Design, Build & Fly of a UAV

Diseño, Construcción y Vuelo de un UAV

Gimenez Bolinches, Andreu

Grado en Ingeniería Aeroespacial
Escuela Técnica Superior de la Ingeniería del Diseño
Universitat Politècnica de Valencia

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ABSTRACT

Five students with different backgrounds have completed the Design, Build and Fly minor in the Aviation Academy of the Amsterdam University of Applied Sciences. The main goal of this minor is to give the students a good practical approach in aircraft design and at the end of it the students have been able to design, build and fly fixed wing, one engine Unmanned Aerial Vehicle that is capable of flying a predetermined route and to drop a small payload. This project includes the concept design, detail design, production plan and evaluation of the project itself considering the flight results.

RESUMEN

Cinco estudiantes con estudios de diversos campos han completado el semestre de Diseño, Construcción & Vuelo en la Academia de Aviación de la universidad de Ámsterdam de ciencias aplicadas. El principal objetivo de este semestre es dar a los estudiantes una buena base práctica en el diseño de aeronaves y al final del semestre han sido capaces de diseñar, construir y volar un Vehículo No Tripulado de ala fija y un único motor, que es capaz de volar una ruta predeterminada y soltar un paquete pequeño. Este proyecto incluye el diseño conceptual, diseño detallado, plan de producción y la evaluación de todo el trabajo considerando los resultados de los vuelos.

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-INTRODUCTION-

The present document is a recompilation of all the deliverables handed during the exchange semester in Amsterdam University of Applied Sciences in the minor Design, Build & Fly which aims to cover all the phases involved in the development of a new Unmanned Aerial Vehicle that has to perform a determined mission.

This project has been carried out with a team of five students (Group DBF-A), whose backgrounds can be found in the Project Plan, with the description of the project itself and how the team planned to develop it.

The initial concept for the UAV with the initial flight mechanics calculations can be found in the Concept Design Presentation, which is less descriptive due to the intrinsic oral character of the presentation. Nevertheless, the Detail Design describes a more detailed version of the concept.

After the Detail Design, the group of students had to face the production phase, therefore a Production Plan was developed. This deliverable had no report layout because it was intended to be used during the manufacturing of the UAV already described in the Detail Design report.

Once the production was finished, the UAV faced the Test Flight and, with some modifications, the Mission Flight. To illustrate the performance of these flights a video montage has been created and can be found here[1].

Then, each group member had to defend his work and the group's design in the Individual Defense Presentation, in this document it is included the presentation corresponding to the thesis author, Andreu Giménez Bolinches.

Finally, the project is evaluated considering the flight outcome in the Project Evaluation. This is probably the most interesting deliverable considering that summarizes all the mistakes and correct decisions taken in the rest of the phases of the project, with a flight dynamics analysis of the real aircraft compared to the simulated version.

Before each deliverable are indicated the contributions of the author of the thesis in the corresponding deliverable, and its grade, if it is available. Unfortunately each deliverable was written and formatted to be presented standalone, so the bookmarks of this document are not as clear as one would like, but it has been considered and improved without re-writing the original deliverables, for example the different tables of contents have been corrected to match the document extension.

[1] https://photos.app.goo.gl/s37RQJie5r7hX2jWA

-PROJECT PLAN-

Contributions

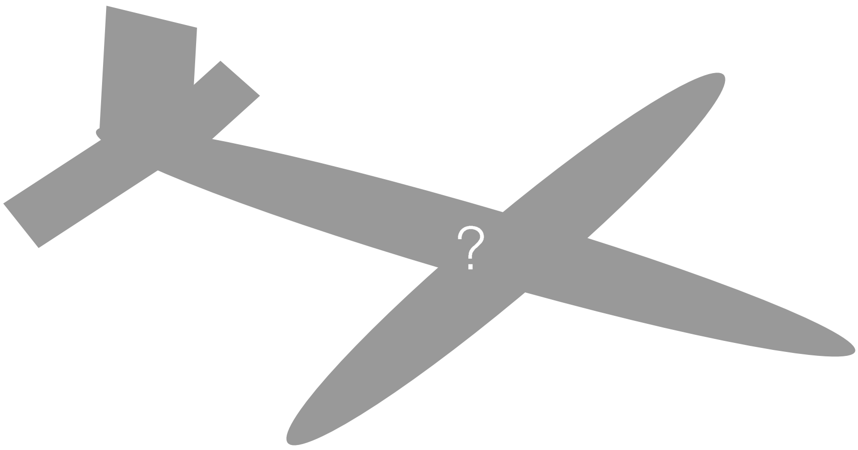
The author of the thesis, Andreu Giménez Bolinches, was responsible of the lay-out of the deliverable and chapter 2 while he also added the Buddy System to chapter 6.

Grading

The project plan grading options were Pass / No Pass and the student group received a Pass.

Design, Build & Fly minor

Project Plan



Group: DBF-A

Student 1 Gimenez Bolinches, Andreu

Student 2 Ginkel, Lars van

Student 3 Janabi, Fahad Al

Student 4 Ommeren, Leandra van

Student 5 Schans, Stefan van der

Aviation Operations/Engineering

Aviation Academy

School of Technology

Amsterdam University of Applied Sciences

Amsterdam, Thursday, July 11, 2019

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Tables and figures

1. Introduction

Several students from a different study background are going to follow the minor Design, Build & Fly at the Aviation Academy of Amsterdam University of Applied Sciences. The main objective of this minor is to give the students a good insight in the aircraft design and at the end of this semester the students must be able to design, construct and fly a fixed wing single engine Unmanned Aerial vehicle (UAV), which is capable of flying a predetermined mission and drop a small package.

To design, Build and test the UAV, there are several activities that are scheduled by the educational institute to support the students. These educational activities have as objective to improve the students engineering skills and to help them to understand the most important principles that are required to build and design the UAV.

The project group DBF-A consists of five students. Each one of them has the full responsibility to make sure that this project group will manage and succeed to deliver the final product. The best way to do that is by starting from the bottom. The bottom and the basic start of any project is understanding the definition, requirements, necessary tools and the main goals of the project. To fulfill that, the students must start-up with a project plan. The project plan is a tool to give a clear path and overview to everyone who is involved in this project, namely the students and the educational institute.

This is the project plan developed by group DBF-A based on Roel Grit's project management method and structure. It is split-up in different chapters that contains the most important details about the execution of the project, for example the results and research statement, definition of project activities, planning and project organization.

Each one of the chapters is explained in detail in this document to give a clear frame about how this project group is going to achieve the final goal and deliver its Unmanned Aerial Vehicle solution.

1.1. Background

Group DBF-A members have different backgrounds (Civil Engineering, Aerospace Engineering, Aviation Operations and Mechanical Engineering) but they share the objective to concept and produce an UAV. The full members information is stated in chapter 6.1 Persons but here one can find a briefing of the motivations of each member.

Fahad studied Mechanical Engineering and has experience in rocket development with a student's group from TU Delft and he is interested in engineering problems solving.

Leandra has been studying Engineering in the aviation academy and this project means bringing together all the knowledge studied during the bachelor in a practical way.

Andreu studies Aerospace Engineering in Spain but has mainly theoretical knowledge so he wants to learn practical matters. Also interested in electronics and autonomous vehicles.

Lars chose to study Aviation Operations but after an internship with Fokker as a reliability engineer is more interested in the engineering branch, so this is a step towards it.

Stefan studies Civil Engineering but he has been in contact with aircraft construction as a hobby from a very young age because of his father. His knowledge in this area is mainly practical and this minor brings him the theoretical background.

2. Results and research statement

In this chapter one can find the expected final results that the group DBF-A must accomplish for the final mission flight. Firstly, there is an overview of the problem that the group will have to solve (2.1) and the objectives the group has to follow to solve the problem in the best way (2.2). Secondly, the restrictions and demands imposed for the correct problem solving (2.3), our own requirements (2.4) and the research questions that will be answered during the development of the solution (2.5).

2.1. Problem statement

In this subchapter one can find the overview of the problem stated by the educational institution:

To design, build and flight a UAV capable of making an automatic mission, that includes a programmed route and landing, and to drop a food package with the maximum allowable quantity of rice while accomplishing the restrictions.

2.2. Objectives

In this subchapter are stated the main objectives of the solution for the problem previously mentioned:

- To carry the maximum payload (rice package)
- To drop the payload accurately in the target
- To follow accurately the programmed route in automatic mode
- To perform a safe landing in automatic mode
- To meet all the safety regulations and the design constrictions

2.3. Restrictions and demands

In this subchapter are summarized the restrictions and demands imposed by the educational institution and the government legislation:

1. Maximum allowable mass: 4 kg (RPAS-regulations)
2. Maximum main wingspan: 2 m
3. Main wingspan skin made of composite materials
4. Electrical components (except servos) provided by the educational institute
5. Fixed wing
6. One engine
7. Static and dynamic stable
8. Capable of change to manual flight at any moment.
9. Hand launched (Safety regulations provided by the educational institute must be accomplished)
10. Climb and wing strength performance by EASA CS-23 (See Appendix II)
11. Airworthiness assessed according to AS-RPAS1. Additional design restrictions briefing:
    a. Emergency descent (Descend from 20m in less than 26 seconds)
    b. Fully maneuverable within 500m of the Pilot In Command (this means take-off, cruise, turn and landing capabilities in that area)

2.4. Own requirements

In this subchapter one can find the requirements that the group imposes by itself as a decision for the development of the problem solution:

- To develop a challenging and innovative idea
    - Avoid using conventional configuration in at least 2 subsystems of the plane

2.5. Research questions

In this subchapter are analyzed the research question needed to fulfill our objectives during the development of the group's solution and its sub questions:

What is the UAV that are we going to build?

- What flight configuration do we want?
- What main wing configuration (airfoil distribution, taper ratio, sweep angle and torsion) and its production method do we want?
- What structural configuration (limit loads) and its production method do we want?
- What control variables gains do we need to perform a stable automatic flight mission?
- What package drop system fits with the aircraft configuration chosen?
- What assembly method minimizes the maintenance costs and gives quick access to repair and check the aircraft components and parts?

The answers to these research questions are not independent or standalone, they conform a tradeoff group where the decision depends on the other research question answers. The dependency between research sub questions is caused by the students limited time and experience capabilities for the production of the UAV and own desire of challenge and innovation.

3. Project activities

In this chapter one can find the project activities that will be performed during the development of the project group.

To design, build and test the UAV, there are several educational activities that are scheduled to support the students. These educational activities have as an objective to improve the students engineering skills and to help them to achieve the final goal of this minor:

For each project group consultancies are scheduled with the project supervisor throughout the whole minor. Most of the weeks two sessions are arranged. The duration may vary to fit the purpose during that specific phase. These consultancies are focused on:

- Project definition and management.
- Individual and team performance.
- Design process and design decisions.

The second important activity are the merlin simulator practical sessions. Weekly, two practical sessions with the Merlin Simulators are scheduled throughout the first block (2 hours per session). During the second block the intensity is decreased to 2 hours per two weeks. Before the students are allowed to start modeling their own design, each student must have successfully modeled the Cessna C140 and Airbus A300 with the Merlin simulators. The assignment descriptions will be published separately on MijnHvA.

The third important activity is the supporting workshops. During the minor various workshops are programmed to support the completion of the assignment:

- Flight Dynamics Workshop (includes an introduction for non-Aviation students) Teacher: Christiaan Schoemaker.
- Composites Workshop Teacher: Maaik Borst.
- Computer Aided Design Workshop Teacher: Nick Ootes.
- Production Technology Workshop Teachers: Jan-Willem Meijer.
- Hazard Analysis Workshop Teacher: Nektarios Karanikas.

During all these educational activities the students must have a clear vision and answers for all the research questions that are mentioned in the previous chapter. All educational activities add up to an amount of approximately 16 contact hours a week on average. The remaining hours of the full-time commitment must be assigned to group and individual work. The project scheme is very tight, which leaves no room for procrastination and trial-and-error.

4. Intermediate Result

In this chapter one can find the intermediate results. The results that are mandatory for the group DBF-After the next 20 weeks. Firstly, is there an overview of all the deadlines for each phase with the responsible chairman and secretary (4.1). Secondly, requirements that each intermediate result needs to comply to (4.2).

4.1. The Mandatory Intermediate Results

In this subchapter is the table with the intermediate results. The Table 4.1-a contains the information about the phase of the course, the intermediate result, the week it needs to be finished with the date of the deadline, the chairman and the Secretary.

Table 4.1-a The intermediate results

Phase	Intermediate Result	Week	Deadline	Chairman	Secretary
Start-up	Project Plan	2	13/02/2019 23:59 hrs	Andreu Gimenez Bolinches	Lars van Ginkel
Concept	Concept Presentation	6	11/03/2019 23:59 hrs Weighing: 20%	Leandra van Ommeren	Andreu Gimenez Bolinches
	Peer Assessment	6	15/03/2019		
Detail	Detail Design Report	9	05/04/2019 23:59 hrs Weighing: 20%	Fahad Al Janabi	Leandra van Ommeren
	Production Plan	10	11/04/2019 23:59 hrs Weighing: 10%		
Build	Aircraft Construction	13	09/05/2019 23:59 hrs Weighing: 20%	Lars van Ginkel	Fahad Al Janabi
	Peer Assessment II	13	10/05/2019 23:59 hrs		
Test & Fly	Airworthiness Test	14	Flexible	Stefan van der Schans	Leandra van Ommeren
	Flight Test	15	Flexible		
	Mission Flight	17	Flexible		
Evaluation	Individual Defense	19	17/06/2019 23:59 hrs Weighing: 15%	Fahad Al Janabi	Stefan van der Schans
	Project Evaluation Report	20	28/06/2019 23:59 hrs Weighing: 15%		
	Peer Assessment III	20	28/06/2019 23:59 hrs		

4.2. The Requirements Concerning the Intermediate Results

In this subchapter are the requirement discussed that are necessary for the intermediate results that needs to comply to these requirements. This is specified according to the Design Build and Fly guidebook.

4.2.1. Project plan

The Project Plan needs to contain the following, which is based upon the Design, Build and Fly guide book and the book Project Management: A practical approach by Roel Grit 2015:

1. Detailed project objective
2. Definition of project scope;
3. Complete set of design requirements;
4. Project organization: roles and responsibilities, meeting structure and documentation of
5. Information, including a logbook for substantiation of all decisions during the design process;
6. Planning: tasks and timeline (preferably in MS Project).

4.2.2. Concept presentation

The sheet of the Concept Design Presentation needs to consist:

1. Justification of the outcome of the design process with a clear view on the applied design
   requirements (at least incl. legislation, minimum required performance, stability, production methods) and considered relevant design options.
2. Description and substantiation of design: configuration, main dimensions, mass estimation, drop mechanism, etc.
3. Calculation of available performance specs (v_{stall}, v_{max}, γ_{max}, R_{max}, E_{max} and r_{min}).
4. Static longitudinal stability analysis (preliminary).
5. Strength analysis (preliminary), including concept of composite lay-up for wing design.
6. Preparation steps for the STPA (definition of accidents, high-level hazards and requirements, drawing the control structure).
7. Artist impressions (renderings) of all the concepts that show the chosen features and an
   animation of the final concept (with Fusion).

4.2.3. Detail Design Report

The Detailed Design Report needs to have chapters that will discuss the following subjects:

1. Visualization of the aircraft assembly (with Fusion).
2. Justification of the outcome of the design process with a clear view on the applied design requirements.
3. Description and substantiation of aircraft design: configuration, dimensions, positioning of all electronics and mass estimation including center of gravity position.
4. Calculation of maximum available performance specs mentioned at the Concept Design, now including validation with the Merlin Simulator.

5. Calculation of static stability specs and a dynamic stability analysis using the Merlin Simulator.
6. Elaboration of the dropping mechanism and a realistic calculation of the path travelled by the package from the intended dropping point to the target.
7. Detailed structural design (lay-up) of composite wing construction, strength analysis and prediction of wing bending (during wing strength test).
8. Hazard analysis using STPA.
9. Substantiation of selected materials and production methods (wherein it is required to use 3D-printing technique for a limited number of parts).

4.2.4. Production Plan

The Production plan of the UAV needs to have:

1. Product Structure Tree
2. Budgeting incl. material cost and predicted man hours for production and assembly.
3. Complete set of Technical Production Drawings for all parts and (sub-)assemblies with equal (traceable) individual contributions.
4. Complete and detailed planning of aircraft construction phase (preferably in MS Project).

4.2.5. Aircraft Construction

For the construction to be final the following is necessary:

1. Successful Wing Strength Test
2. Aircraft is finished (including working electronics).

For the Assessment of the UAV are the following criteria's important:

1. Aircraft is built according to plan
2. Quality of aircraft construction.

4.2.6. Flight Test

For the flight the test are the following requirements mandatory:

1. The Airworthiness Test has been attended.
2. The constructed aircraft must be approved by the NLR personnel.
3. The position of the neutral point and the intended center of gravity should be clearly marked on the wing chord.
4. A before take-off checklist must be completed.
5. The flight plan must be discussed with the pilot.

4.2.7. Mission Flight

In order to be permitted to take part in the mission flight are the following requirements necessary:

1. The Test Flight Day has been attended.
2. The aircraft must be in perfect airworthy condition (e.g.: the use of tape is not allowed, the Pixhawk placement has been validated by checking the vibrations of the test flight, etc.).
3. The mission (route) must be adequately set-up.

4. A basic Risk Analysis (and Mitigation) for the mission must have been performed.
5. A before take-off checklist must be completed.

4.2.8. Individual Defense

For the individual defense are these the requirements that every student need to comply with:

1. The presentation must be handed in digitally via MijnHvA in final state before the deadline.
2. The duration of the presentation must be less than 10 minutes.
3. Hand-outs must be available for the tutor and the second assessor.

4.2.9. Project Evaluation

The Project Evaluation Report needs an evaluation that consist out of the following:

1. Budgeting and production
2. Mission execution
3. Aircraft flight dynamics (Flight Data Log vs. simulator model) containing at least:
    a. Drag polar
    b. Power curve
    c. Maximum speed in level flight
    d. Maximum climb angle
    e. Flight envelope
4. Conclusion and recommendations for improvement, including a brief list of tips intended for the next group.

5. Quality

In this chapter, there will be described how the quality will be measured. This will be described in different chapters: quality control during interim results (5.1), quality control project results (5.2), feedback sessions (5.3), resources that will be used (5.4), software that will be used (5.5), quality about external resources including advice (5.6) and quality measurement by the use of drafts (5.7). After this chapter, it will be clear how the project group will measure quality and how the group ensures for a good project end result.

5.1. Quality control interim results

Each member of the project groups gets his own tasks. After finishing each task, the student has to check his own work for grammar and the agreed layout. By doing this, the quality of each person's work will be improved. The student also has to check if the correct data is used. These checks will speed up the final check at the end, because everything is already checked personally.

5.2. Quality control project results

The quality of total results is based on the interim results. As mentioned, every student has to check his own work. If some errors are detected in the students' work, the student can't continue. So, the student has to correct his work before continuing. By using this way of working, errors are excluded in the end result.

5.3. Feedback

During this minor, there are several times the students gets feedback on their work.

At first, two meetings are scheduled with their consultant. On Tuesday and on Thursday with D. Jatiningrum and R.P.A.M. Teunissen. Besides the meetings with the consultants, the students scheduled their own meeting every Monday to give each other feedback and discuss issues.

5.4. Resources

During this minor, several books will be used, knowledge out of the workshops will be used and, if necessary, resources from the internet will be used. All resources will be noted and mentioned at the end.

The resources will be processed into APA style into the bibliography.

5.5. Software

Every member of the project group will use the same kind of software. The software that will be used are:

- Microsoft Office Word to type reports.
- Microsoft Office PowerPoint to create presentations.
- Asta Power Project will be used to create the schedule.
- Microsoft Office Excel will be used for possible supporting activities.

Sharing software:

- Google Drive will be used to share documents.
- Dropbox will be used as a back-up to share documents.

5.6. External sources and external advice

In the minor, the interim results will be judged by the consultants and lecturers. Those people will give the students extra feedback and advice to improve the quality. If necessary, the consultants and lecturers could give extra resources to provide more information to the students.

5.7. Drafts

Every time an adjustment is made in a file, the document will be saved as new. This will be done, because otherwise important information could be lost what was included in previous documents.

6. Project organization

In this chapter the following items can be found: Information about the persons within the project (6.1), meeting hours (6.2), tasks during consultancy lessons (6.3), communication resources (6.4, sharing resources (documents) (6.5) and the selection of the treasurer and controller (6.6) and the work buddies (6.7). This chapter includes the names of the group members with their e-mail address and phone number.

6.1. Persons

In this subchapter one can find the contact information of the group members.

In Table 6.1-a the group members are visible with their belonging phone number and e-mail address.

Table 6.1-a Group Members

Name	Phone Number	E-mail
Fahad Al Janabi	+31 6 40681921	fahad.aljanabi.90@gmail.com
Leandra van Ommeren	+31 6 36222744	leandravanommeren@gmail.com
Andreu Gimenez Bolinches	+34 672 344465	angibo2@etsid.upv.es
Lars van Ginkel	+31 6 48879789	lars.van.ginkel@hva.nl
Stefan van der Schans	+31 6 42472505	stefan.van.der.schans@hva.nl

6.2. Meeting hours

In this subchapter is stated the group DBF-A agreement with respect to the meetings.

The project group will meet during the following activities:

- Consultancy lessons
- Scheduled meetings (By agreement, the meeting time will be scheduled at every Monday or Tuesday)
- Workshops

6.3. Tasks consultancy lessons

In this subchapter one can find the group DBF-A agreement with respect of the consultancy lessons tasks.

In Table 6.3-a the schedule is viewed about the tasks every person has every week.

The chairman will take the lead during the meetings and the secretary will take notes during the meetings.

Table 6.3-a Chairman and secretary schedule

Week	Phase of minor	Chairman	Secretary
6	*Startup*	Andreu	Lars
7			
8	*Concept*	Leandra	Andreu
9			
10			
11			
12	*Detail*	Fahad	Leandra
13			
14			
15			
16	*Build*	Lars	Fahad
17			
18	*May break*		
19			
20	*Test & Fly*	Stefan	Leandra
21			
22			
23			
24	*Evaluation*	Fahad	Stefan
24			
26			
27			

6.4. Communication resources

In this subchapter are stated the tools that will be used to arrange meetings and to communicate outside the meetings.

The project group will communicate with the following communication resources:

- WhatsApp
- Phone
- E-mail
- Skype

6.5. Sharing documents

In this subchapter is summarized the software that will be used only for the purpose of sharing resources.

Documents will be shared with the following two online tools:

- Google Drive

- Dropbox

6.6. Treasurer and Controller

In this subchapter is stated the Treasurer in charge of the group money transactions and responsible of the fund raising from the group members. Is also stated the Controller that will check all the Treasurer work and decisions.

Table 6.6-a Treasurer and Controller

Treasurer	Stefan van der Schans
Controller	Leandra van Ommeren

6.7. Buddy system

In this chapter one can find the chosen buddy system for work help and revision, we have taken into consideration the multidisciplinary character of the group to compensate the individual weaknesses and improve the overall performance.

In Figure 6.7-a is stated the buddy system that is made in a diagram form, with Table 6.7-a as a legend.

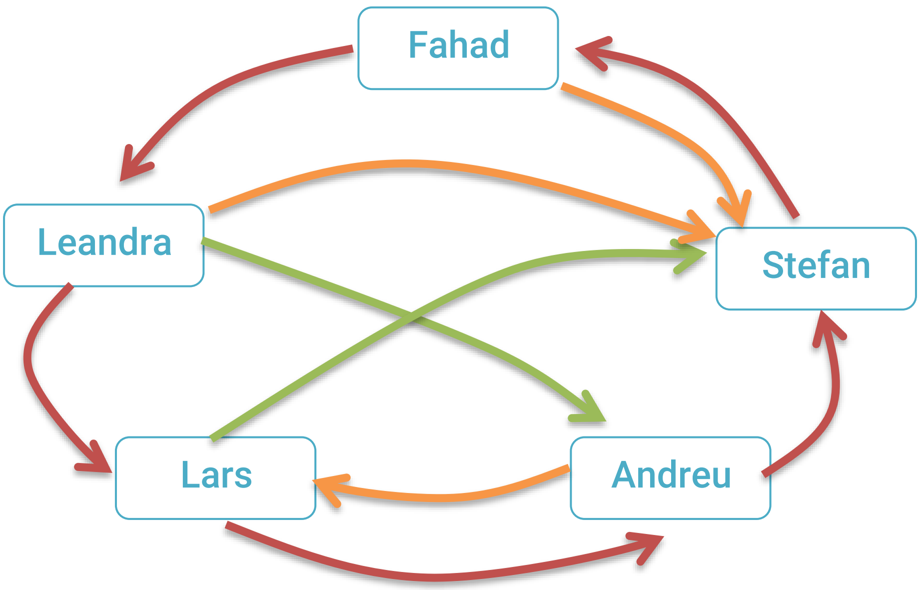


Figure 6.7-a Buddy System Diagram

Table 6.7-a Buddy Diagram Legend

Color	Meaning
Red	General work check
Green	Legislation and safety measures help and revision
Orange	Aircraft performance and general engineering help and revision

7. Planning

This chapter describes every aspect related to the planning for the minor Design, Build & Fly.

The planning for the upcoming semester is made in Asta Power Project. It's similar planning software as Microsoft Project but mostly used for construction planning.

Because there is quite a lack of information and knowledge about the minor it’s difficult to plan every action accurate. Because of that, the planning can vary or needs to be adjusted per phase.

The planning is a rough schedule of our actions and activities. The planning is seen in the appendix of the project plan Appendix I Project Gantt Chart.

8. Costs and benefits

This chapter describes every cost related to the minor Design, Build & Fly of semester 2, college year 2018/2019. Throughout the minor, there will be certain type of costs to complete the minor with success. The amount of costs depends on the phase of the project. The costs can be divided into costs related to the theoretical part of the minor (design) and the costs related to building the UAV (practical). In addition to that, there will be costs for transport to the Netherlands Aerospace Centre (NLR) for the Airworthiness Test, the Flight Test, and the Mission Flight.

In the first week, prior to the building and test phase, (which are the most expensive phases), it's hard to budget the upcoming costs. In Table 8.1-a is stated our estimation of the costs for each phase.

8.1. Costs per phase

At the start-up, the Project Plan is handed in digitally in PDF format, so there will be no cost during this phase. In the phases Concept, Detail, Individual Defense and Project Evaluation there will be costs resulted from printing the reports made relevant to the specific phase.

At the end of the Concept phase, a presentation must be given to the lectures and other students about the chosen concept. In this presentation, the philosophy behind the design is explained.

Hand-outs need to be available for the lectures which give the project group some costs. In the Detail phase, the Detail Design Report must be hand in hardcopy, which means there will be costs for printing. Also, the Production Plan is made within this phase. This report must be printed for workplace personnel in the basement of the HvA.

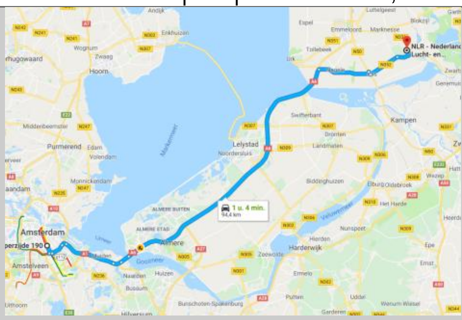
The budgeting for the construction of the airplane seen in table 1 is estimated because of the lack of knowledge about the costs of aircraft materials.

The correct budgeting for the construction of the UAV will further be elaborated in the Project Plan. In the Test & fly phase, the UAV tests will be performed at the NLR's test site in Marknesse. To reach Marknesse the car will be used as the transport method, from the HvA it's around 95 kilometers to the NLR. For a two way, it's 190 kilometers, which costs around €10,11 each time. In total, NLR test field must be visited 2 times.

At the end of the minor, during the Evaluation phase, an individual presentation is given. A handout given to the lecture is mandatory, which brings the costs of printing. In the last product of the minor, the Project Evaluation Report there will be costs made for printing as well. The costs of the Project Evaluation Report are estimated for around €3,20 per person.

Table 8.1-a Estimated costs per phase

Phase	Product	Type of costs	Costs Description
Start-up	Project Plan	Non (digital hand in)	€0, -

Concept	Concept presentation	Hand-outs	€0,30-0,40 each page, approximately 40 slides * 2 (lecture and second assessor) = €32, - / 5 = €6,40 per person
Detail	Detail Design Report	Production Plan Report	€0,30-0,40 each page, approximately 60 pages = €24, - / 5 = €4,80 per person
		Report for workplace personnel	€0,30-0,40 each page, approximately 40 pages = €16, - / 5 = €3,20 per person
Build	Wing strength test	Material for building the wing	Composite Skin: Approximately €20, - per person
	Aircraft construction	Building the complete UAV	Batteries, engine and electronics are included. Servo's and structure of the UAV is sponsored by the students group. Estimated cost per person: €60, -
Test & fly	Airworthiness Test	Transport to the NLR	 To drive to the NLR by car it's a distance of 95 km for one way from the HvA. That means to go to the NLR once it's approximately 190 km. With a car driving 1:12 it's around 15,8 L of fuel. 15,8 L of fuel times the fuel price of €1,60 = €25,28 For 3 retour drives to Marknesse the total cost will be 3 times the cost above. Total cost of transport: €25,28 * 3 ≈€76, - / 5 = €15,20 per person
	Flight Test	Transport to the NLR	
	Mission Flight	Transport to the NLR	
Evaluation	Individual Defense	Hand-out individual presentations	€0,30-0,40 each page, approximately 20 slides * 0,40 = €8, - per person
	Project Evaluation Report	Report of max. 20 pages	€0,30-0,40 each page approximately 40 pages * 0,40 = €16, - / 5 = €3,20 per person
Total cost per person			+- €121

8.2. Benefits

In this subchapter are stated the benefits that the group DBF-A will receive from the developing of the project.

The benefits the students will perceive after the development of the project are the following learned abilities:

- Effectively manage and function within a multidisciplinary design project
- Design a model aircraft using composite materials and integration of autopilot technology
- Use Engineering software and simulators for design validation and prediction
- Production phase experience and feedback of the importance of the design protocols in the production stage
- Critically assess design quality
- Prepare and execute unmanned aerial missions

9. Risk analysis

This chapter contains the overall risks of this project in general. It is important to know where the risks and possible bottlenecks are in a project when one decides to start one with a project group. When the risks are known one can decide whether to start this project or not. It is also important to identify the risks, so that it can be taken into consideration when making decisions. This will be rendered in a graphical chart and table (9.1).

9.1. The risks

In this subchapter one can look at the graphical chart and the table which contains vital items (such as time factor, complexity etc.) that have a risks factor during a project.

These vital items got a maximum score. The maximum score and graded score are based upon an Excel sheet that have been made by Jurgen Winkel. He has made this risk Excel sheet with the vital items based upon his 22 years of project management experience. The Excel Sheet contains specific questions that every project management can use to determine the risks when doing a project. See Appendix III Risk Analysis Calculations for the specific information.

Table 9.1-a Risk Table

Category	Maximum Score	Graded Score	Percentage %
Time Factor	40	16	40
Complexity	80	40	50
Project Group	65	35	54
Project Management	129	39	30
Project Definition	119	19	16
Total	433	149	34

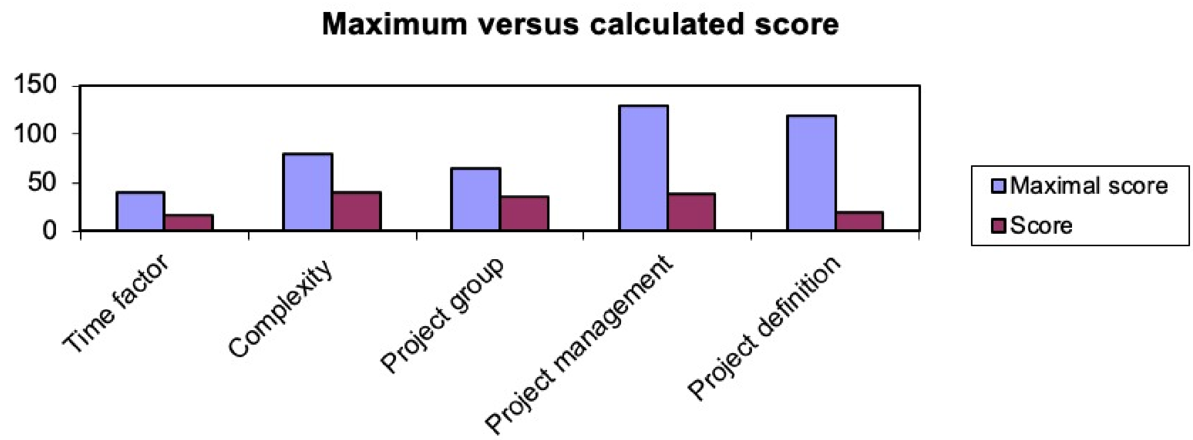


Figure 9.1-a Maximum versus Calculated Risk Score

If one looks at the first item, time factor (table 9.1-a) one can see that the time factor has a relative low rating. This is because the time given (20 weeks) is enough to design and construct the UAV. The only issue that could jeopardize this rating could be that the group DBF-A does not follow the schedule as planned due to circumstances. When the schedule is not followed important deadlines could be missed which have a huge impact on the time factor.

If one looks at the next item, complexity, one can see that complexity has a rating that could have a serious influence on the final results of this project. The complexity of this project has this rating and influence due to the fact that not every member of the group DBF-A has the same broad knowledge about aviation engineering.

If one looks at the third item project group, one can see that the project group is even almost important as the complexity. The reason the project group has also an important influence on the project is that every member of the group DBF-A has a different culture background. Language, costumes and working experience in project groups can be a barrier between the members. This needs to be monitored to prevent any changes in the group dynamic and formation.

If one looks at the fourth item project management one can see that this is has a relative low rating. The project management will be well accomplished by making use of the list of chairman and secretary, the buddy system list and the consultation done by the consultants.

If one looks at the last item project definition, one can see that this has the lowest rating. The definition of this project is well defined by using the Design, Build and fly guide book. It is also defined by making this project plan.

After this analysis, can be concluded that the success of the project will depend mostly on the behavior of the group as a team. If the group is able to work together balancing the background differences and weaknesses (“Complexity” risk item) and outstanding the cultural differences (“Project group” risk item) the probability of success is favorable.

Bibliography

Böing, B. (2019, February 6). *Design, Build and Fly guide book*. Retrieved from https://studiedelen.mijnhva.nl/studiedelen/ft-6000MDBF18/1819/Documents/Guidebook%20Aviation%20Minor%20DBF%202018-2019%20SEM2%202019-01-25.pdf

Conrad. (2019, April 3). *Kavan scharnier (10 stuks)*. Retrieved from www.conrad.nl: https://www.conrad.nl/p/kavan-scharnier-10-stuks-228770?WT.mc_id=gshop&gclid=Cj0KCQjws5HlBRDIARIsAOomqA1tGQmUjScGgqpXrbd4wzPxVFUs5uABgMb1nNMWTCdPLooPuV7ZWPYaAqNvEALw_wcB&tid=965091570_48108088975_pla-296303633664_pla-228770&WT.srch=1&vat=true&insert_kz=8J

DBF-A. (2019). *Detail Design Report.*

EASA. (n.d.). *EASA CS-23 Normal, Utility, Aerobatic and Commuter Aeroplanes, Amendment 5*. Retrieved February 11, 2019, from www.easa.europa.eu: https://www.easa.europa.eu/sites/default/files/dfu/CS-23%20Amendment%205.pdf

Grit, R. (2015). *Project Management: A practical approach.* Groningen/Houten, the Netherlands: Noordhoff Uitgevers.

IIT Kanpur. (n.d.). *Flight Determination of the Drag Polar*. Retrieved February 22th, 2019, from http://www.iitk.ac.in/aero/fltlab/flight.html

John D. Anderson, J. (1999). *Aircraft Performance and Design.* McGraw-Hill.

John D. Anderson, J. (2011). *Fundamentals of Aerodynamics.* Mcgraw-Hill Education - Europe.

NLR. (n.d.). *AS-RPAS1*. Retrieved February 11, 2019, from www.nlr.nl: https://www.nlr.nl//downloads/technical-requirements-class-1-rpas.pdf

Safety Flight Foundation. (n.d.). *Skybrary*. Retrieved June 27th, 2019, from Flight Envelope: https://www.skybrary.aero/index.php/Flight_Envelope

Winkel, J. (n.d.). *Risk sheet*. Retrieved February 11, 2019, from https://www.google.com/search?q=risk+sheet+by+jurgen+winkel&oq=risk&aqs=chrome.1.69i59l2j69i57j35i39j69i59j69i60.5872j0j4&sourceid=chrome&ie=UTF-8

Appendix I Project Gantt Chart

In the following link one can find the proper Gantt Chart in full scale in a pdf format
https://drive.google.com/open?id=1blnP3MdStNKCO4WiG8UM4jtA07_jRqKC

Appendix II EASA CS-23 Requirements that must be fulfilled

CS 23.2120 Climb requirements

The design must comply with the following minimum climb performance out of ground effect:

(a) with all engines operating and in the initial climb configuration(s):

(1) for Level-1 and -2 low-speed aeroplanes, a climb gradient of 8.3 % for landplanes and 6.7 % for seaplanes and amphibians; and

(2) for Level-1 and -2 high-speed aeroplanes and all Level-3 and -4 aeroplanes, a climb gradient at take-off of 4 %.

(b) after a critical loss of thrust on multi-engine aeroplanes:

(1) for Level-1 and -2 low-speed aeroplanes that do not meet single-engine crashworthiness requirements, a climb gradient of 1.5 % at a pressure altitude of 1 524 m (5 000 ft) in the cruise configuration;

(2) for Level-1 and -2 high-speed aeroplanes, and Level-3 low-speed aeroplanes, a 1 % climb gradient at 122 m (400 ft) above the take-off surface with the landing gear retracted and flaps in the take-off configuration; and

(3) for Level-3 high-speed aeroplanes and all Level-4 aeroplanes, a 2 % climb gradient at 122 m (400 ft) above the take-off surface with the landing gear retracted and flaps in the approach configuration;

(c) a climb gradient of 3 % during balked landing, without creating undue pilot workload, with the landing gear extended and flaps in the landing configuration(s).

CS 23.2125 Climb information

(a) The applicant must determine, as applicable, climb and/or descent performance:

(1) for all engines operating;

(2) following a critical loss of thrust on take-off; and

(3) after a critical loss of thrust, during the en route phase of flight.

CS 23.2235 Structural strength

The structure must support:

(a) limit loads without:

(1) interference with the safe operation of the aeroplane; and

(2) detrimental permanent deformation.

(b) ultimate loads.

Appendix III Risk Analysis Calculations

Risk analysis

Risk Analysis	Print date
	13/02/2019

Risk		Value *	Factor **	Weight ***	Total risk
Time factor		↓maak keuze↓			
1	Estimated duration of project	3 - 6 months	1	4	4
2	Does the project have a definite deadline?	Yes	2	4	8
3	Is there enough time to complete the project within the time permitted?	enough	1	4	4
Complexity of project		↓maak keuze↓			
4	Number of functional subsectors involved	3+	3	4	12
5	Number of functional subsectors that will make use of the results of the project	4	2	2	4
6	Is is a new project or one that will be adapted?	New project	3	5	15
7	To what extend do current authorizations in the organization have to be adjusted?	Not	0	5	0
8	Are other projects dependent on this project?	No	0	5	0
9	How are users (of the project results) likely to respond to it?	Enthousiastic	0	5	0
10	Is the project broken down into phases and does the project depend on coordination between them?	Strongly	3	3	9
The project group					
11	Where do the project workers come from?	Mainly externally	3	4	12
12	Where is the project located?	1 location	0	2	0
13	How many project members work for more than 80% at peak hours?	5-10	2	5	10
14	Balance between subject experts and project experts	Avarage	2	5	10
15	Are users involved in the project?	to a reasonable extend	1	3	3
Project management		↓maak keuze↓			
16	Does the project management team have any knowledge of the subject?	a reasonable amount	2	3	6
17	Does the project management have any knowledge of how to plan a project?	little	4	3	12
18	How much experience does the project manager have with a project like this?	a reasonable amount	1	3	3
19	Does the adviser have much knowledge of the field of the project?	a lot	0	5	0
20	Do the subject experts have much knowledge of the field?	a lot	0	5	0
21	How involved are responsible managers in the project?	reasonably involved	2	5	10
22	Is there any chance that the project team will change during the project?	little chance	0	5	0
23	Is the project team using existing methods or are they creating their own tools?	some existing methods	2	4	8

Risk analysis continued ….

	Risk	Value *	Factor **	Weight **	Total risk
Project definition		↓maak keuze↓			
24	Are project members sufficiently aware of problems and objectives?	most of them	1	5	5
25	Is the field of result (scope) sufficiently defined?	reasonably	2	5	10
26	Is there enough distinction between this project and other projects?	considerable	0	4	0
27	Has enough time been resereved for coordination and decision-making?	reasonable	1	4	4
28	Are the boundaries and preconditions clear?	yes	0	4	0
29	Are the boundaries limiting enough?	yes	0	5	0
			Total		**149**
			Risk percentage * **		**34.41%**

** Value chosen by project manager*
*** Defined factor in this model.*
**** Risk percentage is total score divided by 433 (maximal score) times 100.*

The risk percentage provides an overview.
If the percentage is higher than 50%, the project should not carried out in this form.
The next table shows the risk percentage per catagory.

