX.			202	707								
Landing field length	S.F.	Ε	1750	1750							1600	
Approach speed	V _{APP}	s/m	20	02							68,94	
Temperature above ISA (288,15K)	ΔT _L	¥	0									
Relative density	ø											
Take-off field length	Cross	8	2300	2500							2210	
Temperature above ISA (288.15K)	AT _{TO}	¥	0	0								
Relative density	2 1 w		•									
Range (max payload)	~	Ę	2600	2600								7400
Cruise Mach number	McR		62'0								0,79	
Wing area	ď	m ₂										
Wing span	ğ	Ε	35.8	35.8							35.8	35.8
Aspect ratio	<											
			0								0	
Maximum take-off mass	ММТО	kg	93500	00076							93500	00078
Payload mass	JdW	kg	24000	24000								
Mass ratio, payload - take-off	тр∟/тито											
Maximum landing mass	m/l	kg	79200	79200								79200
Mass ratio, landing - take-off	MML/MMTO											
Operating empty mass	m _{OE}	kg										
Mass ratio, operating empty - take-off moe/mmro	ff moe/mwro											
wing loading	TIMTO/OW	rg/m²	11000	1								1
Maximum zero tuel mass	MMZF	Kg	00997	00997								00967
Number of engines	٣		2								2	2
Fraine type	MIFA	D-14 (41%) D	PW11									PW1133G- IM
Take-off thrust for one engine	To one engine KN	Ž.									. 00	147.3309258
Total take-off thrust	Tro	Z										
Thrust to weight ratio	Tro/(m _{MTo} *g)	(6										
Bypass ratio	_		12,5									12,5
Specific Fuel Comsumption (dry)		kg/N s										
Specific Fuel Comsumption (cruise)	SFC (cruise	e kg/N s										
Available fuel volume	Vfuel, available	u,	29,474	29								32,94
Cruise speed	V _{CR}	m/s	231,5								231,5	222,22
Cruise altitude	hcr	E	11278									11278
oweep angle	Ф25											
Mean aerodynamic chord	OMAC	E										
Position of maximum camber	X(y_c),max	%c										
Camber	(yc)max/C	%с										
Position of maximum thickness	X _{t,max}	%с										
Relative thickness	t/c	%										
Taper Communication rotion	<											
Overall pressure ratio	CAPR	ļ										
lurbine entry temperature	=	¥										

Aeroplane Specifications

	Data to apply	reverse engineering			
				LL	UL
Landing field length	Known	s_{LFL}	1750 m		
Approach speed	Known	V_{APP}	70,00 m/s	70,0	70,0
Temperature above ISA (288,15K)		ΔT_L	0 K		
Relative density		σ	1		
Take-off field length	Known	s _{TOFL}	2300 m	2300	2300
Temperature above ISA (288,15K)		ΔT_TO	0 K		
Relative density		σ	1,000		
Range (maximum payload)		R	3024 NM		
Cruise Mach number		M_{CR}	0,79		
Wing area		S _W	122 m²		
Wing span	Known	b_W	35,8 m ²	35,8	35,8
Aspect ratio		Α	10,47		
Maximum take-off mass		m _{MTO}	93500 kg		
Maximum payload mass		m_{PL}	24000 kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,257		
Maximum landing mass		m _{ML}	79200 kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,847		
Operating empty mass		m_{OE}	49200 kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,526		
Wing loading		m_{MTO}/S_W	763,9 kg/m²		
Number of engines		n _E	2		
Take-off thrust for one engine		T _{TO,one engine}	147,3 kN		
Total take-off thrust		T_TO	294,6 kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,321		
Bypass ratio		μ	12,5		
Available fuel volume		V _{fuel,available}	23,86 m³		

Data to optimize V/V _{md}	Data	to	optimize	V/V_{md}
------------------------------------	------	----	----------	------------

	Data to 0	Pullinge V/Vmd			
				LL	UL
Cruise speed		V_{CR}	232 m/s		
Cruise altitude		h_{CR}	11278 m		
Speed ratio		V/V_{md}	1,000 -	1	1,316
	Data to execu	te the verification	ı		
				Ran	ge
Sweep angle		φ_{25}	24,967 °		
Mean aerodynamic chord		C _{MAC}	4,3 m		
Position of maximum camber		x _{(y_c),max}	30 %c	15 - 50	%с
Camber		$(y_c)_{max}/c$	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,5 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimization of V/Vmd						
	Quantity	Original value	RE value	Unit	Deviation	
Landing field length	S _{LFL}	1750	1750	m	0,00%	
Approach speed	V_{APP}	70,00	70,0	m/s	0,00%	
Take-off field length	s _{TOFL}	2300	2300	m	0,0¢%	
Span	b_W	35,8	35,8	m	0,00%	
Aspect ratio	Α	10,47	10,47		0,00%	
Cruise speed	V_{CR}	231,5	235	m/s	1,37%	
Cruise altitude	h_{CR}	11278	10558	m	-6,3 8%	
Squared Sum Absolute maximum deviation					4,26E-03 6,4%	
	Results rev	erse engineering				
Maximum lift coefficient, landing	$C_{L,max,L}$	3,46				
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,42		Povo	rse Engineering	
Maximum aerodynamic efficiency	E _{max}	20,10		Reve	ise Engineening	
Specific fuel consumption	SFC	1,25E-05 kg/	/N/s			

1) Maximum Lift Coefficient for Landing and Take-off

Landing					
Landing field length	S _{LFL}	1750 m			
Temperature above ISA (288,15K)	ΔT_L	0 K			
Relative density	σ	1,000			
Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$			
Approach speed	V_{APP}	70,00 m/s			
Factor, landing	k_L	0,107 kg/m³			
Mass ratio, landing - take-off	${\sf m_{ML}/m_{TO}}$	0,85			
Wing loading at maximum take-off mass	m_{MTO}/S_W	763,9 kg/m²			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,46			
Tai	ke-off				
Take-off field length	S _{TOFL}	2300 m			
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K			
Relative density	σ	1,00			
Factor	\mathbf{k}_{TO}	2,34 m³/kg			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,321			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,42			
2nd Segment					
Aspect ratio A 10,471					
Lift coefficient, take-off	$C_{L,TO}$	1,68			
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,029			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Profile drag coefficient	$C_{D,P}$	0,049			
Oswald efficiency factor; landing configuration	e	0,7			
Glide ratio in take-off configuration	E _{TO}	9,79			
Number of engines	n _E	2			
Climb gradient	sin(γ)	0,024			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,252			
Missed approach					
Lift coefficient, landing	C _{L,L}	2,04			
Lift-independent drag coefficient, clean	C _{D.0} (Missed approach)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,047			
Lift-independent drag coefficient, slats	$\Delta C_{D, slat}$	0,000			
Choose: Certification basis	JAR-25 resp. CS-25	no			
	FAR Part 25	yes			
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015			
Profile drag coefficient	C _{D,P}	0,082			
Glide ratio in landing configuration	EL	7,75			
Climb gradient	sin(γ)	0,021			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,254			
The sector monghit ratio	· 10/(···M10 9/	0,207			

2) Maximum Aerodynamic Efficiency

Constant parameters						
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g	9,81 m/s ²				
Air pressure, ISA, standard	p_0	101325 Pa				
Oswald eff. factor, clean	е	0,85				
Sp	ecifications					
Mach number, cruise	M _{CR}	0,79				
Aspect ratio	Α	10,47				
Bypass ratio	μ	12,50				
Wing loading	m_{MTO}/S_W	764 kg/m²				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,321				
Variables						
	V/V_{md}	1,0				
Calculations						
Zero-lift drag coefficient	C _{D,0}	0,017				
Lift coefficient at E _{max}	$C_{L,md}$	0,70				
Ratio, lift coefficient	$C_L/C_{L,md}$	1,000				
Lift coefficient, cruise	C_L	0,696				
Actual aerodynamic efficiency, cruise	E	20,10				
Max. glide ratio, cruise	E _{max}	20,10				
Newton-Raphson for the maximum lift-to-	drag ratio					
Iterations		2	3			
f(x)	0,38	-0,03	0,00			
f(x)	-0,09	-0,10	-0,10			
E _{max}	16	20,42	20,10			

3) Specific Fuel Consumption

Constant parameters					
Ratio of specific heats, air	γ	1,4			
Earth acceleration	g	9,81	m/s²		
Air pressure, ISA, standard	p_0	101325			
Fuel density	$ ho_{fuel}$	800	kg/m³		
Specific	ations				
Range	R	3024	NM		
Mach number, cruise	M _{CR}	0,79			
Bypass ratio	μ	12,50			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,321			
Available fuel volume	$V_{fuel,available}$	23,86	m³		
Maximum take-off mass	m_{MTO}	93500	kg		
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,257			
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,526			
Calculate	d values				
Actual aerodynamic efficiency, cruise	E	20,10			
Cruise altitude	h _{CR}	10558	m		
Cruise speed	V _{CR}	235	m/s		
Mission fus					
Type of aeroplane (according to Roskam) Transport jet					
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990			
Fuel-Fraction, taxi	M _{ff,taxi}	0,990			
Fuel-Fraction, take-off	M _{ff,TO}	0,995			
Fuel-Fraction, climb	M _{ff,CLB}	0,980			
Fuel-Fraction, descent	M _{ff,DES}	0,990			
Fuel-Fraction, landing	M _{ff,L}	0,992			
-	·	0,002			
Calcula		2017			
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,217			
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,783			
Available fuel mass	m _F ,available	19088	kg		
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,204			
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,812			
Distance to alternate	S _{to_alternate}	200	NM		
Distance to alternate	S _{to alternate}	370400	m		
Choose: FAR Part121-Reserves	domestic	yes			
	international	no			
Extra-fuel for long range		5%			
Extra flight distance	S _{res}	370400	m		
Loiter time	t _{loiter}	2700	s		
Specific fuel consumption	SFC	1,25E-05	kg/N/s		

4) Verification Specifications

Maximum lift coefficients

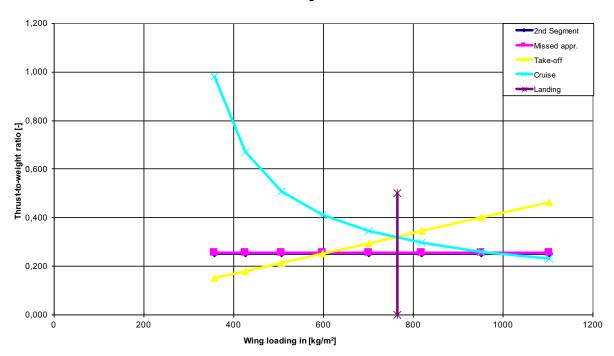
General wing specifications	Airfoil type:	NACA 4 digit
Wing span	b_W	35,8 m
Structural wing span	$b_{W,struct}$	39,49 m
Wing area	S_W	122,4 m²
Aspect ratio	Α	10,47
Sweep	φ_{25}	24,967 °
Mean aerodynamic chord	C _{MAC}	4,3 m
Position of maximum camber	x _{(y_c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	X _{t.max}	30 %c
Relative thickness	t/c	11,5 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	70,00 m/s
Mach number, landing	M_APP	0,21
Mach number, cruise	M_{CR}	0,79
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,0 %c
Leading edge sweep	ϕ_{LE}	28,3 °
Reynoldsnumber	Re	2,1E+07
Maximum lift coefficient, base	C _{L,max,base}	1,57
Correction term, camber	$\Delta_1 c_{L,max}$	0,19
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,081
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,836
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	ΔC _{L,max}	-0,01
Lift coefficient, wing	C _{L,max}	1,46

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathrm{\phi}}}$	0,87
Flap group A		
0,3c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	1,73
Use flapped span	b_W,fA	27,92 m
Percentage of flaps allong the wing		71%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	1,06
• Flap group B	40	0.75
0,3c Plain flap Use flapped span	Δc _{L,max,fB} b W,fB	0,75 0 m
Percentage of flaps allong the wing	D_VV,1D	0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0.00
Increase in maximum lift coefficient, flap	ΔC _{L,max,f}	1,06
moreage in maximum in coomboni, nap	□9∟,max,r	1,00
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	ΦH.L.	27 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,91
Use slatted span	b_W,sA	31,5 m
Percentage of slats allong the wing Increase in maximum lift coefficient, slat group A	4.0	80%
Slat group B	$\Delta C_{L,max,sA}$	0,64
0,3c Nose flap	Λο	0,91
Use slatted span	Δc _{L,max,SB} b W,sB	0 m
Percentage of slats allong the wing	D_44,5D	0%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0.00
Increase in maximum lift coefficient, slat	ΔC _{L,max,s}	0,64
	— -c.,max,s	5,0 .
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	3,12
RE value maximum lift coefficient, landing		3,46
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,18
RE value maximum lift coefficient, take-off		2,42
-10%		
Aerodynamic efficie	ncy	
Real aircraft average	k_{WL}	2,83
End plate	k _{e,WL}	1,10
Span	b _W	35,8 m
Winglet height	h	2,43 m
Aspect ratio	A	10,47
Effective aspect ratio	$A_{ m eff}$	11,50
Efficiency factor, short range	k _E	16,19
Relative wetted area	S_{wel}/S_W	7,01
Verification value maximum aerodynamic efficiency	E _{max}	20,7
RE value maximum aerodynamic efficiency	-max	20,10
3%		,

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,790	
Cruise altitude	h_{CR}	11278 m	
By Pass Ratio	μ	12,50	
Take-off Thrust (one engine)	T _{TO,one engine}	147,30 kN	
Overall Pressure ratio	OAPR	44,01	
Turbine entry temperature	TET	1465,69	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η_{inlet}	0,91	
Ventilator efficiency	η _{ventilator}	0,89	
Compressor efficiency	$\eta_{compresor}$	0,88	
Turbine efficiency	η_{turbine}	0,90	
Nozzle efficiency	η_{nozzle}	0,99	
Temperature at SL	T_0	288,15 K	
Temperature lapse rate in troposhpere	L	0,0065 K/m	
Temperature (ISA) at tropopause	T_S	216,65 K	
Temperature at cruise altitude	T(H)	216,65 K	
Dimensionless turbine entry temperature	ф	6,77	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,12	
Temperature function	χ	2,19	
Gas generator efficiency	$\eta_{ m gasgen}$	0,97	
Gas generator function	G	2,04	
Verification value specific fuel consumption	SFC	0.53 kg/da	aN/h
Verification value specific fuel consumption	SFC	1,46E-05 kg/N	/s
RE value specific fuel consumption	SFC	1,25E-05 kg/N	/s
17%		,	

Matching Chart



Appendix G Airbus A319-100

				_		2	2	4	n	٥	,	0	,
Parameter ing field length oach speed				Source: Aircraft characteristics		Jane's	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux Data collection	ata collection	Webs
ling field length oach speed	Symbol	Units	Chosen value	Tor airport planning	Ę.	Basic Option	707.0			77	707 707		
			156		156	124-145	153-124			142	142 134-124		
	SIFL	Ε	1430	1370-1400		1430	1350	0		1356	1350	1350	
		m/s	29		65		62,39	6		69,44		88'99	
l emperature above ISA (288,15K)		×	0					0		0			
Relative density	s				_								
Take-off field length	Stoel	8	2200	1400-2200		1720	2640 1750	G			1750	1750	1950
ISA (288.15K)		~	0			2		0					
Range (max payload)	~	km	4630	44	4630	3357 68	6846 2509,46	9		2200	1296		6950
	McR		0,78			0,78		8,0			0,78	0,79	0,78
Wing area	Sw	m²	122.4			122.4	122.4	4		122.4	122.44		122.6
		E	34,09	(7)	34.1	34,09	33,91	_		33,91	33,91	35,8	34.1
0			9,4				9,3945106	9		9,4	62'6		
Maximum take-off mass	Мито	kg	75500	66000-76500	0	64000 755	75500 64000	0		64000	64000	64000	75500
Payload mass n	ШР	kg	17900	17.	17400	17900	17390	0			17642		58500
te-off	MPL/MMT0						0,27	8			0,276		
Maximum landing mass		kg	61000	61000-62500	0	61000 625	62500 61000	0		61000	61000		
ke-off	Мм∟Мито						0,9	5					
Operating empty mass		kg	41200			40160 412	41203 39200	0			39358		40800
perating empty - take-off								2			0,615		
	NS.	kg/m²	616,8				616,8 522,87582	7			523		
Maximum zero tuel mass	MMZF	Dy Cd	00686	9/000-58500	2	000/9	000/9 000	0			000/9		
ngines	JE											2	2
	CFM56-5A (10%), -5B (5	10%), -5B (5	끙	CFM56-5A	CFM56-	CFM56-5A5	CFM56	끙				CFM56-5B	
ne engine	ne engine	KN	104,5			97,9	104,5 99,7	7 97,860884			98,76	6 86	98 98-120
	Tro	ΚN	509										
ght ratio	T _{TO} /(m _{MTO} *g)		0,32		0,3	0,312051426 0,324970753	753 0,3175968				0,31		
			2,9					5,9			5,9		
Specific Fuel Comsumption (dry) Specific Fuel Comsumption (cruise) S	SFC (dry) kg/N s	kg/N s kg/N s	9,06E-06					9,056E-06			9,00E-06		
Available fuel volume	Vfuel, available	m³	23,859	23,0	23,859	23,86	23,86	(C)			23,859		
Cruise speed	VcR	m/s	230			180	229,44-250, 5 3	53				231,5	230
		Е	11278				11277,6-10	0 10668			11278		
Sweep angle	4 25		25				2	2			25		25
namic chord		E	4,2				4,288	80			4,19		
per	max	%c											
		%с											
ım thickness	ax	%с											
/e thickness	_	%	11,8								15,2-11,8-10,8		
	Y		0,24				0,24				0,246		
Overall pressure ratio	OAPR	,	24,1					24,1					

Aeroplane Specifications

Data to apply reverse engineering LL UL **1430** m Landing field length Known S_{LFL} 67,00 m/s Approach speed Known V_{APP} 67,0 67.0 Temperature above ISA (288,15K) ΔT_{L} 0 K Relative density 1 σ Take-off field length Known **2200** m 2200 2200 STOFL Temperature above ISA (288,15K) 0 K ΔT_{TO} Relative density 1,000 R Range (maximum payload) 1813 NM M_{CR} Cruise Mach number 0,78 Wing area S_W 122 m² Wing span Known b_{W} 34,09 m² 34,09 34,09 Aspect ratio 9,49 Α Maximum take-off mass 75500 kg \mathbf{m}_{MTO} Maximum payload mass ${\rm m}_{\rm PL}$ 17900 kg Mass ratio, payload - take-off 0,237 m_{PL}/m_{MTO} Maximum landing mass 61000 kg $m_{ML} \\$ 0,808 Mass ratio, landing - take-off m_{ML}/m_{MTO} **41200** kg Operating empty mass $m_{\text{OE}} \\$ Mass ratio, operating empty - take-off $m_{\text{OE}}/m_{\text{MTO}}$ 0,546 Wing loading 616,8 kg/m² m_{MTO}/S_W Number of engines 2 n_{E} Take-off thrust for one engine $T_{\text{TO,one engine}}$ 104,5 kN 209 kN Total take-off thrust T_{TO} Thrust to weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,282 Bypass ratio 6,2

fuel, available

23,86 m³

Data	to	optimize	V/V _{md}
Dala	w	ODUITIE	V/Vmd

				LL	UL
Cruise speed		V_{CR}	230 m/s		
Cruise altitude		h _{CR}	11278 m		
Speed ratio		V/V_{md}	1,053 -	1	1,316
	Data to execu	te the verification	ı		
				Ran	ge
Sweep angle		Ψ25	24,967 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,6 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimiz	zation	OΤ	v/vma
-------------------------------	--------	----	-------

11071	rise engineering	a optimization of v	/ / III u		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1430	1430	m	0,00%
Approach speed	V_{APP}	67,00	67,0	m/s	0,00%
Take-off field length	s _{TOFL}	2200	2200	m	0,00%
Span	b_W	34,09	34,09	m	0,00%
Aspect ratio	Α	9,49	9,49		0,00%
Cruise speed	V_{CR}	230,0	230	m/s	0,08%
Cruise altitude	h_{CR}	11278	11278	m	0,00%
Squared Sum Absolute maximum deviation					6,90E-07 ♂,1%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,26			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,33		Reve	rse Engineering
Maximum aerodynamic efficiency	E _{max}	17,65		11000	130 Engineering
Specific fuel consumption	SFC	1,62E-05 kg/	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

L	anding	
Landing field length	S _{LFL}	1430 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	67,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,81
Wing loading at maximum take-off mass	m_{MTO}/S_W	616,8 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,26
Ta	ake-off	
Take-off field length	S _{TOFL}	2200 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,282
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,33
2nd	Segment	
Aspect ratio	A	9,495
Lift coefficient, take-off	$C_{L,TO}$	1,61
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,026
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,046
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	9,47
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,259
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,93
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_D,flap$	0,041
Lift-independent drag coefficient, slats	$\Delta C_D,slat$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	$C_{D,P}$	0,076
Glide ratio in landing configuration	EL	7,58
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,247
•		

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81	m/s²
Air pressure, ISA, standard	p_0	101325	Pa
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,78	_
Aspect ratio	Α	9,49	
Bypass ratio	μ	6,20	
Wing loading	m_{MTO}/S_W	617	kg/m²
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,282	
	Variables		
	V/V_{md}	1,1	
Ca	alculations		
Zero-lift drag coefficient	$C_{D,0}$	0,020	
Lift coefficient at E _{max}	$C_{L,md}$	0,72	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,902	
Lift coefficient, cruise	CL	0,648	
Actual aerodynamic efficiency, cruise	E	17,55	
Max. glide ratio, cruise	E _{max}	17,65	
Novitor Donbook for the monitoring lift to	dan a wati a		
Newton-Raphson for the maximum lift-to-o	drag ratio	2	2
Iterations f(x)	0,18	-0,01	0,00
f(x)	-0,11	-0,01	-0,11
E _{max}	16	17,70	17,65
- max	10	17,70	17,00

3) Specific Fuel Consumption

Constant par	ameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{ m fuel}$	800	kg/m³
Specificat	ions		
Range	R	1813	NM
Mach number, cruise	M _{CR}	0,78	
Bypass ratio	μ	6,20	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,282	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	75500	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,237	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,546	
Calculated v	values		
Actual aerodynamic efficiency, cruise	E	17,55	
Cruise altitude	h _{CR}	11278	m
Cruise speed	V_{CR}	230	m/s
Mission fuel	fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ m ff,engine}$	0,990	
Fuel-Fraction, taxi	M _{ff,taxi}	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Calculation	one		
Mission fuel fraction (acc. to PL and OE)	m _E /m _{MTO}	0,217	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,783	
impositives indesien (deet to 1 2 and 62)	•••п	0,700	
Available fuel mass	m _{F,available}	19088	kg
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,253	
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,762	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,62E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

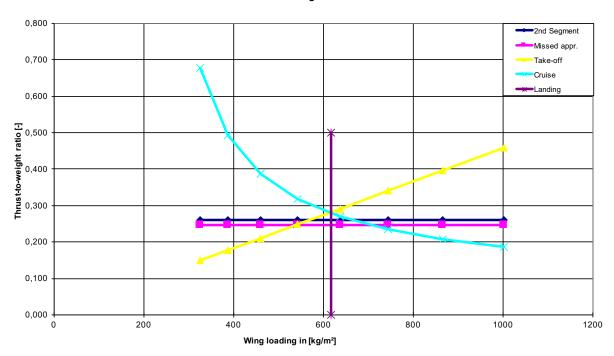
General wing specifications	Airfoil type:	NACA 4 digit
Wing span	b_W	34,09 m
Structural wing span	$b_{W,struct}$	37,60 m
Wing area	S_W	122,4 m²
Aspect ratio	Α	9,49
Sweep	φ_{25}	24,967 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t.max}$	30 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	67,00 m/s
Mach number, landing	M_{APP}	0,20
Mach number, cruise	M_{CR}	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,0 %c
Leading edge sweep	ϕ_{LE}	28,7 °
Reynoldsnumber	Re	2,0E+07
Maximum lift coefficient, base	C _{L,max,base}	1,58
Correction term, camber	$\Delta_1 c_{L,max}$	0,18
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,076
Maximum lift coefficient, airfoil	C _{L.max.clean}	1,829
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	ΔC _{L,max}	0,00
Lift coefficient, wing	C _{L,max}	1,46

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87
Flap group A	·	
0,3c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	1,73
Use flapped span	b_W,fA	26,6 m
Percentage of flaps allong the wing		71%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	1,06
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,75
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	1,06
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΨH.L.	27 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	7,5 m
Percentage of slats allong the wing		20%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,16
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	21,8 m
Percentage of slats allong the wing		58%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,47
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,63
Wing Verification value maximum lift coefficient, landing RE value maximum lift coefficient, landing Verification value maximum lift coefficient, take-off	$C_{L,max,L}$ $C_{L,max,TO}$	3,10 3,26 2,21
RE value maximum lift coefficient, take-off	L,IIIax, TO	2,33
-5%		
Aerodynamic effic	iency	
Real aircraft average	k_{WL}	2,83
End plate		1,05
Span	k _{e,WL}	34,09 m
Winglet height	b _W	·
Aspect ratio	h A	1,1 m 9,49
Effective aspect ratio	A _{eff}	9,93
Elicotive dopost ratio	' Yeπ	0,00
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{we}/S_{W}	6,35
Verification value maximum aerodynamic efficiency	E _{max}	18,9
RE value maximum aerodynamic efficiency		17,65
7%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,780	
Cruise altitude	h_{CR}	11278	m
By Pass Ratio	μ	6,20	
Take-off Thrust (one engine)	T _{TO,one engine}	104,50	kN
Overall Pressure ratio	OAPR	24,10	
Turbine entry temperature	TET	1443,44	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η_{inlet}	0,94	
Ventilator efficiency	$\eta_{ m ventilator}$	0,86	
Compressor efficiency	$\eta_{compresor}$	0,86	
Turbine efficiency	$\eta_{ m turbine}$	0,90	
Nozzle efficiency	η_{nozzle}	0,98	
Temperature at SL	T_0	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T _S	216,65	K
Temperature at cruise altitude	T(H)	216,65	K
Dimensionless turbine entry temperature	ф	6,66	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,12	
Temperature function	χ	1,66	
Gas generator efficiency	η_{gasgen}	0,98	
Gas generator function	G	2,18	
Verification value specific fuel consumption	SFC	0.60	kg/daN/h
Verification value specific fuel consumption	SFC	1,66E-05	•
DE value and if a feel and any month of	050	4.005.05	1/81/-
RE value specific fuel consumption	SFC	1,62E-05	kg/N/s

Matching Chart



Appendix H Boeing 737-700

S24 S01	Source: 6007	A 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	e's B 1493 66,8777778 1677 5	Jenkinson 149-128 1356	Engine	Scholz Paul M	Paul Müller Elodie F 149 149-126	Elodie Roux Data collection 49-126	Webs
Symbol Units	118 28 28 34,32 60328 17010 58060	1 66,3833 1 70080 60 17554 58604 58	66,8777778 1677 1677 5	1356			149 149-126		
Stort M Stort K S Stort K S Stort K S S S S S S S M M A A A A A A A A A A A	36, 38, 38, 37, 37, 37, 37, 37, 37, 37, 37, 37, 37	1 66,3633. 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	1433 66,8777778 0 1677						
Str. m M. VAPP m/s S	34,32	10 66,36333 70080 70080 600 17554 58604 58604	66,877	1356					
Name Mark	34,32	66,36333 226 226 24 34 70080 600 17554 58604 58604	66,877				1356	1356 1400	
A11, K Sropt. m ATro K Sr R R R R MARR Bw m² Bw	36, 32	11 28 34 70080 600 17554 58604 58604		-		,	66,94	70,478889	
STOFIL M	35 36,32 34,32 37	70080 70080 70080 17554 58604 586		0			0		
STOPL III	34,32	70080 70080 70080 607 17554 58604 586		0000				7600	2400
National State National State	36 34,32 34,32	28 34 70080 600 17554 580	•	2042				000	7400
R	34,32	70080 607 17554 58604 586		SQ.					
Mer	34,32	70080 600 17554 58604 586	5648				6009	631	6230
Sw m² bw m bw m bw m munco kg macumano kg moemano kg moemano kg muro/Sw kg/m² ne kg ne kg ne kg r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r r	34,32	70080 600 17554 58604 586	0,785		8'0			0,79 0,785	0,785
A	37	70080 600 17554 58604 580		124,6			125	124,6	
A	37/	70080 603 17554 58604 586	35,79	34,3		.,		34,32 34,3	35,7
Marco kg	37/	70080 607 17554 58604 580	9,4	9,44213483			9,4	9,45	
MP-L Kg MP-L Kg MAL MAL MAL MAL MOE Kg MOE Kg MOE Kg MALOS Kg ME To one engine KN Tro (Marro*g) U SFC (dry) Kg Ks U SFC (dry) Kg U SFC (dry) Kg U SFC (dry) Kg U West available West available West available West available West available Malos available West available Malos available West a	37	28(70080	69400		9	66369	60326 66320	70000
Me_Imarro	37	28(11610				17010	
m _{ML} kg m _{ML} m _{ML} m _{ML} m _{ML} m _{ML} m _M m _{ML} m _{ML}	37	280		0,16729107				0,282	
ThuLIMATO ROE	37648	38.	28605	28060		40	58059 5	28060	28600
mose	01070	30	147	0,83659942				07640	00450
March Marc			Ì	0 54157061				0.624	00100
Nu _{NZF} Kg CFMS6-7B		482,6		556,982343				484	
DE CFM56-7B	54658	55202 54655	25200	24650			4,	54658	
CFM56-7B				8				2	2
Troone angle KN Tro	4 CFM56-7B20/-7B22/-7B24	/-7B24 CFM56-7B20	CFM56-7B24 (CFM56-7B20 CI	CFM56-7B20		CFM56-7B20	CFM56-7	
Tro(m _{Arro} *g) Tro(m _{Arro} *g) µ SFC (dry) kgN s SFC (cruise kgN s			101	-	91,63337		6	91,633 89	116
Tro(maro*9) µ SFC (dry) kgN s SFC (cruise kgN s V _{tool arvaliable} m²									
p SFC (dry) kg/N s se) SFC (cruise kg/N s V _{tool arreliable} m²		0,31015446	0,29406575	0,26145173	(0,31	
se) SFC (cruise kg/N s Vatet available m³					5,6 1 02E 05		100	5,6	
Viuel available m³					1,02E-03		1.75	1,79E-05	
Vfuel, available m ³									
	26,022	26,025		26,024			2	26,022	26,02
m/s				232,53				236,64444	230
		12500	11700	11887,2	10668			11887	
Sweep angle \$\phi_{25}\$ ° 25				25				25	25,02
E				4,17				4,17	
of maximum camber x _{(y_c),max} %c									10
(yc)max/c %c									0,8
im thickness x _{t,max} %c									29,7
e thickness 1/c %		0000	77700	0200	-			070	12,5
Overall pressure ratio OAPR 22.7		0,2100	0,216914160	0,278	22.7			0,219	
TET K									

Aeroplane Specifications

	Data to apply	reverse engineering			
				LL	UL
Landing field length	Known	s_{LFL}	1400 m		
Approach speed	Known	V_{APP}	67,00 m/s	67,0	67,0
Temperature above ISA (288,15K)		ΔT_L	0 K		
Relative density		σ	1		
Take-off field length	Known	s _{TOFL}	1800 m	1800	1800
Temperature above ISA (288,15K)		ΔT_TO	0 K		
Relative density		σ	1,000		
Range (maximum payload)		R	1540 NM		
Cruise Mach number		M _{CR}	0,785		
Wing area		S_W	125 m²		
Wing span	Known	b_W	34,32 m ²	34,32	34,32
Aspect ratio		Α	9,45		
Maximum take-off mass		m_{MTO}	69400 kg		
Maximum payload mass		m_PL	17010 kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,245		
Maximum landing mass		m_ML	58060 kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,837		
Operating empty mass		m_OE	38147 kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,550		
Wing loading		m_{MTO}/S_W	557,0 kg/m²		
Number of engines		n _E	2		
Take-off thrust for one engine		T _{TO,one engine}	101 kN		
Total take-off thrust		T_TO	202 kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,297		
Bypass ratio		μ	5,6		
Available fuel volume		V _{fuel,available}	26,022 m³		

	Data to o	ptimize V/V _{md}				
					LL	UL
Cruise speed		V_{CR}	232	m/s		
Cruise altitude		h _{CR}	11887	m		
Speed ratio		V/V_{md}	1,049	-	1	1,316
	Data to execu	ite the verification	l			
					Rar	nge
Sweep angle		ϕ_{25}	25	•		
Mean aerodynamic chord		c _{MAC}	4,17	m		
Position of maximum camber		X _{(y_c),max}	30	%с	15 - 50	%с
Camber		(y _c) _{max} /c	4	%с	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	11,5	%		
Taper		λ	0,219			

Reverse Engineering

Reverse engineering & optimization

IVEA	erse engineering	a optimization of v	Villa		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1400	1400	m	0,00%
Approach speed	V_{APP}	67,00	67,0	m/s	0,00%
Take-off field length	s _{TOFL}	1800	1800	m	0,00%
Span	b_W	34,32	34,32	m	0,00%
Aspect ratio	Α	9,45	9,45		0,00%
Cruise speed	V_{CR}	232,0	232	m/s	-0,14%
Cruise altitude	h_{CR}	11887	11887	m	0,00%
Squared Sum Absolute maximum deviation					2,07E-06 0,1%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,11			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,44		Reverse Engineering	
Maximum aerodynamic efficiency	E _{max}	17,99		Revei	Se Lingineering
Specific fuel consumption	SFC	1,72E-05 kg/l	N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Li	anding	
Landing field length	S _{LFL}	1400 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	1,70 (m/s²) ^{0.6}
Approach speed	V_{APP}	67,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	$\rm m_{ML}/m_{TO}$	0,84
Wing loading at maximum take-off mass	m_{MTO}/S_W	557,0 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,11
Ta	ake-off	
Take-off field length	s _{TOFL}	1800 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,297
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,44
2nd	Segment	
Aspect ratio	A	9,453
Lift coefficient, take-off	$C_{L,TO}$	1,69
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,030
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,050
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	9,02
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,270
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,84
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_D,flap$	0,037
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	$C_{D,P}$	0,072
Glide ratio in landing configuration	EL	7,83
Climb gradient	sin(γ)	0,021

2) Maximum Aerodynamic Efficiency **Constant parameters** Ratio of specific heats, air 1,4 9,81 m/s² Earth acceleration g Air pressure, ISA, standard 101325 Pa p_0 Oswald eff. factor, clean 0,85 е **Specifications** Mach number, cruise 0,785 M_{CR} Aspect ratio Α 9,45 5,60 Bypass ratio μ Wing loading 557 kg/m² m_{MTO}/S_W Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,297 **Variables** 1.0 V/V_{md} **Calculations** Zero-lift drag coefficient $C_{D,0}$ 0,020 Lift coefficient at Emax 0,70 $C_{L,md}$ Ratio, lift coefficient $C_L/C_{L,md}$ 0,908 Lift coefficient, cruise C_L 0,637 Actual aerodynamic efficiency, cruise Ε 17,90 Max. glide ratio, cruise 17,99 E_{max} Newton-Raphson for the maximum lift-to-drag ratio 0,22 -0,01 f(x) 0,00 f'(x)-0,11 -0,12 -0,11

16

18,06

17,99

 E_{max}

3) Specific Fuel Consumption

Constant	parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	•	m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Speci	fications		
Range	R	1540	NM
Mach number, cruise	M_{CR}	0,785	
Bypass ratio	μ	5,60	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,297	
Available fuel volume	$V_{fuel,available}$	26,022	m³
Maximum take-off mass	m_{MTO}	69400	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,245	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,550	
Calcula	ted values		
Actual aerodynamic efficiency, cruise	E	17,90	
Cruise altitude	h_{CR}	11887	m
Cruise speed	V _{CR}	232	m/s
Mission	uel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	M _{ff,taxi}	0,990	
Fuel-Fraction, take-off	M _{ff.TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	$M_{\rm ff,DES}$	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
	ulations	0,205	
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}		
Mission fuel fraction (acc. to PL and OE)	M_ff	0,795	
Available fuel mass	M _{F,available}	20817,6	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,300	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,714	
Distance to alternate	c	200	NM
Distance to alternate	S _{to_alternate}	370400	
Choose: FAR Part121-Reserves	s _{to_alternate} domestic		Ш
Choose. FAR Fait121-Reserves	international	yes no	
Extra-fuel for long range	international	5%	
Extra flight distance	e	370400	m
	s _{res}		
Loiter time	t _{loiter}	2700	5
Specific fuel consumption	SFC	1,72E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

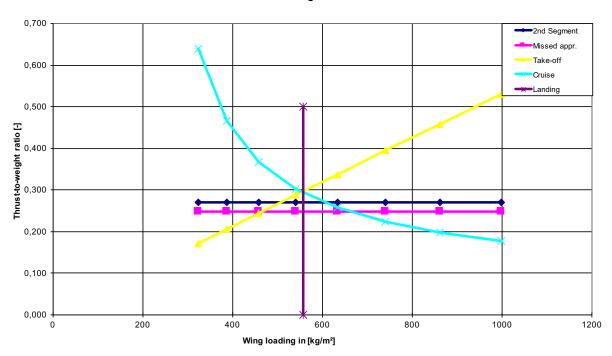
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b_W	34,32 m
Structural wing span	$b_{W,struct}$	37,87 m
Wing area	s_{w}	124,6 m²
Aspect ratio	Α	9,45
Sweep	φ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	4,17 m
Position of maximum camber	x _{(y_c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t,max}$	30 %c
Relative thickness	t/c	11,5 %
Taper	λ	0,219
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	67,00 m/s
Mach number, landing	M_{APP}	0,20
Mach number, cruise	M_{CR}	0,785
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,1 %c
Leading edge sweep	ϕ_{LE}	28,9 °
Reynoldsnumber	Re	2,0E+07
Maximum lift coefficient, base	C _{L,max,base}	1,25
Correction term, camber	$\Delta_1 c_{L,max}$	0,40
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,036
Maximum lift coefficient, airfoil	C _{L.max.clean}	1,693
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,87
Correction term, Mach number	$\Delta C_{L,max}$	0,00
Lift coefficient, wing	C _{L,max}	1,47

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{oldsymbol{\phi}}}$	0,87
Flap group A		
Double-slotted flap	$\Delta c_{L,max,fA}$	1,44
Use flapped span	b_W,fA	6,9 m
Percentage of flaps allong the wing		18%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,23
Flap group B		
Double-slotted flap	$\Delta c_{L,max,fB}$	1,44
Use flapped span	b_W,fB	11,8 m
Percentage of flaps allong the wing		31%
Increase in maximum lift coefficient, flap group B	\DeltaC_L,max,fB	0,39
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,62
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΨH.L.	27 °
Slat group A		
0,1c Kruger flap	$\Delta c_{L,max,sA}$	0,67
Use slatted span	b_W,sA	4,5 m
Percentage of slats allong the wing		12%
Increase in maximum lift coefficient, slat group A	$\Delta C_{\!L,max,sA}$	0,07
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,91
Use slatted span	b_W,sB	25,4 m
Percentage of slats allong the wing		67%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,54
Increase in maximum lift coefficient, slat	\DeltaC_L,max,s	0,61
Wing	_	
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,67
RE value maximum lift coefficient, landing	_	3,11
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,09
RE value maximum lift coefficient, take-off		2,44
-14	//0	
A dr	a officiona.	
Aerodynamic	с епісіепсу	
Real aircraft average	k_{WL}	2,83
End plate	$k_{e,WL}$	1,11
Span	b _W	34,32 m
Winglet height	h	2,49 m
Aspect ratio	Α	9,45
Effective aspect ratio	A_{eff}	10,45
Efficiency feator, short range	le .	15 15
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{we}/S_{W}	6,35
Verification value maximum aerodynamic efficiency	E _{max}	19,4
RE value maximum aerodynamic efficiency	IIIMA	17,99
8%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_CR	0,785	
Cruise altitude	h _{CR}	11887	m
By Pass Ratio	μ	5,60	
Take-off Thrust (one engine)	T _{TO,one engine}	101,00	kN
Overall Pressure ratio	OAPR	22,70	
Turbine entry temperature	TET	1440,79	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	$oldsymbol{\eta}_{inlet}$	0,95	
Ventilator efficiency	$\eta_{ m ventilator}$	0,86	
Compressor efficiency	$\eta_{compresor}$	0,86	
Turbine efficiency	$\eta_{turbine}$	0,89	
Nozzle efficiency	η_{nozzle}	0,98	
Temperature at SL	T_0	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T _S	216,65	K
Temperature at cruise altitude	T(H)	216,65	K
Dimensionless turbine entry temperature	ф	6,65	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperat	ture υ	1,12	
Temperature function	χ	1,62	
Gas generator efficiency	η_{gasgen}	0,98	
Gas generator function	G	2,18	
Verification value specific fuel consumption	SFC	0.62	kg/daN/h
Verification value specific fuel consumption	SFC	1,71E-05	0
DE color and if a first constant	050	4 705 05	1
RE value specific fuel consumption 0%	SFC	1,72E-05	kg/N/s
0 /0	•		

Matching Chart



Appendix I Boeing 777-300ER

Partimeter Symbol Units Choosen value Sounds Author Choosen value Sounds Choosen value Sounds Choosen value Sounds Choosen value Sounds Choosen value Substitution Symbol Units Stratol Choosen value Substitution Symbol Units Symbol Choosen value Substitution Substitut		4 5 6	7 8	6
length str. m 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 11770 1944 117	Jane's	Scholz	Paul Müller Elodie Roux Data collectior	Webs
Fig. 1844 1770 1944 1970 1944 1970 1944 1944 1970 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 1944 19			550-370	
end Number of ALTA K 0 77.17 Property show (SAA (288,15K)) ATL K 0 0 77.17 Property show (SAA (288,15K)) ATL K 0 0 15 Property show (SAA (288,15K)) ATL K 0 0.84 3200 15 show (SAA (288,15K)) ATL K 0 0.84 0.84 15 show (SAA (288,15K)) ATL K 427.8 427.8 427.8 427.8 number (288,15K) May (284,15K) 64.79 64.8 64.8 64.8 64.8 show (188) max (188) AA 64.79 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 64.8 <			1800	
above 15A (208,15K)	-		76,652222	
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Aeroplane Specifications

	Data to apply	reverse engineering			
				LL	UL
Landing field length	Known	s_{LFL}	1844 m		
Approach speed	Known	V_{APP}	77,00 m/s	77,0	77,0
Temperature above ISA (288,15K)		ΔT_L	0 K		
Relative density		σ	1		
Take-off field length	Known	s _{TOFL}	3050 m	3050	3050
Temperature above ISA (288,15K)		ΔT_TO	0 K		
Relative density		σ	1,000		
Range (maximum payload)		R	5008 NM		
Cruise Mach number		M _{CR}	0,84		
Wing area		S _W	428 m²		
Wing span	Known	b_W	64,79 m ²	64,79	64,79
Aspect ratio		Α	9,81		
Maximum take-off mass		m _{MTO}	351535 kg		
Maximum payload mass		m_PL	69853 kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,199		
Maximum landing mass		m_{ML}	251290 kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,715		
Operating empty mass		m_OE	167829 kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,477		
Wing loading		m_{MTO}/S_W	821,7 kg/m²		
Number of engines		n _E	2		
Take-off thrust for one engine		T _{TO,one engine}	511,5 kN		
Total take-off thrust		T _{TO}	1023 kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,297		
Bypass ratio		μ	7,2		
Available fuel volume		V _{fuel,available}	23,86 m³		

Data	to e	ptimize	V/V_{md}
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					LL	UL
Cruise speed		V_{CR}	252	m/s		
Cruise altitude		h _{CR}	10668	m		
Speed ratio		V/V_{md}	1,094	-	1	1,316
	Data to execu	ite the verification				
					Ran	ge
Sweep angle		ϕ_{25}	31,64	۰		
Mean aerodynamic chord		C _{MAC}	4,2	m		
Position of maximum camber		$\mathbf{x}_{(y_c),max}$	30	%с	15 - 50	%с
Camber		(y _c) _{max} /c	5,9	%с	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	10,8	%		
Taper		λ	0,24			

Reverse Engineering

Reverse engineering	& o	ptimization	of	V/Vmd
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Kevi	erse engineering	a optimization or	v/viiiu		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1844	1844	m	0,00%
Approach speed	V_{APP}	77,00	77,0	m/s	0,00%
Take-off field length	s _{TOFL}	3050	3050	m	0,00%
Span	b_W	64,79	64,79	m	0,00%
Aspect ratio	Α	9,81	9,81		0,00%
Cruise speed	V_{CR}	252,0	249	m/s	-1,11%
Cruise altitude	h_{CR}	10668	10649	m	-0,17 <mark>%</mark>
Squared Sum Absolute maximum deviation					1,27E-04 1,1%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,98			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,13		Povo	roo Enginooring
Maximum aerodynamic efficiency	E _{max}	16,25		Revei	rse Engineering
Specific fuel consumption	SFC	1,22E-05 kg	g/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Lan	iding	
Landing field length	S _{LFL}	1844 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	1,70 (m/s²) ^{0.5}
Approach speed	V_{APP}	77,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,71
Wing loading at maximum take-off mass	m_{MTO}/S_W	821,7 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,98
Tak	e-off	
Take-off field length	S _{TOFL}	3050 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,297
Maximum lift coefficient, take-off	C _{L,max,TO}	2,13
040		
Aspect ratio	egment A	9,812
Lift coefficient, take-off	C _{L,TO}	1,48
Lift-independent drag coefficient, clean	C _{D.0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,019
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C _{D.P}	0,039
Oswald efficiency factor; landing configuration	e e	0,7
Glide ratio in take-off configuration	E _{TO}	10,56
	-10	,
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,237
Missed	approach	
Lift coefficient, landing	C _{L,L}	1,76
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,033
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Profile drag coefficient	$C_{D,P}$	0,068
Glide ratio in landing configuration	EL	8,31
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,202
ŭ	10 (1110 0/	•

2) Maximum Aerodynamic Efficiency

Const	ant parameters				
Ratio of specific heats, air	γ	1,4			
Earth acceleration	g	9,81 m/s ²			
Air pressure, ISA, standard	p_0	101325 Pa			
Oswald eff. factor, clean	е	0,85			
Specifications					
Mach number, cruise	M _{CR}	0,84			
Aspect ratio	A	9,81			
Bypass ratio	μ	7,20			
Wing loading	m_{MTO}/S_W	822 kg/m²			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,297			
Variables					
-	V/V _{md}	1,1			
	· · · · ma	-,-			
C	alculations				
Zero-lift drag coefficient	$C_{D,0}$	0,025			
Lift coefficient at E _{max}	$C_{L,md}$	0,81			
Ratio, lift coefficient	$C_L/C_{L,md}$	0,836			
Lift coefficient, cruise	C_L	0,674			
Actual aerodynamic efficiency, cruise	E	15,99			
Max. glide ratio, cruise	E _{max}	16,25			
Newton-Raphson for the maximum lift-to-	drag ratio				
Iterations	1	2	3		
f(x)	0,03	0,00	0,00		
f'(x)	-0,12	-0,12	-0,12		
E _{max}	16	16,25	16,25		

3) Specific Fuel Consumption

Constant parameters							
Ratio of specific heats, air	γ	1,4					
Earth acceleration	g		m/s²				
Air pressure, ISA, standard	p_0	101325					
Fuel density	$ ho_{ m fuel}$	800	kg/m³				
Specificat	ions						
Range	R	5008	NM				
Mach number, cruise	M_{CR}	0,84					
Bypass ratio	μ	7,20					
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,297					
Available fuel volume	$V_{\text{fuel,available}}$	23,86	m³				
Maximum take-off mass	m _{MTO}	351535	kg				
Mass ratio, landing - take-off	m_{PL}/m_{MTO}	0,199					
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,477					
Calculated values							
Actual aerodynamic efficiency, cruise	E	15,99					
Cruise altitude	h _{CR}	10649	m				
Cruise speed	V _{CR}	249	m/s				
·							
Type of aeroplane (according to Roskam)	Transport jet						
Fuel-Fraction, engine start	M _{ff,engine}	0,990					
Fuel-Fraction, taxi	M _{ff,taxi}	0,990					
Fuel-Fraction, take-off	M _{ff,TO}	0,995					
Fuel-Fraction, climb	M _{ff,CLB}	0,980					
Fuel-Fraction, descent	M _{ff,DES}	0,980					
Fuel-Fraction, landing	M _{ff,L}	0,992					
-	•	0,002					
Calculations							
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,324					
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,676					
Available fuel mass	MF,available	19088	kg				
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,054					
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,965					
	·						
Distance to alternate	S _{to_alternate}		NM				
Distance to alternate	S _{to_alternate}	370400	m				
Choose: FAR Part121-Reserves	domestic	no					
Extra fuel for long range	international	yes 5%					
Extra-fuel for long range		5%					
Extra flight distance	S _{res}	834141	m				
Loiter time	t _{loiter}	1800	s				
Specific fuel consumption	SFC	1,22E-05	kg/N/s				

4) Verification Specifications

Maximum lift coefficients

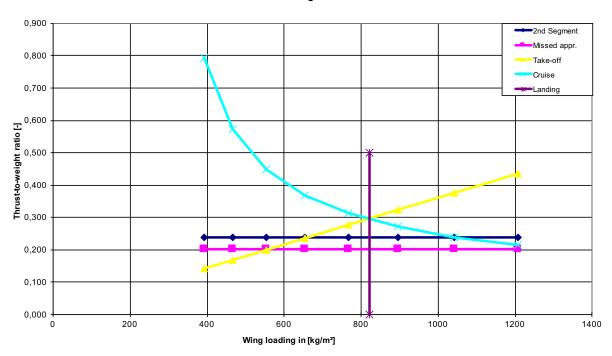
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b_W	64,79 m
Structural wing span	$b_{W,struct}$	76,10 m
Wing area	S_W	427,8 m ²
Aspect ratio	Α	9,81
Sweep	ϕ_{25}	31,64 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	x _{(y_c),max}	30 %c
Camber	$(y_c)_{max}/c$	5,9 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
Relative thickness	t/c	10,8 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	77,00 m/s
Mach number, landing	M_{APP}	0,23
Mach number, cruise	M _{CR}	0,84
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,0 %c
Leading edge sweep	ϕ_{LE}	35,2 °
Reynoldsnumber	Re	2,3E+07
Maximum lift coefficient, base	$\mathbf{c}_{L,max,base}$	1,19
Correction term, camber	$\Delta_1 c_{L,max}$	0,55
Correction term, thickness	$\Delta_2 \mathbf{c}_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,066
Maximum lift coefficient, airfoil	C _{L.max.clean}	1,805
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,90
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	C _{L,max}	1,61

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,83
Flap group A	•	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,57
Use flapped span	b_W,fA	11,4 m
Percentage of flaps allong the wing		15%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,20
Flap group B		0.00
Single-slotted flap	Δc _{L,max,fB}	0,86 26,7 m
Use flapped span Percentage of flaps allong the wing	b_W,fB	35%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,25
Increase in maximum lift coefficient, flap	ΔC _{L,max,f}	0,45
more and maximum in accomplishing map	LGL,max,r	0,10
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	Ψ _{H.L.}	34 °
Slat group A	_	4.00
0,3c Nose flap	Δc _{L,max,sA}	1,00
Use slatted span	b_W,sA	12,2 m
Percentage of slats allong the wing Increase in maximum lift coefficient, slat group A	۸۲	16% 0,13
Slat group B	$\Delta C_{L,max,sA}$	0,13
0,3c Nose flap	Δc _{L.max.SB}	1,00
Use slatted span	b_W,sB	45,2 m
Percentage of slats allong the wing	5_11,05	59%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,49
Increase in maximum lift coefficient, slat	ΔC _{L,max,s}	0,62
	,,	
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,65
RE value maximum lift coefficient, landing	_,,_	2,98
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,89
RE value maximum lift coefficient, take-off		2,13
-11%		
Aerodynamic efficier	ісу	
Real aircraft average	k_{WL}	2,83
End plate	k _{e,WL}	1,04
Span	b _W	64,79 m
Winglet height	h	2 m
Aspect ratio	A	9,81
Effective aspect ratio	$A_{ m eff}$	10,25
Efficiency factor, short range	k _E	16,19
Relative wetted area	S_{wet}/S_W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	20,6
RE value maximum aerodynamic efficiency		16,25
27%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,840	
Cruise altitude	h _{CR}	10668	m
By Pass Ratio	μ	7,20	
Take-off Thrust (one engine)	T _{TO,one engine}	511,50	kN
Overall Pressure ratio	OAPR	42,00	
Turbine entry temperature	TET	1504,36	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η_{inlet}	0,94	
Ventilator efficiency	η _{ventilator}	0,90	
Compressor efficiency	$\eta_{compresor}$	0,88	
Turbine efficiency	n _{turbine}	0,91	
Nozzle efficiency	η_{nozzle}	1,00	
Temperature at SL	T_0	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T _S	216,65	K
Temperature at cruise altitude	T(H)	218,81	K
Dimensionless turbine entry temperature	ф	6,88	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,14	
Temperature function	χ	2,18	
Gas generator efficiency	$\eta_{ m gasgen}$	0,97	
Gas generator function	G	2,15	
Verification value specific fuel consumption	SFC	0,54	kg/daN/h
Verification value specific fuel consumption	SFC	1,49E-05	
RE value specific fuel consumption	SFC	1,22E-05	kg/N/s
22%			

Matching Chart



Appendix J Airbus A330-300

Data Collection	ction		A330-300		_		2	ဇ	4	2	9	7	8	6
			$\overline{}$	Source:	Aircraft characteristics for airport planning	or airport planning	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Data collection	Webs
Parameter	Symbol	Units	Chosen value		WV026	WV082	Basic Option		2	1000	5	S C C C C C C C C C C C C C C C C C C C		2201
PAX			375		300		375-379	440-335-295			412	412 375-295		
Landing field length	ā	Ε	1750		1750	1820		1600			1815	1600	1700	
Approach speed	VADD	s/m	202		70.5			96 69			72.22		66 877778	
Temperature above ISA (288.15K)	ΔŢ		2 0		0			0			0			
Relative density	ø													
Tobo off field longth	į	8	2320		2300	3860	2515	2320				2320	2300	2500
Temperature above ISA (288 15K)	AT _{TO}	≣ ⊻	0		0007	0000	ıc					0707	7007	2007
Relative density	2 1 w	:	•		,									
Range (max payload)	œ	km	7000		7700	0	10371	7200,6			6500	6297		11750
Cruise Mach number	McR		0,82				0,82					0,82	0,81	0,82
Wing area	Š	m ₂	361.6				361.6	363.1			363.1	363.1		361.6
Wing span	ğ	8	60.3		60.3	_	63.68	28			60.3	60.3	60.3	60.3
Aspect ratio	4		10,01					9,26466538			10	10,02		
Maximum take-off mass	Мито	kg	242000		217000	242000	230000 233000	217000			230000	230000	230000	242000
Payload mass	ШРГ	kg	48400		45300	0	48400	48400				53269		45900
Mass ratio, payload - take-off	MPL/MMT0							0,2				0,232		
Maximum landing mass	mML	kg	185000		185000	187000	185000 187000	_			177000	185000		187000
Mass ratio, landing - take-off	MML/MMT0							0,82488479				701077		00000
Operating empty mass	moe	ĝ	124600				124600	118189				119/31		124000
Mina loading	III MOE/MMTO	ka/m²	633				633 4 644 4					0,521		
Maximum zero fuel mass	MAZE OW	ž Š	173000		173000	175000	-					173000		175000
Number of engines	ä							2				N		2
Engine type	GE CF6 (1	GE CF6 (17%), PW4000	-		KK I KEN I 700 Series	00 Series	K-K Irent //2-60///2B-60A	A CF6-80E1A2	1 rent /68-60	0		CF6-80E1A2 Irent //2-60	-60 GE CF6-80E1	CCC
Total take off thrust	T	Z 3	310,201				010	000						920
Thrust to weight ratio	Tro/(mwro*a)	(D	0.28					0.2818529				0.25	.28	
Bypass ratio			4,89						4,97				4,89	
Specific Fuel Comsumption (dry)		kg/N s												
Specific Fuel Comsumption (cruise)		e kg/N s	1,60E-05									0,0000159 1,60E-05	-05	
Available fuel volume	Vfuel, available	m ₃	97,53		97,53	8	97,885	98,25				97,53		139,09
Cruise speed	VcR	m/s					185,2	239,2-257,2					244,36111	241,94
Cruise altitude	hca	Ε	11887					11887,2-100 5 8,	3,4			11887		
Sweep angle	ф 25		29.7					29.7				29.7		30
Mean aerodynamic chord	OMAC	Ε	7,28					7,26				7,28		
Position of maximum camber	X(y_c),max	%с												
Camber	(yc)max/c	%c												
Position of maximum inickness Relative thickness	Xt,max 1/c	o% %	15 3-11 3-10 G									15 3-11 3-10 G		
Taper	2 ~	2	0.235					0.251				0.235		
Overall pressure ratio	OAPR		36,8						35,2				36,8	
Touching andmy do not a section	TET	¥												

Aeroplane Specifications

Available fuel volume

ı	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1750	m		
Approach speed	Known	V_{APP}	70,00	m/s	70,0	70,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s_{TOFL}	2320	m	2320	2320
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	3780	NM		
Cruise Mach number		M_{CR}	0,82			
Wing area		S_W	362	m²		
Wing span	Known	b_W	60,3	m²	60,3	60,3
Aspect ratio		Α	10,06			
Maximum take-off mass		m_{MTO}	242000	kg		
Maximum payload mass		m_PL	48400	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,200			
Maximum landing mass		m_ML	185000	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,764			
Operating empty mass		m_OE	124600	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,515			
Wing loading		m_{MTO}/S_W	669,2	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	316,267	kN		
Total take-off thrust		T _{TO}	632,534	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,266			
Bypass ratio		μ	4,89			

V_{fuel,available}

23,86 m³

Data	to	optimize	V/V_{md}
------	----	----------	------------

				LL	UL
Cruise speed		V_{CR}	242 m/s		
Cruise altitude		h _{CR}	11887 m		
Speed ratio		V/V_{md}	1,000 -	1	1,316
	Data to execu	te the verification			
				Rar	nge
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,1 %		
Taper		λ	0,24		

Reverse Engineering

Reverse	engineering	ደ	optimization	οf	V/Vmd
Me vei se	engineering	α	opullization	u	v/viiiu

Reverse engineering & optimization of V/Vmd							
	Quantity	Original value	RE value	Unit	Deviation		
Landing field length	S _{LFL}	1750	1750	m	0,00%		
Approach speed	V_{APP}	70,00	70,0	m/s	0,00%		
Take-off field length	s _{TOFL}	2320	2320	m	0,00%		
Span	b_W	60,3	60,3	m	0,00%		
Aspect ratio	Α	10,06	10,06		0,00%		
Cruise speed	V_{CR}	242,0	242	m/s	0,00%		
Cruise altitude	h_{CR}	11887	11867	m	-0,17%		
Squared Sum Absolute maximum deviation					2,97E-06 0,2%		
	Results rev	erse engineering					
Maximum lift coefficient, landing	$C_{L,max,L}$	2,73					
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,53		Porto	roo Enginoorina		
Maximum aerodynamic efficiency	E _{max}	19,19		Reve	rse Engineering		
Specific fuel consumption	SFC	1,55E-05 kg	g/N/s				

1) Maximum Lift Coefficient for Landing and Take-off

Land	ding	
Landing field length	S _{LFL}	1750 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	$1,70 \text{ (m/s}^2)^{0.5}$
Approach speed	V_{APP}	70,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,76
Wing loading at maximum take-off mass	m_{MTO}/S_W	669,2 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,73
Take	e-off	
Take-off field length	S _{TOFL}	2320 m
Temperatur above ISA (288,15K)	ΔT _{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,266
Maximum lift coefficient, take-off	C _{L,max,TO}	2,53
2nd Se	amont	
Aspect ratio	A	10,056
Lift coefficient, take-off	C _{L,TO}	1,76
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,033
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C _{D,P}	0,053
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	9,12
Number of engines	_	2
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024 0,267
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,267
Missed a		
Lift coefficient, landing	C _{L,L}	1,62
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,026
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
Lift independent drag coefficient landing sees	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C _{D,P}	0,061
Glide ratio in landing configuration	EL	9,03
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,201
	· · · · · · · · · · · · · · · · · · ·	

2) Maximum Aerodynamic Efficiency

Const	ant parameters					
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g	9,81 m/s ²				
Air pressure, ISA, standard	p_0	101325 Pa				
Oswald eff. factor, clean	е	0,85				
Sp	ecifications					
Mach number, cruise	M _{CR}	0,82				
Aspect ratio	A	10,06				
Bypass ratio	μ	4,89				
Wing loading	m _{MTO} /S _W	669 kg/m²				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,266				
Variables						
	V/V _{md}	1,0				
Calculations						
Zero-lift drag coefficient	C _{D,0}	0,018				
Lift coefficient at E _{max}	$C_{L,md}$	0,70				
Ratio, lift coefficient	C _L /C _{L,md}	1,000				
Lift coefficient, cruise	C_L	0,700				
Actual aerodynamic efficiency, cruise	E	19,19				
Max. glide ratio, cruise	E _{max}	19,19				
Newton-Raphson for the maximum lift-to-o	drag ratio					
Iterations	1	2	3			
f(x)	0,32	-0,02	0,00			
f(x)	-0,10	-0,11	-0,11			
E _{max}	16	19,39	19,19			

3) Specific Fuel Consumption

Constant par	ameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81	m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Specificat	ions		
Range	R	3780	NM
Mach number, cruise	M_{CR}	0,82	
Bypass ratio	μ	4,89	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,266	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	242000	kg
Mass ratio, landing - take-off	m_{PL}/m_{MTO}	0,200	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,515	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	19,19	
Cruise altitude	h _{CR}	11867	m
Cruise speed	V_{CR}	242	m/s
Mission fuel	fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Calculati	one		
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,285	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,715	
Available fuel mass	M _F ,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,079	
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,940	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,55E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

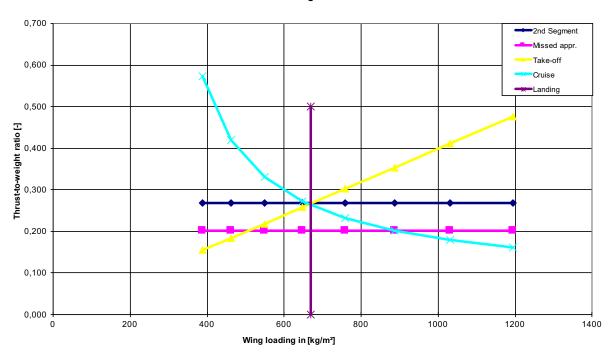
General wing specifications	Airfoil type:	N	ACA 4 digit
Wing span	b_W	60,3 n	า
Structural wing span	$b_{W,struct}$	66,53 n	า
Wing area	S_W	361,6 n	1 ²
Aspect ratio	Α	10,06	
Sweep	ϕ_{25}	25 °	
Mean aerodynamic chord	C _{MAC}	4,2 m	า
Position of maximum camber	$\mathbf{x}_{(y_{-c}), max}$	30 %	6С
Camber	(y _c) _{max} /c	4 %	6С
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %	6С
Relative thickness	t/c	11,1 %	6
Taper	λ	0,24	
General aircraft specifications			
Temperature above ISA (288,15K)	ΔT_L	0 K	
Relative density	σ	1	
Temperature, landing	T_L	273,15 K	
Density, air, landing	ρ	1,225 k	g/m³
Dynamic viscosity, air	μ	1,72E-05 k	g/m/s
Speed of sound, landing	a_{APP}	331 n	n/s
Approach speed	V_{APP}	70,00 m	n/s
Mach number, landing	M_APP	0,21	
Mach number, cruise	M_{CR}	0,82	
Calculations maximum clean lift coefficient			
Leading edge sharpness parameter	Δy	2,9 %	6С
Leading edge sweep	ϕ_{LE}	28,5 °	
Reynoldsnumber	Re	2,1E+07	
Maximum lift coefficient, base	$c_{L,max,base}$	1,55	
Correction term, camber	$\Delta_1 c_{L,max}$	0,22	
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00	
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,060	
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,825	
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80	
Correction term, Mach number	$\Delta C_{L,max}$	-0,01	
Lift coefficient, wing	C _{L,max}	1,45	

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{o}}}$	0,87
Flap group A	Ψ	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,42
Use flapped span	b_W,fA	40,1 m
Percentage of flaps allong the wing	,	60%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,74
Flap group B	z,max,,,,	
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	\DeltaC_L,max,f	0,74
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΨH.L.	32 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	10,3 m
Percentage of slats allong the wing		15%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,12
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	43,1 m
Percentage of slats allong the wing		65%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,49
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,61
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,77
RE value maximum lift coefficient, landing	2,11103,2	2,73
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,57
RE value maximum lift coefficient, take-off	L,max, r o	2,53
1%		,
Aerodynamic effic	ciency	
Real aircraft average	k _{WL}	2,83
End plate	k _{e.WL}	1,07
Span	b _W	60,3 m
Winglet height	h h	2,74 m
Aspect ratio	A	10,06
Effective aspect ratio	A _{eff}	10,71
Eliective aspect ratio	C eff	10,71
Efficiency factor, short range	k _E	16,19
Relative wetted area	S _{we} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	21,0
RE value maximum aerodynamic efficiency	∟ max	19,19
RE Value maximum aerodynamic emiciency		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,820
Cruise altitude	h _{CR}	11887 m
By Pass Ratio	μ	4,89
Take-off Thrust (one engine)	T _{TO,one engine}	316,27 kN
Overall Pressure ratio	OAPR	36,80
Turbine entry temperature	TET	1494,70
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	n _{ventilator}	0,89
Compressor efficiency	$\eta_{compresor}$	0,87
Turbine efficiency	$\eta_{ m turbine}$	0,91
Nozzle efficiency	η_{nozzle}	0,99
Temperature at SL	T_o	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T _S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,90
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,13
Temperature function	χ	2,04
Gas generator efficiency	η_{gasgen}	0,98
Gas generator function	G	2,22
Verification value specific fuel consumption	SFC	0,56 kg/daN/h
Verification value specific fuel consumption	SFC	1,57E-05 kg/N/s
RE value specific fuel consumption	SFC	1,55E-05 kg/N/s

Matching Chart



Appendix K Boeing 787-9

No.	Data Collection	ction		787-9		1	2	3	4	2	9	7	8	6	
	Darameter	Over	l laife		Son	Aircraft characteristics for airport planning	Jane's	Jenkinson	Engine	Scholz	Paul Müller∃ld	odie Roux	rta collectior	Webs	
No. 1,		0000	2	420		290-406-420	280							38	39-222
No. No.															
No. No.	Landing field length	SFL	Ε,	1870		1870									
Sel-150 Sel-150	Approach speed Temperature shows ISA (288 15K)	V _{APP}	s/w	c											
	Relative density	S	4)		>									
Second March Mar															
No. No.	Take-off field length	STOFL	Ε	3140		3020									3140
Name	Temperature above ISA (288,15K) Relative density	ΔΤτο	¥	0		0									
No. No.	(1010)	5													
Near	Range (max payload)	œ	Æ	9720		9720	15927								15750
Shape Reference Shape Reference Shape Reference Shape Reference Shape Reference Shape Reference Shape Shap	Cruise Mach number	McR		0,85		0,85	0,85						0,85		0,85
bbw min 6012 6012 6035 6035 6001 6001 6001 6001 6001 6001 6001 6001 6001 6001 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 6000 60	Wing area	S _w	m²	325											325
A A A A A A A A A A	Wing span	þw	ε	60,12		60,12	63,35						1,09		60,1
March kg 254011 254011 244960 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 65325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69325 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 69086 6908	Aspect ratio	⋖		11,1											
The continue contin	Maximum take-off mass	Мито	ķ	254011		254011	244950						253000		250836
187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187 187	Payload mass	ШРĹ	kg	65325		98099	65325								
The column Figs 192776 190960 190960 190960 190776 190960 190960 190960 190960 190960 190960 190960 190960 190960 190960 190960 190960 190960 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 19096000 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 19096000 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 1909600 19096000 1909600 1909600 1909600 1909600 1909600 1909600	Mass ratio, payload - take-off	МР∪Мито													
This control This	Maximum landing mass	m M	kg	192776		192776	190950								192777
18 18 18 18 18 18 18 18	Mass ratio, landing - take-off	MML/MMTO		0.00			0.00								
Total Secretary Total Secr	Operating empty mass Mass ratio operating empty - takes	Moe Mor Mirror	Đ	115350			Occell								
Troop Line	Wing loading	mmo/Sw	kg/m²												
Tropic manufacture Tropic	Maximum zero fuel mass	MMZF	kg	181436		181436	179625								181437
Trought House, RN Carrot Laye, RN Carrot Layer Carrot Laye				c					C				C		C
Troce	Number of engines	I C	4000	_			Coort 4000	C				(7	Tax 4074/75	7
Troil manual control of the contro	Engine type Take-off thrust for one engine	GE GENX-	1B (49%), RI	_			235-311	3 "				9	320	329 61325	320
Tro(Inturo 9) Horistians Factorial Rights F	Total take-off thrust	Tro	Z Z	3									070	050,0,050	070
Lange Lang	Thrust to weight ratio	T _{TO} /(m _{MTO} *	(a)												
Clarical SFC (Ctry) kg/N s	Bypass ratio	_		6			9,0-12,0		7				8,8	3-8,1	
VivelEnciable SFC (Crutise kgN s SFC (Crutise kgN s T26,429 T26,917 T26,917 T26,429 T26,917 T26,91	Specific Fuel Comsumption (dry)		kg/N s												
V _{Luck Devicationside States m³ 126,429 126,917 126,917 1 V_{CR} m/s 252 252,07778 25 h_{CRS} m 32,2 252,07778 25 ow.c m 32,2 25 ow.c m 32,2 25 ow.c m 25 v.c. %c v.c. <}	Specific Fuel Comsumption (cruise		e kg/N s												
V _{CR} m/s π/s 252 252,07778 25 h _{CR} m m 252,07778 252,07778 25 φ _{2S} mac m 32,2 25,07778 25 eer x _{V_C,D_Imax} %c %c 25 25,07778 25 ness x _I max %c 25 25,07778 25 ness x _I max %c 25 25 25 OAPR 55,4 46,3-55,4 25 25	Available fuel volume	Vfuel, available		126,429		126,429	126,917								138,7
hcs m	Cruise speed	V _{CR}	s/m	252									252,07778		253,61
φ ₂₅ ° 32,2 Oakc m Color Ky, c, lmax %c Color Yc, max %c Color Nc γc Color A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A B B A B B A B B A B B A <th< td=""><td>Cruise altitude</td><td>hcR</td><td>ε</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></th<>	Cruise altitude	hcR	ε												
OANC M	Sweep angle	ě		32.2											32.2
Def X _(V, C) Draw 2 % C (V _C) _{max} C % C (V _C) _{max} C % C 1 V _C max C % C (V _C) max C % C A A A A 55,4 (V _C) Max C	Mean aerodynamic chord	OAAC	Ε	7(10)											1
(Volumer	Position of maximum camber	Xiv c) max	%c												
Hess X _{Limax} %c	Camber	(yc)max/c	%c												
νς % Λ OAPR 55,4	Position of maximum thickness	X _{t,max}	%с												
A	Relative thickness	t/c	%												
OAPK 35,4	Taper	× !		i									,		
	Overall pressure ratio	OAPR		55,4									46	,3-55,4	

Aeroplane Specifications

Data to apply reverse engineering

	Data to apply r	everse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1870	m		
Approach speed	Unknown	V_{APP}	70,00	m/s	73,6	73,6
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	3140	m	3140	3140
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	5248	NM		
Cruise Mach number		M _{CR}	0,85			
Wing area		S _W	325	m²		
Wing span	Known	b_W	60,12	m²	60,12	60,12
Aspect ratio		Α	11,12			
Maximum take-off mass		m _{MTO}	254011	kg		
Maximum payload mass		m_PL	65325	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,257			
Maximum landing mass		m_{ML}	192776	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,759			
Operating empty mass		m_OE	115350	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,454			
Wing loading		m_{MTO}/S_W	781,6	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	330	kN		
Total take-off thrust		T _{TO}	660	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,265			
Bypass ratio		μ	9			
Available fuel volume		V _{fuel,available}	23,86	m³		

	Data to o	ptimize V/V _{md}				
					LL	UL
Cruise speed		V_{CR}	252	m/s		
Cruise altitude		h_{CR}	10668	m		
Speed ratio		V/V_{md}	1,086	-	1	1,316
	Data to execu	te the verification				
					Rar	nge
Sweep angle		ϕ_{25}	25	0		
Mean aerodynamic chord		C _{MAC}	4,2	m		
Position of maximum camber		X _{(y_c),max}	30	%с	15 - 50	%с
Camber		(y _c) _{max} /c	4	%с	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	10,6	%		
Taper		λ	0,24			

Reverse Engineering

Reverse engineering &	coptimization of V/Vmd
-----------------------	------------------------

	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1870	1870	m	0,00%
Approach speed	V_{APP}	Unknown	73,6	m/s	0,00%
Take-off field length	s _{TOFL}	3140	3140	m	0,00%
Span	b_W	60,12	60,12	m	0,00%
Aspect ratio	Α	11,12	11,12		0,00%
Cruise speed	V_{CR}	252,0	252	m/s	0,04%
Cruise altitude	h_{CR}	10668	10669	m	0,01%
Squared Sum					1,40E-07
Absolute maximum deviation					0,0%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,96			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,20		Povor	se Engineering
Maximum aerodynamic efficiency	E _{max}	20,08		- Nevel	Se Engineening
Specific fuel consumption	SFC	1,23E-05 kg	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Li	anding	
Landing field length	S _{LFL}	1870 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	1,70 (m/s²) 0.
Approach speed	V_{APP}	73,59 m/s
Factor, landing	${f k}_{f L}$	0,107 kg/m³
Mass ratio, landing - take-off	${\sf m_{ML}/m_{TO}}$	0,76
Wing loading at maximum take-off mass	m_{MTO}/S_W	781,6 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,96
T	ake-off	
Take-off field length	S _{TOFL}	3140 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,265
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,20
2nd	Segment	
Aspect ratio	A	11,121
Lift coefficient, take-off	$C_{L,TO}$	1,53
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,021
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,041
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	11,17
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,227
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,75
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,033
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C_D,P	0,068
Glide ratio in landing configuration	EL	9,06
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,199