Category (maximum score versus calculated score)				
Time factor	Maximal	40	Score	16
Complexity	Maximal	80	Score	40
Project group	Maximal	65	Score	35
Project management	Maximal	129	Score	39
Project definition	Maximal	119	Score	19

In the following link one can also find the Excel file used for the calculations shown above:

https://drive.google.com/open?id=14PFdjljeR9FBjZu3EL15VwfzPBthpEVG

-CONCEPT DESIGN PRESENTATION-

Contributions

The author of the thesis, Andreu Giménez Bolinches, was responsible of the lay-out of the deliverable, the sketching of the concepts, provided the voting tool in order to chose the final concept, made the preparation steps of the STPA provided in the concept phase, was responsible of the 3D design and renders and the initial flight mechanics calculus and mass estimation.

Grading

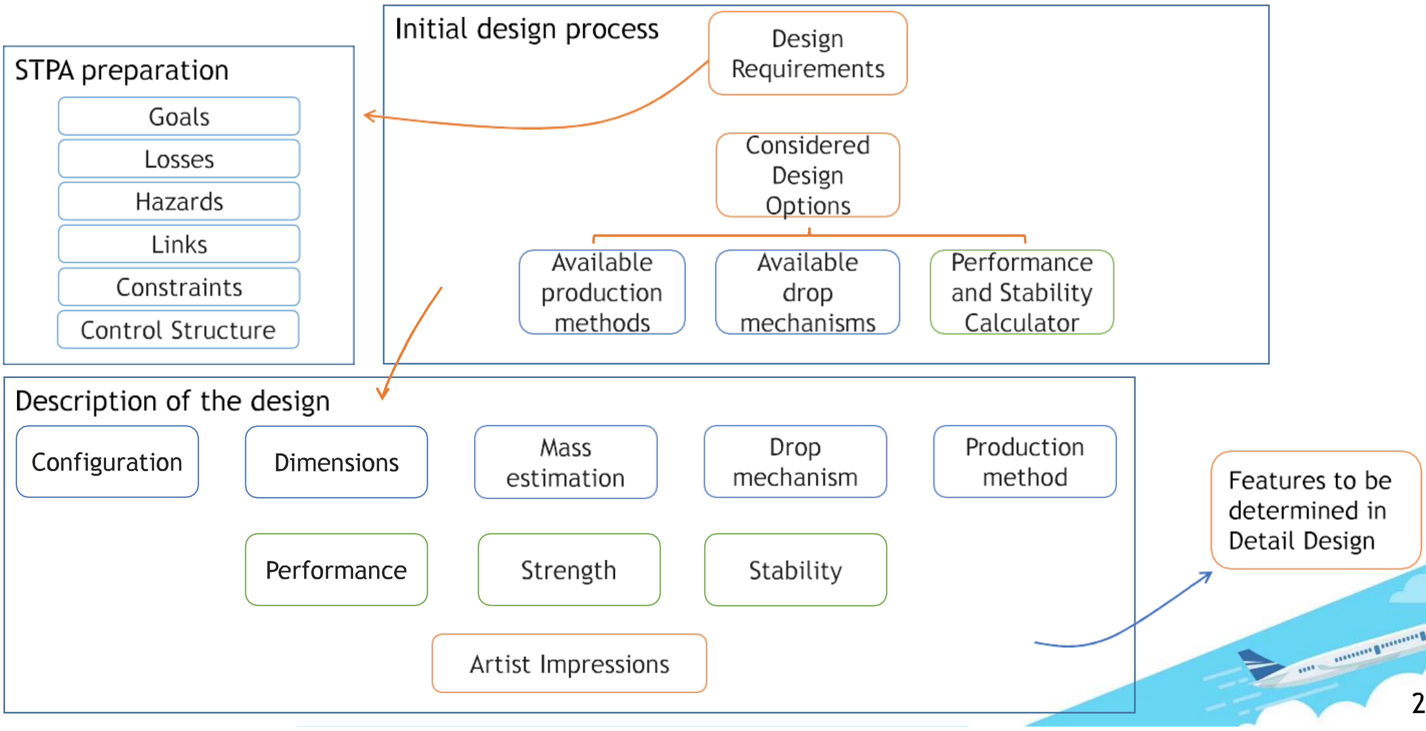
The overall grade of the presentation is 7.2 out of 10, having also the following comments about specific points graded by teachers that were not present during the oral defense.

Strength analysis (Preliminary), including concept of composite lay-up for wing design	Nice complete overview
Hazard analysis using STPA	There are more goals in the DBF manual. H3 and H4 refer to specific components not to the system, H4 is part of H2 without navigation sense the system is uncontrolled. There are more safety constraints. Controller 1 has no feedback for the position of the system, he knows the position of it from the human in ground station, according to the control loop.
Artist impression of the aircraft design (with Fusion 360)	The final concept is very nicely worked out, animation is also fine. Definitely had a spacious enough. Only miss the concepts from the rest of the group, not only in the presentation but also in fusion I can see that 3 of the five members there is no to almost no toils have put in.

Concept Design Presentation

Presented by:
Andreu Gimenez
Lars van Ginkel
Leandra van Ommeren
Fahad al Janabi
Stefan van der Schans

Flow Chart



List of requirements

Design parameters limitations:
- **Able to accelerate to Take-Off speed from 5 m/s quickly**
- **Enough lift at landing speed 8 m/s (stall speed equal to landing speed)**
- Full Thrust: Climbing gradient of 8.3% -> 4.7° Path Angle (Minimum Limit Load Factor)
- **Fully manoeuvrable within 500m of the Pilot In Command (take-off, cruise, turn and landing)**
- Limited Cost (affordable for everyone)
- **Design speed between 15-20 m/s confidence speed of the pilot**
- To perform a safe landing in automatic mode
- **Reusable, needs to fly at least 2 times (test flight & mission flight)**
- **Right and Left, Front and Rear parts distinguishably: Navigation lights/distinguishing colours/LED**
- **Paint package in a distinguishing colour, recognizable between the grass of the NLR airfield**

- Maximum allowable mass: 4 kg (RPAS-regulations)
- **To carry the maximum payload (rice package with a maximum weight of 200 grams, the use of parachute is not necessary)**
- **Aim for 3kg with payload**
- Maximum main wingspan: 2 m
- Main wingspan skin made of composite materials
- Electrical components (except servos) provided by the educational institute
- **Thrust limited (2.2 kg (eCalc))**
- Drag limited
- Static and dynamic stable
- Hand launched
- Fixed wing
- One engine

List of requirements

Specific Subsystems:
- **To drop the payload accurately in the target**
- **To follow accurately the programmed route in automatic mode**

Additional requirements:
- Restricted flight areas:
  - Traffic, contiguous buildings, ports, industrial area's or people crowds
  - A protected nature reserve above which a ban has been imposed as a result of nature conservation legislation
  - A temporary restriction of prohibition, published with a NOTAM
  - Nearby CTR's (neither general- , military- or civil aviation)

- Pilot is in possession of a RPA-L certificate
- **Maximum altitude of 120m above ground level, maximum altitude of 500m at the NLR**
- **The UAV must be in sight at all times**
- Flying at night or after sunset is prohibited → navigation lights, strobes and beacon lights do not have to be designed (maybe for orientation of the pilot)
- Distance of at least 3 KM from uncontrolled nearby airports

STPA: Goals

ID	Title
SG-1	To carry the maximum payload
SG-2	To perform a safe landing in automatic mode
SG-3	To follow accurately the programmed route in automatic mode
SG-4	To drop the payload accurately in the target

STPA: Losses

ID	Title
A-1	Not to carry any payload (H-3)
A-2	Not performing a safe landing in automatic mode (H-4,H-2,H-1)
A-3	Not following the accurately programmed route in automatic mode (H-2,H-1)
A-4	Not to drop the payload accurately in the target (H-4,H-3,H-2)

STPA: Hazards

ID	Title
H-1	Not maintaining a safety distance between the UAV and environmental obstacles
H-2	Inadequate control of the system
H-3	Malfunction of the dropping system
H-4	Loss of the navigation sense

STPA: Constraints

ID	Title
SC0.1	Keeping a safety distance between the UAV and environmental obstacles (A-4,A-3.A-2)
SC0.2	The UAV system shall be adequate controlled (A-3,A-2)
SC0.3	The payload dropping ability shall be maintained (A-4,A-1)
SC0.4	The navigation sense shall be kept (A-4,A-3.A-2)

STPA: Links

ID	Title
A-1	Not to carry any payload (H-3)
A-2	Not performing a safe landing in automatic mode (H-4,H-2,H-1)
A-3	Not following the accurately programmed route in automatic mode (H-2,H-1)
A-4	Not to drop the payload accurately in the target (H-4,H-3,H-2)

ID	Title
H-1	Not maintaining a safety distance between the UAV and environmental obstacles
H-2	Inadequate control of the system
H-3	Malfunction of the dropping system
H-4	Loss of the navigation sense

ID	Title
SC0.1	Keeping a safety distance between the UAV and environmental obstacles (A-4,A-3.A-2)
SC0.2	The UAV system shall be adequate controlled (A-3,A-2)
SC0.3	The payload dropping ability shall be maintained (A-4,A-1)
SC0.4	The navigation sense shall be kept (A-4,A-3.A-2)

STPA: Goals

No.	System Goal
SG-1	To carry the maximum payload (rice package)
SG-2	To perform a safe landing in automatic mode
SG-3	To follow accurately the programmed route in automatic mode
SG-4	To drop the payload accurately in the target
SG-5	To contain the payload (rice) in its envelope

STPA: Losses

ID	Title
A-1	Not to carry any payload
A-2	Not to perform a safe landing in automatic mode
A-3	Not to follow the programmed route in automatic mode
A-4	Not to drop the payload in the target
A-5	Not to contain the payload in its envelope

STPA: Hazards

ID	Title
H-1	Not maintaining a safety distance between the UAV and environmental obstacles
H-2	Inadequate control of the system
H-3	Malfunction of the dropping system
H-4	Loss of the navigation sense
H-5	Produced UAV characteristics does not match the required performance

STPA: Constraints

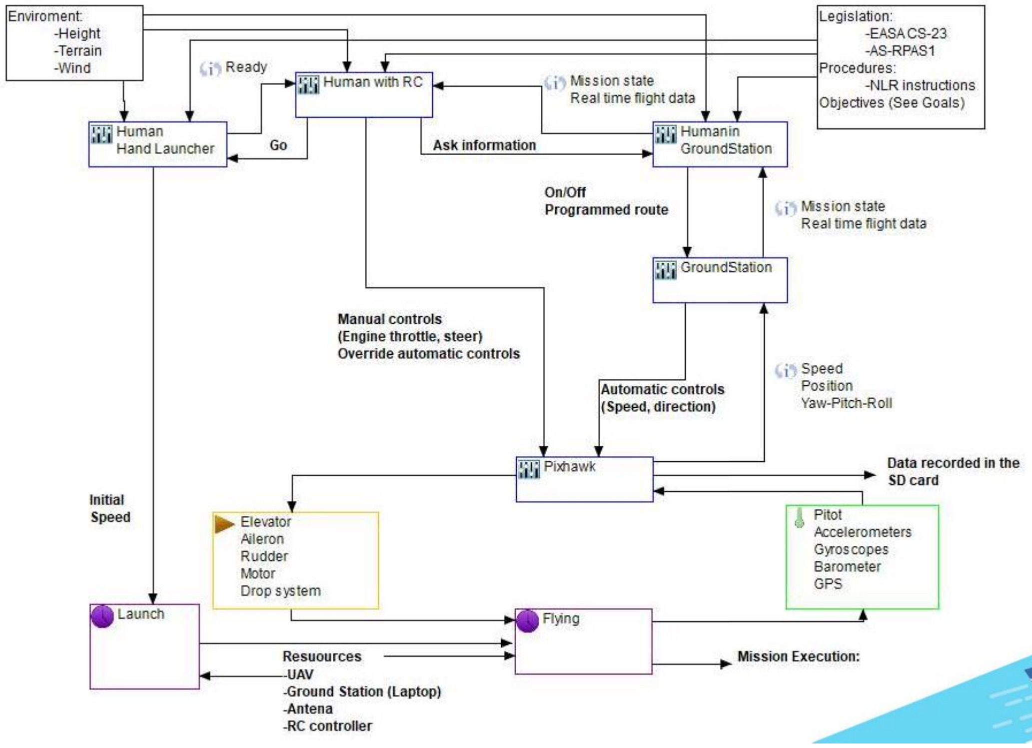
ID	Safety Constraint
SC0.1	Safety distance between the UAV and the environmental obstacles shall be mantained
SC0.2	The UAV shall be controlled properly
SC0.3	The payload dropping ability shall be maintained
SC0.4	The navigation sense shall be kept
SC0.5	The produced UAV characteristics shall match the required performance

STPA: Links

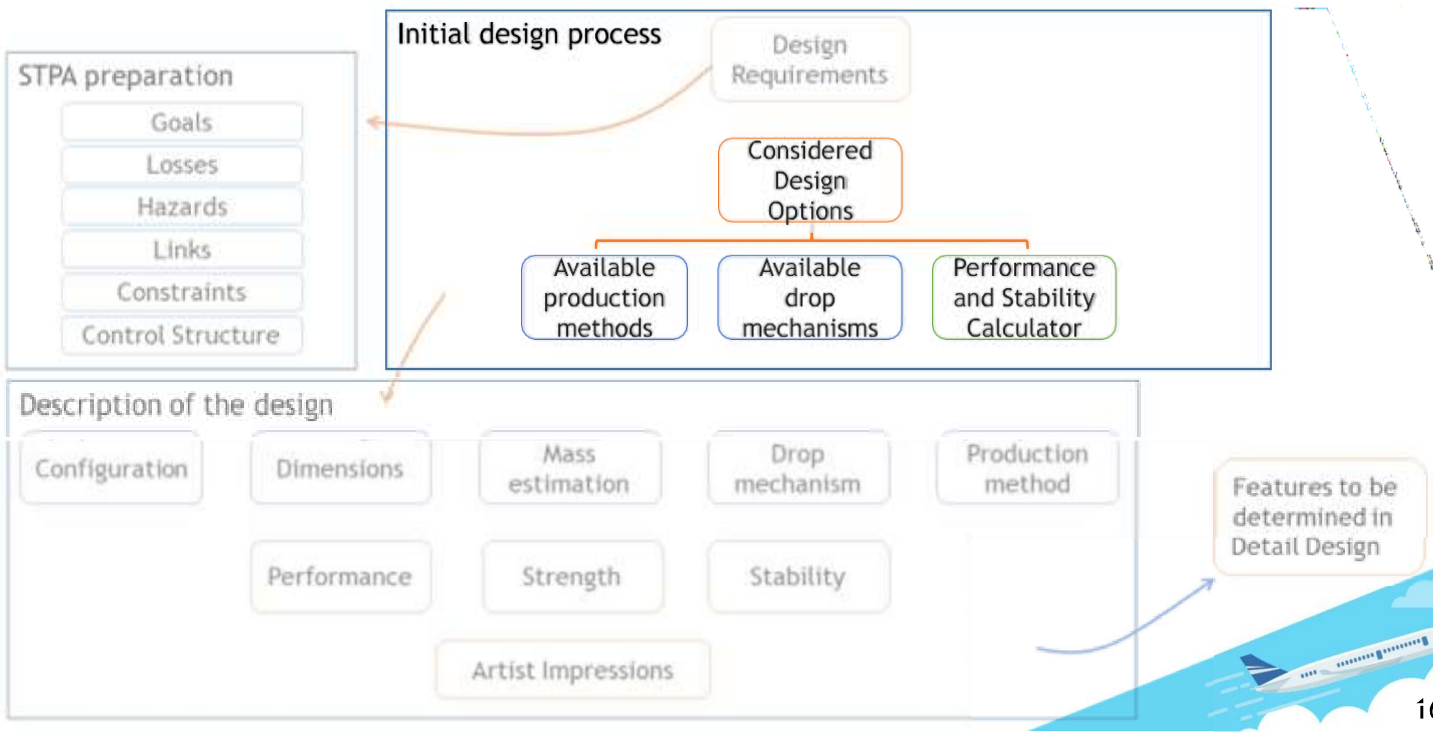
ID	Title	
A-1	Not to carry any payload	H-3, H-5
A-2	Not to perform a safe landing in automatic mode	H-4, H-2, H-1
A-3	Not to follow the programmed route in automatic mode	H-4, H-1, H-2, H-5
A-4	Not to drop the payload in the target	H-3, H-4, H-5
A-5	Not to contain the payload in its envelope	H-3, H-1

ID	Title
H-1	Not maintaining a safety distance between the UAV and environmental obstacles
H-2	Inadequate control of the system
H-3	Malfunction of the dropping system
H-4	Loss of the navigation sense
H-5	Produced UAV characteristics does not match the required performance

STPA: Control Structure

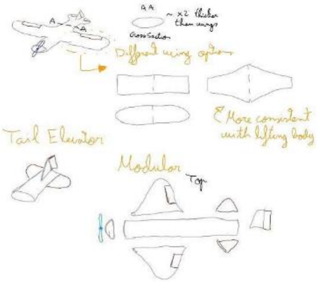


Flow Chart

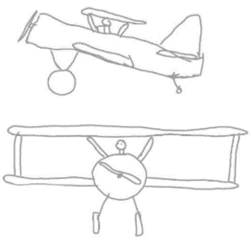


Design Options

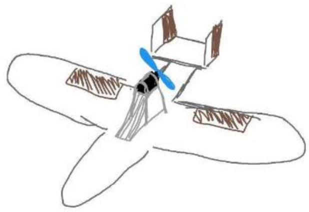
Lifting body



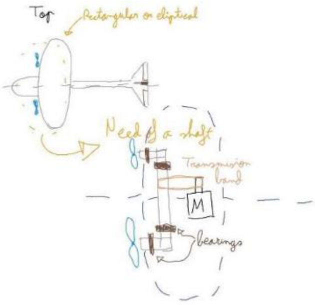
Bi-plane



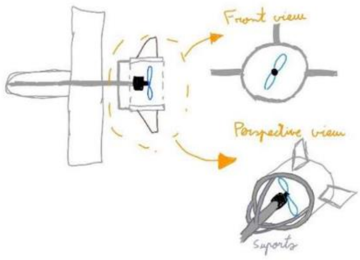
Boeing A10



2 Propeller plane



Covered propeller plane



Dihedral wing plane

Available Production Methods

Body

Beams

Laser cut, balsa wood…

3D print

Foam

Polystyrene, Polyurethane …

Available Production Methods

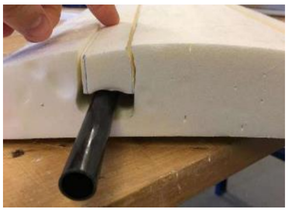
Surface

Shrinking Foil

Composite Skin

Resin coating

Reinforcements



Carbon fiber tubes

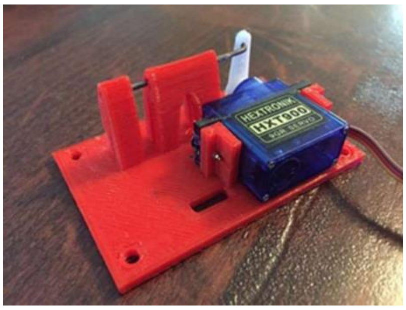
Wood beams
Local composite skin
...

Available Dropping Systems

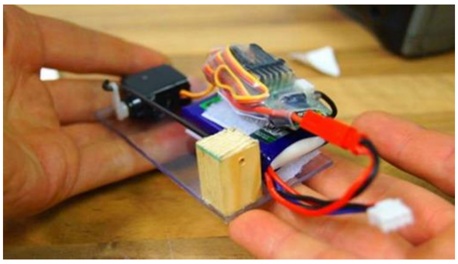
- Own requirements:
  - Payload stored inside fuselage
  - Custom drop system

If it’s too complex we will switch to payload stored outside fuselage

- Frame options

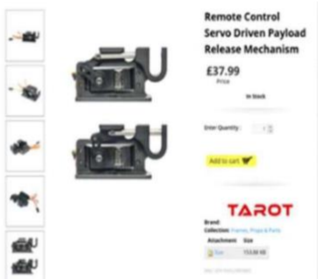


3D printed dropping system



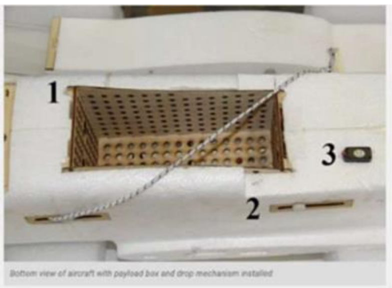
Dropping system on Plexiglas/wooden plate

Remote control servo driven payload release mechanism

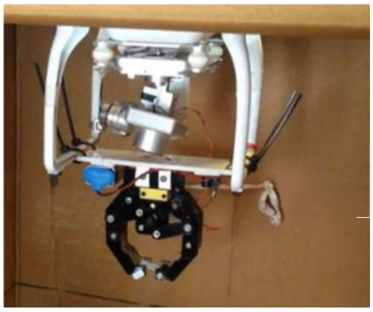


Available Dropping Systems

- Release mechanisms options

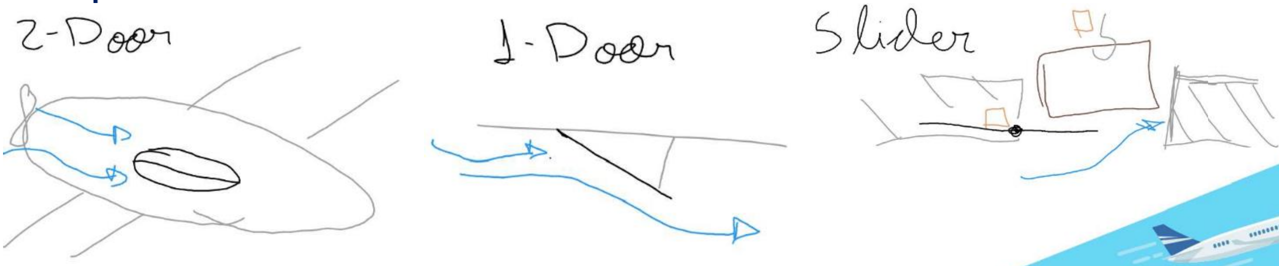


Box



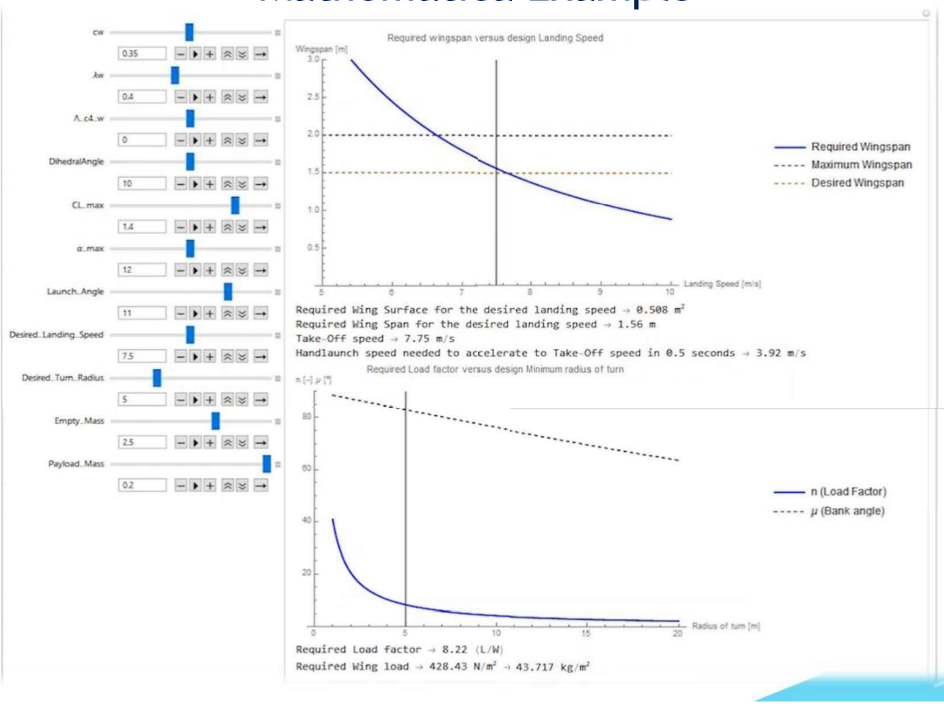
Hook

- Door options



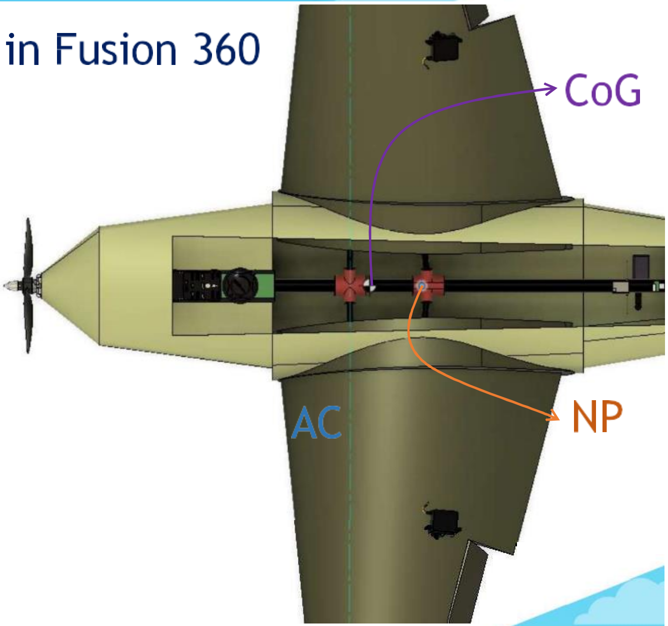
Performance Calculator

Mathematica Example



Stability Calculator

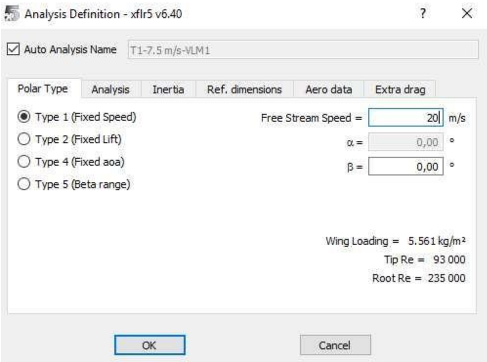
- Graphically in Fusion 360



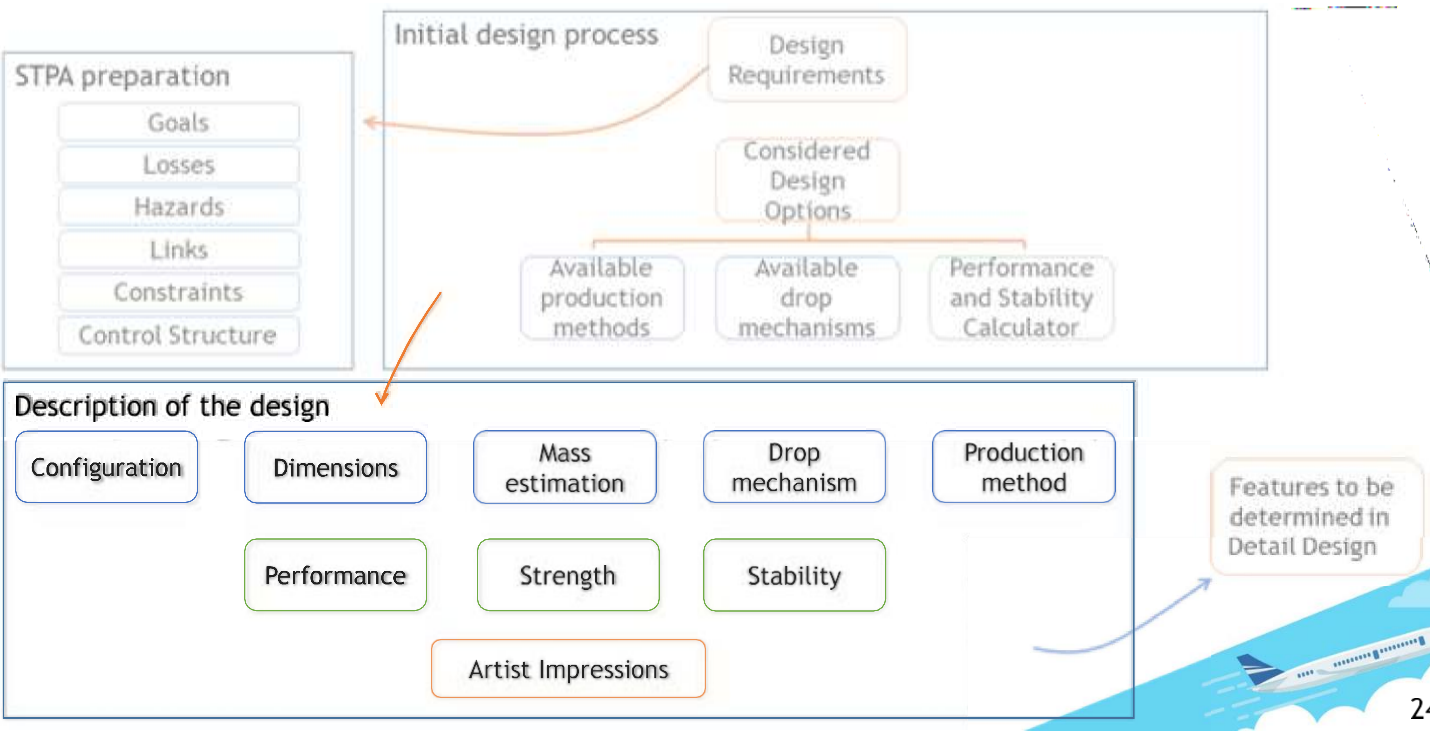
- More in detail calculus in Mathematica

$$ME = \text{STATIC MARGIN} = \left|\frac{xCoG - xNP}{c_w}\right| > 0$$

- XFLR model and analysis



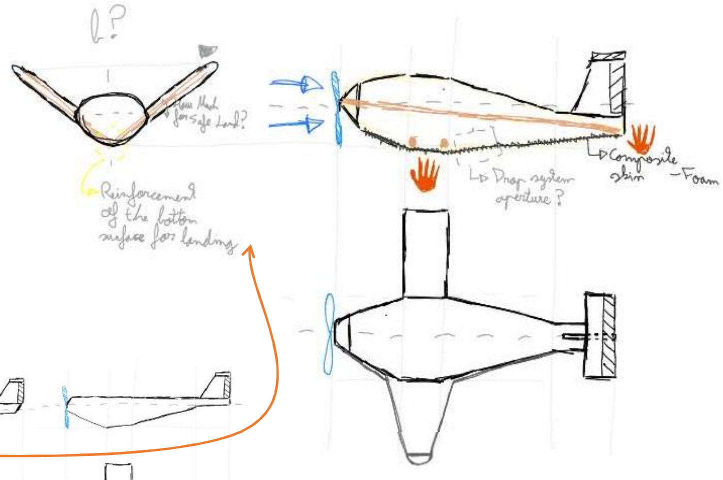
Flow Chart

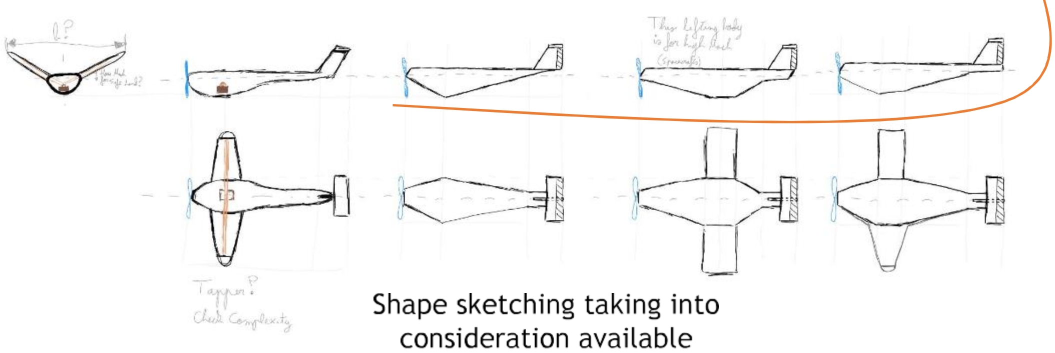


Design Chosen

Dihedral wing plane

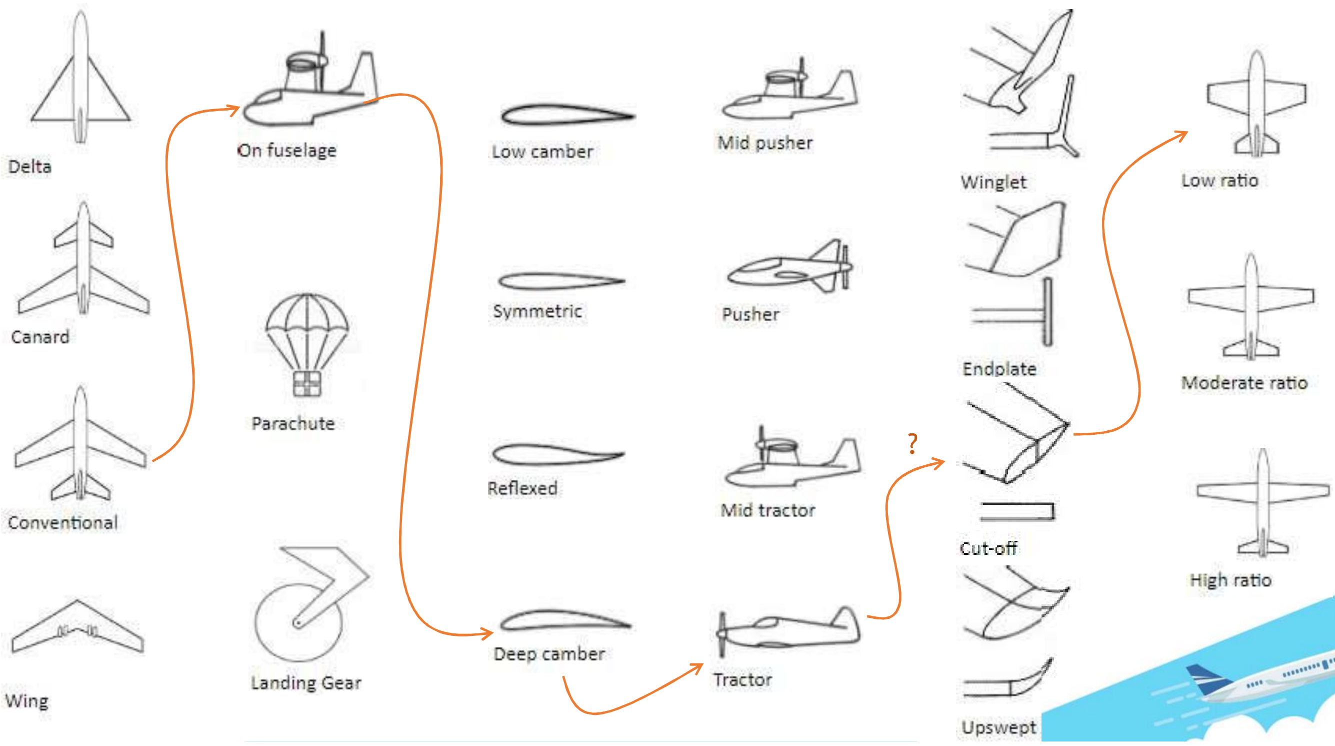
- Personal reasons
  - Voting
- Production wise





Shape sketching taking into consideration available production methods

Morphological Overview



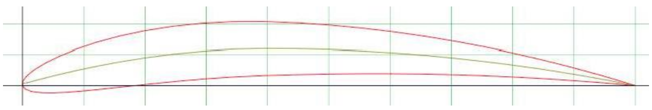
Configuration

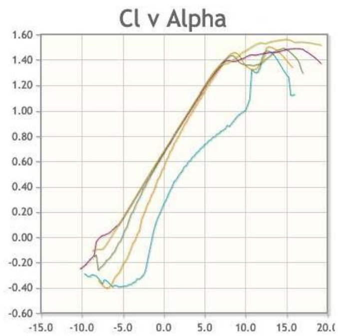
Main non-conventional features

- Dihedral
- T-tail
- Slight lifting body
- Drop package in fuselage

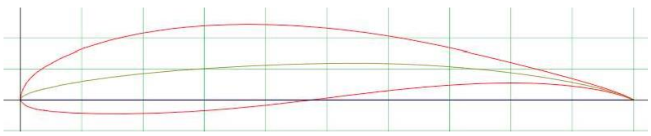
Configuration: Wing Airfoils

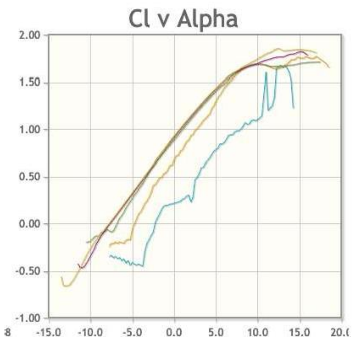
- NACA 6409





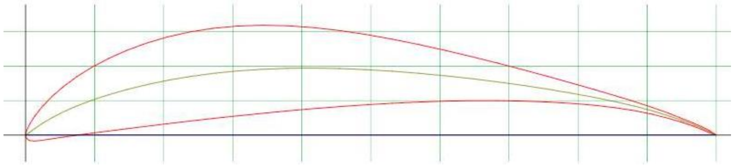
- WORTMANN FX 63-137 AIRFOIL

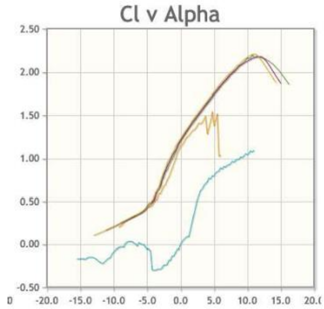




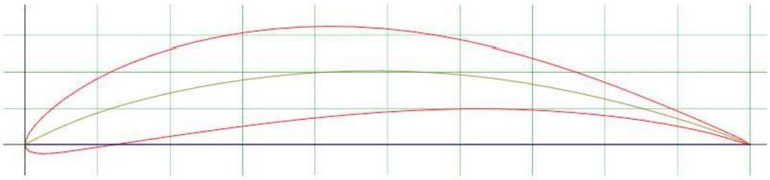
Configuration: Wing Airfoils

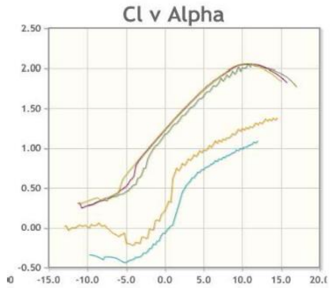
- FX 74-Cl5-140 MOD



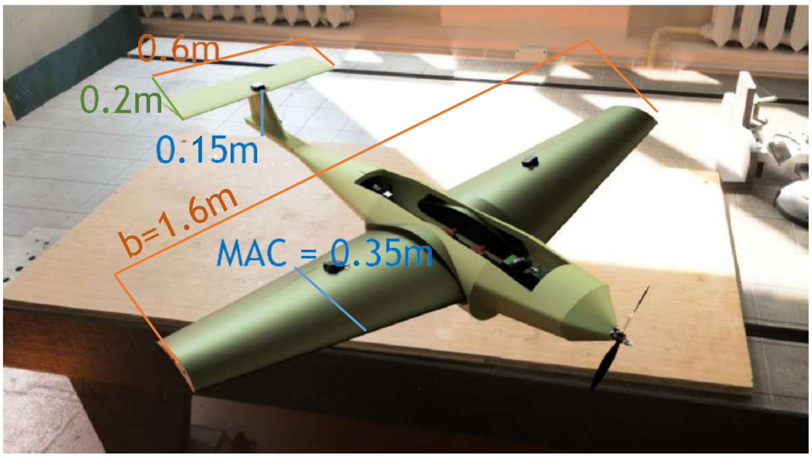


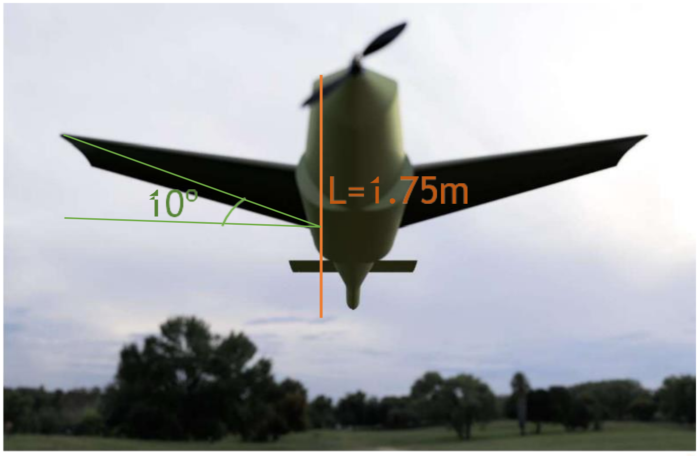
- CH 10-48-13 Chosen





Dimensions

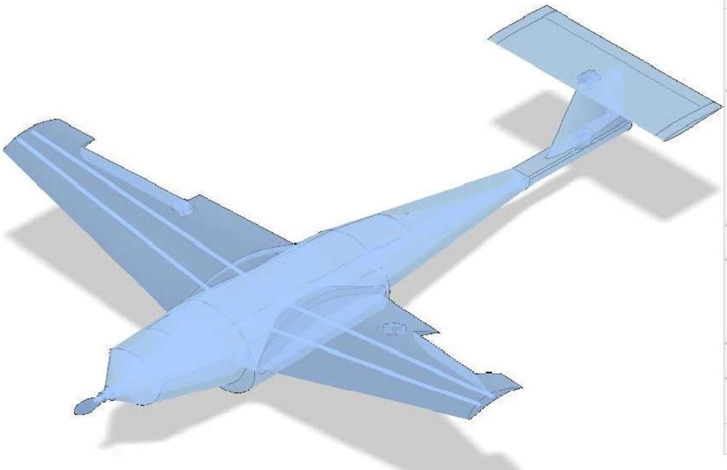


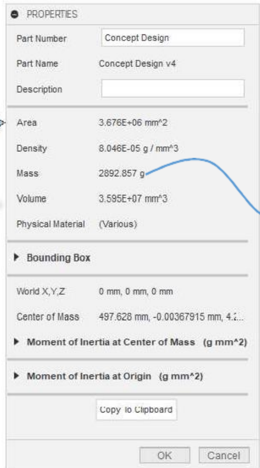


Mass Estimation

- Fusion 360 estimation

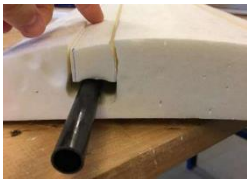
- How?
  - Components real weights
  - Wing density with fiber glass estimation from tests
  - Foam density over estimation, compensation for glue or coatings





Top empty weight limit:
2,9 kg

Chosen production methods



- Polystyrene- / polyurethane foam (to be determined)
- Composite glass fiber skin
- Carbon rod connection between wings & fuselage
- 3D printed connection between rods

Why?

- More confident in the chosen production method
- Easier to practice with our design shapes
- Easy to repair when necessary
- High flexibility, adjusting some elements is easy
- Relative low weight
- High strength & impact resistance

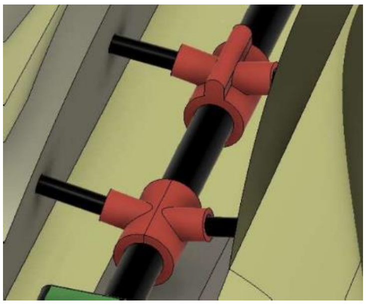
Foam

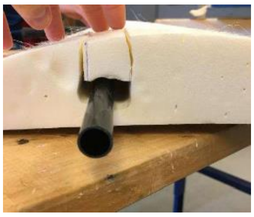
- Most common ones are Polystyrene (EPS/XPS) or Polyurethane foam (PU)
- Lightweight
- Easy to process and create every desired shape using hot wire thread & sanding machines
- 4 times stiffer than Balsa wood, almost same modulus of elasticity
- Waterproof
- Cheaper than Balsa wood
- Toxic fumes when heated, gas masks are recommended

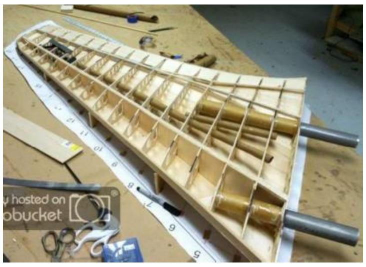
First attempt chambered & tapered wing

Carbon rods

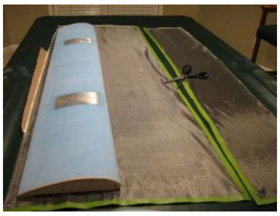
- Connection between wings and fuselage
- Preventing torsion of the wing
- High strength low weight ratio
- Connection between carbon rods will be 3D printed according to the principle below
- Wires can be stored inside the foam parallel to the carbon rods





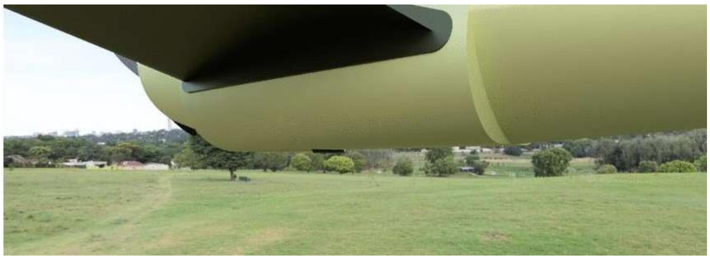


Composite skin



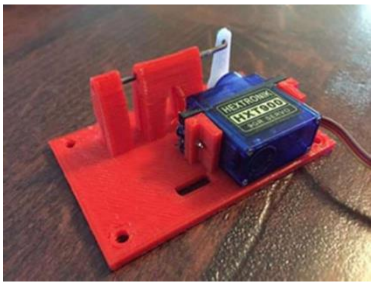
- Highest strength-weight ratio of all structures
- Lightweight
- Design flexibility, every desired shape can be created
- High strength, can be engineered to be strong in a specific desired direction
- High elasticity, a lot of flex without breaking
- Can withstand high impact when the resin has dried
- Durable
- Lower material costs
- Heat resistance
- Glass or carbon fibres used, depends on needed strength and budget

Chosen dropping system



3D printed mounting with hook
Advantages:
- Easy to install.
- Very easy to install the system outside the aircraft in case we can't make the door

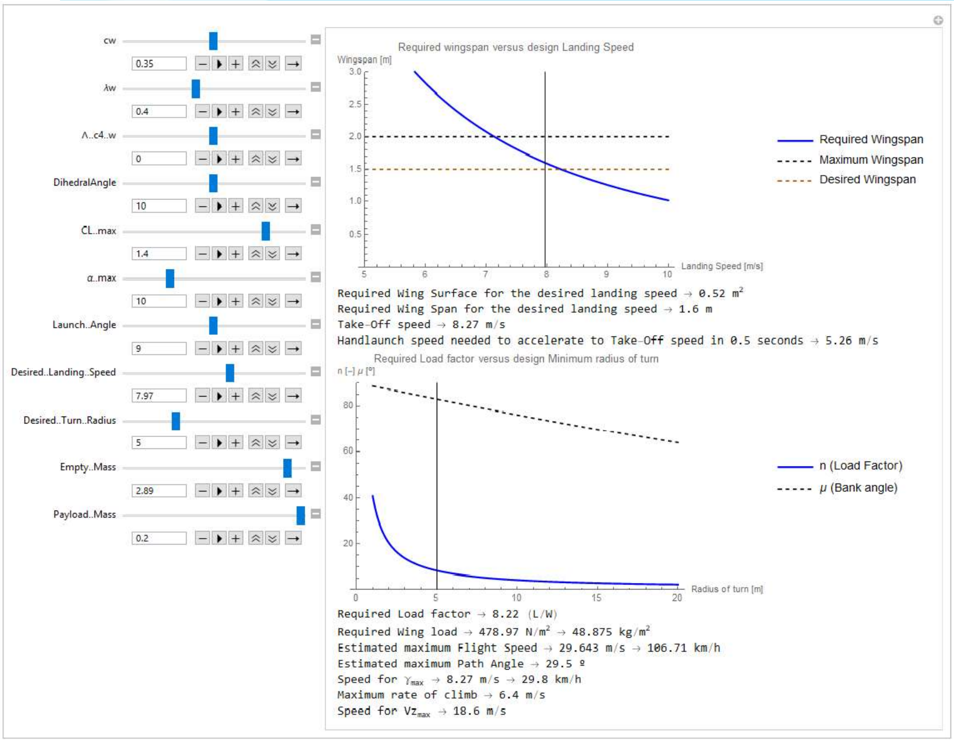
Disadvantage:
- Space needed inside the fuselage



Closing door
Advantages:
- Airflow will automatically close the door

Disadvantages:
- Challenging to produce and install a closing door
- Time to open the door

Performance



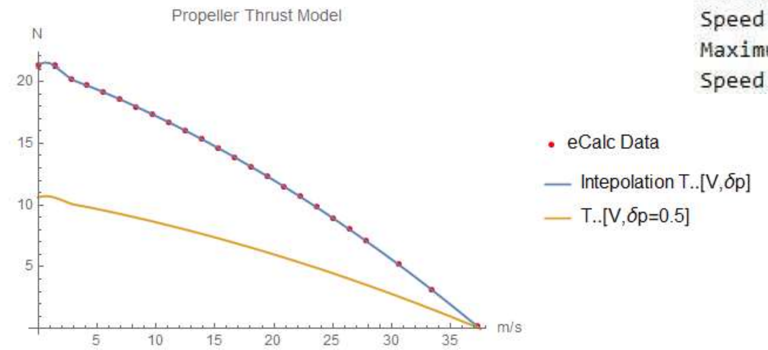
- Cruise

CL in cruise (V = 20 m/s) → 0.238

- Stall
  - Take-Off (With Payload)
    8.27 m/s
  - Landing (Without Payload)
    7.97 m/s

Performance: V_{max} and γ_{max}

- Thrust model extracted from eCalc



- Performance calculations

Estimated maximum Flight Speed → 29.643 m/s → 106.71 km/h
Estimated maximum Path Angle → 29.5 º
Speed for γ_{max} → 8.27 m/s → 29.8 km/h
Maximum rate of climb → 6.4 m/s
Speed for Vz_{max} → 18.6 m/s

- eCalc check ~ ± 10%

Airplane

All-up Weight:	3000 g
	105.8 oz
Wing Load:	58 g/dm²
	19 oz/ft²
Cubic Wing Load:	8.0
est. Stall Speed:	35 km/h
	22 mph
est. Speed (level):	95 km/h
	59 mph
est. Speed (vertical):	- km/h
	- mph
est. rate of climb:	7.1 m/s
	1396 ft/min

Performance: Range, endurance, radius of turn

- eCalc Flight Time

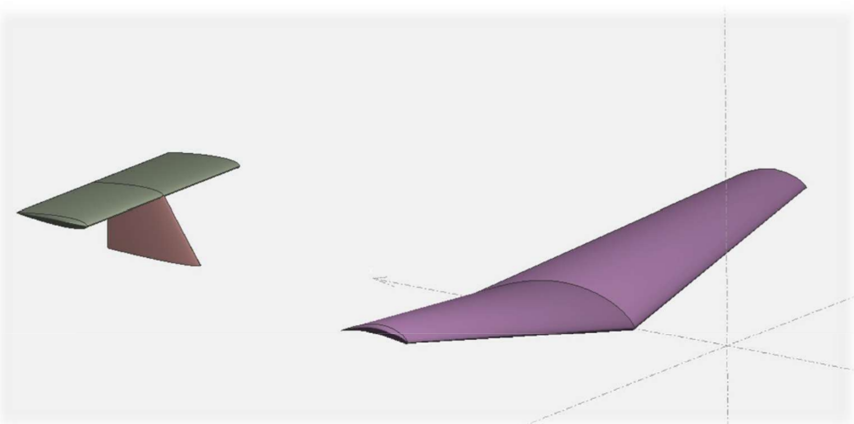
Battery	
Load:	6.35 C
Voltage:	14.53 V
Rated Voltage:	14.80 V
Energy:	88.8 Wh
Total Capacity:	6000 mAh
Used Capacity:	5100 mAh
min. Flight Time:	8.0 min
Mixed Flight Time:	10.6 min

Estimated Range → 12720. m → 12.7 km

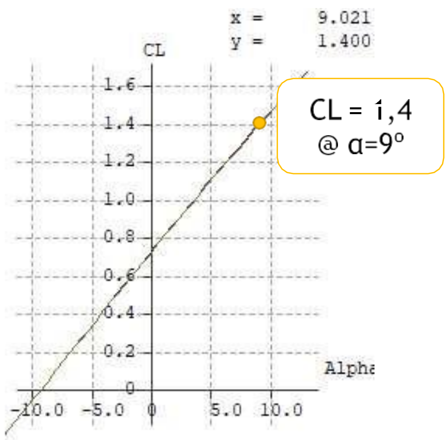
- Radius of turn
  7m
  - Needed Load factor
    5.9
  - Wing loading
    344.542 N/m^2 = 35.16 kg/m^2
  - Bank Angle
    80º

Performance: CL max, XFLR5 model

- Model created in XFLR5



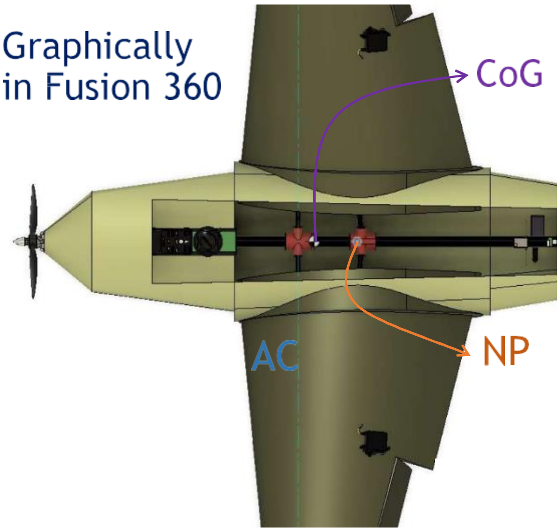
- 3D Lift Coefficient calculations



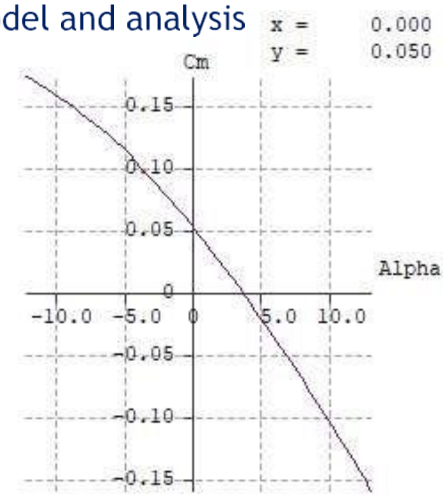
- From airfoil experimental data, maximum α around 10º

Longitudinal Stability

- Graphically in Fusion 360



- XFLR model and analysis

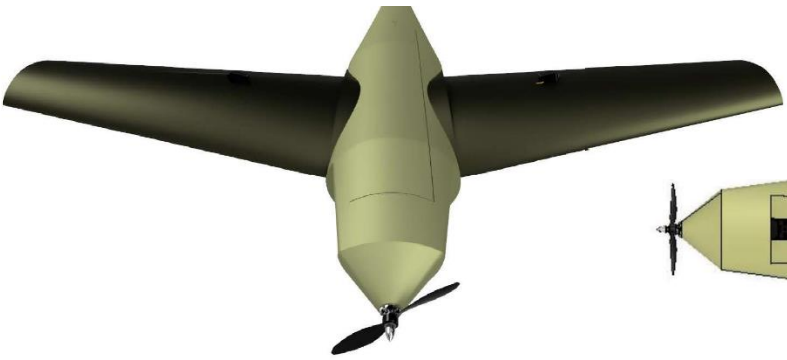


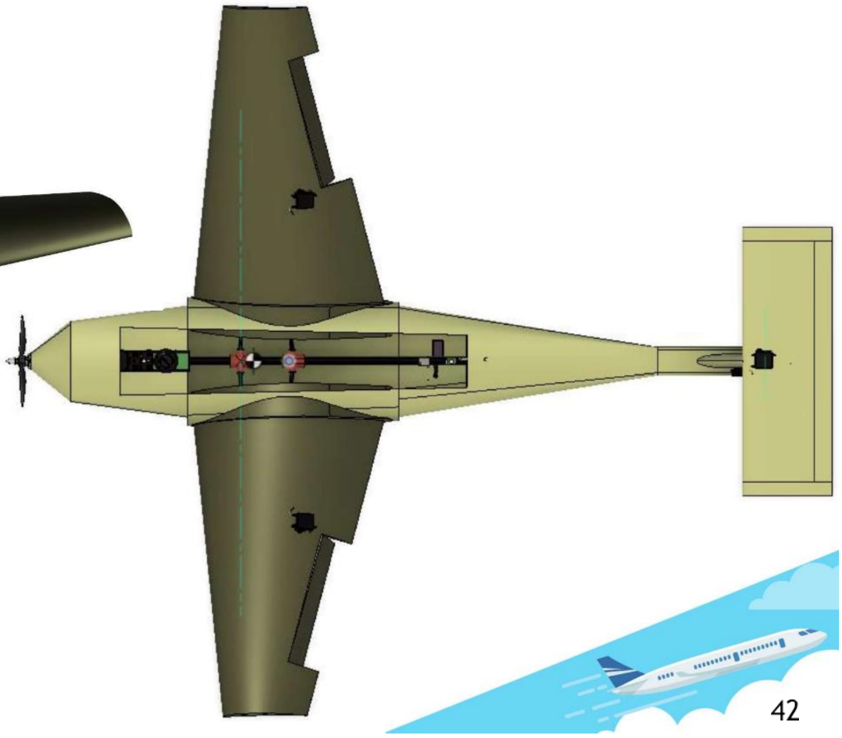
- CONDITIONS FOR STATIC LONGITUDINAL STABILITY
  - dCm/dα <0
  - Cm0 > 0

- More in detail calculus in Mathematica

`Static Margin → 0.228`

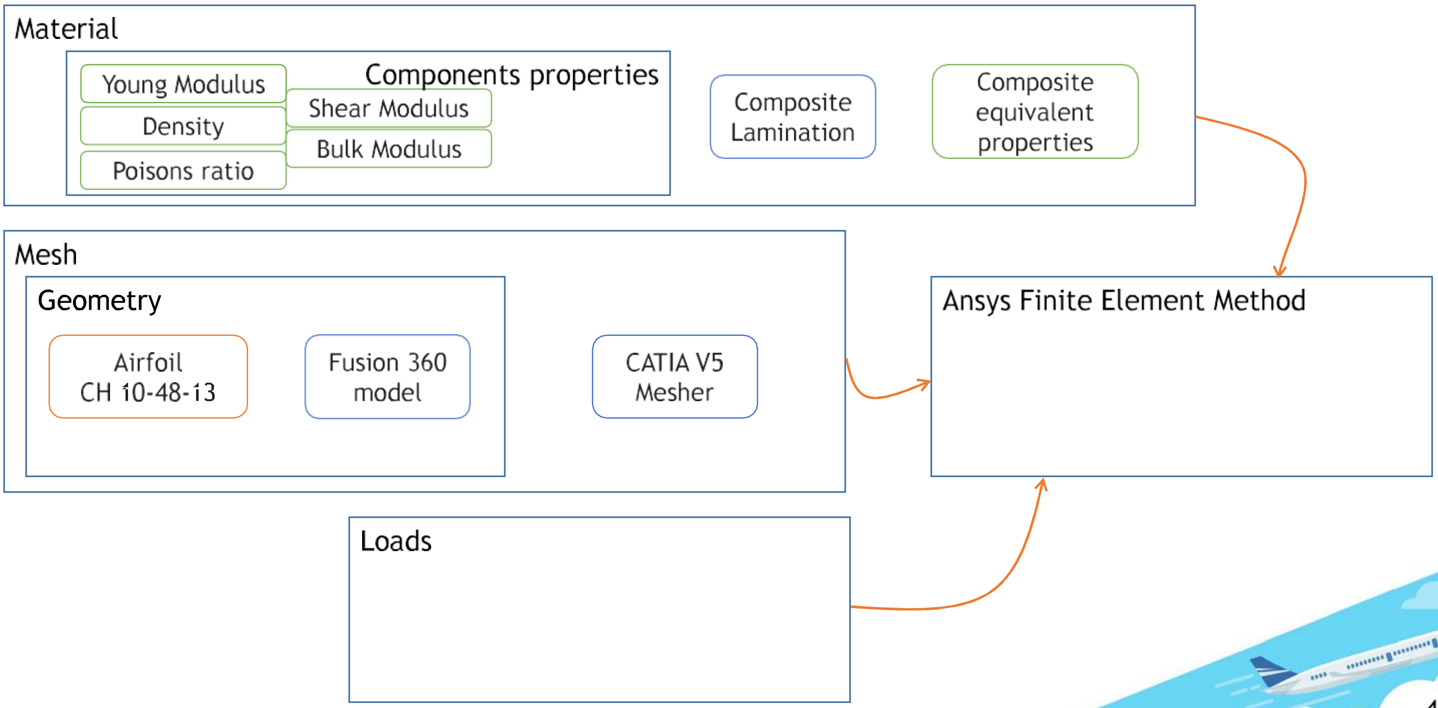
Longitudinal Stability: Electronics Configuration





Next step:
- Elevator Trim

Strength Analysis Procedure



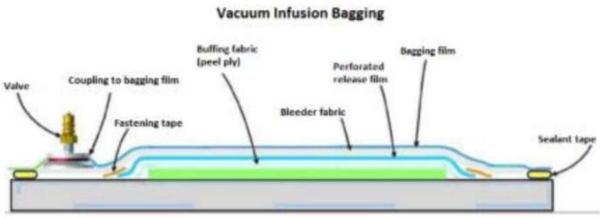
Strength Analysis Loads Estimation

Load calculations:

1-Weight of the aircraft = 3 Kg
2-Design load factor = 6
3-Total load acting on aircraft = 3 * 6 = 18 kg
4-Factor of Safety = 1.5
5-Design load = 18 * 1.5 = 27 kg
6- As we know, the total lift load on the aircraft is distributed as 80% and 20% on wing and fuselage respectively.
7-So the lift load on the wing = 0.8 * 27 = 21.6 kg
8-Load acting on each wing = 21.6 kg/ 2 = 10.8 kg on each wing (10.8 * 9.81) = **105.9 N**
9-Pressure = 105.9 N / (0.52 m^2 [Wing surface] /2) = 407.3 N/m^2
10-Air density = 1.225Kg/m^3
11-Inlet velocity = 20 m/s

Composite Concept Lay-Up: Preliminar

Composite skin process



Calculate the needed composite area

Calculate the needed glasfibre depending on:

- Strength of used glassfibre
- Disired strength we would like to achieve
- Quality of the glassfibre
- Length of the glassfibre
- Composite area
- Shape of the design

Calculate the needed resin depending on:

- Type of resin used
- Quality of the resin
- Composite area

Calculate the amount of hardener and resin

Order the amount of supplies

Composite Concept Lay-Up: Procedure

Composite skin process

Preparing the workspace in the basement of the HvA (clean, dust & dirt free)

Preparing the foam produced element (wing, fuselage, tail)

Wrapping the glassfibre around the element

Wearing personal safety equipment Glasses, gloves, protective clothes & gasmask

Mixing the resin based on the calculations we made

Applying the resin to the element with brushes

Smooth out the glass fibre surface

Wrapping the perforated film around the element

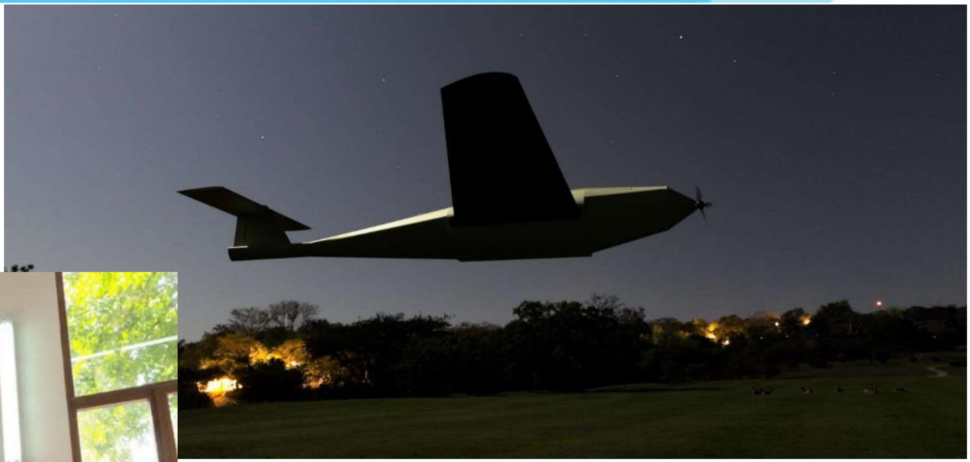
Wrapping the bleeder around the element

Wrapping the bagging film around the element

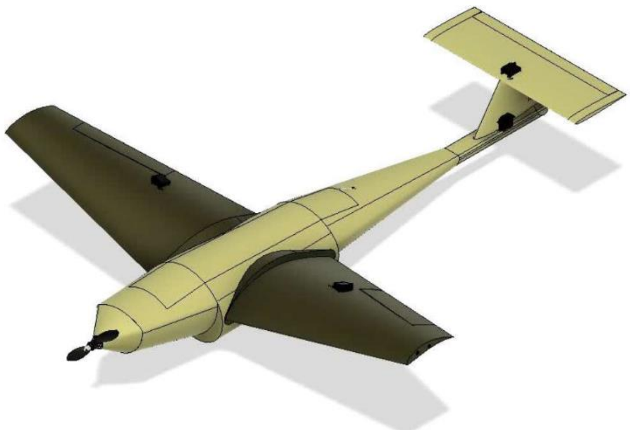
Applying the valve

Applying the seal tape & connecting to the vacuum pump

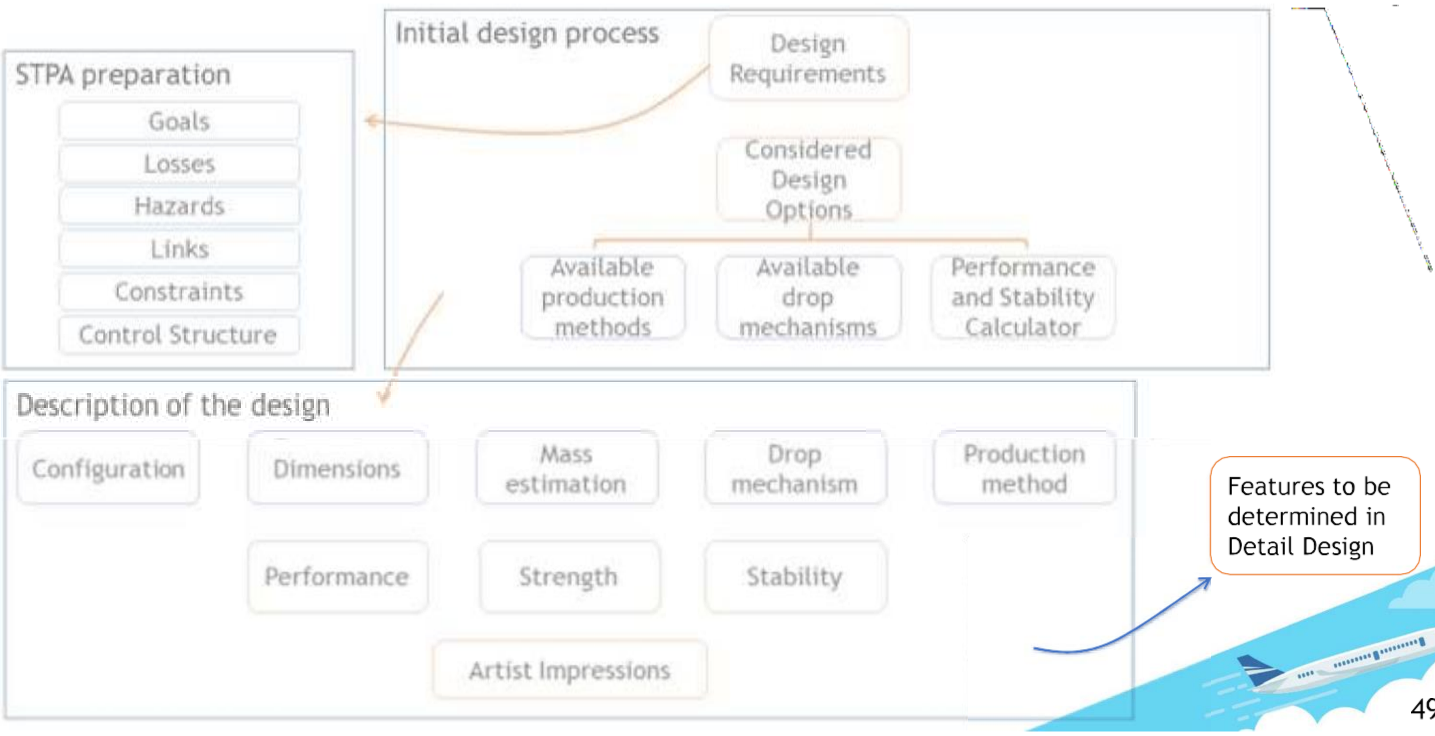
Some more Artist Impressions



Artist Impressions: Animation



Flow Chart



Detail Design

- Span of carbon rod in wing
- Stabilizer airfoils, NACA0012 and NACA0006 as initial guess
- Static Longitudinal Trim
- Fuselage carving
- Wingtips
- Components access
- Negative incidence of the wing

Concept Design Presentation

Presented by:
Andreu Gimenez
Lars van Ginkel
Leandra van Ommeren
Fahad al Janabi
Stefan van der Schans

Extra STPA: Goals Further Description

SG-2	To perform a safe landing in automatic mode

Safe landing: Landing that allows the UAV to flight again inmediatelly after the landing without any modifications or repairs except the change or recharge of the battery.

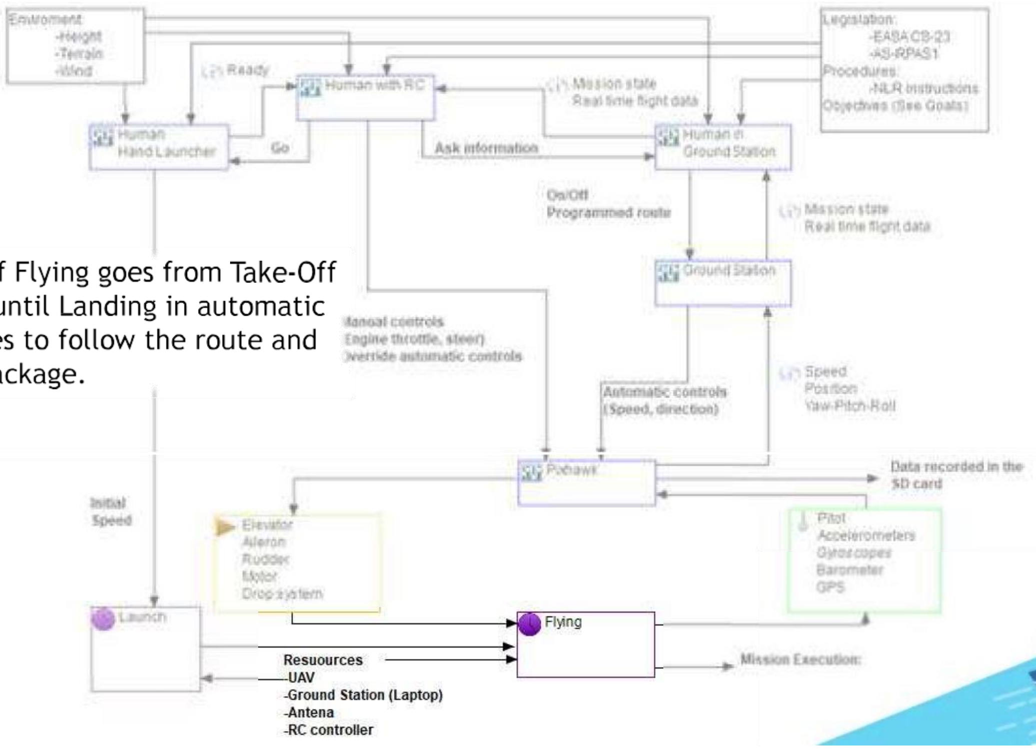
SG-3	To follow accurately the programmed route in automatic mode
SG-4	To drop the payload accurately in the target

Accuratelly: To be defined by the educational institute

Extra STPA: Hazards Further Description

ID	Title	Description
H-1	Not maintaining a safety distance between the UAV and environmental obstacles	Environmental obstacles examples: - Trees - Cars - Buildings
H-2	Inadequate control of the system	For example: - Loss of control of the UAV (reached stall) - Loss of connection between UAV and ground systems (Unable to manual control the UAV or to change the automatic orders) - Erroneous control and navigation algorithm (The programmed route doesn't match the desired one)
H-3	Malfunction of the dropping system	For example: - Unable to drop the package - Package envelope unable to resist the dropping procedure Dropping procedure: Includes the following actions: -Drop system engagement -Package drop from the UAV -Package free fall from the UAV towards the ground -Package impact on the ground
H-4	Loss of the navigation sense	For example: Loss of the GPS signal
H-5	Produced UAV characteristics does not match the required performance	Unable to carry payload (Not enough lift or already 4kg plane). Unable to meet safe landing speeds. Unable to meet hand launch consistent take-off speeds.

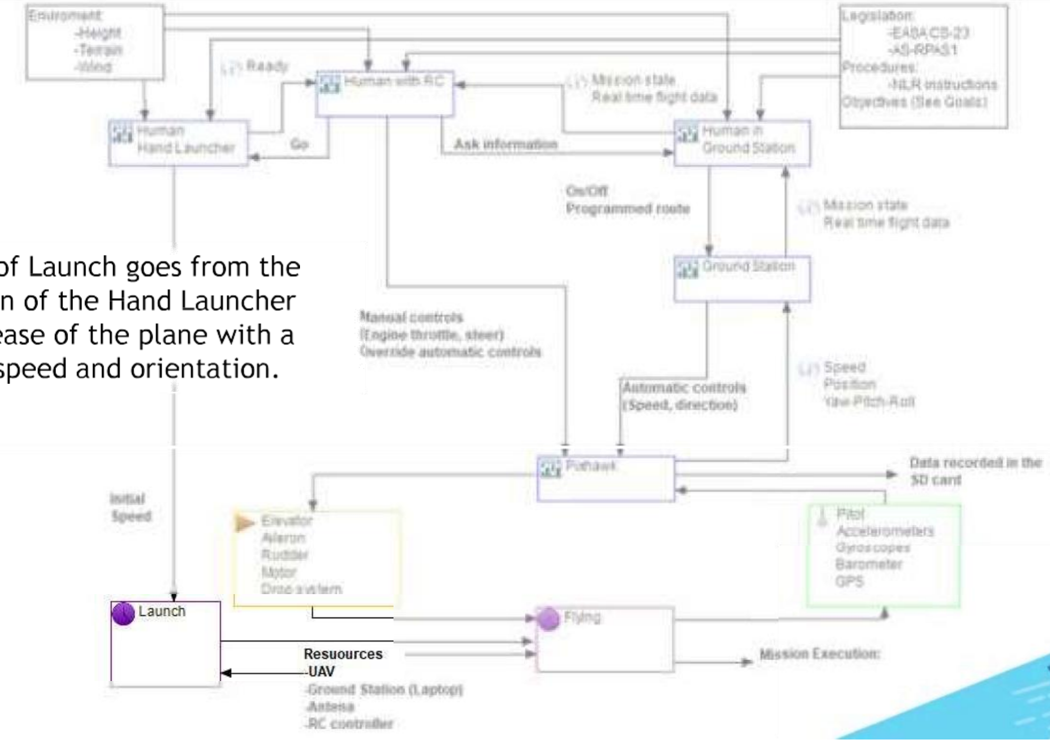
Extra STPA: Control Structure



The process of Flying goes from Take-Off after Launch until Landing in automatic mode. Includes to follow the route and to drop the package.

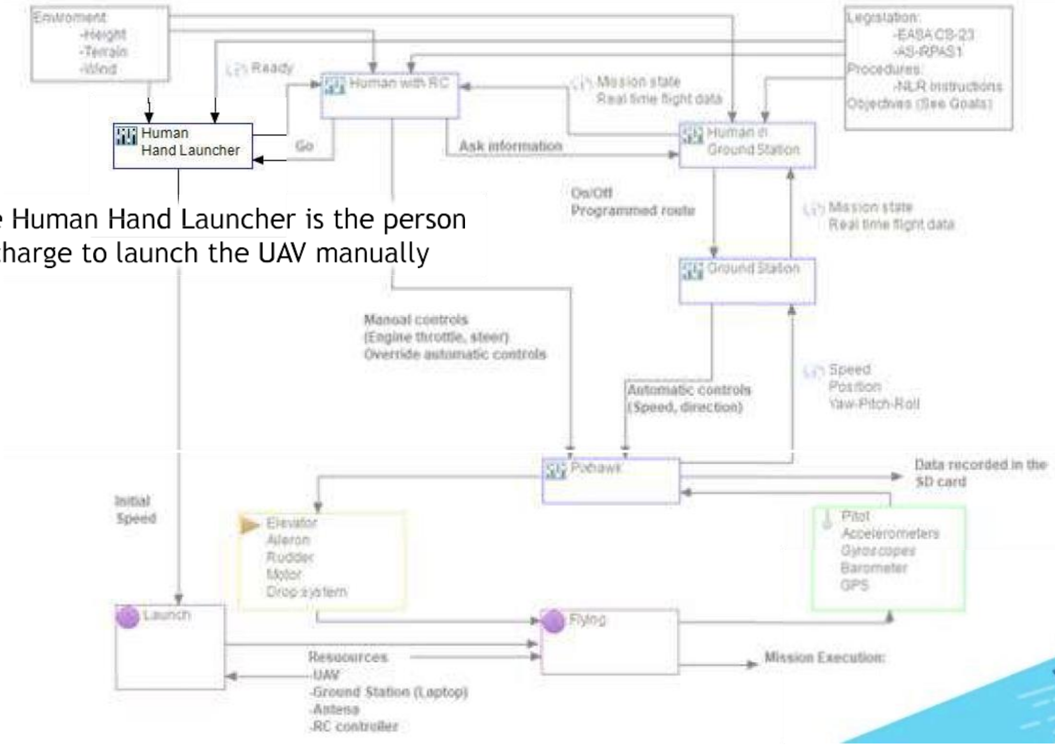
Extra STPA: Control Structure

The process of Launch goes from the static position of the Hand Launcher until the release of the plane with a given initial speed and orientation.