2) Maximum Aerodynamic Efficiency

Cons	stant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
s	pecifications		
Mach number, cruise	M _{CR}	0,85	
Aspect ratio	Α	11,12	
Bypass ratio	μ	9,00	
Wing loading	m_{MTO}/S_W	782 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,265	
	Variables		
	V/V _{md}	1,1	_
	Calculations		
Zero-lift drag coefficient	$C_{D,0}$	0,018	
Lift coefficient at E _{max}	$C_{L,md}$	0,74	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,848	
Lift coefficient, cruise	C_L	0,627	
Actual aerodynamic efficiency, cruise	E	19,81	
Max. glide ratio, cruise	E _{max}	20,08	
Newton-Raphson for the maximum lift-to	o-drag ratio		
Iterations	1	2	3
f(x)	0,37	-0,03	0,00
f'(x)	-0,08	-0,10	-0,10
E _{max}	16	20,39	20,08

3) Specific Fuel Consumption

Ratio of specific heats, air	t parameters	1,4	
Earth acceleration	γ g	•	m/s²
Air pressure, ISA, standard	p ₀	101325	
Fuel density	$ ho_{ m fuel}$		kg/m³
•			•
Spec Range	ifications R	5248	NM
Mach number, cruise	M _{CR}	0,85	INIVI
Bypass ratio	μ	9,00	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,265	
Available fuel volume	V _{fuel.available}	23,86	m³
Maximum take-off mass	m _{MTO}	254011	
Mass ratio, landing - take-off	m _{PL} m _{MTO}	0,257	3
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	0,454	
Calcula Actual aerodynamic efficiency, cruise	ated values E	19,81	
Cruise altitude	h _{CR}	10669	m
Cruise speed	V _{CR}	252	m/s
·			
Mission Type of aeroplane (according to Roskam)	fuel fraction Transport jet		
Fuel-Fraction, engine start	M _{ff,engine}	0,990	
Fuel-Fraction, taxi	M _{ff,taxi}	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
-			
Calc Mission fuel fraction (acc. to PL and OE)	culations m _F /m _{MTO}	0,289	
,	1 11110		
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,711	
Available fuel mass	M _{F,available}	19088	kg
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,075	
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,944	
Distance to alternate	S _{to alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	
Choose: FAR Part121-Reserves	domestic	no	
	international	yes	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	856365	m
Loiter time	t _{loiter}	1800	
Loiter time	Toilei		

4) Verification Specifications

Maximum lift coefficients

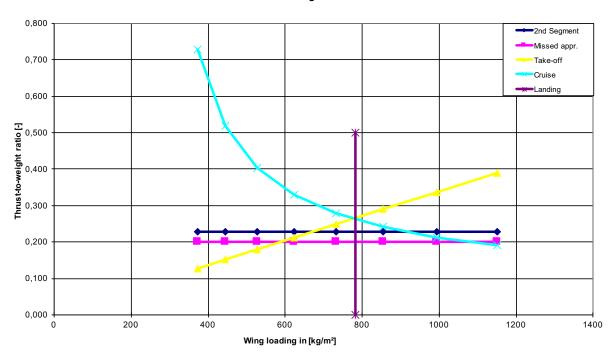
General wing specifications	Airfoil type:	NACA 4 digit
Wing span	b_W	60,12 m
Structural wing span	$b_{W,struct}$	66,34 m
Wing area	S _W	325,0 m ²
Aspect ratio	Α	11,12
Sweep	φ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	x _{(y_c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	X _{t.max}	30 %c
Relative thickness	t/c	10,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	73,59 m/s
Mach number, landing	M_APP	0,22
Mach number, cruise	M _{CR}	0,85
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,8 %c
Leading edge sweep	ϕ_{LE}	28,2 °
Reynoldsnumber	Re	2,2E+07
Maximum lift coefficient, base	C _{L,max,base}	1,52
Correction term, camber	$\Delta_1 c_{L,max}$	0,25
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,045
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,816
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	$\Delta C_{L,max}$	-0,02
Lift coefficient, wing	$C_{L,max}$	1,44

Calculations increase of lift coefficient due to flaps		1 flap type		
Correction factor, sweep	K_{ω}	0,87		
Flap group A	Ψ	-,		
0,4c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	2,01		
Use flapped span	b W,fA	40,7 m		
Percentage of flaps allong the wing	D_***,#*	61%		
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	1,07		
Flap group B	L,max,iA	•		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74		
Use flapped span	b W,fB	0 m		
Percentage of flaps allong the wing		0%		
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00		
Increase in maximum lift coefficient, flap	ΔC _{L,max,f}	1,07		
more deed in maximum interesting map	=9L,max,r	1,01		
Calculations increase of lift coefficient due to slats		2 slat types		
Sweep angle of the hinge line	Ψ _{H.L.}	34,5 °		
Slat group A				
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,89		
Use slatted span	b_W,sA	13,36 m		
Percentage of slats allong the wing		20%		
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,15		
Slat group B				
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,89		
Use slatted span	b_W,sB	40,08 m		
Percentage of slats allong the wing		60%		
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,44		
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,59		
Wing Verification value maximum lift coefficient, landing RE value maximum lift coefficient, landing Verification value maximum lift coefficient, take-off RE value maximum lift coefficient, take-off 3%	$C_{L,max,L}$ $C_{L,max,TO}$	3,04 2,96 2,26 2,20		
Aerodynamic efficiency				
Aerodynamic em	iciency			
Real aircraft average	\mathbf{k}_{WL}	2,83		
End plate (kWL = 2,13)	$k_{e,WL}$	1,41		
Span	b _W	60,12 m		
Winglet height	h	2,7 m		
Aspect ratio	A	11,12		
Effective aspect ratio	$A_{\rm eff}$	15,68		
	OII			
Efficiency factor, short range	k _E	16,19		
Relative wetted area	S_{wet}/S_W	6,35		
Verification value maximum aerodynamic efficiency	E _{max}	25,4		
RE value maximum aerodynamic efficiency	111965	20,08		
27%				

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,850
Cruise altitude	h _{CR}	10668 m
By Pass Ratio	μ	9,00
Take-off Thrust (one engine)	T _{TO,one engine}	330,00 kN
Overall Pressure ratio	OAPR	55,40
Turbine entry temperature	TET	1495,76
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,93
Ventilator efficiency	$\eta_{ m ventilator}$	0,90
Compressor efficiency	$\eta_{compresor}$	0,88
Turbine efficiency	η _{turbine}	0,91
Nozzle efficiency	η_{nozzle}	0,99
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	218,81 K
Dimensionless turbine entry temperature	ф	6,84
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,14
Temperature function	χ	2,46
Gas generator efficiency	η _{gasgen}	0,97
Gas generator function	G	1,94
Verification value specific fuel consumption	SFC	0,54 kg/daN/h
Verification value specific fuel consumption	SFC	1,50E-05 kg/N/s
RE value specific fuel consumption	SFC	1,23E-05 kg/N/s
21%		

Matching Chart



Appendix L Airbus A350-900

ength ed above ISA (288,15K) ity ity supposed is above ISA (288,15K) ity supposed is above ISA (288,15K) ity supposed is above ISA (288,15K) pumber supposed is above ISA (288,15K) pumber profit mass supposed is above ISA (288,15K) pty mass serating empty - take-off pty mass	Units	$\overline{}$	_							
off		Chosen value	SOUICE: Aircraft characteristics for airport planning WV000 WV022	Jane's Jenkinson	nson Engine	Scholz	Paul Müller		Elodie Roux Data collection	Webs
off		315	315					314		
off	Ε	1960	1960						ď	
off	s/m	72	72						79.738889	
off	×	0	0							
July 1										
JJ0	E	2830	2830							
JJ.	×	0	0							
Range (max payload) Cruise Mach number Wing area Wing span Aspect ratio Maximum take-off mass Mass ratio, payload - take-off Mass ratio, landing take-off Mass ratio, landing take-off Mass ratio, landing take-off Mass ratio, landing take-off Mass ratio, payload - take-off Mass ratio, landing take-off Mass ratio, percenting empty take-off Mass ratio, operating empty take-off										
Cruise Mach number More Wing area Sw. Wing span bw. Aspect ratio Bw. Maximum take-off mass me. Payload mass me. Mass ratio, payload - take-off me. Mass ratio, landing take-off me.	Æ	10000	10800	15000				8900		15000
Wing area Sw. Wing span bw. Appect ratio A A Maximum take-off mass me. Payload mass me. Mass ratio, payload - take-off me. Mass ratio, palding - take-off me. Mass ratio, and grass me.		0,85		0,85				0,85	0,85	0,85
Wing span Aspect ratio A Amazimum take-off mass Maximum take-off mass Maximum landing mass matic, payload - take-off mass ratio, landing - take-off Maximum landing mass Mass ratio, landing - take-off Maximum landing - take-off - take-	Ę	443		443				443		443
Aspect ratio Maximum take-off mass Payload mass Mass ratio, payload-take-off Maximum landing mass Mass ratio, landing - take-off Maximum landing - take-off Maximum landing - take-off Mass ratio, operating empty mass Mass ratio, operating empty - take-off Mass ratio, operating empty - take-	Ε	64,75	64,75	64				64	64,75	64,75
Maximum take-off mass mmro Payload mass me. Mass ratio, payload - take-off me. Maximum landing mass mm. Mass ratio, landing - take-off mm. Mass ratio, landing - take-off moe. Mass ratio, operating empty mass moe. Mass ratio, operating empty take-off moe.		9,25						9,25		
Payload mass met. Mass ratio, payload - take-off met.man. Maximum landing mass mm. Mass ratio, landing - take-off mm. Mass ratio, landing - take-off moe. Mass ratio, operating empty - take-off moe. Mass ratio, operating empty - take-off moe.	2	265000	268000 280000	265000				265000	268000	280000
Mass ratio, payload - take-off me_man Maximum landing mass ma. Mass ratio, landing - take-off me_m Operating empty mass moe Mass ratio, operating empty - take-off moe Mass ratio, operating empty - take-off moe	<u> </u>	49800						49800		
Maximum landing mass m _{ML} Mass ratio, landing - take-off m _{ML} m _{MD} Operating empty mass moe Mass ratio, operating empty - take-off moe								0,188		
Mass ratio, landing - take-off m _{Mu} Lm _{MTO} Operating empty mass m _{OE} Mass ratio, operating empty - take-off m _{OE} m _{MTO}	kg	202500	205000	202500				202500		207000
Operating empty mass moe Mass ratio, operating empty - take-off moemuro	\neg									
Mass ratio, operating empty - take-off moerming	kg	130700						130700		115/00
	0 ka/m²	208		598.2				0,493		
Maximum zero fuel mass		189500	192000	189500				180500		195700
	P									
ngines		2		2		2		2		2
	t XWB	Trent XWB-83		RR Trent XWB-74/-83/-92	Trent 1000	0		GEnx 1A72	Trent XW	
ne engine	gine KN	369		329/369/409	235,7558	80		320	374	374
	Z (C						0		
Finds to weight ratio 170/(IIMTO 9)	(6 o	0,23			0,10	0 00		0,2,0		
Specific Fuel Comsumption (drv) SFC (drv)	v) kg/N s	2			2			Ď.		
(eg	SFC (cruise kg/N s									
Available fuel volume	ble m³	138	138	138				150		141
Cruise sneed		250.5							250.53444	250.83
0	Ε	13100						13100		
		20		30				c		
	-	co i		Co				07		
	E	8,35						8,35		14
or maximum camber	T	5 5								5 5
Camber (yc)haw/C	o%	8, 0								8, C
Relative thickness	%	3 5								15
	!	0,113						0,113		
l pressure ratio										
Turbine entry temperature	¥									

Aeroplane Specifications

D	ata to apply	reverse engineering				
					LL	UL
Landing field length	Known	S _{LFL}	1960			
Approach speed	Known	V_{APP}	72,00		72,0	72,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	2830	m	2830	2830
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	5400	NM		
Cruise Mach number		M _{CR}	0,85			
Wing area		S_W	443	m²		
Wing span	Known	b_W	64,75	m²	64,75	64,75
Aspect ratio		Α	9,46			
Maximum take-off mass		m _{MTO}	265000	kg		
Maximum payload mass		m_{PL}	49800	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,188			
Maximum landing mass		m_{ML}	207000	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,781			
Operating empty mass		m_OE	130700	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,493			
Wing loading		m_{MTO}/S_W	598,2	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	369	kN		
Total take-off thrust		T _{TO}	738	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,284			
Bypass ratio		μ	8,9			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to	optimize	V/V_{md}
------	----	----------	------------

		LL	UL
V_{CR}	251 m/s		
h_{CR}	11887 m		
V/V_{md}	1,000 -	1	1,316
to execute the verification	n		
		Rar	ige
ϕ_{25}	35 °		
C _{MAC}	8,35 m		
X _{(y c),max}	30 %c	15 - 50	%с
$(y_c)_{max}/c$	4 %c	2 - 6	%с
$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
ıknown t/c	10,6 %		
λ	0,113		
	$\begin{array}{c} h_{CR} \\ V/V_{md} \\ \\ \hline \textbf{to execute the verificatio} \\ \\ \phi_{25} \\ c_{MAC} \\ x_{(y_c),max} \\ (y_c)_{max}/c \\ x_{t,max} \\ \\ \textbf{known} \end{array}$	h _{CR} 11887 m V/V _{md} 1,000 - to execute the verification φ ₂₅ 35 ° c _{MAC} 8,35 m x _{(y_c),max} 30 %c (y _c) _{max} /c 4 %c x _{t,max} 30 %c known t/c 10,6 %	$\begin{array}{cccccccccccccccccccccccccccccccccccc$

Reverse Engineering

Reverse engineering & optimization of V/Vmd

Kevel	se engineering	a optimization of v	villa		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1960	1960	m	0,00%
Approach speed	V_{APP}	72,00	72,0	m/s	o,o d %
Take-off field length	s _{TOFL}	2830	2830	m	0,00%
Span	b_W	64,75	64,75	m	0,00%
Aspect ratio	Α	9,46	9,46		0,00%
Cruise speed	V_{CR}	250,5	251	m/s	0,14%
Cruise altitude	h_{CR}	11887	11795	m	-0,77%
Squared Sum Absolute maximum deviation					6,14E-05 0,8%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,23			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,74		D	F !!-
Maximum aerodynamic efficiency	E _{max}	22,02		Reve	rse Engineering
Specific fuel consumption	SFC	1,54E-05 kg/	N/s		

1) Maximum Lift Coefficient for Landing and Take-off

	anding	
Landing field length	s_{LFL}	1960 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_APP	1,70 (m/s²) ^{0.8}
Approach speed	V_{APP}	72,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,78
Wing loading at maximum take-off mass	m_{MTO}/S_W	598,2 kg/m ²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,23
T	ake-off	
Take-off field length	S _{TOFL}	2830 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,284
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,74
2nd	Segment	
Aspect ratio	A	9,464
Lift coefficient, take-off	$C_{L,TO}$	1,21
ift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,005
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C_D,P	0,025
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	12,62
Number of engines	n_{E}	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,206
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,32
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,011
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Profile drag coefficient	C_D,P	0,046
Glide ratio in landing configuration	EL	10,19
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,186

2) Maximum Aerodynamic Efficiency

ant parameters		
γ	1,4	
g	9,81 m/s ²	
p_0	101325 Pa	
е	0,85	
ecifications		
M _{CR}	0,85	
Α	9,46	
μ	8,90	
m_{MTO}/S_W	598 kg/m²	
$T_{TO}/(m_{MTO}^*g)$	0,284	
Variables		
V/V_{md}	1,0	
alculations		
C _{D,0}	0,013	
$C_{L,md}$	0,57	
	1,000	
	0,574	
E	22,02	
E _{max}	22,02	
drag ratio		
1	2	3
0,52	-0,07	0,00
	0.10	-0,10
-0,08	-0,10	-0,10
	γ g p ₀ e ecifications M _{CR} A μ m _{MTO} /S _W T _{TO} /(m _{MTO} *g) Variables V/V _{md} alculations C _{D,0} C _{L,md} C _L /C _{L,md} C _L E E E _{max} drag ratio 1 0,52	7 1,4 g 9,81 m/s² p₀ 101325 Pa e 0,85 ecifications M _{CR} 0,85 A 9,46 μ 8,90 m _{MTO} /S _W 598 kg/m² T _{TO} /(m _{MTO} *g) 0,284 Variables V/V _{md} 1,0 alculations C _{D,0} 0,57 C _L /C _{L,md} 0,57 C _L /C _{L,md} 1,000 C _L 0,574 E 22,02 E _{max} 22,02 drag ratio 1 2 0,52 -0,07

3) Specific Fuel Consumption

	nt parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	Pfuel	800	kg/m³
-	cifications		
Range	R	5400	
Mach number, cruise	M _{CR}	0,85	
Bypass ratio	μ	8,90	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,284	
Available fuel volume	$V_{fuel,available}$	23,86	
Maximum take-off mass	m_{MTO}	265000	•
Mass ratio, landing - take-off	m_PLm_MTO	0,188	
Mass ratio, operating empty - take-off	$m_{OE/}m_{MTO}$	0,493	
Calcul	ated values		
Actual aerodynamic efficiency, cruise	E	22,02	
Cruise altitude	h_{CR}	11795	m
Cruise speed	V_{CR}	251	m/s
Mission	fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{\sf ff,CLB}$	0,980	
Fuel-Fraction, descent	$M_{\sf ff,DES}$	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
Cale	culations		
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,319	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,681	
Available fuel mass	MF.available	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,072	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,947	
Distance to alternate	Succession	200	NM
Distance to alternate	S _{to_alternate}	370400	
Choose: FAR Part121-Reserves	s _{to_alternate} domestic	370400 no	***
5115556. 1711(1 ditti2 1-116561165	international	yes	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	870440	m
Loiter time	t _{loiter}	1800	s
			kg/N/s

4) Verification Specifications

Maximum lift coefficients

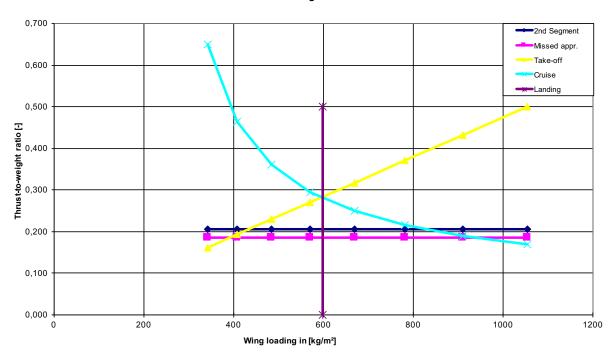
General wing specifications	Airfoil type:	NACA 64 series
Wing span	b_W	64,75 m
Structural wing span	$b_{W,struct}$	79,05 m
Wing area	S_W	443,0 m ²
Aspect ratio	Α	9,46
Sweep	φ_{25}	35 °
Mean aerodynamic chord	C _{MAC}	8,35 m
Position of maximum camber	x _{(y_c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t.max}$	30 %c
Relative thickness	t/c	10,6 %
Taper	λ	0,113
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	72,00 m/s
Mach number, landing	M_{APP}	0,22
Mach number, cruise	M_{CR}	0,85
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,3 %c
Leading edge sweep	ϕ_{LE}	39,8 °
Reynoldsnumber	Re	4,3E+07
Maximum lift coefficient, base	C _{L.max,base}	1,33
Correction term, camber	$\Delta_1 c_{L,max}$	0,39
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,028
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,749
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	ΔC _{L,max}	-0,01
Lift coefficient, wing	C _{L,max}	1,39

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,81
Flap group A	•	
Single-slotted flap	$\Delta c_{L,max,fA}$	0,74
Use flapped span	b_W,fA	15,2 m
Percentage of flaps allong the wing		19%
Increase in maximum lift coefficient, flap group A	\DeltaC_L,max,fA	0,12
Flap group B	•-	0.74
Single-slotted flap	ΔC _{L,max,fB}	0,74
Use flapped span Percentage of flaps allong the wing	b_W,fB	22,9 m 29%
Increase in maximum lift coefficient, flap group B	۸۲. –	0,18
Increase in maximum lift coefficient, flap	ΔC _{L,max,fB}	0,29
increase in maximum int coemcient, nap	$\Delta C_{L,max,f}$	0,29
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΨH.L.	36 °
Slat group A		
0,3c Nose flap	ΔC _{L,max,sA}	0,86
Use slatted span	b_W,sA	14,2 m 18%
Percentage of slats allong the wing Increase in maximum lift coefficient, slat group A	۸۵	0,12
Slat group B	$\DeltaC_{\!L,max,sA}$	0,12
0,3c Nose flap	Δc _{L.max.SB}	0,86
Use slatted span	b W,sB	39,5 m
Percentage of slats allong the wing	5_11,55	50%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,35
Increase in maximum lift coefficient, slat	ΔC _{L,max,s}	0,47
Wing	0	0.44
Verification value maximum lift coefficient, landing RE value maximum lift coefficient, landing	$C_{L,max,L}$	2,14 2,23
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,67
RE value maximum lift coefficient, take-off	OL,max,TO	1,74
-4%		1,17
Aerodynamic effici	ency	
Real aircraft average	k_{WL}	2,83
End plate (kWL = 2,13)	k _{e,WL}	1,41
Span	b _W	64,75 m
Winglet height	h	2,43 m
Aspect ratio	Α	9,46
Effective aspect ratio	A_{eff}	13,34
F.G. is a sufficient of the state of the sta	L	40.40
Efficiency factor, short range	k _E	16,19
Relative wetted area	S_{we}/S_W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	23,5
RE value maximum aerodynamic efficiency	TIMA	22,02
7%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,850
Cruise altitude	h _{CR}	11887 m
By Pass Ratio	μ	8,90
Take-off Thrust (one engine)	T _{TO,one engine}	369,00 kN
Overall Pressure ratio	OAPR	31,36
Turbine entry temperature	TET	1498,32
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,93
Ventilator efficiency	η _{ventilator}	0,90
Compressor efficiency	$\eta_{compresor}$	0,88
Turbine efficiency	$\eta_{ m turbine}$	0,91
Nozzle efficiency	η_{nozzle}	0,99
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T _S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,92
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,14
Temperature function	χ	1,92
Gas generator efficiency	η_{gasgen}	0,97
Gas generator function	G	2,31
Verification value specific fuel consumption	SFC	0,56 kg/daN/h
Verification value specific fuel consumption	SFC	1,54E-05 kg/N/s
RE value specific fuel consumption 0%	SFC	1,54E-05 kg/N/s

Matching Chart



Appendix M Airbus A330-200

Parameter Sym Landing field length 8.F.L. Approach speed V _{APP} Temperature above ISA (288,15K) ∆T _L Relative density \$ Take-off field length \$\text{Srort} Temperature above ISA (288,15K) ∆Tro Relative density \$ Range (max payload) R	logu		Source:		mort planning				_				Wohe
ing field length acach speed perature above ISA (288,15K) roff field length perature above ISA (288,15K) tive density tive density tive density perature above ISA (288,15K)		- In its	Cilor accedo	Aircraft characteristicsfor air	WAY062	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Paul Müller Elodie Roux Data collection	Data collectior	VVEDS
		SILO	375	247	700.44	375-379	380-293-253				375-253		
				!									
		ε	1750	1740	1750	1722 1753					1750	1800	
		m/s	02	02		_ !	69,45					72,02	
5A (288,15K)		~	0	0		15	0						
5A (288,15K)													
3A (288,15K)		5	2500	2740	3660	2530 2652	2 2470				2470	2300	2220
		~	0	0		2							
		E S	7400	8500		12315	7627				7400		13450
			0,82			0.82	5	0.82	22		0.82	0.81	0.82
		m²	361,6			361,6	363,1				363,1		361,6
Wing span bw		Ε	60,3	60,3		63,68	28				60,3	60,3	60,3
Aspect ratio A			10,01				9,26466538				10,02		
Maximum take-off mass		9	242000	230000	242000	230000	230000				230000	230000	242000
		ę p	47400	45300							49052		36400
load - take-off	Мито						0,15826087				0,213		
		kg	180000	180000	182000	180000 182000	L				180000		182000
g-off	Мито						0,77						
		kg	120600			120600	120200				120948		120000
Mass ratio, operating empty - take-off moe/mmro											0,526		
	m _{MTo} /S _W k	kg/m²	633			633,4 644,4	633				633		
Maximum zero fuel mass m _{MZF}		kg	168000	168000	170000	168000 170000	0 165142				170000		170000
			•				C				C	C	C
ngines	7000		2 4022	1100	Ť	00 000000000000000000000000000000000000	2				2	7	7
	CF6 (29%	PW4000	1 rent / /2B-60	KK I KEN I 700 Series	T	K-K Irent //2-60///2B-60A	CF6-80E1A4	=	0 9			CF6-80E	CCC
ne engine	ane engine	2 3	316,279			316		297,452605 316,26858	20		797,451	306	320
Total take-oil tritust Thoust to weight ratio	(m, m,	N.	0.28				0.27478615	0	œ		0.26		
	(6)		4.89					5 4.89	6.00		2,5		
Comsumption (dry)	SFC (dry)	kg/N s					3	9,5654E-06			0,00000957		
(e)	SFC (cruise kg/N s	kg/N s	1,60E-05					1,60E-05	35				
Available fuel volume V _{fuel}	V _{fuel,} available	m³	139,09	139,09		139,09	139,09				139,09		139,09
Cruise speed		m/s	241,79			185,2	241,8					241,79	241,94
6		ε	11887				11887,2	10668	98		11887		
Sweep angle		0	29.7				29.7				29.7		30
namic chord	,	Ε	7.28				7.26				7.28		
per	max	%c											
		%c											
um thickness		0											
re thickness		%	15,3-11,3-10,6								15,3-11,3-10,6		
			0,235				0,251				0,235		
Overall pressure ratio OAF	OAPR		36,8					33,7 36,8	œ,				

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_LFL	1750	m		
Approach speed	Known	V_{APP}	70,00	m/s	70,0	70,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	S _{TOFL}	2500	m	2500	2500
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	3996	NM		
Cruise Mach number		M _{CR}	0,82			
Wing area		S_W	362	m²		
Wing span	Known	b_W	60,3	m²	60,3	60,3
Aspect ratio		Α	10,06			
Maximum take-off mass		m_{MTO}	242000	kg		
Maximum payload mass		m_PL	47400	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,196			
Maximum landing mass		m_ML	180000	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,744			
Operating empty mass		m_OE	120600	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,498			
Wing loading		m_{MTO}/S_W	669,2	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	316,279	kN		
Total take-off thrust		T _{TO}	632,558	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,266			
Bypass ratio		μ	4,89			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data to optimize V/V,	md
-----------------------	----

	Data to 0	Pulling V V md			
				LL	UL
Cruise speed		V_{CR}	242 m/s		
Cruise altitude		h_{CR}	11887 m		
Speed ratio		V/V_{md}	1,000 -	1	1,316
	Data to execu	ite the verification			
				Ran	ige
Sweep angle		ϕ_{25}	29,7 °		
Mean aerodynamic chord		C _{MAC}	7,28 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,1 %		
Taper		λ	0,235		

Reverse Engineering

Reverse engineering & optimization of V/Vr

Deviation
_ = = = = = = = = = = = = = = = = = = =
0,00%
¢,00%
0,00%
¢,00%
0,00%
0,09%
<mark>-0</mark> ,17%
3,66E-06 0,2%
worse Engineering
everse Engineering

1) Maximum Lift Coefficient for Landing and Take-off

Land	ling		
Landing field length	S _{LFL}	1750	m
Temperature above ISA (288,15K)	ΔT_L	0	K
Relative density	σ	1,000	
Factor, approach	k _{APP}	1,70	(m/s²) ^{0.5}
Approach speed	V_{APP}	70,00	m/s
Factor, landing	\mathbf{k}_{L}	0,107	kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,74	
Wing loading at maximum take-off mass	m_{MTO}/S_W	669,2	kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,66	
Take	-off		
Take-off field length	S _{TOFL}	2500	m
Temperatur above ISA (288,15K)	ΔT_{TO}		K
Relative density	σ	1,00	
Factor	k _{TO}	2,34	m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,266	
Maximum lift coefficient, take-off	C _{L,max,TO}	2,35	
2nd Se	ament		
Aspect ratio	A	10,056	
Lift coefficient, take-off	$C_{L,TO}$	1,63	
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020	
Lift-independent drag coefficient, flaps	$\Delta C_{D, flap}$	0,027	
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000	
Profile drag coefficient	C _{D.P}	0,047	
Oswald efficiency factor; landing configuration	e	0,7	
Glide ratio in take-off configuration	E _{TO}	9,77	
Number of engines	n-	2	
Climb gradient	n _E sin(γ)	0,024	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,024	
This set to Worght Land	10/(0,200	
Missed a		4 ==	
Lift coefficient, landing	C _{L,L}	1,57	
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020	
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,024	
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000	
Choose: Certification basis	JAR-25 resp. CS-25	no	
Lift-independent drag coefficient, landing gear	FAR Part 25	yes 0,015	
Profile drag coefficient	$\Delta C_{D,gear}$	0,015	
Glide ratio in landing configuration	C _{D,P}		
Glide Tatio III fariding configuration	EL	9,22	
Climb gradient	sin(γ)	0,021	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,193	

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,82	
Aspect ratio	A	10,06	
Bypass ratio	μ	4,89	
Wing loading	m_{MTO}/S_W	669 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,266	
,	Variables		
	V/V _{md}	1,0	
C	alculations		
Zero-lift drag coefficient	C _{D,0}	0,018	
Lift coefficient at E _{max}	$C_{L,md}$	0,70	
Ratio, lift coefficient	C _L /C _{L,md}	1,000	
Lift coefficient, cruise	C_L	0,700	
Actual aerodynamic efficiency, cruise	E	19,19	
Max. glide ratio, cruise	E _{max}	19,19	
Newton-Raphson for the maximum lift-to-o	drag ratio		
Iterations	1	2	3
f(x)	0,32	-0,02	0,00
f'(x)	-0,10	-0,11	-0,11
E _{max}	16	19,39	19,19

3) Specific Fuel Consumption

Consta	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81	
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Spe	ecifications		
Range	R	3996	NM
Mach number, cruise	M _{CR}	0,82	
Bypass ratio	μ	4,89	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,266	
Available fuel volume	$V_{fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	242000	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,196	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,498	
Calcu	ulated values		
Actual aerodynamic efficiency, cruise	Е	19,19	
Cruise altitude	h _{CR}	11867	m
Cruise speed	V_{CR}	242	m/s
Missio	n fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	$M_{\sf ff,DES}$	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Ca	lculations		
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,306	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,694	
Available fuel mass	mF.available	19088	ka
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,079	9
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,940	
isinosion tuoi naotion (acc. to tuoi capacity)	™ff	0,540	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,64E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

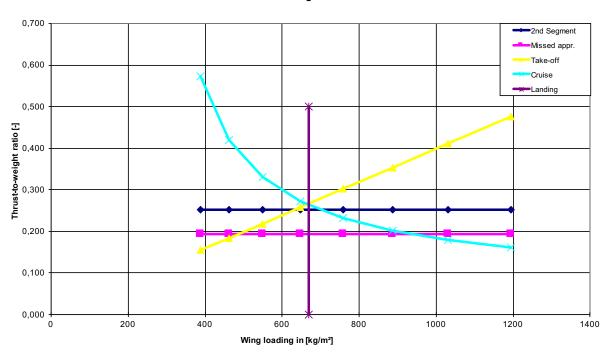
General wing specifications	Airfoil type:		NACA 4 digit
Wing span	b_W	60,3	m
Structural wing span	$b_{W,struct}$	69,42	m
Wing area	S_W	361,6	m²
Aspect ratio	Α	10,06	
Sweep	φ_{25}	29,7	•
Mean aerodynamic chord	C _{MAC}	7,28	m
Position of maximum camber	$\mathbf{x}_{(y_{-c}), max}$	30	%с
Camber	(y _c) _{max} /c	4	%с
Position of maximum thickness	$\mathbf{x}_{t,max}$	30	%с
Relative thickness	t/c	11,1	%
Taper	λ	0,235	
General aircraft specifications			
Temperature above ISA (288,15K)	ΔT_L	0	K
Relative density	σ	1	
Temperature, landing	T_L	273,15	K
Density, air, landing	ρ	1,225	kg/m³
Dynamic viscosity, air	μ	1,72E-05	kg/m/s
Speed of sound, landing	a_{APP}	331	m/s
Approach speed	V_{APP}	70,00	m/s
Mach number, landing	M_{APP}	0,21	
Mach number, cruise	M _{CR}	0,82	
Calculations maximum clean lift coefficient			
Leading edge sharpness parameter	Δy	2,9	%с
Leading edge sweep	ϕ_{LE}	33,2	•
Reynoldsnumber	Re	3,6E+07	
Maximum lift coefficient, base	$\mathbf{c}_{L,max,base}$	1,55	
Correction term, camber	$\Delta_1 c_{L,max}$	0,22	
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00	
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,080	
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,845	
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,78	
Correction term, Mach number	$\Delta C_{L,max}$	-0,01	
Lift coefficient, wing	C _{L,max}	1,42	

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{o}}}$	0,85
Flap group A		
Double-slotted flap	$\Delta c_{L,max,fA}$	1,40
Use flapped span	b_W,fA	40,1 m
Percentage of flaps allong the wing		58%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,68
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,73
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{\!L,max,f}$	0,68
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΨH.L.	32 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,88
Use slatted span	b_W,sA	10,3 m
Percentage of slats allong the wing	_ ′	15%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,11
Slat group B	_,,	
0,3c Nose flap	Δc _{L.max.SB}	0,88
Use slatted span	b_W,sB	43,1 m
Percentage of slats allong the wing		62%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,46
Increase in maximum lift coefficient, slat	ΔC _{L,max,s}	0,58
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,65
RE value maximum lift coefficient, landing		2,66
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,34
RE value maximum lift coefficient, take-off		2,35
0%		
Aerodynamic eff	ficiency	
Aerouynamic en	liciency	
Real aircraft average	k_{WL}	2,83
End plate	$k_{e,WL}$	1,07
Span	b_W	60,3 m
Winglet height	h	2,74 m
Aspect ratio	Α	10,06
Effective aspect ratio	$A_{ m eff}$	10,71
Efficiency factor, short range	k _E	16,19
Relative wetted area	S_{wet}/S_{W}	6,35
Verification value maximum aerodynamic efficiency	E _{max}	21,0
RE value maximum aerodynamic efficiency	-max	19,19
·		
10%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,820
Cruise altitude	h _{CR}	11887 m
By Pass Ratio	μ	4,89
Take-off Thrust (one engine)	T _{TO,one engine}	316,28 kN
Overall Pressure ratio	OAPR	36,80
Turbine entry temperature	TET	1494,71
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	$\eta_{ventilator}$	0,89
Compressor efficiency	$\eta_{compresor}$	0,87
Turbine efficiency	$\eta_{ ext{turbine}}$	0,91
Nozzle efficiency	η_{nozzle}	0,99
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,90
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,13
Temperature function	χ	2,04
Gas generator efficiency	η_{gasgen}	0,98
Gas generator function	G	2,22
Verification value specific fuel consumption	SFC	0,56 kg/daN/h
Verification value specific fuel consumption	SFC	1,57E-05 kg/N/s
RE value specific fuel consumption -4%	SFC	1,64E-05 kg/N/s

Matching Chart



Appendix N Embraer 190

1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,000 1,00	Data Collection	tion		Embraer 190			-			2		က	4	2	e	7	80	6
Parameter Simple Unite Control Contr					Source:	Aircraft cha	wacteristics for airport plan	ming		Jane's		lonkingo	Giodi		Jour Millor		Data collection	Moh
1 1 1 1 1 1 1 1 1 1	Parameter	Symbol	Units	Chosen value		STD	LR			Long-Range		Delikilisoli	eligiia		ani Miliei		Data collection	MADS
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,	PAX			106			106									104-94		
Part	Landina field lenath	o o	Ε	1323			1250			1392						1323	1286	
1,	Approach speed	V _{APP}	s/m															
1, 10, 10, 10, 10, 10, 10, 10, 10, 10,	Temperature above ISA (288,15K)	ΔT _L	ᅩ	0			0											
No. Color	Relative density	s																
No.	Take-off field length	STOFL	ε	2076		2000	2200	2300		2107						2076	1190	
1	Temperature above ISA (288,15K)	ΔΤτο	×	0														
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,	Relative density	s																
National Part National Par	Range (max payload)	œ	k	1852		1852	2778	3333,6			4259					1926		4260
Systate Syst	Cruise Mach number	McR		0,78			0,78			0,82						0,78	0,82	
No. 1	Wind area	ď	m ₂	92.53			92.5			92.53						92.5		
A B B B B B B B B B	Wing span	à	: E	28.72			28.72			28,72						28.72	33.7	28.72
Marco Marc	Aspect ratio	4		8,92			8,1									8,92		
The color of the	Maximum take off mass	É	5	21800		47790	50300	51800	47790	50300	51800					47790	56400	5180
The manage	Payload mass	E E	. ā	12900		1290		13000		13530						12900		5
The control bit The contro	Mass ratio, payload - take-off	МР∪Мито	,													0,27		
	Maximum landing mass	m _{ML}		43000		4300	0	44000	4300	0	44000					43000		
1	Mass ratio, landing - take-off	тми/тито																
Class Application Class Application Class Class Application Class Class Application Appl	Operating empty mass	MoE		27900			27900		2808	0	28180					27900		28080
Public Say Kignet Single Say Single	Mass ratio, operating empty - take-of	f moe/mwro														0,584		
Transport Tran	Wing loading	m _{MTO} /S _W	kg/m²	516,5				0000	516,5		8,655					517		
Time	Maximum zero ruel mass	MMZF	ğ	40800		4080	2	40900	4080		40900					40800		
CECF34 CF34-10E5 CF34-10E5A, -10E6A, -10EAA, -10E6A, -10EAA, -10E6A, -10EAA, -10	Number of engines	=		2				2								2	2	
Troces are size NA Se 2,292	Engine type	GE CF34		CF34-10E5		-10E5A,	-10E5A1, -10E6		F34-10E, -10E	6, -10E6A1, -10E	E5, -10E5A1						90	
Tio kM Lio kM Lio		T _{TO} , one engir	e KN	82,292						6,88						82,292	85-102	82,3
Tro(Implice) 0,355 1,08E-05 0,36043215 0,361446866 0,350655726 0,35043215 0,361446866 0,350655726 0,355 1,08E-05 0,356 1,08E-05 0,361446866 0,350655726 0,356 1,08E-05		T 0	ᇫ															
Vortigie SFC (cruities kg/N s 1,08E-05	Thrust to weight ratio	Tro/(m _{MTO}	,a)	0,35					0,380749315		0,350655726					0,35		
Carulise SFC (carulise kg/N s 1,08E-02) Carulise kg/N s 1,08E-02	Bypass ratio	٦ . د د د د د د د د د د د د د د د د د د د		5												5		
Course SPC (Cruise Rg/n's No. 236 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029 16,029	Specific Fuel Comsumption (dry)	SFC (dry)	kg/N s	1,08E-05												1,08E-05		
Visit Number of the Color of the C	Specific Fuel Comsumption (cruise)	SFC (cruis	se kg/N s															
V _{CR} hrat m/s 236 10669 10668 h _{CR} h _M co _M c m 3,68 8 8 erf X _{K, C, DMAC} S _M co _M c m 3,68 8 8 less X _{K, C, DMAC} S _M co _M c m 3,68 8 8 h _C S _M co _M c	Available fuel volume	V _{fuel} , available		16,029			16,029			16,153						16,029		
hcs m 10669 10668 φsc m 3,68 9 err X _{to clumax} %c 9 less X _{tomax} %c to yc	Cruise speed	V _{CR}	m/s	236														236,1
фуз " выс т замс т п замс п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п п <t< td=""><td>Cruise altitude</td><td>hcR</td><td>Ε</td><td>10669</td><td></td><td></td><td>10668</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>	Cruise altitude	hcR	Ε	10669			10668											
er X _{V, c, c, max} %c 3,68 er X _{V, c, c, max} %c %c (V _{c, b, av} C %c No. N _c %c	Sweep angle	\$ 25	۰															
	Mean aerodynamic chord	OMAC	ε	3,68						3,68								
(Vc)hayC Vc Vc A OAPR	Position of maximum camber	X _{(y_c),max}	%c															
Hess X _{1,max} VC A OAPR	Camber	(yc)max/c	%с															
t/c λ OAPR	Position of maximum thickness	X _{t,max}	%с															
OAPR	Relative thickness	t/c	%															
2 1	Open Process and	< C																
	Overall pressure ratio	OAPR	>		1													

Aeroplane Specifications

Available fuel volume

Data to apply reverse engineering LL UL Landing field length Known 1323 m s_{LFL} Approach speed **Unknown** V_{APP} 70,00 m/s 61,9 61,9 Temperature above ISA (288,15K) 0 K ΔT_L Relative density 1 σ Take-off field length 2076 m 2076 2076 Known STOFL Temperature above ISA (288,15K) 0 K ΔT_{TO} 1,000 Relative density σ 1000 NM Range (maximum payload) R M_{CR} Cruise Mach number 0,78 Wing area S_W 93 m² 28,72 m² Wing span Known 28,72 28,72 b_W Aspect ratio Α 8,91 Maximum take-off mass **51800** kg m_{MTO} Maximum payload mass 12900 kg ${\rm m}_{\rm PL}$ Mass ratio, payload - take-off 0,249 m_{PL}/m_{MTO} Maximum landing mass 43000 kg m_{ML} Mass ratio, landing - take-off 0,830 $m_{ML}\!/m_{MTO}$ Operating empty mass m_{OE} 27900 kg Mass ratio, operating empty - take-off 0,539 m_{OE}/m_{MTO} Wing loading 559,8 kg/m² m_{MTO}/S_W Number of engines 2 n_E Take-off thrust for one engine 82,292 kN T_{TO,one engine} Total take-off thrust T_{TO} 164,584 kN Thrust to weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,324 Bypass ratio 5

V_{fuel.available}

23,86 m³

Data to optimize V/V _m	Data	to c	ptimi	ze V	/V
-----------------------------------	------	------	-------	------	----

		Ptilize trang			
				LL	UL
Cruise speed		V_{CR}	236 m/s		
Cruise altitude		h _{CR}	10669 m		
Speed ratio		V/V_{md}	1,246 -	1	1,316
	Data to execu	te the verification			
				Ran	ige
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	3,68 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,6 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimization of V/Vmd

erse engineering	a optimization of	v/vma		
Quantity	Original value	RE value	Unit	Deviation
s_{LFL}	1323	1323	m	0,00%
V_{APP}	Unknown	61,9	m/s	0,00%
s _{TOFL}	2076	2076	m	0,00%
b_W	28,72	28,72	m	0,00%
Α	8,91	8,91		0,00%
V_{CR}	236,0	231	m/s	-1,93%
h_{CR}	10669	10637	m	-0,30 <mark>%</mark>
				3,82E-04
				1,9%
Results rev	erse engineering			
$C_{L,max,L}$	3,28			
$C_{L,max,TO}$	1,95		Boyou	roo Enginooring
	14,41		Revei	rse Engineering
SFC	1,80E-05	kg/N/s		
	Quantity SLFL VAPP STOFL bW A VCR hCR Results rev CL,max,L CL,max,TO Emax	Quantity Original value SLFL 1323 VAPP Unknown STOFL 2076 bW 28,72 A 8,91 VCR 236,0 hCR 10669 Results reverse engineering CL,max,L 3,28 CL,max,TO 1,95 Emax 14,41	SLFL 1323 1323 VAPP Unknown 61,9 STOFL 2076 2076 bW 28,72 28,72 A 8,91 8,91 VCR 236,0 231 hCR 10669 10637 Results reverse engineering CL,max,L 3,28 CL,max,TO 1,95 Emax 14,41	Quantity Original value RE value Unit SLFL 1323 1323 m VAPP Unknown 61,9 m/s STOFL 2076 2076 m bW 28,72 m 28,72 m A 8,91 m/s 8,91 m/s VCR 236,0 m/s 231 m/s hCR 10669 m/s 10637 m Results reverse engineering CL,max,L CL,max,TO L,max,TO L,max,T

1) Maximum Lift Coefficient for Landing and Take-off

Land	ing	
Landing field length	S _{LFL}	1323 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	61,90 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,83
Wing loading at maximum take-off mass	m_{MTO}/S_W	559,8 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,28
Take	-off	
Take-off field length	S _{TOFL}	2076 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,324
Maximum lift coefficient, take-off	C _{L,max,TO}	1,95
0.10.		
Aspect ratio 2nd Seg	gment A	8,914
Lift coefficient, take-off	$C_{L,TO}$	1,35
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,013
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,033
Oswald efficiency factor; landing configuration	e e	0,7
Glide ratio in take-off configuration	E _{TO}	10,74
	-10	
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,234
Missed ap	oproach	
Lift coefficient, landing	C _{L,L}	1,94
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D, flap}$	0,042
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	$C_{D,P}$	0,077
Glide ratio in landing configuration	EL	7,21
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,265
	.5 (1110 5)	

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,78	
Aspect ratio	A	8,91	
Bypass ratio	μ	5,00	
Wing loading	m_{MTO}/S_W	560 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,324	
,	Variables		
	V/V _{md}	1,2	
C	alculations		
Zero-lift drag coefficient	C _{D,0}	0,029	
Lift coefficient at E _{max}	$C_{L,md}$	0,83	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,644	
Lift coefficient, cruise	C_L	0,532	
Actual aerodynamic efficiency, cruise	E	13,12	
Max. glide ratio, cruise	E _{max}	14,41	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	1	2	3
f(x)	-0,22	-0,01	0,00
f'(x)	-0,14	-0,13	-0,13
E _{max}	16	14,45	14,41

3) Specific Fuel Consumption

Consta	nt parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81	
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Spe	cifications		
Range	R	1000	NM
Mach number, cruise	M _{CR}	0,78	
Bypass ratio	μ	5,00	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,324	
Available fuel volume	$V_{fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	51800	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,249	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,539	
Calcu	lated values		
Actual aerodynamic efficiency, cruise	E	13,12	
Cruise altitude	h_{CR}	10637	m
Cruise speed	V_{CR}	231	m/s
Missior	n fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{\mathrm{ff,taxi}}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{\sf ff,CLB}$	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Cal	culations		
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,212	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,788	
Available fuel mass	F.available	19088	ka
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,368	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,644	
mission rue traction (acc. to rue capacity)	IVI f f	0,044	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,80E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

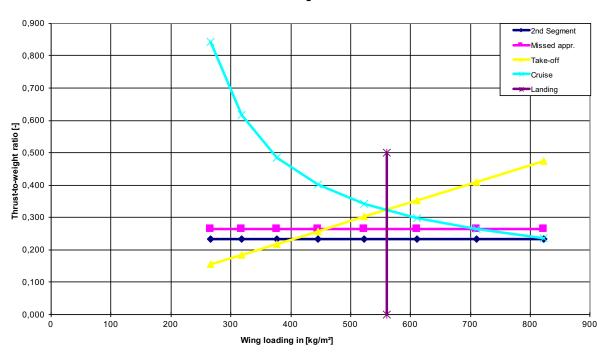
General wing specifications	Airfoil type:	NACA 65 series
Wing span	b_W	28,72 m
Structural wing span	$b_{W,struct}$	31,69 m
Wing area	S_W	92,5 m²
Aspect ratio	Α	8,91
Sweep	φ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	3,68 m
Position of maximum camber	$x_{(y_c),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t.max}$	30 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	\mathbf{a}_{APP}	331 m/s
Approach speed	V_{APP}	61,90 m/s
Mach number, landing	M_{APP}	0,19
Mach number, cruise	M_CR	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,2 %c
Leading edge sweep	ϕ_{LE}	28,9 °
Reynoldsnumber	Re	1,6E+07
Maximum lift coefficient, base	$c_{L,max,base}$	1,32
Correction term, camber	$\Delta_1 c_{L,max}$	0,40
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,015
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,726
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,85
Correction term, Mach number	ΔC _{L,max}	0,00
Lift coefficient, wing	C _{L,max}	1,46

Double-slotted flap Δc _{L,max,fA} 1,43 Use flapped span b_W,fA 8,5 m Percentage of flaps allong the wing Increase in maximum lift coefficient, flap group A ΔC _{L,max,fA} 0,33 • Flap group B Δc _{L,max,fB} 1,43 Use flapped span Percentage of flaps allong the wing Increase in maximum lift coefficient, flap group B ΔC _{L,max,fB} 0,50 Increase in maximum lift coefficient, flap ΔC _{L,max,f} 0,83
Use flapped span b_W,fA 8,5 m Percentage of flaps allong the wing 27% Increase in maximum lift coefficient, flap group A ΔCL,max,fA 0,33 • Flap group B ΔCL,max,fB 1,43 Use flapped span b_W,fB 12,8 m Percentage of flaps allong the wing 40% Increase in maximum lift coefficient, flap group B ΔCL,max,fB 0,50 Increase in maximum lift coefficient, flap ΔCL,max,f 0,83
$\begin{array}{llllllllllllllllllllllllllllllllllll$
Increase in maximum lift coefficient, flap group A $\Delta C_{L,max,fA}$ 0,33 • Flap group B Double-slotted flap Use flapped span Percentage of flaps allong the wing Increase in maximum lift coefficient, flap group B $\Delta C_{L,max,fB}$ 1,43 $\Delta C_{L,max,fB}$ 12,8 m $\Delta C_{L,max,fB}$ 0,50 Increase in maximum lift coefficient, flap group B $\Delta C_{L,max,fB}$ 0,50
• Flap group B Double-slotted flap
$\begin{array}{cccccccccccccccccccccccccccccccccccc$
$\begin{array}{cccccccccccccccccccccccccccccccccccc$
Percentage of flaps allong the wing 40% Increase in maximum lift coefficient, flap group B $\Delta C_{L,max,fB}$ 0,50 Increase in maximum lift coefficient, flap $\Delta C_{L,max,f}$ 0,83
Increase in maximum lift coefficient, flap group B $\Delta C_{L,max,fB}$ 0,50 Increase in maximum lift coefficient, flap $\Delta C_{L,max,f}$ 0,83
Increase in maximum lift coefficient, flap $\Delta C_{L,max,f}$ 0,83
O local allows have a set 100 and 60 local days to a local
Calculations increase of lift coefficient due to slats 2 slat types
Sweep angle of the hinge line $\phi_{H,L}$ 29 °
Slat group A
0,3c Nose flap $\Delta c_{L,max,sA}$ 0,90
Use slatted span b_W,sA 4,8 m
Percentage of slats allong the wing 15%
Increase in maximum lift coefficient, slat group A
Slat group B
0,3c Nose flap $\Delta c_{L,max,SB}$ 0,90
Use slatted span b_W,sB 20,1 m
Percentage of slats allong the wing 63%
Increase in maximum lift coefficient, slat group B $\Delta C_{L,max,sB}$ 0,50
Increase in maximum lift coefficient, slat $\Delta C_{L,max,s}$ 0,62
Wing Verification value requirement lift coefficient landing
Verification value maximum lift coefficient, landing C _{L,max,L} 2,87
RE value maximum lift coefficient, landing 3,28 Verification value maximum lift coefficient, take-off $C_{L,max,TO}$ 1,71
Verification value maximum lift coefficient, take-off C _{L,max,TO} 1,71 RE value maximum lift coefficient, take-off 1,95
-12%
Aerodynamic efficiency
Real aircraft average k _{WL} 2,83
-
$\begin{array}{cccccccccccccccccccccccccccccccccccc$
Winglet height h 1,59 m Aspect ratio A 8,91
Effective aspect ratio A _{eff} 9,63
Effective aspect fatio 7,03
Efficiency factor, short range k _E 15,15
Relative wetted area S _{wel} /S _W 6,35
Verification value maximum aerodynamic efficiency E _{max} 18,7
RE value maximum aerodynamic efficiency 14,41
29%

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,780
Cruise altitude	h_{CR}	10669 m
By Pass Ratio	μ	5,00
Take-off Thrust (one engine)	T _{TO,one engine}	82,29 kN
Overall Pressure ratio	OAPR	29,00
Turbine entry temperature	TET	1422,79
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	$\eta_{ m ventilator}$	0,85
Compressor efficiency	$\eta_{compresor}$	0,85
Turbine efficiency	$\eta_{ ext{turbine}}$	0,89
Nozzle efficiency	η_{nozzle}	0,98
Temperature at SL	T_o	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	218,80 K
Dimensionless turbine entry temperature	ф	6,50
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,81
Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Gas generator function	G	1,98
Verification value specific fuel consumption	SFC	0,62 kg/daN/h
Verification value specific fuel consumption	SFC	1,72E-05 kg/N/s
RE value specific fuel consumption -4%	SFC	1,80E-05 kg/N/s

Matching Chart



Appendix O Embraer 175

arameter Symbol and the property of the mass and the mass		Source:				2	က	4	2	9	7	œ	ກ
Symbol Units	en value 86		Aircraft charact	Aircraft characteristics for airport planning	uning	Jane's	lonkingon	Caipo	Cohol3	Don't Millor	Flodio Doug	oollootion	Moho
Acres March Marc	98	STD) LR	TT	AR	Standard Long-Range	Jerikiiisoii	eligile	3011015	raul Muller	raul Muller Elouie Noux Data collection	collection	Mens
According Acco			84	02	98 (78					86-78		
Name	204	-	-	1270		1300	9				1294	1350	1261
Stock Stoc	107			0.131		202					107	2	1031
Single S	0				C								
A													
Store Marco Store Marco Store Marco Say Marco			0007	1010	0000	100					7777	7070	000
re alove ISA (286,13K) relity re payload) R R R R R R R R R R R R R	41 0		000	Ocol	2300	4071					7	13/0	5744
New	5				0								
h number Sw m² Bw m² A A A A A A A A A A A A A A	815		1852 24	2400		3518	6 0				1815		4074
Sw m² bw m A A A Bw mc B	82,0				0,78	0,82					0,78		0,75
ke-off mass man kg sas sas man man man man man man	2.72			72.72		72.72					72.72		72.72
Re-off mass man with the continuous mass man with the continuous mass man will man with the continuous mass mass man with the continuous mass mass mass with the continuous mass mass mass mass mass mass mass ma	26			26		26					26	33	26
Mwro kg Mp. kg Mp. kg Mp. kg Mp. Mp. kg Mp. Mp	6,3			8,6		2					9,3	5	9,3
Mwro Kg													
The Kg	0370	33	37500 38	38790 38600	40370	37500 38790	0				37500	44800	40370
The Jumpro Marcharto Mar	0020			10201		0686					10200		10094
Troy	4100	+	34000		24400	34000					34000		24400
. take-off moem.moro . take-off moem.moro . mw.ro/S.w. kg/m² . mw.re . kg . mw.re . kg . Tro.ome.morine kN . Tro.ome.morine kN . Tro/(mw.ro²g) . u . dry) . SFC (dry) kg/N s . cruise) . SFC (cruise kg/N s . v.c. mr/s	3		7040		5	00010					00046		6
empty - take-off moerfluino ass m _{Morg} kg/m² m _{Morg} kg/m² ne n	1500		21500	0	22500	21810					21500		21810
885 m _{MZF} kg/m² ne ne GE CF34 Tro one engine Tro (Marro'9) ption (dry) SFC (dry) Vuel available Vuel available Vuel Available Vuel Available MS											0,573		
eass m _{MZF} kg ne GE CF34 GE CF34 Tro, orne engine NN Tro/(m _M rro*g) p p pu Tro/(m _M rro*g) Kg/N s reption (dry) SFC (dry) Votes Notes and the second of t	15,7					515,7 533,4	_				516		
ne GE CF34 GE CF34 Toome engine KN Tro (muro*g) μ μ μ μ μ μ μ γ μ μ γ γ γ γ γ ν ν γ ν ν ν ν	1700		31700	31510	32000	31700					31700		
GE CF34 GR CF34 KN	0										6	0	0
rengine Troomengere KN Troomengere KN Troomengere KN TrofmArro'g) p TrofmArro'g) p TrofmArro'g) p Vocationalizable m² Vocationalizable m²	24-8E2		CE34 -	- 8F5A1 - 8F5	10	CF34-8F5 -8F5A1						DW1700G	1
Tro (m.m.o*g) Tro/(m.m.o*g) proption (dry) SFC (dry) Vuel available Most miss Voes Miss	275		5	63.2		63.2					LC.	67	62.3
Tro/(muro*g) µ Tro/(muro*g) kg/N s reption (dru)s SFC (cruise kg/N s Vuel available m² Voe m/s												i	
ption (dry) SFC (dry) kg/N s reption (cruise) SFC (cruise kg/N s V _{tuel, available} m² V _{CR} m/s),34					0,343571772 0,332380509	6				0,34		
nption (dry) SFC (dry) kg/N s nption (cruise) SFC (cruise kg/N s V _{tuel,tranilable} m² V _{CR} m/S	2										2		
nption (cruise) SFC (cruise kg/N s Vool contained m³ Voor m/s	1E-05										1,11E-05		
Vuoi available m³ VcR m/s													
V _{CR} m/s	,625			11,625		11,625					11,625		11,625
-	21,4												221,39
Cruise airtude ncr m IU000	8990			10668									
Sween and a													
brodo cimo	105					2 105							
war war	3					2							
A(y_c),max													
of maximum thickness X													
t/c													
~													
ture													

Aeroplane Specifications

	Data to apply r	everse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1294	m		
Approach speed	Unknown	V_{APP}	70,00	m/s	61,2	61,2
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	1714	m	1714	1714
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	980	NM		
Cruise Mach number		M _{CR}	0,78			
Wing area		S_W	73	m²		
Wing span	Known	b_W	26	m²	26	26
Aspect ratio		Α	9,30			
Maximum take-off mass		m _{MTO}	40370	kg		
Maximum payload mass		m_PL	10200	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,253			
Maximum landing mass		m_ML	34100	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,845			
Operating empty mass		m_OE	21500	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,533			
Wing loading		m_{MTO}/S_W	555,1	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	62,275	kN		
Total take-off thrust		T _{TO}	124,55	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,314			
Bypass ratio		μ	5			
Available fuel volume		${ m V}_{ m fuel,available}$	23,86	m³		

Data	to opt	timize	V/V_{md}
------	--------	--------	------------

				LL	UL
	V_{CR}	221	m/s		
	h _{CR}	10668	m		
	V/V_{md}	1,241	-	1	1,316
Data to execu	te the verification				
				Ran	ge
	ϕ_{25}	25	•		
	C _{MAC}	3,195	m		
	X _{(y_c),max}	30	%с	15 - 50	%с
	(y _c) _{max} /c	4	%с	2 - 6	%с
	$\mathbf{x}_{t,max}$	30	%с	30 - 45	%с
Unknown	t/c	11,6	%		
	λ	0,24			
	Data to execu	$\begin{array}{c} V_{CR} \\ h_{CR} \\ V/V_{md} \end{array}$ Data to execute the verification $\begin{array}{c} \phi_{25} \\ c_{MAC} \\ x_{(y_c),max} \\ (y_c)_{max}/c \\ x_{t,max} \\ \text{Unknown} \end{array}$	$\begin{array}{cccc} V_{CR} & 221 \\ h_{CR} & 10668 \\ V/V_{md} & 1,241 \\ \hline \\ \textbf{Data to execute the verification} \\ & & \varphi_{25} & 25 \\ c_{MAC} & 3,195 \\ x_{(y_c),max} & 30 \\ (y_c)_{max}/c & 4 \\ x_{t,max} & 30 \\ \textbf{Unknown} & t/c & 11,6 \\ \hline \end{array}$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$

Reverse Engineering

Reverse engineering & optimization of V/Vmd

Reverse engineering & optimization of V/Vmd					
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1294	1294	m	0,00%
Approach speed	V_{APP}	Unknown	61,2	m/s	0,00%
Take-off field length	s _{TOFL}	1714	1714	m	0,00%
Span	b_W	26	26	m	0,00%
Aspect ratio	Α	9,30	9,30		0,00%
Cruise speed	V_{CR}	221,4	231	m/s	4,37%
Cruise altitude	h_{CR}	10668	10745	m	0,72%
Squared Sum Absolute maximum deviation					1,96E-03 4,4%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,39			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,41		Reverse Engineering	
Maximum aerodynamic efficiency	E _{max}	15,02		Reve	rise Engineering
Specific fuel consumption	SFC	1,94E-05 kg	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Landing					
Landing field length	S _{LFL}	1294 m			
Temperature above ISA (288,15K)	ΔT_L	0 K			
Relative density	σ	1,000			
Factor, approach	k _{APP}	1,70 (m/s²) ^{0.5}			
Approach speed	V_{APP}	61,22 m/s			
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³			
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,84			
Wing loading at maximum take-off mass	m_{MTO}/S_W	555,1 kg/m²			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,39			
Tak	e-off				
Take-off field length	S _{TOFL}	1714 m			
Temperatur above ISA (288,15K)	ΔΤ _{ΤΟ}	0 K			
Relative density	σ	1,00			
Factor	k _{TO}	2,34 m ³ /kg			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,314			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,41			
2nd S	egment				
Aspect ratio	A	9,296			
Lift coefficient, take-off	$C_{L,TO}$	1,67			
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,029			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Profile drag coefficient	C _{D.P}	0,049			
Oswald efficiency factor; landing configuration	e	0,7			
Glide ratio in take-off configuration	E _{TO}	9,01			
Number of engines	n.	2			
Climb gradient	n _E sin(γ)	0,024			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,270			
		, -			
Missed approach Lift coefficient, landing C _{L,L} 2,00					
Lift-independent drag coefficient, clean	C _{L,L} C _{D.0} (Missed approach)	0,020			
	_,,, ,	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$				
Lift-independent drag coefficient, slats Choose: Certification basis	$\Delta C_{D,slat}$	0,000			
Choose: Certification basis	JAR-25 resp. CS-25 FAR Part 25	no yes			
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015			
Profile drag coefficient	C _{D,P}	0,080			
Glide ratio in landing configuration	E _L	7,24			
Chae fado in landing configuration	ч.	7,27			
Climb gradient	sin(γ)	0,021			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,269			

2) Maximum Aerodynamic Efficiency

Constant parameters						
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g	9,81 m/s ²				
Air pressure, ISA, standard	p_0	101325 Pa				
Oswald eff. factor, clean	е	0,85				
Specifications						
Mach number, cruise	M _{CR}	0,78				
Aspect ratio	A	9,30				
Bypass ratio	μ	5,00				
Wing loading	m _{MTO} /S _W	555 kg/m²				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,314				
Variables						
Variables V/V _{md} 1,2						
	v / v md	1,2				
Calculations						
Zero-lift drag coefficient	$C_{D,0}$	0,028				
Lift coefficient at E _{max}	$C_{L,md}$	0,83				
Ratio, lift coefficient	$C_L/C_{L,md}$	0,649				
Lift coefficient, cruise	CL	0,537				
Actual aerodynamic efficiency, cruise	E	13,72				
Max. glide ratio, cruise	E _{max}	15,02				
Newton-Raphson for the maximum lift-to-drag ratio						
Iterations	1	2	3			
f(x)	-0,13	0,00	0,00			
f'(x)	-0,13	-0,13	-0,13			
E _{max}	16	15,04	15,02			

3) Specific Fuel Consumption

Constant parameters						
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g	•	m/s²			
Air pressure, ISA, standard	p_0	101325				
Fuel density	$ ho_{fuel}$	800	kg/m³			
Specifications						
Range	R	980	NM			
Mach number, cruise	M _{CR}	0,78				
Bypass ratio	μ	5,00				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,314				
Available fuel volume	$V_{ m fuel,available}$	23,86	m³			
Maximum take-off mass	m_{MTO}	40370	kg			
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,253				
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,533				
Calculated values						
Actual aerodynamic efficiency, cruise	E	13,72				
Cruise altitude	h _{CR}	10745				
Cruise speed	V _{CR}	231	m/s			
·						
Type of aeroplane (according to Roskam)	Transport jet					
Fuel-Fraction, engine start	M _{ff,engine}	0,990				
Fuel-Fraction, taxi	,	0,990				
•	M _{ff,taxi}	-				
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995				
Fuel-Fraction, climb	M _{ff,CLB}	0,980				
Fuel-Fraction, descent	$M_{ff,DES}$	0,990				
Fuel-Fraction, landing	$M_{ff,L}$	0,992				
Calculations						
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,215				
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,785				
Available fuel mass	^M F,available	19088	kg			
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,473				
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,538				
Distance to alternate	S _{to alternate}	200	NM			
Distance to alternate	S _{to_alternate}	370400	m			
Choose: FAR Part121-Reserves	domestic	yes				
	international	no				
Extra-fuel for long range		5%				
Extra flight distance	S _{res}	370400	m			
Loiter time	t _{loiter}	2700	s			
Specific fuel consumption	SFC	1,94E-05	kg/N/s			

4) Verification Specifications

Maximum lift coefficients

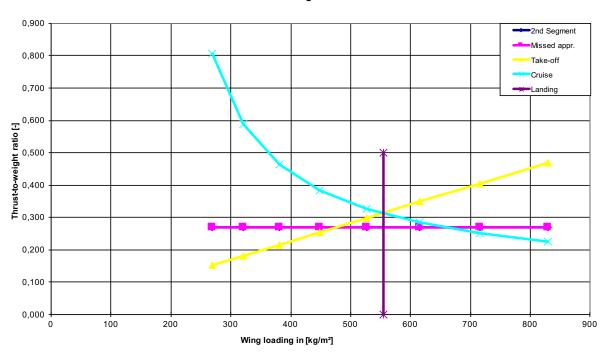
General wing specifications	Airfoil type:	NACA 65 series
Wing span	b_W	26 m
Structural wing span	$b_{W,struct}$	28,69 m
Wing area	S_W	72,7 m ²
Aspect ratio	Α	9,30
Sweep	φ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	3,195 m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	61,22 m/s
Mach number, landing	M_APP	0,18
Mach number, cruise	M_{CR}	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,2 %c
Leading edge sweep	ϕ_{LE}	28,8 °
Reynoldsnumber	Re	1,4E+07
Maximum lift coefficient, base	$c_{L,max,base}$	1,32
Correction term, camber	$\Delta_1c_{L,max}$	0,40
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,010
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,722
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,85
Correction term, Mach number	$\Delta C_{L,max}$	0,00
Lift coefficient, wing	C _{L,max}	1,46

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{o}}}$	0,87
Flap group A	,	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,43
Use flapped span	b_W,fA	7,7 m
Percentage of flaps allong the wing		27%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,33
Flap group B	_	
Double-slotted flap	$\Delta c_{L,max,fB}$	1,43
Use flapped span Percentage of flaps allong the wing	b_W,fB	11,6 m 40%
Increase in maximum lift coefficient, flap group B	۸	0,50
Increase in maximum lift coefficient, flap	ΔC _{L,max,fB}	0,83
increase in maximum in coemcient, nap	$\Delta C_{L,max,f}$	0,03
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	$\phi_{H.L.}$	27 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	4,3 m
Percentage of slats allong the wing		15%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,12
Slat group B Can blood floor	40	0.00
0,3c Nose flap	Δc _{L,max,SB}	0,90
Use slatted span Percentage of slats allong the wing	b_W,sB	18,2 m 63%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,51
Increase in maximum lift coefficient, slat	ΔC _{L,max,s} B	0,63
morease in maximum int coemolent, slat	△Q,max,s	0,00
MC		
Wing Verification value maximum lift coefficient, landing	C	2,88
RE value maximum lift coefficient, landing	$C_{L,max,L}$	3,39
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,05
RE value maximum lift coefficient, take-off	CL,max,10	2,41
-15%		2,
Aerodynamic effici	encv	
Real aircraft average	k_{WL}	2,83
End plate	$k_{e,WL}$	1,09
Span	b_W	26 m
Winglet height	h	1,57 m
Aspect ratio	A	9,30
Effective aspect ratio	$A_{\rm eff}$	10,11
Efficiency factor, short range	k_{E}	15,15
Relative wetted area	S _{wel} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	19,1
RE value maximum aerodynamic efficiency	- max	15,02
27%		. 5,52
·		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,780
Cruise altitude	h _{CR}	10668 m
By Pass Ratio	μ	5,00
Take-off Thrust (one engine)	T _{TO,one engine}	62,28 kN
Overall Pressure ratio	OAPR	28,50
Turbine entry temperature	TET	1391,54
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	$\eta_{ventilator}$	0,83
Compressor efficiency	$\eta_{compresor}$	0,84
Turbine efficiency	$\eta_{ m turbine}$	0,88
Nozzle efficiency	η_{nozzle}	0,97
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	Ts	216,65 K
Temperature at cruise altitude	T(H)	218,81 K
Dimensionless turbine entry temperature	ф	6,36
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,80
Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Gas generator function	G	1,85
Verification value specific fuel consumption	SFC	0,66 kg/daN/h
Verification value specific fuel consumption	SFC	1,82E-05 kg/N/s
RE value specific fuel consumption -6%	SFC	1,94E-05 kg/N/s

Matching Chart



Appendix P Boeing 737-900ER

Symbol S	Data Collection	ction		737-900ER		1		2	3	4	2	9	7	80	6
Futzmender Symbol Units Creek valide Try Sept						ircraft characteristics for airport plannin,			.lenkinson	Fngine		Paul Müller	Flodie Roux	Data collection	Webs
Part		Symbol	Units	Chosen value						2		_	YDON		500
Second	PAX			215		177-186-215	18	9-215					215-180		
Page 1900 Page	l andina field length	ā	8	1660		1700		662							
Second S	Approach speed	VAPP	s/m	72			72.53	1666667							
Second S	Temperature above ISA (288,15K)	ΔT _L	×	0		0									
Second Registration	Relative density	S			+										
120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120 120	Take-off field length	STOFL	Ε	2600		2990	259								2450
Payload R R R R R R R R R R	Temperature above ISA (288,15K)	ΔΤτο	¥	0		0		0							
Pay-bad R Rm 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 3120 31	Relative density	v													
125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125 125	Range (max payload)	ď	Æ	3120		3120-3890	381						4800		4995-5925
Sw mr 125 34,32-35,79 41,155 34,317 35,79 A A	Cruise Mach number	McR		0,785			0	,785		8,0					0,78
keoff mass A 94 34,32 34,32-35,79 34,31 35,79 keoff mass m.m. kg 79015 74389 85139 74840 79015 payload - Lake-off mass m.m. kg 17830 17830 23045 78015 payload - Lake-off mass m.m. kg 42493 44677 42493 66360 66810 anding mass m.m. kg 42493 44677 42493 46670 66360 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 66810 668	Wing area	Š	m ²	125				125					124.6 (B737-900)		
ke-off mass m _{kro} kg 79015 74389 85139 74840 79015 ses m _{kro} kg 77015 74389 85139 74840 79015 ses m _{kro} kg 17830 17830 66360 66810 andiog - take-off mass m _{kro} kg 42493 44677 42493 andiog - take-off me, m _{kro} kg 42493 44677 42493 andiog - take-off me, m _{kro} kg 62730 67721 62730 68810 andiog - take-off me, m _{kro} kg 62730 677721 62730 68840 and broad mass m _{kro} kg 62730 677721 62730 68640 and broad mass m _{kro} kg 62730 677721 62730 68640 and broad mass m _{kro} kg 62730 677721 67766-7826 6776-774 and broad mass m 117,433 115,5714 117 114 and broad mass	Wing span	þw	Ε	34,32		34,32-35,79	34,3						34,32		35,7
un take-off mass march kg 79015 74389 66139 74840 79015 at mass mass 17830 17830 23045 74840 79015 at mass mass 17830 17830 66360 66810 at lo, landing- take-off mass mass mass mass mass 42493 42493 44677 42493 atio, landing- take-off mesharo mass mass kg/m² 595,1 62730 66810 66810 atio, landing- take-off mesharo mass state, correcting empty- take-off mesharo mass kg/m² 556,1 62730 63840 67721 62730 63840 and, operating empty- take-off mesharo mass kg/ms 62730 62732 67721 62730 63840 and, operating empty- take-off mesharo mass kg/ms 62730 62732 67721 62730 67840 and filtures to fuel mass mass kg/ms 177,433 117,433 117,433 117,433 117,433 117,433 117,44 117,44 117,44 117,44	Aspect ratio	⋖		9,4				9,4							
of mass and mass and market mines and mass and market mines and mass and market mines and market mass and market	Movimum tolor off mono	1	3	70016									06130		76000 95100
The control co	Daylood mass	OLWIN	2 3	17830									23045		00000
um zero fuell mass max kg 66360 66361 71350 66360 66810 aratio, landing-take-off more many asid, landing mass maxman kg 42493 44677 42493 aratio, landing-take-off more many asid, popular asid, popular asid, popular asid, popular and popular asid, popular and popu	Mass ratio payload - take-off	Mel/MATO	2				2						0.271		
Part of the consumption (chicle) Part of the consumption (chicle) Part of the chicles Part of the chic	Maximum landing mass		Š	66360									71350		66350
ling empty mass more kg 42493 44677 42493 44677 42493 44677 42493 44677 42493 44677 42493 44677 42493 44677 42493 44677 42493 44677 42493 44677 42493 44677 42493 44677 42493 42493 42493 426730 426730 426730 426730 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867 422867	Mass ratio, landing - take-off	MML/MMT0													
autio, operating empty - take-off mo _E m _{Marc} Say, kg/m² 599,1 62730 62732 67721 62730 63840 632,1 632,1 632,1 62730 m _{Marc} Kg/m 62730 62730 62732 67721 62730 63840 63840 6370 63840 6370 63840 6370 63840 63840 6370 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840 63840	Operating empty mass	MoE		42493		44677	.4	2493					44676		44675
oading that the consumption (dy) SFC (dy) Aginate (dy) SFC (dy) Aginate (dy) SFC (dy) Aginate (dy)	Mass ratio, operating empty - take-c	off moe/mmro											0,525		
ref engines n _{kucr} kg 62730 62732 67721 62730 63840	Wing loading	m _{MTo} /S _w	kg/m²	595,1											
Troise regimes Troise regime Troise regi	Maximum zero fuel mass	MMZF	kg	62730									67721		
CFMS6-7B CFMS6-7B CFMS6-7B26 CFMS6-7B27 CFMS6-7	Nimber of engines	č											2		2
Aff funct for one engine Trocesses engine KN 117,433 115,5714 117 121,4 11 ake-off thrust Trocesses engine KN 0,32 0,32088307 0,31397174 171,4 17 171,4 17 171,4 17 171,4 17 171,4 17 171,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17,4 17 17 17,4 17 17 17,4 17 17 17,4 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 17 <	Engine type	CFM56-7B	-	CFM56-7B26		CFM56-7B26/-7B27	CFM56-7B26			3FM56-7B26			CFM56-7B20		I
ake off thrust Tro (marro*g) kN 0,32088307 0,31397174 to weight ratio Tro/(marro*g) 1,08E-05 0,32088307 0,31397174 s ratio y ratio 1,08E-05 0,32088307 0,31397174 ic Fuel Comsumption (duse) SFC (dry) kg/N s 1,08E-05 1,08E-05 ic Fuel Comsumption (cruise) SFC (cruise kg/N s 1,08E-05 29,665 29,665 speed Vor m/s 228,61 28,666 29,665 10820 altitude hcs m 11215 10820 10820 an agle psecd m 11215 10820 10820 an agle psecd m 11215 10820 10820 an of maximum camber psecd psecd psecd psecd psecd an of maximum thickness x _{crossor} psecd psecd psecd psecd an of maximum thickness to 22,73 psecd psecd psecd an of maximum thickness	Take-off thrust for one engine	TTO, one engine	¥	117,433		115,5714	11			117,433061			91,633		121,4
to weight ratio Tro/(m _{ort} o* ₉) 0,32 0,32088307 0,31397174 s ratio Ju	Total take-off thrust	Tro	ᇫ												
s ratio μ 5,6 ic Fuel Comsumption (dry) SFC (dry) kg/N s 1,08E-05 ic Fuel Comsumption (cruise) SFC (cruise kg/N s 1,08E-05 ble fuel volume V _{Local area market} m² 29,663 29,665 speed V _{CR} m/s 228,61 11215 10820 speed V _{CR} m 11215 10820 stritude m 11215 10820 and of maximum camber x _{V_{CR}-lonax} %c 25,02 and of maximum thickness x _{Lonax} %c 0,8 and of maximum thickness x _{Lonax} %c 29,7 And 12,5 0,219 0,218914186	Thrust to weight ratio	T _{TO} /(m _{MTO} *	(a)	0,32			0,3208830						0,22		
ic Fuel Comsumption (dry) SFC (dry) kg/N s 1,08E-05 ic Fuel Comsumption (cruise) SFC (cruise kg/N s 29,663 27,974 29,666 29,665 speed V _{CR} m/s 228,61 11215 10820 speed V _{CR} m/s 25,02 11215 10820 angle parallel m 11215 10820 108 angle driving chord parallel pc 0,8 10 12,5 an of maximum thickness trans. %c 29,7 12,5 12,5 an of maximum thickness to 0,219 0,218914186 12,6 12,6	Bypass ratio	_		5,6						5,1			5,6		
ic Fuel Comsumption (cruise) SFC (cruise kg/N s) 29,663 27,974 29,666 29,665 speed V _{treal avoilination} m/s 228,61 11215 10820 11 speed V _{CR} m 11215 10820 11 and littude h _{CR} m 25,02 11 11 and leavedynamic chord o _{MAC} m 10 11 11 11 11 arr (y _{Chard} C %c 0,8 10 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 12 <	Specific Fuel Comsumption (dry)		kg/N s	1,08E-05						1,08E-05			1,02E-05		
Speed Visit and include Visit and includ	Specific Fuel Comsumption (cruise)		se kg/N s										1,79E-05		
Speed V_CR m/s 228,61	Available fuel volume	Vfuel, available		29,663				2					29,663		29,66
angle descriptioned by the secretary and the sec	Cruise speed	V _{CR}	s/m	228,61											228,61
aerodynamic chord o _{Mec} m 25,02	Cruise altitude	hcR	Ε	11215			1121			10668					
aerodynamic chord	Sweep angle	ф 25		25.02											25,02
in of maximum camber	Mean aerodynamic chord	OMAC	ε												
an of maximum thickness	Position of maximum camber	X _{(y_c),max}	э%	10											10
n of maximum thickness X _{cmax} %c 29,7 et hickness tr	Camber	(yc) _{max} /c	%с	8,0											8,0
te thickness	Position of maximum thickness	X _{t,max}	%с	29,7											29,7
0,219 0,218914186	Relative thickness	t/c	%	12,5	+										12,5
	Taper	٧ (_	0,219	+		12,0	3914186		0			0,219		
VATR	Overall pressure ratio	OAPR	;	27,9	+					27,9					

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	S _{LFL}	1660			
Approach speed	Known	V_{APP}	72,00	m/s	72,0	72,0
Temperature above ISA (288,15K)		ΔT_L		K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	2600	m	2600	2600
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	1685	NM		
Cruise Mach number		M _{CR}	0,785			
Wing area		S_W	125	m²		
Wing span	Known	b_W	34,32	m²	34,32	34,32
Aspect ratio		Α	9,42			
Maximum take-off mass		m _{MTO}	79015	kg		
Maximum payload mass		m_PL	17830	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,226			
Maximum landing mass		m_ML	66360	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,840			
Operating empty mass		m_OE	42493	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,538			
Wing loading		m_{MTO}/S_W	632,1	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	117,433	kN		
Total take-off thrust		T _{TO}	234,866	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,303			
Bypass ratio		μ	5,6			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data to optimize V/V _m	Data	to	optimize	V/V _m
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		p			
				LL	UL
Cruise speed		V_{CR}	229 m/s		
Cruise altitude		h_{CR}	11215 m		
Speed ratio		V/V_{md}	1,100 -	1	1,316
	Data to execu	te the verification			
				Rar	nge
Sweep angle		φ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,5 %		
Taper		λ	0,219		

Reverse Engineering

Reverse engineering	& o	ptimization	of V/Vmd
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Reverse engineering & optimization of viving							
Quantity	Original value	RE value	Unit	Deviation			
S _{LFL}	1660	1660	m	0,00%			
V_{APP}	72,00	72,0	m/s	0,00%			
s _{TOFL}	2600	2600	m	0,00%			
b_W	34,32	34,32	m	0,00%			
Α	9,42	9,42		0,00%			
V_{CR}	228,6	232	m/s	1,34%			
h _{CR}	11215	11215	m	0,00%			
				1,79E-04 1,3%			
Results reverse engineering							
$C_{L,max,L}$	2,99						
$C_{L,max,TO}$	1,88		Povo	rse Engineering			
E _{max}	16,00		Kever	Se Linginieering			
SFC	1,77E-05 kg/	/N/s					
	Quantity SLFL VAPP STOFL bW A VCR hCR Results reve CL,max,L CL,max,TO Emax	Quantity Original value SLFL 1660 VAPP 72,00 STOFL 2600 bW 34,32 A 9,42 VCR 228,6 hCR 11215 Results reverse engineering CL,max,L 2,99 CL,max,TO 1,88 Emax 16,00	Quantity Original value RE value S _{LFL} 1660 1660 V _{APP} 72,00 72,0 S _{TOFL} 2600 2600 b _W 34,32 34,32 A 9,42 9,42 V _{CR} 228,6 232 h _{CR} 11215 11215 Results reverse engineering C _{L,max,L} 2,99 C _{L,max,TO} 1,88 E _{max} 16,00	Quantity Original value RE value Unit SLFL 1660 1660 m VAPP 72,00 72,0 m/s STOFL 2600 2600 m bW 34,32 34,32 m A 9,42 9,42 VCR 228,6 232 m/s hCR 11215 11215 m Results reverse engineering CL,max,L CL,max,TO 1,88 Emax 16,00			

1) Maximum Lift Coefficient for Landing and Take-off

La	nding				
Landing field length	S _{LFL}	1660 m			
Temperature above ISA (288,15K)	ΔT_L	0 K			
Relative density	σ	1,000			
Factor, approach	\mathbf{k}_{APP}	1,70 (m/s²) ^{0.5}			
Approach speed	V_{APP}	72,00 m/s			
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³			
Mass ratio, landing - take-off	${\sf m_{ML}/m_{TO}}$	0,84			
Wing loading at maximum take-off mass	m_{MTO}/S_W	632,1 kg/m²			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,99			
Ta	ke-off				
Take-off field length	S _{TOFL}	2600 m			
Temperatur above ISA (288,15K)	ΔT_TO	0 K			
Relative density	σ	1,00			
Factor	k _{TO}	2,34 m³/kg			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,303			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,88			
2nd Segment					
Aspect ratio	A	9,423			
Lift coefficient, take-off	C_L,TO	1,30			
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,010			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Profile drag coefficient	$C_{D,P}$	0,030			
Oswald efficiency factor; landing configuration	е	0,7			
Glide ratio in take-off configuration	E _{TO}	11,62			
Number of engines	n _E	2			
Climb gradient	sin(γ)	0,024			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,220			
Missed	l approach				
Lift coefficient, landing	C _{L,L}	1,77			
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,033			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Choose: Certification basis	JAR-25 resp. CS-25	no			
	FAR Part 25	yes			
Lift-independent drag coefficient, landing gear	$\DeltaC_{D,gear}$	0,015			
Profile drag coefficient	C_D,P	0,068			
Glide ratio in landing configuration	EL	8,06			
Climb gradient	sin(γ)	0,021			

2) Maximum Aerodynamic Efficiency

Constant parameters						
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g	9,81 m/s ²				
Air pressure, ISA, standard	p_0	101325 Pa				
Oswald eff. factor, clean	е	0,85				
Sp	ecifications					
Mach number, cruise	M _{CR}	0,785				
Aspect ratio	Α	9,42				
Bypass ratio	μ	5,60				
Wing loading	m_{MTO}/S_W	632 kg/m²				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,303				
Variables						
Variables						
V/V _{md} 1,1						
Calculations						
Zero-lift drag coefficient	$C_{D,0}$	0,025				
Lift coefficient at E _{max}	$C_{L,md}$	0,79				
Ratio, lift coefficient	$C_L/C_{L,md}$	0,826				
Lift coefficient, cruise	C_L	0,649				
Actual aerodynamic efficiency, cruise	E	15,71				
Max. glide ratio, cruise	E_{max}	16,00				
Newton-Raphson for the maximum lift-to-	drag ratio					
Iterations	1	2	3			
f(x)	0,00	0,00	0,00			
f'(x)	-0,12	-0,12	-0,12			
E _{max}	16	16,00	16,00			

3) Specific Fuel Consumption

Constant pa	rameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Specifica	tions		
Range	R	1685	NM
Mach number, cruise	M_{CR}	0,785	
Bypass ratio	μ	5,60	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,303	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	79015	kg
Mass ratio, landing - take-off	m_{PL}/m_{MTO}	0,226	
Mass ratio, operating empty - take-off	$m_{OE/}m_{MTO}$	0,538	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	15,71	
Cruise altitude	h _{CR}	11215	
Cruise speed	V _{CR}	232	m/s
•			
Type of aeroplane (according to Roskam)			
	Transport jet	0,990	
Fuel-Fraction, engine start	$M_{ff,engine}$		
Fuel-Fraction, taxi	M _{ff,taxi}	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
Calculat			
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,237	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,763	
Available fuel mass	MF,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,242	
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,774	
Distance to alternate	S _{to alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,77E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

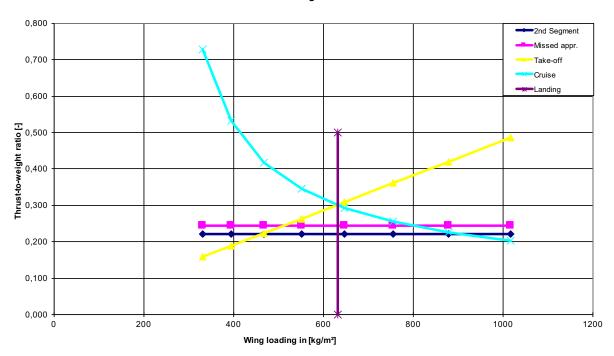
Wing span b _W 34,32 m Structural wing span b _{W, struct} 37,87 m Wing area S _W 125,0 m² Aspect ratio A 9,42 Sweep Φ25 25 ° Mean aerodynamic chord C _{MC} 4,2 m Position of maximum camber (½c)max 30 %c Camber (½c)max/c 4 %c Position of maximum thickness x _{1,max} 30 %c Relative thickness ½c 11,5 % Taper λ 0,219 General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Repeature, landing T _L 273,15 K Density, air, landing p 1,225 kg/m² Dynamic viscosity, air μ 1,72E-05 kg/m² Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 72,00 m/s Mach number, landing M _{APP} 0,22 Mach number, cruise M _{CR} 0,785	General wing specifications	Airfoil type:	NACA 4 digit
Structural wing span Dw, struct 37,87 m Wing area Sw 125,0 m²	• .		•
Wing area S _W 125,0 m² Aspect ratio A 9,42 Sweep φ25 25 ° Mean aerodynamic chord C _{MAC} 4,2 m Position of maximum camber X _{V,C),max} 30 %c Camber (y _C) _{max} /C 4 %c Position of maximum thickness X _{Lmax} 30 %c Relative thickness ½C 11,5 % Taper λ 0,219 General aircraft specifications Temperature above ISA (288,15K) ΔTL 0 K Relative density σ 1 Temperature, landing TL 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 72,00 m/s Mach number, landing M _{APP} 0,22 Mach number, landing M _{APP} 0,22 Mach number, cruise Δy 3,0 %c Calculations maximum			37,87 m
Aspect ratio A 9,42 Sweep φ25 25° Mean aerodynamic chord c _{MAC} 4,2 m Position of maximum camber x _{(y_c),max} 30 %c Camber (y _c),max 30 %c Position of maximum thickness x _{t,max} 30 %c Relative thickness t/c 11,5 % Taper λ 0,219 General aircraft specifications Temperature above ISA (288,15K) ΔTL 0 K Relative density σ 1 Temperature, landing TL 273,15 K Density, air, landing p 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m² Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 72,00 m/s Mach number, landing M _{APP} 0,22 Mach number, cruise M _{CR} 0,785 Calculations maximum clean lift coefficient Leading edge sweep φ _L 2,8,9°	• .	,	•
Mean aerodynamic chord c _{MAC} 4,2 m Position of maximum camber x _{(y_c),max} 30 %c Camber (y _c) _{max} /c 4 %c Position of maximum thickness x _{t,max} 30 %c Relative thickness t/c 11,5 % Taper λ 0,219 General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 72,00 m/s Mach number, landing M _{APP} 0,22 Mach number, cruise M _{CR} 0,785 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 3,0 %c Leading edge sweep φ _L 2,2E+07 Maximum lift coefficient, ba	•	**	•
Position of maximum camber	Sweep	Ψ25	25 °
Camber (y _c) _{max} /C 4 %c Position of maximum thickness x _{t,max} 30 %c Relative thickness t/c 11,5 % Taper λ 0,219 General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing τ _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 72,00 m/s Mach number, landing M _{APP} 0,22 Mach number, cruise M _{CR} 0,785 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 3,0 %c Leading edge sweep φ _{LE} 28,9 ° Reynoldsnumber Re 2,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,57 Correction term, camber Δ ₂ C _{L,max} 0,18 Correction term, Reynolds' number Δ ₂ C _{L,max} 0,00 Correction term, Reynolds' number Δ ₂ C _{L,max} 0,00 Correction term, Reynolds' number Δ ₂ C _{L,max} 0,00 Correction term, Mach number Δ ₂ C _{L,max} 0,80 Correction term, Mach number Δ ₂ C _{L,max} 0,80 Correction term, Mach number Δ ₂ C _{L,max} 0,00	Mean aerodynamic chord	C _{MAC}	4,2 m
Camber (y _c) _{max} /c 4 %c Position of maximum thickness x _{t,max} 30 %c Relative thickness t/c 11,5 % Taper λ 0,219 General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 72,00 m/s Mach number, landing M _{APP} 0,22 Mach number, cruise M _{CR} 0,785 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 3,0 %c Leading edge sweep φ _{LE} 28,9 ° Reynoldsnumber Q _L 2,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,57 Correction term, camber	Position of maximum camber	X _{(v c),max}	30 %c
Relative thickness tc tc tc tc tc tc tc tc	Camber		4 %c
General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 72,00 m/s Mach number, landing M _{APP} 0,22 Mach number, cruise M _{CR} 0,785 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 3,0 %c Leading edge sweep φ _{LE} 28,9 ° Reynoldsnumber Re 2,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,57 Correction term, camber Δ ₁ C _{L,max} 0,18 Correction term, thickness Δ ₂ C _{L,max} 0,00 Correction term, Reynolds' number Δ ₂ C _{L,max} 0,084 Maximum lift coefficient, airfoil C _{L,max,clean} 1,838 Li	Position of maximum thickness	X _{t.max}	30 %c
General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 72,00 m/s Mach number, landing M _{APP} 0,22 Mach number, cruise M _{CR} 0,785 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 3,0 %c Leading edge sweep φ _{LE} 28,9 ° Reynoldsnumber Re 2,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,57 Correction term, camber Δ ₁ C _{L,max} 0,18 Correction term, thickness Δ ₂ C _{L,max} 0,00 Correction term, Reynolds' number Δ ₃ C _{L,max} 0,084 Maximum lift coefficient, airfoil C _{L,max,clean} 1,838 Lif	Relative thickness	t/c	11,5 %
Temperature above ISA (288,15K) $\Delta T_L \qquad 0 \text{ K}$ Relative density $\sigma \qquad 1$ Temperature, landing $T_L \qquad 273,15 \text{ K}$ Density, air, landing $\rho \qquad 1,225 \text{ kg/m}^3$ Dynamic viscosity, air $\mu \qquad 1,72E-05 \text{ kg/m/s}$ Speed of sound, landing $a_{APP} \qquad 331 \text{ m/s}$ Approach speed $V_{APP} \qquad 72,00 \text{ m/s}$ Mach number, landing $M_{APP} \qquad 0,22$ Mach number, cruise $M_{CR} \qquad 0,785$ $Calculations \ maximum \ clean \ lift \ coefficient$ Leading edge sharpness parameter $\Delta y \qquad 3,0 \text{ \%c}$ Leading edge sweep $\phi_{LE} \qquad 28,9 \text{ °}$ Reynoldsnumber $Re \qquad 2,2E+07$ Maximum lift \ coefficient, \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	Taper	λ	0,219
Temperature above ISA (288,15K) $\Delta T_L \qquad 0 \text{ K}$ Relative density $\sigma \qquad 1$ Temperature, landing $T_L \qquad 273,15 \text{ K}$ Density, air, landing $\rho \qquad 1,225 \text{ kg/m}^3$ Dynamic viscosity, air $\mu \qquad 1,72E-05 \text{ kg/m/s}$ Speed of sound, landing $a_{APP} \qquad 331 \text{ m/s}$ Approach speed $V_{APP} \qquad 72,00 \text{ m/s}$ Mach number, landing $M_{APP} \qquad 0,22$ Mach number, cruise $M_{CR} \qquad 0,785$ $Calculations \ maximum \ clean \ lift \ coefficient$ Leading edge sharpness parameter $\Delta y \qquad 3,0 \text{ \%c}$ Leading edge sweep $\phi_{LE} \qquad 28,9 \text{ °}$ Reynoldsnumber $Re \qquad 2,2E+07$ Maximum lift \ coefficient, \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	General aircraft specifications		
Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 72,00 m/s Mach number, landing M _{APP} 0,22 Mach number, cruise M _{CR} 0,785 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 3,0 %c Leading edge sweep φ _{LE} 28,9 ° Reynoldsnumber Re 2,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,57 Correction term, camber Δ ₁ c _{L,max} 0,18 Correction term, thickness Δ ₂ c _{L,max} 0,00 Correction term, Reynolds' number Δ ₃ c _{L,max} 0,084 Maximum lift coefficient, airfoil c _{L,max,clean} 1,838 Lift coefficient ratio C _{L,max} /c _{L,max} 0,80 Correction term, Mach number ΔC _{L,max} -0,01		ΔT_1	0 K
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	•	_	1
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Temperature, landing	T_L	273,15 K
Speed of sound, landing a_{APP} 331 m/sApproach speed V_{APP} $72,00$ m/sMach number, landing M_{APP} $0,22$ Mach number, cruise M_{CR} $0,785$ Calculations maximum clean lift coefficientLeading edge sharpness parameter Δy $3,0 \% c$ Leading edge sweep ϕ_{LE} $28,9 \% c$ ReynoldsnumberRe $2,2E+07$ Maximum lift coefficient, base $C_{L,max,base}$ $1,57$ Correction term, camber $\Delta_1C_{L,max}$ $0,18$ Correction term, thickness $\Delta_2C_{L,max}$ $0,00$ Correction term, Reynolds' number $\Delta_3C_{L,max}$ $0,084$ Maximum lift coefficient, airfoil $C_{L,max,clean}$ $1,838$ Lift coefficient ratio $C_{L,max}/C_{L,max}$ $0,80$ Correction term, Mach number $\Delta C_{L,max}$ $-0,01$	Density, air, landing	ρ	1,225 kg/m ³
Approach speed V_{APP} 72,00 m/s Mach number, landing M_{APP} 0,22 Mach number, cruise M_{CR} 0,785 M_{CR} 0,980 M_{CR} 0,785 M_{CR} 0,785 M_{CR} 0,785 M_{CR} 0,984 M_{CR} 0,090 M_{CR} 0,090 M_{CR} 0,090 M_{CR} 0,090 M_{CR} 0,091 M_{CR} 0,090 M_{CR} 0,091 M_{CR} 0,090 M_{CR} 0,091 $M_{$	Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Mach number, landing M_{APP} $0,22$ Mach number, cruise M_{CR} $0,785$ Calculations maximum clean lift coefficientLeading edge sharpness parameter Δy $3,0 \% c$ Leading edge sweep ϕ_{LE} $28,9 \%$ ReynoldsnumberRe $2,2E+07$ Maximum lift coefficient, base $C_{L,max,base}$ $1,57$ Correction term, camber $\Delta_1C_{L,max}$ $0,18$ Correction term, thickness $\Delta_2C_{L,max}$ $0,00$ Correction term, Reynolds' number $\Delta_3C_{L,max}$ $0,084$ Maximum lift coefficient, airfoil $C_{L,max,clean}$ $1,838$ Lift coefficient ratio $C_{L,max}/C_{L,max}$ $0,80$ Correction term, Mach number $\Delta C_{L,max}$ $-0,01$	Speed of sound, landing	a_{APP}	331 m/s
Mach number, cruise M_{CR} $0,785$ Calculations maximum clean lift coefficient Δy $3,0 \% c$ Leading edge sharpness parameter Δy $3,0 \% c$ Leading edge sweep ϕ_{LE} $28,9 \% c$ ReynoldsnumberRe $2,2E+07$ Maximum lift coefficient, base $C_{L,max,base}$ $1,57 c$ Correction term, camber $\Delta_1 C_{L,max}$ $0,18 c$ Correction term, thickness $\Delta_2 C_{L,max}$ $0,00 c$ Correction term, Reynolds' number $\Delta_3 C_{L,max}$ $0,084 c$ Maximum lift coefficient, airfoil $C_{L,max,clean}$ $1,838 c$ Lift coefficient ratio $C_{L,max}/C_{L,max}$ $0,80 c$ Correction term, Mach number $\Delta C_{L,max}$ $-0,01 c$	Approach speed	V_{APP}	72,00 m/s
	Mach number, landing	M_{APP}	0,22
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Mach number, cruise	M _{CR}	0,785
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Calculations maximum clean lift coefficient		
ReynoldsnumberRe $2,2E+07$ Maximum lift coefficient, base $C_{L,max,base}$ $1,57$ Correction term, camber $\Delta_1 C_{L,max}$ $0,18$ Correction term, thickness $\Delta_2 C_{L,max}$ $0,00$ Correction term, Reynolds' number $\Delta_3 C_{L,max}$ $0,084$ Maximum lift coefficient, airfoil $C_{L,max,clean}$ $1,838$ Lift coefficient ratio $C_{L,max}/C_{L,max}$ $0,80$ Correction term, Mach number $\Delta C_{L,max}$ $-0,01$	Leading edge sharpness parameter	Δy	3,0 %c
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Leading edge sweep	ϕ_{LE}	28,9 °
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Reynoldsnumber	Re	2,2E+07
$\begin{array}{llll} \text{Correction term, thickness} & \Delta_2 c_{L,max} & 0,00 \\ \text{Correction term, Reynolds' number} & \Delta_3 c_{L,max} & 0,084 \\ \text{Maximum lift coefficient, airfoil} & c_{L,max,clean} & 1,838 \\ \text{Lift coefficient ratio} & C_{L,max}/c_{L,max} & 0,80 \\ \text{Correction term, Mach number} & \Delta C_{L,max} & -0,01 \\ \end{array}$	Maximum lift coefficient, base	C _{L,max,base}	1,57
$\begin{array}{lllll} \text{Correction term, Reynolds' number} & \Delta_3 c_{L,max} & 0,084 \\ \text{Maximum lift coefficient, airfoil} & c_{L,max,clean} & 1,838 \\ \text{Lift coefficient ratio} & C_{L,max}/c_{L,max} & 0,80 \\ \text{Correction term, Mach number} & \Delta C_{L,max} & -0,01 \\ \end{array}$	Correction term, camber	$\Delta_1 C_{L,max}$	0,18
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Lift coefficient ratio $C_{L,max}/c_{L,max}$ 0,80 Correction term, Mach number $\Delta C_{L,max}$ -0,01	Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,084
Lift coefficient ratio $C_{L,max}/c_{L,max}$ 0,80 Correction term, Mach number $\Delta C_{L,max}$ -0,01	Maximum lift coefficient, airfoil	,	1,838
Correction term, Mach number $\Delta C_{L,max}$ -0,01	Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
	Correction term, Mach number		-0,01
	Lift coefficient, wing		1,45

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87
Flap group A	•	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,42
Use flapped span	b_W,fA	6,9 m
Percentage of flaps allong the wing		18%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,23
Flap group B		
Double-slotted flap	$\Delta c_{L,max,fB}$	1,42
Use flapped span	b_W,fB	11,8 m
Percentage of flaps allong the wing		31%
Increase in maximum lift coefficient, flap group B	ΔC _{L,max,fB}	0,39
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,61
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	Ψ _{H.L.}	27 °
Slat group A		
0,1c Kruger flap	$\Delta c_{L,max,sA}$	0,66
Use slatted span	b_W,sA	4,5 m
Percentage of slats allong the wing		12%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,07
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	25,4 m
Percentage of slats allong the wing		67%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,54
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,61
Wing	•	0.04
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,64
RE value maximum lift coefficient, landing	0	2,99
Verification value maximum lift coefficient, take-off RE value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,66
-12%		1,88
-1270		
Aerodynamic effici	iencv	
	- j	
Real aircraft average	\mathbf{k}_{WL}	2,83
No winglets	$k_{e,WL}$	1,00
Span	b _W	34,32 m
Winglet height	h	2,49 m
Aspect ratio	Α	9,42
Effective aspect ratio	$A_{\rm eff}$	9,42
Efficiency factor, short range	k _E	15,15
Relative wetted area		6,35
Neiauve wetted alea	S _{wet} /S _W	0,30
Verification value maximum aerodynamic efficiency	E _{max}	18,5
RE value maximum aerodynamic efficiency		16,00
15%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,785
Cruise altitude	h _{CR}	11215 m
By Pass Ratio	μ	5,60
Take-off Thrust (one engine)	T _{TO,one engine}	117,43 kN
Overall Pressure ratio	OAPR	27,90
Turbine entry temperature	TET	1451,88
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	η _{ventilator}	0,87
Compressor efficiency	$\eta_{compresor}$	0,86
Turbine efficiency	η_{turbine}	0,90
Nozzle efficiency	η_{nozzle}	0,98
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	Ts	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,70
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,78
Gas generator efficiency	η _{gasgen}	0,98
Gas generator function	G	2,16
Verification value specific fuel consumption	SFC	0,59 kg/daN/h
Verification value specific fuel consumption	SFC	1,64E-05 kg/N/s
RE value specific fuel consumption	SFC	1,77E-05 kg/N/s

Matching Chart



Appendix Q Bombardier CRJ200

Street S	Data Collection	ction		CRJ200	_		-			2		က	4	2	9	7	80	6
Parameter Symbol Julie Diseant all Society S					Source:	Aircraft charact	teristics for airport 1	lanning					Engino		Millor	Flodio Doux	Data colloction	Wobs
State blooms Stat	Parameter	Symbol	Units	Chosen value		200	200ER	200LR	200	H			engine		aui Muller	Elodie Roux	Data collection	vvens
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																_		
Column C	Landing field length	SLFL	Ε	1478		1440		0	1423	1478						1478		
1,	Approach speed	VAPP	s/w	2 0		2				69,45								
1 1 1 1 1 1 1 1 1 1	lemperature above ISA (288,13K)	ΔIL	2	>														
17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.00 17.0	Relative density	v																
Auto-broken	Take-off field length	STOFI	E	1768		1500	1720	1870	1527	1768	1917					1768		
Company Comp	Temperature above ISA (288,15K)	ΔΤτο	¥															
Mach number	Relative density	S																
Mach Interference (Mach Inte	Range (max navload)	α	Ę	1064 9		1064 9		2222 4	1787	3046	3713					1833		3045-3713
Control Cont	Criico Mosh number	M		0,770	İ	0,100		- (-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-	5	0.77	2			İ		200		0.78
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A Part Par	Wing span	Ď.	ε	21,21			21.23			21.21						21.21		21.21
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Option by Applicated integrated	Payload mass	Шы	ķ	6125		2307	612	4	2411	6124						6125		6124
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ske-off thrust Tro/Immort 5) kN 0,38799 0,38799 0,381826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,338799 0,34826 0,34826 0,338799 0,34826 0,34826 0,338799 0,34826 0,34826 0,338799 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 0,34826 <td>Take-off thrust for one engine</td> <td>T_{TO}, one engine</td> <td>Σ</td> <td>41,012</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>38,8 - 41</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>38,83-41,01</td>	Take-off thrust for one engine	T _{TO} , one engine	Σ	41,012						38,8 - 41								38,83-41,01
1	Total take-off thrust	Tro	ᇫ															
Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure Figure F	Thrust to weight ratio	Tro/(m _{MTO} *	(a)	0,39					0,38799		0,34826							
c Fuel Comsumption (dxy) SFC (dxy) kgNs 9,80E-06 9,80E-06 c Fuel Comsumption (cruise) SFC (cruise) SFC (cruise) RAN 8,081 6,081 6,33 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081 8,081	Bypass ratio	_		6,3												-	6	
of Fuel Comsumption (cruise) SFC (cruise) SFC (cruise) SFC (cruise) SFA (Mask of the fuel volume) SFA (Mask of the fuel vo	Specific Fuel Comsumption (dry)		kg/N s	9,80E-06											0	-	2	
Speed V_CR m's 225 8,081 8,081 5,3 - 8,08 Speed Spee	Specific Fuel Comsumption (cruise)		e kg/N s															
speed V _{CR} m/s T1278 218,1 218,1 alitude m 11278 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,9 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0 24,0	Available fuel volume	Vfuel, available		8,081		5,3		8,081	4	5,3 - 8,08						∞ –		
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angle φ ₂₅ • 24.9 • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • • <	Cruise altitude	hcr	Ε	11278												11278		
47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5 47.5		-	0	200						+						0.50		
Berodynamic chord Q _{ANC} m n of maximum camber x _{(V,c)max} %c n of maximum thickness x _{Lmax} %c e thickness t/c % n of maximum thickness t/c %c e thickness t/c % n op-PR 0,248 0,248	oweep angle	φ25		6,43												6,42		
n of maximum camber	Mean aerodynamic chord	OMAC	E :															
or of maximum thickness (Vc)has/c %c n of maximum thickness Vc %c e thickness Vc % A 0,248 I pressure ratio OAPR 0,248	Position of maximum camber	X(y_c),max	%c															
n of maximum thickness X _{Lmax} %c %c thickness U / % % 0,248 h	Camber	(yc)max/c	%c															
e mixiness	Position of maximum thickness	Xt,max	%c															
pressure ratio OAPR U,246	Relative mickness	nc.	%	900					- 6	0100017								
OAPK	laper	<		0,248					oʻ.	247503353								
	Overall pressure ratio	SAPR F										+						

Aeroplane Specifications

Available fuel volume

	Data to apply	reverse engineering	3			
					LL	UL
Landing field length	Known	s_{LFL}	1660	m		
Approach speed	Known	V_{APP}	72,00	m/s	72,0	72,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	2600	m	2600	2600
Temperature above ISA (288,15K)		ΔT_{TO}	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	1685	NM		
Cruise Mach number		M_{CR}	0,785			
Wing area		S _W	125	m²		
Wing span	Known	b_W	34,32	m²	34,32	34,32
Aspect ratio		Α	9,42			
Maximum take-off mass		m_{MTO}	79015	kg		
Maximum payload mass		m_PL	17830	kg		
Mass ratio, payload - take-off		m _{PL} /m _{MTO}	0,226			
Maximum landing mass		m _{ML}	66360	kg		
Mass ratio, landing - take-off		m _{ML} /m _{MTO}	0,840			
Operating empty mass		m_OE	42493	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,538			
Wing loading		m_{MTO}/S_W	632,1	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	117,433	kN		
Total take-off thrust		T _{TO}	234,866	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,303			
Bypass ratio		μ	5,6			

V_{fuel,available}

23,86 m³

Data to optimize V/V _{md}	Data	to o	ptimi	ze \	V/V_{md}
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	Data to o	Ptilling V/ V ma			
				LL	UL
Cruise speed		V_{CR}	229 m/s		
Cruise altitude		h_{CR}	11215 m		
Speed ratio		V/V_{md}	1,100 -	1	1,316
	Data to execu	te the verification			
				Ran	ige
Sweep angle		φ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$X_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,5 %		
Taper		λ	0,219		

Reverse Engineering

Reverse engineering & optimization of V/Vmd

IVEA.	erse engineering	a optimization of v	/ VIIIu		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1660	1660	m	0,00%
Approach speed	V_{APP}	72,00	72,0	m/s	0,00%
Take-off field length	s _{TOFL}	2600	2600	m	0,00%
Span	b_W	34,32	34,32	m	0,00%
Aspect ratio	Α	9,42	9,42		0,00%
Cruise speed	V_{CR}	228,6	232	m/s	1,34%
Cruise altitude	h_{CR}	11215	11215	m	0,00%
Squared Sum Absolute maximum deviation					1,79E-04
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,99			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,88		Povoi	rse Engineering
Maximum aerodynamic efficiency	E _{max}	16,00		Kevel	ise Engineering
Specific fuel consumption	SFC	1,77E-05 kg	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

L:	anding	
Landing field length	S _{LFL}	1660 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	72,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,84
Wing loading at maximum take-off mass	m_{MTO}/S_W	632,1 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,99
Ta	ake-off	
Take-off field length	S _{TOFL}	2600 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	\mathbf{k}_{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,303
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,88
2nd	Segment	
Aspect ratio	A	9,423
Lift coefficient, take-off	$C_{L,TO}$	1,30
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,010
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,030
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	11,62
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,220
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,77
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_D,flap$	0,033
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C_D,P	0,068
Glide ratio in landing configuration	EL	8,06
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,244
	10 (MIO 3 /	•

2) Maximum Aerodynamic Efficiency

Constant parameters							
Ratio of specific heats, air	γ	1,4					
Earth acceleration	g	9,81 m/s ²					
Air pressure, ISA, standard	p_0	101325 Pa					
Oswald eff. factor, clean	е	0,85					
Sp	ecifications						
Mach number, cruise	M _{CR}	0,785					
Aspect ratio	Α	9,42					
Bypass ratio	μ	5,60					
Wing loading	m_{MTO}/S_W	632 kg/m²					
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,303					
Variables							
	V/V _{md}	1,1					
C	alculations						
Zero-lift drag coefficient	C _{D,0}	0,025					
Lift coefficient at E _{max}	$C_{L,md}$	0,79					
Ratio, lift coefficient	C _L /C _{L,md}	0,826					
Lift coefficient, cruise	C_L	0,649					
Actual aerodynamic efficiency, cruise	E	15,71					
Max. glide ratio, cruise	E _{max}	16,00					
Newton-Raphson for the maximum lift-to-o	drag ratio						
Iterations	1	2	3				
f(x)	0,00	0,00	0,00				
f'(x)	-0,12	-0,12	-0,12				
E _{max}	16	16,00	16,00				

3) Specific Fuel Consumption

Constant pa	rameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Specifica	itions		
Range	R	1685	NM
Mach number, cruise	M_{CR}	0,785	
Bypass ratio	μ	5,60	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,303	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	79015	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,226	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,538	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	15,71	
Cruise altitude	h _{CR}	11215	
Cruise speed	V _{CR}	232	m/s
Mission fuel	function.		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	M _{ff,engine}	0,990	
Fuel-Fraction, taxi	M _{ff,taxi}	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff.L}	0,992	
-	,-	5,552	
Calculat			
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,237	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,763	
Available fuel mass	MF,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,242	
Mission fuel fraction (acc. to fuel capacity)	\mathbb{M}_{ff}	0,774	
Distance to alternate	S _{to alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,77E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

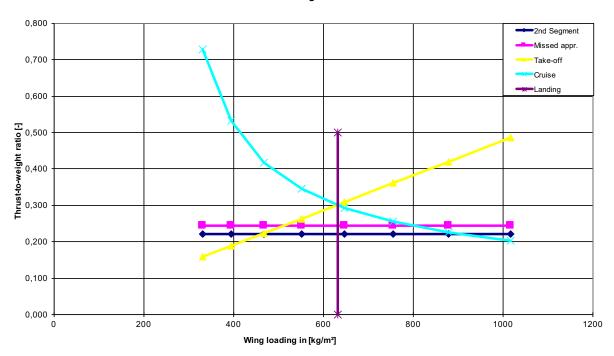
General wing specifications	Airfoil type:	NACA 4 digit
Wing span	b_W	34,32 m
Structural wing span	$b_{W,struct}$	37,87 m
Wing area	S_W	125,0 m ²
Aspect ratio	Α	9,42
Sweep	φ_{25}	25 °
Mean aerodynamic chord	c _{MAC}	4,2 m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t,max}$	30 %c
Relative thickness	t/c	11,5 %
Taper	λ	0,219
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	72,00 m/s
Mach number, landing	M_{APP}	0,22
Mach number, cruise	M_{CR}	0,785
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,0 %c
Leading edge sweep	ϕ_{LE}	28,9 °
Reynoldsnumber	Re	2,2E+07
Maximum lift coefficient, base	C _{L,max,base}	1,57
Correction term, camber	$\Delta_1 c_{L,max}$	0,18
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,084
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,838
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	C _{L,max}	1,45

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{o}}}$	0,87
Flap group A	•	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,42
Use flapped span	b_W,fA	6,9 m
Percentage of flaps allong the wing		18%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,23
Flap group B		
Double-slotted flap	$\Delta c_{L,max,fB}$	1,42
Use flapped span	b_W,fB	11,8 m
Percentage of flaps allong the wing		31%
Increase in maximum lift coefficient, flap group B	ΔC _{L,max,fB}	0,39
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,61
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΦH.L.	27 °
Slat group A		
0,1c Kruger flap	$\Delta c_{L,max,sA}$	0,66
Use slatted span	b_W,sA	4,5 m
Percentage of slats allong the wing		12%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,07
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	25,4 m
Percentage of slats allong the wing		67%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,54
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,61
Wing	_	
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,64
RE value maximum lift coefficient, landing		2,99
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,66
RE value maximum lift coefficient, take-off		1,88
-1270		
A d		
Aerodynamic efficie	ency	
Real aircraft average	k_{WL}	2,83
No winglets	$k_{e,WL}$	1,00
Span	b _W	34,32 m
Winglet height	h	2,49 m
Aspect ratio	Α	9,42
Effective aspect ratio	$A_{ m eff}$	9,42
Efficiency factor, short range	k_{E}	15,15
•		
Relative wetted area	S_{we}/S_{W}	6,35
Verification value maximum aerodynamic efficiency	E _{max}	18,5
RE value maximum aerodynamic efficiency	· · · · · · · · · · · · · · · · · · ·	16,00
15%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,785
Cruise altitude	h_{CR}	11215 m
By Pass Ratio	μ	5,60
Take-off Thrust (one engine)	T _{TO,one engine}	117,43 kN
Overall Pressure ratio	OAPR	27,90
Turbine entry temperature	TET	1451,88
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	$\eta_{ventilator}$	0,87
Compressor efficiency	$\eta_{compresor}$	0,86
Turbine efficiency	$\eta_{ m turbine}$	0,90
Nozzle efficiency	$\eta_{ m nozzle}$	0,98
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T _S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,70
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,78
Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Gas generator function	G	2,16
Verification value specific fuel consumption	SFC	0,59 kg/daN/h
Verification value specific fuel consumption	SFC	1,64E-05 kg/N/s
RE value specific fuel consumption -8%	SFC	1,77E-05 kg/N/s

Matching Chart



Appendix R Boeing 767-300

1	Data Collection	ction		767-300		1			2		3	4	5	9	7	8	6
No. Color		11.11	-		Aircraft characteristics for airport	planning		Jane's	Č	Jenkinson	Engine	Schol			Data collection	Webs	
No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No. No.		эхшро	Onits	Chosen value 290		261-290		3GB	3FB 269-350	SKB	290-261-216			316	3 290-261		
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	Approach speed	V _{APP}	s/w	9,4,6		c		74,6		/6,14	72,54			(7,5			
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	Mass ratio, payload - take-off	MPL/MMT0									0,250113427						
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1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05 1,63E-05	Specific Fuel Comsumption (dry)		kg/N s	9,00E-06									58E-06				
Vote Wilst-paralleles W. Ga, 216 Ga,	Specific Fuel Comsumption (cruise		se kg/N s	1,63E-05								1,6301E-05					
V _{CRR} m/s m/s 236.5 10700 10730 236.64-251.56 mm 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 11887 <td>Available fuel volume</td> <td>Vfuel, available</td> <td></td> <td>63,216</td> <td></td> <td>63,216</td> <td></td> <td></td> <td>63,216</td> <td></td> <td>63,216</td> <td></td> <td></td> <td></td> <td>63,216</td> <td></td> <td></td>	Available fuel volume	Vfuel, available		63,216		63,216			63,216		63,216				63,216		
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everal color * 31.5 cm 31.5 cm <th< td=""><td>Cruise altitude</td><td>hcr</td><td>ε</td><td>11887</td><td>10668-</td><td>11887</td><td></td><td>10700</td><td>10</td><td>730</td><td>11887,2</td><td>10668</td><td></td><td></td><td>11887</td><td></td><td></td></th<>	Cruise altitude	hcr	ε	11887	10668-	11887		10700	10	730	11887,2	10668			11887		
object m 6,98 6,98 6,98 object 20 6,98 6,98 6,98 (Volundo Montal Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon Marcon	Sween andle	-0		31.5							31.5				31.5		
Perf X _{V,O shad} %c 20 (Volbaud'c %c 1.5 1.1.5 1.1.5 Nc % 1.20 1.1.5 Nc % 0.207 0.207 OAPR 30,4 29,9	Mean aerodynamic chord	Canac	ε	86.9							86.9				6.98		
No-hand %c 1,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 11,5 <th< td=""><td>Position of maximum camber</td><td>X(v c) max</td><td>%c</td><td>50</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>20</td></th<>	Position of maximum camber	X(v c) max	%c	50													20
Na. Trans. %c 20 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 <	Camber	(yc)max/c	%c	1,5													1,5
ψc % 11,5 11,5 11,5 λ 0,207 0,207 0,207 0,207 OAPR 30,4 29,9 0,207	Position of maximum thickness	Xt,max	%c	20													20
A 0,207 0,267211202 0,207 30,4 29,9	Relative thickness	t/c	%	11,5							11,5				11,5		12
OAPR 30,4	Taper	~		0,207					,267211202		0,207				0,207		
+1+	Overall pressure ratio	OAPR		30,4								30,4	29,9				

Aeroplane Specifications

Data to apply reverse engineering LL UL **1646** m Landing field length Known s_{LFL} Approach speed Known V_{APP} 74,60 m/s 74,6 74,6 Temperature above ISA (288,15K) 0 K ΔT_L Relative density 1 σ Take-off field length 2545 m 2545 2545 Known STOFL Temperature above ISA (288,15K) ΔT_{TO} 0 K Relative density σ 1,000 2091 NM Range (maximum payload) R M_{CR} Cruise Mach number 0,8 Wing area S_W 283 m² Wing span Known 47,57 m² 47,57 47,57 b_W Aspect ratio Α 7,99 Maximum take-off mass 158758 kg m_{MTO} Maximum payload mass 39140 kg ${\rm m}_{\rm PL}$ Mass ratio, payload - take-off 0,247 m_{PL}/m_{MTO} Maximum landing mass 136078 kg m_{ML} Mass ratio, landing - take-off 0,857 $m_{ML}\!/m_{MTO}$ Operating empty mass m_{OE} 84541 kg Mass ratio, operating empty - take-off 0,533 m_{OE}/m_{MTO} Wing loading 560,4 kg/m² m_{MTO}/S_W 2 Number of engines n_E Take-off thrust for one engine 231,351 kN T_{TO,one engine} Total take-off thrust T_{TO} 462,702 kN Thrust to weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,297 Bypass ratio 5,3 23,86 m³ Available fuel volume V_{fuel.available}

Data			

		P				
					LL	UL
Cruise speed		V_{CR}	237 m	n/s		
Cruise altitude		h_{CR}	11887 m	n		
Speed ratio		V/V_{md}	1,000 -		1	1,316
	Data to execu	ite the verification				
					Ran	ige
Sweep angle		φ_{25}	31,5 °			
Mean aerodynamic chord		C _{MAC}	6,98 m	n		
Position of maximum camber		$\mathbf{x}_{(y_c),max}$	30 %	6С	15 - 50	%с
Camber		(y _c) _{max} /c	4 %	6С	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30 %	6С	30 - 45	%с
Relative thickness	Unknown	t/c	11,3 %	6		
Taper		λ	0,207			

Reverse Engineering

Specific fuel consumption

Reverse engineering &	optimization	of V/Vmd
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		y a optimization of			
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1646	1646	m	0,00%
Approach speed	V_{APP}	74,60	74,6	m/s	0,00%
Take-off field length	S _{TOFL}	2545	2545	m	0,00%
Span	b_W	47,57	47,57	m	0,00%
Aspect ratio	Α	7,99	7,99		0,00%
Cruise speed	V_{CR}	236,5	236	m/s	-0,17%
Cruise altitude	h_{CR}	11887	11828	m	-0,50%
Squared Sum					2,77E-05
Absolute maximum deviation					0,5%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,73			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,73		Reve	erse Engineering
Maximum aerodynamic efficiency	E _{max}	17,44		1/6/6	arse Engineening

1,52E-05 kg/N/s

SFC

1) Maximum Lift Coefficient for Landing and Take-off

Land	ing	
Landing field length	S _{LFL}	1646 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	74,60 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,86
Wing loading at maximum take-off mass	m_{MTO}/S_W	560,4 kg/m ²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,73
Take	off	
Take-off field length	S _{TOFL}	2545 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,297
Maximum lift coefficient, take-off	C _{L,max,TO}	1,73
,	- L,max, 10	.,
2nd Seg		
Aspect ratio	A	7,988
Lift coefficient, take-off	C _{L,TO}	1,20
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,005
Lift-independent drag coefficient, slats	$\DeltaC_D,slat$	0,000
Profile drag coefficient	$C_{D,P}$	0,025
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	11,17
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,227
·		
Lift coefficient, landing		1 61
	C _{L,L}	1,61
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,026
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25 FAR Part 25	no yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C _{D,P}	0,013
Glide ratio in landing configuration		7,72
Gilde Tatio III landing configuration	Ęį	1,12
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,258

2) Maximum Aerodynamic Efficiency

Const	tant parameters					
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g	9,81 m/s ²				
Air pressure, ISA, standard	p_0	101325 Pa				
Oswald eff. factor, clean	е	0,85				
Sp	ecifications					
Mach number, cruise	M _{CR}	0,8				
Aspect ratio	Α	7,99				
Bypass ratio	μ	5,30				
Wing loading	m_{MTO}/S_W	560 kg/m²				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,297				
Variables						
	V/V_{md}	1,0	_			
c	alculations					
Zero-lift drag coefficient	C _{D,0}	0,018				
Lift coefficient at E _{max}	$C_{L,md}$	0,61				
Ratio, lift coefficient	$C_L/C_{L,md}$	1,000				
Lift coefficient, cruise	C_L	0,611				
Actual aerodynamic efficiency, cruise	E	17,44				
Max. glide ratio, cruise	E _{max}	17,44				
Newton-Raphson for the maximum lift-to-drag ratio						
Iterations	1	2	3			
f(x)	0,17	0,00	0,00			
f(x)	-0,11	-0,12	-0,12			
E _{max}	16	17,48	17,44			

3) Specific Fuel Consumption

Constant par	ameters						
Ratio of specific heats, air	γ	1,4					
Earth acceleration	g		m/s²				
Air pressure, ISA, standard	p_0	101325					
Fuel density	$ ho_{fuel}$	800	kg/m³				
Specifications							
Range	R	2091	NM				
Mach number, cruise	M _{CR}	0,8					
Bypass ratio	μ	5,30					
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,297					
Available fuel volume	$V_{ m fuel,available}$	23,86					
Maximum take-off mass	m_{MTO}	158758	kg				
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,247					
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,533					
Calculated v	values						
Actual aerodynamic efficiency, cruise	E	17,44					
Cruise altitude	h _{CR}	11828	m				
Cruise speed	V_{CR}	236	m/s				
Mission fuel	fraction						
Type of aeroplane (according to Roskam)	Transport jet						
Fuel-Fraction, engine start	$M_{ m ff,engine}$	0,990					
Fuel-Fraction, taxi	$M_{\rm ff,taxi}$	0,990					
Fuel-Fraction, take-off	$M_{\rm ff,TO}$	0,995					
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980					
Fuel-Fraction, descent	$M_{ff,DES}$	0,990					
Fuel-Fraction, landing	$M_{ff,L}$	0,992					
Calculati	ons						
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,221					
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,779					
Available fuel mass	200	10000	ka				
	F,available	19088	kg				
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,120					
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,898					
Distance to alternate	S _{to_alternate}	200	NM				
Distance to alternate	S _{to_alternate}	370400	m				
Choose: FAR Part121-Reserves	domestic	no					
	international	yes					
Extra-fuel for long range		5%					
Extra flight distance	S _{res}	564027					
Loiter time	t _{loiter}	1800	S				
Specific fuel consumption	SFC	1,52E-05	kg/N/s				

4) Verification Specifications

Maximum lift coefficients

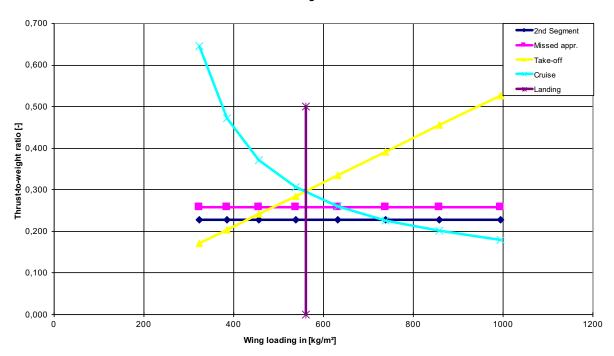
General wing specifications	Airfoil type:	NACA 65 series
Wing span	b_W	47,57 m
Structural wing span	b _{W,struct}	55,79 m
Wing area	S_W	283,3 m ²
Aspect ratio	Α	7,99
Sweep	φ_{25}	31,5 °
Mean aerodynamic chord	C _{MAC}	6,98 m
Position of maximum camber	$\mathbf{x}_{(y_{-c}), max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
Relative thickness	t/c	11,3 %
Taper	λ	0,207
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	74,60 m/s
Mach number, landing	M_{APP}	0,23
Mach number, cruise	M_{CR}	0,8
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,2 %c
Leading edge sweep	ϕ_{LE}	36,2 °
Reynoldsnumber	Re	3,7E+07
Maximum lift coefficient, base	$\mathbf{c}_{L,max,base}$	1,29
Correction term, camber	$\Delta_1 c_{L,max}$	0,40
Correction term, thickness	$\Delta_2 \mathbf{c}_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 \mathbf{c}_{L,max}$	0,040
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,733
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,83
Correction term, Mach number	ΔC _{L,max}	-0,03
Lift coefficient, wing	C _{L,max}	1,41

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	K_{ω}	0,84
Flap group A	Ψ	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,39
Use flapped span	b W,fA	36,9 m
Percentage of flaps allong the wing	~,	66%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,77
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,72
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	ΔC _{L,max,f}	0,77
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	$\phi_{H.L.}$	34 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,88
Use slatted span	b_W,sA	9,7 m
Percentage of slats allong the wing		17%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,13
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,88
Use slatted span	b_W,sB	36,4 m
Percentage of slats allong the wing		65%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,47
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,60
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,74
RE value maximum lift coefficient, landing	CL,max,L	2,73
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,75
RE value maximum lift coefficient, take-off	OL,max,TO	1,73
1%		1,73
Aerodynamic ef	ficiency	
5		
Real aircraft average	k _{WL}	2,83
End plate	$k_{e,WL}$	1,10
Span	b_W	47,57 m
Winglet height	h	3,4 m
Aspect ratio	Α	7,99
Effective aspect ratio	A_{eff}	8,81
Efficiency factor, short range	k _E	15,15
Relative wetted area	S _{wel} /S _W	5,44
Varification value maximum coradunamia officionav	E	19,3
Verification value maximum aerodynamic efficiency	E _{max}	•
RE value maximum aerodynamic efficiency		17,44
11%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,800
Cruise altitude	h _{CR}	11887 m
By Pass Ratio	μ	5,30
Take-off Thrust (one engine)	T _{TO,one engine}	231,35 kN
Overall Pressure ratio	OAPR	30,40
Turbine entry temperature	TET	1485,42
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	$\eta_{ m ventilator}$	0,89
Compressor efficiency	$\eta_{compresor}$	0,87
Turbine efficiency	$\eta_{ m turbine}$	0,91
Nozzle efficiency	η_{nozzle}	0,99
Temperature at SL	T_o	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,86
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,13
Temperature function	χ	1,86
Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Gas generator function	G	2,27
Verification value specific fuel consumption	SFC	0,57 kg/daN/h
Verification value specific fuel consumption	SFC	1,58E-05 kg/N/s
RE value specific fuel consumption 4%	SFC	1,52E-05 kg/N/s

Matching Chart



Appendix S Bombardier CRJ900

Parameter g field length ch speed rature above ISA (288,15K) e density ffield length rature above ISA (288,15K) e density ffield length rature above ISA (288,15K) e density max payload) Mach number ratio mulanding mass aftio, payload - take-off amass aftio, payload - take-off mulanding mass art of engines bype fifthrust for one engine statio c Fuel Comsumption (dry) c Fuel Comsumption (cruise) let fuel volume angle		_	2		8	4	9	7	80	6
Parameter Symbol Units g field length St.F.L m ch speed V _{APP} m/S rature above ISA (288,15K) ΔT.C K e density s rope. m rature above ISA (288,15K) ΔTro K e density s rope. m rature above ISA (288,15K) ΔTro K m cature above ISA (288,15K) ΔTro K m cature above ISA (288,15K) A rope. m m cature above ISA (288,15K) A rope. m m cature above ISA (288,15K) R Km m cature above ISA (288,15K) M _{CR} M m cature above ISA (288,15K) R M m cature above ISA (288,15K) R M m cature above ISA (288,15K) M _{CR} M m cature above ISA (288,15K) M _{CR} M m cature above ISA (288,15K) M _{CR} M m cature above ISA (288,15K) M _{CR} M _{CR} m cature above ISA (288,15K) M _{CR} M _{CR}	Source:	Aircraft characteristics	Jane's	4	lenkinson Fro	Engine Scholz	Paul Miller		Flodie Boux Data collection	Webs
Sepecial English		for airport planning	900 900ER	900LR					Data collection	webs
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Troone engine Troone engine RN		GE CF34-8C5	CF34-8C5		CF3	CF34-8C5			CF34-8C5	
Tro KN	58,4		58,4 - 63,4		64	64,4992		64,499	58,4	58,4
to weight ratio								6		
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c Fuel Comsumption (dry) SFC (dry) kg/N s 1 c Fuel Comsumption (cruise) SFC (cruise kg/N s 1 speed V _{total available} m² speed V _{CR} m/s atitude h _{CR} m angle φ ₂₅ ° angle φ ₂₅ ° nof maximum camber X _{V_C S, max} %c n 0 (y _c h _{max} /c) %c n 0 (y _c h _{max} /c) %c n 0 (y _c h _{max} /c) %c e trickness t/c %					;	4,9		4,9		
In the common forms Common forms Common forms					1,10	E-05		1,11E-05		
Note Volume Vol										
speed V _{CR} m/s altitude h _{CR} m angle φ ₂₅ ° nor maximum camber x _{(y, c)max} %c nor maximum thickness X _{(max} %c nor maximum thickness t/c %c	10,989	10,989	10,989					11,148		
altitude hcR angle φ ₂₅ serodynamic chord Q _{AnC} n of maximum camber X _{V-chmax} nr (V _{C-bmax} C n of maximum thickness X _{Chmax} C trickness V _C	244								235,615556	244,72
angle ϕ_{23} retrodynamic chord α_{MoC} α_{MoC} of maximum camber $X_{V_C, c_{I,max}}$ or of maximum thickness $X_{f,max}$ thickness $X_{f,max}$										
rerodynamic chord G _{AMC} n of maximum camber X _{ty. c,nmax} rr (yc,h _{max} /c n of maximum thickness X _{t,max} tr tr tr tr tr tr tr tr tr t										
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if of maximum thickness $x_{i,max}$ of thickness $t_{i,max}$										
n of maximum thickness $x_{t,max}$ e thickness t/c										
e thickness t/c										
		+								
OAPR	_									
Turbine entry temperature TET K										$\left \right $

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1596	m		
Approach speed	Known	V_{APP}	71,50	m/s	71,5	71,5
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	1878	m	1878	1878
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	987	NM		
Cruise Mach number		M _{CR}	0,78			
Wing area		S _W	69	m²		
Wing span	Known	b_W	23,24	m²	23,24	23,24
Aspect ratio		Α	7,87			
Maximum take-off mass		m _{MTO}	38329	kg		
Maximum payload mass		m_{PL}	10205	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,266			
Maximum landing mass		m_{ML}	33340	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,870			
Operating empty mass		m_OE	21432	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,559			
Wing loading		m_{MTO}/S_W	558,5	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	58,4	kN		
Total take-off thrust		T _{TO}	116,8	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,311			
Bypass ratio		μ	4,9			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to	optimize	V/V_{md}
------	----	----------	------------

		1110		1.1	1.11
Crudes aread		M	244/-	LL	UL
Cruise speed		V_{CR}	244 m/s		
Cruise altitude		h_CR	11278 m		
Speed ratio		V/V_{md}	1,086 -	1	1,316
	Data to execu	te the verification			
				Rar	ige
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		c _{MAC}	4,2 m		
Position of maximum camber		$\mathbf{x}_{(y_c),max}$	30 %c	15 - 50	%с
Camber		$(y_c)_{max}/c$	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,6 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimization of V/Vm

	•				
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1596	1596	m	0,00%
Approach speed	V_{APP}	71,50	71,5	m/s	0,00%
Take-off field length	S _{TOFL}	1878	1878	m	0,00%
Span	b_W	23,24	23,24	m	0,00%
Aspect ratio	Α	7,87	7,87		0,00%
Cruise speed	V_{CR}	244,0	230	m/s	-5,66%
Cruise altitude	h_{CR}	11278	11278	m	0,00%
Squared Sum Absolute maximum deviation					3,20E-03 5,7%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,84			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,24		Boyer	se Engineering
Maximum aerodynamic efficiency	E _{max}	15,17		Rever	se Engineering
Specific fuel consumption	SFC	1,47E-05 kg/	N/s		
-F	.	.,			

1) Maximum Lift Coefficient for Landing and Take-off

Lai	nding	
Landing field length	S _{LFL}	1596 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	1,70 (m/s²) ^{0.5}
Approach speed	V_{APP}	71,50 m/s
Factor, landing	k_L	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,87
Wing loading at maximum take-off mass	m_{MTO}/S_W	558,5 kg/m ²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,84
Tal	ke-off	
Take-off field length	S _{TOFL}	1878 m
Temperatur above ISA (288,15K)	ΔT _{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,311
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,24
2nd S	Segment	
Aspect ratio	A	7,870
Lift coefficient, take-off	$C_{L,TO}$	1,56
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,023
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C _{D,P}	0,043
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	8,52
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,283
Misson	approach	
Lift coefficient, landing	C _{L,L}	1,68
Lift-independent drag coefficient, clean	C _{D.0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,029
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	$C_{D,P}$	0,064
Glide ratio in landing configuration	EL	7,39
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,272
ast to moight ratio	· 10/ (···M10 9/	V,=1 =

2) Maximum Aerodynamic Efficiency

Const	tant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
0			
	ecifications	0.70	
Mach number, cruise	M _{CR}	0,78	
Aspect ratio	Α	7,87	
Bypass ratio	μ	4,90	
Wing loading	m_{MTO}/S_W	558 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,311	
	Variables		
		4.4	
	V/V_{md}	1,1	
C	alculations		
Zero-lift drag coefficient	C _{D,0}	0,023	
Lift coefficient at E _{max}	$C_{L,md}$	0,69	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,848	
Lift coefficient, cruise	C_L	0,587	
Actual aerodynamic efficiency, cruise	E	14,97	
Max. glide ratio, cruise	E _{max}	15,17	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	1	2	3
f(x)	-0,11	0,00	0,00
f'(x)	-0,13	-0,13	-0,13
E _{max}	16	15,18	15,17

3) Specific Fuel Consumption

Constant	parameters	
Ratio of specific heats, air	γ	1,4
Earth acceleration	g	9,81 m/s ²
Air pressure, ISA, standard	p_0	101325 Pa
Fuel density	$ ho_{fuel}$	800 kg/m³
Specifi	cations	
Range	R	987 NM
Mach number, cruise	M_{CR}	0,78
Bypass ratio	μ	4,90
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,311
Available fuel volume	$V_{ m fuel,available}$	23,86 m³
Maximum take-off mass	m_{MTO}	38329 kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,266
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,559
Calculate	ed values	
Actual aerodynamic efficiency, cruise	E	14,97
Cruise altitude	h _{CR}	11278 m
Cruise speed	V _{CR}	230 m/s
Type of aeroplane (according to Roskam)	el fraction Transport jet	
Fuel-Fraction, engine start		0,990
Fuel-Fraction, taxi	M _{ff,engine}	0,990
•	M _{ff,taxi}	·
Fuel-Fraction, take-off	M _{ff,TO}	0,995
Fuel-Fraction, climb	M _{ff,CLB}	0,980
Fuel-Fraction, descent	M _{ff,DES}	0,990
Fuel-Fraction, landing	$M_{ff,L}$	0,992
	ations	
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,175
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,825
Available fuel mass	F,available	19088 kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,498
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,512
Distance to alternate	S _{to_alternate}	200 NM
Distance to alternate	S _{to_alternate}	370400 m
Choose: FAR Part121-Reserves	domestic	yes
	international	no
Extra-fuel for long range		5%
Extra flight distance	S _{res}	370400 m
Loiter time	t _{loiter}	2700 s
Specific fuel consumption	SFC	1,47E-05 kg/N/s

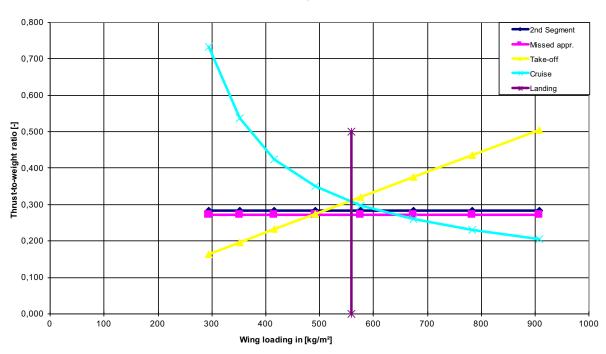
4) Verification Specifications

Maximum lift coefficients

General wing specifications	Airfoil type:	NACA 4 digit
Wing span	b _W	23,24 m
Structural wing span	b _{W,struct}	25,64 m
Wing area	S _W	68,6 m ²
Aspect ratio	A	7,87
Sweep	ϕ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	X _{t.max}	30 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	71,50 m/s
Mach number, landing	M_{APP}	0,22
Mach number, cruise	M _{CR}	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,0 %c
Leading edge sweep	ϕ_{LE}	29,5 °
Reynoldsnumber	Re	2,1E+07
Maximum lift coefficient, base	C _{L.max.base}	1,58
Correction term, camber	$\Delta_1 c_{L,max}$	0,18
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,086
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,838
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,79
Correction term, Mach number	ΔC _{L,max}	-0,02
Lift coefficient, wing	C _{L,max}	1,45

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87
Flap group A	·	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,42
Use flapped span	b_W,fA	15,3 m
Percentage of flaps allong the wing		60%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,73
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing	AC	0% 0,00
Increase in maximum lift coefficient, flap group B	ΔC _{L,max,fB}	
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,73
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	Ψ _{H.L.}	30 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	20 m
Percentage of slats allong the wing		78%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,61
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing Increase in maximum lift coefficient, slat group B	AC	0% 0.00
	ΔC _{L,max,sB}	
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,61
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,75
RE value maximum lift coefficient, landing		2,84
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,16
RE value maximum lift coefficient, take-off		2,24
-3%		
Aerodynamic effic	eiency	
Real aircraft average	k	2,83
_	k _{WL}	
End plate	k _{e,WL}	1,08
Span	b _W	23,24 m
Winglet height Aspect ratio	h A	1,32 m 7,87
Effective aspect ratio	A _{eff}	8,51
Endourd adpost ratio	ren	0,01
Efficiency factor, short range	k_{E}	15,15
Relative wetted area	S _{wel} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	17,5
RE value maximum aerodynamic efficiency		15,17
16%		

Matching Chart



Appendix T Embraer ERJ-145

Parameter Symbol Units Chosen value	000000		1			2		3	4	2	9	7	8	6
Symbol Units	Source.	Aircraft charae	Aircraft characteristics for airport planning	planning		Jane's		lenkinson	Fnoine	Scholz	Paul Miller	Flodie Roux	Flodie Roux Data collection	Webs
15K) ATL K	value	쏪	씸	×	ER	꿈	XX	- 1	2			STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STORE OF STO		
15K) ATL K			00					06			20	09		
15K AT, K	0	1375	1400	1450	1390		1430	1290			1290	1400	1400	1400
15K) ATL K S								64.8			61.11			
Since. M			0					0			0			
Stock. M														
15K) ATro Km	9	1800	2300	2050	1070		0800	7500				0700	1770	0200
S	,	200	2004	2007	2		2007					0177	2	0177
R Km Mcs m² Sw m² Dw m A mmro kg mer.maro kg macr kg macr kg macr kg macr kg macr kg macr kg Toone engine kN Toone engine		•												
Mea Sw m²	69	1760	2130	3333		3000	3704	1574,2			2800	1759		2900
Sw, m² bw, m A mano kg mer, kg mer, kg mer, kg mer, more mer, kg me	80				0,78		8'0					0,64	0,78	0,78
Dw min A marco Merican Meri	<u> </u>		4 12			71 18		7,10			27	71		51.2
A A MINO KG MATO KG MA	2 2	NO 00		50		20,12		20,10			20,50	20,50	NO 00	2,10
Mario Kg Merio Kg Merio Kg Merion Kg Merion Merion Kg Merion Merion Kg Merion M	2 3	r0,02	7,8	17		7,9		7,846846424			7,9	7,85	50,03	1 0,0 2
Mario Naj Mario Naj Mario Naj Mario Ma	5	00900	00000	04400	00900	00000	04400	10000			10000	00900	00000	00000
The manufacture of manufacture of manufacture of more manufacture of manufacture of more manufacture of more manufacture of manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more manufacture of more more manufacture of more more manufacture of more more more more more more more more	3 22	5153	5786	5909	5160	5800	5920	5515			2020	5153	0000	5786
Take-off me.march. Take-off moemarch. Take-off moemarch. Take-off moemarch. Take-off moemarch. Take-off moemarch. Troome regime. NM Troome								0,287239583				0,25		
Take-off mose. Mar.	00	18700	19300	20000	18700	19300	20000	18700			18700	18700		19300
take-off moemuno muro/Sw kg/m² muro/Sw kg/m² muzr kg ne ne ne ne ne ne ne ne ne ne ne ne ne								0,973958333						
ff moemano marzoSav kg/m² marzoSav kg/m² marzo kg marzo kg marzo kg marzo km Troome engine kN STC (dry) kg/N s SFC (dry) kg/N s SFC (cruise kg/N s	40	11947	12114	12591	11940	12100	12580	11585				11947	-	11667-11740
marc/Sw, kg/m² macr kg ne ne Tro.me sogine Tro.me sogine Tro/(marc°g) Tro/(marc°g) SPC (cruise kg/N s								0,603385417				0,58		
m _{MSF} kg ne RRAE3007 Tr _{Oome engine} kN Tr _O (m _M n°9) p p p p SFC (dry) kg/N s SFC (cruise kg/N s	5,5				402,5	429,8	470,9	375,1465416				403		
ne RR AE3007 Troome engine kN Tro/(marc*g) p p p SFC (dry) kg/N s SFC (cruise kg/N s	00	17100	17900	18200	17100	17900	18500	17100				17100		
RR AE3007 Troome engine						2		2				2	2	2
Troone engine KN Tro Tro Tro(marro*g) µ SFC (dry) kg/N s SFC (cruise kg/N s	7A1/1	AE3007 A1 - A1/1		AE3007 A1E	AE 3007A - AE 3007A1P		AE 3007A1Es A	AE3007A			4	AE3007A1/1 AE-3007A		
Tro/(marro*g) µ SFC (dry) kg/N s SFC (cruise kg/N s	17				33,7-37,1		39,6	31,32				33,717	31,3	33
Tro/(maro*g) µ SFC (dry) kg/N s SFC (cruise kg/N s														
μ SFC (dry) kg/N s SFC (cruise kg/N s	3				0,3345601	0,3130086	0,334560054	0,332568807				0,33		
SFC (dry)	m											5,3		
Available fuel volume V _{fuel available} m³ 5,146	94	5,146	968'9	7,438	5,091	6,352	7,382	5,146				5,146		
V _{CR} m/s	5				231,5		-	188,8-210,92					231,5	231,67
6	78		11278				O	9753,6-11277,6				11278		
Sweep andle								22.73				22.7		
namic chord	8							3,13				3,13		
ber X _{(y c),max} %c														
(yc)may/c														
of maximum thickness x _{t,max} %c														
ve thickness t/c %						0010101		11				11		
Control accounts and CADD 254	4				'n	0,254278729		0,231				0,254		22
2												Ī		3

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1400	m		
Approach speed	Known	V_{APP}	65,00	m/s	65,0	65,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	2270	m	2270	2270
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	950	NM		
Cruise Mach number		M _{CR}	0,78			
Wing area		S _W	51	m²		
Wing span	Known	b_W	20,04	m²	20,04	20,04
Aspect ratio		Α	7,85			
Maximum take-off mass		m _{MTO}	20600	kg		
Maximum payload mass		m_PL	5153	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,250			
Maximum landing mass		m_ML	18700	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,908			
Operating empty mass		m_OE	11940	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,580			
Wing loading		m_{MTO}/S_W	402,5	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	33,717	kN		
Total take-off thrust		T _{TO}	67,434	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,334			
Bypass ratio		μ	5,3			
Available fuel volume		fuel,available	23,86	m³		

Data	to	optimize	V/V_{md}

		P				
					LL	UL
Cruise speed		V_{CR}	232	m/s		
Cruise altitude		h _{CR}	11278	m		
Speed ratio		V/V_{md}	1,256	-	1	1,316
	Data to execu	te the verification				
					Rar	ige
Sweep angle		ϕ_{25}	22,7	•		
Mean aerodynamic chord		C _{MAC}	3,13	m		
Position of maximum camber		X _{(y_c),max}	30	%с	15 - 50	%с
Camber		$(y_c)_{max}/c$	4	%с	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	11,6	%		
Taper		λ	0,254			

Reverse Engineering

Reverse engineering 8	k optimization of V/Vmd
-----------------------	-------------------------

	•			
Quantity	Original value	RE value	Unit	Deviation
S _{LFL}	1400	1400	m	0,00%
V_{APP}	65,00	65,0	m/s	0,00%
s _{TOFL}	2270	2270	m	0,00%
b_W	20,04	20,04	m	0,00%
Α	7,85	7,85		0,00%
V_{CR}	231,5	230	m/s	-0,57%
h_{CR}	11278	11278	m	0,00%
				3,20E-05 0,6%
Results rev	erse engineering			
$C_{L,max,L}$	2,44			
	1,24		Pover	rse Engineering
E _{max}	15,70		Kever	se Engineering
SFC	1,37E-05 kg/	/N/s		
	S _{LFL} V _{APP} S _{TOFL} b _W A V _{CR} h _{CR} Results reversely C _{L,max,L} C _{L,max,TO} E _{max}	SLFL 1400 VAPP 65,00 STOFL 2270 bW 20,04 A 7,85 VCR 231,5 hCR 11278 Results reverse engineering CL,max,L CL,max,TO Emax 11,24 Emax 15,70	SLFL 1400 1400 VAPP 65,00 65,0 STOFL 2270 2270 bW 20,04 20,04 A 7,85 7,85 VCR 231,5 230 hCR 11278 11278 Results reverse engineering CL,max,L CL,max,TO 1,24 Emax 15,70	S _{LFL} 1400 1400 m V _{APP} 65,00 65,0 m/s S _{TOFL} 2270 2270 m b _W 20,04 m 20,04 m A 7,85 7,85 V _{CR} 231,5 230 m/s h _{CR} 11278 11278 m Results reverse engineering C _{L,max,L} C _{L,max,TO} 1,24 C _{L,max,TO} E _{max} 15,70 Rever

1) Maximum Lift Coefficient for Landing and Take-off

Lan	ding	
Landing field length	S _{LFL}	1400 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	1,70 (m/s²) ^{0.5}
Approach speed	V_{APP}	65,00 m/s
Factor, landing	k_L	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,91
Wing loading at maximum take-off mass	m_{MTO}/S_W	402,5 kg/m ²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,44
Tak	e-off	
Take-off field length	S _{TOFL}	2270 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,334
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,24
2nd Sc	egment	
Aspect ratio	A	7,847
Lift coefficient, take-off	$C_{L,TO}$	0,86
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,000
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C _{D,P}	0,020
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	13,66
Number of engines	n-	2
Climb gradient	n _E sin(γ)	0,024
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,194
•		,
Lift coefficient, landing	approach C	1,44
Lift-independent drag coefficient, clean	C _{L,L} C _{D.0} (Missed approach)	0,020
Lift-independent drag coefficient, clean Lift-independent drag coefficient, flaps	-1	0,020
	$\Delta C_{D,flap}$	0,000
Lift-independent drag coefficient, slats Choose: Certification basis	$\Delta C_{D,slat}$ JAR-25 resp. CS-25	•
CHOOSE. CERTIFICATION DASIS	FAR Part 25	no yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C _{D,P}	0,052
Glide ratio in landing configuration	E _L	8,35
	− ⊾	-,
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,256

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
	ecifications		
Mach number, cruise	M_{CR}	0,78	
Aspect ratio	Α	7,85	
Bypass ratio	μ	5,30	
Wing loading	m_{MTO}/S_W	403 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,334	
	Variables		
	V/V _{md}	1,3	
c	alculations		
Zero-lift drag coefficient	C _{D,0}	0,021	
Lift coefficient at E _{max}	$C_{L,md}$	0,67	
Ratio, lift coefficient	C _L /C _{L,md}	0,634	
Lift coefficient, cruise	C_L	0,423	
Actual aerodynamic efficiency, cruise	E	14,20	
Max. glide ratio, cruise	E _{max}	15,70	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations		2	3
f(x)	-0,04	0,00	0,00
f(x)	-0,13	-0,13	-0,13
E _{max}	16	15,70	15,70

3) Specific Fuel Consumption

Constant para	ameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	•	m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Specificat	ions		
Range	R		NM
Mach number, cruise	M _{CR}	0,78	
Bypass ratio	μ	5,30	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,334	
Available fuel volume	$V_{ m fuel,available}$	23,86	
Maximum take-off mass	m_{MTO}	20600	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,250	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,580	
Calculated v	values		
Actual aerodynamic efficiency, cruise	E	14,20	
Cruise altitude	h _{CR}	11278	m
Cruise speed	V_{CR}	230	m/s
Mission fuel	fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{\rm ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{\rm ff,CLB}$	0,980	
Fuel-Fraction, descent	$M_{ff,DES}$	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
Calculation	ons		
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,170	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,830	
,	"	,	
Available fuel mass	F,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,927	
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,075	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,37E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

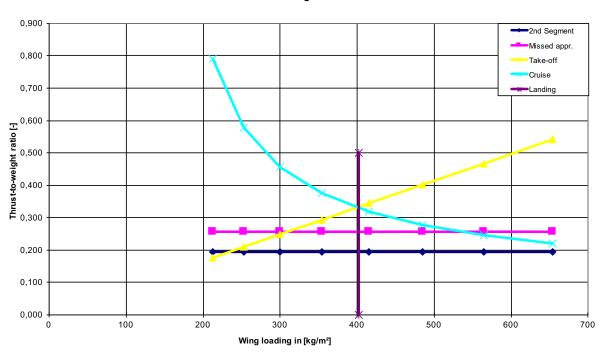
General wing specifications	Airfoil type:	NACA 4 digit
Wing span	b_W	20,04 m
Structural wing span	$b_{W,struct}$	21,72 m
Wing area	S _W	51,2 m²
Aspect ratio	Α	7,85
Sweep	φ_{25}	22,7 °
Mean aerodynamic chord	C _{MAC}	3,13 m
Position of maximum camber	x _{(y_c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	X _{t.max}	30 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,254
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	65,00 m/s
Mach number, landing	M_APP	0,20
Mach number, cruise	M_{CR}	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,0 %c
Leading edge sweep	ϕ_{LE}	27,0 °
Reynoldsnumber	Re	1,5E+07
Maximum lift coefficient, base	C _{L,max,base}	1,58
Correction term, camber	$\Delta_1 c_{L,max}$	0,18
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,038
Maximum lift coefficient, airfoil	C _{L.max.clean}	1,790
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,81
Correction term, Mach number	$\Delta C_{L,max}$	0,00
Lift coefficient, wing	C _{L,max}	1,44

Calculations increase of lift coefficient due to fla	ps	1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,88
Flap group A		
Double-slotted flap	$\Delta c_{L,max,fA}$	1,41
Use flapped span	b_W,fA	14,4 m
Percentage of flaps allong the wing	46	66%
Increase in maximum lift coefficient, flap group A	\DeltaC_L,max,fA	0,82
Flap group B O,3c Plain flap	40	0,74
Use flapped span	$\Delta c_{L,max,fB}$ b_W,fB	0,74 0 m
Percentage of flaps allong the wing	5_44,15	0%
Increase in maximum lift coefficient, flap group B	\DeltaC_L,max,fB	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,82
more decomposition, map	s_,max,i	0,02
Calculations increase of lift coefficient due to sla	ts	No slats
Sweep angle of the hinge line	ΨH.L.	26 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	20 m
Percentage of slats allong the wing		92%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,74
Slat group B		0.00
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span Percentage of slats allong the wing	b_W,sB	0 m 0%
Increase in maximum lift coefficient, slat group B	۸.	0,00
Increase in maximum lift coefficient, slat	$\Delta C_L,max,sB$	0,00
	— - <u>L</u> ,max,s	5,55
Wing	0	2.22
Verification value maximum lift coefficient, landing RE value maximum lift coefficient, landing	$C_{L,max,L}$	2,22 2,44
Verification value maximum lift coefficient, take-off	$C_{L.max.TO}$	1,13
RE value maximum lift coefficient, take-off	OL,max,TO	1,24
The value maximum int coemicient, take-on	-9%	1,24
,		
Aerodyn	amic efficiency	
Real aircraft average	k_WL	2,83
No winglets	k _{e,WL}	1,00
Span	b _W	20,04 m
Winglet height	h	2,7 m
Aspect ratio	A	7,85
Effective aspect ratio	A_{eff}	7,85
Efficiency factor, short range	k _E	15,15
Relative wetted area	S _{we} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	16,8
RE value maximum aerodynamic efficiency	1164	15,70
	7%	

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,780
Cruise altitude	h _{CR}	11278 m
By Pass Ratio	μ	5,30
Take-off Thrust (one engine)	T _{TO,one engine}	33,72 kN
Overall Pressure ratio	OAPR	23,00
Turbine entry temperature	TET	1282,73
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	$\eta_{ m ventilator}$	0,76
Compressor efficiency	η _{compresor}	0,82
Turbine efficiency	η _{turbine}	0,84
Nozzle efficiency	$\eta_{ m nozzle}$	0,94
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T _S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	φ	5,92
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,63
Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Gas generator function	G	1,51
Verification value specific fuel consumption	SFC	0,83 kg/daN/h
Verification value specific fuel consumption	SFC	2,32E-05 kg/N/s
RE value specific fuel consumption	SFC	1,37E-05 kg/N/s
69%		, = 33 .