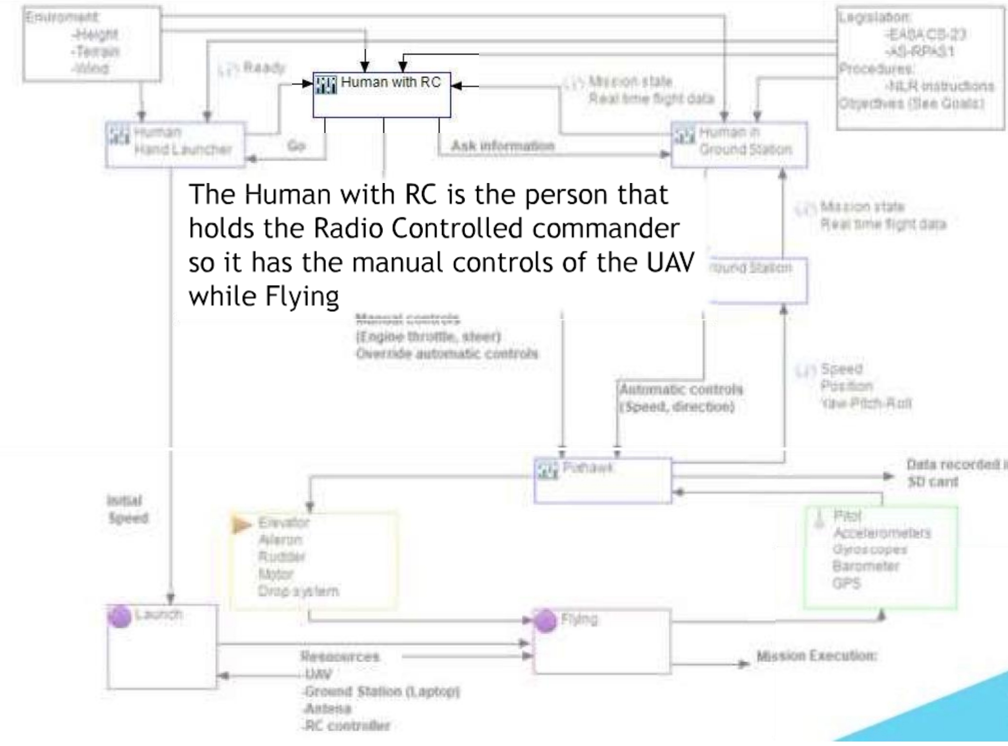


Extra STPA: Control Structure

The Human Hand Launcher is the person in charge to launch the UAV manually

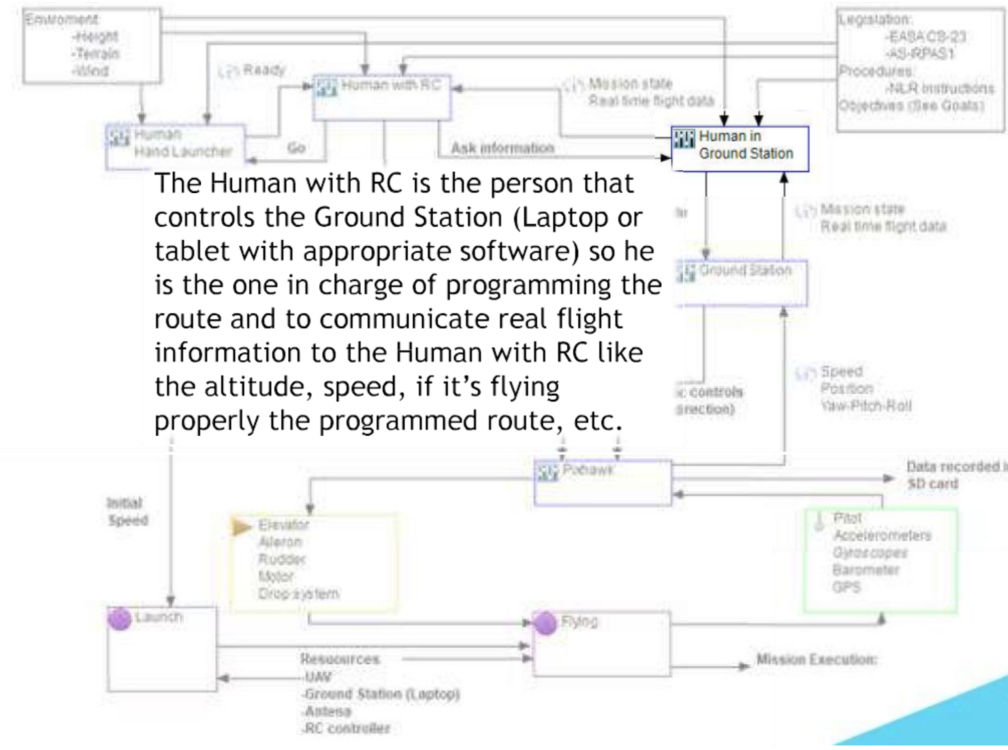


Extra STPA: Control Structure



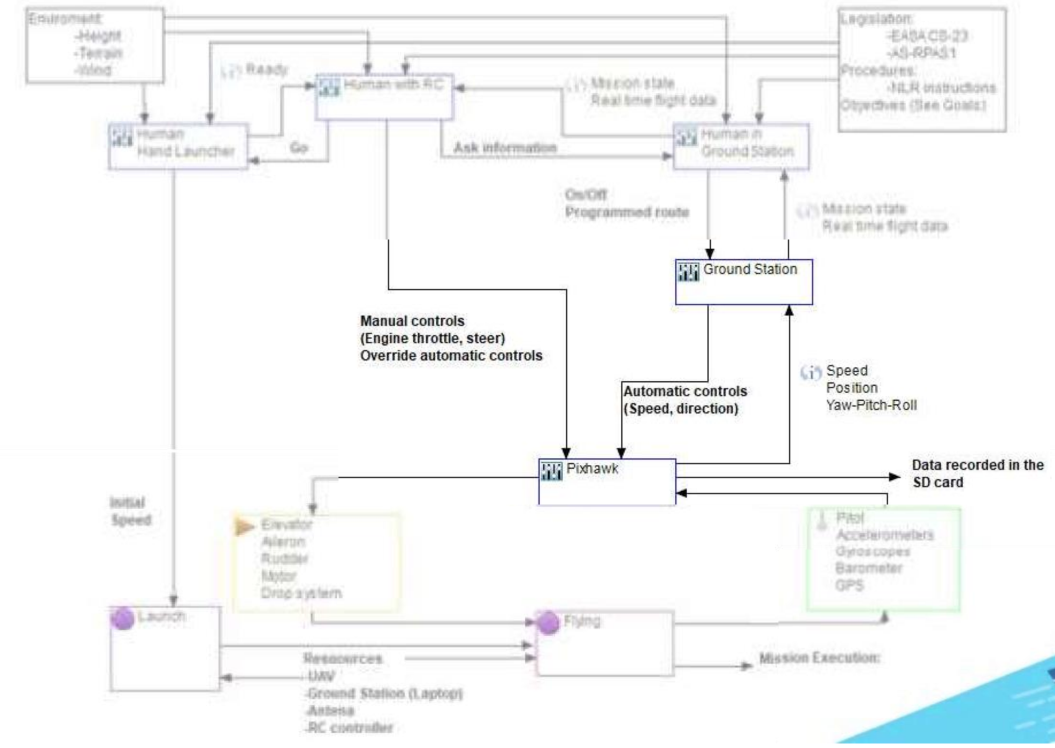
The Human with RC is the person that holds the Radio Controlled commander so it has the manual controls of the UAV while Flying

Extra STPA: Control Structure



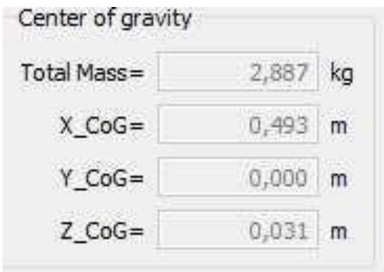
The Human with RC is the person that controls the Ground Station (Laptop or tablet with appropriate software) so he is the one in charge of programming the route and to communicate real flight information to the Human with RC like the altitude, speed, if it's flying properly the programmed route, etc.

Extra STPA: Control Structure



Extra: Longitudinal Stability: XFLR model

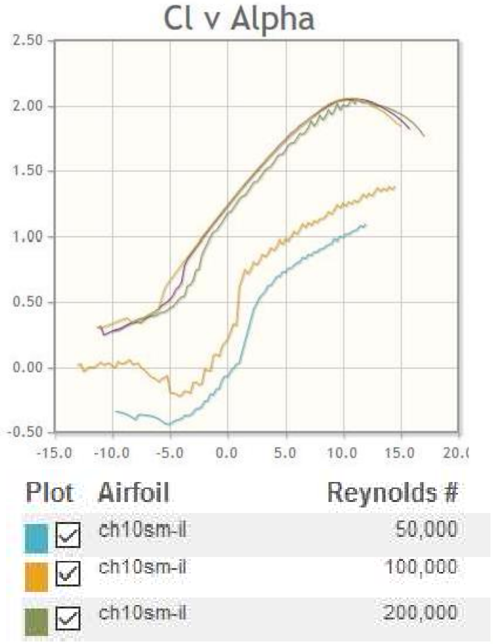
- Approximately same mass and center of gravity than Fusion 360 model



Extra: Reynolds Numbers

Velocity	20	m/s	44.739 mph	72 kph
Chord width	0.18	m	0.59055 ft	7.0866 in
Kinematic Viscosity	1.4207E-5	m^2/s	1.529e-4 ft^2/s	
Reynolds Number	253,396			
	Calculate			

Velocity	8	m/s	17.895 mph	28.8 kph
Chord width	0.18	m	0.59055 ft	7.0866 in
Kinematic Viscosity	1.4207E-5	m^2/s	1.529e-4 ft^2/s	
Reynolds Number	101,358			
	Calculate			



Extra: eCalc input

all data without guarantee - Accuracy: +/-10%

propCalc - Propeller Calculator

News | Toolbox | Easy View | Help | Submit Specs | Language: english

General	Model Weight: 3000 g incl. Drive; 105.8 oz	# of Motors: 1 (on same Battery)	Wing Area: 52 dm²; 806 in²	Drag: simplified; 0.05 Cd	Cross Section: 0 dm²; 0 in²	Field Elevation: 0 m.ASL; 0 ft.ASL	Air Temperature: 25 °C; 77 °F	Pressure (QNH): 1013 hPa; 29.91 inHg	
Battery Cell	Type (Cont. / max. C) - charge state: LiPo 6000mAh - 65/100C - normal	Configuration: 4 S 1 P	Cell Capacity: 6000 mAh; 6000 mAh total	max. discharge: 85%	Resistance: 0.0018 Ohm	Voltage: 3.7 V	C-Rate: 65 C cont.; 100 C max	Weight: 167 g; 5.9 oz	
Controller	Type: max 60A	Current: 60 A cont.; 60 A max	Resistance: 0.0045 Ohm	Weight: 80 g; 2.8 oz	Battery extension Wire: AWG10=5.27mm²	Length: 0 mm; 0 inch	Motor extension Wire: AWG10=5.27mm²	Length: 0 mm; 0 inch	
Motor	Manufacturer - Type (Kv) - Cooling: T-Motor - AT2820-830² (830); medium; search...	KV (w/o torque): 830 rpm/V; Prop-Kv-Wizard	no-load Current: 1.1 A @ 10 V	Limit (up to 15s): 800 W	Resistance: 0.055 Ohm	Case Length: 42 mm; 1.65 inch	# mag. Poles: 14	Weight: 132 g; 4.7 oz	
Propeller	Type - yoke twist: custom - 0°	Diameter: 11 inch; 279.4 mm	Pitch: 7 inch; 177.8 mm	# Blades: 2	PConst / TConst: 1.2 / 1.0	Gear Ratio: 1 : 1	Flight Speed: 72 km/h; 44.7 mph	calculate	

Extra: eCalc output

Remarks:

Battery	
Load:	6.60 C
Voltage:	14.51 V
Rated Voltage:	14.80 V
Energy:	88.8 Wh
Total Capacity:	6000 mAh
Used Capacity:	5100 mAh
min. Flight Time:	7.7 min
Mixed Flight Time:	10.9 min
Weight:	668 g
	23.6 oz

Motor @ Optimum Efficiency	
Current:	18.05 A
Voltage:	14.59 V
Revolutions*:	10826 rpm
electric Power:	263.3 W
mech. Power:	224.0 W
Efficiency:	85.0 %

Motor @ Maximum	
Current:	39.61 A
Voltage:	14.34 V
Revolutions*:	9524 rpm
electric Power:	567.9 W
mech. Power:	453.8 W
Efficiency:	79.9 %
est. Temperature:	75 °C
	167 °F

Wattmeter readings	
Current:	39.61 A
Voltage:	14.51 V
Power:	574.7 W

Propeller	
Static Thrust:	2414 g
	85.1 oz
Revolutions*:	9524 rpm
Stall Thrust:	- g
	- oz
avail.Thrust @ 72 km/h:	1353 g
avail.Thrust @ 44.7 mph:	47.7 oz
Pitch Speed:	102 km/h
	63 mph
Tip Speed:	502 km/h
	312 mph
specific Thrust:	4.25 g/W
	0.15 oz/W

Total Drive	
Drive Weight:	968 g
	34.1 oz
Power-Weight:	195 W/kg
	89 W/lb
Thrust-Weight:	0.80 : 1
Current @ max:	39.61 A
P(in) @ max:	586.2 W
P(out) @ max:	453.8 W
Efficiency @ max:	77.4 %
Torque:	0.46 Nm
	0.34 lbf.ft

Airplane	
All-up Weight:	3000 g
	105.8 oz
Wing Load:	58 g/dm²
	19 oz/ft²
Cubic Wing Load:	8.0
est. Stall Speed:	35 km/h
	22 mph
est. Speed (level):	95 km/h
	59 mph
est. Speed (vertical):	- km/h
	- mph
est. rate of climb:	7.1 m/s
	1396 ft/min

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-DETAIL DESIGN-

Contributions

The author of the thesis, Andreu Giménez Bolinches, was responsible of the 3D design and renders, the flight mechanics calculus, mass and balance estimation and the production methods and materials.

Grading

This report has an overall grade of 5.9 out of 10. A detailed grading structure is presented in the following table.

Criterion	WF	Grade
Report Structure	6%	6
Summary and Introduction	6%	2
Use of Sources	6%	2
Report Elements and Layout	6%	4
Language Use	6%	6
Justification of the outcome of the design process with a clear view on the applied design requirements	10%	6

Criterion	WF	Grade
Description and substantiation of aircraft design: configuration, dimensions, positioning of all electronics and mass estimation including centre of gravity position	10%	8
Calculation of maximum available performance specs and stability analysis, both including validation with the Merlin Simulator	20%	8
Elaboration of the dropping mechanism and calculation of the path from the intended dropping point	5%	6
Detailed structural design (lay-up) of composite wing construction, strength analysis and prediction of wing deflection (during wing test)	10%	2
Substantiation of selected materials and production methods (wherein it is required to use 3D-printing technique for a limited number of parts)	5%	8
Hazard analysis using STPA	10%	8

Due to the low grade received in the lay-out and format of the report this part has been corrected without altering significantly the content of it, if one wants to find the original report with comments of the corrector it can be done here[2].

2 https://upvedues-my.sharepoint.com/:b:/g/personal/angibo2_upv_edu_es/EfOw3yTCS0BCh_Vdit6JNfcBUlCmQp-va9qmIMsn9Q791Q?e=uHLfCE

Detail Design Report

Andreu Gimenez Bolinches

Lars van Ginkel
Fahad al Janabi
Leandra van Ommeren
Stefan van der Schans

Aviation Engineering
Aviation Academy
Amsterdam University of Applied Sciences

05 April 2019

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Detail Design Report.

HvA – Aviation Academy FT_TEMDB01

Andreu Gimenez Bolinches	500817256
Lars van Ginkel	500726973
Fahad al Janabi	500652650
Leandra van Ommeren	500752301
Stefan van der Schans	500717602

Table of content

Tables and Figures

Chapter 1: Introduction

During the minor Design, Build and Fly (DBF) on the HvA are students with different educational backgrounds given a task. This task is to design, construct and fly a fixed wing single engine Unmanned Aerial Vehicle (UAV), which is capable of flying a predetermined mission and drop a small package. This task is split up in several phases, each having their own milestone. The group of students that are anticipating in this minor are also divided into smaller groups. Each group needs to achieve this task with a design of their choosing.

The first two phases of this minor were to write a project plan and to make a concept design which was presented by a PowerPoint presentation. For the project plan was it important to make a good; schedule containing with every deadline, a research statement, cost and benefits weighing and a risk analysis. During the concept design presentation was it important to compare the requirements of the task with the design options. Through this method a concept design was chosen which comply with the requirements of the task and can conduct the task.

Now for the new phase and the third phase of this minor is it important to write a detail design report. The groups need to write a detail design report about their concept design that was chosen. Based on the detail design report can one make the conclusion if the UAV in theory complies with every requirement.

Chapter 2: Description and substantiation of chosen aircraft design

2.1 Configuration

2.1.1 Introduction

The configuration is the start of the design where all the calculations and simulations are based on. The configuration of the design is already discussed in the concept design presentation and in this chapter, the project group describe the configuration step by step and more in-depth. The project group discusses the arguments for the chosen configuration.

Before the concept design presentation, the project plan followed the morphological overview provided by the educational institute the HvA to determine the configuration.

The project group had also their own preferences for the design.

One of the preferences is to make an airplane which is innovative and not been made before at the minor DBF. On the other hand, some of the project members wanted to make a conventional plane as much as possible due to the difficulty of production. In order to accomplish everyone's needs, there is a combination made of everyone's references.

All these preferences and choices result in the design it is right now. The design path is seen in the morphological overview in Figure 2-a.

In this overview is seen that is started with a conventional aircraft design, the project group chose this design because it will be easier to manufacture and some of the project members wanted to make a conventional plane.

The choice for landing on the fuselage is made because adding landing gear to the airplane will increase the weight and difficulty of the design. It must withstand the forces on impact while landing so it needs to be designed strong and therefore heavily.

The landing gear can easily be skipped because landing on the fuselage is possible.

However, its needed to take the length of the propeller into account and make sure it doesn't reach the ground and damage right after. Because of this, the fuselage will be reinforced and made bigger, so there will be no problem while landing. One of the requirements is to land with low stall speed. Also, the airplane can't be given a high initial speed so it must have enough lift at the launch. Because of these requirements, the project group chose a high cambered wing because of the low take-off and landing speed. Another requirement, this one from the guidebook is that the airplane must be hand launched. Because of the safety, the decision is made to make a tractor, so the propeller and engine are at the front while the launcher's hand is located underneath the fuselage. In this case, there will be no problem or danger while launching the airplane.

Because the estimation calculations say that the engine will deliver a lot of thrust, it's not necessary to make winglets to reduce drag. It's time-consuming to produce the winglets and makes the wing heavier. Maybe if there is enough time in the production phase, the project group will come back to this and consider producing winglets. The wings will have a cut-off geometry at the end right now.

One of the requirements is to get a high cruise speed and because of that, the choice is made to design an airplane with a low aspect ratio. The airplane will have tapered wings as well. The choice is made to make a T-tail because the project members wanted to do something different than just the conventional tail.

Also, because the design has a high cambered wing, it will produce a lot of downwash from them. In order to get maximum controllability, the choice is made to design T-tail.

In this case, the airplane will be better controllable due the downwash has no influence on the T-tail. This morphological overview results in the airplane design.

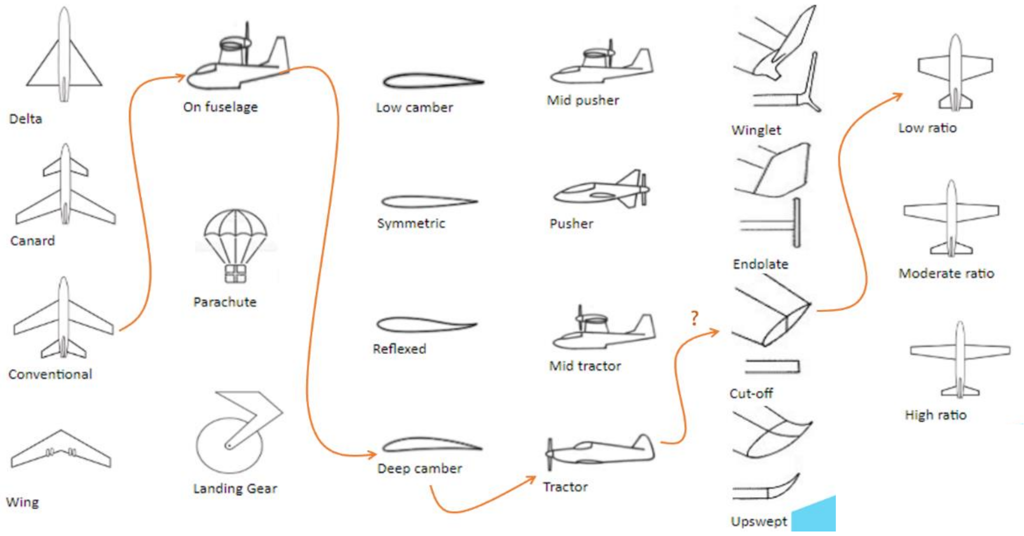


Figure 2-a Morphological overview

Because the project group wanted to add some innovative design aspects that hasn't been made before they added a dihedral of 10 degrees to the wings and the fuselage has slightly lifting body capabilities because of its shape. The dihedral of the wings will give the airplane also some stability in lateral direction. In Figure 2-b the result/configuration of the design is shown.

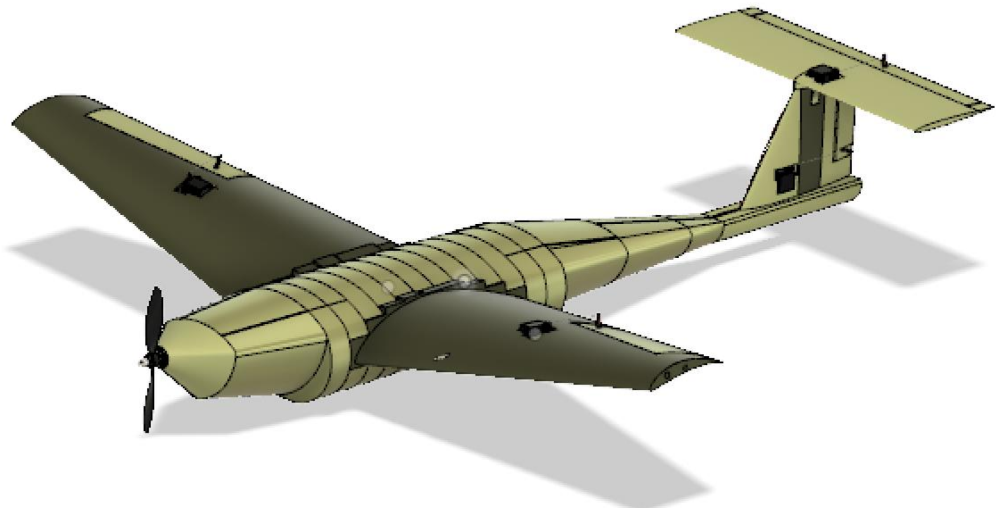


Figure 2-b Detail Design

2.2 Dimensions

This chapter describes every dimension of the airplane design. This will be the general dimensions of the airplane, the dimensions of the control surfaces and all the other smaller parts which are needed to create the designed airplane.

The dimensions of the electronics are placed in a parts catalog because they have no influence on the aircraft design by itself. Secondly, they are not that important as every group has the same or slightly the same electronics. Also, they are provided by the educational institute the HvA so they know which electronics are used and why. Only the biggest piece of the electronics, the battery, is mentioned in this chapter. This is because of the fact that it will be a challenge to store this big piece in the airplane.

The main dimensions of the airplane are already seen in the concept design presentation but aren't changed. The total length of the airplane from propeller tip to elevator tip will be 1.853 meters. The fuselage length will be 1.75 meters as seen in the Figure 2-c.

These dimensions come directly out of Fusion 360 3D design software.

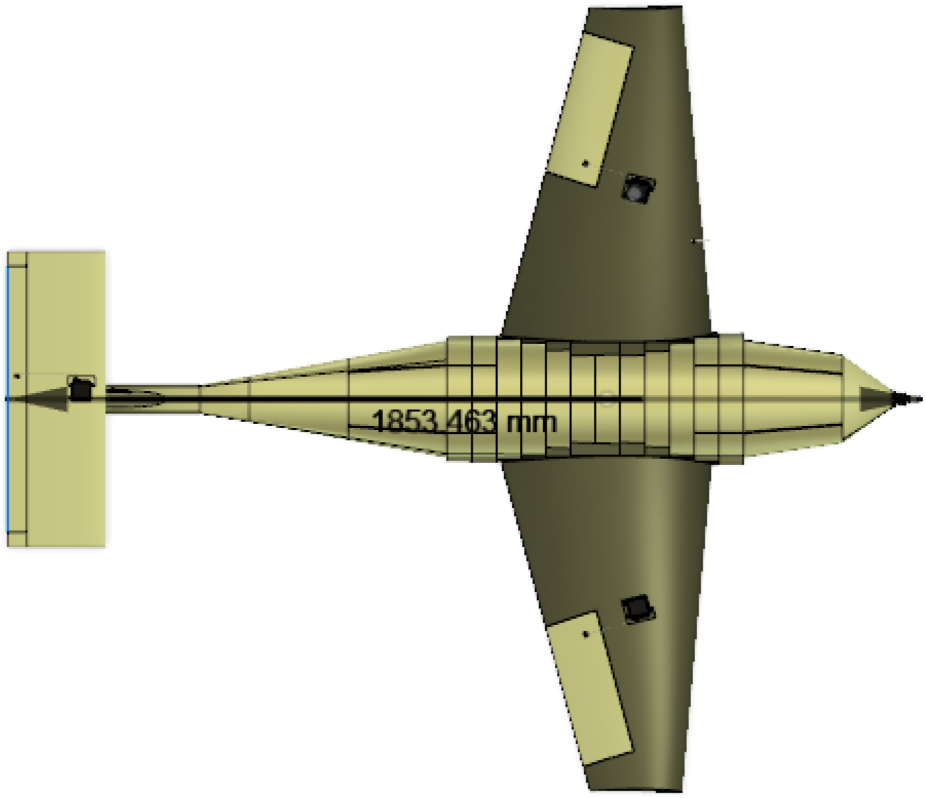


Figure 2-c Total length of the whole airplane

Figure 2-d Total length of the fuselage section

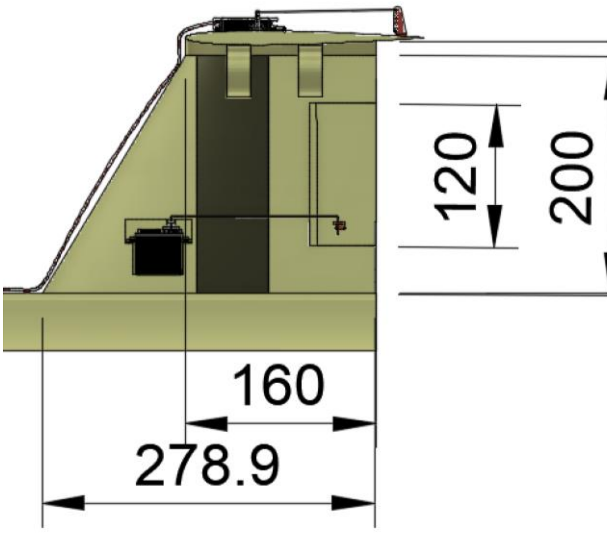


Figure 2-e Main dimensions of the vertical stabilizer and rudder all in mm.

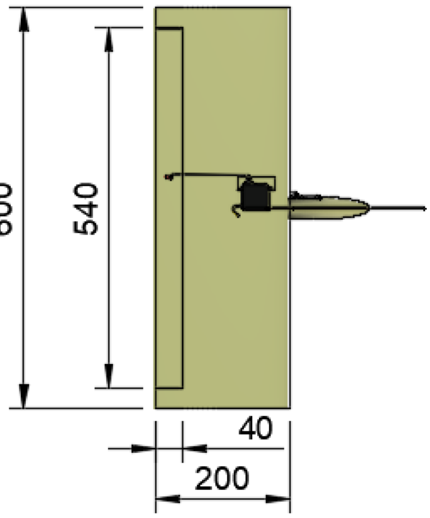


Figure 2-f. Main dimensions of the horizontal stabilizer and elevator all in mm.

In Figure 2-e and Figure 2-f one can see the main dimensions of the horizontal and vertical stabilizer including the elevator and the rudder.

These dimensions come from the calculations made in Mathematica coming from the stability calculations which are further in this detail design described. The MAC of 0,35 meter stated in the concept design presentation will be used and hasn't changed at all.

The total wingspan will be around 1.6 meters, seen in Figure 2-g.

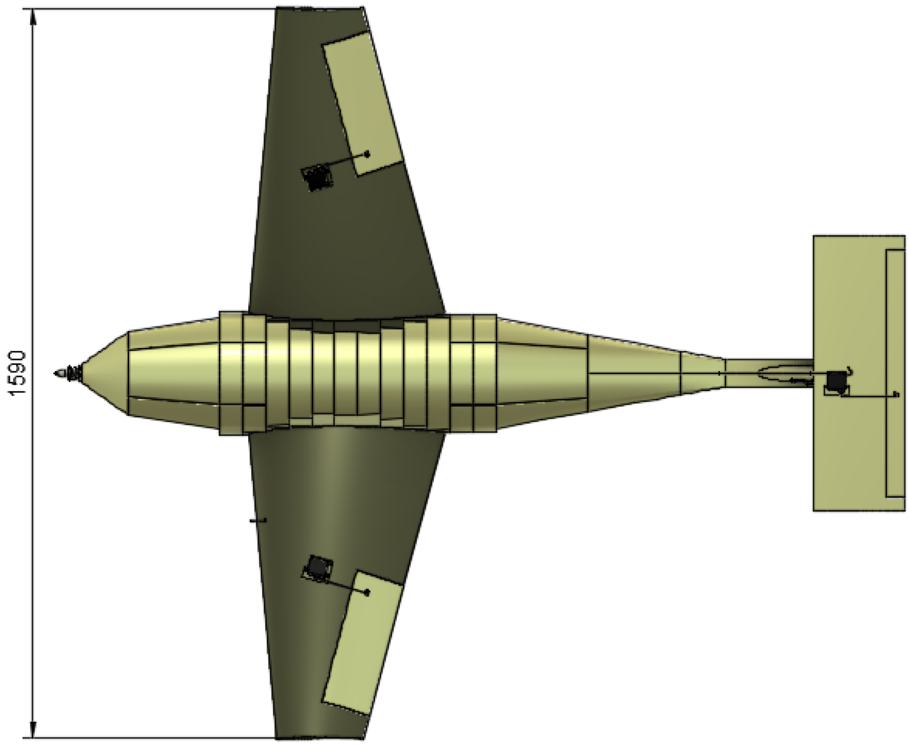


Figure 2-g Dimension of the total wingspan, dimension is in mm.

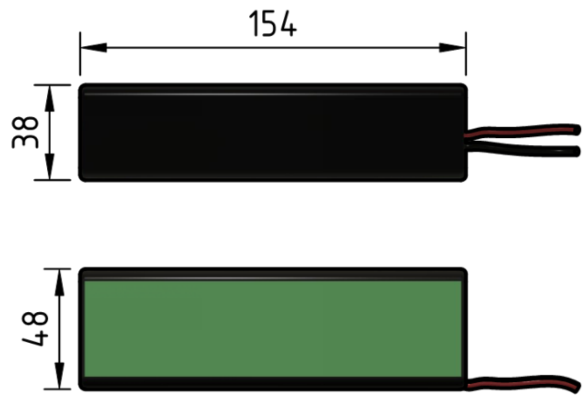


Figure 2-h Main dimensions of the battery, all in mm.

The battery as seen in Figure 2-h is 154 mm and 38 mm wide. The height of the battery is 48mm. The weight of the battery is one of the heaviest parts of the whole airplane. It's around 600 grams.

All the other dimensions of the airplane, including all the electronics are seen in the parts catalog in the appendix. The project group reference to this appendix to have a clear overview of all the electronics included in the design.

2.3 Positioning of all electronics

In this chapter the position of all the electronics inside or outside the aircraft are described.

This includes for example: the battery, GPS, Pixhawk, ESC, and so on.

The project group strive for all the electronics inside the aircraft to have a smoother and nicer result. Also, the more electronics are outside the airplane the more drag it causes which results in a lower speed.

To start with the most important part of the electronics, the battery. The battery is needed to provide the engine with energy to create thrust. The battery is in relation to the other electronics, very big and heavy. It needs a lot of space to be placed. Because of the heavy weight, the placement of the battery has big influence on the position of the centre of gravity (from now on CG). The project group placed the battery in the front with enough surrounding space, so the battery has the ability to move forward or backward to change and calibrate the position of the CG.

In Figure 2-i, the battery is highlighted inside de red rectangular. Because of the placement of the battery in the front, we create a lot of open space in the middle of the fuselage. This can be used for the droppable payload and to store more of the other electronics.

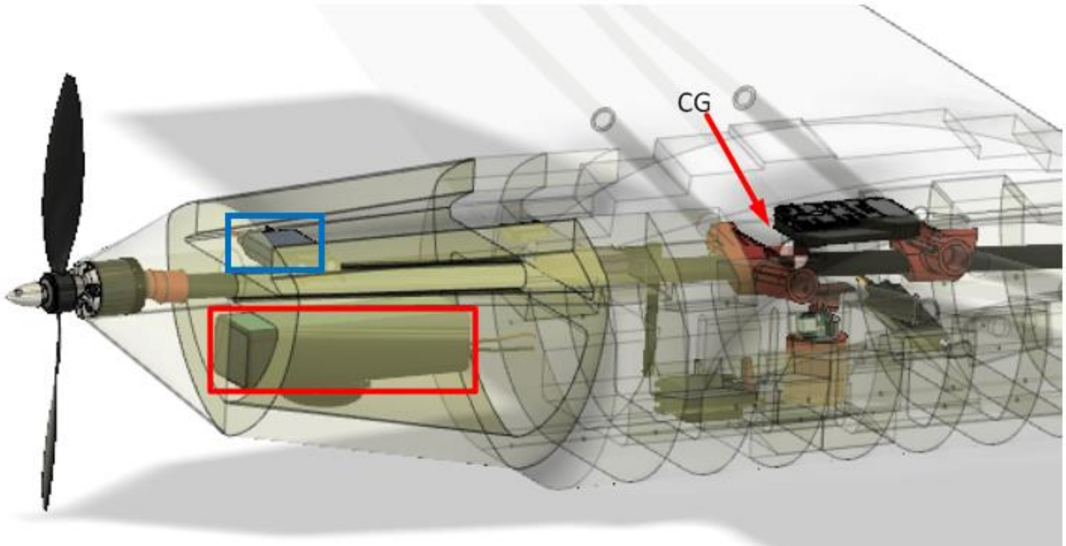


Figure 2-i. Placement of the battery in relation to the CG. Isometric view of the design.

As also seen in Figure 2-i, is the placement of the engine and the propeller. As a result of the morphological overview and the design, the project group chose for a tractor configuration. This means that the engine is mounted at the front of the fuselage. The engine is a T-motor (brand) and the type is KV830.

The engine will be connected to the carbon rod by a 3D-printed connection piece. For these dimensions and specifications please consult the parts catalog in the appendix.

The ESC is placed also in the front, because it needs to be connected to both the engine and the battery. Because more wires add more weight, it's desired to place the ESC as close as possible to the battery and engine. The ESC is highlighted in the blue rectangular.

The GPS receiver is placed and attached underneath the battery, it can be switched to the top of the battery or next to it.

The Pixhawk is placed in the CG, because the Pixhawk has his own accelerometer and gyroscope. For better controllability, it is desired to place the Pixhawk in the CG as stated in the Pixhawk manual. In the design, the Pixhawk will be mounted above the carbon rod connections. The mounting of where the Pixhawk rests on will be made out of foam, which is also seen in the part catalog in the appendix. The foam mounting is connected to the foam of the fuselage. In Figure 2-j , the top view of the design is seen. The Pixhawk (the black small box, surrounded by the red rectangular) is placed between the connections of the wing connection carbon rods and in the CG.

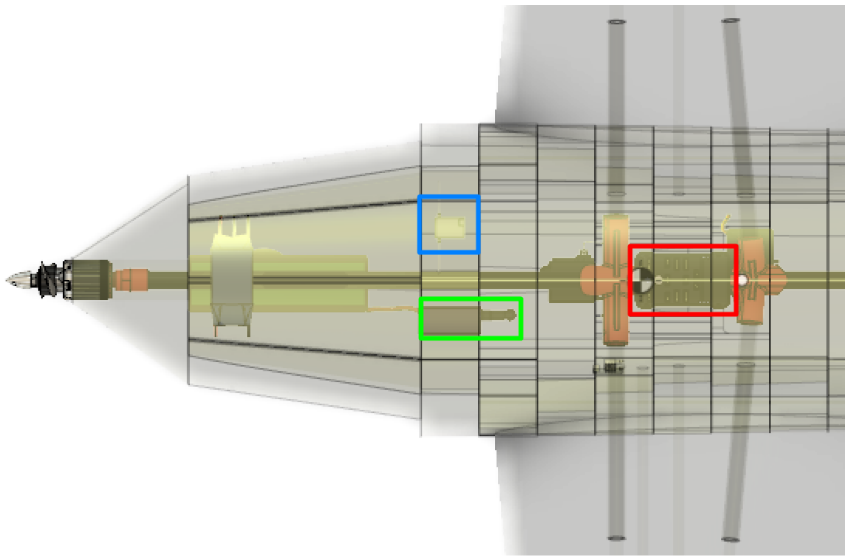


Figure 2-j Top view of the airplane design, position of electronics.

In the green rectangular, the telemetry module is located. This is a small electronic device which is used to retrieve and send data about the aircraft to the receiver.

It's a small piece with a low weight. It's placed in this position because the antenna needs some space and it must be placed separately from other electronics to avoid a loss of signal due to other electronic signals.

The element marked in blue is the RC-Receiver. The receiver collects the inputs given from the transmitter (the human with the controller) and passes it through the Pixhawk.

The dropping system is a 3D printed hook system with a servo.

It's placed in the CG. This is done because when the payload/package is deployed the CG won't change so it stays in the same place. In this case, the behavior and maneuverability of the airplane won't change that much, except the total weight is less.

In Figure 2-k the dropping system with the servo's is seen. The dropping system uses two servos, one for the door and the other one to release the payload.

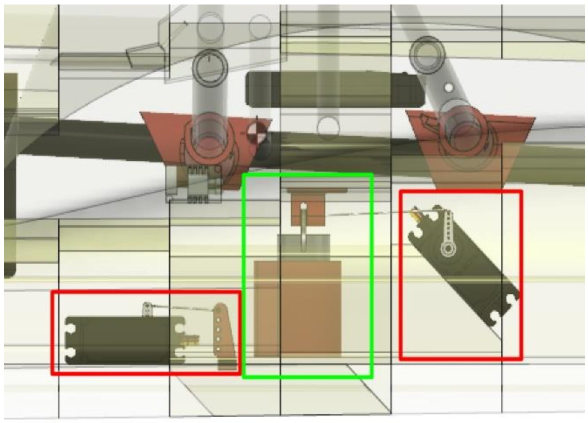


Figure 2-k Section view of the fuselage, dropping system (green) with servos (red)

In the Table 2-a below is the position of the electronics stated. The X-distance, Y-distance and Z-distance from the origin of the Fusion model. The origin has the coordinates of 0,0,0. The engine is placed in the origin with coordinates of 0,0,0.

The Z-distances of the components aren't that important because it doesn't affect the CG very much. Secondly, the components are placed on top of other surfaces like foam mountings. Because of this, the Z-distances are not mentioned in the Table 2-a.

All the X- and Y-distances are taken from the end/beginning of the components to the origin.

The placement of the servos is not mentioned in this Table 2-a because in the parts catalog it is much clearer were their positions are.

When the Y-distance has a value of 0, it means that the middle of the component is located in the Y-axis.

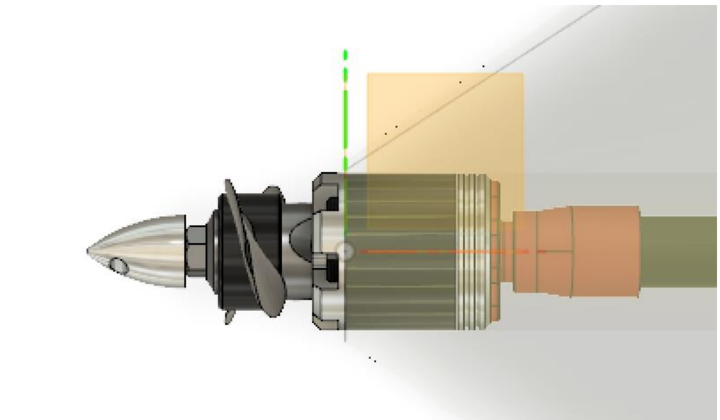


Figure 2-l Position of the origin 0,0,0

Table 2-a Summary of the electronics position

Item	*X-distance in mm*	*Y-distance in mm*
Engine & propeller	0	0
ESC	119,361	0
Battery	100,021	0
GPS	138,675	0
Telemetry module	298,20	22,4
RC-receiver	313,0	36,6
Pixhawk	484,35	0

2.4 Mass estimation with center of gravity

This subchapter describes the mass estimation and the center of gravity.

2.4.1 The mass estimation

The materials that we are going to use for the UAV are: foam, carbon rod, wood, glass fiber, PLA and glue. The density of the foam is stated higher than the given density. The reasoning behind this decision is that the aircraft will be assembled together with wood glue and glass fiber. If one estimates a bit more weight than necessary is it easier to comply to the design requirements.

2.4.2 The center of gravity

The center of gravity and the neutral point in the aircraft is visible in Figure 2-m.

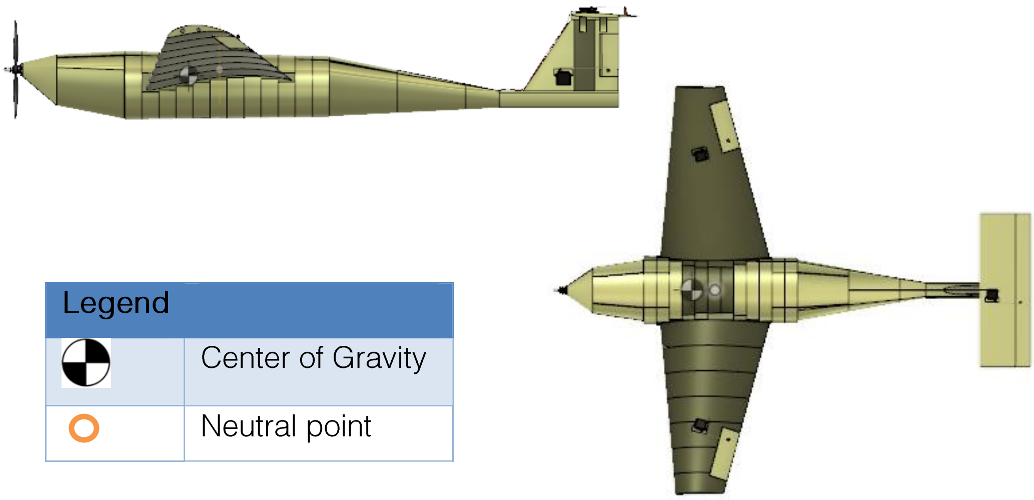


Figure 2-m Center of Gravity positioning

The center of mass in x, y and z directions are given in Table 2-b.