Matching Chart



Appendix U Boeing 787-8

Data Collection	ction		8-787		2	3	4	5	9	7	8	6	
Parameter	Symbol	Units	Chosen value	Aircraft characteristics for airport planning GE RR	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Paul Müller∃lodie Roux∂ata collectior	Webs	s
PAX	6	2	440	242-359-38	237-375-440							7	440-327
Landina field lenath	ū	Ε	1520	1630							1520		
Approach speed	VAPP	s/m	72								72,022222		
Temperature above ISA (288,15K)	DT	¥	0	0									
Relative density	Ø												
Take-off field length	STOFL	Ε	3100	3090							3100		3140
Temperature above ISA (288,15K)	DT _{TO}	×	0	0									
Relative density	S												
Range (max payload)	œ	k	10180	10180	14816								15200
Cruise Mach number	McR		0,85	0,85	0,85						0,85		0,85
Wing	ď	3 ²	325										325
Wing span	à	Ε	60.12	60.12	60.12						60.1		09
Aspect ratio	A		11,1										11,0769
			000000	000000	0.00								000000
Maximum take-on mass	ПМТО	Đ.	227930	227930	719330						720000		22/930
Payload mass	m _P		52165	52765	03050								
Maximim landing mass	O WILLIAM CO	2	167825	172365	167825								172365
Mass ratio. landing - take-off	mw. Marto		220101	0007	20101								2007
Operating empty mass	m _{OE}	ā	108860		108860								117480
Mass ratio, operating empty - take-off moe/mmTo	ff m _{OE} /m _{MTO}												
Wing loading	m _{MTO} /S _W	kg/m²											
Maximum zero fuel mass	MMZF	g	161025	161025	156500								161025
Number of engines	٤		0				0				0		2
Engine type	GE GEnx-	GE GEnx-1B (60%), RR	Gen		Genx/Trent 1000		GEnx 72A1 Trent 1000	0				GEnx-1B70	1
Take-off thrust for one engine	Tro-one engine KN	KN S	_		235-311		235,7558 235,756				280	310,4859	280
Total take-off thrust	Tro	<u>₹</u>											
Thrust to weight ratio	Tro/(m _{MTo} *g)	,*g)											
Bypass ratio	_		6		9,0-12,0		7				Ó	9-8,3	
Specific Fuel Comsumption (dry)		kg/N s											
Specific Fuel Comsumption (cruise)	SFC (cruise kg/N s	se kg/N s											
Available fuel volume	V _{fuel} ,available	m ₃	126,917	126,206	126,917								126,92
Cruise speed	N	s/m	252								252.07778		253.61
Cruise altitude	hcR	Ε											
Space accomo	¥	۰	32.2										32.2
Sweep angle	4 25	1	32,2										2,20
Mean aerodynamic chord	OMAC	E %											
Position of maximum camper	X(y_c),max	%C											
Position of maximum thickness	(yc)max/C	2%											
Relative thickness	t/c	%											
Taper	٧												
Overall pressure ratio	OAPR		53,3								4	43,8-53,3	
Turbine entry temperature	TET	¥											

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_LFL	1630			
Approach speed	Known	V_{APP}	72,00	m/s	72,0	72,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	3100	m	3100	3100
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	5496	NM		
Cruise Mach number		M _{CR}	0,85			
Wing area		S_W	325	m²		
Wing span	Known	b_W	60,12	m²	60,12	60,12
Aspect ratio		Α	11,12			
Maximum take-off mass		m_{MTO}	227930	kg		
Maximum payload mass		m_{PL}	52165	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,229			
Maximum landing mass		m_ML	167825	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,736			
Operating empty mass		m_OE	108860	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,478			
Wing loading		m_{MTO}/S_W	701,3	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	310	kN		
Total take-off thrust		T_{TO}	620	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,277			
Bypass ratio		μ	9			
Available fuel volume		V _{fuel,available}	23,86	m³		

	Data to o	ptimize V/V _{md}				
					LL	UL
Cruise speed		V_{CR}	252	m/s		
Cruise altitude		h _{CR}	10668	m		
Speed ratio		V/V_{md}	1,156	-	1	1,316
	Data to execu	te the verification				
					Rai	nge
Sweep angle		ϕ_{25}	32,2	0		
Mean aerodynamic chord		C _{MAC}	4,2	m		
Position of maximum camber		X _{(y_c),max}	30	%с	15 - 50	%с
Camber		(y _c) _{max} /c	4	%с	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	10,6	%		
Taper		λ	0,24			

Reverse Engineering

|--|

1107	crac criginicaring	a optimization of v	Villa		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1630	1630	m	0,00%
Approach speed	V_{APP}	72,00	72,0	m/s	0,00%
Take-off field length	s _{TOFL}	3100	3100	m	0,00%
Span	b_W	60,12	60,12	m	0,00%
Aspect ratio	Α	11,12	11,12		0,00%
Cruise speed	V_{CR}	252,0	252	m/s	0,04%
Cruise altitude	h_{CR}	10668	10669	m	0,01%
Squared Sum					1,40E-07
Absolute maximum deviation					0,0%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,96			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,91		Davi	oroo Enginooring
Maximum aerodynamic efficiency	E _{max}	19,73		Rev	erse Engineering
Specific fuel consumption	SFC	1,16E-05 kg/	N/s		

1) Maximum Lift Coefficient for Landing and Take-off

	anding	
Landing field length	S _{LFL}	1630 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	1,70 (m/s²) 0.
Approach speed	V_{APP}	72,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,74
Wing loading at maximum take-off mass	m_{MTO}/S_W	701,3 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,96
Т	ake-off	
Take-off field length	S _{TOFL}	3100 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	\mathbf{k}_{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,277
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,91
2nd	Segment	
Aspect ratio	A	11,121
Lift coefficient, take-off	$C_{L,TO}$	1,33
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,011
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,031
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	12,85
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,204
Misse	d approach	
ift coefficient, landing	C _{L,L}	1,75
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,033
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C_D,P	0,068
Glide ratio in landing configuration	EL	9,07
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,193

2) Maximum Aerodynamic Efficiency

Cons	tant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	pecifications		
Mach number, cruise	M_{CR}	0,85	
Aspect ratio	Α	11,12	
Bypass ratio	μ	9,00	
Wing loading	m_{MTO}/S_W	701 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,277	
	Variables		
	V/V_{md}	1,2	
	Calculations		
Zero-lift drag coefficient	$C_{D,0}$	0,019	
Lift coefficient at E _{max}	$C_{L,md}$	0,75	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,748	
Lift coefficient, cruise	C_L	0,563	
Actual aerodynamic efficiency, cruise	E	18,92	
Max. glide ratio, cruise	E _{max}	19,73	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	1	2	3
f(x)	0,35	-0,03	0,00
f(x)	-0,09	-0,10	-0,10
E _{max}	16	19,99	19,73

3) Specific Fuel Consumption

Ratio of specific heats, air	nt parameters γ	1,4	
Earth acceleration	g g		m/s²
Air pressure, ISA, standard	p_0	101325	Pa
Fuel density	$ ho_{fuel}$	800	kg/m³
Spec	cifications		
Range	R	5496	NM
Mach number, cruise	M_{CR}	0,85	
Bypass ratio	μ	9,00	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,277	
Available fuel volume	$V_{\text{fuel,available}}$	23,86	m³
Maximum take-off mass	m_{MTO}	227930	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,229	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,478	
Calcul	ated values		
Actual aerodynamic efficiency, cruise	E	18,92	
Cruise altitude	h_CR	10669	m
Cruise speed	V _{CR}	252	m/s
Mission	fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{\rm ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{\sf ff,CLB}$	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Calo	culations		
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,294	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,706	
Available fuel mass	mF,available	19088	ka
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,084	9
Mission fuel fraction (acc. to fuel capacity)	V ff	0,935	
	•••п	0,000	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	no	
	international	yes	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	879330	m
Loiter time	t _{loiter}	1800	s

4) Verification Specifications

Max	imum	lift	coeff	icien	ıte

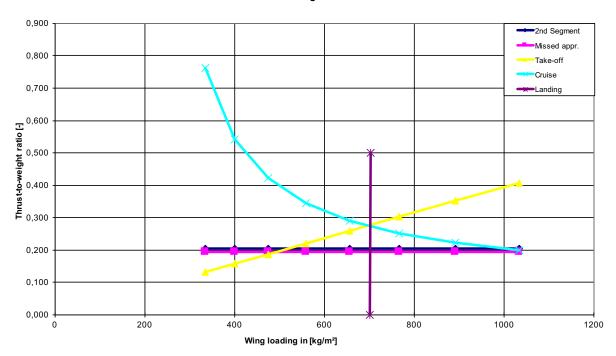
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b_W	60,12 m
Structural wing span	$b_{W,struct}$	71,05 m
Wing area	S_W	325,0 m ²
Aspect ratio	Α	11,12
Sweep	φ_{25}	32,2 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	$\mathbf{x}_{(\mathbf{y}_{\mathbf{c}}),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
Relative thickness	t/c	10,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Геmperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	72,00 m/s
Mach number, landing	M_APP	0,22
Mach number, cruise	M_{CR}	0,85
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	1,9 %c
Leading edge sweep	ϕ_{LE}	35,4 °
Reynoldsnumber	Re	2,2E+07
Maximum lift coefficient, base	C _{L,max,base}	1,17
Correction term, camber	$\Delta_1 c_{L,max}$	0,39
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,062
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,622
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,91
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	$C_{L,max}$	1,46

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\scriptscriptstyle{oldsymbol{\phi}}}$	0,83
Flap group A		
0,4c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	2,04
Use flapped span	b_W,fA	40,7 m
Percentage of flaps allong the wing		57%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,97
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,75
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	\DeltaG_L,max,fB	0,00
Increase in maximum lift coefficient, flap	$\Delta G_{L,max,f}$	0,97
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	Φ H.L.	34,5 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,91
Use slatted span	b_W,sA	13,4 m
Percentage of slats allong the wing		19%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,14
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,91
Use slatted span	b_W,sB	40,1 m
Percentage of slats allong the wing		56%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,42
Increase in maximum lift coefficient, slat	$\DeltaG_{\!L,max,s}$	0,56
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,95
RE value maximum lift coefficient, landing	-L,max,L	2,96
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,90
RE value maximum lift coefficient, take-off	CL,IIIAX, TO	1,91
Q 0%		1,5
Aerodynamic e	fficiency	
Real aircraft average	k wL	2,83
End plate (kWL = 2,13)	$\mathbf{k}_{e,WL}$	1,41
Span	bw	60,12 m
Winglet height	h	2,7 m
Aspect ratio	A	11,12
Effective aspect ratio	A _{eff}	15,68
Efficiency factor, short range	k _E	16,19
Relative wetted area	S _{wel} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	25,4
RE value maximum aerodynamic efficiency	⊷max	19,73
29%		10,10

Specific fuel consumption (Herrmann 2010) Cruise Mach number 0,850 M_{CR} Cruise altitude 10668 m h_{CR} By Pass Ratio 9,00 μ Take-off Thrust (one engine) 310,00 kN T_{TO,one engine} Overall Pressure ratio OAPR 53,30 Turbine entry temperature TET 1494,19 ΔΡ/Ρ 2% Inlet pressure loss 0,93 Inlet efficiency η_{inlet} Ventilator efficiency 0,90 $\eta_{ventilator}$ Compressor efficiency 0,88 $\eta_{compresor}$ Turbine efficiency 0,91 $\eta_{turbine}$ Nozzle efficiency 0,99 η_{nozzle} Temperature at SL T_0 288,15 K Temperature lapse rate in troposhpere 0,0065 K/m L Temperature (ISA) at tropopause T_S 216,65 K Temperature at cruise altitude T(H) 218,81 K Dimensionless turbine entry temperature 6,83 φ Ratio of specific heats, air 1,40 γ 1,14 Ratio between stagnation point temperature and temperature υ 2,42 Temperature function χ 0,97 Gas generator efficiency η_{gasgen} Gas generator function 1,96 SFC Verification value specific fuel consumption 0,54 kg/daN/h Verification value specific fuel consumption SFC 1,50E-05 kg/N/s SFC RE value specific fuel consumption 1,16E-05 kg/N/s

30%

Matching Chart



Appendix V Boeing 777-200ER

Parameter Symbol Units Choosen value Source Aunthonomies Fame Aunthonomies Aun			
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Tuel Communition (dry) SFC (dry) kgN s 9.18E-06 Fuel Communition (dry) SFC (dry) kgN s 1.47E-05 Fuel Communition (cruise) SFC (cruze kgN s) 1.47E-05 177.3 Fuel volume V _{crit} m/s 111.56 177.176 read titude hcs m/s 31.6 11005 11005 rigle \$\times \text{min} \$\times \text{min} \$\times \text{min} \$\times \text{min} \$\times \text{min} right aximum camber \$\times \text{comm} \$\times \text{min} \$\times \text{min} \$\times \text{min} rimsximum thickness \$\times \text{min} \$\times \text{min} \$\times \text{min} \$\times \text{min} rimsximum thickness \$\times \text{min} \$\times \text{min} \$\times \text{min} \$\times \text{min}		8,4 6,15 6,41 6,4	6,2 8,4
Fuel Community (cruise) SFC (cruise kg/N s) 1,47E-05 177,3 177,176 Fuel volume V _{inst strendbles} m² 117,348 117,33 177,176 Hudde V _{inst} m° 11155 11005 11005 India A _{inc} m 8,75 11005 11005 India M _{inc} M _{inc} M _{inc} M _{inc} M _{inc} Indix maximum thickness V _{inc} M _{inc} M _{inc} M _{inc} M _{inc} Indix min thickness V _{inc} M _{inc} M _{inc} M _{inc} M _{inc}	9,17		9,18E-06
fuel volume V _{sectional strainments} m² 117,348 117,3 171,176 seed V _{cos} m/s 11155 10820 11005 ittude hcs m 31,6 0 11005 ngle фss s 31,6 0 11005 ngle pss s 37,6 0 11005 nd maximum camber X _{to curse} sc sc 14,5-11,1-10,4 nickness V sc 14,5-11,1-10,4 sc sc	1,47	1,47E-05	1,47E-05
beed V _{SR} m/s 11155 11050 11005 litude h _{CR} m 31,6 11050 11005 ngle \$\phi_{CA}\$ s 31,6 \$\phi_{CA}\$ \$\phi_{CA}\$ rodynamic chord \$\phi_{CA}\$ \$\phi_{CA}\$ \$\phi_{CA}\$ \$\phi_{CA}\$ of maximum camber \$\phi_{CA}\$ \$\phi_{CA}\$ \$\phi_{CA}\$ \$\phi_{CA}\$ of maximum thickness \$\phi_{CA}\$ \$\phi_{CA}\$ \$\phi_{CA}\$ \$\phi_{CA}\$ hickness \$\phi_{CA}\$ \$\phi_{CA}\$ \$\phi_{CA}\$ \$\phi_{CA}\$	8		117,348
littude h _{CR} m 11155 10820 11005 11 righe \$\phi_{22}\$ * 31.6 * 11055 10050 11005 11 rodynamic chord \$\phi_{22}\$ m 8,75 * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * <td>244,88-256,71</td> <td></td> <td></td>	244,88-256,71		
gle odynamic chord o _{Asic} m 8,75	10820 11005 11887,2	10668	11887
rodynamic chord Quoc m 8/75 of maximum camber X _{f_2 plane} %c of maximum thickness X _{cmax} %c of maximum thickness V _c 14,5,11,1-10,4	31,6		31,6
of maximum camber X _{V₀-olmax} %C (y ₀) _{mul} C %C YG of maximum thickness X ₁ , x ₀ YG thickness VC % 14,5-11,1-10,4	8,75		8,75
Of maximum thickness X _{craxx} %c thickness 1/c 14,5-11,1-10,4			
X _{cross} %c 14,5-11,1-10,4			
ve thickness v / (-2-11/1-10,4)			
			14,5-11,1-10,4
Dressure ratio OAPR	0,110	39.3 37 34.2	0,140
Turbine entry temperature TET K		5	

Aeroplane Specifications

Available fuel volume

	Data to apply	reverse engineering			
				LL	UL
Landing field length	Known	s_LFL	1585 m		
Approach speed	Known	V_{APP}	71,00 m/s	s 71,0	71,0
Temperature above ISA (288,15K)		ΔT_L	0 K		
Relative density		σ	1		
Take-off field length	Known	s _{TOFL}	2135 m	2135	2135
Temperature above ISA (288,15K)		ΔT_TO	0 K		
Relative density		σ	1,000		
Range (maximum payload)		R	2603 NM	Л	
Cruise Mach number		M _{CR}	0,84		
Wing area		S _W	428 m²	:	
Wing span	Known	b_W	60,93 m ²	60,93	60,93
Aspect ratio		Α	8,68		
Maximum take-off mass		m_{MTO}	242670 kg		
Maximum payload mass		m_{PL}	54635 kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,225		
Maximum landing mass		m_{ML}	200050 kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,824		
Operating empty mass		m_OE	135550 kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,559		
Wing loading		m_{MTO}/S_W	567,3 kg/	/m²	
Number of engines		n _E	2		
Take-off thrust for one engine		T _{TO,one engine}	377 kN	1	
Total take-off thrust		T _{TO}	754 kN	1	
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,317		
Bypass ratio		μ	8,4		

V_{fuel,available}

23,86 m³

Data	to	optimize	V/V_{md}
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				LL	UL
Cruise speed		V_{CR}	252 m/s		
Cruise altitude		h _{CR}	11155 m		
Speed ratio		V/V_{md}	1,137 -	1	1,316
	Data to execu	te the verification			
				Rar	ige
Sweep angle		ϕ_{25}	31,6 °		
Mean aerodynamic chord		C _{MAC}	8,75 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	10,8 %		
Taper		λ	0,149		

Reverse Engineering

Reverse e	engineering	& o	ptimization	of	V/Vmd
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	oree engineering	, a optimization of v	, , , , , ,		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S_LFL	1585	1585	m	0,00%
Approach speed	V_{APP}	71,00	71,0	m/s	0,00%
Take-off field length	s _{TOFL}	2135	2135	m	0,00%
Span	b_W	60,93	60,93	m	0,00%
Aspect ratio	Α	8,68	8,68		0,00%
Cruise speed	V_{CR}	252,0	248	m/s	-1,63%
Cruise altitude	h_{CR}	11155	11155	m	0,00%
Squared Sum Absolute maximum deviation					2,65E-04 1,6%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,76			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,96		Boyes	roo Engineering
Maximum aerodynamic efficiency	E _{max}	17,81		Reve	rse Engineering
Specific fuel consumption	SFC	1,26E-05 kg/	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Landing					
Landing field length	S _{LFL}	1585 m			
Temperature above ISA (288,15K)	ΔT_L	0 K			
Relative density	σ	1,000			
Factor, approach	k_{APP}	1,70 (m/s²) ^{0.5}			
Approach speed	V_{APP}	71,00 m/s			
Factor, landing	k_{L}	0,107 kg/m³			
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,82			
Wing loading at maximum take-off mass	m_{MTO}/S_W	567,3 kg/m²			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,76			
Takı	e-off				
Take-off field length	S _{TOFL}	2135 m			
Temperatur above ISA (288,15K)	ΔT_TO	0 K			
Relative density	σ	1,00			
Factor	k _{TO}	2,34 m ³ /kg			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,317			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,96			
2nd Se	egment				
Aspect ratio	A	8,678			
Lift coefficient, take-off	$C_{L,TO}$	1,36			
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,013			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Profile drag coefficient	$C_{D,P}$	0,033			
Oswald efficiency factor; landing configuration	e	0,7			
Glide ratio in take-off configuration	E _{TO}	10,44			
Number of engines	n _E	2			
Climb gradient	sin(γ)	0,024			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,240			
Missed approach					
Lift coefficient, landing	C _{L,L}	1,63			
Lift-independent drag coefficient, clean	C _{D.0} (Missed approach)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,027			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Choose: Certification basis	JAR-25 resp. CS-25	no			
	FAR Part 25	yes			
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015			
Profile drag coefficient	$C_{D,P}$	0,062			
Glide ratio in landing configuration	EL	8,11			
Climb gradient	sin(γ)	0,021			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,238			
act to morgin radio	- 10' ('''MIO 9 /	0,200			

2) Maximum Aerodynamic Efficiency

Constant parameters					
Ratio of specific heats, air	γ	1,4			
Earth acceleration	g	9,81 m/s ²			
Air pressure, ISA, standard	p_0	101325 Pa			
Oswald eff. factor, clean	е	0,85			
0					
	ecifications	2.24			
Mach number, cruise	M _{CR}	0,84			
Aspect ratio	Α	8,68			
Bypass ratio	μ	8,40			
Wing loading	m_{MTO}/S_W	567 kg/m²			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,317			
	Mandalala a				
	Variables				
	V/V _{md}	1,1			
С	alculations				
Zero-lift drag coefficient	C _{D,0}	0,018			
Lift coefficient at E _{max}	$C_{L,md}$	0,65			
Ratio, lift coefficient	$C_L/C_{L,md}$	0,774			
Lift coefficient, cruise	C_L	0,503			
Actual aerodynamic efficiency, cruise	E	17,24			
Max. glide ratio, cruise	E _{max}	17,81			
Newton-Raphson for the maximum lift-to-drag ratio					
Iterations	1	2	0,00		
f(x)	0,20	-0,01			
f'(x)	-0,10	-0,11	-0,11		
E _{max}	16	17,87	17,81		

3) Specific Fuel Consumption

	nt parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	•	m/s²
Air pressure, ISA, standard	P ₀	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
	cifications		
Range	R	2603	
Mach number, cruise	M_CR	0,84	
Bypass ratio	μ	8,40	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,317	
Available fuel volume	$V_{fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	242670	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,225	
Mass ratio, operating empty - take-off	$m_{OE/}m_{MTO}$	0,559	
Calcu	lated values		
Actual aerodynamic efficiency, cruise	E	17,24	
Cruise altitude	h_{CR}	11155	m
Cruise speed	V _{CR}	248	m/s
Mission	n fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	M _{ff,taxi}	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	, -	0,990	
	$M_{ff,DES}$	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
	culations		
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,216	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,784	
Available fuel mass	MF,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,079	
Mission fuel fraction (acc. to fuel capacity)	\mathbb{M}_{ff}	0,940	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	
Choose: FAR Part121-Reserves	domestic	no	
	international	yes	
Extra-fuel for long range		5%	
Extra flight distance	s _{res}	611438	m
Loiter time	t _{loiter}	1800	
Londi unio	loiter	1000	3
Specific fuel consumption	SFC	1,26E-05	ka/N/s

4) Verification Specifications

Maximum lift coefficients

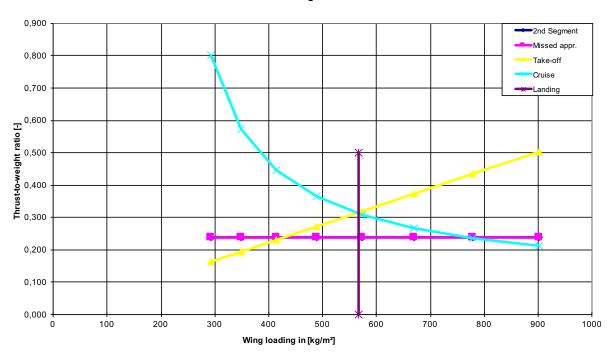
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b _W	60,93 m
Structural wing span	b _{W,struct}	71,54 m
Wing area	S _W	427,8 m ²
Aspect ratio	A	8,68
Sweep	ϕ_{25}	31,6 °
Mean aerodynamic chord	C _{MAC}	8,75 m
Position of maximum camber	X _{(y_c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	X _{t,max}	30 %c
Relative thickness	t/c	10,8 %
Taper	λ	0,149
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T _L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	71,00 m/s
Mach number, landing	M_{APP}	0,21
Mach number, cruise	M_{CR}	0,84
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,0 %c
Leading edge sweep	ϕ_{LE}	36,5 °
Reynoldsnumber	Re	4,4E+07
Maximum lift coefficient, base	C _{L,max,base}	1,19
Correction term, camber	$\Delta_1 c_{L,max}$	0,39
Correction term, thickness	$\Delta_2 c_{\text{L.max}}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L.max}$	0,074
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,652
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,90
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	C _{L,max}	1,48

Calculations increase of lift coefficient due to flap	os	2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{oldsymbol{\phi}}}$	0,84
Flap group A		
Double-slotted flap	$\Delta c_{L,max,fA}$	1,45
Use flapped span	b_W,fA	10,8 m
Percentage of flaps allong the wing		15%
Increase in maximum lift coefficient, flap group A	\DeltaC_L,max,fA	0,18
Flap group B		
Single-slotted flap	$\Delta c_{L,max,fB}$	0,79
Use flapped span	b_W,fB	25,1 m
Percentage of flaps allong the wing	4.5	35%
Increase in maximum lift coefficient, flap group B	ΔC _{L,max,fB}	0,23
Increase in maximum lift coefficient, flap	$\Delta C_{\!L,max,f}$	0,41
Calculations increase of lift coefficient due to slat	ts	2 slat types
Sweep angle of the hinge line	$\phi_{H.L.}$	34 °
Slat group A		
0,3c Nose flap	$\Delta c_{L.max.sA}$	0,92
Use slatted span	b_W,sA	11,5 m
Percentage of slats allong the wing		16%
Increase in maximum lift coefficient, slat group A	\DeltaC_L,max,sA	0,12
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,92
Use slatted span	b_W,sB	42,5 m
Percentage of slats allong the wing	••	59%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,45
Increase in maximum lift coefficient, slat	\DeltaC_L,max,s	0,57
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,44
RE value maximum lift coefficient, landing		2,76
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,74
RE value maximum lift coefficient, take-off		1,96
	-11%	
Aerodyna	amic efficiency	
Pool aircraft average	l.	2 02
Real aircraft average	k _{WL}	2,83
No winglets	$\mathbf{k}_{e,WL}$	1,00
Span	bw	60,93 m
Winglet height	h	2,7 m
Aspect ratio	A	8,68 8,68
Effective aspect ratio	A_{eff}	0,00
Efficiency factor, short range	k _E	15,15
, , , , , , , , , , , , , , , , , , , ,	_	•
Relative wetted area	S_{wet}/S_{W}	6,35
	_	
Verification value maximum aerodynamic efficiency	E _{max}	17,7
RE value maximum aerodynamic efficiency	40/	17,81
_	-1%	

Specific fuel consumption (Herrmann 2010)

8,40 70,one engine 377,00 APR 40,00 ET 1498,78 P/P 2% nlet 0,93	
TO,one engine 377,00 APR 40,00 ET 1498,78 P/P 2% callet 0,93	
APR 40,00 ET 1498,78 P/P 2% plet 0,93	kN
APR 40,00 ET 1498,78 P/P 2% ollet 0,93	
P/P 2% nlet 0,93	
0,93	
rentilator 0,90	
ompresor 0,88	
urbine 0,91	
ozzle 0,99	
288,15	K
0,0065	K/m
216,65	K
(H) 216,65	K
6,92	
1,40	
1,14	
2,13	
asgen 0,97	
2,21	
FC 0,54	kg/daN/h
EC 1.40E.05	kg/N/s
1,49E-03	
	6,92 1,40 1,14 2,13 0,97 2,21

Matching Chart



Appendix W McDonnel Douglas MD-83

Symbol Julie Chaosen Name Support Junic Assumption Symbol Julie Support Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Julie Symbol Symbol Julie Symbol	Data Collection	ction		MD-83	1	2	3	4	2	9	7	8	6
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alked off thrust Tro/Inhards kN 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 0,27 1,47E-0.5 1	Take-off thrust for one engine	TO one engine	Z	96,526		4		93,412662			96,526		82.3
to weight ratio to the weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio to weight ratio weight ratio to weight ratio weig	Total take-off thrust	T _{TO}	조										
s ratio p 1,8 1,8 1,18 1,18 1,18 1,18 1,18 1,18 1,18 1,18 1,18 1,18 1,147E-05	Thrust to weight ratio	T _{TO} /(m _{MTO} *g		0,27		0,262992	0,271063685				0,27		
ic Fuel Comsumption (dry) SFC (dry) kg/N s 1,47E-05 1,47E-05 1,47E-05 ic Fuel Comsumption (dry) SFC (cruise kg/N s 2,09E-05 2,09E-05 <td>Bypass ratio</td> <td>_</td> <td></td> <td>1,8</td> <td></td> <td></td> <td></td> <td>1,72</td> <td></td> <td></td> <td>1,8</td> <td></td> <td></td>	Bypass ratio	_		1,8				1,72			1,8		
ic Fuel Comsumption (cuise) SFC (cruise) kg/N s 2,09E-05 2,09E-05 2,09E-05 ole fuel volume V _{Luel wordlande} m³ 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 <	Specific Fuel Comsumption (dry)	SFC (dry)	kg/N s	1,47E-05				1,4688E-05			1,47E-05		
ble fuel volume V _{Locitationshibits} m³ 26,426 26,26 26,495 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426 26,426	Specific Fuel Comsumption (cruise)	SFC (cruis	s N/gy	2,09E-05				2,0857E-05			2,09E-05		
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I pressure ratio OAPR 20,1	Taner	2 ~	2	0.195		0.156028	0.195				0.195		-
X	Overall pressure ratio	OAPR		20.1				20.1			, , , ,		
	Turbine entry temperature	TET	~										

Aeroplane Specifications

Number of engines

Total take-off thrust

Bypass ratio

Thrust to weight ratio

Available fuel volume

Take-off thrust for one engine

Data to apply reverse engineering LL UL Landing field length Known 1585 m s_{LFL} 71,51 m/s 71,5 Approach speed Known V_{APP} 71,5 Temperature above ISA (288,15K) ΔT_{L} 0 K Relative density σ **2551** m 2551 2551 Take-off field length Known STOFL Temperature above ISA (288,15K) 0 K ΔT_{TO} 1,000 Relative density Range (maximum payload) R 1806 NM Cruise Mach number M_{CR} 0,76 Wing area 112 m² S_W Wing span Known 32,87 m² 32,87 $b_{\!W}$ 32,87 Aspect ratio 9,62 Α Maximum take-off mass 72575 kg m_{MTO} Maximum payload mass m_{PL} 18721 kg 0,258 Mass ratio, payload - take-off m_{PL}/m_{MTO} $m_{ML} \\$ 63276 kg Maximum landing mass Mass ratio, landing - take-off 0,872 m_{ML}/m_{MTO} Operating empty mass 35300 kg m_{OE} Mass ratio, operating empty - take-off $m_{\text{OE}}/m_{\text{MTO}}$ 0,486 Wing loading 646,3 kg/m² m_{MTO}/S_W

 n_E

 T_TO

T_{TO,one engine}

 $T_{TO}/(m_{MTO}^*g)$

V_{fuel,available}

2

96,526 kN

193,052 kN

1,8

23,86 m³

0,271

Data to optimize \

			LL	UL
	V_{CR}	225 m/s		
	h_{CR}	10668 m		
	V/V_{md}	1,171 -	1	1,316
Data to execu	te the verification			
			Rai	nge
	φ_{25}	24,5 °		
	c _{MAC}	4,08 m		
	X _{(v c),max}	30 %c	15 - 50	%с
	(y _c) _{max} /c	4 %c	2 - 6	%с
	$\mathbf{x}_{t,max}$	36 %c	30 - 45	%с
Unknown	t/c	11,8 %		
	λ	0,195		
	Data to execu	$\begin{array}{c} h_{CR} \\ V/V_{md} \\ \\ \hline \\ Data \ to \ execute \ the \ verification \\ \\ \phi_{25} \\ c_{MAC} \\ x_{(y_c),max} \\ (y_c)_{max}/c \\ x_{t,max} \\ \hline \\ Unknown \end{array}$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$

Reverse Engineering

Reverse	engineering	&	optimization	of	V/Vmd
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- IVe A	erse engineering	a optimization of v	/ VIIIu		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1585	1585	m	0,00%
Approach speed	V_{APP}	71,51	71,5	m/s	0,00%
Take-off field length	s _{TOFL}	2551	2551	m	0,00%
Span	b_W	32,87	32,87	m	0,00%
Aspect ratio	Α	9,62	9,62		0,00%
Cruise speed	V_{CR}	225,0	225	m/s	0,17%
Cruise altitude	h_{CR}	10668	10671	m	0,03%
Squared Sum					3,13E-06
Absolute maximum deviation					0,2%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,32			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,19		Davis	ree Engineering
Maximum aerodynamic efficiency	E _{max}	14,39		Reve	erse Engineering
Specific fuel consumption	SFC	1,61E-05 kg	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

La	anding	
Landing field length	S _{LFL}	1585 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	$1,70 \text{ (m/s}^2)^{0.5}$
Approach speed	V_{APP}	71,51 m/s
Factor, landing	\mathbf{k}_L	0,107 kg/m³
Mass ratio, landing - take-off	$\rm m_{ML}/m_{TO}$	0,87
Wing loading at maximum take-off mass	m_{MTO}/S_W	646,3 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,32
Ta	ake-off	
Take-off field length	S _{TOFL}	2551 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,271
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,19
2nd	Segment	
Aspect ratio	A	9,621
Lift coefficient, take-off	$C_{L,TO}$	1,52
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,021
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C _{D,P}	0,041
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	10,13
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,245
Micco	d approach	
Lift coefficient, landing	C _{L,L}	1,97
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,043
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C _{D,P}	0,078
Glide ratio in landing configuration	EL	7,53
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,268
This set to moight fallo	· IO/(···MIO 9/	0,200

2) Maximum Aerodynamic Efficiency

Constant parameters						
Ratio of specific heats, air	γ	1,4	_			
Earth acceleration	g	9,81 m/s ²				
Air pressure, ISA, standard	p_0	101325 Pa				
Oswald eff. factor, clean	е	0,85				
Sp	ecifications					
Mach number, cruise	M _{CR}	0,76				
Aspect ratio	A	9,62				
Bypass ratio	μ	1,80				
Wing loading	m_{MTO}/S_W	646 kg/m²				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,271				
Variables						
	V/V_{md}	1,2				
Calculations						
Zero-lift drag coefficient	C _{D,0}	0,031				
Lift coefficient at E _{max}	C_L,md	0,89				
Ratio, lift coefficient	$C_L/C_{L,md}$	0,730				
Lift coefficient, cruise	C_L	0,651				
Actual aerodynamic efficiency, cruise	E	13,70				
Max. glide ratio, cruise	E _{max}	14,39				
Newton-Raphson for the maximum lift-to-drag ratio						
Iterations		2	3			
f(x)	-0,22	-0,01	0,00			
f(x)	-0,14	-0,13	-0,13			
E _{max}	16	14,43	14,39			

3) Specific Fuel Consumption

Constant parameters						
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g		m/s²			
Air pressure, ISA, standard	p_0	101325				
Fuel density	$ ho_{fuel}$	800	kg/m³			
Specificat	ions					
Range	R	1806	NM			
Mach number, cruise	M_{CR}	0,76				
Bypass ratio	μ	1,80				
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,271				
Available fuel volume	$V_{ m fuel,available}$	23,86	m³			
Maximum take-off mass	m_{MTO}	72575	kg			
Mass ratio, landing - take-off	m_{PL}/m_{MTO}	0,258				
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,486				
Calculated values						
Actual aerodynamic efficiency, cruise	E	13,70				
Cruise altitude	h _{CR}	10671	m			
Cruise speed	V_{CR}	225	m/s			
Mission fuel fraction						
Type of aeroplane (according to Roskam)	Transport jet					
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990				
Fuel-Fraction, taxi	$M_{\rm ff,taxi}$	0,990				
Fuel-Fraction, take-off	M _{ff,TO}	0,995				
Fuel-Fraction, climb	M _{ff,CLB}	0,980				
Fuel-Fraction, descent	M _{ff.DES}	0,990				
Fuel-Fraction, landing	M _{ff,L}	0,992				
Calculati	one					
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,256				
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,744				
		0,				
Available fuel mass	m _{F,available}	19088	kg			
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,263				
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,752				
Distance to alternate	S _{to_alternate}	200	NM			
Distance to alternate	S _{to_alternate}	370400	m			
Choose: FAR Part121-Reserves	domestic	yes				
	international	no				
Extra-fuel for long range		5%				
Extra flight distance	s _{res}	370400				
Loiter time	t _{loiter}	2700	s			
Specific fuel consumption	SFC	1,61E-05	kg/N/s			

4) Verification Specifications

Maximum lift coefficients

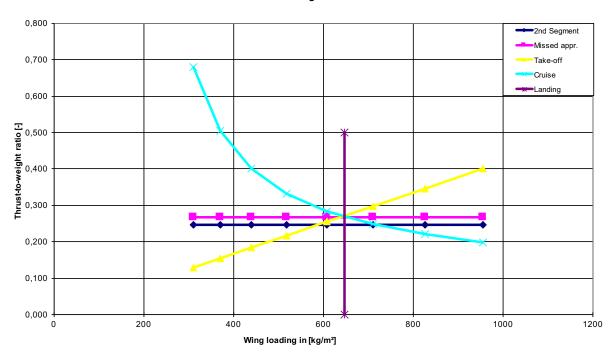
General wing specifications	Airfoil type:	NACA 4 digit
Wing span	b_W	32,87 m
Structural wing span	$b_{W,struct}$	36,12 m
Wing area	S_W	112,3 m ²
Aspect ratio	Α	9,62
Sweep	φ_{25}	24,5 °
Mean aerodynamic chord	C _{MAC}	4,08 m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t,max}$	36 %c
Relative thickness	t/c	11,8 %
Taper	λ	0,195
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	71,51 m/s
Mach number, landing	M_APP	0,22
Mach number, cruise	M_{CR}	0,76
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,1 %c
Leading edge sweep	ϕ_{LE}	28,5 °
Reynoldsnumber	Re	2,1E+07
Maximum lift coefficient, base	C _{L,max,base}	1,51
Correction term, camber	$\Delta_1 c_{L,max}$	0,16
Correction term, thickness	$\Delta_2 \mathbf{c}_{L,max}$	0,03
Correction term, Reynolds' number	Δ ₃ c _{L.max}	0,091
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,793
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	$\Delta C_{L,max}$	-0,02
Lift coefficient, wing	C _{L,max}	1,42

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{oldsymbol{\phi}}}$	0,87
Flap group A	_	4.00
Double-slotted flap	Δc _{L,max,fA}	1,39
Use flapped span	b_W,fA	22 m
Percentage of flaps allong the wing	4.0	61%
Increase in maximum lift coefficient, flap group A Flap group B	$\Delta C_{\!L,max,fA}$	0,74
0,3c Plain flap	۸۵	0,72
Use flapped span	$\Delta c_{L,max,fB}$	0 m
Percentage of flaps allong the wing	D_44,1D	0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	ΔC _{L,max,f}	0,74
moreage in maximum in occinoion, nap	24,max,r	0,14
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	ΦH.L.	27 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,88
Use slatted span	b_W,sA	29,6 m
Percentage of slats allong the wing		82%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,64
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,88
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing		0%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,00
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,64
Wing Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,76
RE value maximum lift coefficient, landing		3,32
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,81
RE value maximum lift coefficient, take-off		2,19
-17%		
Aerodynamic e	efficiency	
Real aircraft average	k	2,83
-	k _{WL}	
No winglets	$k_{e,WL}$	1,00
Span	bW	32,87 m
Winglet height	h	2,7 m
Aspect ratio	A	9,62
Effective aspect ratio	A_{eff}	9,62
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{wet}/S_W	6,56
Verification value maximum aerodynamic efficiency	E _{max}	18,3
RE value maximum aerodynamic efficiency		14,39
28%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,760
Cruise altitude	h _{CR}	10668 m
By Pass Ratio	μ	1,80
Take-off Thrust (one engine)	T _{TO,one engine}	96,53 kN
Overall Pressure ratio	OAPR	20,10
Turbine entry temperature	TET	1437,12
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	$\eta_{ m inlet}$	0,97
Ventilator efficiency	n _{ventilator}	0,82
Compressor efficiency	$\eta_{compresor}$	0,82
Turbine efficiency	$\eta_{turbine}$	0,90
Nozzle efficiency	η_{nozzle}	0,98
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	218,81 K
Dimensionless turbine entry temperature	ф	6,57
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,51
Gas generator efficiency	η _{gasgen}	0,99
Gas generator function	G	2,07
Verification value specific fuel consumption	SFC	0,74 kg/daN/h
Verification value specific fuel consumption	SFC	2,04E-05 kg/N/s
RE value specific fuel consumption	SFC	1,61E-05 kg/N/s

Matching Chart



Appendix X Boeing 757-200

1 1 1 1 1 1 1 1 1 1	Data Collection	ction		757-200			-			2			3	4		9	7	80	6
Note 10 10 10 10 10 10 10 1					m	Aircraft charact	eristics for airport planning		-				.lenkinson	Fnair	•	Paul Miller	Flodie Roux	Data colle	
No. 1	Parameter			Chosen value					V	O	В	۵		5			Y ODG		
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No. Column Colu	Relative density	ø																	
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Signature 14 14 14 14 14 14 14 1	Cruise Mach number	McR		8,0			8,0			8,0	-				0,0		8,0		8,0
No. 1	Wing area			185.25						185.2			185.25			185.25	185.25		7
A A A A A A A A A A	Wing span			38.05			38,05			38.05			38.05			38,05	38,05		
	Aspect ratio			7,8					_	7,8			7,815398111			7,8	7,82		
	Maximum take-off mass			115650		866	300-115650		06266		1156	52	115900			104325	00866		
	Payload mass			22650	2525			350					25690				22650		
Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max Max	Mass ratio, payload - take-off												0,221656601				0,227		
Table Fig.	Maximum landing mass			89800		88	800-95250		89815		9525	5	95450			89810	89800		
Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part Part	Mass ratio, landing - take-off			0000		0	0000		1000		000	0000	0,823554789				0000		+
Figure Particular Figure Operating empty mass			00000	2790	000000	9-0000	8	26323	26220	20390	28020	04000				00000			
Table Part	Mass ratio, operating empty - take			1.002					1		700		0,500776531				0,609		+
Purpose 14 14 14 14 14 14 14 1	Wing loading Maximum zero fuel mass		. E.	930,7		83	450-85300		93460		84370		022,0410250				93450		+
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Trope From	Engine type	PW2000 (43%	, RR RB2	3B211-535E4	PW2037			211-535E4E PV		11-535E4: PW		211-535E4-B	RB211-535E4B R	B.211-535E4B-37	RB.211-535E4-		RB.211-535E4 PW2	2040 RB211-53	5E4B
Trop MAI Alta A	Take-off thrust for one engine	Tro, one engine KN	_	178,5	165,361			191,588345	168,2	178,8	178,4	193,5	191,3	191,7183682	178,373702	2			193,5
Timplimeria U.547 U.547 U.5474 Total take-off thrust	T ₇₀ Kh	_									000000000000000000000000000000000000000	1				0			
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-	Overall pressure ratio		Ī	25,8					_					25,8	7°22	m		-	+

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	S _{LFL}	1550			
Approach speed	Known	V_{APP}	68,00	m/s	68,0	68,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	2225	m	2225	2225
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	2397	NM		
Cruise Mach number		M _{CR}	0,8			
Wing area		S _W	185	m²		
Wing span	Known	b_W	38,05	m²	38,05	38,05
Aspect ratio		Α	7,82			
Maximum take-off mass		m _{MTO}	115650	kg		
Maximum payload mass		m_PL	22650	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,196			
Maximum landing mass		m _{ML}	89800	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,776			
Operating empty mass		m_OE	60800	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,526			
Wing loading		m_{MTO}/S_W	624,3	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	178,5	kN		
Total take-off thrust		T _{TO}	357	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,315			
Bypass ratio		μ	4,4			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to o	ptimize	V/V _{md}
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				LL	UL
Cruise speed		V_{CR}	241 m/s		
Cruise altitude		h _{CR}	11795 m		
Speed ratio		V/V_{md}	1,000 -	1	1,316
	Data to execu	te the verification			
				Ran	ge
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	5,64 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,3 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & o	optimization of V/	Vmd
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Rev	erse engineering	g & optimization of t	v/vma		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1550	1550	m	0,00%
Approach speed	V_{APP}	68,00	68,0	m/s	0,00%
Take-off field length	s _{TOFL}	2225	2225	m	0,00%
Span	b_W	38,05	38,05	m	0,00%
Aspect ratio	Α	7,82	7,82		0,00%
Cruise speed	V_{CR}	241,0	236	m/s	-2,04%
Cruise altitude	h_{CR}	11795	11737	m	-0,4 <mark>9%</mark>
Squared Sum Absolute maximum deviation					4,38E-04 2,0%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,92			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,09		Boyer	mo Engineering
Maximum aerodynamic efficiency	E _{max}	15,54		Rever	se Engineering
Specific fuel consumption	SFC	1,74E-05 kg	g/N/s		
Specific fuel consumption	5FC	1,74E-05 KQ	g/IN/S		

1) Maximum Lift Coefficient for Landing and Take-off

Land	ing				
Landing field length	S _{LFL}	1550 m			
Temperature above ISA (288,15K)	ΔT_L	0 K			
Relative density	σ	1,000			
Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$			
Approach speed	V_{APP}	68,00 m/s			
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³			
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,78			
Wing loading at maximum take-off mass	m_{MTO}/S_W	624,3 kg/m ²			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,92			
Take	off				
Take-off field length	S _{TOFL}	2225 m			
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K			
Relative density	σ	1,00			
Factor	k _{TO}	2,34 m³/kg			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,315			
Maximum lift coefficient, take-off	C _{L,max,TO}	2,09			
·		_,			
2nd Seg		7.045			
Aspect ratio	A	7,815			
Lift coefficient, take-off	C _{L,TO}	1,45			
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,017			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Profile drag coefficient	$C_{D,P}$	0,037			
Oswald efficiency factor; landing configuration	e	0,7			
Glide ratio in take-off configuration	E _{TO}	9,08			
Number of engines	n _E	2			
Climb gradient	_ sin(γ)	0,024			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,268			
Missed approach					
Lift coefficient, landing	C _{L,L}	1,73			
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,031			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Choose: Certification basis	JAR-25 resp. CS-25	no			
	FAR Part 25	yes			
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015			
Profile drag coefficient	C _{D,P}	0,066			
Glide ratio in landing configuration	E	7,19			
Climb gradient	sin(γ)	0,021			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,249			
Thrust to Holgin Tado	יוטי(ייישוט ש)	0,270			

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	8,0	
Aspect ratio	A	7,82	
Bypass ratio	μ	4,40	
Wing loading	m _{MTO} /S _W	624 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,315	
	Variables		
	V/V _{md}	1,0	
С	alculations		
Zero-lift drag coefficient	C _{D,0}	0,022	
Lift coefficient at E _{max}	$C_{L,md}$	0,67	
Ratio, lift coefficient	C _L /C _{L,md}	1,000	
Lift coefficient, cruise	CL	0,672	
Actual aerodynamic efficiency, cruise	E	15,54	
Max. glide ratio, cruise	E _{max}	15,54	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	1	2	3
f(x)	-0,06	0,00	0,00
f'(x)	-0,13	-0,13	-0,13
E _{max}	16	15,54	15,54

3) Specific Fuel Consumption

Constant par	ameters					
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g		m/s²			
Air pressure, ISA, standard	p_0	101325				
Fuel density	$ ho_{ m fuel}$	800	kg/m³			
Specificat	ions					
Range	R	2397	NM			
Mach number, cruise	M _{CR}	0,8				
Bypass ratio	μ	4,40				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,315				
Available fuel volume	$V_{ m fuel,available}$	23,86	m³			
Maximum take-off mass	m _{MTO}	115650	kg			
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,196				
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,526				
Calculated	values					
Actual aerodynamic efficiency, cruise	E	15,54				
Cruise altitude	h _{CR}	11737				
Cruise speed	V _{CR}	236	m/s			
Mission fuel						
Type of aeroplane (according to Roskam)	Transport jet	0.000				
Fuel-Fraction, engine start	M _{ff,engine}	0,990				
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990				
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995				
Fuel-Fraction, climb	$M_{\rm ff,CLB}$	0,980				
Fuel-Fraction, descent	$M_{ff,DES}$	0,990				
Fuel-Fraction, landing	$M_{ff,L}$	0,992				
Calculations						
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,278				
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,722				
Available fuel mass	m _{F,available}	19088	kg			
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,165				
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,852				
Distance to alternate	S _{to_alternate}		NM			
Distance to alternate	S _{to_alternate}	370400	m			
Choose: FAR Part121-Reserves	domestic	yes				
Fidus firel for languages	international	no				
Extra-fuel for long range		5%				
Extra flight distance	S _{res}	370400	m			
Loiter time	t _{loiter}	2700	s			
Specific fuel consumption	SFC	1,74E-05	kg/N/s			

4) Verification Specifications

Maximum lift coefficients

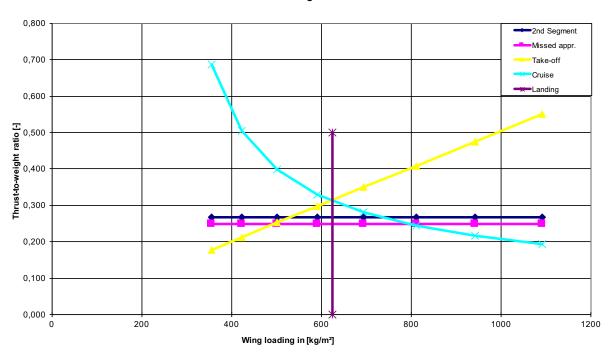
General wing specifications	Airfoil type:	NACA 4 digi
Wing span	b_W	38,05 m
Structural wing span	$b_{W,struct}$	41,98 m
Wing area	S_W	185,3 m ²
Aspect ratio	Α	7,82
Sweep	φ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	5,64 m
Position of maximum camber	$x_{(y_c),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
Relative thickness	t/c	11,3 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	68,00 m/s
Mach number, landing	M_APP	0,21
Mach number, cruise	M_{CR}	0,8
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,9 %c
Leading edge sweep	ϕ_{LE}	29,5 °
Reynoldsnumber	Re	2,7E+07
Maximum lift coefficient, base	C _{L,max,base}	1,56
Correction term, camber	$\Delta_1 c_{L,max}$	0,20
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,096
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,855
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,79
Correction term, Mach number	$\Delta C_{L,max}$	0,00
Lift coefficient, wing	C _{L.max}	1,47

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle\mathbf{\phi}}$	0,87
Flap group A	·	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,44
Use flapped span	b_W,fA	28,8 m
Percentage of flaps allong the wing	_	69%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,86
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,75
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_L,max,fB$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,86
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΨH.L.	28 °
Slat group A	. 11.6.	
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,91
Use slatted span	b_W,sA	6,9 m
Percentage of slats allong the wing		16%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,13
Slat group B	_,,	
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,91
Use slatted span	b_W,sB	25,6 m
Percentage of slats allong the wing	_	61%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,49
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,62
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,91
RE value maximum lift coefficient, landing		2,92
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,08
RE value maximum lift coefficient, take-off		2,09
0%		
Aerodynamic ef	ficiency	
	noiency	
Real aircraft average	k_{WL}	2,83
No winglets	$k_{e,WL}$	1,00
Span	$b_{\mathbf{W}}$	38,05 m
Winglet height	h	2,5 m
Aspect ratio	Α	7,82
Effective aspect ratio	A_{eff}	7,82
Efficiency factor, short range	k _E	15,15
Relative wetted area	S _{wel} /S _W	5,61
Verification value maximum aerodynamic efficiency	E _{max}	17,9
RE value maximum aerodynamic efficiency	—max	15,54
15%		10,01

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,800
Cruise altitude	h _{CR}	11795 m
By Pass Ratio	μ	4,40
Take-off Thrust (one engine)	T _{TO,one engine}	178,50 kN
Overall Pressure ratio	OAPR	25,80
Turbine entry temperature	TET	1475,18
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,95
Ventilator efficiency	$\eta_{ m ventilator}$	0,87
Compressor efficiency	$\eta_{compresor}$	0,86
Turbine efficiency	$\eta_{turbine}$	0,91
Nozzle efficiency	η_{nozzle}	0,99
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,81
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,13
Temperature function	χ	1,73
Gas generator efficiency	η_{gasgen}	0,98
Gas generator function	G	2,27
Verification value specific fuel consumption	SFC	0,60 kg/daN/h
Verification value specific fuel consumption	SFC	1,68E-05 kg/N/s
RE value specific fuel consumption	SFC	1,74E-05 kg/N/s

Matching Chart



Appendix Y Airbus A380-800

Data Collection	ction		A380-800		2	3	4	2	9	7	80	6
Parameter	Svmbol	Units	Chosen value	Source: Aircraft characteristics for airport planning	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Data collection	Webs
PAX			853	555	222					853-555		555-853
Landing field length	SLFL	Ε	1940	1940	2103					2100	2010	
Approach speed	V _{APP}	m/s	7.	71	72,5						70,993333	
Relative density	ر ا	4			2							
Take-off field length	STOFL	ε	2987	2950	2987					2990	2950	2750
Temperature above ISA (288,15K)	ΔΤτο	×	0	0	15							
Relative density	ø											
Range (max payload)	œ	km	12149	12200	14816					12149		14800
Cruise Mach number	McR		0,85		0,82		0,85			0,85	0,85	0,85
Wing area	Š	m²	845,82		845					845,82		845
Wing span	ρw	E	79,75	79,75	79,8					79,75	79,75	79,75
Aspect ratio	4		7,52		2,5					7,52		
Maximum take-off mass	Мито	ķ	575000	575000	260000					260000	560000	575000
Payload mass	MPL	kg	83600	83600	90985					84320		
Mass ratio, payload - take-off	MPL/MMTO									0,151		
Maximum landing mass	mML	kg	395000	395000	386000					386000		394000
Mass ratio, landing - take-off	ММ⊔Мито											
Operating empty mass	Moe	ğ	270015		270015					276680		276000
Mass ratio, operating empty - take-off moe/mmro	off moe/mwro	Latim2	CSS		7 683					0,494		
Maximim zero fuel mass	M M M	<u> </u>	361000	369000	361000					361000		369000
	-IMZF	2	2									
Number of engines	пе									4	4	4
Engine type	EA GP720	EA GP7200 (42%), RR T	Trent 970-84		RR Trent 970		GP7270				GP7200	GP7270-Trent 970/B
Take-off thrust for one engine	Tro, one engine KN	KN	374		374		311,376			311,374 334,282	82 311	311
Total take-off thrust	T ₁₀	Z ,	70.0		0 2202005						70	
Bypass ratio	TOVITIMIO 9)		8.7		0,550,550		8.7			2,0	7.1	
Specific Fuel Comsumption (dry)	SFC (dry)	kg/N s	5				5					
Specific Fuel Comsumption (cruise)		e kg/N s										
Available fuel volume	Vfuel, available	E E	324,562	323,546	323,546 310-355,85					324,562		320
Cruise speed	V _{CR}	m/s	267,5								267,51111	
Cruise altitude	hck	E	10668		10670-13100		10668			13100°		
Sweep angle	ф 25	0	33,5		35					33,5		
Mean aerodynamic chord	OMAC	ε	12,3		12,3					12,3		
Position of maximum camber	X _{(y_c),max}	%с	81									81
Camber	(yc)max/c	%c	2,5									2,5
Position of maximum thickness	X _{t,max}	%с	37									37
Relative thickness	AC	%	13,4-9,1-9,2							13,4-9,1-9,2		14
Overall pressure ratio	OAPR		45.6				45.6			0,22,0		
ממום המסמום	2		2				2					

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	S _{LFL}	1940			
Approach speed	Known	V_{APP}	71,00	m/s	71,0	71,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	2987	m	2987	2987
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	6560	NM		
Cruise Mach number		M _{CR}	0,85			
Wing area		S_W	846	m²		
Wing span	Known	b_W	79,75	m²	79,75	79,75
Aspect ratio		Α	7,52			
Maximum take-off mass		m _{MTO}	575000	kg		
Maximum payload mass		m_PL	83600	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,145			
Maximum landing mass		m_ML	395000	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,687			
Operating empty mass		m_OE	270015	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,470			
Wing loading		m_{MTO}/S_W	679,8	kg/m²		
Number of engines		n _E	4			
Take-off thrust for one engine		T _{TO,one engine}	374	kN		
Total take-off thrust		T _{TO}	1496	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,265			
Bypass ratio		μ	8,7			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to	αo	tim	ize	V/	V
Data		v		120	•,	w mad

				LL	UL
Cruise speed		V_{CR}	268 m/s	3	
Cruise altitude		h _{CR}	10668 m		
Speed ratio		V/V_{md}	1,000 -	1	1,316
	Data to execu	ite the verification			
				Ra	nge
Sweep angle		ϕ_{25}	35 °		
Mean aerodynamic chord		C _{MAC}	12,3 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %0	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	10,6 %		
Taper		λ	0,225		

Reverse Engineering

Reverse engineering & optimization of V/Vmd

		у с. оринишиной от	.,		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1940	1940	m	0,00%
Approach speed	V_{APP}	71,00	71,0	m/s	0,00%
Take-off field length	s _{TOFL}	2987	2987	m	0,00%
Span	b_W	79,75	79,75	m	0,00%
Aspect ratio	Α	7,52	7,52		0,00%
Cruise speed	V_{CR}	267,5	253	m/s	-5,50%
Cruise altitude	h_{CR}	10668	10483	m	-1 <mark>,73%</mark>
Squared Sum Absolute maximum deviation					3,33E-03 5,5%
Absolute maximum deviation					3,3 70
	Results rev	erse engineering			
Maximum lift coefficient, landing	$\mathbf{C}_{L,max,L}$	2,25			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,01		Reve	rse Engineering
Maximum aerodynamic efficiency	E _{max}	18,94		. 1070	gg
Specific fuel consumption	SFC	1,48E-05 kg	g/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Landi	ng	
Landing field length	S _{LFL}	1940 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	71,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,69
Wing loading at maximum take-off mass	m_{MTO}/S_W	679,8 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,25
Take-	off	
Take-off field length	S _{TOFL}	2987 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,265
Maximum lift coefficient, take-off	C _{L.max.TO}	2,01
Aspect ratio 2nd Seg	ment A	7,519
Lift coefficient, take-off		1,39
	C _{L,TO}	
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,015
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,035
Oswald efficiency factor; landing configuration	e	<mark>0,7</mark> 9,15
Glide ratio in take-off configuration	E _{TO}	9,15
Number of engines	n _E	4
Climb gradient	sin(γ)	0,030
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,186
Missed ap	proach	
Lift coefficient, landing	C _{L,L}	1,33
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,012
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C _{D,P}	0,047
Glide ratio in landing configuration	E _L	8,66
Climb gradient	sin(γ)	0,027
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,131

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,85	
Aspect ratio	Α	7,52	
Bypass ratio	μ	8,70	
Wing loading	m_{MTO}/S_W	680 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,265	
,	Variables		
	V/V _{md}	1,0	
C	alculations		
Zero-lift drag coefficient	C _{D,0}	0,014	
Lift coefficient at E _{max}	$C_{L,md}$	0,53	
Ratio, lift coefficient	$C_L/C_{L,md}$	1,000	
Lift coefficient, cruise	C_L	0,530	
Actual aerodynamic efficiency, cruise	E	18,94	
Max. glide ratio, cruise	E _{max}	18,94	
Newton-Raphson for the maximum lift-to-o	drag ratio		
Iterations	1	2	3
f(x)	0,28	-0,02	0,00
f'(x)	-0,09	-0,10	-0,10
E _{max}	16	19,09	18,94

3) Specific Fuel Consumption

Constant par	ameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{ m fuel}$	800	kg/m³
Specificat	ions		
Range	R	6560	
Mach number, cruise	M_{CR}	0,85	
Bypass ratio	μ	8,70	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,265	
Available fuel volume	$V_{ m fuel,available}$	23,86	
Maximum take-off mass	m_{MTO}	575000	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,145	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,470	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	18,94	
Cruise altitude	h _{CR}	10483	m
Cruise speed	V_{CR}	253	m/s
Mission fuel	fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	$M_{ff,DES}$	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Calculati	ons		
Mission fuel fraction (acc. to PL and OE)	m _E /m _{MTO}	0,385	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,615	
Available fuel mass	MF,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,033	
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,986	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	no	
	international	yes	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	977856	m
Loiter time	t _{loiter}	1800	s
Specific fuel consumption	SFC	1,48E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

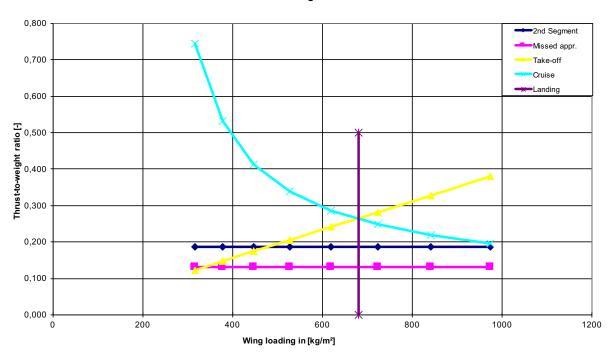
General wing specifications	Airfoil type:	NACA 63 series
Wing span	b_W	79,75 m
Structural wing span	$b_{W,struct}$	97,36 m
Wing area	s_{w}	845,8 m ²
Aspect ratio	Α	7,52
Sweep	ϕ_{25}	35 °
Mean aerodynamic chord	C _{MAC}	12,3 m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t.max}$	30 %c
Relative thickness	t/c	10,6 %
Taper	λ	0,225
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	71,00 m/s
Mach number, landing	M_{APP}	0,21
Mach number, cruise	M _{CR}	0,85
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,3 %c
Leading edge sweep	ϕ_{LE}	39,8 °
Reynoldsnumber	Re	6,2E+07
Maximum lift coefficient, base	C _{L,max,base}	1,36
Correction term, camber	$\Delta_1 c_{L,max}$	0,38
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,018
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,760
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,78
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	C _{L,max}	1,36

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle\mathbf{\omega}}$	0,81
Flap group A	*	
Single-slotted flap	$\Delta c_{L,max,fA}$	0,73
Use flapped span	b_W,fA	45,3 m
Percentage of flaps allong the wing		47%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,28
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,69
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\DeltaC_{L,max,f}$	0,28
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	Ψ _{H.L.}	37 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,84
Use slatted span	b_W,sA	59,3 m
Percentage of slats allong the wing		61%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,41
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,84
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing		0%
Increase in maximum lift coefficient, slat group B	$\Delta G_{L,max,sB}$	0,00
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,41
Wing Verification value maximum lift coefficient, landing RE value maximum lift coefficient, landing Verification value maximum lift coefficient, take-off RE value maximum lift coefficient, take-off	$C_{L,max,L}$ $C_{L,max,TO}$	2,03 2,25 1,81 2,01
-10%		2,01
Aerodynamic ef	ficiency	
Real aircraft average	k_{WL}	2,83
End plate	k _{e,WL}	1,08
Span	b _W	79,75 m
Winglet height	h	4,57 m
Aspect ratio	A	7,52
Effective aspect ratio	$A_{\rm eff}$	8,14
Efficiency factor, short range	k_{E}	17,25
Relative wetted area	S _{wel} /S _W	6,30
Verification value maximum aerodynamic efficiency	E _{max}	19,6
RE value maximum aerodynamic efficiency	IIIWA	18,94
4%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_CR	0,850	
Cruise altitude	h _{CR}	10668	m
By Pass Ratio	μ	8,70	
Take-off Thrust (one engine)	T _{TO,one engine}	374,00	kN
Overall Pressure ratio	OAPR	45,60	
Turbine entry temperature	TET	1498,61	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η _{inlet}	0,93	
Ventilator efficiency	$\eta_{ventilator}$	0,90	
Compressor efficiency	$\eta_{compresor}$	0,88	
Turbine efficiency	$\eta_{ m turbine}$	0,91	
Nozzle efficiency	η_{nozzle}	0,99	
Temperature at SL	T_o	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T_S	216,65	K
Temperature at cruise altitude	T(H)	218,81	K
Dimensionless turbine entry temperature	ф	6,85	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temp	erature υ	1,14	
Temperature function	χ	2,26	
Gas generator efficiency	$oldsymbol{\eta}_{gasgen}$	0,97	
Gas generator function	G	2,08	
Verification value specific fuel consumption	SFC	0.54	kg/daN/h
Verification value specific fuel consumption	SFC	1,50E-05	0
DE color on effective constitution	050	4.405.05	L /N.1 /n
RE value specific fuel consumption	SFC 1%	1,48E-05	kg/N/S