Table 2-b Center of Mass positioning

X	Y	Z
489,665 mm	-0,984639 mm	-19,2404 mm

2.4.3 Moments of inertia

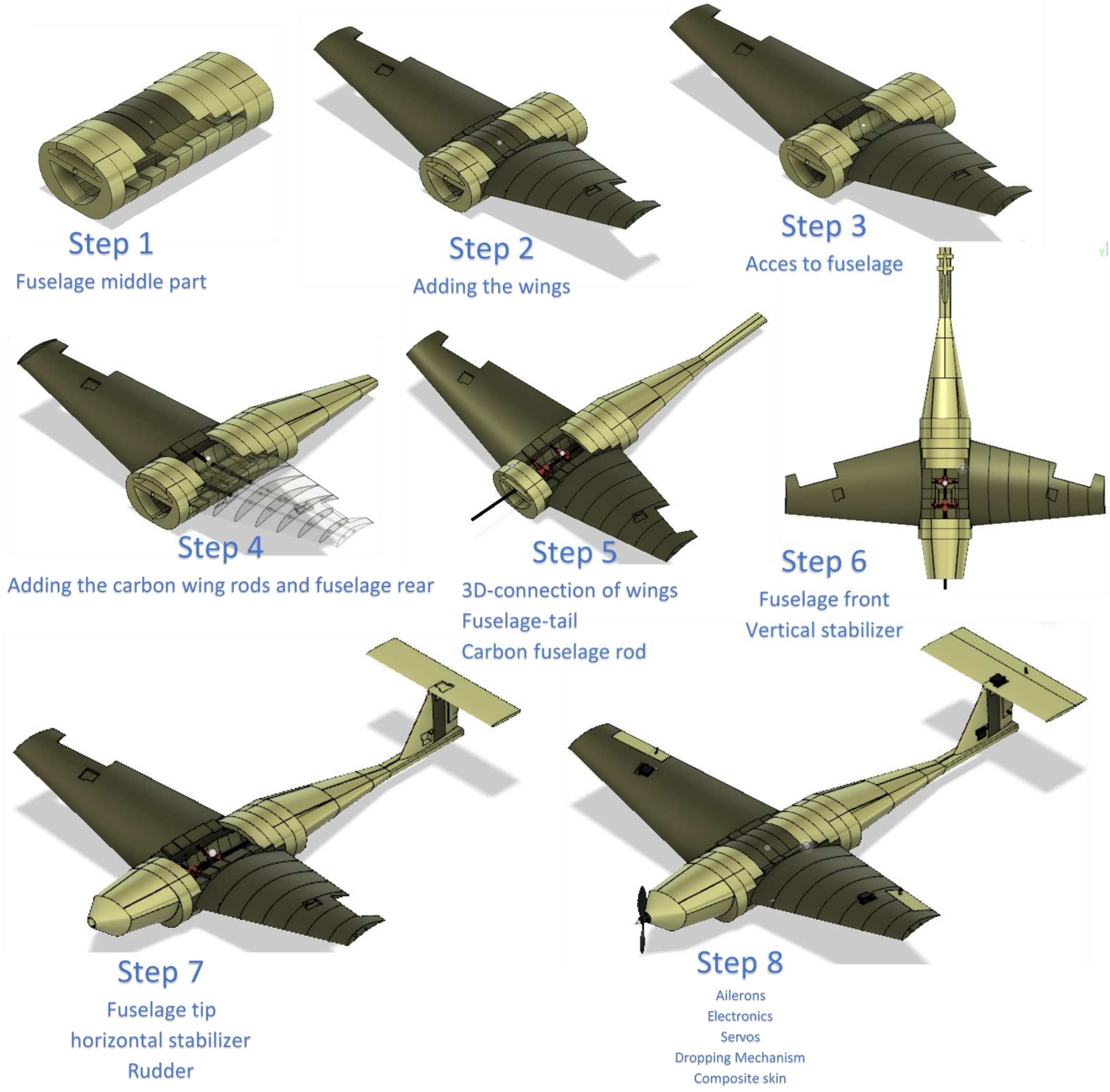
In Table 2-c one can see the moments of inertia at the center of mass.

Table 2-c Moments of inertia

▼ Moment of Inertia at Center of Mass (g mm^2)		
Ixx = 1.254E+08	Ixy = -4.292E+05	Ixz = -7.770E+06
Iyx = -4.292E+05	Iyy = 4.451E+08	Iyz = -9.157E+04
Izx = -7.770E+06	Izy = -9.157E+04	Izz = 5.528E+08

2.5 Visualization of the aircraft assembly

This subchapter is described in which order the aircraft will be produced. The order of the production is visualized by the images below.



3.1 List of design requirements

Table 3-a List of Design Requirements

Requirements:	Design meaning:
Hand launch	Take-off speed: 5 m/s
Land safe (also in automatic mode)	Land with stall speed/landing speed of 8 m/s
Climbing gradient of 8,3%	4,7° path angle
Pilot in command	Fully maneuverable within 500m of the pilot
Limited costs	
Confidence speed of pilot	Between 10 and 20 m/s
Needs to fly at least 2 times	No major damages allowed in landing, good controllability is desirable to avoid crash
Right and Left, Front and Rear parts distinguishably: Navigation lights/distinguishing colors/LED	
Paint package in a distinguishing color, recognizable between the grass of the NLR airfield	
Maximum allowable mass	4 kg
Carry the maximum payload	200 grams
Maximum main wingspan	2 m
Wing covered with composite skin	
Electronic components provided by educational institution	
Thrust limited	2,038 kg (Motor test)
Static and dynamic stable	
Fixed wing	
One engine	
Drop payload accurately in the target	
Follow accurately the programmed route in automatic mode	
Do not fly in restricted area's	
The pilot needs to be in command of an RPA-L certificate	
Maximum altitude	Maximum altitude of 500 m at the NLR area.
The UAV must be in sight at all times	
Flying at night or after sunset is prohibited	Navigation lights, strobes and beacon lights do not have to be designed
Distance from uncontrolled nearby airports	Not nearer than 3 km
Own Requirements	
To have two non-conventional configuration features	
Aim for a specific weight with payload	3 kg

Payload storage inside the fuselage	Spacious fuselage

3.2 Applied design requirements

Table 3-b Applied design features

Design decision	Reason	Disadvantage
Dihedral wing	The requirement is to land safely without any major damage. Therefore, dihedral wings allow a mid-wing configuration and low risk of damage during landing. In addition, extra stability longitudinal axis will arise.	Could cause difficulties during the production phase.
No landing gear	It is time consuming to produce, it would mean extra weight and extra drag that it is not desirable.	The forces during impact could damage the aircraft. So, a strong belly is required.
Deep camber wing	The requirement was to land with low stall speed. And the aircraft need enough lift during take-off. Therefore, a deep camber wing is chosen.	High camber wing causes more drag and a higher moment coefficient. The higher drag results in lower speed. It also produces a huge downwash that will affect our tail configuration
Tractor propeller	The requirement was to hand launch the aircraft. Therefore, it was safer to design a tractor propeller installed in the front of the aircraft.	Heavier nose, the propeller can be damaged due to no protection during landing.
Cut-off wing	Winglets it is time-consuming during the production and design phase and drag is not our main concern due to the powerful engine provided.	The wingtips produce more drag without winglets.
Low aspect ratio	The dihedral configuration brings as a week point the connection of the two sides of the wing, therefore a less structural demanding wing is a reasonable option. Considering also that the thrust to weight ratio is 2/3 the drag disadvantage is not critical.	Because of the low aspect ratio, the airplane must have higher amount of thrust overcome the induced drag.
T-Tail	One of the requirements was to do something different compared with other groups. Therefore, a T-Tail is designed. Because of the T-Tail, less downwash comes down on the horizontal stabilizer.	Heavier tail section because the vertical stabilizer must withstand the forces and weight of the horizontal stabilizer, which causes the CG to move aft.
Lifting body fuselage features	While designing the aircraft, the project group wants to design a fuselage with characteristics of a lifting body to provide extra stall protection. The fuselage is designed in an aerodynamical shape and big enough to store the electronics, dropping system and dropping package inside.	A big fuselage will give the aircraft extra drag and will mean extra design and production effort.

Chapter 4: Maximum available performance specifications

4.1 Calculations made for maximum available performance

Using the developed Mathematica calculator described in the Appendix the project group has been able to estimate the maximum available performances

```
Landing speed → 7.88 m/s
Take-Off speed → 8.12 m/s
Handlaunch speed needed to accelerate to Take-Off speed in 0.5 seconds → 5.61 m/s
Required Load factor → 5.92 (L/W)
Required Wing load → 334.69 N/m² → 34.152 kg/m²
Estimated maximum Flight Speed → 27.195 m/s → 97.902 km/h
Estimated maximum Path Angle → 24.1 º
Speed for γmax → 8.12 m/s → 29.2 km/h
Maximum rate of climb → 5.07 m/s
Speed for Vzmax → 17.9 m/s
```

Figure 4-a Maximum available performance

4.2 Results of the tests made in Merlin

After some flight tests in the Merlin Simulator (our model is described in the Appendix) the aircraft configuration was adjusted and several maximum performance tests were performed.

In Table 4-a the outcomes are given provided by the Merlin simulator test.

Table 4-a Results of the tests made in Merlin

Variable	
Roll rate	40 º/s
Stall speed	7,2 m/s
Maximum speed at level flight	16,5 m/s
Cruise speed (Trimmed without elevator deflection)	12 m/s
Maximum rate of climb	~800 ft/min = 4 m/s

4.1 Conclusion based on all the results

The propulsion and drag model used by the Merlin differs greatly from the one used in our calculations, which affects to the maximum speed and rate of climb mainly. The cruise speed then is adjusted to get a 0 elevator deflection when trimmed.

The rest of the parameters are similar to the expected ones and the behavior of the airplane is consistent with our expectations in that areas. Roll and climb rates have been proved to be sufficient.

Chapter 5: Static and dynamic stability specifications and analysis

In this chapter we will review the longitudinal stability calculus we made for the concept presentation and extend it to lateral-directional and dynamic behaviour. The tools used for this purpose are a Mathematica Calculator, XFLR5 software and Merlin Simulator, one can find detailed descriptions of the models used and the parameters introduced in the simulation's software in the Appendices.

5.1 System of reference and nomenclature used

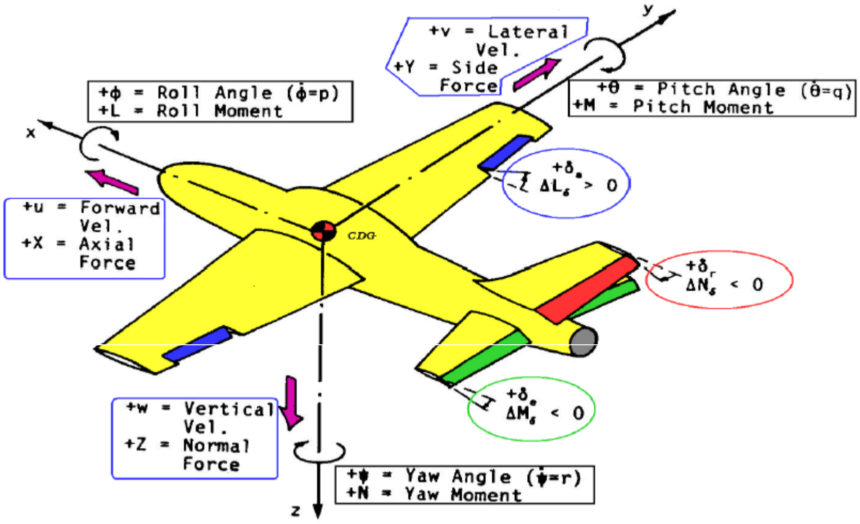


Figure 5-a System of reference

5.2 Calculations made for stability specifications

5.2.1 Longitudinal Static

From the past analysis of stability, it's known that the natural response of the aircraft against an increase in angle of attack is to pitch down.

It's been also stated that the moment coefficient at 0 angle of attack should be positive, condition that is not fulfilled by the group aircraft because of the deep camber airfoil is producing lift even in -5° of angle of attack, therefore the UAV would be able to climb even with negative angles of attack.

An additional condition for the stability in longitudinal direction is that the Drag Coefficient in trimmed conditions should increase with speed, it's the Speed Stability, the XFLR5 viscous simulations show that our model fulfils the requirement.

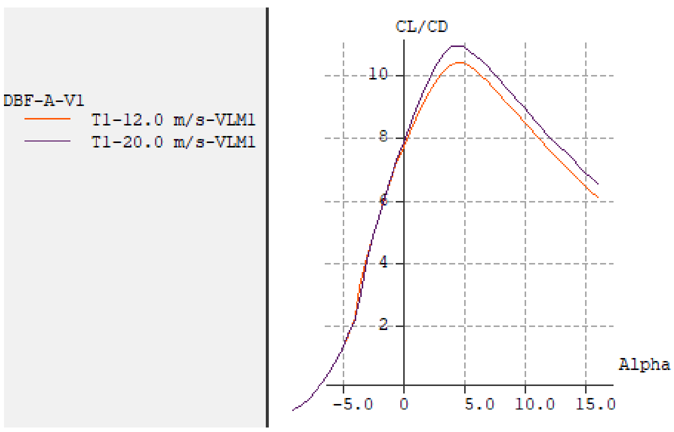


Figure 5-b Speed Stability analysis

Finally, here one can find a briefing of the Longitudinal Static Stability.

Conditions for Longitudinal Static Stability

$CM\alpha < 0 \rightarrow CM\alpha = -1.16$ ✓

$CM0 > 0 \rightarrow CM0 = -0.116$ X

$xNP > xCoG \rightarrow xNP - xCoG = 0.0881\ m$ ✓

Static Margin $\rightarrow 0.252$

Horizontal Stabilizer Tail Volume $\rightarrow V_H = 0.758$

Figure 5-c Conditions for longitudinal static stability

5.2.2 Longitudinal Dynamic

Here the project group realized an analysis of the conditions needed to demonstrate longitudinal dynamic stability in the Short Period Oscillation and the Phugoid modes.

From the linearization of the equations of motion of the aircraft we can extract some conditions needed to reach dampening in the Short Period Oscillation, stated in the two first conditions of Figure 5-d.

Moreover, one can approximate the values of the damping and natural frequency of that modes, stated also in Figure 5-d.

Conditions for Longitudinal Dynamic Stability

$CM\alpha + CMq * \left(\frac{\rho * S * c}{m} \frac{CL\alpha}{4}\right) < 0 \rightarrow$ ✓

$CL\alpha > (CMq + CM_{D\alpha}) * \left(\frac{m * c^2}{2 * Iyy}\right) \rightarrow$ ✓

Short Period Mode $0.35 \leq \zeta_{SP} \leq 1.30 \rightarrow \zeta_{SP} = 0.961 , \omega_{SP} = 9.31$ ✓

Phugoid Mode $\zeta_{Phugoid} > 0.04 \rightarrow \zeta_{Phugoid} = 0.411 , \omega_{Phugoid} = 0.385$ ✓

Figure 5-d Conditions for longitudinal dynamic stability

This approximation could be done due of some additional simplifications in the modes:

- In the Short Period Oscillation
  - Aircraft speed doesn't change significantly during the oscillation due to its high frequency.
  - Vertical forces due a vertical acceleration and pitch rate are negligible.
  - Pitch angle is approximately 0.

$$\omega_{CP} \approx V_0 \sqrt{-\frac{\rho Sc\ CM_\alpha}{2I_{yy}} - \left(\frac{\rho Sc\ CM_q}{4I_{yy}}\right)\left(\frac{\rho Sc\ (CD_{TRIM} + CL_\alpha)}{2\,m}\right)}$$

$$\varsigma_{CP} \approx \frac{\rho S\left(\frac{CD_{TRIM} + CL_\alpha}{2m} - \frac{(CM_q + CM_{\dot{\alpha}})c^2}{4I_{yy}}\right)}{2\sqrt{-\frac{\rho Sc\ CM_\alpha}{2I_{yy}} - \left(\frac{\rho Sc\ CM_q}{4I_{yy}}\right)\left(\frac{\rho Sc\ (CD_{TRIM} + CL_\alpha)}{2\,m}\right)}}$$

Figure 5-e Short Period Oscillation approximate values (CP stands for Short Period)

- In the Phugoid mode
    - Pitch Moment coefficient does not change significantly with speed
    - For the damping coefficient other significative simplifications are applied, but they are not going to be explained here because that would mean a deep analysis of the equations of moment.

$$\omega_F \approx \sqrt{\frac{g\ \rho\ S\ \ CL_{TRIM}}{m}}$$

$$\varsigma_F \approx\approx \frac{\rho S V_0^2}{2mg}\sqrt{2}CD_{TRIM}$$

Figure 5-f Phugoid approximate values (F stands for “Fugoide”)

5.2.3 Lateral-Directional

Several conditions are needed to prove Lateral-Directional Stability, first of all the Lateral force should oppose to the increase in slip angle (Slip angle sign convention follows the right hand rule with the Z axis that points downwards), this is accomplished by the use of a vertical stabilizer that sees the slip angle as an angle of attack and provides “Lift” in the opposite lateral direction.

Secondly this lateral force must be applied in a point where the effective Yaw produced is positive, that means that the aircraft tends naturally to reduce the Slip angle. This is accomplished by having the vertical stabilizer aft from the centre of gravity. Additionally, the Yaw moment produced when the slip angle is zero should be zero too.

Thirdly the Yaw moment and the Roll moment should oppose the roll rate, providing roll stability, this is achieved by the effective dihedral angle and the vertical stabilizer behaviour itself.

Finally, as a dynamic parameter we can find in the literature a Yaw coefficient that must be positive in order to have Dutch Roll stability, this doesn’t ensure the stability by itself but is a minimum requisite to have it:

$$CN_{\beta\_dynamic} = CN_\beta \cos\alpha - \left(\frac{I_{zz}}{I_{xx}}\right) Cl_\beta \sin\alpha$$

Figure 5-g Dutch Roll stability parameter

This coefficient has been evaluated in the maximum angle of attack and accomplishes the condition, here one can find also the briefing of all the conditions calculated:

Conditions for Lateral–Directional Stability

$CY\beta < 0 \rightarrow CY\beta = -0.0803$ ✓

$CN\beta > 0 \rightarrow CN\beta = 0.055$ ✓

$CN0 == 0 \rightarrow CN0 = 0.$ ✓

$CNp < 0 \rightarrow CNp = -0.0666$ ✓

$Cl\beta < 0 \rightarrow Cl\beta = Cl\beta_{\Gamma} + Cl\beta_{VStab} = -0.173 + -0.00357 = -0.176$ ✓

$Cl\beta_{dynamic} > 0 \rightarrow Cl\beta_{dynamic} = 0.215$ ✓

$Clp < 0 \rightarrow Clp = -0.823$ ✓

Vertical Stabilizer Tail Volume $\rightarrow V_{VT} = 0.0553$

Figure 5-h Conditions for lateral-directional stability

5.2.4 Control and Trimming

Some approximations were made with the linearized theory to get a first value of the mounting incidence of tail and wing. After the Merlin tests the configuration was slightly changed so the calculus is not fully representative of the final configuration anymore, but it's interesting to see the differences with the Merlin output.

Conditions for proper Control and Trimming

$5 < \alpha_{trim}$@V=Cruise $< 5 \rightarrow \alpha_{trim}$@V=12m/s = 1.99 º ✓

α_{trim}@V=V_{max} m/s $< \alpha_{max}$ (12º) $\rightarrow \alpha_{trim}$@V=27.m/s = -4.92 º ✓

α_{trim}@V=Take-Off m/s $\leq \alpha_{max}$ (12º) $\rightarrow \alpha_{trim}$@V=8.17m/s = 12. º ✓

α_{trim}@V=Landing m/s $\leq \alpha_{max}$ (12º) $\rightarrow \alpha_{trim}$@V=7.9m/s = 12.2 º ✓

δe_{trim}@V=Cruise m/s $\sim 0 \rightarrow \delta e_{trim}$@V=18m/s = -1.9 º ✓

δe_{trim}@V=V_{max} m/s $< \delta e_{max}/2$ (30º) $\rightarrow \delta e_{trim}$@V=27.m/s = -0.527 º ✓

δe_{trim}@V=Take-Off m/s $< \delta e_{max}/2$ (30º) $\rightarrow \delta e_{trim}$@V=8.17m/s = -11.4 º ✓

δe_{trim}@V=Landing m/s $< \delta e_{max}$ (30º) $\rightarrow \delta e_{trim}$@V=7.88m/s = -11.5 º ✓

$\delta e_{CM=0}$@$\alpha=\alpha_{max} < \delta e_{max}$ (30º) $\rightarrow \delta e_{trim}$@$\alpha$=12º = -11.4 º ✓

Figure 5-i Final configuration Control calculus with merlin

5.2.5 Validation with XFLR

Here the group compared the linearized calculus made in Mathematica with the results of the XFLR5 model simulated in inviscid mode at cruise speed.

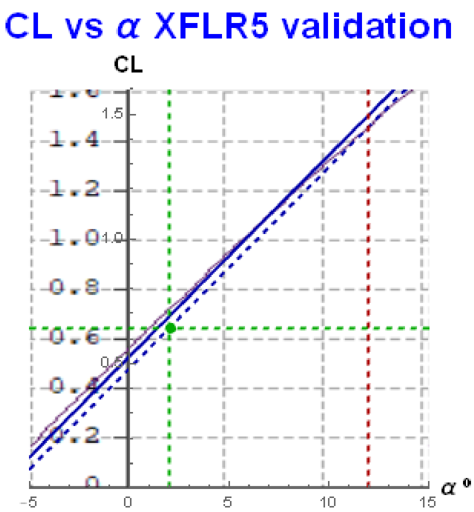


Figure 5-j Lift Model XFLR5 validation

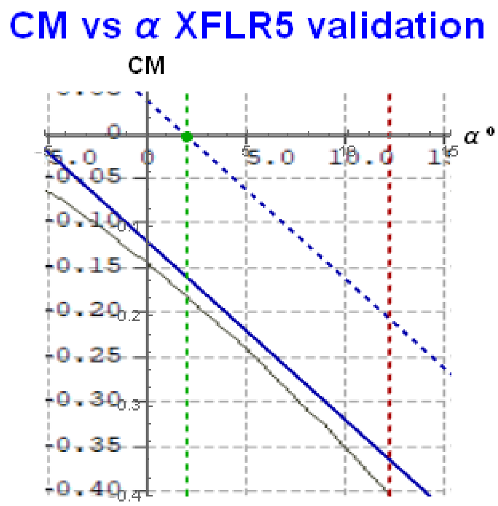
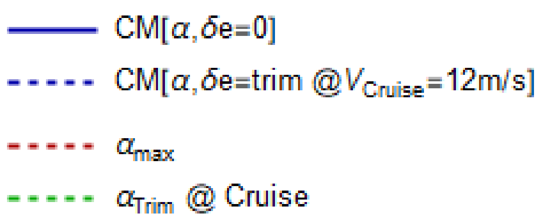


Figure 5-k Pitching moment Model XFLR5 validation



The first impression is that the lift linearized approach is very similar to the XFLR5 panel method results, but if one move to the pitching moment model it's easy to see that the non-linear effects gain importance, outside the range shown in the graph the differences increase and increase.

One of the main reasons of this difference is that the linearized calculus takes the moment coefficient in the wing airfoil as constant against the angle of attack in the applicable range of the linear theory, but the high cambered airfoil is highly sensible to angle of attack changes at low Reynolds as one can see in the following graphs, look closely the scale.

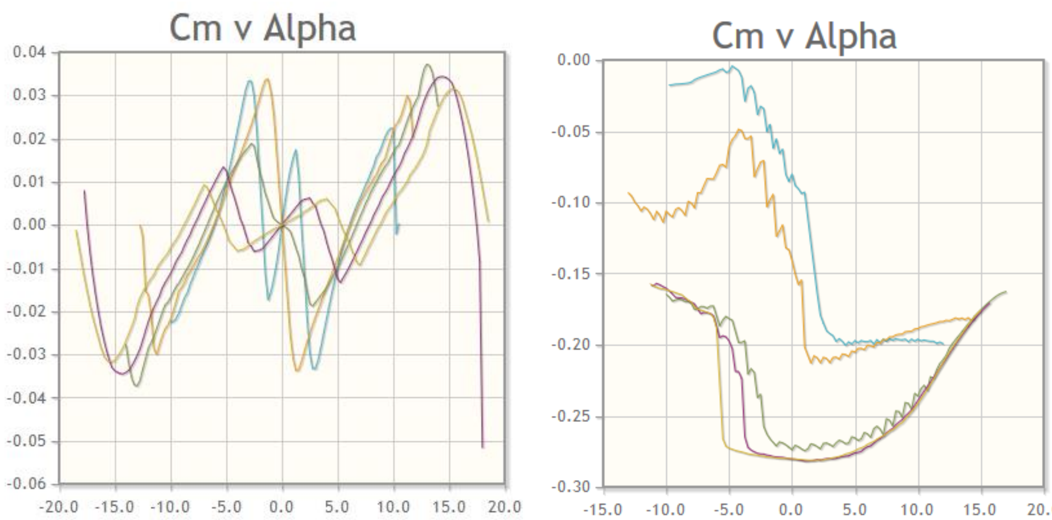


Figure 5-l CM-Alpha airfoils comparison (Left CH 10-48-13, Right NACA0012)

5.3 Results of the tests made in Merlin

To validate the made calculations about the performance specifications and the behavior (stability) of the aircraft the Merlin Simulation is used.

In this simulator, specific values of the designed aircraft can be used as input. Merlin uses this input and transfers it to geometry. With this geometry can be flown. The fuselage, wings, horizontal- and vertical stabilizer can all be seen as geometry. This is the way Merlin works.

After the values were put into Merlin it was time to fly the model. Mr. Teunissen, former captain at KLM Royal Dutch Airlines flew the model to test it correctly. With several tests he made, the behavior and controllability of the airplane can be validated. Merlin has a built-in function which collects data about all the aspects and input values. For example, the elevator deflection, rudder deflection, thrust and so on.

The tests Mr. Teunissen did are described below, each test has its own results and based on these results the project group can conclude if the airplane reaches the desired stability and therefore the calculated stability.

Firstly, Mr. Teunissen performed some turns to check if the ailerons and rudder were working properly, they both responded very sensitive. The project group degreased the ailerons by half and firstly, the rudder was put in Merlin as an all flying rudder.

After changes were made to make them respond correctly, the model reacts good in longitudinal axis and turning.

5.3.1 Lateral (pitch) stability

Now Mr. Teunissen performed some stability tests. In the graph below, the first test of Mr. Teunissen is seen. This graph contains the angle of attack vs elevator pitch up.

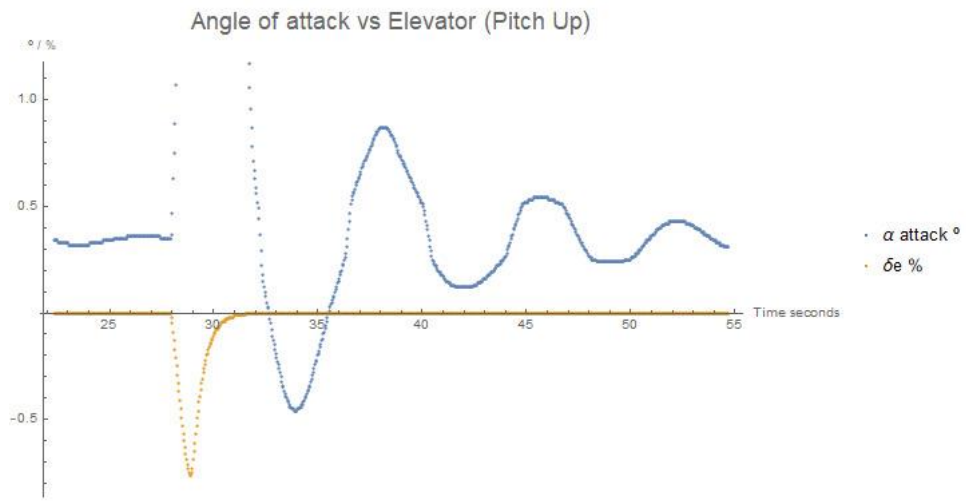


Figure 5-m Angle of attack vs elevator deflection (pitch down) test graph

This test is done to check the lateral stability. When pulling the stick up, the elevator deflects upwards. The airplane will pitch up and the angle of attack increases. To check the lateral stability of the airplane, the airplane is called stable when the elevator is deflected upwards, pitching the airplane up, increasing the angle of attack and when the pilot let the stick loose, the airplane must re-establish to level-flight. The smaller the phugoid motion, the more stable the airplane is because it needs less time to re-establish. The airplane dampens itself to level-flight. As seen in the graph above, created by the Merlin data, the airplane model is designed stable in lateral direction because the phugoid motion dampens pretty fast.

In Figure 5-n, it's actually the same situation as above, except the test pilot is now pitching down instead of pitching up.

The graph is nearly the same except that it's the other way around, it starts with the elevator deflection downwards, pitching the airplane down. As seen in the graph, the time of the test is longer to get a better view of the dampening of the phugoid motion.

The phugoid motion will stop after some time, going back to the previous position (level-flight). This meaning, the airplane is stable in both pitch up and pitch down and therefore lateral direction.

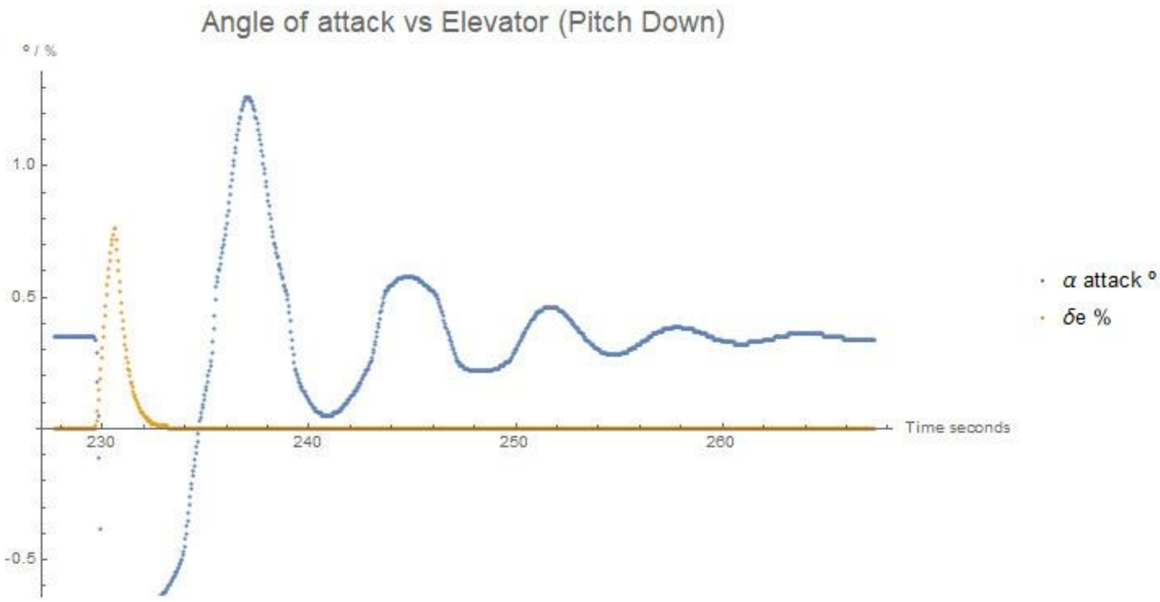


Figure 5-n Angle of attack vs elevator deflection (pitch down) test graph

5.3.2 Lateral-Directional stability

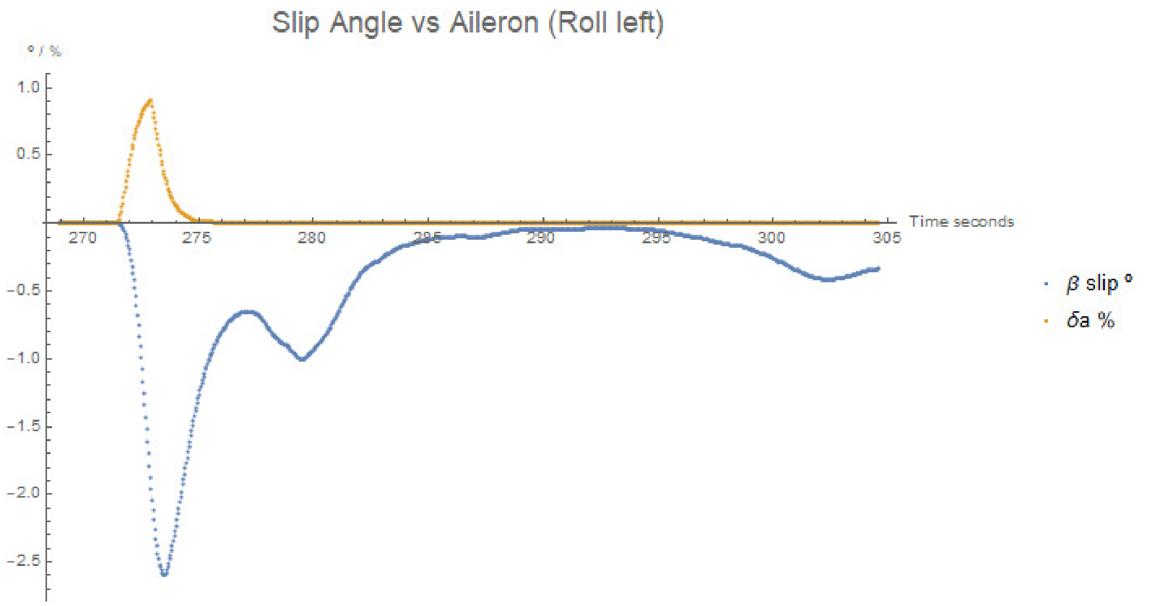


Figure 5-o Slip angle vs aileron deflection (roll left) test graph

In Figure 5-o is the graph about the slip angle vs aileron seen. With this graph, the longitudinal stability can be proofed. The test pilot banked the airplane to the left (the stick) with the use of aileron. When banking, the slip angle increases as seen in the graph. With the slip angle increasing, the g-forces increase too. At a certain point, at around 272 seconds the test pilot released the controls. As seen, the aileron deflection went back to 0% immediately.

The slip angle at the point of releasing the controls decreases drastically. This is explainable by the aircraft design, because of the 10-degree dihedral of the wings.

This type of wing configuration stables the aircraft in longitudinal (roll) direction by itself because of the difference in lift coefficient of the wings.

The phugoid motion, is almost completely dampened as seen in the graph. The time is very short which means the roll stability is high.

To conclude that the designed airplane is stable in vertical (yaw) axis, having a look at the data which came from Merlin is necessary.

To test the yaw stability correctly, the test pilot applied maximum aileron deflection with maximum rudder in opposite direction. This causes a big slip angle as seen in blue in the graph below. At the maximum slip angle, at the top of the parabolic function, the controls were released. The airplane immediately slipped to the other side (positive slip angle instead of negative) and dampens fast after. The dampening is high, while the time between the periods is short (like +- 6 seconds). This means that the airplane in yaw axis is stable as well. The phugoid motion doesn't increase but decreases fast.

In the graph below, the slip angle vs the rudder deflection is seen.

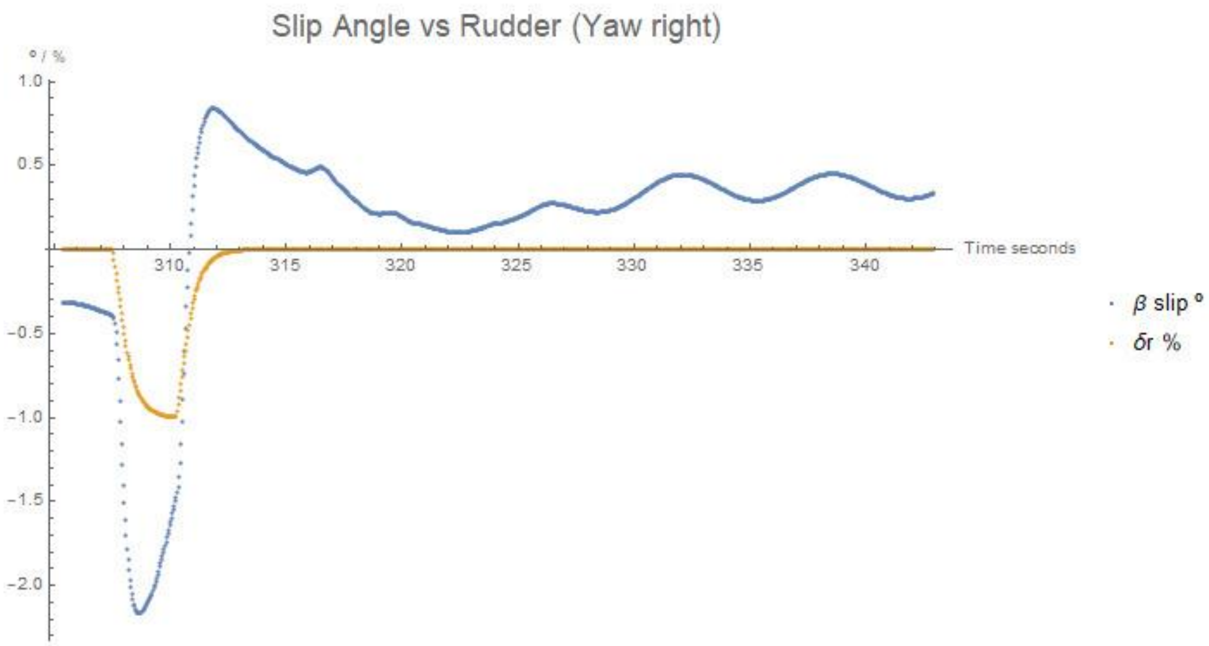


Figure 5-p Slip angle vs rudder deflection (yaw right)

5.3.3 Merlin Symmetry

Because of the fact that Merlin uses symmetrical geometry, the graphs for lateral, longitudinal and yaw stability are also applicable for the other way around.

For example, the graph of the longitudinal stability, were a left roll is performed is also applicable when a right roll is performed. The project group assumes the result will be the same but mirrored around the x-axis.

This is the same for the yaw stability graph, instead of using rudder to the right and turning to the left by the ailerons, the graphs will look the same but mirrored when using rudder to the left and turning to the right by the ailerons.

5.4 Conclusion based on all the results

The aircraft developed by the project group is as stable as expected, which is highly stable both in longitudinal and lateral-directional, with a very high dampening in the longitudinal modes.

As a task to do before the test flight the project group agrees to make a flight envelope and a briefing of handling capabilities to show the flight behavior of this aircraft that a priori can seem very strange.

Chapter 6: The package drop mechanism

6.1 Chosen design mechanism for the packaged drop

One of the requirements during this project was to drop a package with rice, with a maximum weight of 200 grams. The project group designed a dropping system. Besides designing a dropping system, the group also decided to install the dropping package with the system inside the fuselage. In addition, a door will be added which can open and close during the flight.

6.1.1 Dropping mechanism:

The group decided to use a kind of hook mechanism for dropping the package. The dropping system is designed in Fusion and the system will be printed with 3D printing.

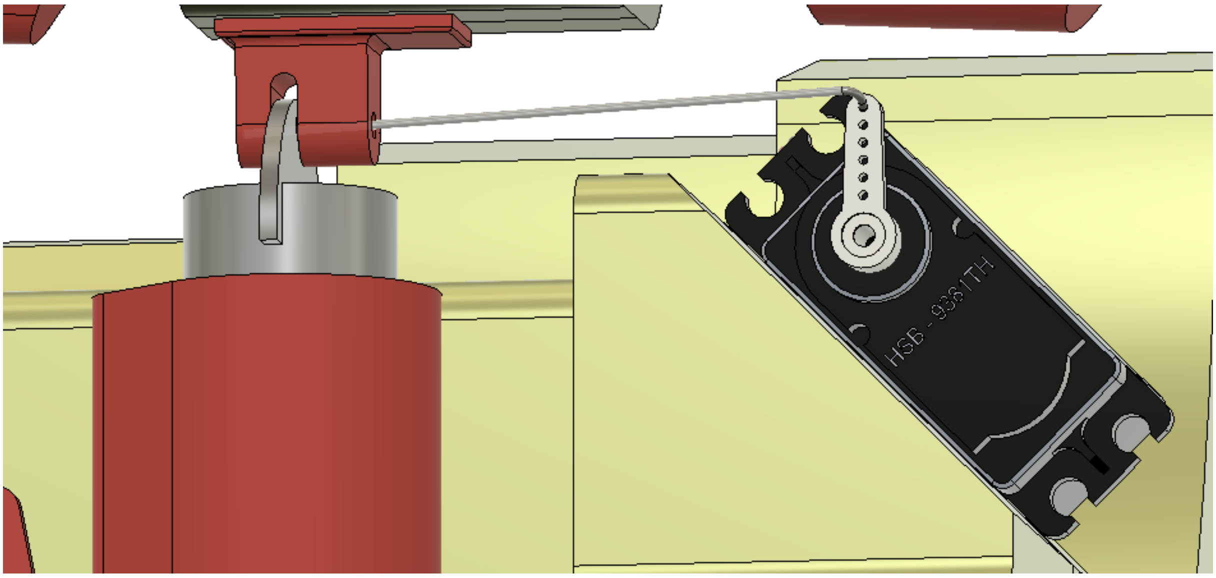


Figure 6-a Dropping mechanism

As one can see in Figure 6-a, a servo is placed. The servo is connected with a metal wire. If the controller on the ground sends a signal to the servo, the servo pulls the metal wire away and the package will be released.

In Figure 6-a one can see the 3D printed dropping system of the project group. The width of the dropping system is minimized to reduce weight.

6.1.2 Package:

The package will be made by different parts. The first part is a 160-gram piece of metal. In the metal, holes will be drilled. A welding wire is attached through the drilled hole. In addition, the weld wire will be bent in a way that it gets the shape of a hook. The ending tips of the weld wire will be soldered together. By using this production method, a hook will be created, and the hook can be hanged on the dropping system. In Figure 6-b a picture is viewed about the metal part.

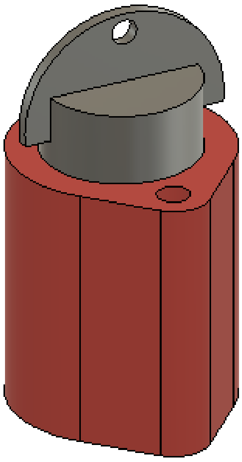


Figure 6-b Payload package

After producing the metal part, a 3D printed cover will be produced to cover the metal. This will be done because extra space is created to store rice. And PLA (3D printing material) is less dangerous with impact on the ground then metal.

6.1.3 Opening door:

As showed in the concept design, a few door opening options were shown. The project group chose the door that will open against the wind flow. This door is chosen because the airflow during the flight will help the door closing again. In addition, the project group doesn't need to buy an extra servo to open and close a second door. The door will be made, by cutting a rectangular hole in the fuselage. After that, the rectangular piece will be attached in the hole again with plastic hinges. With the hinges, the door can open and close. The project will choose plastic hinges (Figure 6-c) because it can be strongly connected with screws on the fuselage and door. And the plastic hinges are light weighted. The project group tested duct tape to use as a hinge. But the glue on the tape doesn't connect well with glass fiber and foam. Metal hinges will be too heavy, so the best option is to choose plastic hinges.

Figure 6-c Hinges (Conrad, 2019)

Basically, the door will open and close the same way as the ailerons operate in the aircraft. A servo will be installed in the bottom of the aircraft. A metal wire will be connected on the servo. At the other end of the wire, the wire will be attached with the door. If the controller gives the servo a signal to open, the servo releases the wire and the door will open. After the package is dropped, the controller on the ground gives a signal to close and the servo will pull on the wire and the door will close. In addition, the airflow will help to close the door. In Figure 6-d and Figure 6-e pictures are shown how the door will be installed and built.

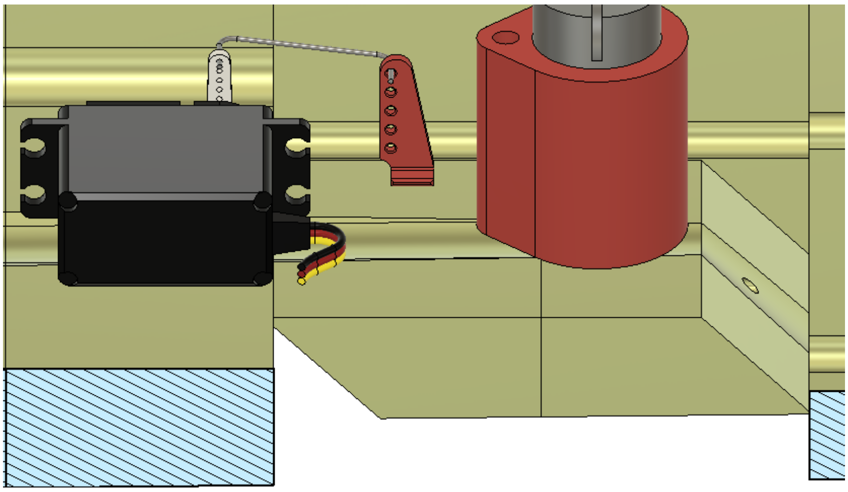


Figure 6-d Package door detail view

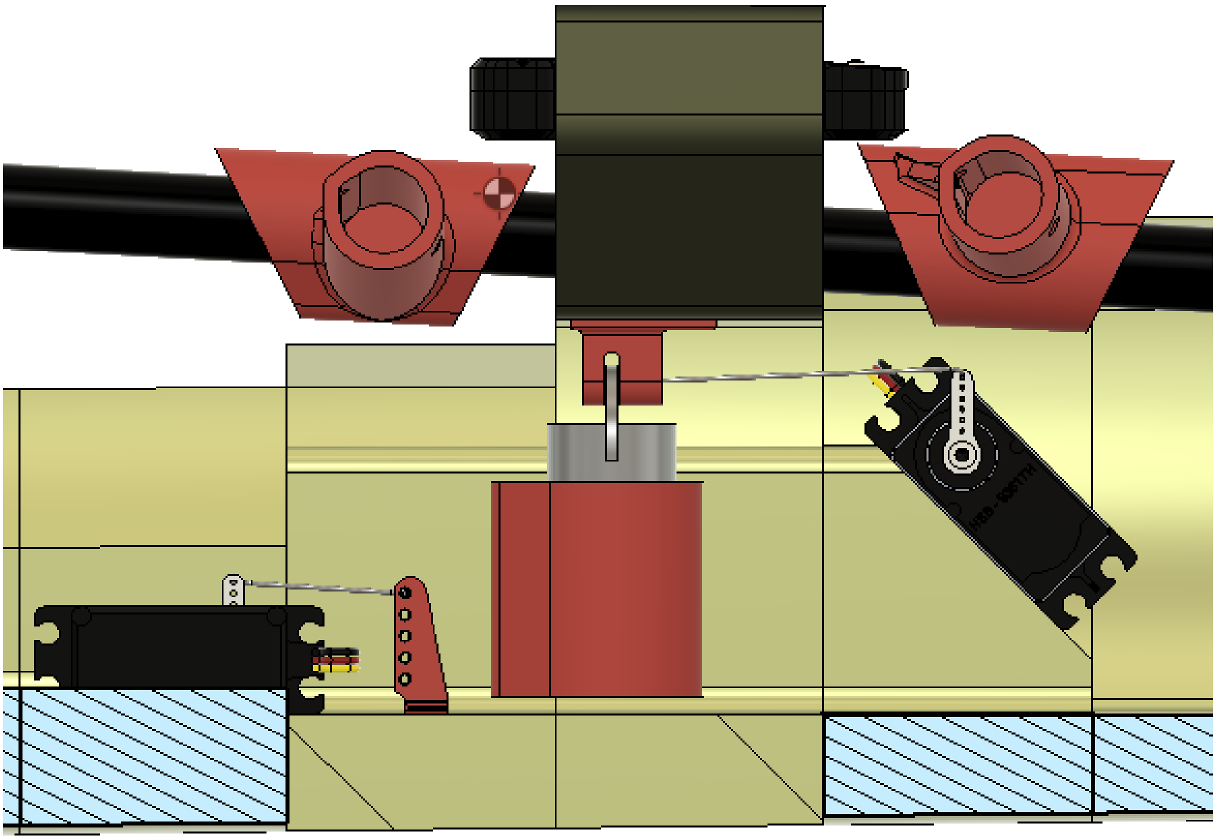


Figure 6-e Dropping mechanism electronics position

6.2 Calculations for the path travelled by the package

After the dropping, the package has to reach a certain target. In this chapter calculations are provided how many distance the package will travel through the air.

The project group developed a calculator in excel to calculate the flight path. So, in case something should be adjusted it can easily be changed. During the calculations wind is not considered, because the aircraft will drop the package at a low altitude and the small size and lack of lifting surfaces make this a reasonable approximation. Also, this simplification is consistent with the intention of including it in the Pixhawk programmed route so the aircraft can adapt easily the timing to activate the drop system according the altitude it is flying.

In this example the assumption is taken that the airplane will reach 14 m/s at an altitude of 20 m. The horizontal dropping distance is calculated as follows:

1. Formula:
   $y = y0 + v0y * t + 0.5 * g * t^2$
2. $0 = (20m) + 0 + 0.5 * (-9.81\ s^2) * t^2$
3. $0 = 20m - 4{,}9\ m/s^2 * t^2$
4. $4{,}9 \frac{m}{s^2} * t^2 = 20$
5. $t^2 = \frac{20\ m}{4{,}9\ m/s^2}$
6. $t = \sqrt{\frac{20}{4{,}9\ sec^2}} = 2{,}02\ sec$
7. $x = v0x * t$
8. $x = \left(14 \frac{m}{s}\right) * 2{,}02\ \text{sec}) = 28{,}28\ m$

So, in this case, the package would travel a horizontal distance of 28,28 m before hitting the target on the ground.

Chapter 7: Composite wing

7.1 Detailed structural design (lay-up)

The unmanned Aerial Vehicle is a devise that is able to fly by gaining support from the air, or in general from the atmosphere of the planet. The human activity that surrounds aircraft is called aviation. The crewed aircraft are flown by an onboard pilot, but the unmanned aerial vehicles may be remotely controlled or self-controlled by onboard computers. The aircraft is classified by different criteria, such as lift type, propulsion, the usage of the aircraft and others criteria. To build and test the UAV, there are several activities that are scheduled by the project group DBF-A. The main focus of this chapter is the strength and the structural analysis of the UAV wing.

Before building the wing of the UAV, the project group needs to study and understand the material properties of all the materials that will be used to make the UAV wing. The project group decided to make the wing from three different materials. These three different materials are:

- Foam
- Carbon fiber
- Glass fiber

7.2 Strength analysis

To make the strength analysis the project group need to figure out what is the load that acting on the wing. The load calculations are:

- Weight of the aircraft = 3 kg
- Design load factor = 6
- Total load acting on the aircraft = 3 * 6 = 18 kg
- Factor of safety = 1.5
- Design load = 18 * 1.5 = 27 kg
- As we know! That the total lift load on the aircraft is distributed respectively as 80% on the wing and 20% on the fuselage.
- The lift load on the wing = 0.8 * 27 = 21.6 Kg
- Load acting on each wing = 21.6 kg / 2 = 10.8 kg on each wing (10.8 * 9.81) = 105.9N
- The pressure = 105.9 N / (0.52 m2 wing surface / 2) = 407.3 N/ m^2.

7.3 Wing bending

In this part, the project group is looking at the wing bending calculations of the fiber glass. The calculations consist of the max bending, the shear force and the deflection of the wing.

The force that acting on the wing is in Newton/millimeter and not Kilo Newton/ meter. Here below Figure 7-a is shown the how the force acting on the UAV wing. The force is highest at the wing root.

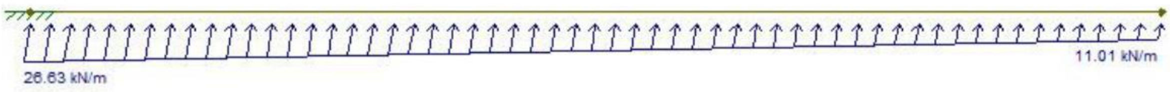


Figure 7-a Force acting on the wing

The bending moment model is the expressions that are derived and can be used for load on the wing to calculate the bending moment. The first step to start with is by integrating the total load to determine the shear force. The next step is to integrate the shear force to be able to calculate the bending moment of the wing. Here below is Figure 7-b of the bending moment of the wing, as expected, the bending moment is highest at the wing root.

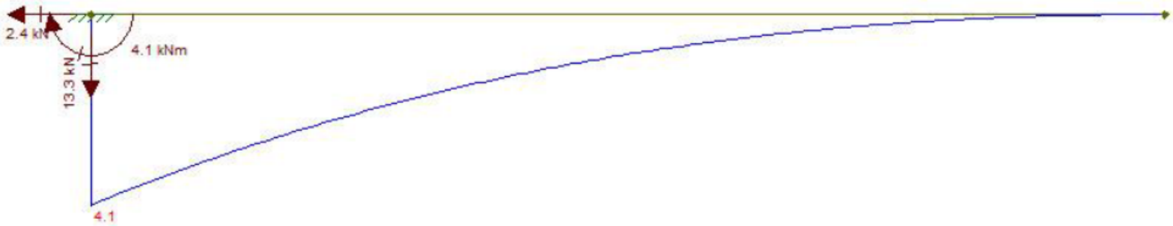


Figure 7-b Bending moment

The shear force that acting of the wing of the UAV is to be shown in the Figure 7-c here below.

Figure 7-c Shear force

The forces that acting on the wing caused a deflection. The wing of the UAV has a deflection of 2.21e-03 Figure 7-d.

Figure 7-d Deflection at wing tip

From the above mentioned calculations and figures, the wing of the UAV can support enough force to make a safe flight. This wing strength calculation is made just for the glass fiber. The UAV wing will be much stronger because the project group will add carbon tube and the foam to the wing.

Chapter 8: Selected materials and production methods

In this chapter the selected materials (8.1) and production methods (8.2) will be described.

8.1 Materials

8.1.1 Foam

The project group chose foam to make the main shapes of the aircraft. We chose foam because the project group noticed during production technology lessons that it was very comfortable to work with it. In addition, the foam has good strength properties. It's stiff, lightweight and adjusting parts is really easy due to working with the hot wire thread. It can also withstand high impact forces which can be caused by landing. After cutting the foam in the desired shapes and forms it will be layered with composites on the wings and at some parts of the fuselage to make it stronger and stiffer. The foam will be used for the fuselage and the wings.

Table 8-a Foam properties

Mechanical Property	Value
Density	760 - 820 kg/m^3
Young's modulus	1,2 - 1,3 GPa
Tensile strength	20 - 22 MPa

8.1.2 Carbon Fiber Rods

Carbon rods will be used to connect the wings with the fuselage. In addition, the carbon rods will give the wings extra strength and prevent them from bending and coming apart. Besides the carbon rods in the wings, a rod will be additionally put in longitudinal direction in the fuselage. This will be done to provide the fuselage with extra strength and to connect the wings too, to prevent them from torsion. In addition, the carbon rod in the fuselage will be used to mount piece parts on it, like the dropping mechanism with the dropping package and the engine at the front of the aircraft.

Table 8-b Carbon fiber rod properties

Mechanical Property	Value
Density	1,55e3 - 1,58e3 kg/m^3
Young's modulus	110 - 131 GPa
Tensile strength	1,48e3 - 1,84e3 MPa

8.1.3 Composite skin

One of the requirements was to cover the wings with composite material. The project group chose for glass fiber, because it is cheaper then other composite materials for example carbon fiber and during the tests was found that the glass fiber would be strong enough to resist the forces during the flight.

Table 8-c Composite skin properties

Mechanical Property	Value
Density	1,82e3 - 1,87e3 kg/m^3
Young's modulus	20,7 GPa
Tensile strength	178 - 222 MPa

8.1.4 Wood

To give the wings the right shape, templates needs to be made to cut out the right airfoil. The project group is going to design the right shapes in AutoCAD. Then the designed shapes will be cut out in the laser cut machine. In addition, wooden templates will be used to reinforce the fuselage tip which connects to the middle, and the fuselage tail which connects to the middle.

8.1.5 PLA

Some parts in the aircraft will be 3D printed. The 3D printed material that will be used is PLA. PLA is strong and lightweight, easy to print and therefore an easy material to design with.

8.1.6 Glue

Epoxy resin

Epoxy resin will be used to connect the glass fiber with the foam. In addition, the epoxy resin ensures that the glass fiber will be solid. When the glass fiber is solid, it can resist high impacts and strengths.

Fast glue

Fast glue will not be used often. It will probably be used for the glass fiber to stay in place before applying the epoxy resin.

8.2 Production methods

8.2.1 Hot wire

As said in previous chapter XPS foam will be used to produce the wings. After the templates of wood are designed and made, the template will be stuck or nailed on the foam. Thereafter members of the project group will cut the foam in the shape of the template with a hot wire. After the hot wire got through the foam, the template can be removed, and a wing shape of foam is created.

8.2.2 Laser cut

Foam

Accuracy is necessary for the fuselage. Because producing the fuselage with a hot wire is difficult. The laser cut machine will be used to cut slices in the right shape in the foam. The shapes of the slices will be designed in Fusion and AutoCAD. After all slices are cut, the slices will be glued together, and the fuselage is created.

Wood

As said in previous chapters, templates need to be made to cut out the right shape of the wings. The templates will be cut out from wood in the laser cut machine. Again, the templates are designed with AutoCAD

8.2.3 3D printing

Some parts will be 3D printed, because with 3D printing the required shapes can be detailed designed. In addition, the 3D printing material (PLA) is light weighted. The shapes will be designed in Fusion. After the design in Fusion is done, the design of a part will be transferred into the 3D printing software and the 3D printing can start.

The following parts will be 3D printed:

- Wing-fuselage connections
- Dropping system hook mounting
- Door horn
- Engine mount
- Control surfaces horns
- Payload cover

For more detailed information about the parts production method and bulk material needed for its manufacturing please see the Parts Catalog in the appendix. Furthermore, all detailed drawings and material costs estimations will be provided in the Production Plan.

Chapter 9: Hazard analysis

In this chapter one can find the preparations steps that are made for the hazard analysis (9.1). In this chapter is as well a safety management system in which the control actions that will be done during the mission flight are being analyzed (9.2).

9.1 STPA preparation steps

In this subchapter the STPA will be discussed. Also, the preparation steps and what STAMP is.

9.1.1 What is STAMP?

STAMP is an acronym which stands for System-Theoretic-Accident-Model-Process. It defines safety as a control problem which can be applied to complex systems. With complex systems is meant software, humans and technology. STAMP usually includes a control loop where the controller influences the controlled process with controlled actions. The controlled process provides feedback about the controlled actions to the controller. This loop continues as the controlled process proceeds.

9.1.2 How do we apply STAMP?

In order to use the STAMP model, it is necessary to do STPA (System-Theoretic-Process-Analysis) preparation steps. STPA steps are a useful tool because it defines the system under analysis. In this analysis process one has to state the system goals (objectives), identify losses (accidents), identify system hazard(s) and based on the hazards, derive system safety constrain(s). It is important to link every aspect in the analysis process because it is important to trace everything back to see if it is correctly done and for revisit analysis. After this analysis process the control structure of the controlled process can be drawl.

9.1.3 STPA preparation steps

In the Table 9-a till Table 9-d below can one see the STPA preparation steps as discussed in subchapter 9.1.2.

Table 9-a System goals

System Goals	
SG-1	To carry the maximum payload (rice package)
SG-2	To perform a safe flight
SG-3	To follow accurately the programmed route in automatic mode
SG-4	To drop the payload accurately in the target
SG-5	To contain the payload (rice) in its envelope

Table 9-b Accidents

Accidents		**Linking**
A-1	Not to carry any payload	*H-3*
A-2	Not to perform a safe flight	*H-1/H-2*
A-3	Not to follow the programmed route in automatic mode	*H-1/H-2*
A-4	Not to drop the payload in the target	*H-1/H-3*
A-5	Not to contain the payload in its envelope	*H-1/H-3*

Table 9-c Hazards

Hazards		**Linking**
H-1	Not maintaining a safety distance between the UAV and environmental obstacles	*A-2/ A-3/ A-4 / A-5*
H-2	Loss of controllability	*A-2/A-3*
H-3	Malfunction of the dropping system	*A-1/A-4/A-5*

Table 9-d Safety Constraints

Safety Constrains		**Linking**
SC-1	Safety distance between the UAV and the environmental obstacles shall be maintained	*A-2/A-3/A-4/A-5*
SC-2	The controllability shall be kept	*A-2/A-3/A-4*
SC-3	The payload dropping shall always be in the specific target location	*A-1/A-4/ A-3/A-5*

9.1.4 Control loop

In the Figure 9-a one can see the control loop that has been made based on the STPA preparations.

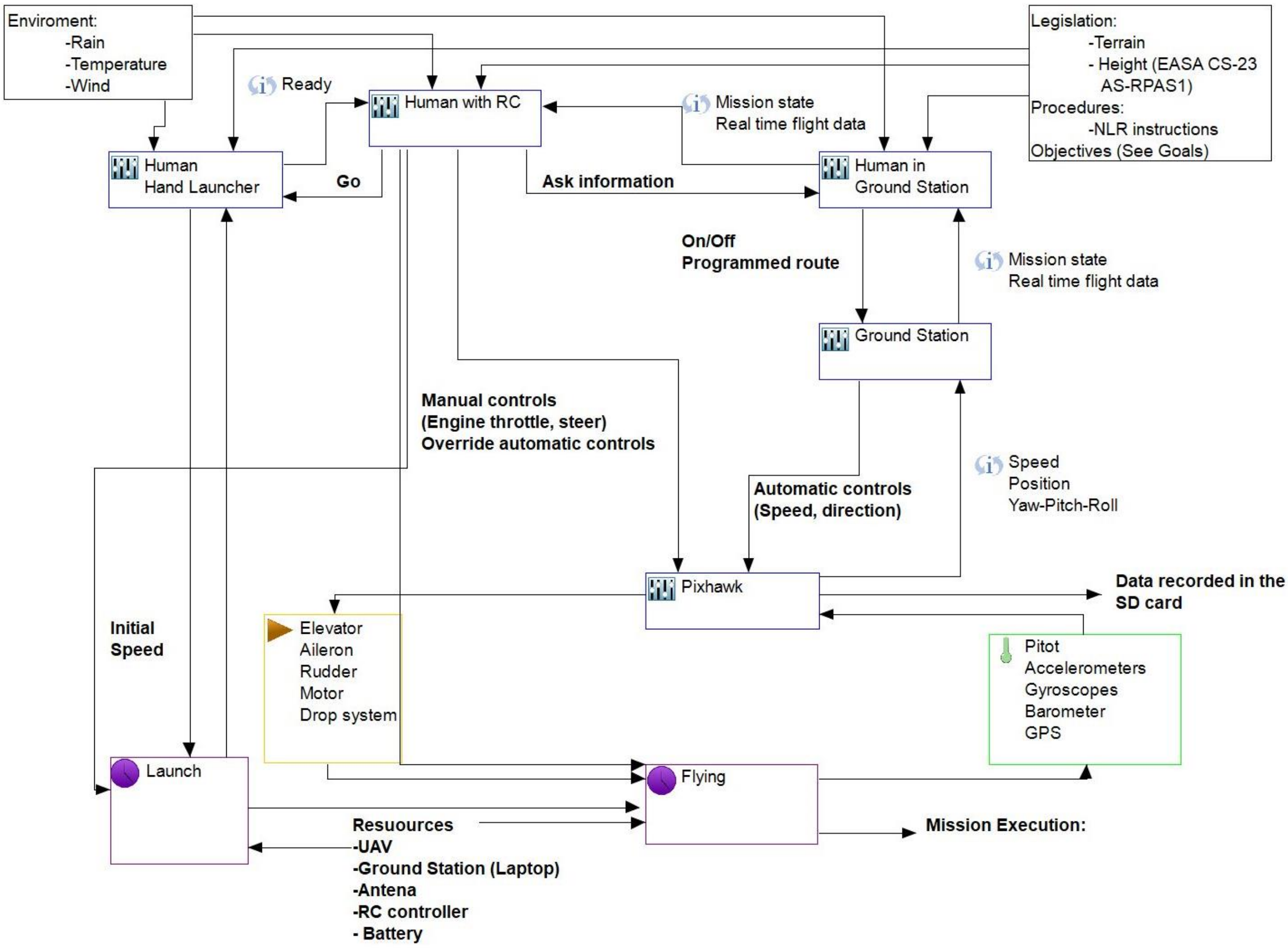


Figure 9-a Control Loop

9.2 Controlled actions

As discussed in the previous subchapter (9.1), STAMP is necessary to define safety. The controller influences the controlled process with controlled actions. In this subchapter will the control actions be discussed, because it is important to state if these controlled actions are safe or not.

8.2.1. What are control actions?

Control actions translate the decision into visible actions. They can be directly applied to the control process or indirectly applied to the process through actuators. One can make a listing of all the controlled actions and group them if possible. Control actions can be unsafe and there are four ways that an unsafe control action can might lead to a hazard. After the unsafe control actions and the hazards that it might can lead to is clear, is it possible to make a safety management system. Based on the unsafe control actions that can might lead to a hazard are constraints determined. Once again in this case the linking is important.

Table 9-e Control Actions

Control Actions	
CA-1	Turning
CA-2	Ascent
CA-3	Decent
CA-4	Drop package
CA-5	Throw
CA-6	Stop engine
CA-7	Land
CA-8	Change speed
CA-9	Switch to automatic mode
CA-10	Switch to manual

9.2.1 The safety management system

In Table 9-f one can find the safety management system which includes the control actions that can lead to unsafe control actions which can become hazardous.

Table 9-f Safety management system

Control action	Not providing causes Hazard	Providing causes Hazard	Too early/Too late, wrong order causes Hazard	Stopping to soon/applying too long causes Hazard
CA-1: Turning	UCA-1.1: controller does not provide a turn when the UAV is close to an obstacle		UCA-1.2: Controller provide a turn too late when UAV is flying too close to an obstacle	
CA-2: Ascent	UCA-2.1: Controller provide not an ascent when UAV is close to an obstacle	UCA-2.2: controller does provide an ascent when UAV is close to the limited altitude of NLR aerospace	UCA-2.3: Controller provides an ascent too late when UAV is close to an obstacle	
CA-3: Decent	UCA-3.1: controller does not provide a descent when UAV is close to the limited altitude of NLR aerospace	UCA-3.2: controller does provide a decent when UAV is close to the ground	UCA-3.3: Human with RC provide a decent too early when the UAV is landing	
CA-4: Drop package	UCA-4.1: controller does not provide drop package when UAV is above target location	UCA-4.2: Controller does provide drop package when UAV is not above target location		
CA-5: Throw		UCA-5.1: controller does provide throw when engine is not started	UCA-5.2: controller provide throw too early when UAV is not going fast enough	
CA-6: Stop engine	UCA-6.1: controller does not stop the engine when UAV is landed	UCA-6.2: controller stop engine when UAV is in flight	UCA-6.2: controller stop engine to soon when UAV is landing	
CA-7: Landing			UCA-7.1: controller provides landing too early when UAV is still flying at a high altitude	
CA-8: Change speed			UCA-8.1: controller change speed too late when UAV is close to stall speed	
CA-9: Switch to automatic mode			UCA-9.1: controller switch to automatic mode too late when UAV battery is almost dead	UCA-9.2: controller stops to soon with switching to automatic mode when UAV is not stable
CA-10: Switch to manual			UCA-10.1: controller switch too early to manual when Human with RC is not ready	UCA-10.2: controller is stopping to soon with switching to manual when UAV is not stable

9.2.2 The corresponding safety constrains

In Table 9-g one can find the corresponding safety constrains for the unsafe control actions.

Table 9-g Controller constrains

Controller constrains		Linking
CC-1	Controller provide a turn when the UAV is close to an obstacle	UCA-1.1
CC-2	Controller shall not turn too late when UAV is flying too close to an obstacle	UCA-1.2
CC-3	Controller shall provide an ascent when UAV is close to an obstacle	UCA-2.1
CC-4	Controller shall not provide an ascent when UAV is close to the limited altitude of NLR aerospace	UCA-2.2
CC-5	Controller shall not provide an ascent too late when UAV is close to an obstacle	UCA-2.3
CC-6	Controller shall provide a descent when UAV is close to the limited altitude of NLR aerospace	UCA-3.1
CC-7	Controller shall not provide a decent when UAV is close to the ground	UCA-3.2
CC-8	Controller shall not provide a decent too early when the UAV is landing	UCA-3.3
CC-9	Controller shall drop package when UAV is above target location	UCA-4.1
CC-10	Controller shall not drop package when UAV is not above target location	UCA-4.2
CC-11	Controller shall not throw too early when UAV is not going fast enough	UCA-5.1
CC-12	Controller shall not throw when engine is not started	UCA-5.2
CC-13	Controller shall stop the engine when UAV is landed	UCA-6.1
CC-14	Controller shall not stop engine when UAV is in flight	UCA-6.2
CC-15	Controller shall not stop engine to soon when UAV is landing	UCA-6.3
CC-16	Controller shall not provide landing too early when UAV is still flying at a high altitude	UCA-7.1
CC-17	Controller shall not change speed too late when UAV is close to stall speed	UCA-8.1
CC-18	Controller shall not switch to automatic mode too late when UAV battery is almost dead	UCA-9.1
CC-19	Controller shall not stop to soon with switching to automatic mode when UAV is not stable	UCA-9.2
CC-20	Controller shall not switch too early to manual when Human with RC is not ready	UCA-10.1
CC-21	Controller shall not stop to soon with switching to manual when UAV is not stable	UCA-10.2

9.3 Conclusion

In this subchapter can one find the conclusion based on the STAMP.

9.3.1 Conclusion STAMP analysis

STAMP is a tool that can identify safety based on control actions. It is difficult to determine safety in complex systems. Hence STAMP is a good tool to determine safety. STAMP itself is also complex to understand and to use. That is why STPA preparation steps helps to complete the STAMP analyze. Using STPA preparation steps made it possible to put constrains on unsafe control actions and gave a broad view on the whole control process.

Bibliography

airfoiltools. (n.d.). *Airfoil tools*. Retrieved 2019, from Chuch Hollinger CH 10-48-13: http://airfoiltools.com/airfoil/details?airfoil=ch10sm-il

Böing, B. (2019, February 6). *Design, Build and Fly guide book*. Retrieved from https://studiedelen.mijnhva.nl/studiedelen/ft-6000MDBF18/1819/Documents/Guidebook%20Aviation%20Minor%20DBF%202018-2019%20SEM2%202019-01-25.pdf

Conrad. (2019, April 3). *Kavan scharnier (10 stuks)*. Retrieved from www.conrad.nl: https://www.conrad.nl/p/kavan-scharnier-10-stuks-228770?WT.mc_id=gshop&gclid=Cj0KCQjws5HlBRDIARIsAOomqA1tGQmUjScGgqpXrbd4wzPxVFUs5uABgMb1nNMWTCdPLooPuV7ZWPYaAqNvEALw_wcB&tid=965091570_48108088975_pla-296303633664_pla-228770&WT.srch=1&vat=true&insert_kz=8J

Grit, R. (2015). *Project Management: A practical approach.* Groningen/Houten, the Netherlands: Noordhoff Uitgevers.

John D. Anderson, J. (2011). *Fundamentals of Aerodynamics.* Mcgraw-Hill Education - Europe.

UPV (DMMT). (2018/2019). *11889_MECÁNICA DE VUELO.*

UPV (DMMT). (2018/2019). *11901 MECÁNICA DE VUELO (II).*

Appendices

Appendix1. Mathematica Student Developed Code

In the following Drive link one can find the Mathematica code developed by the project group:

https://drive.google.com/open?id=1d8mbYAxo76_kmD4kprwbRVO3-2iu-xHv

Nevertheless, some main features are explained here.

Appendix2. Thrust model

The thrust model has been extracted from the eCalc online calculator and then scaled down to match the maximum static thrust proved by the test realized.

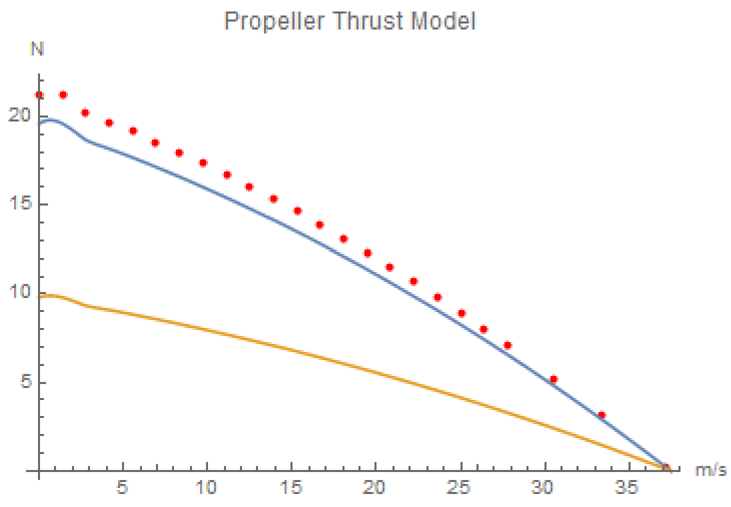


Figure Apx 2-1 Propeller Thrust Model

Appendix3. Drag polar

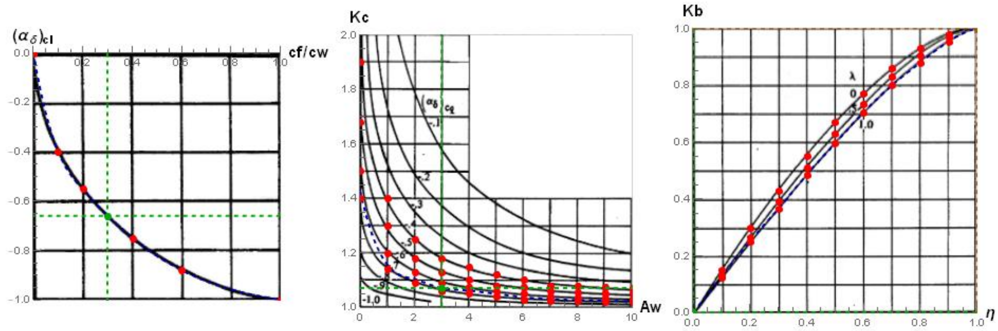
Experimental correlations have been coded and used to get CD0 values of the different parts of the aircraft (fuselage, wings, stabilizers...). Also, the project group has used the incompressible and constant air density approaches due the low speed and altitude flying environment.

Appendix4. Linearized Equations of Motion

To approach the pitching moment, lift and drag models one has used the linearization approach. For example, the pitching moment coefficient depends in several variables (angle of attack, elevator deflection, pitching rate, etc.) so the total pitching moment coefficient is the sum of different coefficients multiplied by each dependent variable.

Appendix5. Control Surfaces Model

Experimental correlations have been used to get the control surface deflection effects:



$$\Delta CL_{3D,\delta F} = \frac{2\,K_c\,K_b\,[\pi - (\theta_F - \sin\theta_F)]\,AR_w}{2 + \sqrt{4 + AR_w^2\,[1 - M^2 + \tan^2(\Lambda_{c/2})]}}\,\delta_F$$

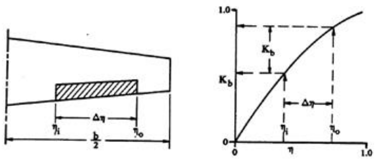
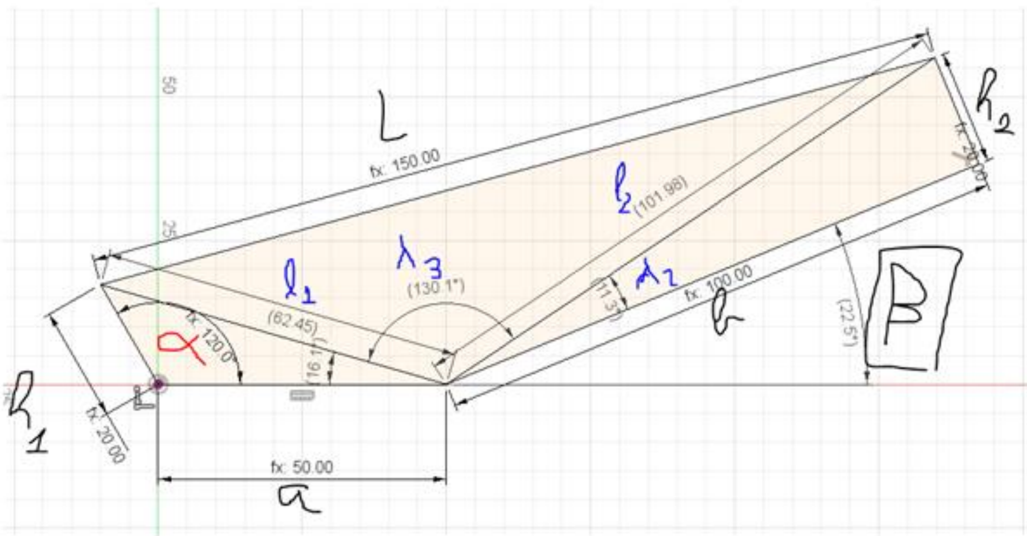


Figure Apx 5-1 Control surfaces experimental correlations

The geometric relations between the servo turning angle and the corresponding attached control surface deflection has been calculated according the simplification one can see in the Figure Apx 5-2.




```
ControlSurfaceδ[α_, a_, b_, L_, h1_, h2_] :=
N[((((λ1 + λ2 + λ3 - 180*Degree) /. {λ3 → ArcCos[(-L^2 + l1^2 + l2^2)/(2*l1*l2)]}) /. {l2 → b/Cos[λ2]}) /. {λ1 → ArcSin[(h1*Sin[90*Degree - α])/l1], λ2 → ArcTan[h2/b]}) /.
  {l1 → Sqrt[a^2 + h1^2 - 2*a*h1*Cos[90*Degree - α]]}]
ControlSurfaceδ[-30*Degree, 50, 100, 150, 20, 20] / Degree
-22.514
```

Figure Apx 5-2 Control surfaces geometry

Appendix6. Merlin Parameters

In the following Drive link one can find the Merlin model developed by the project group:

https://drive.google.com/open?id=19wlGfULcUXf3lnGxKbCRJTLS7OLWfxlv

Nevertheless, some key features are explained here

Panels

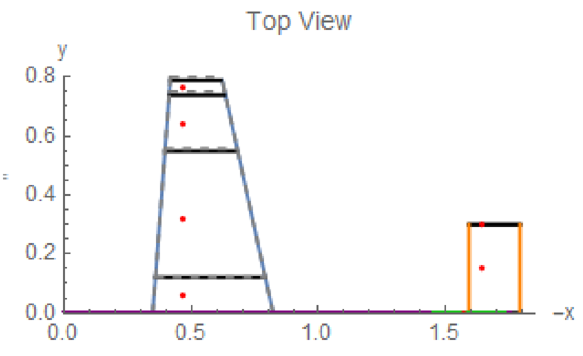


Figure Apx 6-1 Panels top view

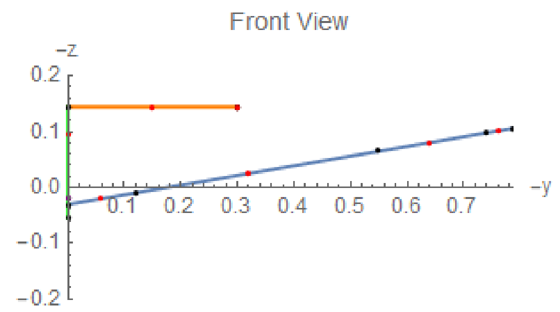


Figure Apx 6-2 Panels front view

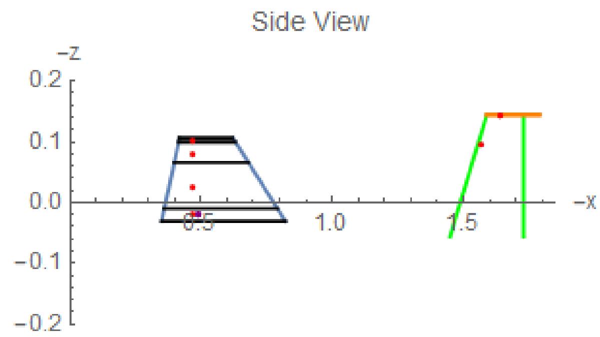


Figure Apx 6-3 Panels side view

The model uses 4 panels for the main wing: inside fuselage, midwing, ailerons and tip.

One panel for the horizontal stabilizer with a full span elevator and one panel for the vertical stabilizer although the rudder is only 60% of the span it is centred so the approximation in one panel is still consistent.

Control Surfaces Model

The XFLR5 software has been used to model the airfoils with flap deflections:

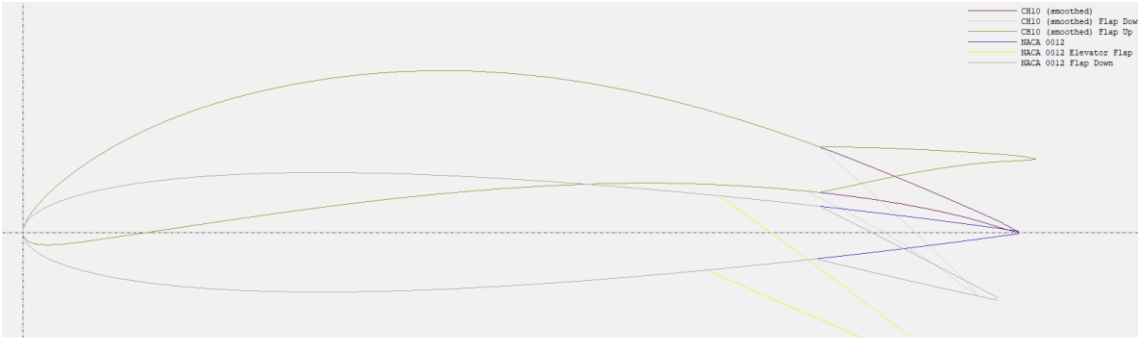


Figure Apx 6-4 XFLR5 airfoil models

One can find here the file with the model:

https://drive.google.com/open?id=1YQCJcH3JKNignfB7a-RQ70gDWLqrmmjQ

Appendix7. XFLR5 Model

The lifting surfaces have been modeled in the XFLR5 panel method software to validate the linearized calculus. The geometry has been extracted from the Fusion 360 3D design.