Matching Chart



Appendix Z Bombardier CRJ700

SA (288,15K)			3		-	2	3	4	2	9	7	8	6
Farameter ling field length oach speed perature above ISA (288,15K) tive density e-off field length perature above ISA (288,15K) tive density ge (max payload)	Γ	:		Source: A	ics	ne's	Jenkinson	Engine	Scholz		Elodie Roux	Paul MüllerElodie RousData collectior	Webs
ling field length cach speed perature above ISA (288,15K) tive density -off field length perature above ISA (288,15K) tive density ge (max payload)		Onits	Chosen value	4	_	Standard LR		,			000		
			8/		70	0					78-66		
		E	1550		1550	1551					1478	1509	1536
		s/m	69,45		69,45								
		*	0		0								
		8	1561		1575	1561 1676					1564	17.65	1805
		≣ 2	5		2						5	2	3
		۷	>		0								
		km	1556		1740	3053 3604					1556		3121
Cruise Mach number McR	~		0,77			0,78					0,77	72,0	0,78
Wing area		m²	68.63			68.63					68.63		70.61
Wing span		E	23,24	İ	23.25	23.24					23.24	23.24	23.24
			7,87			7,4					7,87		
Maximum take-off mass		kg	34019		32999	32999 34019	6				32999	34000	34019
		kg	8528			8528					8990		8527
(e-off	Ш Р∟/ Ш МТО										0,272		
		kg	30390		30390	30390					30390		
ge-off	ММ⊔Мито												
Operating empty mass moe	ш	kg	19269		19731	19731					19269		20069
erating empty - take-off											0,584		
	ν N	kg/m²	480,8		000	480,8 495,7					481		, 0000
Maximum zero tuel mass m _{MZF}	ZF	K g	58259		58259	28259					69787		78801
Number of enginee			c		C						C	C	0
	GE CE34		CE34-8C1		GE CE34-8C5	CE34-8C1		CE34-8C1 CE34-8C5	ı,			GE CE34 - 8C	7
st for one engine		Z	61.341			56.4 - 61.3			32			61.3	56.4
	olie eligile	Z	· • • •			26			!		:	2	
0	(m _{MTO} *q)		0.38			0,34826 0,33788					0.38		
			4,9					4,9 4,9	6,		4,9		
Comsumption (dry)	SFC (dry)	kg/N s	1,05E-05						35		1,05E-05		
Specific Fuel Comsumption (cruise) SFC	SFC (cruise kg/N s	kg/N s											
Available fuel volume	Vfuel, available	m³	10,989		10,989	10,989					11,5		
Cruise speed		m/s	228			228,4						227,38444	225
		ε											
Sweep andle		0	26.6								26.6		
namic chord		E		İ									
ber	max	%c											
		%c											
of maximum thickness		%c											
		%											
Taper													
	R		27					27					
Turbine entry temperature TET		~											

Aeroplane Specifications

Available fuel volume

Data to apply reverse engineering UL LL **1550** m Landing field length Known S_{LFL} Approach speed Known V_{APP} 69,45 m/s 69,4 69,4 ΔT_{L} Temperature above ISA (288,15K) 0 K Relative density 1 σ Take-off field length Known **1564** m 1564 1564 STOFL Temperature above ISA (288,15K) 0 K ΔT_{TO} Relative density 1,000 Range (maximum payload) R 840 NM Cruise Mach number M_{CR} 0,77 Wing area S_W 69 m² Wing span Known 23,24 m² 23,24 23,24 b_W Aspect ratio Α 7,87 Maximum take-off mass 34019 kg m_{MTO} Maximum payload mass ${\rm m}_{\rm PL}$ 8528 kg Mass ratio, payload - take-off 0,251 m_{PL}/m_{MTO} Maximum landing mass 30390 kg m_{ML} Mass ratio, landing - take-off m_{ML}/m_{MTO} 0,893 Operating empty mass **19269** kg m_{OE} Mass ratio, operating empty - take-off 0,566 m_{OE}/m_{MTO} Wing loading m_{MTO}/S_W 495,7 kg/m² Number of engines 2 n_E Take-off thrust for one engine T_{TO,one engine} 61,341 kN Total take-off thrust 122,682 kN T_{TO} Thrust to weight ratio 0,368 $T_{TO}/(m_{MTO}*g)$ Bypass ratio 4,9

fuel,available

23,86 m³

Data	to	optimize	V/V_{md}
------	----	----------	------------

				LL	UL
Cruise speed		V_{CR}	228 m/s		
Cruise altitude		h _{CR}	11278 m		
Speed ratio		V/V_{md}	1,205 -	1	1,316
	Data to execu	te the verification			
				Rar	nge
Sweep angle		ϕ_{25}	26,6 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,7 %		
Taper		λ	0,24		

Reverse Engineering

Davaraa		0	optimization	of \//\/ma	4
Reverse	enaineerina	Œ	optimization	or v/vmc	3

	,			
Quantity	Original value	RE value	Unit	Deviation
S _{LFL}	1550	1550	m	0,00%
V_{APP}	69,45	69,4	m/s	0,00%
s _{TOFL}	1564	1564	m	0,00%
b_W	23,24	23,24	m	0,00%
Α	7,87	7,87		0,00%
V_{CR}	228,0	227	m/s	-0,33%
h_{CR}	11278	11278	m	0,00%
				1,11E-05 0,3%
Results rev	erse engineering			
$C_{L,max,L}$	2,67			
$C_{L,max,TO}$	2,02		Paya	rse Engineering
E _{max}	13,54		Keve	ise Engineering
SFC	1,48E-05 kg	/N/s		
	S _{LFL} V _{APP} S _{TOFL} b _W A V _{CR} h _{CR} Results rev C _{L,max,L} C _{L,max,TO} E _{max}	SLFL 1550 VAPP 69,45 STOFL 1564 bW 23,24 A 7,87 VCR 228,0 hCR 11278 Results reverse engineering CL,max,L CL,max,TO CL,max,TO Emax 13,54	s _{LFL} 1550 1550 V _{APP} 69,45 69,4 s _{TOFL} 1564 1564 b _W 23,24 23,24 A 7,87 7,87 V _{CR} 228,0 227 h _{CR} 11278 11278 Results reverse engineering C _{L,max,L} C _{L,max,TO} 2,02 E _{max} 13,54	s _{LFL} 1550 1550 m V _{APP} 69,45 69,4 m/s s _{TOFL} 1564 1564 m b _W 23,24 m 23,24 m A 7,87 7,87 V _{CR} 228,0 227 m/s 11278 m N _{CR} 11278 11278 m 11278 m

1) Maximum Lift Coefficient for Landing and Take-off

Landing						
Landing field length	S _{LFL}	1550 m				
Temperature above ISA (288,15K)	ΔT_L	0 K				
Relative density	σ	1,000				
Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$				
Approach speed	V_{APP}	69,45 m/s				
Factor, landing	k_{L}	0,107 kg/m³				
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,89				
Wing loading at maximum take-off mass	m_{MTO}/S_W	495,7 kg/m²				
Maximum lift coefficient, landing	$C_{L,max,L}$	2,67				
Take-	off					
Take-off field length	S _{TOFL}	1564 m				
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K				
Relative density	σ	1,00				
Factor	k _{TO}	2,34 m³/kg				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,368				
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,02				
2nd Seg	ıment					
Aspect ratio	A	7,870				
Lift coefficient, take-off	$C_{L,TO}$	1,40				
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020				
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,015				
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000				
Profile drag coefficient	C _{D,P}	0,035				
Oswald efficiency factor; landing configuration	e	0,7				
Glide ratio in take-off configuration	E _{TO}	9,44				
Number of engines	n _E	2				
Climb gradient	sin(γ)	0,024				
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,260				
-						
Missed approach Lift coefficient, landing C _{L,L} 1,58						
Lift-independent drag coefficient, clean	C _{L,L} C _{D.0} (Missed approach)	0,020				
Lift-independent drag coefficient, flaps	_,-,-,	0,020				
	$\Delta C_{D,flap}$	0,024				
Lift-independent drag coefficient, slats Choose: Certification basis	$\Delta C_{D,slat}$ JAR-25 resp. CS-25	0,000 no				
Onoose. Octuiication pasis	FAR Part 25	yes				
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015				
Profile drag coefficient	C _{D,P}	0,059				
Glide ratio in landing configuration	E _L	7,77				
	L	- ,				
Climb gradient	$sin(\gamma)$	0,021				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,267				

2) Maximum Aerodynamic Efficiency

Const	ant parameters				
Ratio of specific heats, air	γ	1,4			
Earth acceleration	g	9,81 m/s ²			
Air pressure, ISA, standard	p_0	101325 Pa			
Oswald eff. factor, clean e		0,85			
Sp	ecifications				
Mach number, cruise	M _{CR}	0,77			
Aspect ratio	Α	7,87			
Bypass ratio	μ	4,90			
Wing loading	m_{MTO}/S_W	496 kg/m²			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,368			
	Variables				
	V/V_{md}	1,2			
Calculations					
Zero-lift drag coefficient	C _{D,0}	0,029			
Lift coefficient at E _{max}	$C_{L,md}$	0,78			
Ratio, lift coefficient	$C_L/C_{L,md}$	0,689			
Lift coefficient, cruise	C_L	0,535			
Actual aerodynamic efficiency, cruise	E	12,65			
Max. glide ratio, cruise	E _{max}	13,54			
Newton-Raphson for the maximum lift-to-	drag ratio				
Iterations	1	2	3		
f(x)	-0,38	-0,02	0,00		
f(x)	-0,16	-0,15	-0,15		
E _{max}	16	13,65	13,54		

3) Specific Fuel Consumption

Constant par	ameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{ m fuel}$	800	kg/m³
Specificat	ions		
Range	R	840	NM
Mach number, cruise	M _{CR}	0,77	
Bypass ratio	μ	4,90	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,368	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	34019	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,251	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,566	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	12,65	
Cruise altitude	h _{CR}	11278	m
Cruise speed	V _{CR}	227	m/s
Mission fuel	fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	M _{ff,taxi}	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
-	•		
Mission fuel fraction (acc. to PL and OE)		0,183	
•	m _F /m _{MTO}		
Mission fuel fraction (acc. to PL and OE)	M_ff	0,817	
Available fuel mass	m _{F,available}	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,561	
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,448	
Distance to alternate	S _{to alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,48E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

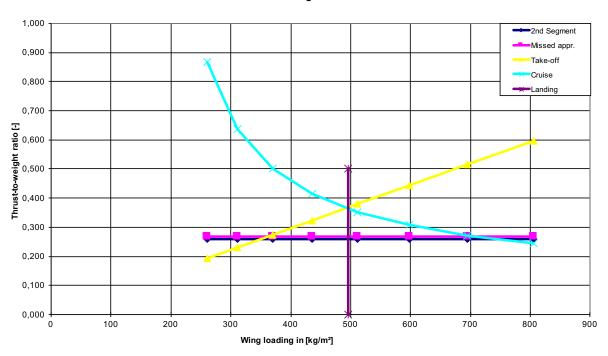
General wing specifications	Airfoil type:	NACA 4 digir
Wing span	b_W	23,24 m
Structural wing span	$b_{W,struct}$	25,99 m
Wing area	S_W	68,6 m ²
Aspect ratio	Α	7,87
Sweep	ϕ_{25}	26,6 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	X _{t.max}	30 %c
Relative thickness	t/c	11,7 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	69,45 m/s
Mach number, landing	M_APP	0,21
Mach number, cruise	M_{CR}	0,77
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	3,0 %c
Leading edge sweep	ϕ_{LE}	31,1 °
Reynoldsnumber	Re	2,1E+07
Maximum lift coefficient, base	$c_{L,max,base}$	1,58
Correction term, camber	$\Delta_1 c_{L,max}$	0,17
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,086
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,835
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,79
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	C _{L,max}	1,44

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathrm{\Phi}}}$	0,86
Flap group A	Ψ	,,,,,
Double-slotted flap	$\Delta c_{L,max,fA}$	1,41
Use flapped span	b_W,fA	15,1 m
Percentage of flaps allong the wing	2_***," *	58%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,70
Flap group B	Lillarin	•
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,73
Use flapped span	b W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,70
moreage in maximum in coomorni, nap	□ □ L,max,r	0,70
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	ΨH.L.	30 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,89
Use slatted span	b_W,sA	20 m
Percentage of slats allong the wing	<u> </u>	77%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,59
Slat group B	Ejillozijori	
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,89
Use slatted span	b W,sB	0 m
Percentage of slats allong the wing		0%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,00
Increase in maximum lift coefficient, slat	ΔC _{L,max,s}	0,59
Wing	0	2.70
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,70
RE value maximum lift coefficient, landing	0	2,67
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,04
RE value maximum lift coefficient, take-off 1%		2,02
176		
Aerodynamic ef	ficiency	
Dool circust everage		0.00
Real aircraft average	k _{WL}	2,83
End plate	$k_{e,WL}$	1,08
Span	b_W	23,24 m
Winglet height	h	1,3 m
Aspect ratio	Α	7,87
Effective aspect ratio	A_{eff}	8,50
Efficiency factor, short range	k _E	15,15
Relative wetted area	S _{we} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	17,5
RE value maximum aerodynamic efficiency	- max	13,54
30%		10,04
3070		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,770
Cruise altitude	h_{CR}	11278 m
By Pass Ratio	μ	4,90
Take-off Thrust (one engine)	T _{TO,one engine}	61,34 kN
Overall Pressure ratio	OAPR	28,50
Turbine entry temperature	TET	1389,58
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η _{inlet}	0,95
Ventilator efficiency	η _{ventilator}	0,83
Compressor efficiency	n _{compresor}	0,84
Turbine efficiency	$\eta_{turbine}$	0,88
Nozzle efficiency	$\eta_{ m nozzle}$	0,97
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	Ts	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,41
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	1,79
Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Gas generator function	G	1,88
Verification value specific fuel consumption	SFC	0,65 kg/daN/h
Verification value specific fuel consumption	SFC	1,80E-05 kg/N/s
RE value specific fuel consumption	SFC	1,48E-05 kg/N/s
21%		

Matching Chart



Appendix AA Comac C919

Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Particular Par	Data Collection	ction		C919		-	2	3	4	2	9	7	8	6	
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Tro(maircig)	Total take-off thrust	T _{TO}													
11	Thrust to weight ratio	T _{TO} /(m _{MTO} *(g)	;						0,275				-	
Activities SFC (cruise) kg/N s Cruises SFC (cruises) kg/N s Cruises	Bypass ratio	1		-						11				11	
Cruise) SFC (cruise) kg/N s Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Capture Ca	Specific Fuel Comsumption (dry)	SFC (ary)	kg/N s												
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V _{GR} m/s 231,5 112 hcs m 11278 112 ebs ° 7965 112 outc m 112 112	Available fuel volume	Vfuel, available		24,45						22,9				24,45	
hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.7 hcr IIIs 2017.	Poor o o o o o o o o o o o o o o o o o o	27		231 E										231 E	
Pick M	nase speed	χ > .	9	0,102						1000				0,107	
φ ₂₅ ° OAAPR Φ OAPR 40	Cruise altitude	ncr	E	112/8						COR/				112/8	
Def Xky, c)max %C Ness Xkmx/C %C No No No No No No OAPR 40 No	Sweep angle	ф 25	•												
Not Depth (Not blank) %C Not blank %C Not UC % A A OAPR 40	Mean aerodynamic chord	OMAC	ε												
(ψ _c haw/c %c %c	Position of maximum camber	X _{(y_c),max}	%c												
hess K _{t,max} %c	Camber	(yc)max/c	%с												
υς % λ OAPR 40	Position of maximum thickness	X _{t,max}	%с												
л А А А О А Р В В В В В В В В В В В В В В В В В В	Relative thickness	t/c	%												
OAPR 40	Taper	~													
	Overall pressure ratio	OAPR		40										40	

Aeroplane Specifications

Total take-off thrust

Bypass ratio

Thrust to weight ratio

Available fuel volume

Data to apply reverse engineering LL UL **1600** m Landing field length Known s_{LFL} Approach speed Known 69,45 m/s 69,5 69,5 V_{APP} Temperature above ISA (288,15K) 0 K ΔT_L Relative density 1 σ **2200** m Take-off field length Known 2200 2200 S_{TOFL} Temperature above ISA (288,15K) ΔT_{TO} 0 K Relative density 1,000 σ Range (maximum payload) R 2200 NM Cruise Mach number M_{CR} 0,73 Wing area S_W 129 m² \mathbf{b}_{W} Wing span Known 35,8 m² 35,8 35,8 Aspect ratio Α 9,92 Maximum take-off mass 77393 kg m_{MTO} **20500** kg Maximum payload mass m_{PL} Mass ratio, payload - take-off 0,265 m_{PL}/m_{MTO} $m_{ML} \\$ Maximum landing mass 66682 kg Mass ratio, landing - take-off 0,862 m_{ML}/m_{MTO} Operating empty mass **42100** kg m_{OE} Mass ratio, operating empty - take-off m_{OE}/m_{MTO} 0,544 599,2 kg/m² Wing loading m_{MTO}/S_W Number of engines 2 n_{E} Take-off thrust for one engine $T_{\text{TO,one engine}}$ 137,9 kN

 T_TO

 $T_{TO}/(m_{MTO}*g)$

V_{fuel,available}

275,8 kN

11

24,45 m³

0.363

Data	to o	ptimize	V/V _{md}
------	------	---------	-------------------

	IIIU			
			LL	UL
	V_{CR}	232 m/s		
	h _{CR}	11278 m		
	V/V_{md}	1,014 -	1	1,316
Data to execu	te the verification			
			Ran	ge
	ϕ_{25}	25 °		
	C _{MAC}	4,2 m		
	X _{(y_c),max}	30 %c	15 - 50	%с
	(y _c) _{max} /c	4 %c	2 - 6	%с
	$x_{t,max}$	30 %c	30 - 45	%с
Unknown	t/c	12,2 %		
	λ	0,24		
	Data to execu	$\begin{array}{c} V_{CR} \\ h_{CR} \\ V/V_{md} \end{array}$ Data to execute the verification $\begin{array}{c} \phi_{25} \\ c_{MAC} \\ x_{(y_c),max} \\ (y_c)_{max}/c \\ x_{t,max} \\ t/c \end{array}$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$

Reverse Engineering

1100	erse engineering	g & optimization of v	, villa		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1600	1600	m	0,00%
Approach speed	V_{APP}	69,45	69,5	m/s	0,00%
Take-off field length	s _{TOFL}	2200	2200	m	0,00%
Span	b_W	35,8	35,8	m	0,00%
Aspect ratio	Α	9,92	9,92		0,00%
Cruise speed	V_{CR}	231,5	215	m/s	-6,94%
Cruise altitude	h_{CR}	11278	11278	m	0,00%
Squared Sum Absolute maximum deviation					4,82E-03 6,9%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,02			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,75		Povo	roo Engineering
Maximum aerodynamic efficiency	E _{max}	17,97		Reve	rse Engineering
Specific fuel consumption	SFC	1,09E-05 kg	g/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

L	anding	
Landing field length	S _{LFL}	1600 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	69,45 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,86
Wing loading at maximum take-off mass	m_{MTO}/S_W	599,2 kg/m ²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,02
T	ake-off	
Take-off field length	S _{TOFL}	2200 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,363
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,75
2nd	Segment	
Aspect ratio	A	9,924
Lift coefficient, take-off	$C_{L,TO}$	1,22
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,006
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,026
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	12,97
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,202
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,78
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,034
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Profile drag coefficient	C_D,P	0,069
Glide ratio in landing configuration	EL	8,29
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,244
-		-

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,73	
Aspect ratio	Α	9,92	
Bypass ratio	μ	11,00	
Wing loading	m_{MTO}/S_W	599 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,363	
	Variables		
	V/V_{md}	1,0	
С	alculations		
Zero-lift drag coefficient	C _{D,0}	0,021	
Lift coefficient at E _{max}	$C_{L,md}$	0,74	
Ratio, lift coefficient	C _L /C _{L,md}	0,972	
Lift coefficient, cruise	C_L	0,716	
Actual aerodynamic efficiency, cruise	E	17,96	
Max. glide ratio, cruise	E _{max}	17,97	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	1	2	3
f(x)	0,22	-0,01	0,00
f(x)	-0,11	-0,11	-0,11
E _{max}	16	18,05	17,97

3) Specific Fuel Consumption

Consta	nt parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	•	m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Spe	cifications		
Range	R	2200	NM
Mach number, cruise	M_{CR}	0,73	
Bypass ratio	μ	11,00	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,363	
Available fuel volume	$V_{fuel,available}$	24,45	m³
Maximum take-off mass	m _{MTO}	77393	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,265	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,544	
Calcu	ılated values		
Actual aerodynamic efficiency, cruise	E	17,96	
Cruise altitude	h_{CR}	11278	m
Cruise speed	V_{CR}	215	m/s
Missio	n fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Ca	Iculations		
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,191	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,809	
Avellah la fivel asses		40500	la sa
Available fuel mass	F,available	19560	ĸg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,253	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,762	
Distance to alternate	S _{to_alternate}		NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t_{loiter}	2700	s

4) Verification Specifications

Maximum lift coefficients

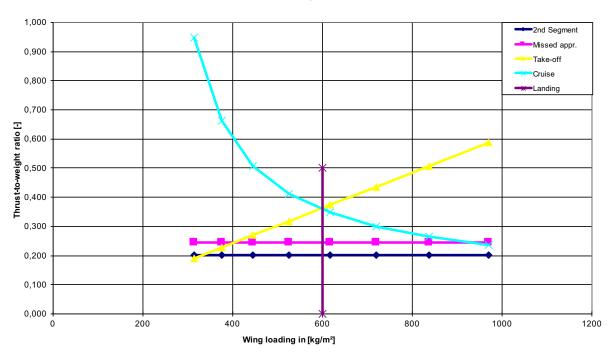
General wing specifications	Airfoil type:		NACA 4 digi
Wing span	b_W	35,8	m
Structural wing span	$b_{W,struct}$	39,50	m
Wing area	S_W	129,2	m²
Aspect ratio	Α	9,92	
Sweep	Φ25	25	•
Mean aerodynamic chord	CMAC	4,2	m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30	%с
Camber	(y _c) _{max} /c	4	%с
Position of maximum thickness	$\mathbf{x}_{t,max}$	30	%с
Relative thickness	t/c	12,2	%
Taper	λ	0,24	
General aircraft specifications			
Temperature above ISA (288,15K)	ΔT_L	0	K
Relative density	σ	1	
Temperature, landing	T_L	273,15	K
Density, air, landing	ρ	1,225	kg/m³
Dynamic viscosity, air	μ	1,72E-05	kg/m/s
Speed of sound, landing	a _{APP}	331	m/s
Approach speed	V_{APP}	69,45	m/s
Mach number, landing	M_{APP}	0,21	
Mach number, cruise	M _{CR}	0,73	
Calculations maximum clean lift coefficient			
Leading edge sharpness parameter	Δy	3,2	%с
Leading edge sweep	φLE	28,5	0
Reynoldsnumber	Re	2,1E+07	
Maximum lift coefficient, base	C _{L,max,base}	1,59	
Correction term, camber	$\Delta_1 c_{L,max}$	0,14	
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00	
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,103	
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,836	
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80	
Correction term, Mach number	$\Delta C_{L,max}$	-0,01	
Lift coefficient, wing	C _{L,max}	1,46	

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\scriptscriptstyle{oldsymbol{\phi}}}$	0,87
Flap group A		
Double-slotted flap	$\Delta c_{L,max,fA}$	1,43
Use flapped span	b_W,fA	8,95 m
Percentage of flaps allong the wing		23%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,28
Flap group B		
Double-slotted flap	$\Delta c_{L,max,fB}$	1,43
Use flapped span	b_W,fB	15,8 m
Percentage of flaps allong the wing		40%
Increase in maximum lift coefficient, flap group B	ΔC _{L,max,fB}	0,50
Increase in maximum lift coefficient, flap	\DeltaC_L,max,f	0,78
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	Ф н.L.	28 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	6,8 m
Percentage of slats allong the wing		17%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,14
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	22,2 m
Percentage of slats allong the wing		56%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,45
Increase in maximum lift coefficient, slat	$\Delta G_{L,max,s}$	0,59
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,78
RE value maximum lift coefficient, landing		3,02
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,62
RE value maximum lift coefficient, take-off		1,75
-8%		
Aerodynamic efficien	су	
Real aircraft average	k wL	2,83
End plate	K _{e,WL}	1,08
Span	b _W	35,8 m
Winglet height	h	1,9 m
Aspect ratio	A	9,92
Effective aspect ratio	A _{eff}	10,68
Ziloonio aoposi rano	. •611	10,00
Efficiency factor, short range	k _E	15,15
Relative wetted area	9 /9	6 3 5
ו/פומוואפ שפונפט מופמ	S _{wet} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	19,6
RE value maximum aerodynamic efficiency		17,97
9%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,730
Cruise altitude	h _{CR}	11278 m
By Pass Ratio	μ	11,00
Take-off Thrust (one engine)	T _{TO,one engine}	137,90 kN
Overall Pressure ratio	OAPR	40,00
Turbine entry temperature	TET	1461,99
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,92
Ventilator efficiency	η _{ventilator}	0,89
Compressor efficiency	η _{compresor}	0,88
Turbine efficiency	η _{turbine}	0,91
Nozzle efficiency	η_{nozzle}	0,99
Temperature at SL	T ₀	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	Ts	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,75
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,11
Temperature function	χ	2,07
Gas generator efficiency	η_{gasgen}	0,97
Gas generator function	G	2,10
Verification value specific fuel consumption	SFC	0,48 kg/daN/h
Verification value specific fuel consumption	SFC	1,35E-05 kg/N/s
vermoation value specific fuel consumption	SFO.	1,33E-03 kg/14/3
RE value specific fuel consumption	SFC	1,09E-05 kg/N/s
24%		

Matching Chart



Appendix AB Mitsubishi MRJ90

March Diese Diese March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March March Marc	Data Collection	ction		MRJ90		-				2		3	4	2	9	7	8		6	
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titude hcs m 11900 ngle	Cruise speed	V _{CR}	s/m	230															230	
ngle 455 rodynamic chord 0 _{AAC} of maximum camber X _{V, D,max} (Y _{C, D,max} of maximum thickness X _{C,max} thickness t A A A A Coorder OAPR	Cruise altitude	hca	ε	11900			11900													
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rodynamic chord A _{AkC} of maximum camber $X_{V_C, Dimax}$ $Y_{V_C, Dimax}$ of maximum thickness $X_{V_C, max}$ thickness λ λ ressure ratio λ	Sweep angle	Ф25																		
of maximum camber X _{K, C, max} (V _{c, haad} of maximum thickness X _{C, max} thickness V to ressure ratio OAPR	Mean aerodynamic chord	OMAC	ε :																	
of maximum thickness X _{nmax} thickness to to A ressure ratio OAPR	Position of maximum camber	X(y_c),max	%c																	
Atmax t/c A OAPR	Camber	(yc)max/C	%c																	
OAPR	Position of maximum thickness	Xt,max	2%C																	
OAPR	Tener	2 ~	0,																	
	Overall pressure ratio	OAPP																		
	Turking pathy formanatura	1 1	7																	

Aeroplane Specifications

Data to apply reverse engineering LL UL **1480** m Landing field length Known S_{LFL} **70,00** m/s Approach speed Known V_{APP} 70,0 70.0 $\Delta \mathsf{T}_\mathsf{L}$ Temperature above ISA (288,15K) 0 K Relative density 1 σ **1500** m Take-off field length Known 1500 1500 STOFL Temperature above ISA (288,15K) 0 K ΔT_{TO} Relative density 1,000 869 NM Range (maximum payload) R M_{CR} Cruise Mach number 0,78 Wing area S_W 86 m² Wing span Known b_{W} 30,9 m² 30,9 30,9 Aspect ratio 11,10 Α Maximum take-off mass 40995 kg \mathbf{m}_{MTO} Maximum payload mass ${\rm m}_{\rm PL}$ 8976 kg Mass ratio, payload - take-off 0,219 m_{PL}/m_{MTO} Maximum landing mass 38400 kg $m_{ML} \\$ Mass ratio, landing - take-off 0,937 m_{ML}/m_{MTO} **24900** kg Operating empty mass $m_{\text{OE}} \\$ Mass ratio, operating empty - take-off $m_{\text{OE}}/m_{\text{MTO}}$ 0,607 Wing loading 476,7 kg/m² m_{MTO}/S_W Number of engines 2 n_{E} Take-off thrust for one engine $T_{\text{TO,one engine}}$ 78,2 kN 156,4 kN Total take-off thrust T_{TO} Thrust to weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,389 Bypass ratio 8,4

fuel, available

23,86 m³

Data	to op	timize	V/V _{md}
------	-------	--------	-------------------

				LL	UL
Cruise speed		V_{CR}	230 m/s	;	
Cruise altitude		h _{CR}	11900 m		
Speed ratio		V/V_{md}	1,241 -	1	1,316
	Data to execu	te the verification			
				Ra	nge
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		$\mathbf{x}_{(y_c),max}$	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,6 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimization of V/Vmd

ue 1480	Unit	Deviation
	m	
	111	0,00%
70,0	m/s	0,00%
1500	m	0,00%
30,9	m	0,00%
1,10		0,00%
230	m/s	0,08%
1900	m	0,00%
		6,90E-07 <i>0</i> ,1%
	Rever	rse Engineering
	Kevei	Se Engineering
	70,0 1500 30,9 1,10 230	70,0 m/s 1500 m 30,9 m 11,10 230 m/s 1900 m

1) Maximum Lift Coefficient for Landing and Take-off

Land	ing		
Landing field length	S _{LFL}	1480	m
Temperature above ISA (288,15K)	ΔT_L	0	K
Relative density	σ	1,000	
Factor, approach	k _{APP}	1,70	(m/s²) ^{0.5}
Approach speed	V_{APP}	70,00	m/s
Factor, landing	k_L	0,107	kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,94	
Wing loading at maximum take-off mass	m_{MTO}/S_W	476,7	kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,82	
Take	-off		
Take-off field length	S _{TOFL}	1500	m
Temperatur above ISA (288,15K)	ΔT_{TO}	0	
Relative density	σ	1,00	
Factor	k _{TO}	-	m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,389	
Maximum lift coefficient, take-off	C _{L.max.TO}	1,91	
0-40-			
Aspect ratio 2nd Seg	gment A	11,102	
Lift coefficient, take-off	C _{L.TO}	1,33	
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020	
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,011	
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000	
Profile drag coefficient	$C_{D,P}$	0,031	
Oswald efficiency factor; landing configuration	e	0,7	
Glide ratio in take-off configuration	E _{TO}	12,82	
Number of engines	n _E	2	
Climb gradient	sin(γ)	0,024	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,204	
Missed ap	pproach		
Lift coefficient, landing	C _{L,L}	1,67	
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020	
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,028	
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000	
Choose: Certification basis	JAR-25 resp. CS-25	no	
	FAR Part 25	yes	
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015	
Profile drag coefficient	$C_{D,P}$	0,063	
Glide ratio in landing configuration	EL	9,40	
Climb gradient	sin(γ)	0,021	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,239	
•		•	

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Spe	ecifications		
Mach number, cruise	M _{CR}	0,78	
Aspect ratio	Α	11,10	
Bypass ratio	μ	8,40	
Wing loading	m_{MTO}/S_W	477 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,389	
	Variables		
	V/V_{md}	1,2	
Ca	alculations		
Zero-lift drag coefficient	$C_{D,0}$	0,024	
Lift coefficient at E _{max}	$C_{L,md}$	0,85	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,649	
Lift coefficient, cruise	C_L	0,553	
Actual aerodynamic efficiency, cruise	E	15,90	
Max. glide ratio, cruise	E _{max}	17,41	
Newton-Raphson for the maximum lift-to-o	drag ratio		
Iterations	1	2	3
f(x)	0,17	0,00	0,00
f'(x)	-0,11	-0,12	-0,12
E _{max}	16	17,45	17,41

3) Specific Fuel Consumption

Constant par	ameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	P_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Specificat	tions		
Range	R	869	NM
Mach number, cruise	M_{CR}	0,78	
Bypass ratio	μ	8,40	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,389	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	40995	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,219	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,607	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	15,90	
Cruise altitude	h _{CR}	11900	m
Cruise speed	V _{CR}	230	m/s
Mission fuel	fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	M _{ff.taxi}	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff.DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Calculati			
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,174	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,174	
Mission rue maction (acc. to r L and OL)	IVI f f	0,020	
Available fuel mass	F,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,466	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,545	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,68E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

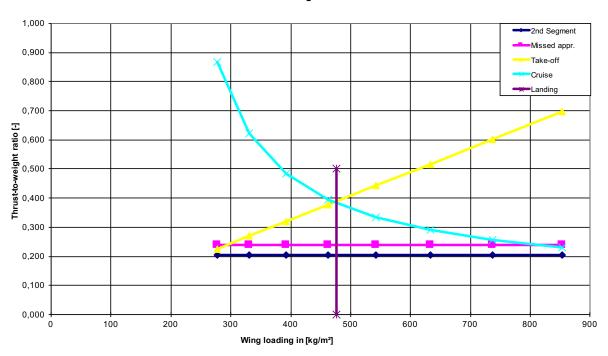
General wing specifications	Airfoil type:	NACA 64 series
Wing span	b_W	30,9 m
Structural wing span	$b_{W,struct}$	34,09 m
Wing area	S _W	86,0 m ²
Aspect ratio	Α	11,10
Sweep	ϕ_{25}	25 °
Mean aerodynamic chord	c _{MAC}	4,2 m
Position of maximum camber	X _{(V c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t,max}$	30 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	70,00 m/s
Mach number, landing	M_APP	0,21
Mach number, cruise	M_{CR}	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,5 %c
Leading edge sweep	ϕ_{LE}	28,2 °
Reynoldsnumber	Re	2,1E+07
Maximum lift coefficient, base	C _{L,max,base}	1,42
Correction term, camber	$\Delta_1 c_{L,max}$	0,35
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,007
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,771
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,81
Correction term, Mach number	$\Delta C_{L,max}$	-0,03
Lift coefficient, wing	C _{L,max}	1,40

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87
Flap group A	·	
0,3c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	1,66
Use flapped span	b_W,fA	8,3 m
Percentage of flaps allong the wing		24%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,35
Flap group B		
0,3c Single-slotted fowler flap	$\Delta c_{L,max,fB}$	1,66
Use flapped span	b_W,fB	12,7 m 37%
Percentage of flaps allong the wing Increase in maximum lift coefficient, flap group B	۸.	0,54
Increase in maximum lift coefficient, flap	ΔC _{L,max,fB}	0,89
increase in maximum in coemcient, nap	$\Delta C_{L,max,f}$	0,09
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΨH.L.	26 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,87
Use slatted span	b_W,sA	5,9 m
Percentage of slats allong the wing	4.0	17%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,14
Slat group B O,3c Nose flap	40	0,87
Use slatted span	$\Delta c_{L,max,SB}$ b_W,sB	20,1 m
Percentage of slats allong the wing	D_VV,SB	59%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,46
Increase in maximum lift coefficient, slat	ΔC _{L,max,s}	0,60
, , , , , , , , , , , , , , , , , , , ,	Lillavia	
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,84
RE value maximum lift coefficient, landing	•	2,82
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,93
RE value maximum lift coefficient, take-off		1,91
176		
Aerodynamic ef	ficiency	
Pool sirereft everes	le .	2.02
Real aircraft average	k _{WL}	2,83
End plate	k _{e,WL}	1,07
Span Winglet height	b _W	30,9 m
Winglet height Aspect ratio	h A	<mark>1,6</mark> m 11,10
Effective aspect ratio	A _{eff}	11,93
Elicotive aspect fatto	ren	11,00
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{wet}/S_W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	20,8
RE value maximum aerodynamic efficiency	—пах	17,41
19%		70 A

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,780	
Cruise altitude	h _{CR}	11900	m
By Pass Ratio	μ	8,40	
Take-off Thrust (one engine)	T _{TO,one engine}	78,20	kN
Overall Pressure ratio	OAPR	29,59	
Turbine entry temperature	TET	1417,70	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	$oldsymbol{\eta}_{inlet}$	0,93	
Ventilator efficiency	$\eta_{ m ventilator}$	0,85	
Compressor efficiency	$\eta_{compresor}$	0,86	
Turbine efficiency	$\eta_{turbine}$	0,89	
Nozzle efficiency	η_{nozzle}	0,97	
Temperature at SL	T_0	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T _S	216,65	K
Temperature at cruise altitude	T(H)	216,65	K
Dimensionless turbine entry temperature	ф	6,54	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	e υ	1,12	
Temperature function	χ	1,83	
Gas generator efficiency	${f \eta}_{ m gasgen}$	0,97	
Gas generator function	G	2,01	
Verification value specific fuel consumption	SFC	0,60	kg/daN/h
Verification value specific fuel consumption	SFC	1,66E-05	kg/N/s
RE value specific fuel consumption -19	SFC	1,68E-05	kg/N/s

Matching Chart



Appendix AC Boeing 737-300

Data Collection	ction		737-300			2	3	4	2	9	7	8	6
a chomoso C	loden, O	4	Source:		Aircraft characteristics for airport planning	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Paul Müller Elodie Roux Data collection	Data collection	Webs
PAX	Syllibol	SIIIS	Chosen value		128-134-149	128-149	149-128			149	149 149-128		
Landing field length	SLFL	Ε	1433	14	1460	1433	1396			1433	1396	1400	
Approach speed	V _{APP}	s/m	69,45			69,45	68,42			69,44		8211118	
Temperature above ISA (288,15K)	ΔT	~	0		0 -	0 -	0			0			
Relative density	s												
Take-off field length	STOFL	Ε	1940	2980		2286	1939				1939	1600	2300
Temperature above ISA (288,15K)	ΔΤτο	ᅩ	0	0	0	15	0						
Relative density	S												
Range (max pavload)	œ	Ē	1464	35	3550	4204	2922			4204	1464		4204
Cruise Mach number	McR		0,745			0,745		8,0			0,74	0,745	0,745
Wing area	Sw	m ₂	105,4			105,4	91,04			105,4	91,04		
Wing span	ρw	ε	28,88	28,88	28,88-31,22	28,88	28,9			28,88		28,9	28,88
Aspect ratio	⋖		6,7			7,9	9,1740993			7,9	9,16		9,11
Maximum take-off mass	DIATO	ka	58967	56472-58967	63276	56470 62820	20 56470			56470	56473	56470	62820
Pavload mass	Ē	S S	16148	16148							16148		
Mass ratio, payload - take-off	Mpi/MMTo	P	2		0.243		0.2838675				0.286		
Maximum landing mass	Ē	ķ	51710	51710		51720 52890				51720	51710		51700
Mass ratio, landing - take-off	Мм∟/Мито	,			0,835		0,91						
Operating empty mass	Moe	kg	31869	31479		32704 33266					31480		32700
Mass ratio, operating empty - take-off moemmro	ff moe/mmro				0,52000759		0				0,557		
Wing loading	m _{MTo} /S _W	kg/m²	535,6				62				620		
Maximum zero fuel mass	MMZF	kg	47627	47627	49714	47625 49715	15 47630				47628		48410
Nimber of engines	ģ		2				0				0	C	0
Fraine type	CEMARA		CEM56-3R1	CEM56-381	CEM56.3R2	CEM56-3C-1	CEM56-3-R1	CEM56.3B1				CEM56-3R1	7
Take-off thrust for one engine	To one engine	Z	88.964		97.7942	89-97.9	88 9644	88.96444			88.964	06	06
Total take-off thrust	T _{To}	3											
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)		0,32				0,3213166				0,32		
Bypass ratio	_		9					9			9		
Specific Fuel Comsumption (dry)		kg/N s	1,08E-05					1,0754E-05			1,08E-05		
Specific Fuel Comsumption (cruise)	SFC (cruise kg/N s	e kg/N s	1,89E-05					1,8876E-05			1,89E-05		
Available fuel volume	Vfuel, available	°E	20,102	20,102	23,827	20,104-23,83	20,105-23,170	0			20,102		23,17
Cruise speed	VcR	s/m	220,7				220,7-252,6					220,69667	
Cruise altitude	hcr	Ε	10668			10195	10668-7924,	10668			10668		
Sweep angle	—	0	25				25				25		25
Moon consolination	677	1	3 73				2 73				2 72		ì
Docition of maximim camber	CMAC	- %	3,5				2.5				2,5		10
Combor	A(y_c),max	0,00	2 0										2 0
Position of maximum thickness	(yc)max/C	2%	29.7										29.7
Relative thickness	t/c	%	12,9				12,89				12,9		12,5
Taper	٧		0,24				3,73				0,24		
Overall pressure ratio	OAPR		22,6					22,6					
Turbine entry temperature	Ī	¥											

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	S _{LFL}	1433			
Approach speed	Known	V_{APP}	69,45	m/s	69,5	69,5
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s_{TOFL}	1940	m	1940	1940
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	790	NM		
Cruise Mach number		M _{CR}	0,745			
Wing area		S _W	105	m²		
Wing span	Known	b_W	28,88	m²	28,88	28,88
Aspect ratio		Α	7,91			
Maximum take-off mass		m _{MTO}	58967	kg		
Maximum payload mass		m_PL	16148	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,274			
Maximum landing mass		m_ML	51710	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,877			
Operating empty mass		m_OE	31869	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,540			
Wing loading		m_{MTO}/S_W	559,5	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	88,964	kN		
Total take-off thrust		T _{TO}	177,928	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,308			
Bypass ratio		μ	6			
Available fuel volume		V _{fuel,available}	20,1	m³		

Data	to	optin	nize	V/V_{md}
------	----	-------	------	------------

				LL	UL
Cruise speed		V_{CR}	221 m/s		
Cruise altitude		h_{CR}	10668 m		
Speed ratio		V/V_{md}	1,103 -	1	1,316
	Data to execu	te the verification			
				Ran	ige
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	3,73 m		
Position of maximum camber		$\mathbf{x}_{(y_c),max}$	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	12,0 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimization of V/Vm	d
--------------------------------------------	---

	,			
Quantity	Original value	RE value	Unit	Deviation
S _{LFL}	1433	1433	m	0,00%
V_{APP}	69,45	69,5	m/s	0,00%
s _{TOFL}	1940	1940	m	0,00%
b_W	28,88	28,88	m	0,00%
Α	7,91	7,91		0,00%
V_{CR}	220,7	221	m/s	0,11%
h _{CR}	10668	10670	m	0,02%
				1,29E-06
				ଫ,1%
Results rev	erse engineering			
$C_{L,max,L}$	3,20			
$C_{L,max,TO}$	2,19		Pov	erse Engineering
E _{max}	14,84		Kev	erse Engineening
SFC	1,78E-05 kg/	/N/s		
	S _{LFL} V _{APP} S _{TOFL} b _W A V _{CR} h _{CR} Results rev C _{L,max,L} C _{L,max,TO} E _{max}	SLFL 1433 VAPP 69,45 STOFL 1940 bW 28,88 A 7,91 VCR 220,7 hCR 10668 Results reverse engineering CL,max,L CL,max,TO Emax 14,84	s _{LFL} 1433 1433 V _{APP} 69,45 69,5 s _{TOFL} 1940 1940 b _W 28,88 28,88 A 7,91 7,91 V _{CR} 220,7 221 h _{CR} 10668 10670 Results reverse engineering C _{L,max,L} C _{L,max,TO} 2,19 E _{max} 14,84	s_LFL 1433 1433 m V_APP 69,45 69,5 m/s s_TOFL 1940 1940 m b_W 28,88 m 28,88 m A 7,91 7,91 VCR 220,7 m/s 221 m/s h_CR 10668 10670 m Results reverse engineering C_L,max,L C_L,max,TO 3,20 2,19 Emax Rev

1) Maximum Lift Coefficient for Landing and Take-off

Lai	nding	
Landing field length	S _{LFL}	1433 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	1,70 (m/s²) ^{0.5}
Approach speed	V_{APP}	69,45 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,88
Wing loading at maximum take-off mass	m_{MTO}/S_W	559,5 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,20
Tal	ke-off	
Take-off field length	S _{TOFL}	1940 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,308
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,19
2nd S	Segment	
Aspect ratio	A	7,913
Lift coefficient, take-off	$C_{L,TO}$	1,52
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,021
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,041
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	8,73
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,277
Missed	approach	
Lift coefficient, landing	C _{L,L}	1,89
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,040
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	$C_{D,P}$	0,075
Glide ratio in landing configuration	EL	6,75
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}*g)$	0,297
•	10 (1110 0)	•

2) Maximum Aerodynamic Efficiency

Constant parameters						
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g	9,81 m/s ²				
Air pressure, ISA, standard	p_0	101325 Pa				
Oswald eff. factor, clean	е	0,85				
Sn	ecifications					
Mach number, cruise	M _{CR}	0,745				
Aspect ratio	A	7,91				
Bypass ratio	μ	6,00				
Wing loading	m _{MTO} /S _W	559 kg/m²				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}*g)$	0,308				
	Variables					
V/V _{md} 1,1						
C	alculations					
Zero-lift drag coefficient	C _{D,0}	0,024				
Lift coefficient at E _{max}	$C_{L,md}$	0,71				
Ratio, lift coefficient	C _L /C _{L,md}	0,822				
Lift coefficient, cruise	C_{l}	0,586				
Actual aerodynamic efficiency, cruise	E	14,56				
Max. glide ratio, cruise	E _{max}	14,84				
Newton-Raphson for the maximum lift-to-	drag ratio					
Iterations	1	2	3			
f(x)	-0,15	0,00	0,00			
f'(x)	-0,13	-0,13	-0,13			
E _{max}	16	14,86	14,84			

3) Specific Fuel Consumption

Constant pa	rameters					
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g		m/s²			
Air pressure, ISA, standard	p_0	101325				
Fuel density	$ ho_{fuel}$	800	kg/m³			
Specifica	tions					
Range	R		NM			
Mach number, cruise	M_{CR}	0,745				
Bypass ratio	μ	6,00				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,308				
Available fuel volume	$V_{\text{fuel,available}}$	20,1				
Maximum take-off mass	m_{MTO}	58967	•			
Mass ratio, landing - take-off	m_{PL}/m_{MTO}	0,274				
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,540				
Calculated	values					
Actual aerodynamic efficiency, cruise	E	14,56				
Cruise altitude	h _{CR}	10670	m			
Cruise speed	V_{CR}	221	m/s			
Mission fuel fraction						
Type of aeroplane (according to Roskam)	Transport jet					
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990				
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990				
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995				
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980				
Fuel-Fraction, descent	$M_{ff,DES}$	0,990				
Fuel-Fraction, landing	$M_{ff,L}$	0,992				
Calculat	ions					
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,186				
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,814				
A wildle for Large		40000				
Available fuel mass	^M F,available	16080	0			
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,273				
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,742				
Distance to alternate	S _{to_alternate}	200	NM			
Distance to alternate	S _{to_alternate}	370400	m			
Choose: FAR Part121-Reserves	domestic	yes				
	international	no				
Extra-fuel for long range		5%				
Extra flight distance	S _{res}	370400	m			
Loiter time	t _{loiter}	2700	s			
Specific fuel consumption	SFC	1,78E-05	kg/N/s			

4) Verification Specifications

Maximum lift coefficients

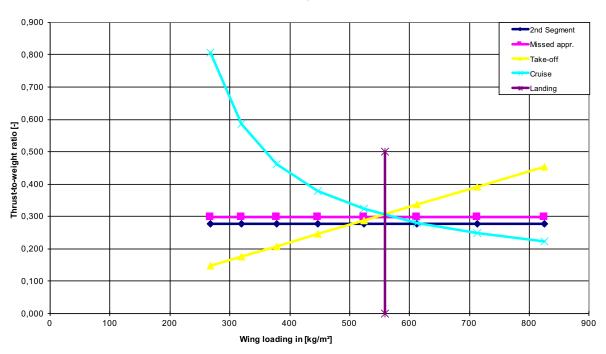
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b_W	28,88 m
Structural wing span	$b_{W,struct}$	31,87 m
Wing area	S_W	105,4 m ²
Aspect ratio	Α	7,91
Sweep	φ_{25}	25 °
Mean aerodynamic chord	c _{MAC}	3,73 m
Position of maximum camber	X _{(y_c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t.max}$	30 %c
Relative thickness	t/c	12,0 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	69,45 m/s
Mach number, landing	M_{APP}	0,21
Mach number, cruise	M_{CR}	0,745
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,2 %c
Leading edge sweep	ϕ_{LE}	29,4 °
Reynoldsnumber	Re	1,8E+07
Maximum lift coefficient, base	$c_{L,max,base}$	1,30
Correction term, camber	$\Delta_1 c_{L,max}$	0,40
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,023
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,720
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,85
Correction term, Mach number	$\Delta C_{L,max}$	-0,02
Lift coefficient, wing	C _{L,max}	1,44

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87
Flap group A		
Double-slotted flap	$\Delta c_{L,max,fA}$	1,41
Use flapped span	b_W,fA	20,8 m
Percentage of flaps allong the wing		65%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,80
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,80
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	Ψ _{H.L.}	28 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,89
Use slatted span	b_W,sA	18,5 m
Percentage of slats allong the wing	_	58%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,46
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,89
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing		0%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,00
Increase in maximum lift coefficient, slat	$\DeltaC_{L,max,s}$	0,46
Wing Verification value maximum lift coefficient, landing RE value maximum lift coefficient, landing Verification value maximum lift coefficient, take-off RE value maximum lift coefficient, take-off	$C_{L,max,L}$ $C_{L,max,TO}$	2,66 3,20 1,83 2,19
Aerodynamic ef	ficiency	
		0.00
Real aircraft average	k _{WL}	2,83
No winglets	$k_{e,WL}$	1,00
Span	b _W	28,88 m
Winglet height	h	2,1 m
Aspect ratio	A	7,91
Effective aspect ratio	A_{eff}	7,91
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{wet}/S_W	5,96
Verification value maximum aerodynamic efficiency	E _{max}	17,5
RE value maximum aerodynamic efficiency		14,84
18%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,745	
Cruise altitude	h_{CR}	10668	m
By Pass Ratio	μ	6,00	
Take-off Thrust (one engine)	T _{TO,one engine}	88,96	kN
Overall Pressure ratio	OAPR	21,15	
Turbine entry temperature	TET	1430,08	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η_{inlet}	0,94	
Ventilator efficiency	$\eta_{ m ventilator}$	0,86	
Compressor efficiency	$\eta_{compresor}$	0,86	
Turbine efficiency	$\eta_{ m turbine}$	0,90	
Nozzle efficiency	η_{nozzle}	0,98	
Temperature at SL	T_0	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T_S	216,65	K
Temperature at cruise altitude	T(H)	218,81	K
Dimensionless turbine entry temperature	ф	6,54	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,11	
Temperature function	χ	1,55	
Gas generator efficiency	$\eta_{ m gasgen}$	0,98	
Gas generator function	G	2,12	
Verification value specific fuel consumption	SFC	0.60	kg/daN/h
Verification value specific fuel consumption	SFC	1,67E-05	0
RE value specific fuel consumption	SFC	1,78E-05	kg/N/s

Matching Chart



Appendix AD Airbus A350-1000

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to weight ratio TT-Offmano gas 0,22 0,22 s ratio 9,6 9,6 8,9 s ratio 9,6 8,9 8,9 s ratio 9,6 8,9 8,9 s ratio 9,6 8,9 8,9 s refered comsumption (cruise) SFC (cruise) kg/N s 156 156 156 speed V _{SR} m/s 250,53 13100 13100 13100 speed V _{SR} m/s 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 <t< td=""><td>Total take-off thrust</td><td>Tro</td><td>Σ</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>	Total take-off thrust	Tro	Σ											
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	Bypass ratio	٦ . د د د د د د د د د د د د د د د د د د د		9,6			96					8,0		
State Combaumption (Critise) ST-C (Critise Kg/N s) ST-C (Critise Kg/N	Specific Fuel Comsumption (dry)	\top	kg/N s											
Speed V _{CRI} m/s speed TSO	Specific ruel Comsumption (cruise)		s N/6x											
speed V _{CR} m/s 250,534444 25 altitude h _{CR} m 12190 11 a angle ф ₂₅ ° 35 28 11 a mol maximum chord d _{MAC} %c 8,35 8,35 8,35 8,35 8,35 8,35 8,35 9 an of maximum chord maximum thickness x _{Creace} %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c <t< td=""><td>Available fuel volume</td><td>V_{fuel,}available</td><td></td><td>156</td><td></td><td>156</td><td>156</td><td></td><td></td><td></td><td></td><td>150</td><td></td><td>159</td></t<>	Available fuel volume	V _{fuel,} available		156		156	156					150		159
a stipuled m 12190 11 a stipuled m 12190 11 a stipul defined description 35 28 28 a strongly manifered in ord maximum camber X _{V, c, lmax} X _{V, c, lmax} %c 8,35 8,35 8,35 an of maximum camber X _{V, c, lmax} X _{V, c, lmax} %c 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 8,35 <td>Cruise speed</td> <td>V_{CR}</td> <td>m/s</td> <td>250,5</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>250,534444</td> <td>250,83</td>	Cruise speed	V _{CR}	m/s	250,5									250,534444	250,83
aerodynamic chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord chord	Cruise altitude	hcR	Ε	12190								13100		12190
qrss m 8,35 20 and dropfunding chord m 8,35 8,35 and dropfunding chord x _{V,v,o,lmax} %c 8,35 ar (y _{c,hmax} /c) %c %c ar no f maximum thickness x _{Lmax} %c ar y _c %c %c personner ratio A 0,113 %c pentry temperature TET K 60,113	oloue acomo	¥	0	r,			r c					ac		21.0
An article and the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the	Moor porodimento phord	425	1	3 0			3					20 0		2.
### Of maximum thickness X _{Chear} C % % % % % % % % % % % % % % % % % %	Desition of maximum comber	CMAC	0%	0,0								6,0		
In of maximum trickness	Combor	A(y_c),max	790											
### Of the Action and Action 1	Doeition of maximum thickness	(yc)max/C	20%											
λ 0,113 pressure ratio OAPR 50 e entry temperature TET K	Relative thickness	t/c	%											
OAPR 50 TET K	Taper	~		0,113								0,113		
TET	Overall pressure ratio	OAPR		20			20							
i	Turbine entry temperature	TET	7											

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	S _{LFL}	2110			
Approach speed	Known	V_{APP}	75,00		75,0	75,0
Temperature above ISA (288,15K)		ΔT_L		K		
Relative density		σ	1			
Take-off field length	Known	s_{TOFL}	2950	m	2950	2950
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	7999	NM		
Cruise Mach number		M_{CR}	0,85			
Wing area		S _W	443	m²		
Wing span	Known	b_W	64,75	m²	64,75	64,75
Aspect ratio		Α	9,46			
Maximum take-off mass		m _{MTO}	316000	kg		
Maximum payload mass		m_{PL}	67250	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,213			
Maximum landing mass		m_ML	236000	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,747			
Operating empty mass		m_OE	115700	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,366			
Wing loading		m_{MTO}/S_W	713,3	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	431	kN		
Total take-off thrust		T _{TO}	862	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,278			
Bypass ratio		μ	9,6			
Available fuel volume		V _{fuel,available}	23,86	m³		

					LL	UL
Cruise speed		V_{CR}	251	m/s		
Cruise altitude		h_{CR}	12190	m		
Speed ratio		V/V _{md}	1,000	-	1	1,316
	Data to execu	ite the verification				
					Rar	nge
Sweep angle		ϕ_{25}	35	0		
Mean aerodynamic chord		C _{MAC}	8,35	m		
Position of maximum camber		x _{(y_c),max}	30	%с	15 - 50	%с
Camber		(y _c) _{max} /c	4	%с	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	10,6	%		
Taper		λ	0,113			

Reverse Engineering

Reverse	engineering	& o	ptimization	of V/Vmd
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IVEA.	erse engineering	a optimization of v	VIIIG		
	Quantity	Original value F	RE value	Unit	Deviation
Landing field length	s_{LFL}	2110	2110	m	0,00%
Approach speed	V_{APP}	75,00	75,0	m/s	0,00%
Take-off field length	S _{TOFL}	2950	2950	m	0,00%
Span	b_W	64,75	64,75	m	0,00%
Aspect ratio	Α	9,46	9,46		0,00%
Cruise speed	V_{CR}	250,5	251	m/s	0,14%
Cruise altitude	h_{CR}	12190	11064	m	-9,24%
Squared Sum					8,53E-03
Absolute maximum deviation					9,2%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,36			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,03		Povo	rse Engineering
Maximum aerodynamic efficiency	E _{max}	20,76		Reve	ise Engineering
Specific fuel consumption	SFC	1,53E-05 kg/l	N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Li	anding	
Landing field length	S _{LFL}	2110 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	1,70 (m/s²) ^{0.6}
Approach speed	V_{APP}	75,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	$\rm m_{ML}/m_{TO}$	0,75
Wing loading at maximum take-off mass	m_{MTO}/S_W	713,3 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,36
Ta	ake-off	
Take-off field length	s _{TOFL}	2950 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,278
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,03
2nd	Segment	
Aspect ratio	A	9,464
Lift coefficient, take-off	$C_{L,TO}$	1,41
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,016
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,036
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	10,74
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,234
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,40
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,015
Lift-independent drag coefficient, slats	$\Delta C_D,slat$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Profile drag coefficient	C_D,P	0,050
Glide ratio in landing configuration	EL	9,73
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,185

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,85	
Aspect ratio	Α	9,46	
Bypass ratio	μ	9,60	
Wing loading	m_{MTO}/S_W	713 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,278	
,	Variables		
	V/V _{md}	1,0	
C	alculations		
Zero-lift drag coefficient	C _{D,0}	0,015	
Lift coefficient at E _{max}	$C_{L,md}$	0,61	
Ratio, lift coefficient	$C_L/C_{L,md}$	1,000	
Lift coefficient, cruise	C_L	0,609	
Actual aerodynamic efficiency, cruise	E	20,76	
Max. glide ratio, cruise	E _{max}	20,76	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	0.42	2	3
f(x) f'(x)	0,42 -0,08	-0,04 -0,10	0,00 -0,10
1 ' '	-0,08	21,19	20,76
E _{max}	10	۷۱,۱۶	20,70

3) Specific Fuel Consumption

	nt parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	P ₀	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
	cifications		
Range	R	7999	
Mach number, cruise	M _{CR}	0,85	
Bypass ratio	μ Τ // *\	9,60	
Thrust-to-weight ratio Available fuel volume	T _{TO} /(m _{MTO} *g)	0,278	
Available ruel volume Maximum take-off mass	V _{fuel,available}	23,86	
	m _{MTO}	316000	•
Mass ratio, landing - take-off	m_{PL}/m_{MTO}	0,213	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,366	
	lated values		
Actual aerodynamic efficiency, cruise	E	20,76	
Cruise altitude	h _{CR}	11064	
Cruise speed	V_{CR}	251	m/s
Mission	n fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	$M_{ff,DES}$	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
Cal	culations		
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,421	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,579	
Available fuel mass	MF,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F.available} /m _{MTO}	0,060	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,959	
Distance to alternate	S _{to alternate}	200	NM
Distance to alternate	Sto_alternate	370400	
Choose: FAR Part121-Reserves	domestic	no no	
	international	yes	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	1111107	m
Loiter time	t _{loiter}	1800	

4) Verification Specifications

Maximum	lift	coeffic	ients
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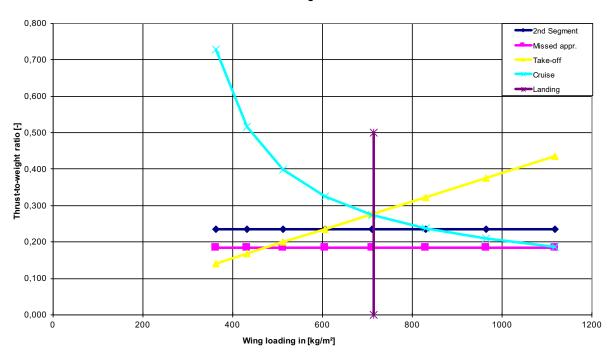
General wing specifications	Airfoil type:	NACA 66 ser
Wing span	b_W	64,75 m
Structural wing span	$b_{W,struct}$	79,05 m
Wing area	S_W	443,0 m ²
Aspect ratio	Α	9,46
Sweep	φ_{25}	35 °
Mean aerodynamic chord	C _{MAC}	8,35 m
Position of maximum camber	$\mathbf{x}_{(\mathbf{y}_{\mathbf{c}}),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
Relative thickness	t/c	10,6 %
Taper	λ	0,113
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Геmperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	75,00 m/s
Mach number, landing	M_{APP}	0,23
Mach number, cruise	M _{CR}	0,85
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	1,9 %c
Leading edge sweep	ϕ_{LE}	39,8 °
Reynoldsnumber	Re	4,5E+07
Maximum lift coefficient, base	C _{L,max,base}	1,17
Correction term, camber	$\Delta_1 c_{L,max}$	0,39
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,079
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,639
Lift coefficient ratio	$C_{L,max}/c_{L,max}$	0,91
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	C _{L,max}	1,48

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,81
Flap group A	- Ψ	
Single-slotted flap	$\Delta c_{L,max,fA}$	0,79
Use flapped span	b W,fA	15,2 m
Percentage of flaps allong the wing	,	19%
Increase in maximum lift coefficient, flap group A	$\Delta C_L,max,fA$	0,12
Flap group B	Z,max,v t	
Single-slotted flap	$\Delta c_{L,max,fB}$	0,79
Use flapped span	b_W,fB	22,8 m
Percentage of flaps allong the wing		29%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,19
Increase in maximum lift coefficient, flap	$\DeltaC_{L,max,f}$	0,31
Coloulations increase of lift coefficient due to plate		2 alat 6 maa
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΦH.L.	36 °
Slat group A	•-	0.00
0,3c Nose flap	Δc _{L,max,sA}	0,92
Use slatted span	b_W,sA	14,2 m
Percentage of slats allong the wing	46	18%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,13
Slat group B O 3 o Noon floor	40	0.03
0,3c Nose flap Use slatted span	ΔC _{L,max,SB}	0,92
Percentage of slats allong the wing	b_W,sB	39,5 m 50%
Increase in maximum lift coefficient, slat group B	۸.	0,37
	ΔC _{L,max,sB}	
Increase in maximum lift coefficient, slat	$\Delta C_{\!L,max,s}$	0,50
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,28
RE value maximum lift coefficient, landing		2,36
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,96
RE value maximum lift coefficient, take-off		2,03
-4%		
Aerodynamic effic	ciency	
Deal since fixed	1.	
Real aircraft average	k _{WL}	2,83
End plate	k _{e,WL}	1,05
Span	b _W	64,75 m
Winglet height	h	2,43 m
Aspect ratio	A	9,46
Effective aspect ratio	A_{eff}	9,97
Efficiency factor, short range	k _E	17,25
Relative wetted area	S_{we}/S_W	5,80
Verification value maximum aerodynamic efficiency	E _{max}	22,6
RE value maximum aerodynamic efficiency	IIIuA	20,76
9%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,850
Cruise altitude	h _{CR}	12190 m
By Pass Ratio	μ	9,60
Take-off Thrust (one engine)	T _{TO,one engine}	431,00 kN
Overall Pressure ratio	OAPR	50,00
Turbine entry temperature	TET	1501,44
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,93
Ventilator efficiency	$\eta_{\text{ventilator}}$	0,90
Compressor efficiency	$\eta_{compresor}$	0,88
Turbine efficiency	$\eta_{turbine}$	0,91
Nozzle efficiency	$\eta_{ m nozzle}$	0,99
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,93
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,14
Temperature function	χ	2,36
Gas generator efficiency	η_{gasgen}	0,97
Gas generator function	G	2,09
Verification value specific fuel consumption	SFC	0,53 kg/daN/h
Verification value specific fuel consumption	SFC	1,47E-05 kg/N/s
RE value specific fuel consumption -4%	SFC	1,53E-05 kg/N/s

Matching Chart



Appendix AE Bombardier CS300 / Airbus A220

PAX Symbol Landing field length 8-F-L Approach speed V _{APP} Temperature above ISA (288,15K) AT_L Relative density S Take-off field length Srop-L Temperature above ISA (288,15K) AT_D Renative density S Range (max payload) R Wing area Sw Wing appan Aw Aspency ratio A		Units	Chosen value 160	Source:	Aircraft characteristics Jane's	nose lenkinson	Z Z	-	Paul MüllerElodie RowData collectio	ousData collection	Webs 100	300
Parameter d length peed e above ISA (288,15K) sity d length e above ISA (288,15K) sity r payload)		olits	Chosen value	-				Scholz			100	
d length peed e above ISA (288,15K) ssity d length e above ISA (288,15K) rsity nsity h number	E E X E X E		160				4					
d length peed e above ISA (288,15K) rsity d length e above ISA (288,15K) rsity r payload) h number	E E Z EZ EZ E				120			160			108-133	130-160
peed e above ISA (288,15K) hsity d length e above ISA (288,15K) hsity number	<u> </u>		1509		1390			1509			1387	1509
rsity d length e above ISA (288,15K) rsity rsity rsity nativ	A E A \$ \$	S/	66,1		66,4			66,1				
nsity d length e above ISA (288,15K) nsity c payload) h number	E \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\		0		0			0				
d length e above ISA (288,15K) sity t payload) h number	E 7 2 1											
e above ISA (288,15K) nsity r payload) n number	▼ </td <td></td> <td>1890</td> <td></td> <td>2370</td> <td></td> <td></td> <td>1890</td> <td></td> <td></td> <td>1463</td> <td>1890</td>		1890		2370			1890			1463	1890
nsity (payload) h number	<u> </u>		0		0			0				
(payload) h number	<u>a</u> <u>k</u>											
n number	Ĩ		3610		3610			6204			5741	6112
	Ë		0,78					0,78			0,78	
		2	112.3					113			112.3	6
	Ε		35,1		35,1			35,3			35,1	_
			10,97					10,97				
	3		27505		60704			37703			E400E 60704	E0074 67E0E
-OII III ass	20 1		07.303		10/00			09770				390/4-0/303
Mass ratio payload - take-off may may record	Т		11/01					1 /01				11/01-0/001
	k	_	51029		52390			59310			51029-52390	56472-58740
JJo-e								0,85				
	β		37051					37051			35221	37081
erating empty - take-off								0,531				
		kg/m²	615					615				
Maximum zero fuel mass m _{MZF}	<u>Ş</u>		55792		50349			55762			50349	55792
Number of engines			2		2			2			2	
	PW1000G (GTF)	F)	PW1525G		PW1519G			PW1500G			PW1521G/24G/25G	24G/25G
ne engine	T _{TO} , one engine KN	_	108,54		87,96			102			97,73/103,6/108,54	6/108,54
	₹ ,		217,08					204,546				
ght ratio	мто g)		0,299					0,299				
Specific Fuel Comsumption (drv) SEC (drv)	dry) kg	ka/N s	0.0000112					1 12F-05				
(e)	SFC (cruise kg/N s	s N										
Available fuel volume V _{fuel,available}	allable m³	8	21,805		21,805			18,9				21,805
Cruise speed	s/m	s,	230					230			230,27	27
	Ε		11126					11126				
Sweep angle	0											
namic chord	Ε											
Position of maximum camber X _{(y_c),max}		S										
		o										
Position of maximum thickness x _{t,max}	%c	o										
re thickness	%											
Taper A												
Turking patra tomografius	_											

Aeroplane Specifications

		reverse engineering			LL	UL
Landing field length	Known	S _{LFL}	1509	m		OL
Approach speed	Known	V _{APP}	66,10	m/s	66,1	66,1
Temperature above ISA (288,15K)		ΔT_1		K		,
Relative density		σ	1			
Take-off field length	Known	S _{TOFL}	1890	m	1890	1890
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	1949	NM		
Cruise Mach number		M _{CR}	0,78			
Wing area		S_W	112	m²		
Wing span	Known	b_W	35,1	m²	35,1	35,1
Aspect ratio		Α	10,97			
Maximum take-off mass		m_{MTO}	67585	kg		
Maximum payload mass		m_PL	18711	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,277			
Maximum landing mass		m_{ML}	51029	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,755			
Operating empty mass		m_OE	37051	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,548			
Wing loading		m_{MTO}/S_W	601,8	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	108,54	kN		
Total take-off thrust		T_{TO}	217,08	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,327			
Bypass ratio		μ	12			
Available fuel volume		V _{fuel,available}	21,805	m³		

	Data to o	ptimize V/V _{md}				
					LL	UL
Cruise speed		V_{CR}	230	m/s		
Cruise altitude		h_{CR}	11126	m		
Speed ratio		V/V_{md}	1,066	-	1	1,316
	Data to execu	te the verification	l			
					Rar	nge
Sweep angle		φ_{25}	25	0		
Mean aerodynamic chord		C _{MAC}	4,2	m		
Position of maximum camber		X _{(y_c),max}	30	%с	15 - 50	%с
Camber		$(y_c)_{max}/c$	4	%с	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	11,6	%		
Taper		λ	0,24			

Reverse Engineering

Specific fuel consumption

Rev	erse engineering	a & optimization of	V/Vmd		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1509	1509	m	0,00%
Approach speed	V_{APP}	66,10	66,1	m/s	0,00%
Take-off field length	S _{TOFL}	1890	1890	m	0,00%
Span	b_W	35,1	35,1	m	0,00%
Aspect ratio	Α	10,97	10,97		0,00%
Cruise speed	V_{CR}	230,0	230	m/s	0,08%
Cruise altitude	h_{CR}	11126	11126	m	0,00%
Squared Sum					6,90E-07
Absolute maximum deviation					0,1%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,81			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,28		Reve	rse Engineering
Maximum aerodynamic efficiency	E _{max}	20,98		1 (CVC)	Se Lingineering

1,26E-05 kg/N/s

SFC

1) Maximum Lift Coefficient for Landing and Take-off

<u> </u>	anding		
Landing field length	s_{LFL}	1509	m
Temperature above ISA (288,15K)	ΔT_L	0	K
Relative density	σ	1,000	0.5
Factor, approach	k_{APP}	1,70	$(m/s^2)^{0.5}$
Approach speed	V_{APP}	66,10	m/s
Factor, landing	k_L	0,107	kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,76	
Wing loading at maximum take-off mass	m_{MTO}/S_W	601,8	kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,81	
Т	ake-off		
Take-off field length	s_{TOFL}	1890	m
Temperatur above ISA (288,15K)	ΔT_TO		K
Relative density	σ	1,00	
Factor	k _{TO}		m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,327	
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,28	
	Segment		
Aspect ratio	Α	10,971	
Lift coefficient, take-off	$C_{L,TO}$	1,58	
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020	
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,024	
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000	
Profile drag coefficient	$C_{D,P}$	0,044	
Oswald efficiency factor; landing configuration	е	0,7	
Glide ratio in take-off configuration	E _{TO}	10,71	
Number of engines	n _E	2	
Climb gradient	sin(γ)	0,024	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,235	
	d approach		
Lift coefficient, landing	$C_{L,L}$	1,67	
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020	
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,028	
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000	
Choose: Certification basis	JAR-25 resp. CS-25	no	
	FAR Part 25	yes	
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015	
Profile drag coefficient	$C_{D,P}$	0,063	
Glide ratio in landing configuration	EL	9,34	
Climb gradient	sin(γ)	0,021	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,193	

2) Maximum Aerodynamic Efficiency

Cons	tant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,78	
Aspect ratio	Α	10,97	
Bypass ratio	μ	12,00	
Wing loading	m_{MTO}/S_W	602 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,327	
	Variables		
	V/V_{md}	1,1	
C	alculations		
Zero-lift drag coefficient	$C_{D,0}$	0,017	
Lift coefficient at E _{max}	$C_{L,md}$	0,70	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,880	
Lift coefficient, cruise	C_L	0,615	
Actual aerodynamic efficiency, cruise	E	20,81	
Max. glide ratio, cruise	E _{max}	20,98	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	1	2	3
f(x)	0,45	-0,05	0,00
f(x)	-0,08	-0,10	-0,10
E _{max}	16	21,47	20,98

3) Specific Fuel Consumption

Constan	t parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	•	m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Spec	ifications		
Range	R	1949	NM
Mach number, cruise	M_{CR}	0,78	
Bypass ratio	μ	12,00	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,327	
Available fuel volume	$V_{ m fuel,available}$	21,805	m³
Maximum take-off mass	m _{MTO}	67585	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,277	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,548	
Calcul	ated values		
Actual aerodynamic efficiency, cruise	E	20,81	
Cruise altitude	h _{CR}	11126	m
Cruise speed	V _{CR}	230	m/s
Mission	fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	M _{ff,taxi}	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	, -	0,990	
Fuel-Fraction, descent Fuel-Fraction, landing	$M_{ff,DES}$	0,990	
· ·		0,002	
	culations	0.475	
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,175	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,825	
Available fuel mass	MF,available	17444	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,258	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,757	
Distance to alternate	S	200	NM
Distance to alternate	S _{to_alternate}	370400	
Choose: FAR Part121-Reserves	s _{to_alternate} domestic	yes	
CHOOSE. FAICE artiz 1-reserves	international	no	
Extra-fuel for long range	momadona	5%	
Extra flight distance	S	370400	m
Loiter time	s _{res}	2700	
Loitei tiille	t _{loiter}	2100	0
Specific fuel consumption	SFC	1,26E-05	kg/N/s

4) Verification Specifications

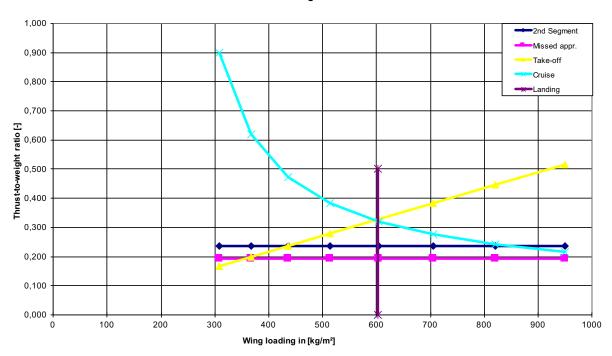
General wing specifications	Airfoil type:	N/A	ACA 66 series
Wing span	b_W	35,1	m
Structural wing span	$b_{W,struct}$	38,73	m
Wing area	S _W	112,3	m²
Aspect ratio	Α	10,97	
Sweep	φ_{25}	25	0
Mean aerodynamic chord	c _{MAC}	4,2	m
Position of maximum camber	X _{(y_c),max}	30	%с
Camber	(y _c) _{max} /c	4	%с
Position of maximum thickness	$x_{t.max}$	30	%с
Relative thickness	t/c	11,6	%
Taper	λ	0,24	
General aircraft specifications			
Temperature above ISA (288,15K)	ΔT_L	0	K
Relative density	σ	1	
Temperature, landing	T_L	273,15	K
Density, air, landing	ρ	1,225	kg/m³
Dynamic viscosity, air	μ	1,72E-05	kg/m/s
Speed of sound, landing	a_{APP}	331	m/s
Approach speed	V_{APP}	66,10	m/s
Mach number, landing	M_{APP}	0,20	
Mach number, cruise	M_{CR}	0,78	
Calculations maximum clean lift coefficient			
Leading edge sharpness parameter	Δy	2,1	%c
Leading edge sweep	ϕ_{LE}	28,2	•
Reynoldsnumber	Re	2,0E+07	
Maximum lift coefficient, base	$\mathbf{c}_{L,max,base}$	1,26	
Correction term, camber	$\Delta_1 c_{L,max}$	0,40	
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00	
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,034	
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,697	
Lift coefficient ratio	C _{L.max} /c _{L.max}	0,87	
Correction term, Mach number	$\Delta C_{L,max}$	0,00	