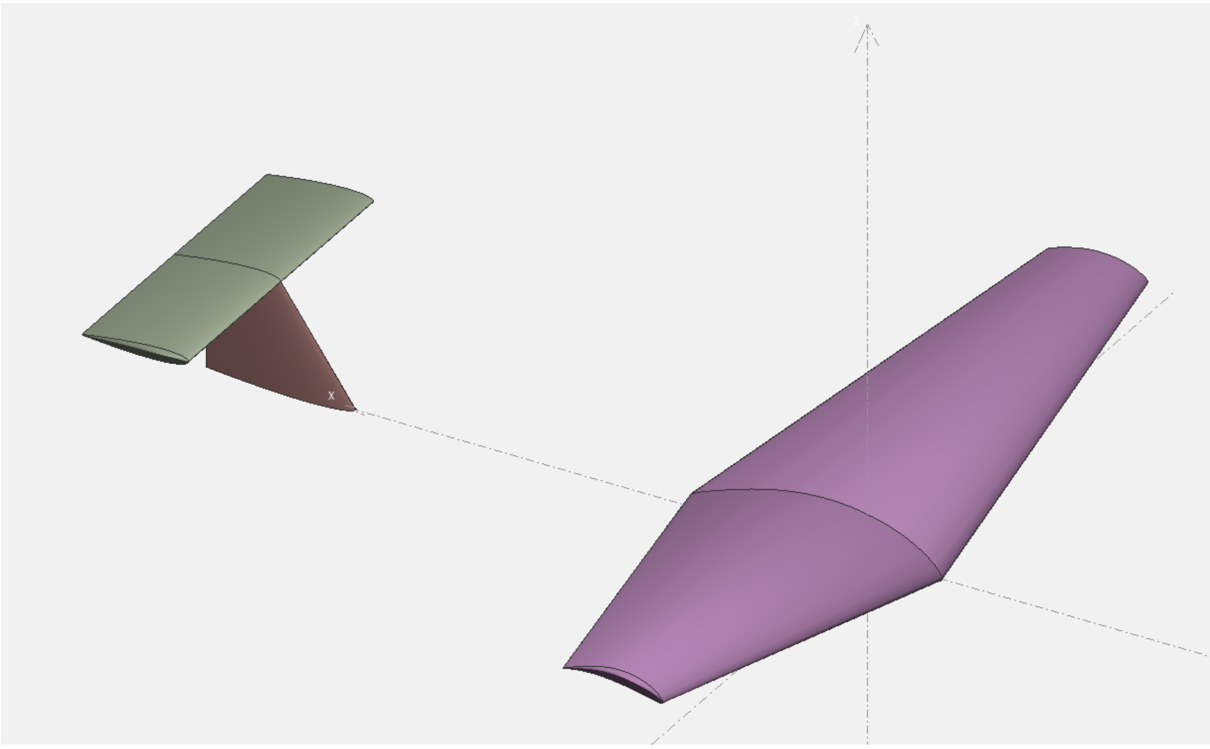


Figure Apx 7-1 XFLR5 model

Appendix8. Tests

In the following Drive folder one can find informal reports of several tests developed, including the motor static thrust.

https://drive.google.com/open?id=1ABVYyamgXvj0NaEBORh7rIqzg7PgZy9-

Appendix9. Parts Catalog

This catalog is present in the Production Plan, in order to avoid its repetition in this compilatory document it has been put at the end of it.

-PRODUCTION PLAN-

Contributions

The author of the thesis, Andreu Giménez Bolinches, was responsible of the technical drawings and parts list, as well as for the 3D printing and laser cut files and the production instructions.

Grading

Overall grade of the Production Plan is 6.75 and the Aircraft Construction is 5 (fair enough considering that the student group didn't meet the deadline).

The following grading system was provided by the production phase teachers with comments that have been translated from Dutch.

Criterion	WF	Grade
Product Structure Tree	25%	9
Budgeting	25%	6
Technical Production Drawings	25%	6
Planning of Aircraft Construction Phase	25%	6
Criterion	**WF**	**Grade**
Successful Wing Structural Test? (non-destructive and reasonable deflection)	Adm. req.	Yes
Aircraft is built according to plan; possible deviations are justified sufficiently.	50%	6
Quality of Aircraft Construction	50%	4

Comments

Product Structure Tree: instead of name in drawing use numbering

Budgeting: no clear overview,

Technical Production Drawings: not really a clear workable planning

Planning of Aircraft Construction Phase: glass fabric failed, balsa = plywood, feather amount is realistic

Quality of Aircraft Construction

servos not fixed, changes not drawn, tail too loose, motor mount, servos fixed

These comments are confusing because a "workable planning" is not a part of the "Technical Drawings" so one can think that they didn't match properly the comments with the sections, and probably neither the grades because the feedback received about the "Technical Drawings" was that they were the best from the rest of the minor and that the only improvement was using part numbers instead of part names.

The "Technical Drawings" chapter has been added at the end of this compilatory document due to its extension and format.

Design, Build and Fly

Production Plan

Group DBF- A

Students:

Andreu Gimenez Bolinches:	5008172556
Fahad Al Janabi:	500652650
Leandra van Ommeren:	500752301
Lars van Ginkel:	500726973
Stefan van der Schans:	500717602

Aviation Engineering

Aviation Academy

Amsterdam University of Applied Sciences

11-04-2019

1. Introduction

Just after that the project group DBF-A has delivered the detailed design report. The approach for the practical construction design must be defined. This report meant to describe how the project group is going to build the UAV. This report is consisting of different chapters. The first chapter is about the product structure tree. This product structure tree meant to describe the different parts that the airplane consists off, the cost of each part and how much does each parts weigh.

The second chapter of this report is about the budgeting inclusive the material cost and predicted man hours for production and assembly. In the third chapter, the project group made a production steps, with complete set of technical production drawings for all parts and (sub-) assemblies with equal (traceable) individual contributions. The last chapter of this report is about the complete and detailed planning of the aircraft construction phase.

Product structure tree		Project Group DBF-A UAV				
Assembly	Sub-Assembly	Element	Qty	Cost	Mass	Comment
Fuselage			1	Part of the total cost	1826,435 g	Total weight
(Fuselage)	Tip		1	Part of the total cost		
(Fuselage)		Tip	1	Part of the total cost	27,503 g	
(Fuselage)	Front		1	Part of the total cost	95,21 g	
(Fuselage)		Front Main	1	Part of the total cost		
(Fuselage)		Front Access	1	Part of the total cost		
(Fuselage)	Middle		1	Part of the total cost	296,264 g	Laser cut
(Fuselage)	(Middle)	F Cut 1	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 1 Access	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 2 Top Left	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 2 Bottom	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 2 Top Right	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 2 Access	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 3 Top	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 3 Bottom	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 4 Top	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 4 Bottom Left	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 4 Bottom Right	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 4 Door	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 5 Top	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 5 Bottom Left	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 5 Bottom Right	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 5 Door	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 6 Top	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 6 Bottom Left	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 6 Bottom Right	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 6 Door	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 7 Top	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 7 Bottom	1	Part of the total cost		Laser cut

(Fuselage)	(Middle)	F Cut 8 Top	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 8 Bottom	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 9 Top	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 9 Bottom	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 10 Top	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 10 Bottom	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 11	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 11 Access	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 12	1	Part of the total cost		Laser cut
(Fuselage)	(Middle)	F Cut 12 Access	1	Part of the total cost		Laser cut
(Fuselage)	Rear		1	Part of the total cost	118,669 g	Laser cut
(Fuselage)	(Rear)	F Rear 1	1	Part of the total cost		Laser cut
(Fuselage)	(Rear)	F Rear 1 Access	1	Part of the total cost		Laser cut
(Fuselage)	(Rear)	F Rear 2	1	Part of the total cost		Laser cut
(Fuselage)	(Rear)	F Rear 3	1	Part of the total cost		Laser cut
(Fuselage)	Tail		1			
(Fuselage)		F Tail	1	Part of the total cost	25,056 g	
(Fuselage)	Carbon Fiber Rod		1			
(Fuselage)		Carbon Fiber Rod	1	Part of the total cost	175.709 g	
(Fuselage)	Drop System		1			
(Fuselage)	(Drop System)	Hoock Structure	1	Part of the total cost		
(Fuselage)	(Drop System)	Servo	2	-	29,396 g	Standaard weight
(Fuselage)	(Drop System)	Horn	1	Part of the total cost	0,604 g	Standaard weight
(Fuselage)	(Drop System)	Wire	2	-	1,594 g	
(Fuselage)	3D Print Connection		1			Fillement for 3D printer
(Fuselage)		AC Connection	1	Part of the total cost	49,747 g	
(Fuselage)		c/2 Connection	1	Part of the total cost	40,893 g	
(Fuselage)	Electronics		1			
(Fuselage)	(Electronics)	Pixhawk	1	-	40,00 g	Supplied by the University
(Fuselage)	(Electronics)	Motor + propeller	1	-	195,826 g	Supplied by the University
(Fuselage)	(Electronics)	ESC	1	-	73,795 g	Supplied by the University
(Fuselage)	(Electronics)	GPS	1	-	30,19 g	Supplied by the University
(Fuselage)	(Electronics)	Battery	1	-	588,324 g	Supplied by the University
(Fuselage)	(Electronics)	Telemetry module	1	-	23,495 g	Supplied by the University
(Fuselage)	(Electronics)	RC receiver	1	-	5,299 g	Supplied by the University
(Fuselage)	Motor Support		1			
(Fuselage)		Motor Connection	1	Part of the total cost		

(Fuselage)		Carbon Rod Connection	1	Part of the total cost	6,082 g	3D printed
Wing			1		903,501 g	The whole wing
(Wing)	Carbon Rods		1			
(Wing)		Carbon Rod AC	1	Part of the total cost	20,672 g	
(Wing)		Carbon Rod c/2	1	Part of the total cost	21,705 g	
(Wing)	Wing Right		1		380,621 g	The right wing
(Wing)	(Wing Right)	W Cut 1	1	Part of the total cost		Laser cut
(Wing)	(Wing Right)	W Cut 2	1	Part of the total cost		Laser cut
(Wing)	(Wing Right)	W Cut 3	1	Part of the total cost		Laser cut
(Wing)	(Wing Right)	W Cut 4	1	Part of the total cost		Laser cut
(Wing)	(Wing Right)	W Cut 5	1	Part of the total cost		Laser cut
(Wing)	(Wing Right)	W Cut 6	1	Part of the total cost		Laser cut
(Wing)	(Wing Right)	W Cut 7	1	Part of the total cost		Laser cut
(Wing)	(Wing Right)	W Cut 8	1	Part of the total cost		Laser cut
(Wing)	Wing Left		1		381,879 g	Mirror of Wing Right
(Wing)	Control Surfaces		1			
(Wing)	(Control Surfaces)	Aileron Right	1	Part of the total cost	4,236 g	Cut from the wing
(Wing)	(Control Surfaces)	Aileron Left	1	Part of the total cost	4,236 g	Cut from the wing
(Wing)	(Control Surfaces)	Servo	2	-	29,396 g	Standaard weight
(Wing)	(Control Surfaces)	Horn	2	Part of the total cost	1,208 g	Standaard weight
(Wing)	(Control Surfaces)	Wire	2	-	1,594 g	
(Wing)	Speed Sensor		1			
(Wing)		Pitot tube	1	-	5,50 g	Supplied by the University
(Wing)		Pitot Electronics	1	-	9,599 g	Supplied by the University
Tail			1		103,099 g	Total weight
(Tail)	Horizontal Stabilizer		1			
(Tail)		Horizontal Stabilizer	1		35,525 g	Including Elevator
(Tail)	Vertical Stabilizer		1			
(Tail)		Vertical Stabilizer	1		31,435 g	Including Rudder
(Tail)	Reinforcements		1			Composite Reinforcements
(Tail)	(Reinforcements)	R Right Front	1	Part of the total cost		Composite Reinforcements
(Tail)	(Reinforcements)	R Right Rear	1	Part of the total cost		Composite Reinforcements
(Tail)	(Reinforcements)	R Left Front	1	Part of the total cost		Composite Reinforcements
(Tail)	(Reinforcements)	R Left Rear	1	Part of the total cost		Composite Reinforcements
(Tail)	(Reinforcements)	VStab to HStab connectio	1	Part of the total cost		Foam Reinforcements
(Tail)	Control Surfaces		1			
(Tail)	(Control Surfaces)	Elevator	1	Part of the total cost		Part of Horizontal stabilizer
(Tail)	(Control Surfaces)	Rudder	1	Part of the total cost		Part of vertical stabilizer
(Tail)	(Control Surfaces)	Servo	2	-	29,396 g	Standaard weight

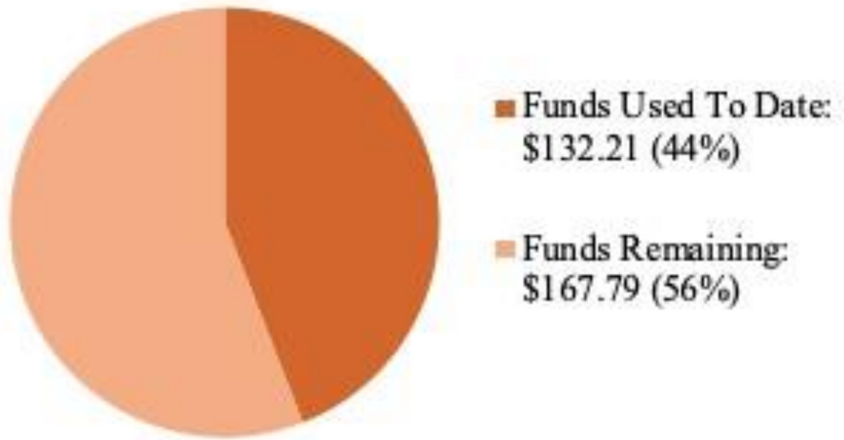
(Tail)	(Control Surfaces)	Horn	2	Part of the total cost	1,208 g	Standaard weight
(Tail)	(Control Surfaces)	Wire	2	-	1,594 g	
Payload			1			
(Payload)	Payload		1		192,565	Total weight
(Payload)	(Payload)	Steel weight	1	Part of the total cost	160 g	
(Payload)	(Payload)	3D printed envelope	1	Part of the total cost	30 g	
(Payload)	(Payload)	Rice	1	Part of the total cost	2,565 g	
Total			120	€ 132,21		

PROJECT INFORMATION

Project Name	Building Design
Project Description	Practically construct a high quality model aircraft (from own technical drawings) using a mix of production and joining techniques
Contractor	DBF-A

FINANCIAL STATUS

Cash Amount	€	300.00
Financed Amount	€	-
Total Allotted Funds	€	300.00
Funds Used To Date	€	132.21
Funds Remaining	€	167.79



Item	Category	Persons	Unit	Hours	Cost
XPS Foam 1	Materials	2	10 cm Thickness		€ 15.00
Balsa Wood	Materials	2	2 plates		€ 9.60
Wood Glue	Materials	1	750 gr		€ 8.99
XPS Foam 2	Materials	2	5 cm Thickniss		€ 15.00
Carbon Rod	materials	1	Diameter 16 mm / length 40 cm		€ 5.00
Resin + Hardner	Materials	1	1 kg		€ 22.00
Vacuum bag	Materials	4	bags		€ 6.04
Peel ply	Materials	2	m^2		€ 7.44
Flat brushes	Materials	3	pieces		€ 5.19
Non-woven absorber	Materials	1	m^2		€ 2.46
Tackytape	Materials	2	m		€ 15.00
Gloves	materials	5	pieces		€ 0.49
PLA	Materials	1	kg		€ 20.00
Total				85	€ 132.21

Category

- Labor
- Materials
- (blank)

Item	Category	Persons	Hours
Making wing template for laser cutting	Labor	1	1
Lasercut Balsa wood	Labor	1	0.5
Making fuselage template for laser cutting	Labor	1	1
Lasercut XPS Foam	Labor	1	0.5
Assembly wing	Labor	5	2
Assembly fuselage	Labor	5	5
Put Glasfiber skin on wing	Labor	5	4
Put Glasfiber skin on fuselage	Labor	5	3
vacuum Glasfiber	Labor	2	24
Print 3D connections and package drop mechanism	Labor	1	5
Make control surfaces	Labor	5	3
Make Tail	labor	5	6
Assembly aircraft	Labor	5	8
Finish design	Labor	5	4
Total			85

Category

- Labor
- Materials
- (blank)

2. Production Steps:

Step 1 (Fuselage middle part):

In the first step, the middle of the fuselage will be created. This step will be executed first because the wings should somewhere be connected to. The middle of the fuselage will be created by cutting foam parts with the laser cut machine. Then the cut foam parts will be connected together, and the middle of the fuselage is created. This method will be used, because inside the middle of the fuselage very abstract shapes are used, for example, to store electronics. Those shapes are very hard to produce with a normal hot wire. Therefore, the laser cut machine will be used.

Step 2 (Building wings):

Like the middle of the fuselage, the wing will also be built up with parts. These parts are produced with the hot wire. The reason why the wing will be built in different parts is that the wing is tapered, and it is a high cambered wing. This would be very difficult to cut it in once with the hot wire. When al different parts are connected to each other, the wing is created. The whole wing will be covered with composite. The project group will use glass fiber as a composite material.

Step 3 (adding wings to fuselage):

After the wings are finished, the wings will be placed in the gaps of the fuselage to see if it fits. Later on, in the production phase, the wings will be connected with rods to the fuselage.

Step 4 (Access to fuselage):

Because every resource (electronics for example) is placed inside the fuselage, the project group needs access to place the resources inside the aircraft. Or if necessary, adjust inside the aircraft. Therefore, a rectangular gap will be created to get access. The cut out rectangular foam part, can be placed back for before flying. So, during the flight, the gap is closed.

Step 5 (adding rods and fuselage rear):

In step 5 the wing connection will be created. This is done by putting 2 carbon rods at each side into the fuselage. These rods will be attached inside the fuselage into 3D printed connections. The second phase of this step is connecting the rear fuselage of the aircraft.

Step 6 (Connecting wings, fuselage tail, and rod):

When the rods are connected in the fuselage into 3D printed connections, the other side of the rods will be attached to the wing. In addition, a rod will be placed through the entire aircraft in a longitudinal direction. This rod is used to give the fuselage extra strength and to attach components to. When the longitudinal rod is placed, the tail part can be attached.

Step 7 (fuselage front and vertical stabilizer):

In this step, a front part of the fuselage will be added, and the vertical stabilizer will be placed on the tail. The vertical stabilizer will be connected with the fuselage-tail by composite material (glass fiber). In addition, this part will be improved by strength because of the composite connection.

Step 8 (Fuselage tip horizontal stabilizer and rudder):

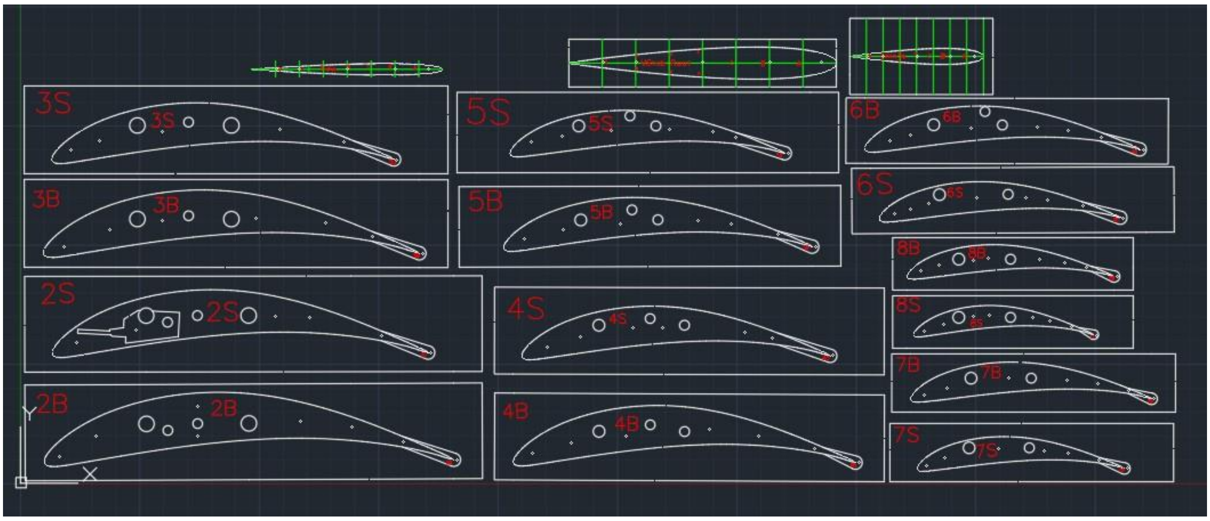
This step is one of the final steps. The last part of the fuselage will be assembled, the fuselage tip. After that, the horizontal stabilizer and rudder will be attached. The horizontal stabilizer will be connected with foam reinforcements between the vertical stabilizer and the horizontal stabilizer. The vertical and horizontal stabilizer will be created with the hot wire method because they don't have too difficult shapes.

Step 9:

In the final step, all the equipment will be installed to fly the plane. Like the ailerons, electronics, servos, and dropping mechanism. Because of step 4 (access inside fuselage), the group made it possible to install it afterwards. In the end, the project group will cover the fuselage with composite where necessary. For example, on the belly to give the belly extra strength to resist the impact of the landing. The same composite material what will be used for the wings will be used also for the fuselage. Namely glass fiber.

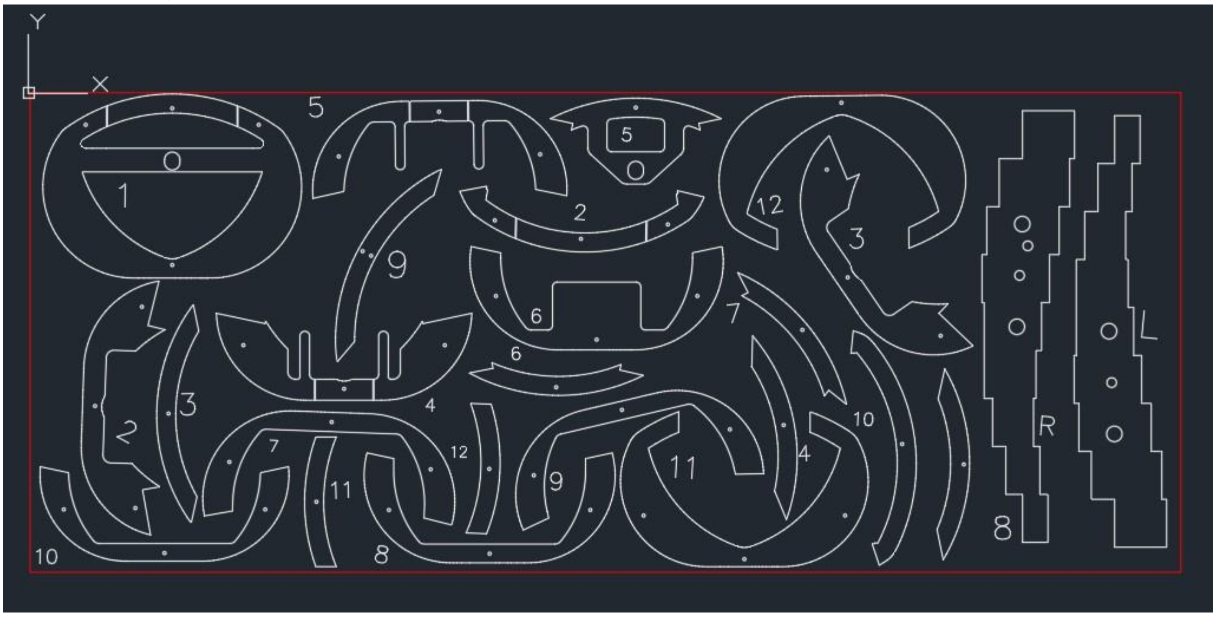
3. Drawings for Laser Cut

Wood templates for wings



121x49 cm

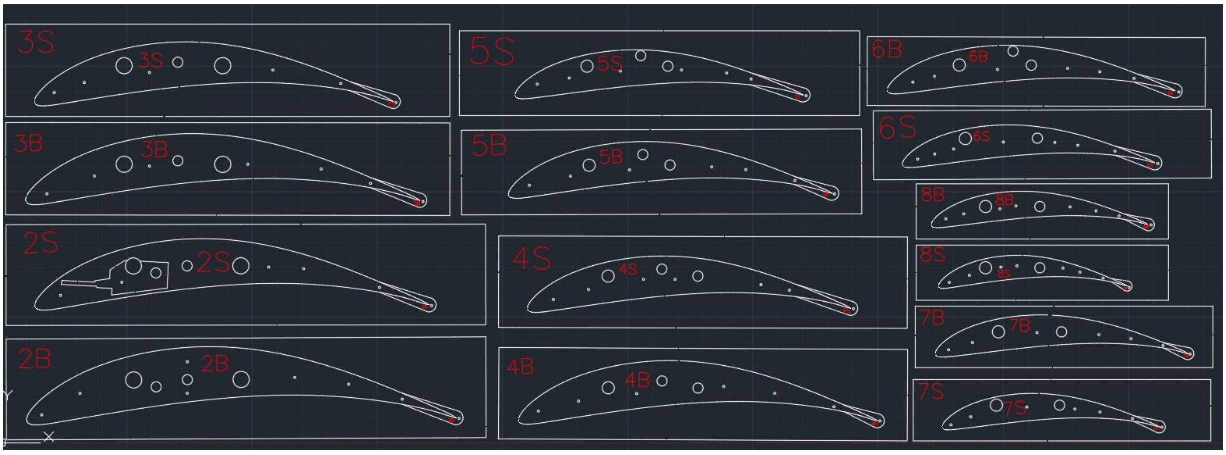
Foam Fuselage middle



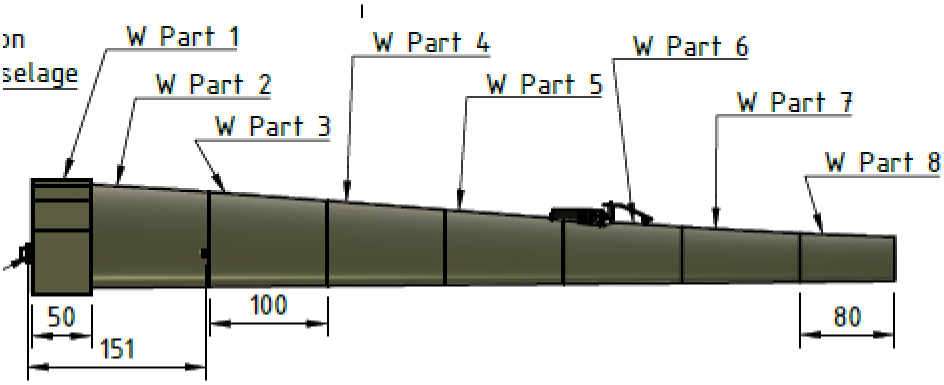
120x50 cm

The rest of drawings will be provided after testing that there is no problem with this ones

4. Production of Wing parts

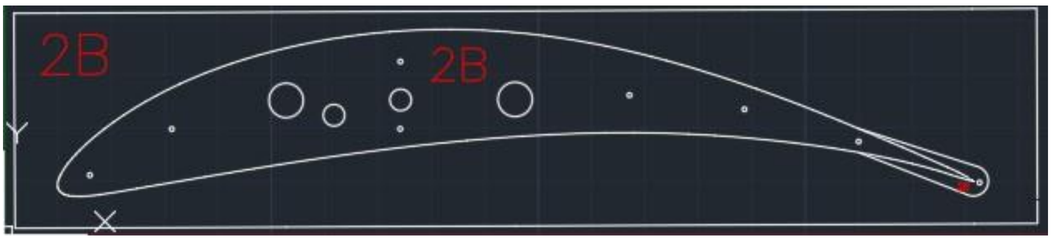


There are two wooden templates for each wing part (Big and Small) being wing parts numbered from left to right:



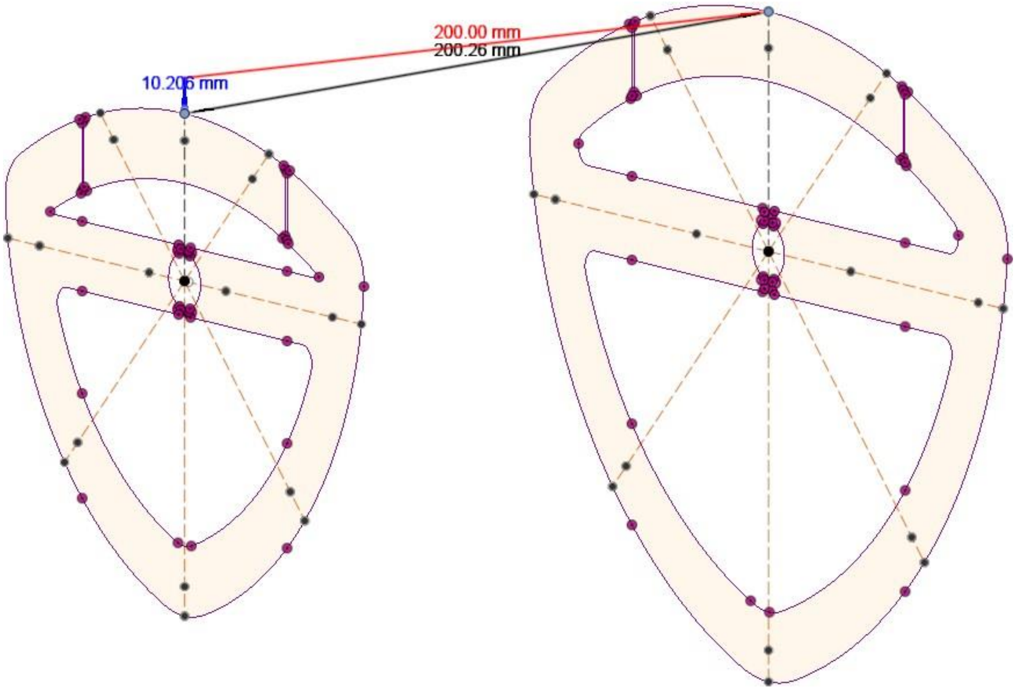
The fuselage connection is part 1 and is laser cut in foam so there is no template for it, the rest of the parts are 10 cm wide except for the part 8 (Tip) which is 8 cm wide.
The procedure is the following:

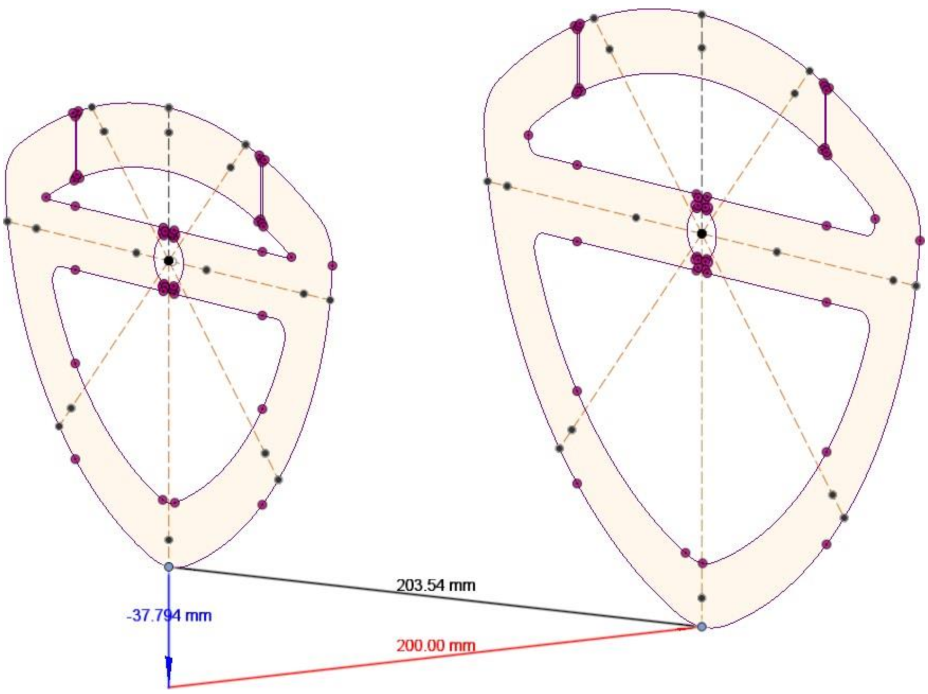
1. Place the big template (including the rectangle around the airfoil) in the foam and cut the bulk block around the rectangle



2. Then remove the rectangle while keeping the airfoil template and drill the two main holes (25% and 50% of the chord)
3. Turn the block around so you see the face with no template and place the template in a way that the holes are aligned (The rectangle should be aligned too)
4. Templates are aligned, ready to cut the airfoil.

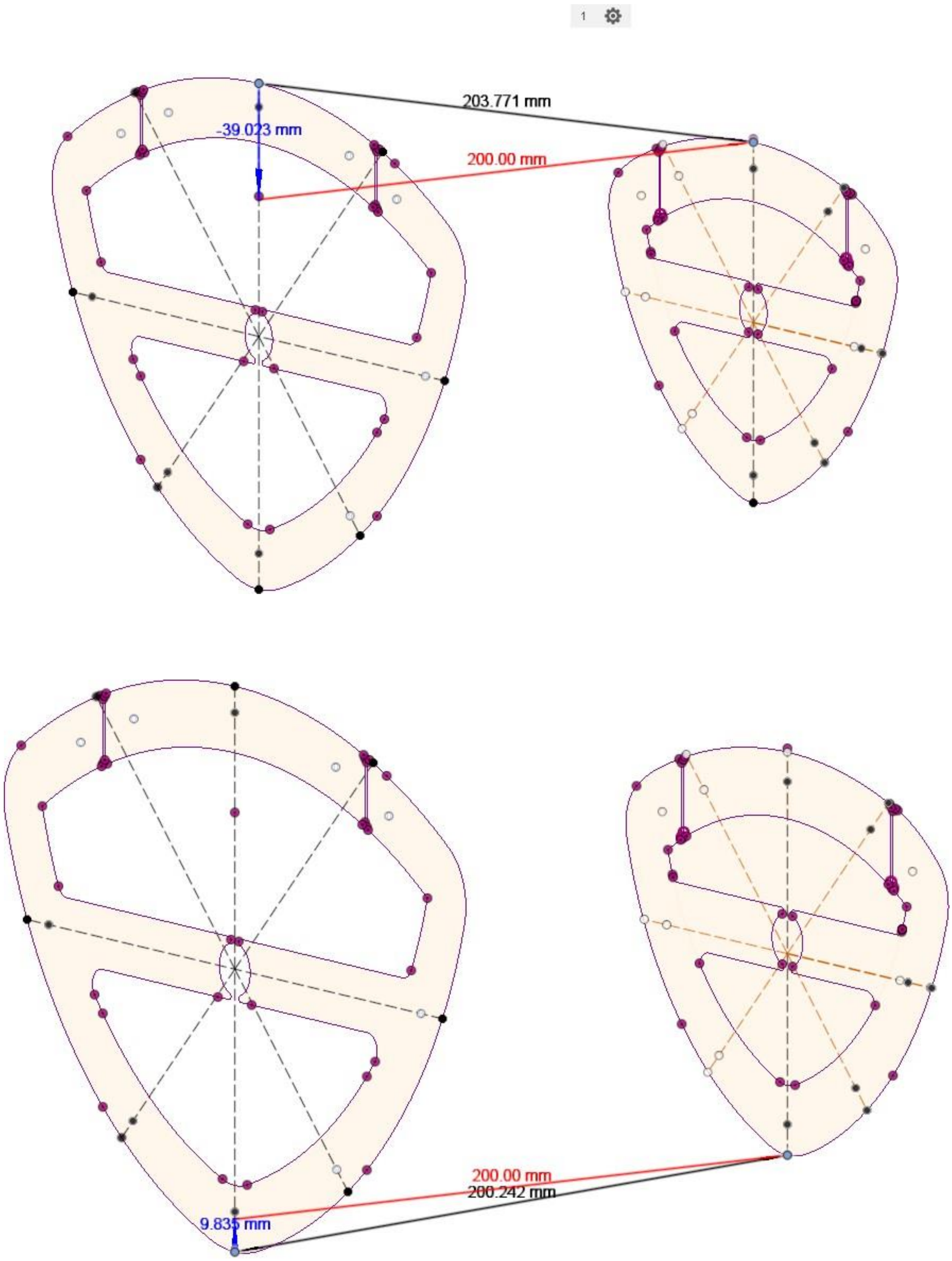
5. Alignment of templates for Fuselage Front



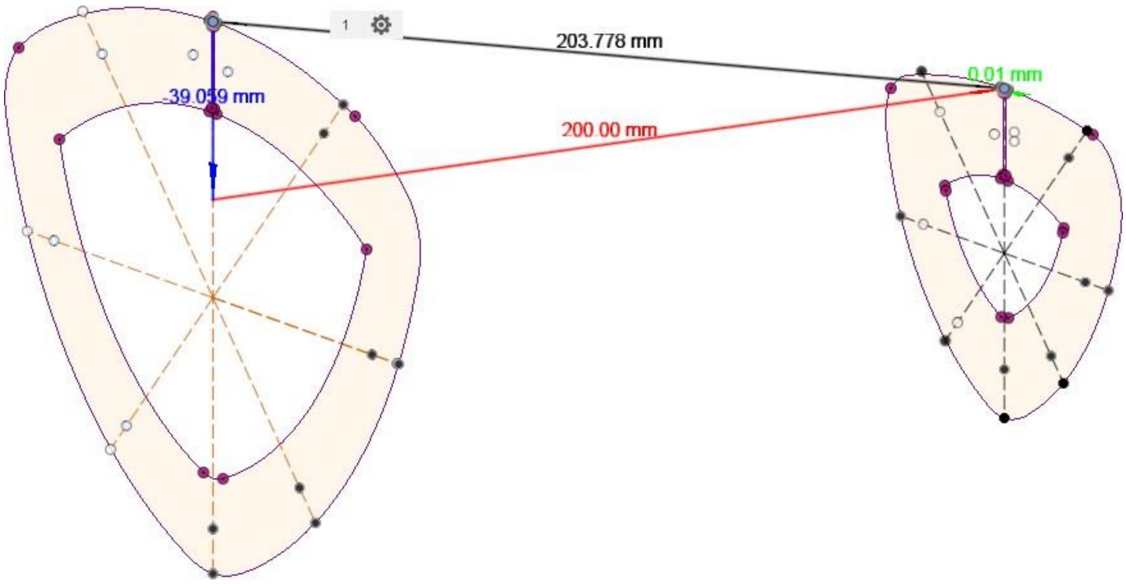


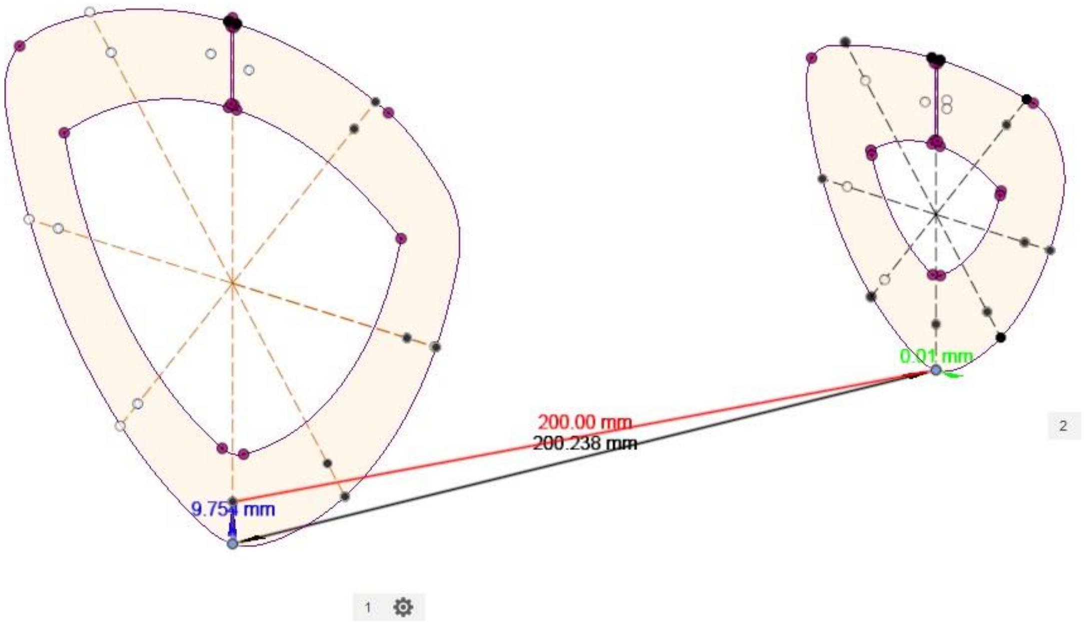
6. **Alignment of templates for Fuselage Rear**