Calculations increase of lift coefficient due to flag	os	2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{oldsymbol{\phi}}}$	0,87
Flap group A		
Single-slotted flap	$\Delta c_{L,max,fA}$	0,79
Use flapped span	b_W,fA	10,53 m
Percentage of flaps allong the wing		27%
Increase in maximum lift coefficient, flap group A	\DeltaC_L,max,fA	0,19
Flap group B		
Single-slotted flap	$\Delta c_{L,max,fB}$	0,79
Use flapped span	b_W,fB	15,4 m
Percentage of flaps allong the wing		40%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,27
Increase in maximum lift coefficient, flap	\DeltaC_L,max,f	0,46
Calculations increase of lift coefficient due to sla	ts	2 slat types
Sweep angle of the hinge line	Φ _{H.L.}	29 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,91
Use slatted span	b_W,sA	7 m
Percentage of slats allong the wing	_	18%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,14
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,91
Use slatted span	b_W,sB	23,9 m
Percentage of slats allong the wing		62%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,49
Increase in maximum lift coefficient, slat	$\DeltaC_{L,max,s}$	0,64
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,55
RE value maximum lift coefficient, landing		2,81
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,06
RE value maximum lift coefficient, take-off		2,28
	-9%	
Aerodyn	amic efficiency	
Real aircraft average	k_{WL}	2,83
End plate	$k_{e,WL}$	1,06
Span	b _W	35,1 m
Winglet height	h	1,5 m
Aspect ratio	Α	10,97
Effective aspect ratio	A_{eff}	11,64
Efficiency feator, about range	l.	15 15
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{wet}/S_W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	20,5
RE value maximum aerodynamic efficiency		20,98
	-2%	

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,780
Cruise altitude	h _{CR}	11126 m
By Pass Ratio	μ	12,00
Take-off Thrust (one engine)	T _{TO,one engine}	108,54 kN
Overall Pressure ratio	OAPR	42,25
Turbine entry temperature	TET	1446,29
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	$oldsymbol{\eta}_{inlet}$	0,91
Ventilator efficiency	η _{ventilator}	0,88
Compressor efficiency	$\eta_{compresor}$	0,87
Turbine efficiency	$\eta_{ m turbine}$	0,90
Nozzle efficiency	η_{nozzle}	0,98
Temperature at SL	T_o	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T _S	216,65 K
Temperature at cruise altitude	T(H)	216,65 K
Dimensionless turbine entry temperature	ф	6,68
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,12
Temperature function	χ	2,15
Gas generator efficiency	$\eta_{ m gasgen}$	0,97
Gas generator function	G	1,98
Verification value specific fuel consumption	SFC	0,54 kg/daN/h
Verification value specific fuel consumption	SFC	1,51E-05 kg/N/s
RE value specific fuel consumption	SFC	1,26E-05 kg/N/s

Matching Chart



Appendix AF Boeing 767-300F

Symbol Units Chosen value Source America tendenciaries for appointming Source	Data collection					-			2				,	o	0
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Trop kN Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log Log	Take-off thrust for one engine	T _{TO} , one engin		276,233	N	269,3794367 269,38/266,		,37944	267		229,483773	254,349334		1,571	220
Tro(Meary State Action Control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control	Total take-off thrust	Tro													
Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line Line	Thrust to weight ratio	Tro/(m _{MTO}	,a)	6,0					0,29154519				0,3	0,31	
Clarity SFC (dry) kg/N s 9,15E-06 9,1258E-06 9,118 9,15E-06 9,118 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,138 9,	Bypass ratio	_									5,31			4,9	
Of Cutuise) SFC (Crutise) Application	Specific Fuel Comsumption (dry)		kg/N s	9,15E-06							8,9994E-06		9,15E-06		
V _{CR} m/s m/s 228.33 91,38 91,38 h _{CR} m/s m 11887 10668-11887 10668 est m 6,98 6,98 6,98 nest N _C max %c 11,5 6,98 nest N _C max %c 11,5 6,98 nest N _C max %c 11,5 7,0207 nest N _C max %c 11,5 1,0207 nest N _C max 1,0207 1,0207 1,0207	Specific Fuel Comsumption (cruise		se kg/N s								1,6301E-05				
V _{CR} brance m 11887 10668-11887 10668 h _{CR} brance m 6,98 8 8 herr No, brance %c 11,5 8 herr No, brance %c 11,5 8 h V C % brance %c 11,5 h A DO 207 A DO 207 8 OAPR 31,6 30,4 29,9 27,1-318	Available fuel volume	Vfuel, available		91,38		91,38							91,38		
V _{CR} m/s m/s 238.33 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668 10668															
hcr m 11887 10668-11887 10668 4ps ** 31,5 ** ** outc m 6,98 ** ** location %* ** ** location %* 11,5 ** location ** ** A APAR 31,8 31,8 **	Cruise speed	V _{CR}	s/m	238,33											238,33
φ _{5S} ° 31,5 ° 6,98 ° ° 6,98 ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° ° °	Cruise altitude	hcs	ε	11887		10668-11887					10668		11887		
Counco m 6,98	Sweep angle	Фэк	•	31.5									31.5		
Name %c Heas X _{i,c,c,c,max} %c No. 11,5 A A OAPR 31,8 30,4 29,9 27,1-31,8 30,4 29,9 27,1-31,8	Mean aerodynamic chord	OMAC	Ε	6.98									6.98		
(V _c haw/c %c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c V _c haw/c %c	Position of maximum camber	X(v c).max	%c												
No. Mark 11,5	Camber	(yc)max/c	%c												1,5
ψc % 11,5 λ 0,207 OAPR 31,8 30,4 29,9 27,1–31,8	Position of maximum thickness	X _{t,max}	%с												.,
λ 0,207 OAPR 31,8 30,4 29,9 27,1–31,8	Relative thickness	t/c	%	11,5									11,5		Ì
OAPR 31,8 30,4	Taper	~		0,207					_						
	Overall pressure ratio	OAPR		31,8							30,4	29,9 27	7,1–31,8		

Aeroplane Specifications

Data to apply reverse engineering

	Data to apply r	everse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1740	m		
Approach speed	Unknown	V_{APP}	66,10	m/s	71,0	71,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	2926	m	2926	2926
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	3000	NM		
Cruise Mach number		M _{CR}	0,8			
Wing area		S _W	283	m²		
Wing span	Known	b_W	47,57	m²	47,57	47,57
Aspect ratio		Α	7,99			
Maximum take-off mass		m _{MTO}	186880	kg		
Maximum payload mass		m_PL	50800	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,272			
Maximum landing mass		m_ML	147871	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,791			
Operating empty mass		m_OE	85275	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,456			
Wing loading		m_{MTO}/S_W	659,7	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	276,233	kN		
Total take-off thrust		T _{TO}	552,466	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,301			
Bypass ratio		μ	5,3			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to	optimize	V/V _{md}
Dala		UDUIIILE	V/Vmc

				LL	UL
Cruise speed		V_{CR}	238 m/s		
Cruise altitude		h _{CR}	11887 m		
Speed ratio		V/V_{md}	1,000 -	1	1,316
	Data to execu	te the verification			
				Ran	ge
Sweep angle		ϕ_{25}	31,5 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		$\mathbf{x}_{(y_c),max}$	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,3 %		
Taper		λ	0,207		

Reverse Engineering

Reverse	engineering	& o	ptimization	of	V/Vmd
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Rev	verse engineering	g & optimization of	V/VIIIu		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1740	1740	m	0,00%
Approach speed	V_{APP}	Unknown	71,0	m/s	0,00%
Take-off field length	s _{TOFL}	2926	2926	m	0,00%
Span	b_W	47,57	47,57	m	0,00%
Aspect ratio	Α	7,99	7,99		0,00%
Cruise speed	V_{CR}	238,3	236	m/s	-0,9 <mark>4%</mark>
Cruise altitude	h_{CR}	11887	11368	m	-4,36%
Squared Sum Absolute maximum deviation					1,99E-03 4,4%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,80			

Maximum lift coefficient, landing	$C_{L,max,L}$	2,80
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,75
Maximum aerodynamic efficiency	E _{max}	15,95
Specific fuel consumption	SFC	1,43E-05 kg/N/s

Reverse Engineering

1) Maximum Lift Coefficient for Landing and Take-off

L	anding	
Landing field length	S _{LFL}	1740 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	70,99 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,79
Wing loading at maximum take-off mass	m_{MTO}/S_W	659,7 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,80
T:	ake-off	
Take-off field length	s _{TOFL}	2926 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,301
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,75
2nd	Segment	
Aspect ratio	A	7,988
Lift coefficient, take-off	$C_{L,TO}$	1,22
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,006
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,026
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	11,06
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,229
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,66
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,028
Lift-independent drag coefficient, slats	$\Delta C_D,slat$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C_D,P	0,063
Glide ratio in landing configuration	EL	7,55
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,243

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Spi	ecifications		
Mach number, cruise	M _{CR}	0,8	
Aspect ratio	Α	7,99	
Bypass ratio	μ	5,30	
Wing loading	m_{MTO}/S_W	660 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,301	
	Variables		
	V/V _{md}	1,0	
C	alculations		
Zero-lift drag coefficient	C _{D,0}	0,021	
Lift coefficient at E _{max}	$C_{L,md}$	0,67	
Ratio, lift coefficient	$C_L/C_{L,md}$	1,000	
Lift coefficient, cruise	C_L	0,669	
Actual aerodynamic efficiency, cruise	E	15,95	
Max. glide ratio, cruise	E _{max}	15,95	
Newton-Raphson for the maximum lift-to-o	drag ratio		
Iterations	1	2	3
f(x)	-0,01	0,00	0,00
f'(x)	-0,13	-0,12	-0,12
E _{max}	16	15,95	15,95

3) Specific Fuel Consumption

Constan	it parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Spec	ifications		
Range	R	3000	NM
Mach number, cruise	M_{CR}	0,8	
Bypass ratio	μ	5,30	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,301	
Available fuel volume	$V_{fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	186880	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,272	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,456	
Calcul	ated values		
Actual aerodynamic efficiency, cruise	E	15,95	
Cruise altitude	h _{CR}	11368	
Cruise speed	V _{CR}	236	m/s
Mindon	fuel freetier		
Type of aeroplane (according to Roskam)	fuel fraction Transport jet		
Fuel-Fraction, engine start	M _{ff,engine}	0,990	
Fuel-Fraction, taxi	, , ,	0,990	
Fuel-Fraction, taxi	M _{ff,taxi}	0,995	
•	M _{ff,TO}	•	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
	culations		
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,272	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,728	
Available fuel mass	MF,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,102	
Mission fuel fraction (acc. to fuel capacity)	\mathbb{M}_{ff}	0,916	
Distance to alternate	S _{to alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,43E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

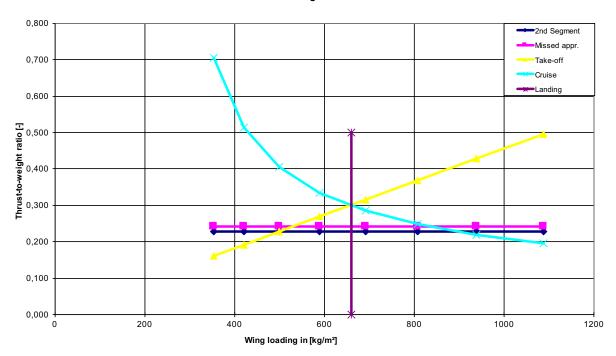
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b_W	47,57 m
Structural wing span	$b_{W,struct}$	55,79 m
Wing area	S_W	283,3 m ²
Aspect ratio	Α	7,99
Sweep	φ_{25}	31,5 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	$\mathbf{x}_{(y_{-c}), max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
Relative thickness	t/c	11,3 %
Taper	λ	0,207
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	70,99 m/s
Mach number, landing	M_{APP}	0,21
Mach number, cruise	M _{CR}	0,8
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,1 %c
Leading edge sweep	ϕ_{LE}	36,2 °
Reynoldsnumber	Re	2,1E+07
Maximum lift coefficient, base	C _{L,max,base}	1,24
Correction term, camber	$\Delta_1 c_{L,max}$	0,40
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	Δ ₃ C _{L.max}	0,044
Maximum lift coefficient, airfoil	C _{L.max.clean}	1,683
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,87
Correction term, Mach number	$\Delta C_{L,max}$	-0,02
Lift coefficient, wing	C _{L,max}	1,44

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	K _φ	0,84
Flap group A	τ	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,41
Use flapped span	b_W,fA	35,7 m
Percentage of flaps allong the wing		64%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,76
Flap group B	_,	
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74
Use flapped span	b W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\DeltaC_{L,max,f}$	0,76
	L,max,i	,
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	Ψ _{H.L.}	34 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,89
Use slatted span	b W,sA	9,7 m
Percentage of slats allong the wing	_ /-	17%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,13
Slat group B	E,max,or (•
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,89
Use slatted span	b_W,sB	36,4 m
Percentage of slats allong the wing	,	65%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,48
Increase in maximum lift coefficient, slat	ΔC _{L,max,s}	0,61
Wing Verification value maximum lift coefficient, landing RE value maximum lift coefficient, landing	$C_{L,max,L}$	2,77 2,80
Verification value maximum lift coefficient, take-off	C	1,73
RE value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,75
-1%		1,75
-170		
Aerodynamic eff	iciency	
Deal circust average	le.	0.00
Real aircraft average	k _{WL}	2,83
No winglets	$k_{e,WL}$	1,00
Span	b _W	47,57 m
Winglet height	h	3,4 m
Aspect ratio	A	7,99
Effective aspect ratio	A_{eff}	7,99
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{wet}/S_W	5,44
Varification value maximum coradynamic officiency	_	18,4
Verification value maximum aerodynamic efficiency	E _{max}	•
RE value maximum aerodynamic efficiency		15,95
13%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,800	
Cruise altitude	h_{CR}	11887 m	
By Pass Ratio	μ	5,30	
Take-off Thrust (one engine)	T _{TO,one engine}	276,23 kN	
Overall Pressure ratio	OAPR	31,80	
Turbine entry temperature	TET	1491,04	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η_{inlet}	0,95	
Ventilator efficiency	$\eta_{ m ventilator}$	0,89	
Compressor efficiency	n _{compresor}	0,87	
Turbine efficiency	n _{turbine}	0,91	
Nozzle efficiency	η_{nozzle}	0,99	
Temperature at SL	T_0	288,15 K	
Temperature lapse rate in troposhpere	L	0,0065 K/m	
Temperature (ISA) at tropopause	T _S	216,65 K	
Temperature at cruise altitude	T(H)	216,65 K	
Dimensionless turbine entry temperature	ф	6,88	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,13	
Temperature function	χ	1,90	
Gas generator efficiency	$\eta_{ m gasgen}$	0,98	
Gas generator function	G	2,28	
Verification value specific fuel consumption	SFC	0,56 kg/daN	l/h
Verification value specific fuel consumption	SFC	1,55E-05 kg/N/s	
RE value specific fuel consumption	SFC	1,43E-05 kg/N/s	
9%			

Matching Chart



Appendix AG Comac ARJ21-700

Data Collection	tion		ARJ21-700	1	2		က	4	5	9	7	8	6	
	1	1 1 1 1	Source:	Aircraft characteristics for airport planning		6	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Paul Müller Elodie RouxData collectior	Webs	
PAX	Symbol	3115	Oloseii vaide	78-90	06	<u> </u>					90-78		78-90	É
Landing field length	SLFL	Ε	1550	1600	1700 1550	1650					1550			
Approach speed	V _{APP}	s/w	•											
l emperature above ISA (288,15K)	ΔIL	4	>											
Relative density	S													
Take-off field length	STORI	Ε	1700	1700	1900 1700	1900					1700		1700	1900
Temperature above ISA (288.15K)	ΔΤτο	¥	0											
Relative density	S													
Range (max payload)	œ	Æ	2225		2000 2222	3704					2225		2200	3700
Cruise Mach number	McR		0,78	0,78							0,78		0,78	
Wing area	ů.	m ₂	79.86	79.86	79.86						79.86		79.86	
Wing span	. Š	E	27.29	27.288	27.29						27.29		27.28	
Aspect ratio	. ⋖		9,32		6,9						9,32			
Maximum take-off mass	ММТО	ķ	43500	40500 43500	405	43500					40500		40500	43500
Payload mass	ШРГ	ğ	8935	8935	8935	10					8935			
Mass ratio, payload - take-off	MPL/MMT0										0,221			
Maximum landing mass	m _M L	kg	37665	37665 40455	155 37665	40455					37665			
Mass ratio, landing - take-off	MML/MMT0													
Operating empty mass	MoE	g	24955	24955	24955	2					24955		24955	
Mass ratio, operating empty - take-off moemmro	f moe/mmro		101		7 100	144.7					0,616			
wing loading	MMTO/5w	kg/m²	1,700		1,700	244,7					700			
Maximum zero tuel mass	MMZF	Kg	33890	33890	33890						33890			
Number of engines	ä		2		2						2			
Engine type	GE CF34-10A	¥0	CF34-10A	CF34-10A	CF34-10A	VO V					CF34-10A		CF34-10A	×.
Take-off thrust for one engine	T _{TO,one engine} KN	¥	68,2		68,2						80,068		75,87	
Total take-off thrust	Tro	Ϋ́												
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	(t	0,4		0,34357	0,31988					0,4			
Bypass ratio	_		2								5			
Specific Fuel Comsumption (dry)	SFC (dry)	kg/N s												
Specific Fuel Comsumption (cruise)	SFC (cruise kg/N s	e kg/N s												
Available fuel volume	Vfuel, available	°E	12,719	13,231	12,719	0					12,719			
Cruise speed	VcR	s/m	230										230	
Cruise altitude	hcr	٤	10668	10668							10668		11900	
Sweep angle	ф25	0	25	25							25		52	
Mean aerodynamic chord	OMAC	Ε												
Position of maximum camber	X(y_c),max	жс												
Camber	(yc)max/c	%c												
Position of maximum thickness	X _{t,max}	%с												
Relative thickness	ţ,c	%												
Taper	٧													
Overall pressure ratio	OAPR					+	+	T						T
Turbine entry temperature	TET	¥												

Aeroplane Specifications

	Data to apply r	everse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1550			
Approach speed	Unknown	V_{APP}	66,10	m/s	67,0	67,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	1700	m	1700	1700
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	1201	NM		
Cruise Mach number		M _{CR}	0,78			
Wing area		S_W	80	m²		
Wing span	Known	b_W	27,29	m²	27,29	27,29
Aspect ratio		Α	9,33			
Maximum take-off mass		m_{MTO}	43500	kg		
Maximum payload mass		m_{PL}	8935	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,205			
Maximum landing mass		m_{ML}	37665	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,866			
Operating empty mass		m_OE	24955	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,574			
Wing loading		m_{MTO}/S_W	544,7	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	68,2	kN		
Total take-off thrust		T _{TO}	136,4	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,320			
Bypass ratio		μ	5			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to	optimize	V/V_{md}
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				LL	UL
Cruise speed		V_{CR}	230 m/s		
Cruise altitude		h _{CR}	10668 m		
Speed ratio		V/V_{md}	1,267 -	1	1,316
	Data to execu	te the verification			
				Ran	ige
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,6 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimization of V	Vmd
-----------------------------------------	-----

11071	or se engineering	a optimization of v	/ V III G		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1550	1550	m	0,00%
Approach speed	V_{APP}	Unknown	67,0	m/s	0,00%
Take-off field length	s _{TOFL}	1700	1700	m	0,00%
Span	b_W	27,29	27,29	m	0,00%
Aspect ratio	Α	9,33	9,33		0,00%
Cruise speed	V_{CR}	230,0	231	m/s	0,57%
Cruise altitude	h_{CR}	10668	10678	m	0,09%
Squared Sum Absolute maximum deviation					3,28E-05 0,6%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,84			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,35		Dave	
Maximum aerodynamic efficiency	E _{max}	14,89		Revi	erse Engineering
Specific fuel consumption	SFC	1,72E-05 kg/	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Landi	ing				
Landing field length	S _{LFL}	1550 m			
Temperature above ISA (288,15K)	ΔT_L	0 K			
Relative density	σ	1,000			
Factor, approach	k _{APP}	1,70 (m/s²) ^{0.5}			
Approach speed	V_{APP}	67,00 m/s			
Factor, landing	k_L	0,107 kg/m ³			
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,87			
Wing loading at maximum take-off mass	m_{MTO}/S_W	544,7 kg/m ²			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,84			
Take-	off				
Take-off field length	S _{TOFL}	1700 m			
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K			
Relative density	σ	1,00			
Factor	k _{TO}	2,34 m³/kg			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,320			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,35			
2nd Seg	ıment				
Aspect ratio	A	9,326			
Lift coefficient, take-off	$C_{L,TO}$	1,63			
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,026			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Profile drag coefficient	C _{D,P}	0,046			
Oswald efficiency factor; landing configuration	e	0,7			
Glide ratio in take-off configuration	E _{TO}	9,26			
Number of engines	n.	2			
Climb gradient	n _E sin(γ)	0,024			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,264			
-		0,201			
Missed approach					
Lift coefficient, landing	C _{L,L}	1,68			
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,029			
Lift-independent drag coefficient, slats Choose: Certification basis	$\Delta C_{D,slat}$	0,000			
Choose: Certification basis	JAR-25 resp. CS-25 FAR Part 25	no ves			
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	yes 0,015			
Profile drag coefficient	C _{D,P}	0,064			
Glide ratio in landing configuration	E _L	8,32			
Sad rate in landing configuration	- L	0,02			
Climb gradient	sin(γ)	0,021			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,244			

2) Maximum Aerodynamic Efficiency

Constant parameters						
Ratio of specific heats, air	γ	1,4				
Earth acceleration	g	9,81 m/s ²				
Air pressure, ISA, standard	p_0	101325 Pa				
Oswald eff. factor, clean	е	0,85				
Sp	ecifications					
Mach number, cruise	M _{CR}	0,78				
Aspect ratio	Α	9,33				
Bypass ratio	μ	5,00				
Wing loading	m_{MTO}/S_W	545 kg/m²				
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,320				
Variables						
	V/V_{md}	1,3				
C	alculations					
Zero-lift drag coefficient	C _{D,0}	0,028				
Lift coefficient at E _{max}	$C_{L,md}$	0,84				
Ratio, lift coefficient	C _L /C _{L,md}	0,623				
Lift coefficient, cruise	C_L	0,521				
Actual aerodynamic efficiency, cruise	E	13,37				
Max. glide ratio, cruise	E _{max}	14,89				
Newton-Raphson for the maximum lift-to-drag ratio						
Iterations	1	2	3			
f(x)	-0,15	0,00	0,00			
f'(x)	-0,13	-0,13	-0,13			
E _{max}	16	14,91	14,89			

3) Specific Fuel Consumption

Constant parameters				
Ratio of specific heats, air	γ	1,4		
Earth acceleration	g	•	m/s²	
Air pressure, ISA, standard	\mathbf{p}_0	101325		
Fuel density	$ ho_{ m fuel}$	800	kg/m³	
Specificat	ions			
Range	R	1201		
Mach number, cruise	M _{CR}	0,78		
Bypass ratio	μ	5,00		
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,320		
Available fuel volume	$V_{ m fuel,available}$	23,86		
Maximum take-off mass	m_{MTO}	43500	•	
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,205		
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,574		
Calculated	values			
Actual aerodynamic efficiency, cruise	E	13,37		
Cruise altitude	h _{CR}	10678	m	
Cruise speed	V_{CR}	231	m/s	
Mission fuel	fraction			
Type of aeroplane (according to Roskam)	Transport jet			
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990		
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990		
Fuel-Fraction, take-off	$M_{\rm ff,TO}$	0,995		
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980		
Fuel-Fraction, descent	$M_{ff,DES}$	0,990		
Fuel-Fraction, landing	$M_{ff,L}$	0,992		
Calculati	ons			
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,221		
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,779		
,	"	•		
Available fuel mass	M _{F,available}	19088	kg	
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,439		
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,573		
Distance to alternate	S _{to_alternate}	200	NM	
Distance to alternate	S _{to_alternate}	370400	m	
Choose: FAR Part121-Reserves	domestic	yes		
	international	no		
Extra-fuel for long range		5%		
Extra flight distance	S _{res}	370400	m	
Loiter time	t _{loiter}	2700	s	
Specific fuel consumption	SFC	1,72E-05	kg/N/s	

4) Verification Specifications

Maximum lift coefficients

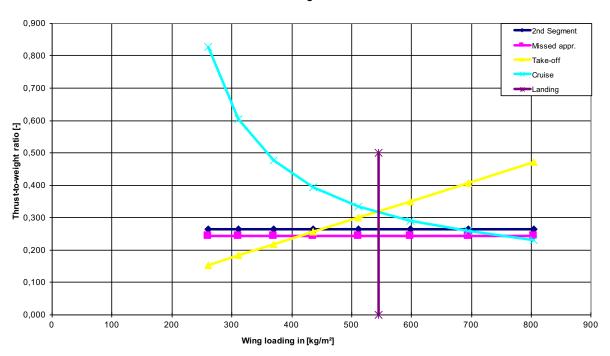
General wing specifications	Airfoil type:	NACA 64 series
Wing span	b_W	27,29 m
Structural wing span	$b_{W,struct}$	30,11 m
Wing area	S_W	79,9 m ²
Aspect ratio	Α	9,33
Sweep	φ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	$\mathbf{x}_{(y_{-c}), max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t,max}$	30 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	67,00 m/s
Mach number, landing	M_APP	0,20
Mach number, cruise	M_{CR}	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,5 %c
Leading edge sweep	ϕ_{LE}	28,8 °
Reynoldsnumber	Re	2,0E+07
Maximum lift coefficient, base	C _{L,max,base}	1,42
Correction term, camber	$\Delta_1 c_{L,max}$	0,35
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,007
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,770
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,80
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	C _{L,max}	1,42

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,87
Flap group A		
Double-slotted flap	$\Delta c_{L,max,fA}$	1,39
Use flapped span	b_W,fA	21 m
Percentage of flaps allong the wing		70%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,84
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,73
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	ΔC _{L,max,fB}	0,00
Increase in maximum lift coefficient, flap	$\DeltaC_{L,max,f}$	0,84
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	Ψ _{H.L.}	27 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,88
Use slatted span	b_W,sA	24,6 m
Percentage of slats allong the wing		82%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,64
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,88
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing		0%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,00
Increase in maximum lift coefficient, slat	$\DeltaC_{L,max,s}$	0,64
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,86
RE value maximum lift coefficient, landing	- L,IIIdX,L	2,84
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,36
RE value maximum lift coefficient, take-off	CL,IIIdX, IO	2,35
0%		_,00
Aerodynamic effic	iency	
Real aircraft average	k_{WL}	2,83
End plate	k _{e,WL}	1,06
Span	b _W	27,29 m
Winglet height	h h	1,2 m
Aspect ratio	A	9,33
Effective aspect ratio	A _{eff}	9,91
	· 1011	0,0.
Efficiency factor, short range	k_{E}	15,15
Relative wetted area	S _{wel} /S _W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	18,9
RE value maximum aerodynamic efficiency	∟ max	14,89

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,780	
Cruise altitude	h _{CR}	10668	m
By Pass Ratio	μ	5,00	
Take-off Thrust (one engine)	T _{TO,one engine}	68,20	kN
Overall Pressure ratio	OAPR	29,00	
Turbine entry temperature	TET	1402,70	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η_{inlet}	0,95	
Ventilator efficiency	$\eta_{ m ventilator}$	0,83	
Compressor efficiency	$\eta_{compresor}$	0,85	
Turbine efficiency	$\eta_{ m turbine}$	0,88	
Nozzle efficiency	η_{nozzle}	0,97	
Temperature at SL	T_0	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T_S	216,65	K
Temperature at cruise altitude	T(H)	218,81	K
Dimensionless turbine entry temperature	ф	6,41	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperatur	e υ	1,12	
Temperature function	χ	1,81	
Gas generator efficiency	$\eta_{ m gasgen}$	0,98	
Gas generator function	G	1,89	
Verification value specific fuel consumption	SFC	0.64	kg/daN/h
Verification value specific fuel consumption	SFC	1,78E-05	•
	050		
RE value specific fuel consumption	SFC	1,72E-05	kg/N/s
3%			

Matching Chart



Appendix AH Comac ARJ21-900

Data Collection	ction		ARJ21-900	-	2	3	4	5	9	7	8	6	
Conceptor	Odmyo	ofice!	N COOL	Source: Aircraft characteristics	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Paul MüllerElodie Roudata collectio	ta collectior	Webs	0
PAX	Symbol	SIIIO	105	10r airpoir pianning	105	2				105-98		98-105	
					3							8	
Landing field length	SLFL	ε	1600		1600	1700				1600			
Approach speed	V _{APP}	s/m	•										
Relative density	ΔIL	۷.	D										
Since of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state	,												
Take-off field length	STOFL	ε	1750		1750 1	1950				1750		1750	1950
Temperature above ISA (288,15K)	ΔΤτο	~	0										
Relative density	Ø												
Range (max payload)	ď	Æ	2222		2222 3	3333				3334		2200	3300
Cruise Mach number	McR		0,78							0,78		0,78	
Wing area	w _w	m ₂	79.86		79.86					79.86		79.86	
Wing span	, Mg	Ε	27,29		27,29					27,29		27,28	
Aspect ratio	¥		9,32		6,3					9,32			
Maximum take off mass	É	3	47182		43616 47	47182				43616		43616	47182
Dayload mass	O E	2 3	11246		46	70				11246		11246	1
Mass ratio. pavload - take-off	MPI/MMTO	2	25		25					0.258		2	
Maximum landing mass	m _M	ķ	40563		40563 43	43879				40563		38513	
Mass ratio, landing - take-off	MML/MMT0												
Operating empty mass	moe	ķ	26270		26270 26	26770				26270		26270	26770
Mass ratio, operating empty - take-off moemmro	iff moe/mwro									0,602			
Wing loading	MMTO/SW	kg/m²	240,2		546,2	590,8				040			
Maximum zero tuel mass	MMZF	Ď.	3/5/6			8016				3/510			
Number of engines	a a		2		2					2			
Engine type	GE CF34-10A	10A	CF34-10A		CF34-10A					CF34-10A		CF34-10A	∢
Take-off thrust for one engine	T _{TO,one} engine KN	KN KN	75,9		75,9					80,08		82	
Total take-off thrust	To	Z.			_								
Thrust to weight ratio	Tro/(m _{MTo} *g)	(B)	0,37		0,35554 0,32	0,32811				78,0			
Bypass ratio	П ОПО ОПО	Iva/N	۵							2			
Specific Fuel Comsumption (cruise)		se kg/N s											
Available fuel volume	Vfuel, available	m ₃	12,719		12,719 13,	13,355				12,719			
Cruise speed	V _{CR}	s/m	230									230	
Cruise altitude	hcR	Ε	10668							10668		11900	
Sween andle	ě	۰	25							25		25	
Mean aerodynamic chord	Q490	Ε								ì		1	
Position of maximum camber	X(v c) max	%c											
Camber	(yc)max/c	%c											
Position of maximum thickness	X _{t,max}	%с											
Relative thickness	t/c	%											
Taper	٧ !												
Overall pressure ratio	OAPR		+										
Turbine entry temperature	텔	¥	 										7

Aeroplane Specifications

Data 1	to ap	ply rev	verse e	ngıneering	J
					Τ

	sata to apply 1	everse engineering			
				LL	UL
Landing field length	Known	s_{LFL}	1600 m		
Approach speed	Unknown	V_{APP}	66,10 m/s	68,1	68,1
Temperature above ISA (288,15K)		ΔT_L	0 K		
Relative density		σ	1		
Take off field length	Known		1750 m	1750	1750
Take-off field length	Known	S _{TOFL}	0 K	1750	1750
Temperature above ISA (288,15K) Relative density		ΔT_{TO}	1,000		
Relative defisity		σ	1,000		
Range (maximum payload)		R	1200 NM		
Cruise Mach number		M_{CR}	0,78		
Wing area		S _W	80 m ²		
Wing span	Known	b_W	27,29 m ²	27,29	27,29
Aspect ratio		Α	9,33		
Maximum take-off mass		m _{MTO}	47182 kg		
Maximum payload mass		m_{PL}	11246 kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,238		
Maximum landing mass		m_{ML}	40563 kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,860		
Operating empty mass		m_{OE}	26270 kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,557		
Wing loading		m_{MTO}/S_W	590,8 kg/m²	2	
Number of engines		n _E	2		
Take-off thrust for one engine		T _{TO,one engine}	75,9 kN		
Total take-off thrust		T _{TO}	151,8 kN		
Thrust to weight ratio		T _{TO} /(m _{MTO} *g)	0,328		
Bypass ratio		μ	5		
-11		F	-		
Available fuel volume		V _{fuel,available}	12,72 m ³		

Data	to	optimize	V/V _{md}
------	----	----------	-------------------

				LL	UL
	V_{CR}	230	m/s		
	h _{CR}	10668	m		
	V/V_{md}	1,242	-	1	1,316
Data to execu	te the verification				
				Rar	nge
	ϕ_{25}	25	0		
	C _{MAC}	4,2	m		
	X _{(y_c),max}	30	%с	15 - 50	%с
	(y _c) _{max} /c	4	%с	2 - 6	%с
	$x_{t,max}$	30	%с	30 - 45	%с
Unknown	t/c	11,6	%		
	λ	0,24			
	Data to execu	$\begin{array}{c} V_{CR} \\ h_{CR} \\ V/V_{md} \end{array}$ Data to execute the verification $\begin{array}{c} \phi_{25} \\ c_{MAC} \\ x_{(y_c),max} \\ (y_c)_{max}/c \\ x_{t,max} \\ \text{Unknown} \end{array}$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$

Reverse Engineering

Maximum aerodynamic efficiency

Specific fuel consumption

Poverse	engineering	Q.	ontimization	٥f	V/Vmd
Reverse	engineering	α	opumization	OI	v/villa

Kev	erse engineerin	g & optimization of	V/VIIIu		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1600	1600	m	0,00%
Approach speed	V_{APP}	Unknown	68,1	m/s	0,00%
Take-off field length	s _{TOFL}	1750	1750	m	0,00%
Span	b_W	27,29	27,29	m	0,00%
Aspect ratio	Α	9,33	9,33		0,00%
Cruise speed	V_{CR}	230,0	231	m/s	0,57%
Cruise altitude	h _{CR}	10668	10678	m	0,09%
Squared Sum					3,28E-05
Absolute maximum deviation					0,6%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,97			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,41		Rev.	erse Engineering
Maximum aerodynamic efficiency	E	1/1 28		Keve	erse Engineering

 $\mathsf{E}_{\mathsf{max}}$

SFC

14,28

1,49E-05 kg/N/s

1) Maximum Lift Coefficient for Landing and Take-off

Landing								
Landing field length	S _{LFL}	1600	m					
Temperature above ISA (288,15K)	ΔT_L	0	K					
Relative density	σ	1,000						
Factor, approach	k _{APP}	1,70	$(m/s^2)^{0.5}$					
Approach speed	V_{APP}	68,07	m/s					
Factor, landing	k_L	0,107	kg/m³					
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,86						
Wing loading at maximum take-off mass	m_{MTO}/S_W	590,8	kg/m²					
Maximum lift coefficient, landing	$C_{L,max,L}$	2,97						
Take-off								
Take-off field length	S _{TOFL}	1750	m					
Temperatur above ISA (288,15K)	ΔT_{TO}	0	K					
Relative density	σ	1,00						
Factor	k _{TO}	2,34	m³/kg					
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,328						
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,41						
2nd Segment								
Aspect ratio	A	9,326						
Lift coefficient, take-off	C _{L.TO}	1,67						
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020						
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,029						
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000						
Profile drag coefficient	C _{D,P}	0,049						
Oswald efficiency factor; landing configuration	e	0,7						
Glide ratio in take-off configuration	E _{TO}	9,04						
Number of anning	_	0						
Number of engines	n _E	2						
Climb gradient Thrust-to-weight ratio	sin(γ)	0,024 0,269						
Trirust-to-weight fatto	$T_{TO}/(m_{MTO}^*g)$	0,209						
Missed approach								
Lift coefficient, landing	C _{L,L}	1,76						
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020						
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,033						
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000						
Choose: Certification basis	JAR-25 resp. CS-25 FAR Part 25	no						
Lift-independent drag coefficient, landing gear		yes 0,015						
Profile drag coefficient	$\Delta C_{D,gear}$	0,015						
Glide ratio in landing configuration	C _{D,P}	8,05						
Glide Tatio in landing configuration	Ęį	6,05						
Climb gradient	sin(γ)	0,021						
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,250						

2) Maximum Aerodynamic Efficiency

Constant parameters								
Ratio of specific heats, air	γ	1,4						
Earth acceleration	g	9,81 m/s ²						
Air pressure, ISA, standard	p_0	101325 Pa						
Oswald eff. factor, clean	е	0,85						
Sp	Specifications							
Mach number, cruise	M _{CR}	0,78						
Aspect ratio	Α	9,33						
Bypass ratio	μ	5,00						
Wing loading	m_{MTO}/S_W	591 kg/m²						
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,328						
Variables								
V/V _{md} 1,2								
C	alculations							
Zero-lift drag coefficient	C _{D,0}	0,031						
Lift coefficient at E _{max}	$C_{L,md}$	0,87						
Ratio, lift coefficient	$C_L/C_{L,md}$	0,648						
Lift coefficient, cruise	C_L	0,565						
Actual aerodynamic efficiency, cruise	E	13,03						
Max. glide ratio, cruise	E _{max}	14,28						
Newton-Raphson for the maximum lift-to-o	drag ratio							
Iterations	1	2	3					
f(x)	-0,24	-0,01	0,00					
f'(x)	-0,14	-0,13	-0,13					
E _{max}	16	14,33	14,28					

3) Specific Fuel Consumption

Consta	nt parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Spec	cifications		
Range	R	1200	NM
Mach number, cruise	M _{CR}	0,78	
Bypass ratio	μ	5,00	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,328	
Available fuel volume	$V_{fuel,available}$	12,72	m³
Maximum take-off mass	m_{MTO}	47182	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,238	
Mass ratio, operating empty - take-off	$m_{OE/}m_{MTO}$	0,557	
Calcui	lated values		
Actual aerodynamic efficiency, cruise	E	13,03	
Cruise altitude	h _{CR}	10678	m
Cruise speed	V_{CR}	231	m/s
Mission	n fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Cal	culations		
Mission fuel fraction (acc. to PL and OE)	m _E /m _{MTO}	0,205	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,795	
·			
Available fuel mass	MF,available	10176	kg
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,216	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,800	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t_{loiter}	2700	s
Specific fuel consumption	SFC	1,49E-05	ka/N/s

4) Verification Specifications

Maximum lift coefficients

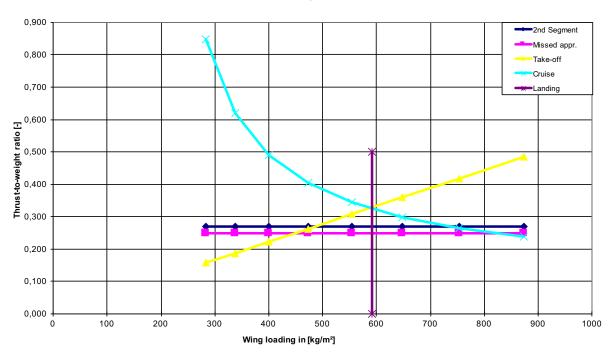
General wing specificationsAirfoil type:NACA AWing span b_W 27,29 mStructural wing span $b_{W,struct}$ 30,11 mWing area S_W 79,9 m²Aspect ratioA9,33Sweep ϕ_{25} 25 °Mean aerodynamic chord c_{MAC} 4,2 mPosition of maximum camber $x_{(yc),max}$ 30 %cCamber $(y_c)_{max}/c$ 4 %cPosition of maximum thickness $x_{l,max}$ 30 %cRelative thickness t/c 11,6 %Taper λ 0,24General aircraft specifications ΔT_L 0 KRelative density σ 1Temperature, landing T_L 273,15 KDensity, air, landing ρ 1,225 kg/m³Dynamic viscosity, air μ 1,72E-05 kg/m/s	4 digit
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
Aspect ratio A 9,33 Sweep ϕ_{25} 25 ° Mean aerodynamic chord ϕ_{25} 25 ° Mean aerodynamic chord ϕ_{25} 25 ° Mean aerodynamic chord ϕ_{25} 30 %c Camber ϕ_{25} 30 %c Camber ϕ_{25} 30 %c Relative thickness ϕ_{25} 30 %c Relative thickness ϕ_{25} 30 %c Taper ϕ_{25} 30 %c Taper ϕ_{25} 30 %c ϕ_{25} 30 %c Relative density ϕ_{25} 31,6 % ϕ_{25} 31,6 % ϕ_{25} 31,15 K Density, air, landing ϕ_{25} 31,225 kg/m³	
Sweep $ \begin{array}{ccccccccccccccccccccccccccccccccccc$	
Mean aerodynamic chord c_{MAC} $4,2$ mPosition of maximum camber $x_{(y_c),max}$ 30 %cCamber $(y_c)_{max}/c$ 4 %cPosition of maximum thickness $x_{t,max}$ 30 %cRelative thickness t/c $11,6$ %Taper λ $0,24$ General aircraft specificationsTemperature above ISA (288,15K) ΔT_L 0 KRelative density σ 1 Temperature, landing T_L $273,15$ KDensity, air, landing ρ $1,225$ kg/m³	
Position of maximum camber $x_{(y_c),max}$ 30 %cCamber $(y_c)_{max}/c$ 4 %cPosition of maximum thickness $x_{t,max}$ 30 %cRelative thickness t/c 11,6 %Taper λ 0,24General aircraft specificationsTemperature above ISA (288,15K) ΔT_L 0 KRelative density σ 1Temperature, landing T_L 273,15 KDensity, air, landing ρ 1,225 kg/m³	
Camber $ (y_c)_{max}/c \qquad 4 \%c $ Position of maximum thickness $ x_{t,max} \qquad 30 \%c $ Relative thickness $ t/c \qquad 11,6 \% $ Taper $ \lambda \qquad 0,24 $	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
Density, air, landing ρ 1,225 kg/m³	
Dynamic viscosity, air μ 1,72E-05 kg/m/s	
Speed of sound, landing a _{APP} 331 m/s	
Approach speed V _{APP} 68,07 m/s	
Mach number, landing M _{APP} 0,21	
Mach number, cruise M _{CR} 0,78	
Calculations maximum clean lift coefficient	
Leading edge sharpness parameter Δy 3,0 %c	
Leading edge sweep ϕ_{LE} 28,8 $^{\circ}$	
Reynoldsnumber Re 2,0E+07	
Maximum lift coefficient, base c _{L.max.base} 1,58	
Correction term, camber $\Delta_1 c_{L,max}$ 0,18	
Correction term, thickness $\Delta_2 c_{L,max}$ 0,00	
Correction term, Reynolds' number $\Delta_3 c_{L,max}$ 0,079	
Maximum lift coefficient, airfoil C _{L,max,clean} 1,831	
Lift coefficient ratio $C_{L,max}/c_{L,max}$ 0,80	
Correction term, Mach number ΔC _{L,max} -0,01	
Lift coefficient, wing C _{L,max} 1,46	

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathrm{\phi}}}$	0,87
Flap group A	*	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,43
Use flapped span	b_W,fA	21 m
Percentage of flaps allong the wing	_	70%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,86
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,86
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	$\phi_{H.L.}$	27 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	24,6 m
Percentage of slats allong the wing		82%
Increase in maximum lift coefficient, slat group A	\DeltaC_L,max,sA	0,66
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing	4.0	0%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,00
Increase in maximum lift coefficient, slat	$\DeltaC_{L,max,s}$	0,66
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,93
RE value maximum lift coefficient, landing	O _{L,max,L}	2,97
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,38
RE value maximum lift coefficient, take-off	OL,max, 10	2,41
-1%		_,
Aerodynamic	efficiency	
Real aircraft average	k _{WL}	2,83
End plate	k _{e,WL}	1,06
Span	b _W	27,29 m
Winglet height	h	1,2 m
Aspect ratio	Ä	9,33
Effective aspect ratio	A_{eff}	9,91
	OII	
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{we}/S_{W}	6,35
Verification value maximum aerodynamic efficiency	E _{max}	18,9
RE value maximum aerodynamic efficiency	- max	14,28
33%		17,40

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,780	
Cruise altitude	h_{CR}	10668	m
By Pass Ratio	μ	5,00	
Take-off Thrust (one engine)	T _{TO,one engine}	75,90	kN
Overall Pressure ratio	OAPR	29,00	
Turbine entry temperature	TET	1414,60	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η _{inlet}	0,95	
Ventilator efficiency	$\eta_{ m ventilator}$	0,84	
Compressor efficiency	$\eta_{compresor}$	0,85	
Turbine efficiency	$\eta_{turbine}$	0,88	
Nozzle efficiency	η_{nozzle}	0,97	
Temperature at SL	T_0	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T_S	216,65	K
Temperature at cruise altitude	T(H)	218,81	K
Dimensionless turbine entry temperature	ф	6,47	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,12	
Temperature function	χ	1,81	
Gas generator efficiency	η_{gasgen}	0,98	
Gas generator function	G	1,94	
Verification value specific fuel consumption	SFC	0.63	kg/daN/h
Verification value specific fuel consumption	SFC	1,75E-05	•
RE value specific fuel consumption	SFC	1,49E-05	kg/N/s

Matching Chart



Appendix AI Boeing 787-10

Data Collection	tion		787-10	1	2	3	4	5	9	7	8	6
Doromotor	Cympol	a linite	School	Source: Aircraft characteristics for airport planning	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Paul Müller∃lodie Roux)ata collectior	Webs
PAX	Syllibol	OIIIS	Crioseri value	330-440								327-396-44
Landing field length	SLFL	Ε	1855	1855								
Approach speed	V _{APP}	m/s										
Temperature above ISA (288,15K)	ΔT _L	¥	0	0								
Relative density	w											
Toke off field length	į	8	2005	2005								
Temperature above ISA (288 15K)	AT ₋₀	Z	2007	000								
Relative density	0 0	4	>									
Vicinity of delivery	,											
Range (max payload)	~	km	7710	7710								12900
Cruise Mach number	McR		0,85	0,85								0,85
Wing area	Sw	m²	325									325
Wing span	þw	Ε	60,12	60,12								09
Aspect ratio	A		11,1									
			054044	440410								000000
Maximum take-on mass	ПМТО	ß.	110467	110407								00000
Payload mass	ШЫ	kg	2/7/6	9/7/6								
Mass ratio, payload - take-off	MPL/MMT0		0,000									0,00
Maximum landing mass	Jw[kg	201848	201848								201849
Mass ratio, landing - take-off	MML/MMT0		000									
Operating empty mass	I Moe	D)	135500									135500
Mina loading empty - take-on moentmo	m.rro/S.	ka/m²										
Maximum zero fuel mass	B. 472	ka Ka	192776	192776								201849
		•										
Number of engines	2		2				2					2
Engine type	GE GEnx 1	GE GEnx 1B (62%), RR	Genx 72A1			_	\vdash	0				Genx
Take-off thrust for one engine	T _{TO,one} engine KN	KN	340				235,756 235,756	-				340
Total take-off thrust	Tro	ΚN										
Thrust to weight ratio	Tro/(m _{MTo} *g)	9)										
Bypass ratio	_						-					
Specific Fuel Comsumption (dry)	SFC (dry)	kg/N s										
Specific Fuel Comsumption (cruise)	SFC (cruise kg/N s	e kg/N s										
Available fuel volume	V _{fuel} , available	ш	138,7	126,429								138,7
Cruise speed	S N	m/s	253.61									253.61
Cruise altitude	hcs	E	10700									10700
Sweep angle	ф25	0	32,2									32,2
Mean aerodynamic chord	OMAC	Ε										
Position of maximum camber	X(y_c),max	%с										
Camber	(yc)max/c	%с										
Position of maximum thickness	X _{t,max}	%c										
Relative thickness	t/c	%										
Taper	~ 0					1						
Overall pressure ratio	OAPR					#						
Turbine entry temperature	핃	~										7

Aeroplane Specifications

Available fuel volume

Da	ata to apply re	everse engineering				
					LL	UL
Landing field length	Known	S _{LFL}	1855	m		
Approach speed	Unknown	V_{APP}	66,10	m/s	73,3	73,3
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	2995	m	2995	2995
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	4163	NM		
Cruise Mach number		M _{CR}	0,85			
Wing area		S_W	325	m²		
Wing span	Known	b_W	60,12	m²	60,12	60,12
Aspect ratio		Α	11,12			
Maximum take-off mass		m _{MTO}	254011	kg		
Maximum payload mass		m_{PL}	57276	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,225			
Maximum landing mass		m _{ML}	201848	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,795			
Operating empty mass		m_{OE}	135500	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,533			
Wing loading		m_{MTO}/S_W	781,6	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	340	kN		
Total take-off thrust		T _{TO}	680	kN		
Thrust to weight ratio		T _{TO} /(m _{MTO} *g)	0,273			
Bypass ratio		μ	9			

V_{fuel,available}

23,86 m³

Data to optimize V/V _{md}	Data	to	optimize	V/Vma
------------------------------------	------	----	----------	-------

		• • • • • • • • • • • • • • • • • • •			
				LL	UL
Cruise speed		V_{CR}	254 m/s		
Cruise altitude		h _{CR}	10700 m		
Speed ratio		V/V_{md}	1,097 -	1	1,316
	Data to execu	te the verification			
				Rar	nge
Sweep angle		ϕ_{25}	32,2 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	10,6 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimization of V/Vmd

Nevel	se engineering	a optimization of v	// VIIIu		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1855	1855	m	0,00%
Approach speed	V_{APP}	Unknown	73,3	m/s	0,00%
Take-off field length	s _{TOFL}	2995	2995	m	0,00%
Span	b_W	60,12	60,12	m	0,00%
Aspect ratio	Α	11,12	11,12		0,00%
Cruise speed	V_{CR}	253,6	252	m/s	-0,63%
Cruise altitude	h_{CR}	10700	10689	m	-0,10 <mark>%</mark>
Squared Sum Absolute maximum deviation					4,05E-05 0,6%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,13			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,24		D	F ii
Maximum aerodynamic efficiency	E _{max}	19,62		Reve	rse Engineering
Specific fuel consumption	SFC	1,14E-05 kg/	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

	anding		
Landing field length	S_{LFL}	1855	m
Temperature above ISA (288,15K)	ΔT_L	0	K
Relative density	σ	1,000	
Factor, approach	k_{APP}	1,70	(m/s²) 0.5
Approach speed	V_{APP}	73,30	m/s
Factor, landing	\mathbf{k}_{L}	0,107	kg/m³
Mass ratio, landing - take-off	$\rm m_{ML}/m_{TO}$	0,79	
Wing loading at maximum take-off mass	m_{MTO}/S_W	781,6	kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,13	
Ta	ake-off		
Take-off field length	S _{TOFL}	2995	m
Temperatur above ISA (288,15K)	ΔT_TO	0	K
Relative density	σ	1,00	
Factor	k _{TO}	2,34	m³/kg
Γhrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,273	
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,24	
2nd	Segment		
Aspect ratio	Α	11,121	
lift coefficient, take-off	$C_{L,TO}$	1,55	
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020	
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,023	
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000	
Profile drag coefficient	C_D,P	0,043	
Oswald efficiency factor; landing configuration	е	0,7	
Glide ratio in take-off configuration	E _{TO}	10,99	
Number of engines	n _E	2	
Climb gradient	sin(γ)	0,024	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}*g)$	0,230	
Misse	d approach		
ift coefficient, landing	C _{L,L}	1,85	
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020	
ift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,038	
ift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000	
Choose: Certification basis	JAR-25 resp. CS-25	no	
	FAR Part 25	yes	
ift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015	
Profile drag coefficient	C_D,P	0,073	
Glide ratio in landing configuration	EL	8,70	
Climb gradient	sin(γ)	0,021	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,216	

2) Maximum Aerodynamic Efficiency

Consta	nt parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81	m/s²
Air pressure, ISA, standard	p_0	101325	Pa
Oswald eff. factor, clean	е	0,85	
Spe	cifications		
Mach number, cruise	M _{CR}	0,85	
Aspect ratio	A	11,12	
Bypass ratio	μ	9,00	
Wing loading	m_{MTO}/S_W	782	kg/m²
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,273	
v	ariables		
	V/V _{md}	1,1	_
Ca	lculations		
Zero-lift drag coefficient	C _{D,0}	0,019	
Lift coefficient at E _{max}	$C_{L,md}$	0,76	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,831	
Lift coefficient, cruise	C_L	0,629	
Actual aerodynamic efficiency, cruise	E	19,29	
Max. glide ratio, cruise	E _{max}	19,62	
Newton-Raphson for the maximum lift-to-di	rag ratio		
Iterations	1	2	3
f(x)	0,34	-0,02	
f(x)	-0,09	-0,10	*
E _{max}	16	19,86	19,62

3) Specific Fuel Consumption

Ratio of specific heats, air	ν.	1,4	
Earth acceleration	γ g		m/s²
Air pressure, ISA, standard	p ₀	101325	
Fuel density	$ ho_{fuel}$		kg/m ³
_			
Range	ecifications R	4163	NM
Mach number, cruise	M _{CR}	0,85	
Bypass ratio	μ	9,00	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,273	
Available fuel volume	V _{fuel,available}	23,86	m³
Maximum take-off mass	m _{MTO}	254011	
Mass ratio, landing - take-off	m _{PL} /m _{MTO}	0,225	
Mass ratio, operating empty - take-off	m _{OE/} m _{MTO}	0,533	
Calar			
Actual aerodynamic efficiency, cruise	ulated values E	19,29	
Cruise altitude	h _{CR}	10689	m
Cruise speed	V _{CR}		m/s
·			
	n fuel fraction		
Type of aeroplane (according to Roskam)	Transport jet	0.000	
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	$M_{ff,DES}$	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
	Iculations		
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,241	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,759	
Available fuel mass	TF,available	19088	kg
Relative fuel mass (acc. to fuel capacity)	$m_{F,available}/m_{MTO}$	0,075	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,944	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s

4) Verification Specifications

Maximum lift coefficients

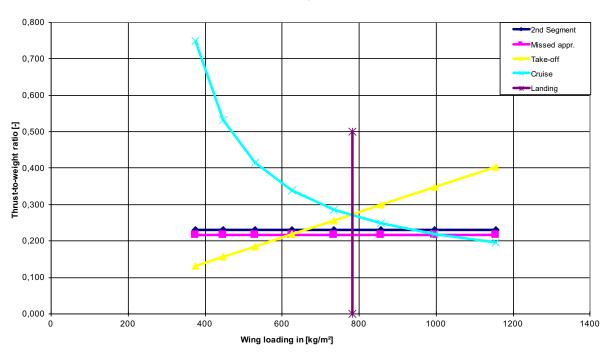
General wing specifications	Airfoil type:	NACA 66 serie
Wing span	b_W	60,12 m
Structural wing span	$b_{W,struct}$	71,05 m
Wing area	S_W	325,0 m ²
Aspect ratio	Α	11,12
Sweep	φ_{25}	32,2 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	$\mathbf{x}_{(\mathbf{y}_{-c}),max}$	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$x_{t,max}$	30 %c
Relative thickness	t/c	10,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Геmperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m ³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	73,30 m/s
Mach number, landing	M_APP	0,22
Mach number, cruise	M_{CR}	0,85
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	1,9 %c
Leading edge sweep	ϕ_{LE}	35,4 °
Reynoldsnumber	Re	2,2E+07
Maximum lift coefficient, base	C _{L,max,base}	1,17
Correction term, camber	$\Delta_1c_{L,max}$	0,39
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,064
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,624
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,91
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	C _{L,max}	1,46

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,83
Flap group A	·	
0,4c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	2,04
Use flapped span	b_W,fA	40,7 m
Percentage of flaps allong the wing		57%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,97
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,75
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,97
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	Φ _{H.L.}	34,5 °
Slat group A	-	
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,91
Use slatted span	b_W,sA	13,4 m
Percentage of slats allong the wing	_	19%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,14
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,91
Use slatted span	b_W,sB	40,1 m
Percentage of slats allong the wing		56%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,42
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,56
Minor		
Wing Verification value maximum lift coefficient, landing	•	2,95
RE value maximum lift coefficient, landing	$C_{L,max,L}$	3,13
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,11
RE value maximum lift coefficient, take-off	C _{L,max,TO}	2,24
-6%		2,24
-076		
Aerodynamic e	fficiency	
Real aircraft average	, l	2.02
· ·	k _{WL}	2,83
No winglets	k _{e,WL}	1,00
Span	b _W	60,12 m
Winglet height	h	1,6 m
Aspect ratio	A	11,12
Effective aspect ratio	A_{eff}	11,12
Efficiency factor, short range	k _E	16,19
Relative wetted area	S_{wel}/S_W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	21,4
RE value maximum aerodynamic efficiency	IIIMA	19,62
9%		•
-		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,850	
Cruise altitude	h _{CR}	10700	m
By Pass Ratio	μ	9,00	
Take-off Thrust (one engine)	T _{TO,one engine}	340.00	kN
Overall Pressure ratio	OAPR	53,30	
Turbine entry temperature	TET	1496,47	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	$\eta_{ m inlet}$	0,93	
Ventilator efficiency	η _{ventilator}	0,90	
Compressor efficiency	$\eta_{compresor}$	0,88	
Turbine efficiency	n _{turbine}	0,91	
Nozzle efficiency	$\eta_{ m nozzle}$	0,99	
Temperature at SL	T ₀	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T_S	216,65	K
Temperature at cruise altitude	T(H)	218,60	K
Dimensionless turbine entry temperature	ф	6,85	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,14	
Temperature function	χ	2,42	
Gas generator efficiency	η_{gasgen}	0,97	
Gas generator function	G	1,98	
Verification value specific fuel consumption	SFC	0,54	kg/daN/h
Verification value specific fuel consumption	SFC	1,49E-05	•
RE value specific fuel consumption	SFC	1,14E-05	kg/N/s
31%			

Matching Chart



Appendix AJ Boeing 747-400

Data Collection	ction		/4/-400						7		,		4				,		٥	a
			Source:	ice:	ircraft characteri	airport planning					Jenkinson	-	Engine		Paul Müller		Elodie Roux		Data collection	Webs
Parameter	Symbol	Onits	Chosen value	+	35	400 KR		95	PB RB	Ī	000 400 440		,		904		620 420			
¥			020	+	4	9		-	-	-000	190-417				490		020-420			
Landing field length	SFE	ε	2100	H	7	2070		_	905		2130				2072		2130		2130	
Approach speed	V _{APP}	s/m	75,1						75,1		78,71				75				82,31111111	
Temperature above ISA (288,15K)	ΔT _L	¥	0			0					0									
Relative density	s			+			+													
Take-off field length	Store	ε	3200		3215		3050	2820		2850	3310						3310		3300	3018
Temperature above ISA (288.15K)	ΔTro	×	0			0			15		0									
Relative density	· s								!											
Range (max payload)	œ	Ě	10695	-	10560	10695	10465	11454	11473	11186	12699,1				9800		8480			13450
Cruise Mach number	McR		0,85			0,85			0,85			8,0		0,85			0,85		0,85	0,85
Wing area	ď.	m ₂	541.16	+				75	541.16		525				524 9		541.16			
Wing span	Å	Ε	64.44	H	64.44-64	-64.92		64.4	64.44-64.92	•	62.3				64.44		64.44		64.4	64.9
Aspect ratio	⋖		7,67						7,7	7,	7,3929333				6,7		7,67			
Maximum take off mase	É	5	396830	-	478098	362874-396894		98	362875		396830				28555		362874		396890	396890
Pavload mass	a a	2 2	63657	6391	63917-67319 63657-67059 62921-67457	7-67059 62921-6	17457	5			61186						63657			
Mass ratio, payload - take-off	MPL/MMT0	,								0	0,1541869						0,175			
Maximum landing mass	mML	kg	260362		260362-28	2-285764		26	260360		285760				260360		260362			
Mass ratio, landing - take-off	MM∪MwTo										0,7201068									
Operating empty mass	moe	ğ	179015	+	178756	179015 1	179752	180485	180845 18	181435	181484						179015			178800
Mass ratio, operating empty - take-off moemino	off moe/myrro		1000	+				- 6	100	i c	0,4573344						0,493			
Wing loading	maro/Sw	kg/m²	6/0,5		AT08AC CT3CAC	00710 073010	04770	2 6	6/0,5	2	755,86667						6/1			
	-1865-	2	710717	-	10012-210212		27177	4			212212						710717			
Number of engines	je L										4								4	4
Engine type	GE CF6-8	GE CF6-80 (37%), PW40	Δ.	CF6	≧		RB211-524G2 CF6-80C2B1F PW4056	30C2B1F PV		RB211-524G P&W4056		ш		RB.211-524G		CF6-80C2B1F PW4056		3.211-524G R	RB.211-524G RB211-524 G/H	
Take-off thrust for one engine	Tro, one engine KN	Z	252	72	257,377383 25	252,2654 257	257,8184	258	252	258	252,4	254,26037 25	252,436599	257,996876		254,259	254,259 252,435	257,996	258	282
Total take-off thrust	Tro T	₹ .	86.0	+			0	89888860	7888080 0 08800	4.	0.0503438					Č	80.0	00.00		
Bypass ratio	2		4.9				Y.		\perp	4	200	5.15	4.85	4.3		, 4	4.9	4.3		
Specific Fuel Comsumption (dry)	SFC (dry) kg/N s	kg/N s	9,06E-06								80		9,056E-06			8,95E-0	8,95E-06 9,06E-06			
Specific Fuel Comsumption (cruise)		s kg/N s									-			1,6131E-05		1,60E-05	10	1,62E-05		
Available fuel volume	Vfuel, available	"E	204,333	203,:	203,501-215,99	204,333-216,824	4	203,523	204,355	204,	204,35-216,85						204,35			216,84
Cruise speed	VcR	s/m	253							252,	252,08-260,82								262,3666667	253,33
Cruise altitude	hcs	ε	10668	+					10575		10668	10668	10668	10668			10668			
Sweep angle	\$ 25	۰	37,5	-							37,5						37,5			
Mean aerodynamic chord	OMAC	ε	9,68								89'6						89'6			
Position of maximum camber	X _{(y c),max}	%с	15																	15
Camber	(yc)max/c	%c	1,4	+																4,1
Position of maximum thickness	Xtmax	%c	35	+			-	+			7						10 4 7 0 0			35
Relative mickness Taper	20 ~	0,	0.278	+				0.277	0.277511962		9,4						0.278			-
Overall pressure ratio	OAPR		30,2	F				1			į	30,4	30,2	32,9			i			

Aeroplane Specifications

Number of engines

Total take-off thrust

Bypass ratio

Thrust to weight ratio

Available fuel volume

Take-off thrust for one engine

Data to apply reverse engineering LL UL Landing field length Known **2100** m s_{LFL} 75,10 m/s Approach speed Known V_{APP} 75,1 75,1 Temperature above ISA (288,15K) ΔT_{L} 0 K Relative density σ **3200** m Take-off field length Known 3200 3200 STOFL 0 K Temperature above ISA (288,15K) ΔT_{TO} Relative density 1,000 Range (maximum payload) R 5775 NM Cruise Mach number M_{CR} 0,85 541 m² Wing area S_W $b_{W} \\$ Wing span Known 64,44 m² 64,44 64,44 Aspect ratio 7,67 Α 396830 kg Maximum take-off mass m_{MTO} Maximum payload mass 63657 kg m_{PL} Mass ratio, payload - take-off $m_{PL}\!/m_{MTO}$ 0,160 Maximum landing mass $m_{ML} \\$ 260362 kg Mass ratio, landing - take-off 0,656 m_{ML}/m_{MTO} Operating empty mass 179015 kg m_{OE} Mass ratio, operating empty - take-off $m_{\text{OE}}/m_{\text{MTO}}$ 0,451 Wing loading 733,3 kg/m²

 m_{MTO}/S_W

 $T_{TO,one\ engine}$

 $T_{TO}/(m_{MTO}^*g)$

Vfuel, available

 n_E

 T_TO

4

252 kN

1008 kN

0,259

4,9

23,86 m³

Data	to	optimize	V/V_{md}
------	----	----------	------------

	Data to o	Ptilling V/ V ma				
					LL	UL
Cruise speed		V_{CR}	253 i	m/s		
Cruise altitude		h_{CR}	10668	m		
Speed ratio		V/V_{md}	1,029	-	1	1,316
	Data to execu	te the verification				
					Rar	nge
Sweep angle		φ_{25}	37,5	0		
Mean aerodynamic chord		C _{MAC}	9,68	m		
Position of maximum camber		X _{(y_c),max}	30 '	%с	15 - 50	%с
Camber		(y _c) _{max} /c	4 '	%с	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	10,6	%		
Taper		λ	0,278			

Reverse Engineering

Reverse engineering & optimization of V/Vmd

Rev	erse engineering	& optimization of	v/vma		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	2100	2100	m	0,00%
Approach speed	V_{APP}	75,10	75,1	m/s	0,00%
Take-off field length	s _{TOFL}	3200	3200	m	0,00%
Span	b_W	64,44	64,44	m	0,00%
Aspect ratio	Α	7,67	7,67		0,00%
Cruise speed	V_{CR}	253,0	252	m/s	-0,35%
Cruise altitude	h_{CR}	10668	10662	m	-0,06 <mark>%</mark>
Squared Sum					1,25E-05
Absolute maximum deviation					0,3%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,14			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,07		Payo	rse Engineering
Maximum aerodynamic efficiency	E _{max}	16,42		Keve	ise Engineering
Specific fuel consumption	SFC	1,46E-05 kg	g/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

La	anding	
Landing field length	S _{LFL}	2100 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	75,10 m/s
Factor, landing	k_L	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,66
Wing loading at maximum take-off mass	m_{MTO}/S_W	733,3 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	2,14
Ta	ake-off	
Take-off field length	S _{TOFL}	3200 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,259
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,07
2nd	Segment	
Aspect ratio	A	7,673
Lift coefficient, take-off	$C_{L,TO}$	1,44
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D, flap}$	0,017
Lift-independent drag coefficient, slats	$\Delta C_D.slat$	0,000
Profile drag coefficient	C _{D,P}	0,037
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	9,02
Number of engines	n _E	4
Climb gradient	sin(γ)	0,030
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,188
Missa	d annroach	
Lift coefficient, landing	d approach C _{L,L}	1,27
Lift-independent drag coefficient, clean	C _{D.0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,008
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\DeltaC_D,gear$	0,015
Profile drag coefficient	$C_{D,P}$	0,043
Glide ratio in landing configuration	EL	9,15
Climb gradient	sin(γ)	0,027
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,119
	- 10- (wild 3 /	-,

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,85	
Aspect ratio	A	7,67	
Bypass ratio	μ	4,90	
Wing loading	m _{MTO} /S _W	733 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,259	
,	Variables		
	V/V _{md}	1,0	
	· · · ma	.,0	
C	alculations		
Zero-lift drag coefficient	$C_{D,0}$	0,019	
Lift coefficient at E _{max}	$C_{L,md}$	0,62	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,944	
Lift coefficient, cruise	C_L	0,589	
Actual aerodynamic efficiency, cruise	E	16,39	
Max. glide ratio, cruise	E _{max}	16,42	
Newton-Raphson for the maximum lift-to-			
Iterations	1	2	3
f(x)	0,05 -0,11	0,00 -0,12	0,00 -0,12
f'(x)	-0,11		
E_{max}	10	16,42	16,42

3) Specific Fuel Consumption

Constant par	ameters						
Ratio of specific heats, air	γ	1,4					
Earth acceleration	g		m/s²				
Air pressure, ISA, standard	p_0	101325					
Fuel density	$ ho_{fuel}$	800	kg/m³				
Specificat	ions						
Range	R	5775	NM				
Mach number, cruise	M _{CR}	0,85					
Bypass ratio	μ	4,90					
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,259					
Available fuel volume	$V_{\text{fuel,available}}$	23,86					
Maximum take-off mass	m_{MTO}	396830	•				
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,160					
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,451					
Calculated	values						
Actual aerodynamic efficiency, cruise	E	16,39					
Cruise altitude	h _{CR}	10662	m				
Cruise speed	V_{CR}	252	m/s				
Mission fuel fraction							
Type of aeroplane (according to Roskam)	Transport jet						
Fuel-Fraction, engine start	$M_{ m ff,engine}$	0,990					
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990					
Fuel-Fraction, take-off	$M_{\rm ff,TO}$	0,995					
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980					
Fuel-Fraction, descent	$M_{ff,DES}$	0,990					
Fuel-Fraction, landing	$M_{ff,L}$	0,992					
Calculati	ons						
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,388					
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,612					
Available fuel mass	200	10000	ka				
	F,available	19088	ку				
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,048					
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,971					
Distance to alternate	S _{to_alternate}	200	NM				
Distance to alternate	S _{to_alternate}	370400	m				
Choose: FAR Part121-Reserves	domestic	no					
	international	yes					
Extra-fuel for long range		5%					
Extra flight distance	s _{res}	905165					
Loiter time	t _{loiter}	1800	S				
Specific fuel consumption	SFC	1,46E-05	kg/N/s				

4) Verification Specifications

Maximum lift coefficients

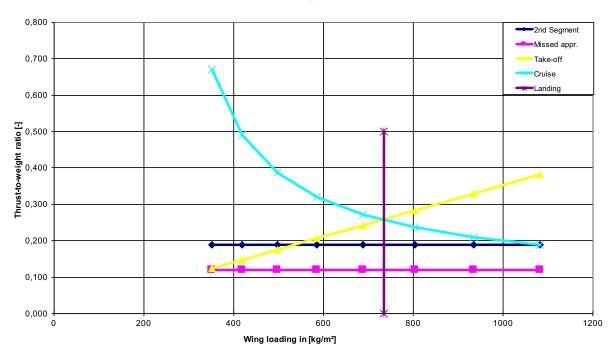
Structural wing span D _{W,struct} 81,22 m	General wing specifications	Airfoil type:	NACA 63 series
Sample	Wing span	b_W	64,44 m
Aspect ratio A 7,67 Sweep φ25 37,5° Mean aerodynamic chord cmAC 9,68 m Position of maximum camber x _{(y-c),max} 30 %c Camber (yc) _{max} /c 4 %c Position of maximum thickness x _{Lmax} 30 %c Relative thickness t/c 10,6 % Taper λ 0,278 General aircraft specifications Temperature above ISA (288,15K) ΔTL 0 K Relative density σ 1 Temperature, landing TL 273,15 K Density, air, landing p 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m³s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient Leading edge sweep φ _{LE} 41,7° <td>Structural wing span</td> <td>$b_{W,struct}$</td> <td>81,22 m</td>	Structural wing span	$b_{W,struct}$	81,22 m
Sweep Φ25 37,5 ° Mean aerodynamic chord C _{MAC} 9,68 m Position of maximum camber X _{(y,c),max} 30 %c Camber (y _c) _{max} /c 4 %c Position of maximum thickness X _L max 30 %c Relative thickness ½c 10,6 % Taper λ 0,278 General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient Leading edge sweep φ _{LE} 41,7 ° Reynoldsnumber Re 5,2E+07	Wing area	S_W	541,2 m ²
Mean aerodynamic chord C _{MAC} 9,68 m Position of maximum camber X _{(Y,c),max} 30 %c Camber (y _c) _{max} /c 4 %c Position of maximum thickness X _{t,max} 30 %c Relative thickness t/c 10,6 % Taper λ 0,278 General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Pensity, air, landing p 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep φ _L 4,1,7 ° Reynoldsnumber	Aspect ratio	Α	7,67
Position of maximum camber x _{(y_c),max} /c 4 %c Camber (y _c),max/c 4 %c Position of maximum thickness x _{t,max} 30 %c Relative thickness t/c 10,6 % Taper λ 0,278 General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient Leading edge sweep φ _{LE} 41,7° Reynoldsnumber Q _L 4,0 Maximum lift coefficient, base C _{L,max,base} 1,36 Correction term, camber Δ _Q C _L	Sweep	Ψ25	37,5 °
Camber (V _C) _{max} /c 4 %c Position of maximum thickness x _{t,max} 30 %c Relative thickness t/c 10.6 % Taper λ 0,278 General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient Δy 2,3 %c Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep φ _{LE} 41,7 ° Reynoldsnumber A ₂ C _{L,max} 0,38 Correction term, camber Δ ₂ C _{L,max} 0,00 Correction term,	Mean aerodynamic chord	C _{MAC}	9,68 m
Position of maximum thickness $x_{t,max} = 30 \% c$ Relative thickness $t/c = 10,6 \%$ Taper $x_{t,max} = 30 \% c$ Relative thickness $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Taper $x_{t,max} = 10,6 \%$ Tap	Position of maximum camber	$\mathbf{x}_{(\mathbf{y}_{\mathbf{c}}),max}$	30 %c
Relative thickness t/c 10,6 % Taper λ 0,278 General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep φ _{LE} 41,7 ° Reynoldsnumber Re 5,2E+07 Maximum lift coefficient, base c _{L,max} ,base 1,36 Correction term, camber Δ _{CL,max} 0,08 Correction term, hickness Δ ₂ C _{L,max} 0,00 Correction term, Reynolds' number Δ ₂ C _{L,max}	Camber	(y _c) _{max} /c	4 %c
General aircraft specifications A 0,278 Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient 3 4 Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep φ _{LE} 41,7 ° Reynoldsnumber Re 5,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,36 Correction term, camber Δ _{PC,max} 0,38 Correction term, thickness Δ _{PC,max} 0,00 Correction term, Reynolds' number Δ _{PC,max} 0,018 Maximum lift coefficient, airfoil C _{L,max,clean} <t< td=""><td>Position of maximum thickness</td><td>$\mathbf{x}_{t,max}$</td><td>30 %c</td></t<>	Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
General aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep φ _{LE} 41,7 ° Reynoldsnumber Reynoldsnumber Re 5,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,36 Correction term, camber Δ ₂ c _{L,max} 0,08 Correction term, Reynolds' number Δ ₃ C _{L,max} 0,018 Maximum lift coefficient, airfoil c _{L,max,clean} 1,760 Lift coefficient ratio C _{L,max} /c _{L,max} 0,01 Co	Relative thickness	t/c	10,6 %
Temperature above ISA (288,15K) ΔT _L 0 K Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient 2 Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep φ _{LE} 41,7 ° Reynoldsnumber Re 5,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,36 Correction term, camber Δ _{CL,max} 0,38 Correction term, thickness Δ _{CL,max} 0,00 Correction term, Reynolds' number Δ _{GC,max} 0,018 Maximum lift coefficient, airfoil c _{L,max,clean} 1,760 Lift coefficient ratio C _{L,max} /c _{L,max} 0,01	Taper	λ	0,278
Relative density σ 1 Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient 2 Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep φ _{LE} 41,7 ° Reynoldsnumber Re 5,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,36 Correction term, camber Δ ₁ c _{L,max} 0,38 Correction term, thickness Δ ₂ c _{L,max} 0,00 Correction term, Reynolds' number Δ ₃ c _{L,max} 0,018 Maximum lift coefficient, airfoil c _{L,max,clean} 1,760 Lift coefficient ratio C _{L,max} /c _{L,max} 0,77 Correction term, Mach number ΔC _{L,max} -0,01	General aircraft specifications		
Temperature, landing T _L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient Δy 2,3 %c Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep φ _{LE} 41,7 ° Reynoldsnumber Re 5,2E+07 Maximum lift coefficient, base C _{L,max,base} 1,36 Correction term, camber Δ ₁ C _{L,max} 0,38 Correction term, thickness Δ ₂ C _{L,max} 0,00 Correction term, Reynolds' number Δ ₃ C _{L,max} 0,018 Maximum lift coefficient, airfoil C _{L,max,clean} 1,760 Lift coefficient ratio C _{L,max} /c _{L,max} 0,77 Correction term, Mach number ΔC _{L,max} -0,01	Temperature above ISA (288,15K)	ΔT_L	0 K
Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 75,10 m/s Mach number, landing M _{APP} 0,23 Mach number, cruise M _{CR} 0,85 Calculations maximum clean lift coefficient a _V 2,3 %c Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep φ _{LE} 41,7 ° Reynoldsnumber Re 5,2E+07 Maximum lift coefficient, base c _{L,max,base} 1,36 Correction term, camber Δ ₂ C _{L,max} 0,38 Correction term, thickness Δ ₂ C _{L,max} 0,00 Correction term, Reynolds' number Δ ₃ C _{L,max} 0,018 Maximum lift coefficient, airfoil c _{L,max,clean} 1,760 Lift coefficient ratio C _{L,max} /c _{L,max} 0,077 Correction term, Mach number ΔC _{L,max} -0,01	Relative density		
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Temperature, landing	T_L	
Speed of sound, landing A_{APP} 331 m/s Approach speed V_{APP} 75,10 m/s Mach number, landing M_{APP} 0,23 Mach number, cruise M_{CR} 0,85 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep ϕ_{LE} 41,7 ° Reynoldsnumber ϕ_{LE} 5,2E+07 Maximum lift coefficient, base ϕ_{LL} 1,36 Correction term, camber ϕ_{LL} 0,38 Correction term, thickness ϕ_{LL} 0,00 Correction term, Reynolds' number ϕ_{LL} 0,018 Maximum lift coefficient, airfoil ϕ_{LL} 0,77 Correction term, Mach number ϕ_{LL} 0,77 Correction term, Mach number ϕ_{LL} 0,77 Correction term, Mach number ϕ_{LL} 0,01	Density, air, landing	ρ	_
Approach speed V_{APP} 75,10 m/s Mach number, landing M_{APP} 0,23 Mach number, cruise M_{CR} 0,85 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep ϕ_{LE} 41,7 ° Reynoldsnumber Re 5,2E+07 Maximum lift coefficient, base $C_{L,max,base}$ 1,36 Correction term, camber $\Delta_{CL,max}$ 0,38 Correction term, thickness $\Delta_{CL,max}$ 0,00 Correction term, Reynolds' number $\Delta_{CL,max}$ 0,018 Maximum lift coefficient, airfoil $C_{L,max,clean}$ 1,760 Lift coefficient ratio $C_{L,max}/C_{L,max}$ 0,77 Correction term, Mach number $\Delta_{CL,max}$ 0,77 Correction term, Mach number $\Delta_{CL,max}$ -0,01	Dynamic viscosity, air	μ	•
Mach number, landing M_{APP} 0,23 Mach number, cruise M_{CR} 0,85 Mach number, cruise M_{CR} 0,85 Mach number, cruise M_{CR} 0,85 Mach number, cruise M_{CR} 0,85 Mach number, cruise M_{CR} 0,85 Mach number M_{CR} 2,3 %c Leading edge sharpness parameter M_{CR} 41,7 ° Reynoldsnumber M_{CR} 8,2E+07 Maximum lift coefficient, base $M_{CL,max}$ 1,36 Maximum lift coefficient, base $M_{CL,max}$ 0,38 Correction term, camber $M_{CL,max}$ 0,38 Correction term, thickness $M_{CL,max}$ 0,00 Correction term, Reynolds' number $M_{CL,max}$ 0,018 Maximum lift coefficient, airfoil $M_{CL,max,clean}$ 1,760 Maximum lift coefficient ratio $M_{CL,max}$ 0,77 Correction term, Mach number $M_{CL,max}$ -0,01	Speed of sound, landing	a_{APP}	
Mach number, cruise M_{CR} 0,85 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 2,3 %c Leading edge sweep ϕ_{LE} 41,7 ° Reynoldsnumber Re 5,2E+07 Maximum lift coefficient, base $C_{L,max,base}$ 1,36 Correction term, camber $\Delta_1 c_{L,max}$ 0,38 Correction term, thickness $\Delta_2 c_{L,max}$ 0,00 Correction term, Reynolds' number $\Delta_3 c_{L,max}$ 0,018 Maximum lift coefficient, airfoil $C_{L,max,clean}$ 1,760 Lift coefficient ratio $C_{L,max}/C_{L,max}$ 0,77 Correction term, Mach number $\Delta C_{L,max}$ -0,01	Approach speed	V_{APP}	75,10 m/s
Calculations maximum clean lift coefficientLeading edge sharpness parameter Δy 2,3 %cLeading edge sweep ϕ_{LE} 41,7 °ReynoldsnumberRe5,2E+07Maximum lift coefficient, base $C_{L,max,base}$ 1,36Correction term, camber $\Delta_1C_{L,max}$ 0,38Correction term, thickness $\Delta_2C_{L,max}$ 0,00Correction term, Reynolds' number $\Delta_3C_{L,max}$ 0,018Maximum lift coefficient, airfoil $C_{L,max,clean}$ 1,760Lift coefficient ratio $C_{L,max}/c_{L,max}$ 0,77Correction term, Mach number $\Delta C_{L,max}$ -0,01	Mach number, landing	M_{APP}	0,23
Leading edge sharpness parameter Δy 2,3 %cLeading edge sweep ϕ_{LE} 41,7 °ReynoldsnumberRe5,2E+07Maximum lift coefficient, base $C_{L,max,base}$ 1,36Correction term, camber $\Delta_1 C_{L,max}$ 0,38Correction term, thickness $\Delta_2 C_{L,max}$ 0,00Correction term, Reynolds' number $\Delta_3 C_{L,max}$ 0,018Maximum lift coefficient, airfoil $C_{L,max,clean}$ 1,760Lift coefficient ratio $C_{L,max}/C_{L,max}$ 0,77Correction term, Mach number $\Delta C_{L,max}$ -0,01	Mach number, cruise	M _{CR}	0,85
Leading edge sweep $ \begin{array}{ccccccccccccccccccccccccccccccccccc$	Calculations maximum clean lift coefficient		
Reynoldsnumber Re $5,2E+07$ Maximum lift coefficient, base $c_{L,max,base}$ $1,36$ Correction term, camber $\Delta_1c_{L,max}$ $0,38$ Correction term, thickness $\Delta_2c_{L,max}$ $0,00$ Correction term, Reynolds' number $\Delta_3c_{L,max}$ $0,018$ Maximum lift coefficient, airfoil $c_{L,max,clean}$ $1,760$ Lift coefficient ratio $c_{L,max}$ $0,77$ Correction term, Mach number $c_{L,max}$ $0,77$	Leading edge sharpness parameter	Δy	
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	Leading edge sweep	ϕ_{LE}	41,7 °
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	Reynoldsnumber	Re	5,2E+07
$\begin{array}{lllll} \text{Correction term, thickness} & \Delta_2 c_{L,max} & 0,00 \\ \text{Correction term, Reynolds' number} & \Delta_3 c_{L,max} & 0,018 \\ \text{Maximum lift coefficient, airfoil} & c_{L,max,clean} & 1,760 \\ \text{Lift coefficient ratio} & C_{L,max}/c_{L,max} & 0,77 \\ \text{Correction term, Mach number} & \Delta C_{L,max} & -0,01 \\ \end{array}$	Maximum lift coefficient, base	C _{L,max,base}	1,36
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	Correction term, camber	$\Delta_1 c_{L,max}$	0,38
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Lift coefficient ratio $C_{L,max}/c_{L,max}$ 0,77 Correction term, Mach number $\Delta C_{L,max}$ -0,01	Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,018
Correction term, Mach number $\Delta C_{L,max}$ -0,01	Maximum lift coefficient, airfoil	C _{L,max,clean}	1,760
Correction term, Mach number $\Delta C_{L,max}$ -0,01	Lift coefficient ratio	C _{L,max} /c _{L,max}	0,77
	Correction term, Mach number		-0,01
	Lift coefficient, wing		1,34

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{o}}}$	0,80
Flap group A	*	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,31
Use flapped span	b_W,fA	41,2 m
Percentage of flaps allong the wing	_ ,	51%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,53
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,68
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,53
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	ΦH.L.	42 °
Slat group A		
0,1c Kruger flap	$\Delta c_{L.max.sA}$	0,61
Use slatted span	b_W,sA	8,7 m
Percentage of slats allong the wing	_ /	11%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,05
Slat group B	_,,	
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,83
Use slatted span	b_W,sB	32,8 m
Percentage of slats allong the wing		40%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,25
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,30
Wing		
Verification value maximum lift coefficient, landing	C .	2,14
RE value maximum lift coefficient, landing	$C_{L,max,L}$	2,14
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,14 2,07
RE value maximum lift coefficient, take-off	OL,max,TO	2,07
Q 0%		2,01
7		
Aerodynamic effic	iency	
		0.00
Real aircraft average	k _{WL}	2,83
End plate	$k_{e,WL}$	1,04
Span	b_W	64,44 m
Winglet height	h	_1,6 m
Aspect ratio	A	7,67
Effective aspect ratio	A_{eff}	7,95
Efficiency factor, short range	k _E	17,25
Relative wetted area	S _{wel} /S _W	6,30
Verification value maximum aerodynamic efficiency	E _{max}	19,4
RE value maximum aerodynamic efficiency	- max	16,42

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,850	
Cruise altitude	h_{CR}	10668 m	
By Pass Ratio	μ	4,90	
Take-off Thrust (one engine)	T _{TO,one engine}	252,00 kN	
Overall Pressure ratio	OAPR	30,20	
Turbine entry temperature	TET	1488,25	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η_{inlet}	0,95	
Ventilator efficiency	$\eta_{ m ventilator}$	0,88	
Compressor efficiency	$\eta_{compresor}$	0,86	
Turbine efficiency	η _{turbine}	0,90	
Nozzle efficiency	η_{nozzle}	0,99	
Temperature at SL	T_o	288,15 K	
Temperature lapse rate in troposhpere	L	0,0065 K/m	
Temperature (ISA) at tropopause	T_S	216,65 K	
Temperature at cruise altitude	T(H)	218,81 K	
Dimensionless turbine entry temperature	ф	6,80	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,14	
Temperature function	χ	1,89	
Gas generator efficiency	η_{gasgen}	0,98	
Gas generator function	G	2,21	
Verification value specific fuel consumption	SFC	0,60 kg/daN/h	
Verification value specific fuel consumption	SFC	1,68E-05 kg/N/s	
RE value specific fuel consumption	SFC	1,46E-05 kg/N/s	
15%			

Matching Chart



Appendix AK Boeing 737-500

Data Collection	tion		737-500	-	2	3	4	5	9	7	8	6
Parameter	Sympo	Units	Chosen value	Source: Aircraft characteristics for airport planning	Jane's Rasic I R	Jenkinson	Engine	Scholz	Paul Müller	Paul Müller Elodie Roux Data collectior	Data collectior	Webs
PAX	0	3	149	108-122-149	08-138	108-130			132	132 149-108		123-132
Landing field length	SLFL	ε	1362	1400	1356	1362			1356	1362	1400	
Approach speed	V _{APP}	s/m	99		65,85	66,8777778			65,8333		65,848889	
Temperature above ISA (288,15K)	ΔT _L	¥	0	0		0						
Relative density	ø											
Take-off field length	STOFL	Ε	1832	2500	2633	1832				1832	1500	2470
Temperature above ISA (288,15K)	ΔΤτο	¥	0	0	15	0						
Relative density	ø											
Range (max payload)	œ	퇃	2518,72	3333,6	4481	2518,72			4481	096		4445
Cruise Mach number	McR		0,745		0,745	0,82	8,0				0,745	0,74
			2		7 107	20			7 10 1			
wing area	MO .	Ł	91,04	000	103,4	91,04			100,4			0
Wing span	ν Q	ε	28,88	28,88	28,88	28,9			28,88	.``	28,8	58,9
Aspect ratio	∢		9 L'6		δ,	9,1740993			ρ,	9,10		
Maximum take-off mass	Мито	ğ	60555	60555-61689	52390 60555	5 52390			52390	52390	52390	60550
Payload mass	ШЬГ	kg	15182	15182		15530				15182		
Mass ratio, payload - take-off	MPL/MMT0					0,29643062				0,29		
Maximum landing mass	JWI	kg	49895	49895	49895	49900			49895	49896		20000
Mass ratio, landing - take-off	пми/пмто	\neg				0,952						
Operating empty mass	Moe	kg	31312	31311	31660 32223					31312		31300
Mass ratio, operating empty - take-off moemmro	f moe/mmto		1							0,598		
Wing loading	mwro/Sw	kg/m²	5/5	00007070707		5/5,4				5/5		
Maximum zero luel mass	MMZF	Đ	40490	40493-40120	40495 40770	46490				40430		
Number of engines	ä		6			0				0	2	2
Engine type	CFM56-3		CFM56-3B1	CFM56-3B1	CFM56-3C-1	CFM56-3-B1R CFM56-3B1	CFM56-3B1			CFM56-3B1 CFM56-3B1	CFM56-3B1	CFM 56-3B-1
Take-off thrust for one engine	Tro, one engine	- X	88,964	88,90410452	82,29-88,97	82,3	88,96444			88,964	89	88
Total take-off thrust	Tro	Ā										
Thrust to weight ratio	Tro/(m _{MTo} *g)	(a)	0,35			0,32026717				0,35		
Bypass ratio	_		9				9			9		
Specific Fuel Comsumption (dry)	SFC (dry)	kg/N s	1,08E-05				1,0754E-05			1,08E-05		
Specific Fuel Comsumption (cruise)	SFC (cruise kg/N s	se kg/N s	1,89E-05				1,8876E-05			1,89E-05		
Available fuel volume	Vfuel, available	°E	20,102	23,168-23,827	20,104-23,83	20,105-23,17				20,102		23,8
Cruise speed	V _{CR}	s/m	221			220,7-253,11					221,21111	216,666667
Cruise altitude	hcR	ε	10668		10440	10668-7924,8	10668			10668		
Sween angle	į.		25			25				25		25
Mean aerodynamic chord	Q110	Ε	3.73			3 73				3 73		3
Position of maximum camber	X(v c) max	%c								2		
Camber	(Vc)max/C	%c										
Position of maximum thickness	X _{t,max}	%с										
Relative thickness	t/c	%	12,9			12,89				12,9		
Taper	~		0,24			0,24				0,24		
Overall pressure ratio	OAPR		22,6				22,6					
Turbine entry temperature	드	¥										

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1362	m		
Approach speed	Known	V_{APP}	66,00	m/s	66,0	66,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s_{TOFL}	1832	m	1832	1832
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	1360	NM		
Cruise Mach number		M _{CR}	0,745			
Wing area		S_W	91	m²		
Wing span	Known	b_W	28,88	m²	28,88	28,88
Aspect ratio		Α	9,16			
Maximum take-off mass		m _{MTO}	60555	kg		
Maximum payload mass		m_PL	15182	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,251			
Maximum landing mass		m_{ML}	49895	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,824			
Operating empty mass		m_OE	31312	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,517			
Wing loading		m_{MTO}/S_W	665,1	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	88,964	kN		
Total take-off thrust		T _{TO}	177,928	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,300			
Bypass ratio		μ	6			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to	optimize	V/V_{md}
------	----	----------	------------

				LL	UL
Cruise speed		V_{CR}	221 m/s		
Cruise altitude		h _{CR}	10668 m		
Speed ratio		V/V_{md}	1,078 -	1	1,316
	Data to execu	te the verification			
				Rar	ige
Sweep angle		ϕ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	3,73 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	12,0 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering	j & o	ptimization	of	V/Vmd
---------------------	-------	-------------	----	-------

	oree engineering	,	, , , , , ,		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S_{LFL}	1362	1362	m	0,00%
Approach speed	V_{APP}	66,00	66,0	m/s	0,00%
Take-off field length	s _{TOFL}	1832	1832	m	0,00%
Span	b_W	28,88	28,88	m	0,00%
Aspect ratio	Α	9,16	9,16		0,00%
Cruise speed	V_{CR}	221,0	221	m/s	-0,02%
Cruise altitude	h_{CR}	10668	10668	m	0,00 <mark>%</mark>
Squared Sum					4,19E-08
Absolute maximum deviation					0,0%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,76			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,84		Reve	rse Engineering
Maximum aerodynamic efficiency	E _{max}	15,11		Keve	ise Engineening
Specific fuel consumption	SFC	1,84E-05 kg	/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

Li	anding	
Landing field length	S _{LFL}	1362 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	$1,70 (m/s^2)^{0.5}$
Approach speed	V_{APP}	66,00 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,82
Wing loading at maximum take-off mass	m_{MTO}/S_W	665,1 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,76
Ti	ake-off	
Take-off field length	S _{TOFL}	1832 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,300
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,84
2nd	Segment	
Aspect ratio	A	9,161
Lift coefficient, take-off	$C_{L,TO}$	1,97
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_D,flap$	0,043
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C _{D,P}	0,063
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	7,69
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,308
Missa	d approach	
Lift coefficient, landing	C _{L,L}	2,23
Lift-independent drag coefficient, clean	C _{D.0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,056
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	$C_{D,P}$	0,091
Glide ratio in landing configuration	EL	6,60
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,284
set to meight radio	· IO·(···MIO 9/	0,20

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M_{CR}	0,745	
Aspect ratio	Α	9,16	
Bypass ratio	μ	6,00	
Wing loading	m_{MTO}/S_W	665 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,300	
	Variables		
	V/V _{md}	1,1	
C	alculations		
Zero-lift drag coefficient	C _{D,0}	0,027	
Lift coefficient at E _{max}	$C_{L,md}$	0,81	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,860	
Lift coefficient, cruise	C_L	0,696	
Actual aerodynamic efficiency, cruise	E	14,94	
Max. glide ratio, cruise	E _{max}	15,11	
Newton-Raphson for the maximum lift-to-o	drag ratio		
Iterations	1	2	3
f(x)	-0,11	0,00	0,00
f'(x)	-0,13	-0,13	-0,13
E _{max}	16	15,13	15,11

3) Specific Fuel Consumption

Constant par	rameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Specifica	tions		
Range	R	1360	NM
Mach number, cruise	M _{CR}	0,745	
Bypass ratio	μ	6,00	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,300	
Available fuel volume	$V_{fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	60555	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,251	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,517	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	14,94	
Cruise altitude	h _{CR}	10668	
Cruise speed	V _{CR}	221	m/s
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start		0,990	
Fuel-Fraction, taxi	M _{ff,engine}	0,990	
•	M _{ff,taxi}	-	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	$M_{ff,DES}$	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
Calculat	ions		
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,232	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,768	
Available fuel mass	^M F.available	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,315	
Mission fuel fraction (acc. to fuel capacity)	\mathbb{M}_{ff}	0,699	
Distance to alternate	•	200	NM
Distance to alternate	S _{to_alternate}	370400	
Choose: FAR Part121-Reserves	s _{to_alternate} domestic		
Choose: FAR Pail 12 1-Reserves	international	yes no	
Extra-fuel for long range	international	5%	
Evtra flight distance	e	370400	m
Extra flight distance Loiter time	S _{res}	2700	
Loiter unite	t _{loiter}	2100	5
Specific fuel consumption	SFC	1,84E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

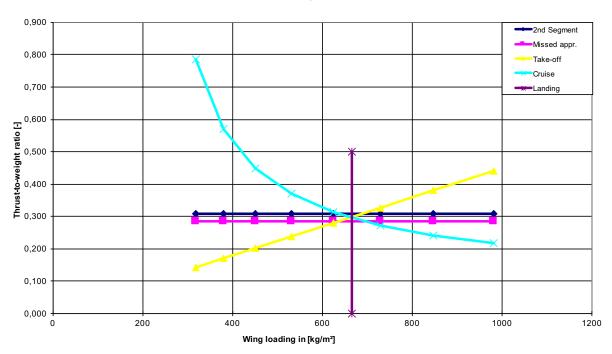
General wing specifications	Airfoil type:	NACA 66 serie
Wing span	b_W	28,88 m
Structural wing span	$b_{W,struct}$	31,87 m
Wing area	S_W	91,0 m ²
Aspect ratio	Α	9,16
Sweep	φ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	3,73 m
Position of maximum camber	$\mathbf{x}_{(y_c),max}$	30 %c
Camber	$(y_c)_{max}/c$	4 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	30 %c
Relative thickness	t/c	12,0 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	66,00 m/s
Mach number, landing	M_{APP}	0,20
Mach number, cruise	M _{CR}	0,745
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,2 %c
Leading edge sweep	ϕ_{LE}	28,8 °
Reynoldsnumber	Re	1,8E+07
Maximum lift coefficient, base	C _{L,max,base}	1,30
Correction term, camber	$\Delta_1 c_{L,max}$	0,40
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,020
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,718
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,85
Correction term, Mach number	ΔC _{L,max}	0,00
Lift coefficient, wing	C _{L,max}	1,46

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathrm{\phi}}}$	0,87
Flap group A	*	
0,4c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	2,04
Use flapped span	b_W,fA	20,8 m
Percentage of flaps allong the wing	<u> </u>	65%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	1,16
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,75
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	1,16
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	ΨH.L.	28 °
Slat group A	******	
0,3c Nose flap	$\Delta c_{L.max.sA}$	0,91
Use slatted span	b_W,sA	19,1 m
Percentage of slats allong the wing	_ /*	60%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,48
Slat group B	_,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,91
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing		0%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,00
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,48
Wing Verification value maximum lift coefficient, landing RE value maximum lift coefficient, landing Verification value maximum lift coefficient, take-off RE value maximum lift coefficient, take-off	$C_{L,max,L}$ $C_{L,max,TO}$	3,04 3,76 2,30 2,84
A a wa ak wa a wai a a sti	-1	
Aerodynamic effi	ciency	
Real aircraft average	k_{WL}	2,83
No winglets	k _{e,WL}	1,00
Span	b _W	28,88 m
Winglet height	h	2,7 m
Aspect ratio	A	9,16
Effective aspect ratio	A _{eff}	9,16
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{wet}/S_W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	18,2
RE value maximum aerodynamic efficiency		15,11
20%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,745
Cruise altitude	h _{CR}	10668 m
By Pass Ratio	μ	6,00
Take-off Thrust (one engine)	T _{TO,one engine}	88,96 kN
Overall Pressure ratio	OAPR	22,60
Turbine entry temperature	TET	1430,08
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,94
Ventilator efficiency	$\eta_{ m ventilator}$	0,86
Compressor efficiency	$\eta_{compresor}$	0,86
Turbine efficiency	$\eta_{ ext{turbine}}$	0,90
Nozzle efficiency	η_{nozzle}	0,98
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	218,81 K
Dimensionless turbine entry temperature	ф	6,54
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,11
Temperature function	χ	1,60
Gas generator efficiency	$\eta_{ m gasgen}$	0,98
Gas generator function	G	2,11
Verification value specific fuel consumption	SFC	0,60 kg/daN/h
Verification value specific fuel consumption	SFC	1,65E-05 kg/N/s
r r r r r r r r r r r r r r r r r r r		,
RE value specific fuel consumption	SFC	1,84E-05 kg/N/s
10%		

Matching Chart



Appendix AL Boeing 777F

Parameter PAX			L///		-	2	3	4	2	9	7	8	6
		24:21		Source: Aircra	Aircraft characteristics	Jane's	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Elodie Roux Data collection	Webs
PAX	Symbol	Onits	Chosen value	tor an	tor airport planning								
Landing field length	SLFL	Ε	1750		1750							1700	
Approach speed	V _{APP}	m/s	72									72,0222222	
Temperature above ISA (288,15K)	ΔT _L	¥	0		0								
Relative density	S												
Take-off field length	Stori	8	3000		3130							2970	2990
Temperature above ISA (288.15K)	ΛĪτο	×	0										
Relative density	s												
Range (max payload)	œ	km	9020		9050	9195							9070
Cruise Mach number	McR		0,84		0,84						0,84	0,84	0,84
Wing area	Sw	m²											
Wing span	bw	E	64,8		64,8						64,8	6'09	64,8
Aspect ratio	∢												
Maximum tolo off mono	8	5	347845		247915	347450					2/7815	347450	247800
Maximum take-on mass	OLIMITO	Ð .	247012		400707	347450					210745	001	000110
Mass ratio powload take off	E E	Đ	103737		103/3/	103073							
Maximum landing mass	O MINIO	27	260816		260818						260816		260818
Mass ratio landing - take-off	The state of	2	2007		2007						21007		2007
Operating empty mass	Moe	2	144379		144379								144400
Mass ratio, operating empty - take-off moemmro	ff moe/mmto	,											
Wing loading		kg/m²											
Maximum zero fuel mass		kg	248115		248115						248115		
Number of engines	ЛE		2								2		2
Engine type	GE90		GE90-110B1L	ŰĚ	-	GE90-110B1L		GE90-110B1			GE90-110B1	GE 90-11	
Take-off thrust for one engine	TTO, one engine KN	Z	489		488,971			489,30442			489,302	489	514
Total take-off thrust	T ₁₀	Ž,									0		
Inrust to weight ratio	TO/(MMTO"g)		67,0								0,29		(
Bypass ratio	1 0	La.M.	מ								7',		מ
Specific Fuel Comsumption (dry)		kg/N s		-									
specific ruel comsumption (cruise)	or c (cruise kg/in s	S N/S											
Available fuel volume	Vfuel, available	m ₃	181,283		181,283						181,283		181,283
Cruise speed	VGR	m/s	252									252.077778	251.39
Cruise altitude	hcr	ε	10668								10668		
Sweep angle	\$ 25		31,64										31,64
Mean aerodynamic chord	QMAC	Ε											
Position of maximum camber	X _{(y_c),max}	%c	90										30
Camber	(yc)max/c	%c	5,9										5,9
Position of maximum thickness	X _{t,max}	%c	30	-									30
Relative thickness	t/c	%	22										22
laper Otoroll properties refin	۷ C		- 27										72
Overall pressure ratio	OAPR		4.5	-	1								4.5
Turbine entry temperature	E	<u>~</u>		-	1								

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1750	m		
Approach speed	Known	V_{APP}	72,00	m/s	72,0	72,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s _{TOFL}	3000	m	3000	3000
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	4887	NM		
Cruise Mach number		M _{CR}	0,84			
Wing area		S_W	428	m²		
Wing span	Known	b_W	64,8	m²	64,8	64,8
Aspect ratio		Α	9,82			
Maximum take-off mass		m _{MTO}	347815	kg		
Maximum payload mass		m_{PL}	103737	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,298			
Maximum landing mass		m_ML	260816	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,750			
Operating empty mass		m_OE	144379	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,415			
Wing loading		m_{MTO}/S_W	813,0	kg/m²		
Number of engines		n _E	2	!		
Take-off thrust for one engine		T _{TO,one engine}	489	kN		
Total take-off thrust		T _{TO}	978	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,287			
Bypass ratio		μ	9			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to	optimize	V/V_{md}
------	----	----------	------------

					LL	UL
Cruise speed		V_{CR}	252	m/s		
Cruise altitude		h _{CR}	10668	m		
Speed ratio		V/V_{md}	1,037	-	1	1,316
	Data to execu	te the verification				
					Rar	ige
Sweep angle		ϕ_{25}	31,64	۰		
Mean aerodynamic chord		C _{MAC}	4,2	m		
Position of maximum camber		$\mathbf{x}_{(y_c),max}$	30	%с	15 - 50	%с
Camber		(y _c) _{max} /c	4	%с	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	10,8	%		
Taper		λ	0,24			

Reverse Engineering

Maximum aerodynamic efficiency

Specific fuel consumption

Reverse	engineering	& o	ptimization	of V/Vr	nd
---------	-------------	-----	-------------	---------	----

IVEA	erse engineering	g & optimization of	V/ VIIIU		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1750	1750	m	0,00%
Approach speed	V_{APP}	72,00	72,0	m/s	0,00%
Take-off field length	s _{TOFL}	3000	3000	m	0,00%
Span	b_W	64,8	64,8	m	0,00%
Aspect ratio	Α	9,82	9,82		0,00%
Cruise speed	V_{CR}	252,0	249	m/s	-1,11%
Cruise altitude	h_{CR}	10668	10649	m	-0,17 <mark>%</mark>
Squared Sum					1,27E-04
Absolute maximum deviation					1,1%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,26			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,21		Povo	rse Engineering
Maximum aerodynamic efficiency	F	18 30		Reve	ise Engineering

 $\mathsf{E}_{\mathsf{max}}$

SFC

18,30

1,19E-05 kg/N/s

1) Maximum Lift Coefficient for Landing and Take-off

Lai	nding	
Landing field length	S _{LFL}	1750 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	1,70 (m/s²) ^{0.5}
Approach speed	V_{APP}	72,00 m/s
Factor, landing	k_L	0,107 kg/m³
Mass ratio, landing - take-off	${\sf m_{ML}/m_{TO}}$	0,75
Wing loading at maximum take-off mass	m_{MTO}/S_W	813,0 kg/m ²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,26
Tal	ke-off	
Take-off field length	S _{TOFL}	3000 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,287
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,21
2nd S	Segment	
Aspect ratio	A	9,815
Lift coefficient, take-off	$C_{L,TO}$	1,54
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,022
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C _{D,P}	0,042
Oswald efficiency factor; landing configuration	e	0,7
Glide ratio in take-off configuration	E _{TO}	10,16
Number of engines	_	2
Number of engines Climb gradient	n _E	2 0,024
Thrust-to-weight ratio	sin(γ) T _{TO} /(m _{MTO} *g)	0,024
Till ust-to-weight ratio	то/(IIIMTO 9)	0,243
	approach	4.00
Lift coefficient, landing	C _{L,L}	1,93
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,041
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
Lift-independent drag coefficient, landing gear	FAR Part 25	yes 0,015
Profile drag coefficient	$\Delta C_{D,gear}$	
_	C _{D,P}	0,076
Glide ratio in landing configuration	ĘĹ	7,76
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}*g)$	0,225
	10 (W10 0/	

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sn	ecifications		
Mach number, cruise	M _{CR}	0,84	
Aspect ratio	A	9,82	
Bypass ratio	μ	9,00	
Wing loading	m _{MTO} /S _W	813 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,287	
	Variables		
	V/V _{md}	1,0	
	V/ V md	1,0	
c	alculations		
Zero-lift drag coefficient	$C_{D,0}$	0,020	
Lift coefficient at E _{max}	$C_{L,md}$	0,72	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,930	
Lift coefficient, cruise	C_L	0,666	
Actual aerodynamic efficiency, cruise	E	18,25	
Max. glide ratio, cruise	E _{max}	18,30	
Newton-Raphson for the maximum lift-to-	drag ratio		
Iterations	1	2	3
f(x)	0,24	-0,01	0,00
f(x)	-0,10	-0,11	-0,11
E _{max}	16	18,40	18,30

3) Specific Fuel Consumption

Constant par	ameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{ m fuel}$	800	kg/m³
Specificat	ions		
Range	R	4887	NM
Mach number, cruise	M _{CR}	0,84	
Bypass ratio	μ	9,00	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,287	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m _{MTO}	347815	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,298	
Mass ratio, operating empty - take-off	$m_{OE/}m_{MTO}$	0,415	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	18,25	
Cruise altitude	h _{CR}	10649	
Cruise speed	V _{CR}	249	m/s
Mission fuel			
Type of aeroplane (according to Roskam)	Transport jet	0.000	
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{\rm ff,CLB}$	0,980	
Fuel-Fraction, descent	$M_{\rm ff,DES}$	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
Calculati	ons		
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,287	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,713	
Available fuel mass	m _{F,available}	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,055	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,964	
Distance to alternate	S _{to_alternate}		NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	no	
E 4 - 6 - 16 - 1	international	yes	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	822936	
Loiter time	t _{loiter}	1800	s
Specific fuel consumption	SFC	1,19E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

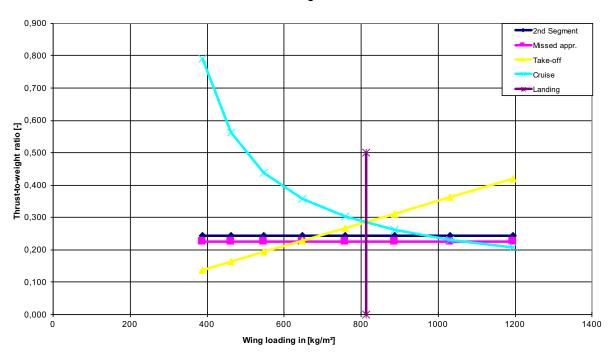
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b _W	64,8 m
Structural wing span	b _{W,struct}	76,11 m
Wing area	S _W	427,8 m ²
Aspect ratio	A	9,82
Sweep	φ_{25}	31,64 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	X _{(v c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	X _{t.max}	30 %c
Relative thickness	t/c	10,8 %
Taper	λ	0,24
Consent shows the second state of		
General aircraft specifications Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1 T
Temperature, landing	o T∟	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a _{APP}	331 m/s
Approach speed	V _{APP}	72,00 m/s
Mach number, landing	M _{APP}	0,22
Mach number, cruise	M _{CR}	0,84
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δγ	2.0 %c
Leading edge sweep	ΨLE	35,2 °
Reynoldsnumber	Re	2,2E+07
Maximum lift coefficient, base	$C_{L,max,base}$	1,19
Correction term, camber	$\Delta_1 c_{L,max}$	0,39
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,059
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,636
Lift coefficient ratio	$C_{L,max}/c_{L,max}$	0,90
Correction term, Mach number	$\Delta C_{L,max}$	-0,01
Lift coefficient, wing	$C_{L,max}$	1,46

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{\phi}}}$	0,83
Flap group A	·	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,43
Use flapped span	b_W,fA	11,4 m
Percentage of flaps allong the wing		15%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,18
Flap group B		4.40
Double-slotted flap	Δc _{L,max,fB}	1,43
Use flapped span Percentage of flaps allong the wing	b_W,fB	26,7 m 35%
Increase in maximum lift coefficient, flap group B	\DeltaC_L,max,fB	0,42
Increase in maximum lift coefficient, flap	ΔC _{L,max,f}	0,60
morease in maximum in coemicient, nap	Δ Q ,max,f	0,00
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	$\phi_{H.L.}$	34 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,91
Use slatted span	b_W,sA	12,5 m
Percentage of slats allong the wing		16%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,12
Slat group B		0.04
0,3c Nose flap	Δc _{L,max,SB}	0,91
Use slatted span Percentage of slats allong the wing	b_W,sB	43,6 m 57%
Increase in maximum lift coefficient, slat group B	\DeltaC_L,max,sB	0.43
Increase in maximum lift coefficient, slat		0,55
morease in maximum int coemicient, stat	\DeltaC_L,max,s	0,55
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,58
RE value maximum lift coefficient, landing	$C_{L,max,TO}$	3,26
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,75
RE value maximum lift coefficient, take-off		2,21
-21%		
Aerodynamic e	fficiency	
Real aircraft average	k_{WL}	2,83
No winglets	k _{e,WL}	1,00
Span	b _W	64,8 m
Winglet height	h	2,7 m
Aspect ratio	A	9,82
Effective aspect ratio	$A_{\rm eff}$	9,82
Efficiency factor, short range	k _E	16,19
Relative wetted area	S _{wet} /S _W	6,35
	-wet -vv	-,00
Verification value maximum aerodynamic efficiency	E _{max}	20,1
RE value maximum aerodynamic efficiency		18,30
10%		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,840
Cruise altitude	h_{CR}	10668 m
By Pass Ratio	μ	9,00
Take-off Thrust (one engine)	T _{TO,one engine}	489,00 kN
Overall Pressure ratio	OAPR	42,00
Turbine entry temperature	TET	1503,64
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,93
Ventilator efficiency	$\eta_{ventilator}$	0,90
Compressor efficiency	$\eta_{compresor}$	0,88
Turbine efficiency	η_{turbine}	0,91
Nozzle efficiency	η_{nozzle}	1,00
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T _S	216,65 K
Temperature at cruise altitude	T(H)	218,81 K
Dimensionless turbine entry temperature	ф	6,87
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,14
Temperature function	χ	2,18
Gas generator efficiency	$\eta_{ m gasgen}$	0,97
Gas generator function	G	2,16
Verification value specific fuel consumption	SFC	0,53 kg/daN/h
Verification value specific fuel consumption	SFC	1,47E-05 kg/N/s
		,
RE value specific fuel consumption	SFC	1,19E-05 kg/N/s
24%		

Matching Chart



Appendix AM Embraer 195

Parameter Symbol Units PAX Landing field length s.e.r. m Approach speed V _{APP} m/s Temperature above ISA (288,15K) ΔT _L K Relative density s m Take-off field length sror. m Take-off field length sror. K Relative density s m Relative density s m Range (max payload) R km Wing area bw m Wing area bw m Maximum take-off mass mmr. kg Maximum take-off mass mmr. kg Maximum landing mass mm. kg Mass ratio, landing - take-off mm. kg Mass ratio, landing - take-off mme. kg Mass ratio, landing - take-off mm. kg Ming loading mm. kg/m² Maximum zero fuel mass mx. kg/m²	Chos	Source					c	4	,	>		,	
				ŀ	Jane's		Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Paul Müller Elodie Roux Data collection	Webs
		n value	for airport planning	Standard Lo	Long-Range	IGW							
	-	118	118	`	108-118						110-106		
		1435	1280		1435						1435	1412	
		0	0										
	22	2251	2130		2251						2251	1490	
		0	0										
	11	1445	2778			3889					1445		2593
	0	0,78	0,78		0,82						0,78	0,82	0,82
	8	2	200		02 62						400		
	92	32,33	25,26		92,33						5,28 77 80		28 72
	8, 8,	8,92	8,1		7,07						8,92	co co	20,12
	70	2000	62200	00287	60700	2000					49700	64500	60700
	13.02	13530	13900	200	12720	00770					13530		8
	<u> </u>	200	200		02121						0.277		
	450	45000	45800	45000		45800					45000		
	286	28970	28700	28970		29070					28970		28970
o fuel mass m _{MZF}											0,594		
MMZF		527,3		527,3	548,9	565,1					527		
	42	200	42600	42500		42600					42500		
ngines		2									2		2
	CF34	CF34-10E5	GEAE CF34-10	GEAE CF34-10 CF34-10E, -10E6, -10E6A1, -10E5, -10E5A1	-10E6A1, -10E	5, -10E5A1					CF34-10E5	PW1900G	
ist for one engine	82,	82,292	82,3	-	6,88						82,292	82,292 85-102	82,3
ght ratio	, o	0,34		0,37241174 0	0,35803795	0,34707761					0,34		
Bypass ratio Provide Eucl Communica (day) SEC (day) La(N)		5 1 08E 05									1 ORF OF		
e) SFC (cruise kg/N		3									20.		
Available fuel volume V _{tuel, available} m³	16,	16,029	16,029		16,153						16,029		
Cruise speed	57	47											247.22
0	100	10668	10668										
Sweep angle													
namic chord	,e	3,68			3,68								
ber X _{(y_c),max}	44	1,2											44,2
(yc)max/c	2	2,7											2,7
ım thickness x _{t,max}	m ;	2											36
Relative thickness t/c %	-	11,8											11,8
per A A A A A A A A A A A A A A A A A A A													
Turbine entry temperature													

Aeroplane Specifications

Data to apply reverse engineering UL LL **1435** m Landing field length Known S_{LFL} 72.00 m/s Approach speed **Unknown** V_{APP} 64,5 64,5 ΔT_{L} Temperature above ISA (288,15K) 0 K Relative density 1 σ Take-off field length Known **2251** m 2251 2251 STOFL Temperature above ISA (288,15K) 0 K ΔT_{TO} Relative density 1,000 780 NM Range (maximum payload) R Cruise Mach number M_{CR} 0,78 Wing area S_W 93 m² Wing span Known 28,72 m² 28,72 28,72 b_W Aspect ratio Α 8,91 Maximum take-off mass **52290** kg m_{MTO} Maximum payload mass ${\rm m}_{\rm PL}$ 13530 kg Mass ratio, payload - take-off 0,259 m_{PL}/m_{MTO} Maximum landing mass 45000 kg m_{ML} Mass ratio, landing - take-off m_{ML}/m_{MTO} 0,861 **28970** kg Operating empty mass m_{OE} Mass ratio, operating empty - take-off 0,554 m_{OE}/m_{MTO} Wing loading m_{MTO}/S_W 565,1 kg/m² Number of engines 2 n_E Take-off thrust for one engine T_{TO,one engine} 82,292 kN Total take-off thrust 164,584 kN T_{TO} Thrust to weight ratio 0,321 $T_{TO}/(m_{MTO}*g)$ Bypass ratio 5 Available fuel volume 23,86 m³

fuel,available

Data	to	optin	nize	V/V_{md}
------	----	-------	------	------------

				LL	UL
Cruise speed		V_{CR}	247 m/s		
Cruise altitude		h _{CR}	10668 m		
Speed ratio		V/V_{md}	1,246 -	1	1,316
	Data to execu	ite the verification			
				Ran	ge
Sweep angle		Ψ25	25 °		
Mean aerodynamic chord		C _{MAC}	3,68 m		
Position of maximum camber		$\mathbf{x}_{(y_c),max}$	44,2 %c	15 - 50	%с
Camber		(y _c) _{max} /c	2,7 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	35 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,6 %		
Taper		λ	0,24		

Reverse Engineering

	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	1435	1435	m	0,00%
Approach speed	V_{APP}	Unknown	64,5	m/s	0,00%
Take-off field length	s _{TOFL}	2251	2251	m	0,00%
Span	b_W	28,72	28,72	m	0,00%
Aspect ratio	Α	8,91	8,91		0,00%
Cruise speed	V_{CR}	247,0	232	m/s	-6,21%
Cruise altitude	h_{CR}	10668	10570	m	-0,92 <mark>%</mark>
Squared Sum Absolute maximum deviation					3,94E-03 6,2%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,17			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,83		Rever	rse Engineering
Maximum aerodynamic efficiency	E _{max}	14,41		Kevei	36 Lingineering
Specific fuel consumption	SFC	1,70E-05 kg	J/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

La	anding	
Landing field length	S _{LFL}	1435 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k _{APP}	1,70 (m/s²) ^{0.5}
Approach speed	V_{APP}	64,47 m/s
Factor, landing	\mathbf{k}_{L}	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,86
Wing loading at maximum take-off mass	m_{MTO}/S_W	565,1 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,17
Ta	ake-off	
Take-off field length	s _{TOFL}	2251 m
Temperatur above ISA (288,15K)	ΔT_TO	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m ³ /kg
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,321
Maximum lift coefficient, take-off	$C_{L,max,TO}$	1,83
2nd	Segment	
Aspect ratio	A	8,914
Lift coefficient, take-off	$C_{L,TO}$	1,27
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,009
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	$C_{D,P}$	0,029
Oswald efficiency factor; landing configuration	е	0,7
Glide ratio in take-off configuration	E _{TO}	11,45
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,223
Misse	d approach	
Lift coefficient, landing	C _{L,L}	1,87
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_D,flap$	0,039
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	$C_{D,P}$	0,074
Glide ratio in landing configuration	EL	7,41
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,268
-		-

2) Maximum Aerodynamic Efficiency

Const	ant parameters				
Ratio of specific heats, air	γ	1,4			
Earth acceleration	g	9,81 m/s ²			
Air pressure, ISA, standard	p_0	101325 Pa			
Oswald eff. factor, clean	е	0,85			
Sn	ecifications				
Mach number, cruise	M _{CR}	0,78			
Aspect ratio	A	8,91			
Bypass ratio	μ	5,00			
Wing loading	m _{MTO} /S _W	565 kg/m²			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,321			
	Variables				
	V/V _{md}	1,2			
С	alculations				
Zero-lift drag coefficient	C _{D,0}	0,029			
Lift coefficient at E _{max}	$C_{L,md}$	0,83			
Ratio, lift coefficient	C _L /C _{L,md}	0,644			
Lift coefficient, cruise	C_L	0,532			
Actual aerodynamic efficiency, cruise	E	13,12			
Max. glide ratio, cruise	E _{max}	14,41			
Newton-Raphson for the maximum lift-to-drag ratio					
Iterations	1	2	3		
f(x)	-0,22	-0,01	0,00		
f'(x)	-0,14	-0,13	-0,13		
E _{max}	16	14,46	14,41		

3) Specific Fuel Consumption

Constant par	rameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Specifica	tions		
Range	R	780	NM
Mach number, cruise	M _{CR}	0,78	
Bypass ratio	μ	5,00	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,321	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	52290	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,259	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,554	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	13,12	
Cruise altitude	h _{CR}	10570	
Cruise speed	V _{CR}	232	m/s
·			
Mission fuel			
Type of aeroplane (according to Roskam)	Transport jet	0.000	
Fuel-Fraction, engine start	M _{ff,engine}	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	$M_{ff,DES}$	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
Calculat	ions		
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,187	_
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,813	
Available fuel mass	TF.available	19088	ka
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,365	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,648	
Mission tast matter (acc. to fact capacity)	т	0,040	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,70E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

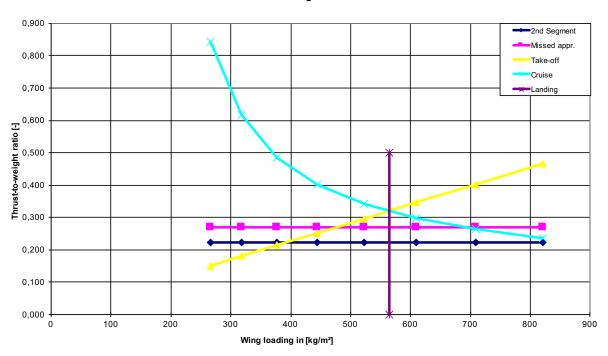
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b_W	28,72 m
Structural wing span	$b_{W,struct}$	31,69 m
Wing area	S_W	92,5 m ²
Aspect ratio	Α	8,91
Sweep	ϕ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	3,68 m
Position of maximum camber	$\mathbf{x}_{(\mathbf{y_c}),max}$	44,2 %c
Camber	(y _c) _{max} /c	2,7 %c
Position of maximum thickness	$\mathbf{x}_{t,max}$	35 %c
Relative thickness	t/c	11,6 %
Taper	λ	0,24
General aircraft specifications		
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T_L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a_{APP}	331 m/s
Approach speed	V_{APP}	64,47 m/s
Mach number, landing	M_APP	0,19
Mach number, cruise	M_{CR}	0,78
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δy	2,1 %c
Leading edge sweep	$\phi_{\sf LE}$	28,9 °
Reynoldsnumber	Re	1,7E+07
Maximum lift coefficient, base	$c_{L,max,base}$	1,26
Correction term, camber	$\Delta_1 c_{L,max}$	0,23
Correction term, thickness	$\Delta_2 c_{L,max}$	0,16
Correction term, Reynolds' number	Δ ₃ C _{L,max}	0,025
Maximum lift coefficient, airfoil	C _{L,max,clean}	1,679
Lift coefficient ratio	C _{L,max} /c _{L,max}	0,87
Correction term, Mach number	$\Delta C_{L,max}$	0,00
Lift coefficient, wing	C _{L,max}	1,46

Calculations increase of lift coefficient due to flaps		2 flap types
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathbf{o}}}$	0,87
Flap group A	•	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,43
Use flapped span	b_W,fA	8,5 m
Percentage of flaps allong the wing		27%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	0,33
Flap group B		
Double-slotted flap	$\Delta c_{L,max,fB}$	1,43
Use flapped span	b_W,fB	12,8 m
Percentage of flaps allong the wing		40%
Increase in maximum lift coefficient, flap group B	\DeltaC_L,max,fB	0,50
Increase in maximum lift coefficient, flap	$\Delta C_{L,max,f}$	0,83
Calculations increase of lift coefficient due to slats		2 slat types
Sweep angle of the hinge line	Φ _{H.L.}	26,5 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	4,8 m
Percentage of slats allong the wing		15%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,12
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	20,1 m
Percentage of slats allong the wing		63%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,51
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,63
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,88
RE value maximum lift coefficient, landing	_	3,17
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,67
RE value maximum lift coefficient, take-off		1,83
-9%		
Aerodynamic effici	ency	
Real aircraft average	k_{WL}	2,83
End plate	k _{e,WL}	1,09
Span	b _W	28,72 m
Winglet height	h	1,7 m
Aspect ratio	Α	8,91
Effective aspect ratio	A_{eff}	9,68
·		•
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{we}/S_W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	18,7
RE value maximum aerodynamic efficiency	∟ max	14,41
The value maximum aerodynamic eniciency		וד,דו

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,780	
Cruise altitude	h _{CR}	10668 m	
By Pass Ratio	μ	5,00	
Take-off Thrust (one engine)	T _{TO,one engine}	82,29 kN	
Overall Pressure ratio	OAPR	29,00	
Turbine entry temperature	TET	1422,79	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	n _{inlet}	0,95	
Ventilator efficiency	$\eta_{ventilator}$	0,85	
Compressor efficiency	$\eta_{compresor}$	0,85	
Turbine efficiency	n _{turbine}	0,89	
Nozzle efficiency	η_{nozzle}	0,98	
Temperature at SL	T_0	288,15 K	
Temperature lapse rate in troposhpere	L	0,0065 K/m	
Temperature (ISA) at tropopause	T_S	216,65 K	
Temperature at cruise altitude	T(H)	218,81 K	
Dimensionless turbine entry temperature	ф	6,50	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,12	
Temperature function	χ	1,81	
Gas generator efficiency	η_{gasgen}	0,98	
Gas generator function	G	1,98	
Verification value specific fuel consumption	SFC	0,62 kg/daN/h	
Verification value specific fuel consumption	SFC	1,72E-05 kg/N/s	
RE value specific fuel consumption 2%	SFC	1,70E-05 kg/N/s	

Matching Chart



Appendix AN Boeing 717-200

Parameter Symbol Units Chosen value Source I value PAX Total ise-off field length 8-n. m/s 69 106 Landing field length 9-n. m/s 69 106 106 Relative density 5-n. K 0 1524 1524 Relative density 5-n. Month 1450 1524 1524 Relative density 5-n. K 0 77 1661-16 1677 1661-16 Renge (max pea) can be by a specific density 8-n. 1375 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,666667 2160,66667 2160,666667 2160,66667 2160,6666	Aircraft characteristics for airport planning	Jane's Jenkinson	Engine	Scholz Paul Müller	er Elodie Roux		
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M							
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kg 54900 kg 14515 kg 49898 kg 49898 kg 31071 kg/m² 537 kg 82,292 ky 82,292 ky 4,7 kg/N s 1,05E-05 m/s 13,905 m/s 225,3 m/s 124,5 m/s 224,5 m 3,88 %c %c		8,675486716	9	. 00			
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Tro KN 0,34	93,34930975	6,76	9 82,292107		82,292		93,4
TrO(HIMTO 9)		0.305003050	0		200		
FC (dry) kg/N s 1,05E-05 SFC (cruise kg/N s 13,905 V _{teel proviliable} m³ 13,905 V _{CR} m/s 225,3 h _{CR} m 10424 ф ₂₅ ° 24,5 A _{(V-Olmax} %c %c (V _{clmax} %c %c		0,30390303	_		4.74		
SFC (cruise kg/N s 13,905 Verel available m² 13,905 VCR m/s 225,3 VCR m 10424 VCR m VCP MAC MC VCP MCP			1,0471E-05		1,05E-05		
V _{Lot lavarilable} m³ 13,905 V _{CR} m/s 225,3 h _{CR} m 10424 φ ₂₅ ° 24,5 Q _{Mod} C m 3,88 X _{(V, c) max} %c (γ _{c) max} %c							
V _{CR} m/s h _{CR} m ф ₂₅ ° Q _{AMC} m X _Q , o _{l,max} %c (V _c) _{max} %c	16,665	13,892-16,065	10		13,905		
hcR m ф25 ° омис Ху ₂ оµmax %cC (ус)лыж %cC		225,3266667	7			223,783333	225,277778
ф25 ° Само П Само (ус.)лах %С (ус.)лах %С (ус.)лах %С		10668	80		10424		10393,68
AMAC m X(y_c),max %c (y_c),max %c		24	22		24.5		
X _{(у_с),тах} %с (у _с _{ртах} /с %с		3,88	8		3,88		
(yc)hay/c							
um thickness x _{t,max} %c							
ve thickness t/c %		11,6	9 %		11,6		
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			02,1				

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	s_{LFL}	1450	m		
Approach speed	Known	V_{APP}	69,00	m/s	69,0	69,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	S _{TOFL}	1677	m	1677	1677
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	742	NM		
Cruise Mach number		M _{CR}	0,77			
Wing area		S _W	93	m²		
Wing span	Known	b _W	28,45	m²	28,45	28,45
Aspect ratio		Α	8,71			
Maximum take-off mass		m _{MTO}	54900	kg		
Maximum payload mass		m_{PL}	14515	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,264			
Maximum landing mass		m_{ML}	49898	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,909			
Operating empty mass		m_OE	31071	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,566			
Wing loading		m_{MTO}/S_W	590,5	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	82,292	kN		
Total take-off thrust		T _{TO}	164,584	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,306			
Bypass ratio		μ	4,7			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data t	o oi	otimiz	V/V _{md}
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				LL	UL
Cruise speed		V_{CR}	225 m/s		
Cruise altitude		h _{CR}	10424 m		
Speed ratio		V/V_{md}	1,205 -	1	1,316
	Data to execu	te the verification			
				Ran	ige
Sweep angle		φ_{25}	24,5 °		
Mean aerodynamic chord		C _{MAC}	3,88 m		
Position of maximum camber		X _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$\mathbf{x}_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	11,7 %		
Taper		λ	0,206		

Reverse Engineering

Maximum aerodynamic efficiency

Specific fuel consumption

Reverse engineering & optimization of

Rev	erse engineering	a optimization of	v/vma		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	s_{LFL}	1450	1450	m	0,00%
Approach speed	V_{APP}	69,00	69,0	m/s	0,00%
Take-off field length	s _{TOFL}	1677	1677	m	0,00%
Span	b_W	28,45	28,45	m	0,00%
Aspect ratio	Α	8,71	8,71		0,00%
Cruise speed	V_{CR}	225,3	229	m/s	1,69%
Cruise altitude	h_{CR}	10424	10450	m	0,24%
Squared Sum					2,92E-04
Absolute maximum deviation					1,7%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,46			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,70		Dayoroa Engineering	
Maximum aerodynamic efficiency	Emay	14.30		Reverse Engineering	

14,30 1,48E-05 kg/N/s

E_{max} SFC

1) Maximum Lift Coefficient for Landing and Take-off

Landing					
Landing field length	S _{LFL}	1450 m			
Temperature above ISA (288,15K)	ΔT_L	0 K			
Relative density	σ	1,000			
Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$			
Approach speed	V_{APP}	69,00 m/s			
Factor, landing	k_L	0,107 kg/m³			
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,91			
Wing loading at maximum take-off mass	m_{MTO}/S_W	590,5 kg/m ²			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,46			
Take	-off				
Take-off field length	S _{TOFL}	1677 m			
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K			
Relative density	σ	1,00			
Factor	k _{TO}	2,34 m³/kg			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,306			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,70			
Aspect ratio 2nd Seg	yment A	8,706			
Lift coefficient, take-off	C _{L,TO}	1,87			
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020			
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,039			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Profile drag coefficient	C _{D,P}	0,059			
Oswald efficiency factor; landing configuration	е	0,7			
Glide ratio in take-off configuration	E _{TO}	7,75			
Number of engines	n _E	2			
Climb gradient	$sin(\gamma)$	0,024			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,306			
Missed approach					
Lift coefficient, landing	$C_{L,L}$	2,05			
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020			
Lift-independent drag coefficient, flaps	$\DeltaC_D,flap$	0,047			
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000			
Choose: Certification basis	JAR-25 resp. CS-25	no			
	FAR Part 25	yes			
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015			
Profile drag coefficient	$C_{D,P}$	0,082			
Glide ratio in landing configuration	EL	6,80			
Climb gradient	sin(γ)	0,021			
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,306			
•		•			

2) Maximum Aerodynamic Efficiency

Constant parameters					
Ratio of specific heats, air	γ	1,4			
Earth acceleration	g	9,81 m/s ²			
Air pressure, ISA, standard	P_0	101325 Pa			
Oswald eff. factor, clean	е	0,85			
Sp	ecifications				
Mach number, cruise	M _{CR}	0,77			
Aspect ratio	Α	8,71			
Bypass ratio	μ	4,70			
Wing loading	m_{MTO}/S_W	591 kg/m²			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,306			
,	Variables				
	V/V _{md}	1,2			
Calculations					
Zero-lift drag coefficient	C _{D,0}	0,028			
Lift coefficient at E _{max}	$C_{L,md}$	0,81			
Ratio, lift coefficient	C _L /C _{L,md}	0,688			
Lift coefficient, cruise	C_L	0,560			
Actual aerodynamic efficiency, cruise	E	13,36			
Max. glide ratio, cruise	E _{max}	14,30			
Newton-Raphson for the maximum lift-to-drag ratio					
Iterations	1	2	3		
f(x)	-0,23	-0,01	0,00		
f(x)	-0,14	-0,13	-0,13		
E _{max}	16	14,35	14,30		

3) Specific Fuel Consumption

Constant parameters					
Ratio of specific heats, air	γ	1,4			
Earth acceleration	g		m/s²		
Air pressure, ISA, standard	p_0	101325			
Fuel density	$ ho_{fuel}$	800	kg/m³		
Specifica	tions				
Range	R	742	NM		
Mach number, cruise	M _{CR}	0,77			
Bypass ratio	μ	4,70			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,306			
Available fuel volume	$V_{\text{fuel,available}}$	23,86	m³		
Maximum take-off mass	m_{MTO}	54900	kg		
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,264			
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,566			
Calculated	values				
Actual aerodynamic efficiency, cruise	E	13,36			
Cruise altitude	h_{CR}	10450	m		
Cruise speed	V _{CR}	229	m/s		
Mission fuel	fraction				
Type of aeroplane (according to Roskam)	Transport jet				
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990			
Fuel-Fraction, taxi	M _{ff.taxi}	0,990			
Fuel-Fraction, take-off	M _{ff,TO}	0,995			
Fuel-Fraction, climb	M _{ff.CLB}	0,980			
Fuel-Fraction, descent	M _{ff.DES}	0,990			
Fuel-Fraction, landing	M _{ff,L}	0,992			
· ·		3,55=			
Calculati		0.470			
Mission fuel fraction (acc. to PL and OE)	m _F /m _{MTO}	0,170			
Mission fuel fraction (acc. to PL and OE)	M_ff	0,830			
Available fuel mass	M _{F,available}	19088	kg		
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,348			
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,666			
Distance to alternate	S _{to alternate}	200	NM		
Distance to alternate	S _{to_alternate}	370400	m		
Choose: FAR Part121-Reserves	domestic	yes			
	international	no			
Extra-fuel for long range		5%			
Extra flight distance	S _{res}	370400	m		
Loiter time	t _{loiter}	2700	s		
Specific fuel consumption	SFC	1,48E-05	kg/N/s		

4) Verification Specifications

Maximum lift coefficients

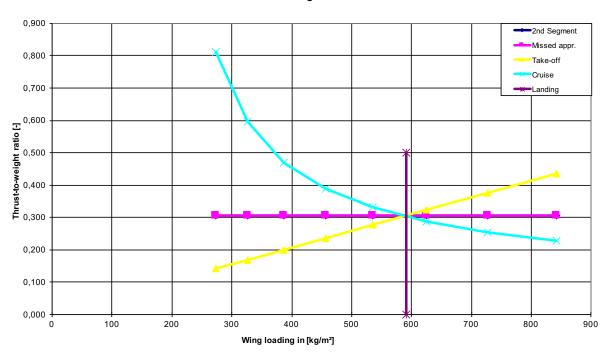
Wing span D _W 28,45 m	General wing specifications	Airfoil type:	NACA 66 series
Structural wing span b _{W,struct} 31,27 m Wing area S _W 93,0 m² Aspect ratio A 8,71 Sweep φ₂5 24,5 ° Mean aerodynamic chord C _{MAC} 3,88 m Position of maximum camber X _{0, c, max} 30 %c Camber (y _c) _{max} /c 4 %c Position of maximum thickness x _{t, max} 30 %c Relative thickness ½ (c 11,7 % Taper λ 0,206 Ceneral aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Ceneral aircraft specifications Temperature, landing ΔT _L 0 K Ceneral aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Ceneral aircraft specifications Temperature above ISA (288,15K) ΔT _L 0 K Density, air, landing p 1,225 kg/m³ Density, air, landing p 1,225 kg/m³	• •		
Wing area S _W 93.0 m² Aspect ratio A 8,71 Sweep φ25 24,5 ° Mean aerodynamic chord C _{MAC} 3,88 m Position of maximum camber X _{V_c,0,max} 30 %c Camber (Yc, max/c 4 %c Position of maximum thickness x _{Lmax} 30 %c Relative thickness Vc 11,7 % Taper λ 0,206 General aircraft specifications Temperature above ISA (288,15K) ΔTL 0 K Relative density σ 1 Temperature, landing TL 273,15 K Pensity, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m³s Speed of sound, landing a _{APP} 331 m/s Approach speed V _{APP} 69,00 m/s Mach number, landing M _{APP} 0,21 Mach number, cruise M _{CR} 0,77 Calculations maximum clean lift coefficient			•
Aspect ratio A 8,71 Sweep φ25 24,5 ° Mean aerodynamic chord CMAC 3,88 m Position of maximum camber X _{V_c,l,max} 30 %c Camber (yc,lmax)C 4 %c Position of maximum thickness X _{L,max} 30 %c Relative thickness t/c 11,7 % Taper λ 0,206 General aircraft specifications Temperature above ISA (288,15K) ΔTL 0 K Repeature above ISA (288,15K) ΔTL 0 K Temperature, landing TL 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing aAPP 331 m/s Approach speed VAPP 69,00 m/s Mach number, landing MAPP 0,21 Mach number, cruise AV 2,1 %c Calculations maximum clean lift coefficient Leading edge sweep φ _L 28,8 ° <td>· .</td> <td>,</td> <td>·</td>	· .	,	·
Sweep φ25 24,5 ° Mean aerodynamic chord C _{MAC} 3,88 m Position of maximum camber Xy_c,nmax 30 %c Camber (yc/max/c 4 %c Position of maximum thickness xt,max 30 %c Relative thickness t/c 11,7 % Taper λ 0,206 General aircraft specifications Temperature above ISA (288,15K) ΔTL 0 K Relative density σ 1 Temperature, landing TL 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a _{APP} 331 m/s Approach speed VAPP 69,00 m/s Mach number, landing M _{APP} 0,21 Mach number, cruise Δy 2,1 %c Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 2,1 %c Leading edge sharpness parameter <t< td=""><td>•</td><td></td><td>•</td></t<>	•		•
Position of maximum camber $x_{(y_c),max}$ $30 \% c$ Camber $(y_c)_{max}/c$ $4 \% c$ Position of maximum thickness $x_{t,max}$ $30 \% c$ Relative thickness t/c $11,7 \%$ $10,206$ $11,7 \%$ Taper $10,206$ $11,7 \%$ $10,206$ $11,7 \%$ Taper $10,206$ $11,7 \%$ $10,206$ $11,7 \%$ Taper $10,206$ $11,7 \%$ $10,206$ $11,7 \%$ Taper $10,206$ $11,7 \%$ $11,7 \%$ Taper $11,7 \%$ $11,7 \%$ Taper $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7 \%$ $11,7$	Sweep	φ ₂₅	24,5 °
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Mean aerodynamic chord	C _{MAC}	3,88 m
Camber $(y_{c})_{max}/c$ 4 %c Position of maximum thickness $x_{L,max}$ 30 %c Relative thickness t/c 11,7 % Taper λ 0,206 General aircraft specifications Temperature above ISA (288,15K) ΔT_L 0 K Relative density σ 1 Temperature, landing σ 1 Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing σ 331 m/s Approach speed V_{APP} 69,00 m/s Mach number, landing M_{APP} 0,21 Mach number, cruise M_{CR} 0,77 Calculations maximum clean lift coefficient Leading edge sharpness parameter Δy 2,1 %c Leading edge sweep ϕ_{LE} 28,8 ° Reynoldsnumber σ 1,9E+07 Maximum lift coefficient, base σ 1,27 Correction term, camber σ σ 1,27 Correction term, R	Position of maximum camber		30 %c
Relative thickness t/c $11,7 \%$ Taper λ λ $0,206$ General aircraft specifications Temperature above ISA (288,15K) ΔT_L 0 K Relative density σ 1 Temperature, landing T_L $273,15 \text{ K}$ Density, air, landing ρ $1,225 \text{ kg/m}^3$ Dynamic viscosity, air ρ $1,72E-05 \text{ kg/m/s}$ Speed of sound, landing ρ $1,72E-05 \text{ kg/m/s}$ Speed of sound, landing ρ ρ $1,225 \text{ kg/m}^3$ Approach speed ρ ρ ρ ρ ρ ρ ρ ρ ρ ρ	Camber	- ·	4 %c
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Position of maximum thickness	X _{t.max}	30 %c
	Relative thickness	4	11,7 %
Temperature above ISA (288,15K) ΔT_L 0 KRelative density σ 1Temperature, landing T_L 273,15 KDensity, air, landing ρ 1,225 kg/m³Dynamic viscosity, air μ 1,72E-05 kg/m/sSpeed of sound, landing a_{APP} 331 m/sApproach speed V_{APP} 69,00 m/sMach number, landing M_{APP} 0,21Mach number, cruise M_{CR} 0,77Calculations maximum clean lift coefficient V_{APP} 0Leading edge sharpness parameter Δy 2,1 %cLeading edge sweep ϕ_{LE} 28,8 °ReynoldsnumberRe1,9E+07Maximum lift coefficient, base $C_{L,max,base}$ 1,27Correction term, camber $\Delta_1 C_{L,max}$ 0,40Correction term, thickness $\Delta_2 C_{L,max}$ 0,00Correction term, Reynolds' number $\Delta_3 C_{L,max}$ 0,029Maximum lift coefficient, airfoil $C_{L,max,clean}$ 1,703	Taper	λ	0,206
Temperature above ISA (288,15K) ΔT_L 0 KRelative density σ 1Temperature, landing T_L 273,15 KDensity, air, landing ρ 1,225 kg/m³Dynamic viscosity, air μ 1,72E-05 kg/m/sSpeed of sound, landing a_{APP} 331 m/sApproach speed V_{APP} 69,00 m/sMach number, landing M_{APP} 0,21Mach number, cruise M_{CR} 0,77Calculations maximum clean lift coefficient V_{APP} 0Leading edge sharpness parameter Δy 2,1 %cLeading edge sweep ϕ_{LE} 28,8 °ReynoldsnumberRe1,9E+07Maximum lift coefficient, base $C_{L,max,base}$ 1,27Correction term, camber $\Delta_1 C_{L,max}$ 0,40Correction term, thickness $\Delta_2 C_{L,max}$ 0,00Correction term, Reynolds' number $\Delta_3 C_{L,max}$ 0,029Maximum lift coefficient, airfoil $C_{L,max,clean}$ 1,703			
Relative density σ 1Temperature, landing T_L $273,15 \text{ K}$ Density, air, landing ρ $1,225 \text{ kg/m}^3$ Dynamic viscosity, air μ $1,72E-05 \text{ kg/m/s}$ Speed of sound, landing a_{APP} 331 m/s Approach speed V_{APP} $69,00 \text{ m/s}$ Mach number, landing M_{APP} $0,21$ Mach number, cruise M_{CR} $0,77$ Calculations maximum clean lift coefficientLeading edge sharpness parameter Δy $2,1 \text{ %c}$ Leading edge sweep ϕ_{LE} $28,8 \text{ °}$ ReynoldsnumberRe $1,9E+07$ Maximum lift coefficient, base $c_{L,max,base}$ $1,27$ Correction term, camber $\Delta_{I}C_{L,max}$ $0,40$ Correction term, thickness $\Delta_{Z}C_{L,max}$ $0,00$ Correction term, Reynolds' number $\Delta_{S}C_{L,max}$ $0,0029$ Maximum lift coefficient, airfoil $c_{L,max,clean}$ $1,703$			
Temperature, landing T_L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air ρ 1,72E-05 kg/m/s Speed of sound, landing ρ 331 m/s Approach speed ρ 40,00 m/s Mach number, landing ρ 69,00 m/s Mach number, cruise ρ 70,77 ρ 82 ρ 83 ρ 84 ρ 85 ρ 86 ρ 86 ρ 87 ρ 87 ρ 87 ρ 87 ρ 87 ρ 88 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 89 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 80 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90 ρ 90	• • • • • • • • • • • • • • • • • • • •	-	* **
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Approach speed V_{APP} 69,00 m/s Mach number, landing M_{APP} 0,21 Mach number, cruise M_{CR} 0,77 M_{CR} 0,77 M_{CR} 0,77 M_{CR} 21 %c Leading edge sharpness parameter M_{CR} 28,8 ° Reynoldsnumber M_{CR} 28,8 ° Reynoldsnumber M_{CR} 28,8 ° Reynoldsnumber M_{CR} 28,8 ° Reynoldsnumber M_{CR} 28,8 ° Reynoldsnumber M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00 M_{CR} 20,00	•	•	_
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Mach number, cruise M_{CR} $0,77$ Calculations maximum clean lift coefficientLeading edge sharpness parameter Δy $2,1$ %cLeading edge sweep ϕ_{LE} $28,8$ °ReynoldsnumberRe $1,9E+07$ Maximum lift coefficient, base $c_{L,max,base}$ $1,27$ Correction term, camber $\Delta_1c_{L,max}$ $0,40$ Correction term, thickness $\Delta_2c_{L,max}$ $0,00$ Correction term, Reynolds' number $\Delta_3c_{L,max}$ $0,029$ Maximum lift coefficient, airfoil $c_{L,max,clean}$ $1,703$	··		
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$ \begin{array}{llllllllllllllllllllllllllllllllllll$	Mach number, cruise	M _{CR}	0,77
Leading edge sweep Reynoldsnumber ϕ_{LE} 28,8 ° Reynoldsnumber Re 1,9E+07 ϕ_{LE} 28,8 ° Reynoldsnumber ϕ_{LE} 28,8 ° Reynoldsnumber ϕ_{LE} 28,8 ° Rew 1,9E+07 ϕ_{LE} 28,8 ° Reynoldsnumber ϕ_{LE} 28,8 ° Rew 1,9E+07 ϕ_{LE} 28,8 ° Rew 1,9E+07 ϕ_{LE} 29,8 ° Rew 1,9E+07 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE} 20,00 ϕ_{LE}	Calculations maximum clean lift coefficient		
ReynoldsnumberRe $1,9E+07$ Maximum lift coefficient, base $c_{L,max,base}$ $1,27$ Correction term, camber $\Delta_1 c_{L,max}$ $0,40$ Correction term, thickness $\Delta_2 c_{L,max}$ $0,00$ Correction term, Reynolds' number $\Delta_3 c_{L,max}$ $0,029$ Maximum lift coefficient, airfoil $c_{L,max,clean}$ $1,703$	Leading edge sharpness parameter	Δy	2,1 %c
$\begin{array}{llllllllllllllllllllllllllllllllllll$	Leading edge sweep	ϕ_{LE}	28,8 °
$\begin{array}{cccc} \text{Correction term, camber} & \Delta_1 c_{\text{L,max}} & 0,40 \\ \text{Correction term, thickness} & \Delta_2 c_{\text{L,max}} & 0,00 \\ \text{Correction term, Reynolds' number} & \Delta_3 c_{\text{L,max}} & 0,029 \\ \text{Maximum lift coefficient, airfoil} & c_{\text{L,max,clean}} & 1,703 \\ \end{array}$	Reynoldsnumber	Re	1,9E+07
$\begin{array}{cccc} \text{Correction term, camber} & \Delta_1 c_{L,max} & 0,40 \\ \text{Correction term, thickness} & \Delta_2 c_{L,max} & 0,00 \\ \text{Correction term, Reynolds' number} & \Delta_3 c_{L,max} & 0,029 \\ \text{Maximum lift coefficient, airfoil} & c_{L,max,clean} & 1,703 \\ \end{array}$			
Correction term, thickness $\Delta_2 c_{L,max}$ 0,00 Correction term, Reynolds' number $\Delta_3 c_{L,max}$ 0,029 Maximum lift coefficient, airfoil $c_{L,max,clean}$ 1,703	Maximum lift coefficient, base	C _{L,max,base}	1,27
Correction term, Reynolds' number $\Delta_3 c_{L,max}$ 0,029 Maximum lift coefficient, airfoil $c_{L,max,clean}$ 1,703	Correction term, camber	$\Delta_1 c_{L,max}$	0,40
Maximum lift coefficient, airfoil c _{L,max,clean} 1,703	Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
	Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,029
Lift coefficient ratio Cumar/Cumar 0.86	Maximum lift coefficient, airfoil	C _{L,max,clean}	1,703
military military	Lift coefficient ratio	$C_{L,max}/c_{L,max}$	0,86
Correction term, Mach number $\Delta C_{L,max}$ -0,02	Correction term, Mach number	$\Delta C_{L,max}$	-0,02
Lift coefficient, wing C _{L,max} 1,45	Lift coefficient, wing		1,45

Calculations increase of lift coefficient due to flag	os	1 flap type
Correction factor, sweep	K₀	0,87
Flap group A	Ť	
Double-slotted flap	$\Delta c_{L,max,fA}$	1,42
Use flapped span	b_W,fA	18,5 m
Percentage of flaps allong the wing		59%
Increase in maximum lift coefficient, flap group A	\DeltaC_L,max,fA	0,73
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing	46	0%
Increase in maximum lift coefficient, flap group B	ΔC _{L,max,fB}	0,00
Increase in maximum lift coefficient, flap	$\DeltaC_{L,max,f}$	0,73
Calculations increase of lift coefficient due to sla	ts	1 slat type
Sweep angle of the hinge line	φ _{H.L.}	28 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,90
Use slatted span	b_W,sA	25,6 m
Percentage of slats allong the wing		82%
Increase in maximum lift coefficient, slat group A	\DeltaC_L,max,sA	0,65
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing	46	0%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,00
Increase in maximum lift coefficient, slat	\DeltaC_L,max,s	0,65
Wing		
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,80
RE value maximum lift coefficient, landing	_	3,46
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,18
RE value maximum lift coefficient, take-off	100/	2,70
	-19%	
Aerodyn	amic efficiency	
Real aircraft average	k _{WL}	2,83
No winglets		1,00
Span	k _{e,WL} b _W	28,45 m
Winglet height	h	2,7 m
Aspect ratio	Ä	8,71
Effective aspect ratio	A _{eff}	8,71
	- U II	-1-
Efficiency factor, short range	k _E	15,15
Relative wetted area	S _{we} /S _W	6,35
	_	4
Verification value maximum aerodynamic efficiency	E _{max}	17,7
RE value maximum aerodynamic efficiency	240/	14,30
,	24%	

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M _{CR}	0,770	
Cruise altitude	h _{CR}	10424 m	
By Pass Ratio	μ	4,70	
Take-off Thrust (one engine)	T _{TO,one engine}	82,29 kN	
Overall Pressure ratio	OAPR	32,10	
Turbine entry temperature	TET	1422,79	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η _{inlet}	0,95	
Ventilator efficiency	$\eta_{ m ventilator}$	0,85	
Compressor efficiency	$\eta_{compresor}$	0,85	
Turbine efficiency	η_{turbine}	0,89	
Nozzle efficiency	η_{nozzle}	0,98	
Temperature at SL	T_0	288,15 K	
Temperature lapse rate in troposhpere	L	0,0065 K/m	
Temperature (ISA) at tropopause	T_S	216,65 K	
Temperature at cruise altitude	T(H)	220,39 K	
Dimensionless turbine entry temperature	ф	6,46	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,12	
Temperature function	χ	1,90	
Gas generator efficiency	η_{gasgen}	0,98	
Gas generator function	G	1,90	
Verification value specific fuel consumption	SFC	0,61 kg/daN/h	
Verification value specific fuel consumption	SFC	1,70E-05 kg/N/s	
RE value specific fuel consumption	SFC	1,48E-05 kg/N/s	

Matching Chart



Appendix AO Boeing 737-400

Parameter Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Symbol Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disease Original Disea				,		>	6
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Lise) SFC (cruise kg/N s) 1,88F-05 1,887 1,887 V _{LineLinealininin} m²s 20,102 20,102 23,827 20,104-23,83 20,105-23,170 V _{CR} m/s 221,22 221,22 221,22 221,22 h _{CR} m 10668 10668-7924,8 25 cohC m 3,73 25 25 cohAc m 3,73 25 cohAc m 3,73 25 x _{V,C,Dmax} %c 20,4 3,73 x _{V,C,max} %c 1,5 25 x _{V,max} %c 1,5 25 x _{V,max} %c 12,9 12,89 x 0,24 0,24 0,24		_	1,1037E-05		1,11E-05		
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V _{CR} m/s 221,2 253,1 h _{CR} m 10668 10668-7924,8 φ ₂₅ ° 25 10668-7924,8 Q _{AAC} m 3,73 25 α _{AAC} or and and an angle of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the contr	20,104-23,83	20,105-23,170					23,8
h _{CR} m 10668 9662 10668-7924,8 φ ₂₅ ° 25 25 Q _{AMC} m 3,73 25 X _{(V, O)max} %c 1,5 3,73 X _{(Lmax} %c 1,5 1,5 X _{(Lmax} %c 39,9 12,89 Vc %c 12,9 12,89 A 0,24 0,24		221,2-253,1				221,21111	216,67
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Одлас m 3,73 Xy, o,max %c 20,4 Yo, haad %c 1,5 X,max %c 39,9 tr % 12,9 A 0,24		25			25		25
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(γ _c) _{max} /c %c 1,5 x _{Lmax} %c 39,9 t/c %c 12,9 λ 0,24							20,4
X _{L/max} %c 39,9 t/c %c 12,9 λ 0,24							1,5
νc % 12,9 λ 0,24							39,9
0,24		12,89			12,9		10
anyo		0,24	0.70		0,24		
CAPR 24,3			24,3				

Aeroplane Specifications

	Data to apply	reverse engineering			
				LL	UL
Landing field length	Known	s_{LFL}	1582 m		
Approach speed	Known	V_{APP}	71,00 m/s	71,0	71,0
Temperature above ISA (288,15K)		ΔT_L	0 K		
Relative density		σ	1		
Take-off field length	Known	s _{TOFL}	2222 m	2222	2222
Temperature above ISA (288,15K)		ΔT_TO	0 K		
Relative density		σ	1,000		
Range (maximum payload)		R	1717 NM		
Cruise Mach number		M _{CR}	0,745		
Wing area		S_W	91 m²		
Wing span	Known	b_W	28,88 m ²	28,88	28,88
Aspect ratio		Α	9,16		
Maximum take-off mass		m_{MTO}	68040 kg		
Maximum payload mass		m_PL	18066 kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,266		
Maximum landing mass		m_ML	54885 kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,807		
Operating empty mass		m_OE	33190 kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,488		
Wing loading		m_{MTO}/S_W	747,4 kg/n	n²	
Number of engines		n _E	2		
Take-off thrust for one engine		T _{TO,one engine}	97,86 kN		
Total take-off thrust		T_TO	195,72 kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,293		
Bypass ratio		μ	5,9		
Available fuel volume		V _{fuel,available}	23,86 m³		

Data	to o	ptim	ize \	//\	md
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		inu inu		LL	UL
Cruise speed		V_{CR}	221 m/s		
Cruise altitude		h _{CR}	10668 m		
Speed ratio		V/V_{md}	1,015 -	1	1,316
	Data to execu	te the verification			
				Ran	ige
Sweep angle		φ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	3,73 m		
Position of maximum camber		$X_{(y_c),max}$	20,4 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	40 %c	30 - 45	%с
Relative thickness	Unknown	t/c	12,0 %		
Taper		λ	0,24		

Reverse Engineering

Reverse engineering & optimization of V/Vmd

Quantity	Original value	RE value	Unit	Deviation
s _{LFL}	1582	1582	m	0,00%
V_{APP}	71,00	71,0	m/s	0,00%
s _{TOFL}	2222	2222	m	0,00%
b_W	28,88	28,88	m	0,00%
Α	9,16	9,16		0,00%
V_{CR}	221,2	221	m/s	-0,11%
h_{CR}	10668	10666	m	-0,02 <mark>%</mark>
				1,20E-06
				G,1%
Results rev	erse engineering			
$C_{L,max,L}$	3,56			
$C_{L,max,TO}$	2,68		Povo	ree Engineering
E _{max}	15,19		Reve	rse Engineering
SFC	1,73E-05 kg/	/N/s		_
	S _{LFL} V _{APP} S _{TOFL} b _W A V _{CR} h _{CR} Results rev C _{L,max,L} C _{L,max,TO} E _{max}	SLFL 1582 VAPP 71,00 STOFL 2222 bW 28,88 A 9,16 VCR 221,2 hCR 10668 Results reverse engineering CL,max,L CL,max,TO CL,max,TO Emax 15,19	s _{LFL} 1582 1582 V _{APP} 71,00 71,0 s _{TOFL} 2222 2222 b _W 28,88 28,88 A 9,16 9,16 V _{CR} 221,2 221 h _{CR} 10668 10666 Results reverse engineering C _{L,max,L} 3,56 C _{L,max,TO} 2,68 E _{max} 15,19	s_LFL 1582 1582 m V_APP 71,00 71,0 m/s s_TOFL 2222 2222 m b_W 28,88 28,88 m A 9,16 9,16 VCR 221,2 221 m/s h_CR 10668 10666 m Results reverse engineering C_L,max,L C_L,max,TO 2,68 E_max 15,19

1) Maximum Lift Coefficient for Landing and Take-off

Lar	nding	
Landing field length	S _{LFL}	1582 m
Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1,000
Factor, approach	k_{APP}	1,70 (m/s²) ^{0.5}
Approach speed	V_{APP}	71,00 m/s
Factor, landing	k_L	0,107 kg/m³
Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,81
Wing loading at maximum take-off mass	m_{MTO}/S_W	747,4 kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,56
Tak	ke-off	
Take-off field length	S _{TOFL}	2222 m
Temperatur above ISA (288,15K)	ΔT_{TO}	0 K
Relative density	σ	1,00
Factor	k _{TO}	2,34 m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,293
Maximum lift coefficient, take-off	C _{L,max,TO}	2,68
2md C	a mant	
Aspect ratio	egment A	9,161
Lift coefficient, take-off	$C_{L,TO}$	1,86
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,038
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Profile drag coefficient	C_D,P	0,058
Oswald efficiency factor; landing configuration	e	0.7
Glide ratio in take-off configuration	E _{TO}	8,08
		•
Number of engines	n _E	2
Climb gradient	sin(γ)	0,024
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,295
	approach	
Lift coefficient, landing	$C_{L,L}$	2,11
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,050
Lift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000
Choose: Certification basis	JAR-25 resp. CS-25	no
Lift independent dreg coefficient landing see-	FAR Part 25	yes
Lift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015
Profile drag coefficient	C _{D,P}	0,085
Glide ratio in landing configuration	EL	6,89
Climb gradient	sin(γ)	0,021
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,268
	10 (MIO 0/	

2) Maximum Aerodynamic Efficiency

Const	ant parameters				
Ratio of specific heats, air	γ	1,4			
Earth acceleration	g	9,81 m/s ²			
Air pressure, ISA, standard	p_0	101325 Pa			
Oswald eff. factor, clean	е	0,85			
Specifications					
Mach number, cruise	M _{CR}	0,745			
Aspect ratio	A	9,16			
Bypass ratio	μ	5,90			
Wing loading	m_{MTO}/S_W	747 kg/m²			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,293			
	Variables				
		1.0			
	V/V_{md}	1,0			
c	alculations				
Zero-lift drag coefficient	$C_{D,0}$	0,026			
Lift coefficient at E _{max}	$C_{L,md}$	0,81			
Ratio, lift coefficient	$C_L/C_{L,md}$	0,971			
Lift coefficient, cruise	C_L	0,782			
Actual aerodynamic efficiency, cruise	E	15,19			
Max. glide ratio, cruise	E _{max}	15,19			
Newton-Raphson for the maximum lift-to-	drag ratio				
Iterations	1	2	3		
f(x)	-0,10	0,00	0,00		
f'(x)	-0,13	-0,13	-0,13		
E _{max}	16	15,21	15,19		

3) Specific Fuel Consumption

Constant par	ameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Specificat	ions		
Range	R	1717	NM
Mach number, cruise	M _{CR}	0,745	
Bypass ratio	μ	5,90	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,293	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m _{MTO}	68040	kg
Mass ratio, landing - take-off	m_{PL}/m_{MTO}	0,266	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,488	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	15,19	
Cruise altitude	h _{CR}	10666	m
Cruise speed	V_{CR}	221	m/s
Mission fuel	fraction		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{\rm ff,engine}$	0,990	
Fuel-Fraction, taxi	M _{ff,taxi}	0,990	
Fuel-Fraction, take-off	M _{ff,TO}	0,995	
Fuel-Fraction, climb	M _{ff,CLB}	0,980	
Fuel-Fraction, descent	M _{ff,DES}	0,990	
Fuel-Fraction, landing	M _{ff,L}	0,992	
Calculati	one		
Mission fuel fraction (acc. to PL and OE)	m _E /m _{MTO}	0,247	
Mission fuel fraction (acc. to PL and OE)	M _{ff}	0,753	
,		7, 55	
Available fuel mass	M _{F,available}	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,281	
Mission fuel fraction (acc. to fuel capacity)	M_{ff}	0,734	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,73E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

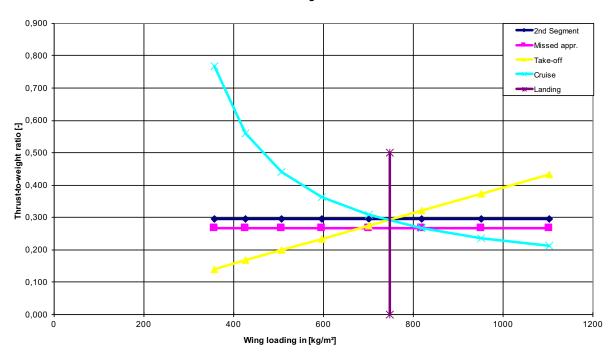
General wing specifications	Airfoil type:	NACA 66 series
Wing span	b _W	28,88 m
Structural wing span	b _{W,struct}	31,87 m
Wing area	S _W	91,0 m²
Aspect ratio	A	9,16
Sweep	Φ25	25 °
Mean aerodynamic chord	C _{MAC}	3,73 m
Position of maximum camber	X _{(y c),max}	20,4 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	X _{t.max}	39,9 %c
Relative thickness	t/c	12,0 %
Taper	λ	0,24
Cananal aircraft area iff actions		
General aircraft specifications Temperature above ISA (288,15K)	ΔT_L	0 K
Relative density	σ	1
Temperature, landing	T _L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a _{APP}	331 m/s
Approach speed	V _{APP}	71,00 m/s
Mach number, landing	M _{APP}	0,21
Mach number, cruise	M _{CR}	0,745
Calculations maximum clean lift coefficient		
Leading edge sharpness parameter	Δγ	2,2 %c
Leading edge sweep	ϕ_{LE}	28,8 °
Reynoldsnumber	Re	1,9E+07
Maximum lift coefficient, base	C _{L,max,base}	1,28
Correction term. camber	Δ ₁ C _{L.max}	0,39
Correction term, thickness	$\Delta_2 C_{L,max}$	0,16
Correction term, Reynolds' number	Δ ₃ C _{L.max}	0,024
Maximum lift coefficient, airfoil	•	1,851
Lift coefficient ratio	c _{L,max,clean} C _{L,max} /c _{L,max}	0,85
Correction term, Mach number	ΔC _{L,max}	-0,03
Lift coefficient, wing		1,55
LIR COGNICION, WING	$C_{L,max}$	1,00

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathrm{\phi}}}$	0,87
Flap group A	Ψ	
0,4c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	2,16
Use flapped span	b_W,fA	20,8 m
Percentage of flaps allong the wing	- '	65%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	1,22
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,79
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0,00
Increase in maximum lift coefficient, flap	$\DeltaC_{L,max,f}$	1,22
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	Ψ _{H.L.}	28 °
Slat group A		
0,3c Nose flap	$\Delta c_{L,max,sA}$	0,96
Use slatted span	b_W,sA	19 m
Percentage of slats allong the wing		60%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,50
Slat group B		
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,96
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing		0%
Increase in maximum lift coefficient, slat group B	ΔC _{L,max,sB}	0,00
Increase in maximum lift coefficient, slat	$\DeltaC_{L,max,s}$	0,50
MG		
Wing Verification value maximum lift coefficient, landing	C	3,21
RE value maximum lift coefficient, landing	$C_{L,max,L}$	3,56
Verification value maximum lift coefficient, take-off	C	2,42
RE value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,68
-10%		2,08
1070		
Aerodynamic eff	iciency	
Pool giroraft average	k	2.83
Real aircraft average	k _{WL}	2,83
No winglets	k _{e,WL}	1,00
Span	b _W	28,88 m
Winglet height Aspect ratio	h A	2,7 m 9,16
Effective aspect ratio		9,16
Effective aspect fatio	A_{eff}	9,10
Efficiency factor, short range	k_{E}	15,15
Relative wetted area	S_{wet}/S_W	6,35
Verification value maximum corodynamic efficiency	E	18,2
Verification value maximum aerodynamic efficiency RE value maximum aerodynamic efficiency	E _{max}	18,2 15,19
RE value maximum aerodynamic eniciency		10,18
20 /0		

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,745
Cruise altitude	h _{CR}	10668 m
By Pass Ratio	μ	5,90
Take-off Thrust (one engine)	T _{TO,one engine}	97,86 kN
Overall Pressure ratio	OAPR	24,30
Turbine entry temperature	TET	1438,25
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η_{inlet}	0,94
Ventilator efficiency	$\eta_{ventilator}$	0,87
Compressor efficiency	$\eta_{compresor}$	0,86
Turbine efficiency	$\eta_{turbine}$	0,90
Nozzle efficiency	η_{nozzle}	0,98
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	218,81 K
Dimensionless turbine entry temperature	ф	6,57
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,11
Temperature function	χ	1,65
Gas generator efficiency	η_{gasgen}	0,98
Gas generator function	G	2,12
Verification value specific fuel consumption	SFC	0,58 kg/daN/h
Verification value specific fuel consumption	SFC	1,62E-05 kg/N/s
RE value specific fuel consumption -6%	SFC	1,73E-05 kg/N/s

Matching Chart



Appendix AP Airbus A300

Simple Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chief Chi	Data Collection	ction		A300-600	_	2	3	4	2	9	7	œ	6
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130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 130000 1300000 130000 130000 130000 130000 130000 130000 1300000 130000 130000 130000 130000 130000 130000 1300000 130000 130000 130000 130000 130000 130000 1300000 130000 130000 130000 130000 130000 130000 1300000 130000 130000 130000 130000 130000 130000 1300000 1300000 1300000000 130000000000	Wing loading	m _{MTo} /S _w	kg/m²	635			655,7692308				635		
type denotines the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and the fire and t	Maximum zero fuel mass	MMZF	kg	130000	126000		130000				130000		
type ECFC (84%), PW4000 CF6-80C2A1 GE CF6-ABOC2A1 GE CF6-BOC2A1 GE CFC-BOC2A1 GE CFC-BCC2A1 GE CFC-BCC2A1<	Number of engines	٤		2			2						2
ske-off thrust for one engine skeed fit thrust for one engine skeed fit thrust for one engine skeed fit thrust for one engine skeed fit thrust for one engine fit thrust for one engine fit thrust for one engine fit thrust for one engine fit thrust for one engine fit thrust for weight ratio ITroof (Mnr ² 5) 674 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 257,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,4 258,	Engine type	GE CF6 (8	14%), PW400C		GE CF6—50	CF6-80C2A5	P&W 4158	CF6-50C2			CF6-80C2A1	GE CF6-50-C2	
ske-off thrust Tro (marc) gl kN 514 0,322 0,32 to weight ratio Tro (marc) gl 0,32 0,32 0,32 0,32 s ratio Evel Comsumption (dry) FC (dry) kgN s 1,08E-05 0,48E-06 9,48E-06 c Fuel Comsumption (cruise) SFC (dry) kgN s 1,78E-05 0,48E-06 1,63E-05 c Fuel Comsumption (cruise) SFC (dry) kgN s 1,78E-05 1,63E-05 1,63E-05 c Fuel Comsumption (cruise) SFC (dry) kgN s 1,78E-05 1,63E-05 1,63E-05 sle fuel volume Vcre m/s 241,79 224,59-246,93 10668 9,48E-06 speed Vcre m/s 241,79 224,59-246,93 10668 9449 angle Vcre m/s 2,8 2 2 2 2 angle Vcre m/s kg-0 kg-0 kg-0 kg-0 kg-0 kg-0 n of maximum camber Vcre Vcre kg-0 kg-0	Take-off thrust for one engine	T _{TO} , one engin	ε V								257,4	233	
to weight ratio Tro/(mλεπ0*g) 0,322 0,307305672 4,31 6,22 0,32 6,22 0,307305672 0,32 0,32 5,2 0,32 5,2 0,32 5,2 0,32 5,2 0,346E-06 0,346E-06 0,346E-06 0,346E-06 0,346E-06 0,46E-06 0,46	Total take-off thrust	Tro	ᇫ	514									
Figure Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jacob Jac	Thrust to weight ratio	T _{TO} /(m _{MTO} *	(b)	0,32			0,307305072				0,32		
c Fuel Communition (arry) SFC (dry) Kg/N s 1,05E-05 9,46E-06 Le Le Communition (cruise) SFC (cruise kg/N s 1,78E-05 1,78E-05 1,63E-05 Set Let Communition (cruise) SFC (cruise kg/N s 1,78E-05 1,63E-05 1,63E-05 Set Let Communition (cruise) V _{Cre} m/s 241,79 234,59-246,93 82 82 speed V _{Cre} m/s 10668 10688-9448,8 10668 9449 angle V _{Cre} m 6,61 6,61 6,437 6,61 6,61 are chymamic chord O _{MAC} m 6,61 6,437 6,437 6,61 are chymamic chord V _{Crimax} %c 10,5 10,5 10,5 are thickness V _{Crimax} %c 0,292 0,292 0,292 In resource ratio OAPRR 30,4 0,30,4 0,30,4 0,30,4	Bypass ratio	_		5,2				4,31			5,2		
c Fuel Commumption (cruise) SFC (cruise kg/N s and legal section) 1,78E-05 1,78E-05 1,78E-05 speed V _{Luction classified} m² 241,79 62 68,150-75,350 62 62 68,150-75,350 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 62 <t< td=""><td>Specific Fuel Comsumption (dry)</td><td></td><td></td><td>1,05E-05</td><td></td><td></td><td></td><td>1,05E-05</td><td></td><td></td><td>9,46E-06</td><td></td><td></td></t<>	Specific Fuel Comsumption (dry)			1,05E-05				1,05E-05			9,46E-06		
Seed Vote Part Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark Mark	Specific Fuel Comsumption (cruise)			1,78E-05				1,78E-05			1,63E-05		
speed V _{CR} m/s 241,79 234,59-246,93 9449 altitude h _{CR} m 10668 10668 9449 angle φ _{2S} ° 28 28 serodynamic chord Q _{AAC} m 6,61 6,437 6,61 n of maximum camber X _{V_C, plmax} %c m 6,61 6,61 n of maximum thickness X _L _{max} %c 10,5 10,5 e thickness λ 0,292 0,292 pressure ratio OAPR 30,4 0,292 0,292	Available fuel volume	Vfuel, available		62	62		68,150-75,350				62		62,9
alithude m 10668-9448,8 10668 9449 angle \$\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{\rightarrow{	Cruise speed	V _{CR}	m/s	241,79			234,59-246,93					241,79	
angle φ ₂₅ 28 28 serodynamic chord m 6,61 6,437 n of maximum camber x _{(y,c)max} %c n of maximum thickness x _{(max} %c n of maximum thickness t/c % thickness t/c % a thickness λ 0,292 pressure ratio OAPR 30,4	Cruise altitude	hcr	ε	10668			10668-9448,8	10668			9448		
serodynamic chord Question E,61 E,437 E,437 nof maximum camber X _{V,c,lmax} %c %c R nr N _{C,max} %c 10,5 R n of maximum thickness V _{C,max} %c 10,5 R n of maximum thickness V _C %c 10,5 R n of maximum thickness V _C %c 0,3 C n or maximum thickness V _C %c 0,3 C n or maximum thickness V _C %c 0,3 C n or maximum thickness V _C M _C C C	Sween			28			28				28		
of maximum camber X _{trinace} %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c %c	Mean aerodynamic chord	978	Ε	661			6 437				661		
or of maximum thickness (V _c) Flead C %C 10,5 70,5 80,4 90,3 90,4 90,3 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,3 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4 90,4	Position of maximum camber	X (v. c) max	%c										
n of maximum thickness x _{cmax} %c 10,5 10,5 0,292 0,3 0 p ressure ratio OAPR 30,4 30,4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0<	Camber	(yc)max/c	%c										
to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hickness to hi	Position of maximum thickness	Xt,max	%с										
A 0,292 0,3 0,3 Pressure ratio OAPR 30,4 30,4	Relative thickness	t/c	%	10,5			10,5				10,5		
30,4	Taper	~		0,292			0,3				0,292		
	Overall pressure ratio	OAPR		30,4				30,4					

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	S _{LFL}	1489	m		
Approach speed	Known	V_{APP}	70,00	m/s	70,0	70,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	s_{TOFL}	2280	m	2280	2280
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	1773	NM		
Cruise Mach number		M _{CR}	0,78			
Wing area		S _W	260	m²		
Wing span	Known	b_W	44,84	m²	44,84	44,84
Aspect ratio		Α	7,73			
Maximum take-off mass		m_{MTO}	170500	kg		
Maximum payload mass		m_PL	43273	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,254			
Maximum landing mass		m_ML	136000	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,798			
Operating empty mass		m_OE	86727	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,509			
Wing loading		m_{MTO}/S_W	655,8	kg/m²		
Number of engines		n _E	2			
Take-off thrust for one engine		T _{TO,one engine}	257	kN		
Total take-off thrust		T_TO	514	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,307			
Bypass ratio		μ	5,2			
Available fuel volume		V _{fuel,available}	23,86	m³		

	Data to o	ptimize V/V _{md}				
					LL	UL
Cruise speed		V_{CR}	242	m/s		
Cruise altitude		h _{CR}	10668	m		
Speed ratio		V/V_{md}	1,088	-	1	1,316
	Data to execu	ite the verification				
					Rai	nge
Sweep angle		ϕ_{25}	28	0		
Mean aerodynamic chord		C _{MAC}	6,61	m		
Position of maximum camber		X _{(y_c),max}	30	%с	15 - 50	%с
Camber		(y _c) _{max} /c	4	%с	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30	%с	30 - 45	%с
Relative thickness	Unknown	t/c	11,6	%		
Taper		λ	0,292			

Reverse Engineering

	0	Original control	DEl	1.1 14	Davidation
	Quantity		RE value	Unit	Deviation
Landing field length	s_{LFL}	1489	1489		0,00%
Approach speed	V_{APP}	70,00	70,0	m/s	0,00%
Take-off field length	s _{TOFL}	2280	2280	m	0,00%
Span	b_W	44,84	44,84	m	0,00%
Aspect ratio	Α	7,73	7,73		0,00%
Cruise speed	V_{CR}	241,8	232	m/s	-4,23%
Cruise altitude	h_{CR}	10668	10600	m	-0,64 <mark>%</mark>
Squared Sum					1,83E-03
Absolute maximum deviation					4,2%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	3,28			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,19		Povo	rse Engineering
Maximum aerodynamic efficiency	E _{max}	14,08		Keve	ise Engineering
Specific fuel consumption	SFC	1,51E-05 kg/	N/s		

1) Maximum Lift Coefficient for Landing and Take-off

	anding		
Landing field length	s_{LFL}	1489	m
Temperature above ISA (288,15K)	ΔT_L	0	K
Relative density	σ	1,000	
Factor, approach	k_{APP}	1,70	(m/s²) ^{0.5}
Approach speed	V_{APP}	70,00	m/s
Factor, landing	\mathbf{k}_{L}	0,107	kg/m³
Mass ratio, landing - take-off	$\rm m_{ML}/m_{TO}$	0,80	
Wing loading at maximum take-off mass	m_{MTO}/S_W	655,8	kg/m²
Maximum lift coefficient, landing	$C_{L,max,L}$	3,28	
Ta	ake-off		
Take-off field length	s_{TOFL}	2280	m
Temperatur above ISA (288,15K)	ΔT_TO	0	K
Relative density	σ	1,00	
Factor	k _{TO}	2,34	m³/kg
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,307	
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,19	
2nd	Segment		
Aspect ratio	A	7,733	
Lift coefficient, take-off	$C_{L,TO}$	1,52	
Lift-independent drag coefficient, clean	C _{D,0} (2 nd Segment)	0,020	
Lift-independent drag coefficient, flaps	$\Delta C_{D,flap}$	0,021	
ift-independent drag coefficient, slats	$\Delta C_D,slat$	0,000	
Profile drag coefficient	$C_{D,P}$	0,041	
Oswald efficiency factor; landing configuration	e	0,7	
Glide ratio in take-off configuration	E _{TO}	8,59	
Number of engines	n _E	2	
Climb gradient	sin(γ)	0,024	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}*g)$	0,281	
Misse	d approach		
ift coefficient, landing	C _{L,L}	1,94	
Lift-independent drag coefficient, clean	C _{D,0} (Missed approach)	0,020	
ift-independent drag coefficient, flaps	$\Delta C_D,flap$	0,042	
ift-independent drag coefficient, slats	$\Delta C_{D,slat}$	0,000	
Choose: Certification basis	JAR-25 resp. CS-25	no	
	FAR Part 25	yes	
ift-independent drag coefficient, landing gear	$\Delta C_{D,gear}$	0,015	
Profile drag coefficient	$C_{D,P}$	0,077	
Glide ratio in landing configuration	EL	6,50	
Climb gradient	sin(γ)	0,021	
-	***		

2) Maximum Aerodynamic Efficiency

Const	ant parameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g	9,81 m/s ²	
Air pressure, ISA, standard	p_0	101325 Pa	
Oswald eff. factor, clean	е	0,85	
Sp	ecifications		
Mach number, cruise	M _{CR}	0,78	
Aspect ratio	Α	7,73	
Bypass ratio	μ	5,20	
Wing loading	m_{MTO}/S_W	656 kg/m²	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,307	
	Variables		
	V/V_{md}	1,1	
C	alculations		
Zero-lift drag coefficient	C _{D,0}	0,026	
Lift coefficient at E _{max}	$C_{L,md}$	0,73	
Ratio, lift coefficient	$C_L/C_{L,md}$	0,845	
Lift coefficient, cruise	C_L	0,620	
Actual aerodynamic efficiency, cruise	E	13,88	
Max. glide ratio, cruise	E _{max}	14,08	
Newton-Raphson for the maximum lift-to-o	drag ratio		
Iterations	1	2	3
f(x)	-0,27	-0,01	0,00
f'(x)	-0,15	-0,14	-0,14
E _{max}	16	14,14	14,08

3) Specific Fuel Consumption

Constant pa	rameters		
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{fuel}$	800	kg/m³
Specifica	ations		
Range	R	1773	NM
Mach number, cruise	M_{CR}	0,78	
Bypass ratio	μ	5,20	
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,307	
Available fuel volume	$V_{ m fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	170500	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,254	
Mass ratio, operating empty - take-off	m_{OE}/m_{MTO}	0,509	
Calculated	values		
Actual aerodynamic efficiency, cruise	F	13,88	
Cruise altitude	h _{CR}	10600	
Cruise speed	V _{CR}		m/s
Craise speed	* CR	202	111/0
Mission fue			
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	$M_{ff,engine}$	0,990	
Fuel-Fraction, taxi	$M_{ff,taxi}$	0,990	
Fuel-Fraction, take-off	$M_{ff,TO}$	0,995	
Fuel-Fraction, climb	$M_{ff,CLB}$	0,980	
Fuel-Fraction, descent	$M_{ff,DES}$	0,990	
Fuel-Fraction, landing	$M_{ff,L}$	0,992	
Calculat	tions		
Mission fuel fraction (acc. to PL and OE)	m _E /m _{MTO}	0,238	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,762	
A. Walle Colonia		40000	
Available fuel mass	F,available	19088	
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,112	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,906	
Distance to alternate	S _{to_alternate}	200	NM
Distance to alternate	S _{to_alternate}	370400	m
Choose: FAR Part121-Reserves	domestic	yes	
	international	no	
Extra-fuel for long range		5%	
Extra flight distance	S _{res}	370400	m
Loiter time	t _{loiter}	2700	s
Specific fuel consumption	SFC	1,51E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

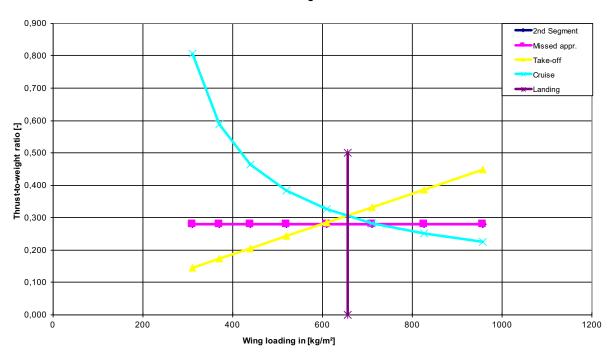
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
Mean aerodynamic chord c_{MAC} $6,61$ mPosition of maximum camber $x_{(y_c),max}$ 30 %cCamber $(y_c)_{max}/c$ 4 %cPosition of maximum thickness $x_{t,max}$ 30 %cRelative thickness t/c $11,6$ %Taper λ $0,292$ General aircraft specificationsTemperature above ISA (288,15K) ΔT_L 0 KRelative density σ 1 Temperature, landing T_L $273,15$ KDensity, air, landing ρ $1,225$ kg/m³Dynamic viscosity, air μ $1,72E-05$ kg/m/sSpeed of sound, landing a_{APP} 331 m/s	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
Relative thickness t/c $11,6\%$ $\%$ Taper λ $0,292$ General aircraft specifications Temperature above ISA (288,15K) ΔT_L 0 K Relative density σ 1 Temperature, landing T_L $273,15$ K Density, air, landing ρ $1,225$ kg/m³ Dynamic viscosity, air ρ $1,72E-05$ kg/m/s Speed of sound, landing a_{APP} 331 m/s	
Taper $ \begin{array}{ccccccccccccccccccccccccccccccccccc$	
Temperature above ISA (288,15K) $\Delta T_L \qquad 0 \text{ K}$ Relative density $\sigma \qquad 1$ Temperature, landing $T_L \qquad 273,15 \text{ K}$ Density, air, landing $\rho \qquad 1,225 \text{ kg/m}^3$ Dynamic viscosity, air $\mu \qquad 1,72E-05 \text{ kg/m/s}$ Speed of sound, landing $a_{APP} \qquad 331 \text{ m/s}$	
Temperature above ISA (288,15K) $\Delta T_L \qquad 0 \text{ K}$ Relative density $\sigma \qquad 1$ Temperature, landing $T_L \qquad 273,15 \text{ K}$ Density, air, landing $\rho \qquad 1,225 \text{ kg/m}^3$ Dynamic viscosity, air $\mu \qquad 1,72E-05 \text{ kg/m/s}$ Speed of sound, landing $a_{APP} \qquad 331 \text{ m/s}$	
Temperature, landing T_L 273,15 K Density, air, landing ρ 1,225 kg/m³ Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a_{APP} 331 m/s	
Density, air, landing $ \begin{array}{ccccccccccccccccccccccccccccccccccc$	
Dynamic viscosity, air μ 1,72E-05 kg/m/s Speed of sound, landing a_{APP} 331 m/s	
Speed of sound, landing a _{APP} 331 m/s	
Approach speed V _{APP} 70,00 m/s	
Mach number, landing M _{APP} 0,21	
Mach number, cruise M _{CR} 0,78	
Calculations maximum clean lift coefficient	
Leading edge sharpness parameter Δy 2,1 %c	
Leading edge sweep $$\phi_{LE}$$ 32,1 $^\circ$	
Reynoldsnumber Re 3,3E+07	
Maximum lift coefficient, base $c_{L,max,base}$ 1,26	
Correction term, camber $\Delta_1 c_{L,max}$ 0,40	
Correction term, thickness $\Delta_2 c_{L,max}$ 0,00	
Correction term, Reynolds' number $\Delta_3 c_{L,max}$ 0,050	
Maximum lift coefficient, airfoil C _{L.max.clean} 1,714	
Lift coefficient ratio C _{L,max} /c _{L,max} 0,86	
Correction term, Mach number $\Delta C_{L,max}$ -0,02	
Lift coefficient, wing C _{L,max} 1,46	

Calculations increase of lift coefficient due to flaps		1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle\mathbf{\phi}}$	0,85
Flap group A	·	
0,3c Single-slotted fowler flap	$\Delta c_{L,max,fA}$	1,73
Use flapped span	b_W,fA	35,9 m
Percentage of flaps allong the wing		71%
Increase in maximum lift coefficient, flap group A	$\Delta C_{L,max,fA}$	1,04
Flap group B		
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,74
Use flapped span	b_W,fB	0 m
Percentage of flaps allong the wing		0%
Increase in maximum lift coefficient, flap group B	ΔC _{L,max,fB}	0,00
Increase in maximum lift coefficient, flap	$\DeltaC_{L,max,f}$	1,04
Calculations increase of lift coefficient due to slats		1 slat type
Sweep angle of the hinge line	ΨH.L.	31 °
Slat group A	••••	
0,1c Kruger flap	$\Delta c_{L,max.sA}$	0,67
Use slatted span	b_W,sA	40,4 m
Percentage of slats allong the wing	_ ′	80%
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,45
Slat group B	_,,	
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90
Use slatted span	b_W,sB	0 m
Percentage of slats allong the wing		0%
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,00
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,45
Wing Verification value maximum lift coefficient, landing	C_L,max,L	2,90
RE value maximum lift coefficient, landing	- L,max,L	3,28
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	1,93
RE value maximum lift coefficient, take-off	L,max, 10	2,19
-129	%	•
Aerodynamic	efficiency	
•		
Real aircraft average	k _{WL}	2,83
No winglets	$k_{e,WL}$	1,00
Span	bw	44,84 m
Winglet height	h	2,7 m
Aspect ratio	A	7,73
Effective aspect ratio	A_{eff}	7,73
Efficiency factor, short range	k _E	15,15
Relative wetted area	S_{wel}/S_W	6,35
Verification value maximum aerodynamic efficiency	E _{max}	16,7
RE value maximum aerodynamic efficiency		14,08
19%	6	

Specific fuel consumption (Herrmann 2010)

Cruise Mach number	M_{CR}	0,780	
Cruise altitude	h_{CR}	10668	m
By Pass Ratio	μ	5,20	
Take-off Thrust (one engine)	T _{TO,one engine}	257,00	kN
Overall Pressure ratio	OAPR	30,40	
Turbine entry temperature	TET	1488,87	
Inlet pressure loss	ΔΡ/Ρ	2%	
Inlet efficiency	η_{inlet}	0,95	
Ventilator efficiency	$\eta_{ m ventilator}$	0,89	
Compressor efficiency	$\eta_{compresor}$	0,87	
Turbine efficiency	η_{turbine}	0,91	
Nozzle efficiency	$\eta_{ m nozzle}$	0,99	
Temperature at SL	T_0	288,15	K
Temperature lapse rate in troposhpere	L	0,0065	K/m
Temperature (ISA) at tropopause	T_S	216,65	K
Temperature at cruise altitude	T(H)	218,81	K
Dimensionless turbine entry temperature	ф	6,80	
Ratio of specific heats, air	γ	1,40	
Ratio between stagnation point temperature and temperature	υ	1,12	
Temperature function	χ	1,85	
Gas generator efficiency	$\eta_{ m gasgen}$	0,98	
Gas generator function	G	2,24	
Verification value specific fuel consumption	SFC	0,56	kg/daN/h
Verification value specific fuel consumption	SFC	1,55E-05	kg/N/s
RE value specific fuel consumption 2%	SFC	1,51E-05	kg/N/s

Matching Chart



Appendix AQ Boeing 747-8

	Data Collection		P		2	3	4	2	9	7	œ	D	
Parameter	Svmbol	Units	Chosen value	 Source: Aircraft characteristics for airport planning	Jame's	Jenkinson	Engine	Scholz	Paul Müller	Elodie Roux	Paul Müller Elodie Roux Data collectior	Webs	
PAX			654	48+467	467					654-467		46	467-581
Landina field lenath	e e	ε	2130	1981.2	2072					2130	2680		
Approach speed	V _{APP}	s/m	74								74.594444		
Temperature above ISA (288,15K)	ΔT	×	0										
Relative density	ø												
Take-off field length	STOE	Ε	3300	3302	3230					3310	3190		
Temperature above ISA (288,15K)	ΔTro	Y	0	0						8			
Relative density	S												
Range (max payload)	α	E	10949.95	10949 95	14816					11437			15000
Cruise Mach number	McR		0,855	0,855						0,855	0,855		0,855
Wing prop	Ü	28	425							425			
Wing span	3 6	E 8	68.5	68.4	68 45					68.5	68 45		68.5
Aspect ratio	Ã	=	8 94	50	2					8 94			2
										-			
Maximum take-off mass	Ммто	kg	447696	447696	439985					439985	447696		447696
Payload mass	MPL	gy	76340	79097	76340					76340			
Mass ratio, payload - take-off	МР∪Мито									0,174			
Maximum landing mass	mML	ķ	306175	312072	306175					306175			309000
Mass ratio, landing - take-off	MML/MMT0	3	211601	901000	211600					244604			
Mose ratio operating empty take off many	IIIOE	2	160117	220120						0.481			
Wing loading	m _{MTO} /S _W	kg/m²	838							838			
Maximum zero fuel mass	MMZF	, D	288031	295289	288030					288031			
Number of engines	JE C		4	CEnv 2067	7900 2000					7900 2000	4	20 029670	2
Engine type Take-off thrust for one engine	GENX-ZB	Z	296 296	GEIIX-ZB0/	7967 796					798 298	7967 296	295 80676	296
Total take-off thrust	Tro	3 3	224		2						2	0	3
Thrust to weight ratio	T _{TO} /(m _{MTO} *g)	(F	0,28		0,274303					0,28			
Bypass ratio			∞							8		8,0-7,4	
Specific Fuel Comsumption (dry)		kg/N s											
Specific Fuel Comsumption (cruise)	SFC (cruise kg/N s	e kg/N s											
Available fuel volume	Vfuel, available	E E	241,619	238,61	243,111					241,619			254,722
Cruise speed	V _{CR}	s/m	255								262,36667		254,722
Cruise altitude	hcR	ε	10668							10668			10668
Sweep angle	6 25	0	37.5							37.5			
Mean aerodynamic chord	OMAC	Ε	9,68							89'6			
Position of maximum camber	X(v c),max	%c											
Camber	(yc)max/c	%с											
Position of maximum thickness	X _{t,max}	%c											
Relative thickness	, tc	%	9,4							9,4			
Taper	< 0		0,275							0,275		7 0 1	1
Overall pressure ratio	CAPR		44,/									44,7-22,4	7,44

Aeroplane Specifications

	Data to apply	reverse engineering				
					LL	UL
Landing field length	Known	S _{LFL}	2130	m		
Approach speed	Known	V_{APP}	74,00	m/s	74,0	74,0
Temperature above ISA (288,15K)		ΔT_L	0	K		
Relative density		σ	1			
Take-off field length	Known	S _{TOFL}	3300	m	3300	3300
Temperature above ISA (288,15K)		ΔT_TO	0	K		
Relative density		σ	1,000			
Range (maximum payload)		R	5912	NM		
Cruise Mach number		M _{CR}	0,855			
Wing area		S _W	525	m²		
Wing span	Known	b_W	68,5	m²	68,5	68,5
Aspect ratio		Α	8,94			
Maximum take-off mass		m _{MTO}	447696	kg		
Maximum payload mass		m_{PL}	76340	kg		
Mass ratio, payload - take-off		m_{PL}/m_{MTO}	0,171			
Maximum landing mass		m_{ML}	306175	kg		
Mass ratio, landing - take-off		m_{ML}/m_{MTO}	0,684			
Operating empty mass		m_OE	211691	kg		
Mass ratio, operating empty - take-off		m_{OE}/m_{MTO}	0,473			
Wing loading		m_{MTO}/S_W	852,8	kg/m²		
Number of engines		n _E	4			
Take-off thrust for one engine		T _{TO,one engine}	296	kN		
Total take-off thrust		T _{TO}	1184	kN		
Thrust to weight ratio		$T_{TO}/(m_{MTO}^*g)$	0,270			
Bypass ratio		μ	8			
Available fuel volume		V _{fuel,available}	23,86	m³		

Data	to	optimize	V/V_{md}
------	----	----------	------------

				LL	UL
Cruise speed		V_{CR}	255 m/s		
Cruise altitude		h _{CR}	10668 m		
Speed ratio		V/V_{md}	1,000 -	1	1,316
	Data to execu	te the verification			
				Ran	ige
Sweep angle		φ_{25}	25 °		
Mean aerodynamic chord		C _{MAC}	4,2 m		
Position of maximum camber		x _{(y_c),max}	30 %c	15 - 50	%с
Camber		(y _c) _{max} /c	4 %c	2 - 6	%с
Position of maximum thickness		$x_{t,max}$	30 %c	30 - 45	%с
Relative thickness	Unknown	t/c	10,6 %		
Taper		λ	0,24		

Reverse Engineering

1107	croc criginicaling	a optimization of	*/******		
	Quantity	Original value	RE value	Unit	Deviation
Landing field length	S _{LFL}	2130	2130	m	0,00%
Approach speed	V_{APP}	74,00	74,0	m/s	0,00%
Take-off field length	s _{TOFL}	3300	3300	m	0,00%
Span	b_W	68,5	68,5	m	0,00%
Aspect ratio	Α	8,94	8,94		0,00%
Cruise speed	V_{CR}	255,0	254	m/s	-0, <mark>35%</mark>
Cruise altitude	h_{CR}	10668	10525	m	-1,34%
Squared Sum Absolute maximum deviation					1,92E-04 1,3%
	Results rev	erse engineering			
Maximum lift coefficient, landing	$C_{L,max,L}$	2,56			
Maximum lift coefficient, take-off	$C_{L,max,TO}$	2,24		Reve	rse Engineering
Maximum aerodynamic efficiency	E _{max}	18,03		Kevel	Se Engineering
Specific fuel consumption	SFC	1,39E-05 kg	g/N/s		

1) Maximum Lift Coefficient for Landing and Take-off

$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Land	ing		
Relative density σ 1,000 Factor, approach k_{APP} 1,70 $(m/s^2)^{0.5}$ Factor, approach speed V_{APP} 74,00 m/s 74,00 m/s Factor, landing k_{L} 0,107 kg/m^3 Mass ratio, landing - take-off m_{AR}/m_{TO} 0,68 Wing loading at maximum take-off mass m_{AT}/S_W 852,8 kg/m^2 Maximum lift coefficient, landing $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$ 2,56 $C_{L,max,L}$			2130 m	
Factor, approach k _{APP} 1,70 (m/s²) 0.5 Approach speed V _{APP} 74,00 m/s Factor, landing k _L 0,107 kg/m³ Mass ratio, landing - take-off m _{ML} /m _{TO} 0,68 Wing loading at maximum take-off mass m _{MLTO} /S _W 852,8 kg/m² Maximum lift coefficient, landing C _{L,max,L} 2,56 Take-off Take-off field length srore. 3300 m Take-off field length srore. 3300 m Temperatur above ISA (288,15K) ΔT _{TO} 0 K Relative density σ 1,00 Factor k _{TO} 2,34 m²/kg Thrust-to-weight ratio Tro/(m _{MTO} *g) 0,270 Maximum lift coefficient, take-off C _{L,max,TO} 2,24 End Segment Aspect ratio A 8,938 Lift-independent drag coefficient, clean C _{D,0} (2 nd Segment) 0,020 Lift-independent drag coefficient, slats ΔC _{D,slat} 0,000 <td cols<="" td=""><td>Temperature above ISA (288,15K)</td><td>ΔT_L</td><td>0 K</td></td>	<td>Temperature above ISA (288,15K)</td> <td>ΔT_L</td> <td>0 K</td>	Temperature above ISA (288,15K)	ΔT_L	0 K
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Relative density	σ		
Factor, landing k_L 0,107 kg/m³ Mass ratio, landing - take-off m_{MA}/m_{TO} 0,68 Wing loading at maximum take-off mass $m_{MTO}S_W$ 852,8 kg/m² 2,56 Maximum lift coefficient, landing $C_{L,max,L}$ 2,56 Take-off $m_{MA}/m_{TO}S_W$ 852,8 kg/m² 2,56 Maximum lift coefficient, landing $C_{L,max,L}$ 2,56 Take-off field length $m_{MA}/m_{TO}S_W$ 3300 m Temperatur above ISA (288,15K) ΔT_{TO} 0 K Relative density σ 1,00 Factor m_{TO}/m_{MTO}^2 0,270 Maximum lift coefficient, take-off m_{TO}/m_{MTO}^2 0,270 Maximum lift coefficient, take-off m_{TO}/m_{MTO}^2 0,270 Maximum lift coefficient, take-off m_{TO}/m_{MTO}^2 0,270 Maximum lift coefficient, clean m_{TO}/m_{MTO}^2 0,224 m_{TO}/m_{MTO}^2 1,56 Lift-independent drag coefficient, clean m_{TO}/m_{MTO}^2 0,023 Lift-independent drag coefficient, slats m_{TO}/m_{MTO}^2 0,023 Lift-independent drag coefficient, slats m_{TO}/m_{MTO}^2 0,000 Profile drag coefficient m_{TO}/m_{MTO}^2 0,043 Oxwald efficiency factor; landing configuration m_{TO}/m_{MTO}^2 0,043 Consider atio in take-off configuration m_{TO}/m_{MTO}^2 0,030 Thrust-to-weight ratio m_{TO}/m_{MTO}^2 0,043 Oxyald efficient, landing m_{TO}/m_{MTO}^2 0,030 Thrust-to-weight ratio m_{TO}/m_{MTO}^2 0,030 Thrust-to-weight ratio m_{TO}/m_{MTO}^2 0,030 Choose: Certification basis m_{TO}/m_{MTO}^2 0,000 Choose: Certification basis m_{TO}/m_{MTO}^2 0,000 Choose: Certification basis m_{TO}/m_{MTO}^2 0,015 Choose: Certification basis m_{TO}/m_{MTO}^2 0,005 Gide ratio in landing configuration m_{TO}/m_{MTO}^2 0,015 Choose: Certification landing configuration m_{TO}/m_{TO}^2 0,005 Gide ratio in landing configuration m_{TO}/m_{TO}^2 0,005 Gide ratio in landing configuration m_{TO}/m_{TO}^2 0,005 Gide ratio in landing configuration m_{TO}/m_{TO}^2 0,005 Gide ratio in landing configuration m_{TO}/m_{TO}^2 0,005 Gide ratio in landing configuration m_{TO}/m_{TO}^2 0,005 Gide ratio in landing configuration m_{TO}/m_{TO}^2 0,005 Gide ratio in landing configuration m_{TO}/m	Factor, approach	k _{APP}	$1,70 (m/s^2)^{0.5}$	
Mass ratio, landing - take-off m_{MTO}/S_W 852,8 kg/m² Wing loading at maximum take-off mass m_{MTO}/S_W 852,8 kg/m² Maximum lift coefficient, landing $C_{L,max,L}$ 2,56 Take-off Take-off field length S_{TOFL} 3300 m Temperatur above ISA (288,15K) ΔT_{TO} 0 K Relative density σ 1,00 Factor k_{TO} 2,34 m³/kg Thrust-to-weight ratio $T_{TO}/(m_{MTO}^+g)$ 0,270 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,24 End Segment Segment Aspect ratio A 8,938 Lift-independent drag coefficient, clean $C_{D,TO}$ 1,56 Lift-independent drag coefficient, flaps $\Delta C_{D,flap}$ 0,023 Lift-independent drag coefficient, slats $\Delta C_{D,slat}$ 0,000 Profile drag coefficient profile drag coefficient, slats $C_{D,T}$ $C_{D,T}$ $C_{D,T}$ Missed approach Lift-independent drag coefficient	Approach speed	V_{APP}	74,00 m/s	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Factor, landing	k_L	0,107 kg/m³	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Mass ratio, landing - take-off	m_{ML}/m_{TO}	0,68	
	Wing loading at maximum take-off mass	m_{MTO}/S_W	852,8 kg/m ²	
Take-off field length s_{TOFL} 3300 m Temperatur above ISA (288,15K) ΔT_{TO} 0 K Relative density σ 1,00 Factor k_{TO} 2,34 m³/kg Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,270 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,24 2nd Segment Aspect ratio A 8,938 Lift coefficient, take-off $C_{L,TO}$ 1,56 Lift-independent drag coefficient, clean $C_{D,0}$ ($2^{2^{nd}}$ Segment) 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D,flap}$ 0,023 Lift-independent drag coefficient, slats $\Delta C_{D,slat}$ 0,000 Profile drag coefficient, landing configuration e 0,7 Glide ratio in take-off configuration E _{TO} 9,37 Number of engines n _E 4 Climb gradient sin(γ) 0,030 Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,182 Missed approach Lift independent drag coefficient, clean $C_{D,0}$ (Missed approach) 0,020 Lift-indepen	Maximum lift coefficient, landing	$C_{L,max,L}$	2,56	
Take-off field length s_{TOFL} 3300 m Temperatur above ISA (288,15K) ΔT_{TO} 0 K Relative density σ 1,00 Factor k_{TO} 2,34 m³/kg Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,270 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,24 2nd Segment Aspect ratio A 8,938 Lift coefficient, take-off $C_{L,TO}$ 1,56 Lift-independent drag coefficient, clean $C_{D,0}$ ($2^{2^{nd}}$ Segment) 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D,flap}$ 0,023 Lift-independent drag coefficient, slats $\Delta C_{D,slat}$ 0,000 Profile drag coefficient, landing configuration e 0,7 Glide ratio in take-off configuration E _{TO} 9,37 Number of engines n _E 4 Climb gradient sin(γ) 0,030 Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,182 Missed approach Lift independent drag coefficient, clean $C_{D,0}$ (Missed approach) 0,020 Lift-indepen	Take	-off		
Temperatur above ISA (288,15K) ΔT_{TO} 0 K Relative density σ 1,00 Factor k_{TO} 2,34 m^3/kg Thrust-to-weight ratio $T_{TO}/(m_{MTC}^*g)$ 0,270 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,24 m^3/kg Thrust-to-weight ratio $T_{TO}/(m_{MTC}^*g)$ 0,270 Maximum lift coefficient, take-off $T_{L,max,TO}$ 2,24 m^3/kg Thrust-to-weight ratio $T_{L,max,TO}$ 2,24 m^3/kg A 8,938 Lift coefficient, take-off $T_{L,TO}$ 1,56 Lift-independent drag coefficient, clean $T_{L,TO}$ 1,56 Lift-independent drag coefficient, flaps $T_{L,TO}$ 1,56 Lift-independent drag coefficient, flaps $T_{L,TO}$ 1,56 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,56 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,56 Lift-independent drag coefficient $T_{L,TO}$ 1,50 Lift-independent drag coefficient $T_{L,TO}$ 1,50 Lift-independent drag coefficient $T_{L,TO}$ 1,50 Lift-independent drag coefficient $T_{L,TO}$ 1,50 Lift-independent $T_{L,TO}$ 1,50 Lift-independent $T_{L,TO}$ 1,51 Lift-independent drag coefficient, clean $T_{L,TO}$ 1,51 Lift-independent drag coefficient, flaps $T_{L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,52 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,52 Lift-independent drag coefficient, slats $T_{L,TO}$ 1,52 Lift-independent drag coefficient, landing gear $T_{L,TO}$ 1,52 Lift-independent drag coefficient, landing gear $T_{L,TO}$ 1,52 Lift-independent drag coefficient, landing gear $T_{L,TO}$ 1,52 Lift-independent drag coefficient $T_{L,TO}$ 1,53 Lift-independent drag coefficient $T_{L,TO}$ 1,54 Lift-independent drag coefficient $T_{L,TO}$ 1,55 Lift-independent drag coefficient $T_{L,TO}$ 1,55 Lift-independent drag coefficient, landing gear $T_{L,TO}$ 1,55 Lift-independent drag coefficient			3300 m	
Relative density σ 1,00 Factor k_{TO} 2,34 m³/kg Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,270 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,24 $m³/kg$ Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,270 Maximum lift coefficient, take-off $T_{C,L,TO}$ 2,24 $m²/kg$ 2 Maximum lift coefficient, take-off $T_{C,L,TO}$ 1,56 Lift-independent drag coefficient, clean $T_{C,L,TO}$ 1,56 Lift-independent drag coefficient, flaps $T_{C,L,TO}$ 1,56 Lift-independent drag coefficient, flaps $T_{C,L,TO}$ 1,56 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,56 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,50 Lift-independent drag coefficient $T_{C,L,TO}$ 1,50 Lift-independent drag coefficient $T_{C,L,TO}$ 1,50 Lift-independent drag coefficient $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, clean $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, clean $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, flaps $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag coefficient, slats $T_{C,L,TO}$ 1,51 Lift-independent drag	_			
Factor k_{TO} 2,34 m³/kg Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,270 Maximum lift coefficient, take-off $C_{L,max,TO}$ 2,24 Table 1			1,00	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	•	k _{TO}	2,34 m³/kg	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Thrust-to-weight ratio		0,270	
Aspect ratio A 8,938 Lift coefficient, take-off	Maximum lift coefficient, take-off		2,24	
Aspect ratio A 8,938 Lift coefficient, take-off	2nd Sac	yment		
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$			8,938	
Lift-independent drag coefficient, clean $C_{D,0}(2^{nd} \text{ Segment})$ 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D,flap}$ 0,023 Lift-independent drag coefficient, slats $\Delta C_{D,slat}$ 0,000 Profile drag coefficient $C_{D,P}$ 0,043 Oswald efficiency factor; landing configuration E_{TO} 9,37 Side ratio in take-off configuration E_{TO} 9,37 Number of engines E_{TO} 1,030 E_{TO} 1,030 Thrust-to-weight ratio E_{TO} 1,51 Lift-independent drag coefficient, clean E_{TO} 1,51 Lift-independent drag coefficient, slats E_{TO} 1,51 Lift-independent drag coefficient, slats E_{TO} 1,62 Lift-independent drag coefficient, slats E_{TO} 1,62 E_{TO} 1,63 E_{TO} 1,64 E_{TO} 1,65 E_{TO} 1,66 E_{TO} 1,66 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67 E_{TO} 1,67	•	C _{L.TO}		
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Lift-independent drag coefficient, clean	C _{D 0} (2 nd Segment)	0,020	
		•		
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$				
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	•	•		
Number of engines n_E 4 Climb gradient $sin(\gamma)$ 0,030 Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g)$ 0,182	_	•		
Climb gradient $sin(\gamma) = 0.030$ Thrust-to-weight ratio $T_{TO}/(m_{MTO}^*g) = 0.182$	Glide ratio in take-off configuration	E _{TO}	9,37	
Climb gradient $sin(\gamma) = 0.030$ Thrust-to-weight ratio $T_{TO}/(m_{MTO}*g) = 0.182$	Number of engines	n.	4	
Thrust-to-weight ratio $T_{TO}/(m_{MTO} *g) \qquad 0,182$ $\frac{\text{Missed approach}}{\text{Lift coefficient, landing}} \qquad C_{L,L} \qquad 1,51$ $\text{Lift-independent drag coefficient, clean} \qquad C_{D,0} \text{ (Missed approach)} \qquad 0,020$ $\text{Lift-independent drag coefficient, flaps} \qquad \Delta C_{D,flap} \qquad 0,021$ $\text{Lift-independent drag coefficient, slats} \qquad \Delta C_{D,slat} \qquad 0,000$ $\text{Choose: Certification basis} \qquad JAR-25 \text{ resp. CS-25} \qquad \text{no} \\ FAR \text{ Part 25} \qquad \text{yes} \\ \text{Lift-independent drag coefficient, landing gear} \qquad \Delta C_{D,gear} \qquad 0,015} \\ \text{Profile drag coefficient} \qquad C_{D,P} \qquad 0,056 \\ \text{Glide ratio in landing configuration} \qquad E_{L} \qquad 8,79}$ $\text{Climb gradient} \qquad \text{sin}(\gamma) \qquad 0,027$	_	-	·	
	_	***	•	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	-		5,152	
Lift-independent drag coefficient, clean $C_{D,0}$ (Missed approach) 0,020 Lift-independent drag coefficient, flaps $\Delta C_{D, flap}$ 0,021 Lift-independent drag coefficient, slats $\Delta C_{D, slat}$ 0,000 Choose: Certification basis JAR-25 resp. CS-25 no FAR Part 25 yes Lift-independent drag coefficient, landing gear $\Delta C_{D, gear}$ 0,015 Profile drag coefficient $C_{D,P}$ 0,056 Glide ratio in landing configuration E_L $s,79$			4.54	
Lift-independent drag coefficient, flaps $\Delta C_{D,flap} \qquad 0,021$ Lift-independent drag coefficient, slats $\Delta C_{D,slat} \qquad 0,000$ Choose: Certification basis $JAR-25 \text{ resp. CS-}25 \qquad \text{no} \\ FAR \text{ Part 25} \qquad \text{yes} \\ \text{Lift-independent drag coefficient, landing gear} \qquad \Delta C_{D,gear} \qquad 0,015$ Profile drag coefficient $C_{D,P} \qquad 0,056$ Glide ratio in landing configuration $E_L \qquad \text{sin}(\gamma) \qquad 0,027$	•			
Lift-independent drag coefficient, slats $\Delta C_{D,slat} \qquad 0,000$ Choose: Certification basis $JAR-25 \text{ resp. CS-}25 \qquad \text{no} \\ FAR \text{ Part }25 \qquad \text{yes} \\ \text{Lift-independent drag coefficient, landing gear} \qquad \Delta C_{D,gear} \qquad 0,015 \\ \text{Profile drag coefficient} \qquad C_{D,P} \qquad 0,056 \\ \text{Glide ratio in landing configuration} \qquad E_L \qquad 8,79 \\ \text{Climb gradient} \qquad \text{sin}(\gamma) \qquad 0,027 \\ \end{array}$	-	_,		
Choose: Certification basis JAR-25 resp. CS-25 no FAR Part 25 yes Lift-independent drag coefficient, landing gear $\Delta C_{D,gear}$ 0,015 Profile drag coefficient $C_{D,P}$ 0,056 Glide ratio in landing configuration E_L 8,79 Climb gradient $\sin(\gamma)$ 0,027				
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Lift-independent drag coefficient, landing gear $\Delta C_{D,gear}$ 0,015 Profile drag coefficient $C_{D,P}$ 0,056 Glide ratio in landing configuration E_L 8,79 Climb gradient $\sin(\gamma)$ 0,027	Choose: Certification dasis	-		
Profile drag coefficient $C_{D,P}$ 0,056 Glide ratio in landing configuration E_L 8,79 Climb gradient $\sin(\gamma)$ 0,027	Lift-independent drag coefficient landing gear		•	
Glide ratio in landing configuration E_L 8,79 Climb gradient $\sin(\gamma)$ 0,027				
Climb gradient $\sin(\gamma)$ 0,027		•		
	Since Tailo III landing configuration	Ч.	0,73	
	Climb gradient	sin(γ)	0,027	
	Thrust-to-weight ratio		0,128	

2) Maximum Aerodynamic Efficiency

Constant parameters					
Ratio of specific heats, air	γ	1,4			
Earth acceleration	g	9,81 m/s ²			
Air pressure, ISA, standard	p_0	101325 Pa			
Oswald eff. factor, clean	е	0,85			
0					
	ecifications	0.055			
Mach number, cruise	M _{CR}	0,855			
Aspect ratio	Α	8,94			
Bypass ratio	μ	8,00			
Wing loading	m_{MTO}/S_W	853 kg/m²			
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}^*g)$	0,270			
Variables					
	V/V _{md}	1,0			
С	alculations				
Zero-lift drag coefficient	C _{D,0}	0,018			
Lift coefficient at E _{max}	$C_{L,md}$	0,66			
Ratio, lift coefficient	$C_L/C_{L,md}$	1,000			
Lift coefficient, cruise	C_L	0,662			
Actual aerodynamic efficiency, cruise	E	18,03			
Max. glide ratio, cruise	E _{max}	18,03			
Newton-Raphson for the maximum lift-to-drag ratio					
Iterations	1	2	3		
f(x)	0,21	-0,01	0,00		
f'(x)	-0,10	-0,11	-0,11		
E _{max}	16	18,11	18,03		

3) Specific Fuel Consumption

Constant parameters			
Ratio of specific heats, air	γ	1,4	
Earth acceleration	g		m/s²
Air pressure, ISA, standard	p_0	101325	
Fuel density	$ ho_{ m fuel}$	800	kg/m³
Specifica	tions		
Range	R	5912	NM
Mach number, cruise	M _{CR}	0,855	
Bypass ratio	μ	8,00	
Thrust-to-weight ratio	T _{TO} /(m _{MTO} *g)	0,270	
Available fuel volume	$V_{fuel,available}$	23,86	m³
Maximum take-off mass	m_{MTO}	447696	kg
Mass ratio, landing - take-off	$m_{PL}m_{MTO}$	0,171	
Mass ratio, operating empty - take-off	$m_{OE/}m_{MTO}$	0,473	
Calculated	values		
Actual aerodynamic efficiency, cruise	E	18,03	
Cruise altitude	h _{CR}	10525	
Cruise speed	V _{CR}	254	m/s
Mission fuel	function		
Type of aeroplane (according to Roskam)	Transport jet		
Fuel-Fraction, engine start	M _{ff,engine}	0,990	
Fuel-Fraction, taxi	M _{ff.taxi}	0,990	
Fuel-Fraction, take-off	•	0,995	
Fuel-Fraction, climb	M _{ff,TO}	0,980	
	M _{ff,CLB}	•	
Fuel-Fraction, descent Fuel-Fraction, landing	M _{ff,DES}	0,990 0,992	
ruel-riaction, landing	$M_{ff,L}$	0,992	
Calculati			
Mission fuel fraction (acc. to PL and OE)	m_F/m_{MTO}	0,357	
Mission fuel fraction (acc. to PL and OE)	M_{ff}	0,643	
Available fuel mass	m _{F,available}	19088	kg
Relative fuel mass (acc. to fuel capacity)	m _{F,available} /m _{MTO}	0,043	
Mission fuel fraction (acc. to fuel capacity)	M _{ff}	0,977	
Distance to alternate	c	200	NM
Distance to alternate	S _{to_alternate}	370400	
Choose: FAR Part121-Reserves	s _{to_alternate} domestic	370400 no	
Choose. FART arriz 1-Reserves	international	yes	
Extra-fuel for long range	international	5%	
Extra flight distance	S _{res}	917851	m
Loiter time		1800	
Londi dillo	t _{loiter}	1000	3
Specific fuel consumption	SFC	1,39E-05	kg/N/s

4) Verification Specifications

Maximum lift coefficients

General wing specifications	Airfoil type:	NACA 66 series
Wing span	b _W	68,5 m
Structural wing span	b _{W,struct}	75,58 m
Wing area	S _W	525,0 m ²
Aspect ratio	Α	8,94
Sweep	φ_{25}	25 °
Mean aerodynamic chord	C _{MAC}	4,2 m
Position of maximum camber	X _{(y_c),max}	30 %c
Camber	(y _c) _{max} /c	4 %c
Position of maximum thickness	$\mathbf{x}_{t.max}$	30 %c
Relative thickness	t/c	10,6 %
Taper	λ	0,24
General aircraft specifications	ΑT	0 K
Temperature above ISA (288,15K) Relative density	ΔT_L σ	1 N
Temperature, landing	T _L	273,15 K
Density, air, landing	ρ	1,225 kg/m³
Dynamic viscosity, air	μ	1,72E-05 kg/m/s
Speed of sound, landing	a _{APP}	331 m/s
Approach speed	V _{APP}	74,00 m/s
Mach number, landing	M _{APP}	0,22
Mach number, cruise	M _{CR}	0,855
Coloulations manipulm along life and finish		
Calculations maximum clean lift coefficient Leading edge sharpness parameter	Δy	1,9 %c
Leading edge sweep	φ_{LE}	28,9 °
Reynoldsnumber	Re	2,2E+07
		4.4-
Maximum lift coefficient, base	C _{L,max,base}	1,17
Correction term, camber	$\Delta_1 c_{L,max}$	0,38
Correction term, thickness	$\Delta_2 c_{L,max}$	0,00
Correction term, Reynolds' number	$\Delta_3 c_{L,max}$	0,067
Maximum lift coefficient, airfoil	$\mathbf{c}_{L,max,clean}$	1,617
Lift coefficient ratio	$C_{L,max}/c_{L,max}$	0,91
Correction term, Mach number	ΔC _{L,max}	-0,01
Lift coefficient, wing	$C_{L,max}$	1,46

Calculations increase of lift coefficient due to flaps			1 flap type
Correction factor, sweep	$K_{\!\scriptscriptstyle{\mathrm{\phi}}}$	0,87	
Flap group A			
Double-slotted flap	$\Delta c_{L,max,fA}$	1,43	
Use flapped span	b_W,fA	43,8	m
Percentage of flaps allong the wing		58%	
Increase in maximum lift coefficient, flap group A Flap group B	$\Delta C_{L,max,fA}$	0,72	
0,3c Plain flap	$\Delta c_{L,max,fB}$	0,75	
Use flapped span	b W,fB	0	m
Percentage of flaps allong the wing	0_44,115	0%	
Increase in maximum lift coefficient, flap group B	$\Delta C_{L,max,fB}$	0.00	
Increase in maximum lift coefficient, flap		0,72	
increase in maximum int coemcient, nap	$\DeltaC_{\!L,max,f}$	0,72	
Calculations increase of lift coefficient due to slats			2 slat types
Sweep angle of the hinge line	$\phi_{H.L.}$	42 1	•
Slat group A			
0,1c Kruger flap	$\Delta c_{L,max,sA}$	0,67	
Use slatted span	b_W,sA	9,3 ।	m
Percentage of slats allong the wing		12%	
Increase in maximum lift coefficient, slat group A	$\Delta C_{L,max,sA}$	0,06	
Slat group B			
0,3c Nose flap	$\Delta c_{L,max,SB}$	0,90	
Use slatted span	b_W,sB	34,8 i	m
Percentage of slats allong the wing		46%	
Increase in maximum lift coefficient, slat group B	$\Delta C_{L,max,sB}$	0,31	
Increase in maximum lift coefficient, slat	$\Delta C_{L,max,s}$	0,37	
Wing			
Verification value maximum lift coefficient, landing	$C_{L,max,L}$	2,51	
RE value maximum lift coefficient, landing	OL,max,L	2,56	
Verification value maximum lift coefficient, take-off	$C_{L,max,TO}$	2,20	
RE value maximum lift coefficient, take-off	CL,max,TO	2,24	
-2%		2,24	
·			
Aerodynamic e	fficiency		
Real aircraft average	k _{WL}	2,83	
End plate	k _{e,WL}	1,03	
Span	b _W	68,5 :	m
Winglet height	h	1,6	
Aspect ratio	Ä	8,94	•••
Effective aspect ratio	A _{eff}	9,24	
Encouve aspect ratio	/ еп	0,24	
Efficiency factor, short range	k _E	17,25	
Relative wetted area	S_{wet}/S_W	6,30	
Verification value maximum aerodynamic efficiency	E _{max}	20,9	
RE value maximum aerodynamic efficiency	⊢ max	18,03	
16%		10,03	
1070			

Specific fuel consumption (Herrmann 2010)

Overall Pressure ratio Turbine entry temperature	OAPR TET	44,70 1492,97
Inlet pressure loss	ΔΡ/Ρ	2%
Inlet efficiency	η _{inlet}	0.93
Ventilator efficiency		0,89
•	n _{ventilator}	0,87
Compressor efficiency	η _{compresor}	.,.
Turbine efficiency	$\eta_{ m turbine}$	0,90
Nozzle efficiency	η _{nozzle}	0,99
Temperature at SL	T_0	288,15 K
Temperature lapse rate in troposhpere	L	0,0065 K/m
Temperature (ISA) at tropopause	T_S	216,65 K
Temperature at cruise altitude	T(H)	218,81 K
Dimensionless turbine entry temperature	ф	6,82
Ratio of specific heats, air	γ	1,40
Ratio between stagnation point temperature and temperature	υ	1,15
Temperature function	χ	2,25
Gas generator efficiency	η _{gasgen}	0,97
Gas generator function	G	2,06
Verification value specific fuel consumption	SFC	0,55 kg/daN/h
Verification value specific fuel consumption	SFC	1,54E-05 kg/N/s
DE 1 15 6 1 11	050	4.005.05.1. (1)
RE value specific fuel consumption	SFC	1,39E-05 kg/N/s
11%		

Matching Chart