Fuselage Rear 1

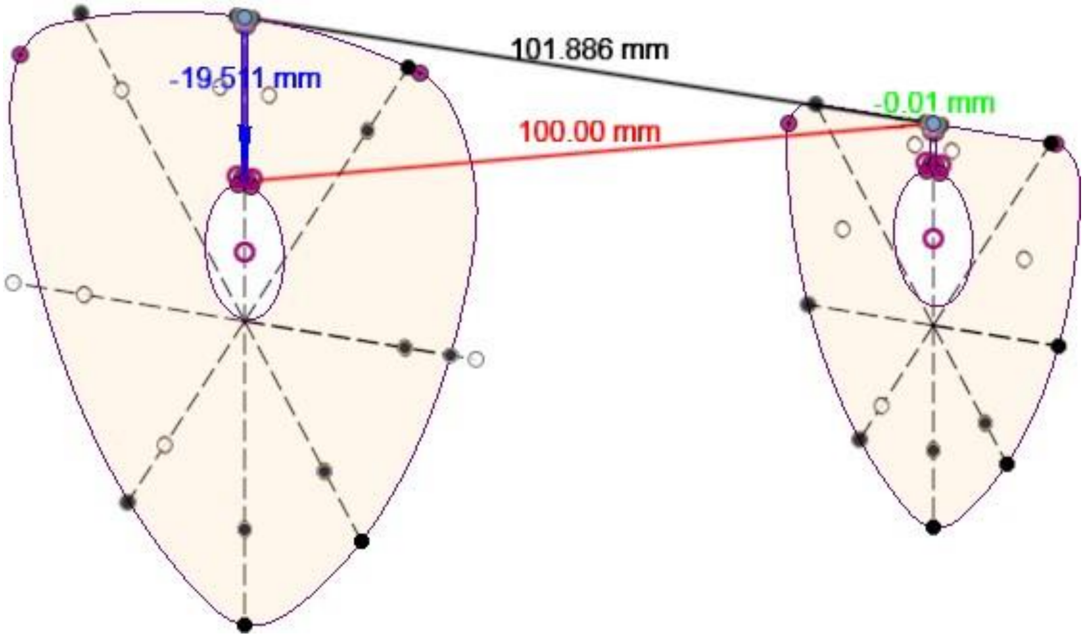


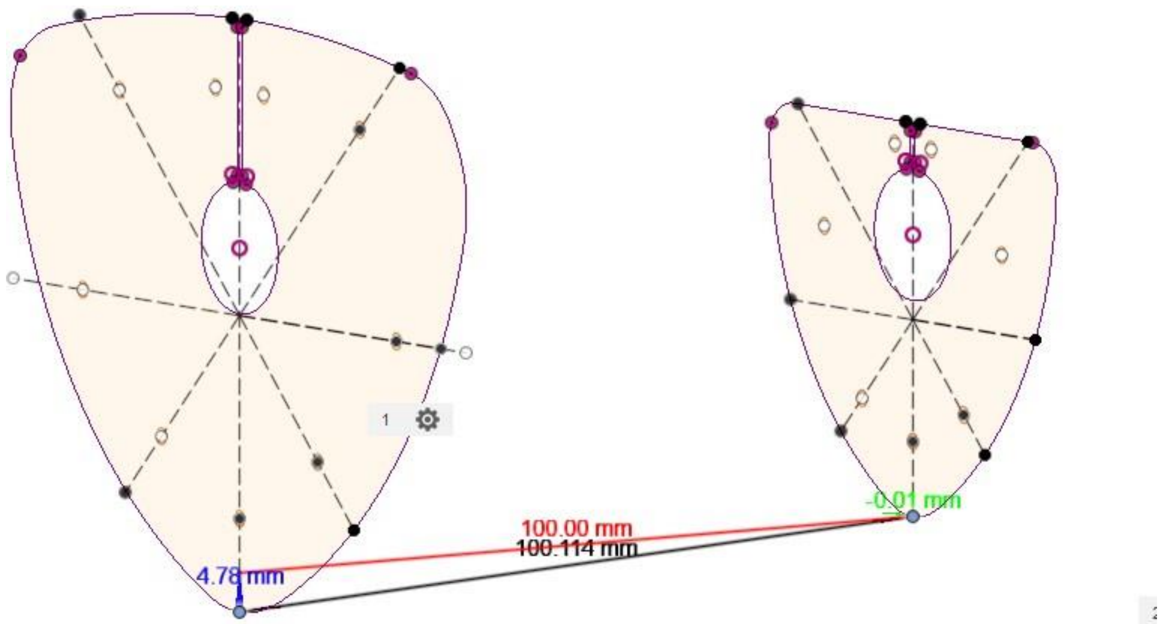
Fuselage Rear 2





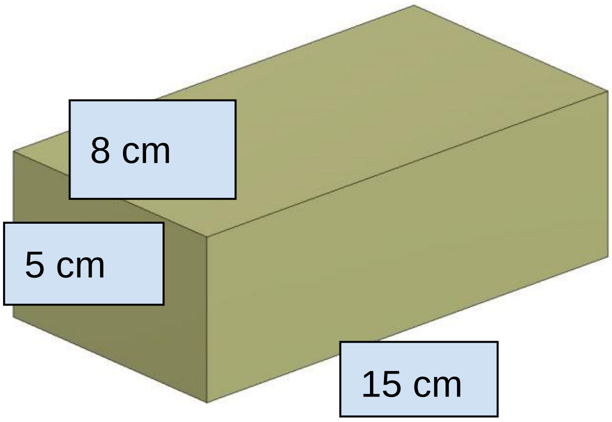
Fuselage Rear 3



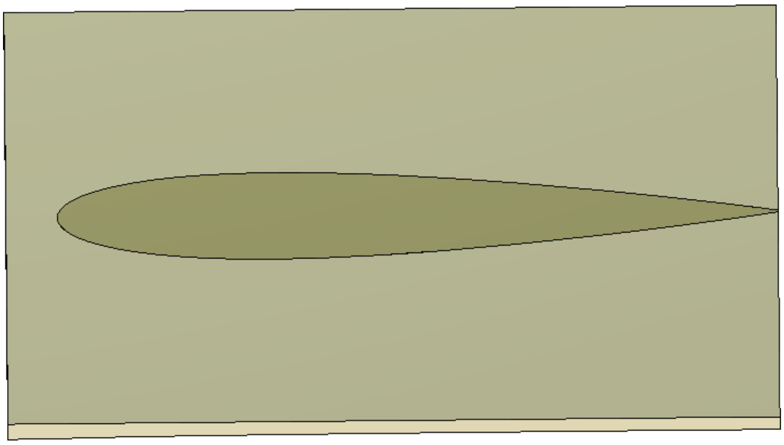


7. Production of Tail Reinforcements

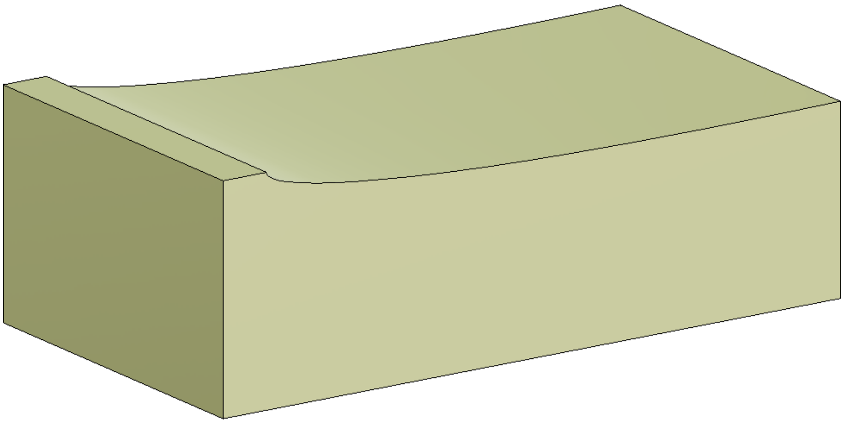
From the minimum block stated in the parts catalog



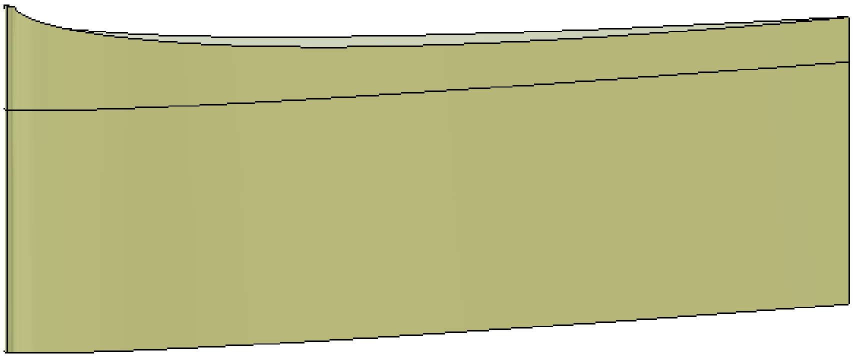
Cut the airfoil shape in the top part, do not remove the airfoil from the block



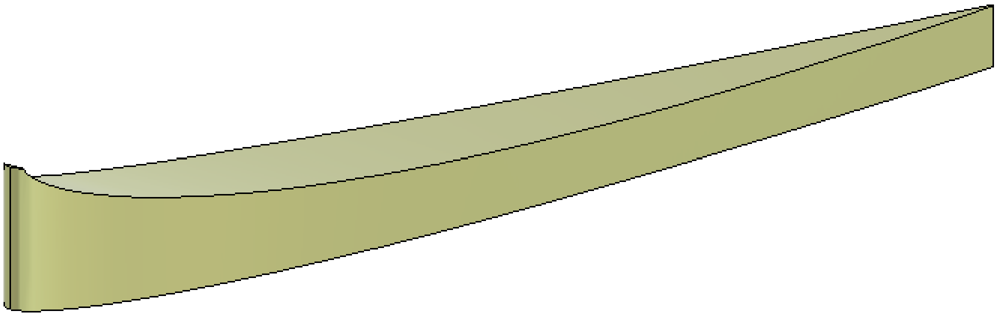
Cut the big lateral using the wood template



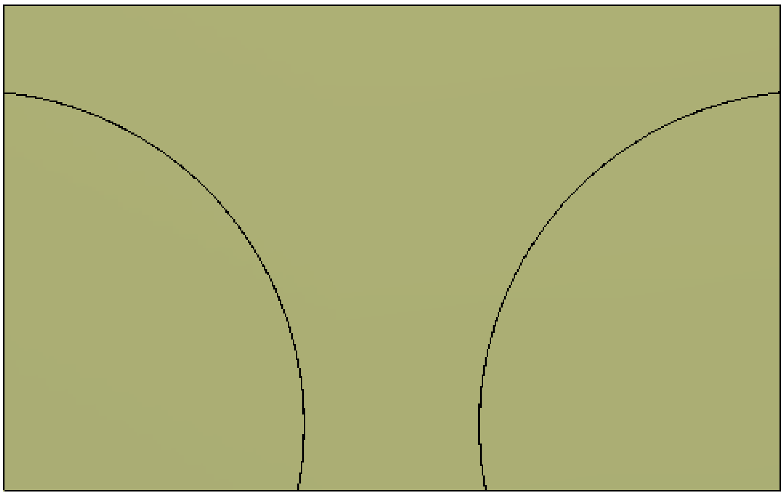
Remove the airfoil shape and cut a flat bottom



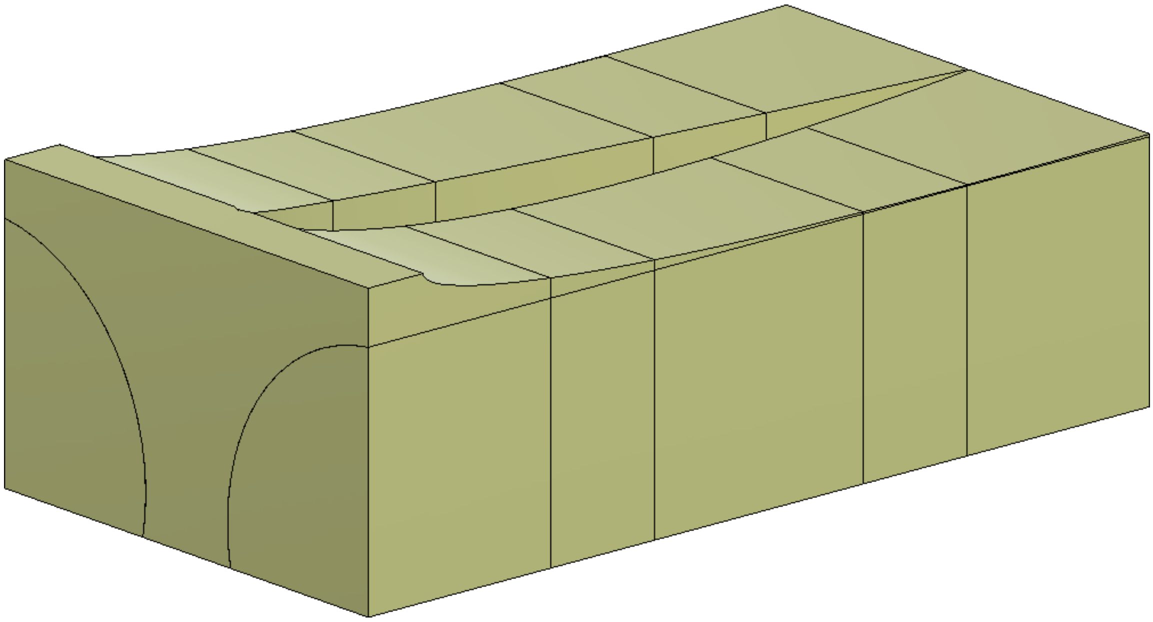
We already have the connection between stabilizers



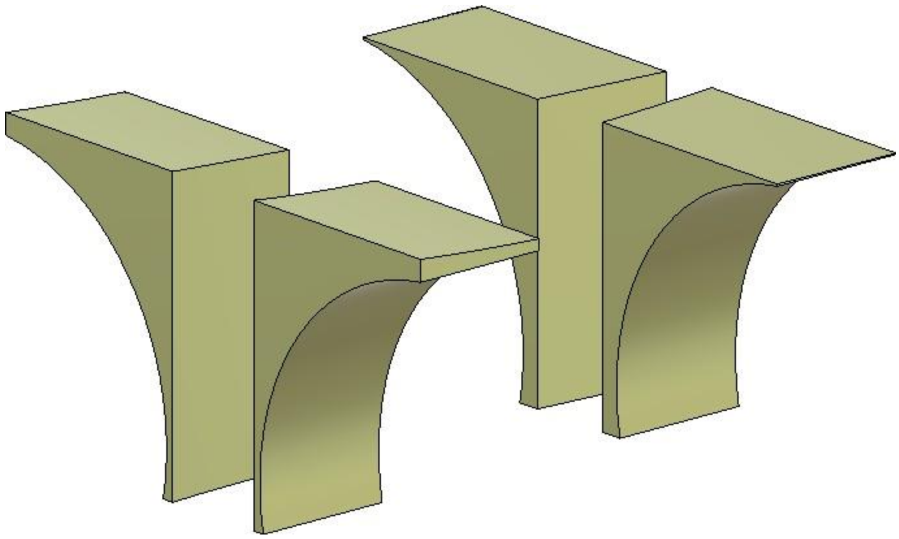
Come back to the rest of the block and cut this shape (from template) in the front side



Cut lateral sections



Remove excedent material



Adjust to good fit

-INDIVIDUAL DEFENSE PRESENTATION-

Contributions

The author of the thesis, Andreu Giménez Bolinches, is the only author of the following deliverable.

Grading

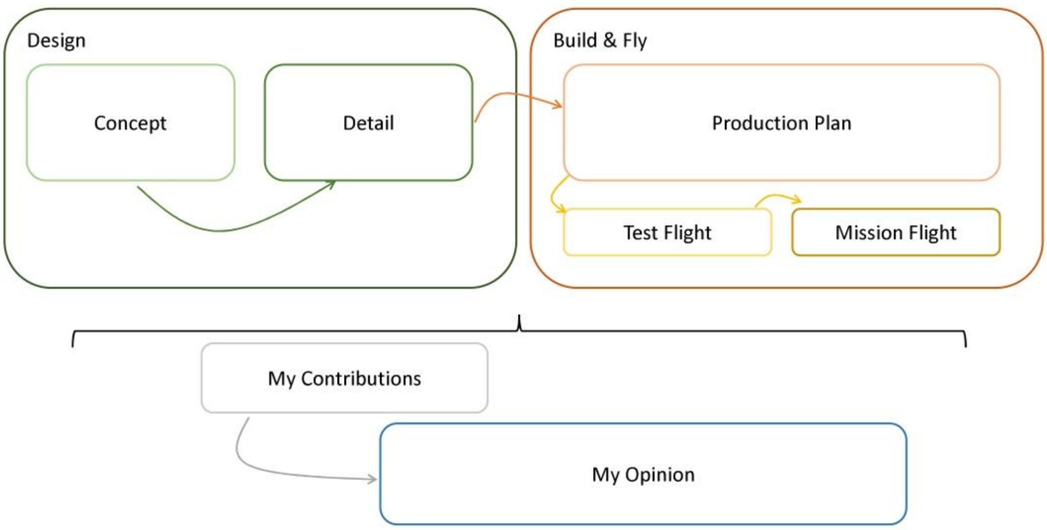
The oral defense was graded as an 8.5 out of 10.

Individual Defense

Andreu Giménez Bolinches

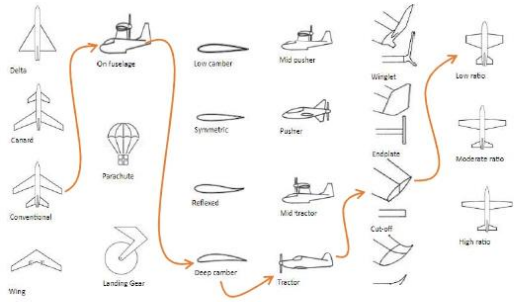
Amsterdam University of Applied Sciences

Flow chart



Concept Design

- Not realistic with the time we had available
- We tried to make everyone satisfied



- Change the deep camber airfoil in further design iterations
- Change dihedral tapered wing to rectangular with flaps

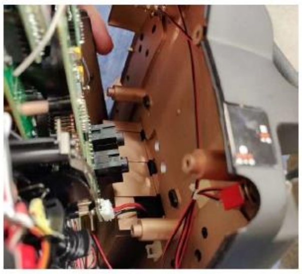
Detail Design

- Made the concept production wise
  - But…
- Overestimated team time availability
  - Resit courses and side jobs
- Balance, Mass Estimation, Wing Connection
- Bad control surfaces design
- Didn't take cable length into account in some electronics positioning
  - Miscommunication with the electronics responsible
- Poor motor support design
- Report writing

Production Plan

- Late electronics configuration
  - Had to handle it myself even if I was not the responsible
- Poor planning
  - Planned on the run
- Lots of mistakes and hurry up failures
  - Wing trailing edge
- Changes on design because of production errors
  - The plane is larger than it should be
- After NLR test the work rate slowed down to avoid burn-out

Test Flight



- Electronics disaster
  - Wrong RC command mode
  - No GPS
  - No logging
  - No airspeed sensor
  - No wireless connection with the computer
  - Made the failsafe on the field
  - We had the servos working two days before and the stabilized mode the day before
- Poor pitch control at take-off
- Very poor lateral-directional controllability

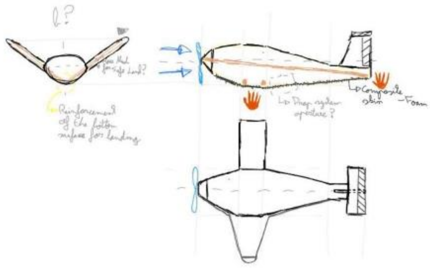
Mission Flight

- Electronics repaired
  - I took the responsibility
- Sensible at pitch
- Battery failsafe problems
- No auto drop
- No auto land

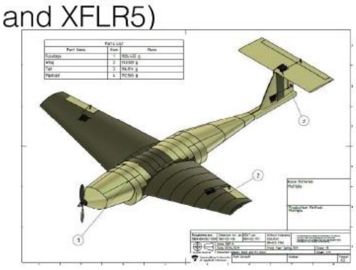
- Helicopter mode

My contributions

- Concept
  - Brainstorming
  - Voting system
  - Sketching the design
  - Flight Mechanics calculus



- Detail Design
  - Flight Mechanics calculus (Mathematica and XFLR5)
  - Merlin Simulator model
  - Weight and Balance
  - 3D design
    - Drop mechanism revision
    - Motor support
    - Parts Catalog



My contributions

- Production Plan and Flights
  - Technical drawings with production methods
  - 3D print and laser cut files
  - Actions List and Leadership
  - Lots of time
  - Electronics
    - Servos travel
    - Dropping mechanism activation
    - Stabilized mode
    - Auto mode
    - Airspeed sensor
    - Final GPS
    - Mission plan
    - Wireless connection

My opinion

- More worried about passing the minor than building the UAV

- The rest of the group didn't expect the difficulty implied in the production phase and got overwhelmed
  - Would ask for a time compromise of the group members during production phase at the beginning of the minor

I put way more effort and time than the one I asked from the rest of the group

Overall satisfied with the results but I had to lower my expectations

-PROJECT EVALUATION-

Contributions

The author of the thesis, Andreu Giménez Bolinches, was responsible of the lay-out of the deliverable, the Chapter 5 (Aircraft flight dynamics) and all the Appendices that are related to it. He also wrote the introduction for the deliverable and corrected and expanded the rest of the chapters.

Grading

This deliverable has not been graded yet.

Design, Build & Fly minor

Project Evaluation

Group: DBF-A

Student 1 Gimenez Bolinches, Andreu

Student 2 Ginkel, Lars van

Student 3 Janabi, Fahad Al

Student 4 Ommeren, Leandra van

Student 5 Schans, Stefan van der

Aviation Operations/Engineering
Aviation Academy
School of Technology
Amsterdam University of Applied Sciences

Amsterdam, Thursday, July 11, 2019

Table of Contents

Appendices 167

Tables and figures

Index of Variables

C_L	Lift coefficient
C_D	Drag coefficient
C_{D_0}	Parasitic drag coefficient
K	Induced drag factor
e	Oswald factor
α	Angle of attack
ε	Thrust deviation angle
γ	Path angle
μ	Bank angle
π	Pi number
ρ	Air density

V	Airspeed
V_z	Vertical speed
S	Wing reference surface
D	Drag
W	Weight
L	Lift
n	Load factor
T	Thrust
Pr	Power required
AR	Wing aspect ratio

1. Introduction

1.1. Goal

The goal of this report is to analyze all decisions made during this minor. These decisions will be evaluated based on the results and implications of the decisions on the requirements stated in the minor guidebook (Böing, 2019).

The Analysis of this report is divided into the three main sections of the minor, Design (Chapter 2), Build (Chapter 3) and Fly (Chapter 4). As well as an analysis of the final UAV. This is in terms of flight performance from flight data compared to the theoretical simulations and estimations (Chapter 5) and final conclusions, further design iterations ideas and recommendations for future teams (Chapter 6).

1.2. Scope

This report aims the subjective review of the Design, Build and Fly phases of the minor with hypothesis that are not verified by means of specific calculations but are based on the group's acquired knowledge. It also includes an objective aircraft flight dynamics analysis based on the mathematical analysis of the flight data with the necessary assumptions for its manipulation.

1.3. Evaluation method

For this purpose, an evaluation table has been added at the end of several chapters which summarizes the requirements that have been met and grades them in a scale of one to ten. The key features needed to understand the mark of each requirement are stated in the "result" column.

Each requirement has not the same importance in the mark of phase. Thus, in the evaluation table are different weights defined for different requirements. In every phase is the grade the result of the weighted average of the different requirements. These weights are assigned by the group subjectively considering the importance of the requirement in the fly performance of the UAV. Its impact in the grades of the rest of the minor deliverables and the direct and indirect repercussion of one requirement with the rest of requirements.

2. Aircraft Design and Design Process

In this chapter one can find the review of the aircraft design and design process.

2.1. Concept Design

In this chapter the concept design phase will be analyzed.

In the concept design, as a first idea the project group intended to make an innovative design. Besides wanting an innovative design, the group also set initial requirements for themselves. The requirements were a body with lifting capabilities and high speeds. There were many different ideas about innovative designs which made the decision of a final configuration be later than other DBF groups.

The final concept was chosen by means of a poll because of the many innovative design options. The outcome of this poll had the following key features; dihedral tapered wing, T mounted tail, slightly lifting body fuselage and payload stored in the fuselage.

Once the configuration was decided the main dimensions were set by means of initial flight mechanics and structural calculations. A dihedral angle of 10 degree was chosen in order to avoid damages of the wings during landing. This decision succeeds in its purpose.

The combination of a dihedral wing and payload installed inside the fuselage made the design of the middle part of the UAV challenging. The middle part became the focus of the group in terms of structural design. This meant repercussion in the production phase with a weak tail structure that needed to be reinforced. This added weight to the design and affected the balance.

2.2. Detail Design

In this chapter the detail design phase will be analyzed from the flight mechanics 0, strength 2.2.2 and production 2.2.3 point of view

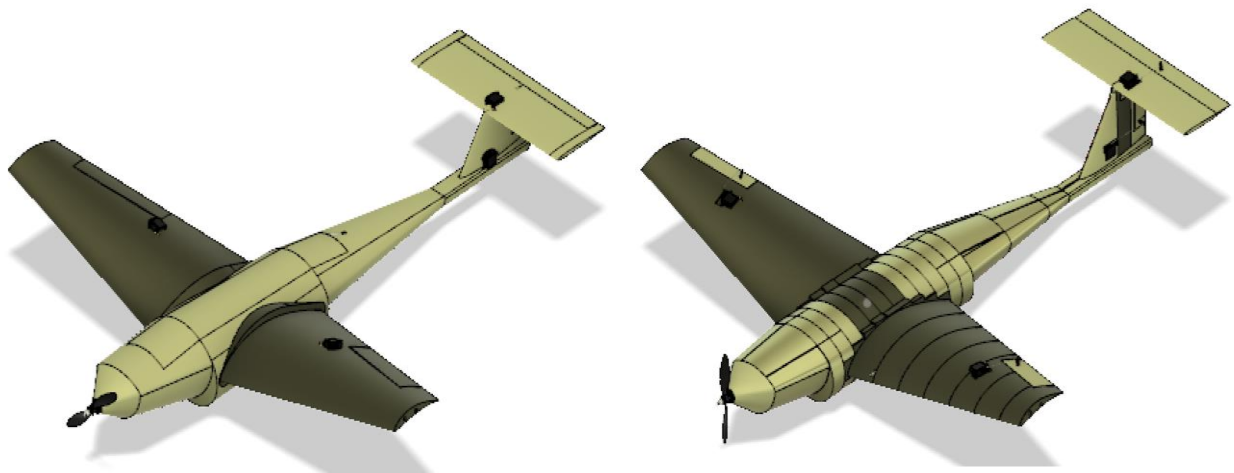


Figure 2.2-1 Concept versus Detail 3D design

2.2.1. Flight Mechanics

During this phase the lateral-directional static stability and the dynamic longitudinal stability was analyzed and improved. The Merlin Simulator was also used to adjust the mounting incidence of wings and horizontal stabilizer. Also, to determine the control surface sizes to achieve a proper controllability. After the test flight the UAV succeed in terms of stability but failed in terms of controllability.

The lateral-directional controls weren't able to generate enough roll moment to make the UAV turn properly. This meant that its size was not big enough to overcome the natural stabilization of the UAV. In the case of the longitudinal control, the pilot needed to deflect the elevator 80% up in order to avoid the UAV to pitch down during take-off. This left a tiny margin for controllability. After analyzing the production phase, the fault seems to be a change in the design due to production errors what made the tail to shift backwards, increasing the moment arm of the horizontal stabilizer. The design mounting incidence made then the UAV to pitch down too much.

The Merlin Simulator also showed that the speed range of the UAV would be slow. This resulted to be true, but not as slow as the Merlin Simulator stated as one can see in the Chapter 5 Aircraft Flight Dynamics.

In terms of weight and balance, the balance design proved to be adaptable to the changes in design due to production errors. This was a success in this part of the design but the weight estimation failed to consider one of the electronics components. Due to extra reinforcements that were applied during the production the final UAV resulted to be 150 grams over weighted.

2.2.2. Strength

The concept design was refined to get a proper structural strength. The key features of the strength design were the carbon fiber rod that extent from the motor support to the connection of the tail, the wing connection by means of 3D printed parts to the main carbon fiber rod, 3D printed motor support and the T mounted tail.

The main carbon fiber rod proved to be a light and strong part, which succeed in its purpose. The fuselage foam parts were supported to it and only the belly was reinforced in terms to withstand extra impact and scratch resistance on landing. This also proved to succeed being a lightweight option.

The wing connection proved to be strong enough already in the first strength test and gave us the modularity needed to transport the big UAV to the mission flight. Reinforcement in top of the middle part of the fuselage was in the design in order to provide extra support apart than the 3D printed parts. This difficulted a lot the electronics access and gave many problems during the flight days. Thus, a revision of this part of the design will be done in further design iterations.

The 3D printed motor support shown to be inadequate during the production phase. It had to be redesigned in order to be reliable and pass the airworthiness test by NLR.

The fuselage middle part took too much of the design attention and the T mounted tail design was idealistic in comparison. During the production phase the tail had to be reinforced in horizontal stabilizer, elevator and vertical stabilizer connection to the main carbon rod.

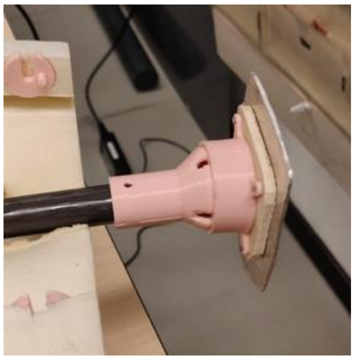


Figure 2.2-2 Redesigned motor support

The strength of parts like the back part of the fuselage (which are empty and don't stand significant stresses) was not a concern during the detail design. The strength calculation for the wings covered with composite skin were performed but only a non-destructive proof load test was performed.

2.2.3. Production

The detail design also focused to make the concept to be production wise. Stating matching the parts with the production methods available. Fuselage middle and wings took most of the attention in this part.

The fuselage middle was designed in order to be laser cut and assembled precisely to match also the connection with the wings. The wings were divided in several parts of 10 cm thick XPS foam. This was in order to cut them quickly and precisely and to have the space inside the wing to store the cables for the aileron's servos. The fuselage middle succeeds in terms of production easiness being assembled like a puzzle, but the wings resulted to have weak trailing edges even after applying the composite skin.

Figure 2.2-3 Assembled fuselage middle

The production time and easiness of the rest of the fuselage parts was overestimated and resulted to be very time consuming. The electronics configuration was also overestimated, being missing many of the cables we needed and causing delays in the mounting of the control surfaces.

2.4. Post Test Flight modifications

After the Test flight at the NLR facilities in Marknesse, the aileron and rudder surfaces were doubled, the mounting incidence of the horizontal stabilizer reduced, and the elevator surface extended too.

The aileron shape was not the same as the wing airfoil, what could have caused some of the roll instability experienced in the mission flight but succeed in terms of giving the necessary roll controllability.

The elevator extension resulted in it being almost 50% of the chord of the horizontal stabilizer what resulted in high pitch sensibility in the mission flight. The reduction of the mounting incidence of the horizontal stabilizer succeed to give the pitch controllability needed at take-off and landing.

2.5. Evaluation

In this subchapter one can find an evaluation of the aircraft design and design process

Table 2.5-1 Aircraft design and design process evaluation

Requirement	Result	Weight	*Mark*
Challenging and innovative idea	Length record, use of mid-mounted wing with dihedral angle	3	10
Whole satisfied with concept	Use of a poll for final concept	1	8
Wingspan less than shorter than 2m	1.6 m	1	10
Weight lower than 4kg	3.1 kg	1	10
Fixed Wing and one engine	✓	1	10
Static and dynamic longitudinal stable	✓	4	8
Maneuverable within 500m from the pilot in command	Controllability problems on test flight	3	2
Hand launched	4 successful launches, no aborted ones	2	10
Able to land safely	3 consecutive landings without damage	4	10
Able to drop the package	Manual drop performed	3	8
Production wise	Time consuming production but design adapted for fast manufacturing	2	7
Weighted average			8,16

3. Budgeting and Production

In this chapter one can find the budgeting of the UAV 3.1, the review about the production phase 3.2 as well as its evaluation 3.3.

3.1. Budgeting

In this subchapter one can find the budgeting of the UAV in Table 3.1-1

Table 3.1-1 Budget sheet

BUDGET SUMMARY

LIST OF EXPENSES

PROJECT FUNDS ALLOTTED	FUNDS USED TO DATE
€ 300.00	€ 279.18

Item	Category	Cuantity	Cost
XPS Foam (10 cm Thickness)	Materials	2 plates (120x50 cm)	€ 15.00
XPS Foam (5 cm Thickness)	Materials	2 plates (120x50 cm)	€ 15.00
Plywood	Materials	2 plates (150x60 cm)	€ 9.60
Wood Glue	Materials	750 gr	€ 8.99
Carbon Rod (16mm Ø)	Materials	Rod of 40 cm length	€ 5.00
Glass fiber	Materials	1 m^2	€ 9.25
Resin + Hardner	Materials	1 kg	€ 22.00
Vacuum plastic film	Materials	2 m^2	€ 6.04
Peel ply	Materials	2 m^2	€ 7.44
Flat brushes	Materials	4 pieces	€ 5.19
Non-woven absorber	Materials	1 m^2	€ 2.46
Sticky tape	Materials	6 m	€ 15.00
Gloves	Materials	5 pairs	€ 0.49
PLA	Materials	1 kg	€ 20.00
Fuel costs	Materials	51.80 liter	€ 74.02
Hinges	Materials	12 pieces	€ 5.00
Ecalc calculator	Materials	3 months subscription	€ 5.00
Servo's	Materials	5 pieces	€ 53.70
Total			€ 279.18
Price per person			€ 55.84

3.2. Production

In this subchapter the production phase will be analyzed.

At the beginning of the production phase the group started as planned according to the schedule made. The schedule was in the beginning easy to follow, but it was more about deadlines of when each part should be completed than a plan of actions to do. Thus, at some point, due to the high number of parts and the waiting times of some of the manufacturing processes the group DBF-A faced delays and deadlines problems. For instant delaying the strength test that one can find in the Appendix 7

One example of the waiting times not considered in the scheduling is that the UAV is constructed out many parts that needed to be glued together. The gluing process needs time to dry before continuing the assembly.

The delays made the production process to be always in a rush what meant mistakes and more delays in some cases. It meant also changes on design because of production errors in other situations. Need to say that most of the production methods stated in the production plan where used without any change, but some of the production methods lacked a full specification and more beforehand tests like the different glue options.

Despite having delays in deadlines, the group was still able to meet all the strength and airworthiness requirements. The UAV of DBF-A has the record of biggest UAV built in the minor history, the Design Build & Fly teachers confirmed it. DBF-A has produced also the only UAV built during the semester that landed successfully without any damage after all the flights (four in total) including an abruptly finished Test Flight.

3.3. Evaluation

In this subchapter one can find an evaluation of the production phase

Table 3.3-1 Production and budgeting evaluation

Requirement	Result	Weight	*Mark*
Main wingspan skin made of composite materials	Strong but no weight symmetry	2	7
Wing strength performance by EASA CS-23	15 kg of punctual load	2	10
Airworthiness assessed according to AS-RPAS1	Not reached the deadline, airworthiness assessed on test flight	2	5
Production consistent with design	Discrepancies with design due to production mistakes	3	6
Schedule	Planning on the run, tight in deadlines	3	2
Materials used and budgeting	Not exceeded the production plan materials usage, except for non-planned modifications	2	6
Production methods	Few changes to the methods described in production plan	3	7
Weighted average			5,94

4. Mission Execution

In this chapter one can find the review of the flights performed during the mission day.

4.1. Flight performance and controllability

The first test flight performed proved that the UAV flight capabilities were not adequate. After the corrections made described in Chapter 2.4 a new test flight was performed before the mission flight on the same day.

That flight demonstrated an adequate but not perfect controllability. The reasons for that are described also in Chapter 2.4. One of the goals of this test flight was to record useful flight data for further analysis of the flight dynamics of the plane. The flight performed lacked to follow some of the maneuvers needed for a full analysis. In Chapter 5 are the assumptions explained order to make the required estimations.

Controller connection failsafe, stabilized mode, GPS and telemetry connection succeed to work. The airspeed sensor showed a bad behavior, what is demonstrated in Appendix 4, thus the mission plan was adapted to not rely on it. The compass and the orientation sensors proved to be well calibrated too.

4.2. Mission Plan

NLR reviewed the mission plan before the mission flight and checked that the route was adequate. One can find the mission planner file at the Appendix 11. The mission consisted in following a “figure 8” route while checking the maximum climb rate and maximum speed of the UAV.

In the Figure 4.2-1 one can see that the UAV took off in stabilized mode (Orange), after which it changed to auto mode (Yellow) and followed the predetermined route (White). The predeterminate route was followed with enough accuracy as we didn’t exceed the NLR area. At the beginning of the third “figure 8”, which had to end with the automatic landing a battery failsafe prompted out, changing the mode to Return to Launch (Blue) and disabling further attempts of auto mode during the flight.

Nevertheless, the UAV succeed in the maximum climb rate, clearing the climb angle required of 4.7° with a successful demonstration of a 5.7° climb angle. Due to the problems with the airspeed sensor the maximum airspeed could not be checked experimentally but the speed ranges observed in the mission flight match with the estimations explained in the Chapter 5.3 and the fact that the real maximum speed was higher than the one stated in the Detail Design Report (DBF-A, 2019) that was obtained via Merlin Simulator.

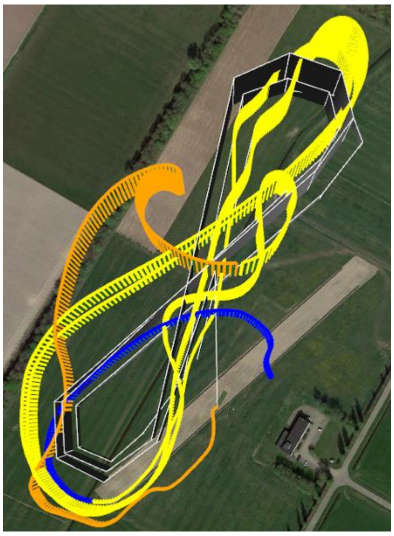
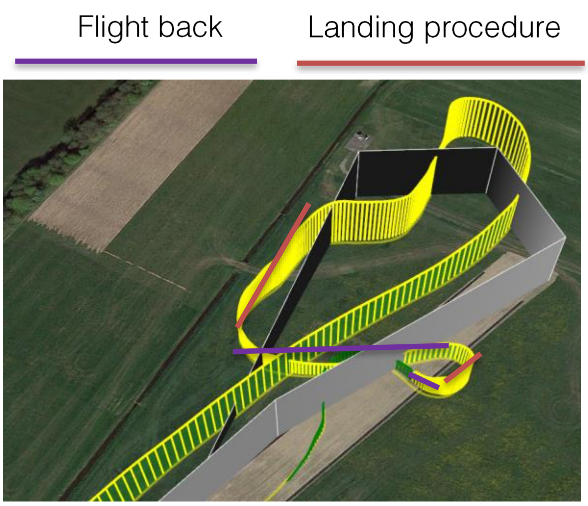


Figure 4.2-1 Figure 8 flight visualization

4.3. Automatic landing and dropping

Just before the battery failsafe prompt the UAV passed the drop waypoint still in auto mode, at the programmed height and a 3 m/s faster than the programmed ground speed. It failed to drop the payload in automatic mode, but it was released afterwards manually so the problem with the automatic drop was a matter of configuration. This was confirmed with posterior flight that had the only goal of repeating the auto drop and landing, where the automatic drop failed again. Further testing before the mission flight would have probably mean a success in this aspect.



In the case of the automatic landing, the low speeds at which the aircraft was able to flight made it very sensitive to the wind. In the extra flight shown IN one can see that the UAV flights back during the land procedure. A tail wind land approach might have meant a successful automatic landing but solving the front wind problem would have need more flight tests with different configurations.

Figure 4.3-1 Extra flight automatic land attempt

4.4. Evaluation

Table 4.4-1 Mission execution evaluation

Requirement	Result	Weight	*Mark*
Drop the payload automatically and accurately	No automatically drop	2	2
Perform a landing in automatic mode	No able to land in automatic mode due to wind and the slow landing speed	2	4
Follow accurately the programmed route in automatic mode	Battery failsafe problem at the end of the mission	3	7
Carry the payload	Only 100g payload	1	8
Capable of change to manual flight at any moment.	✓	1	10
Hand launched	No hand launch problems	2	10
Fully maneuverable within the mission area	Some pitch and roll sensitivity and stability problems but full controllable	2	8
UAV transported to the mission zone	UAV damaged in the trip back from the mission flight	1	6
Extract useful flight data	Airspeed sensor not well calibrated and no optimal flight for performance calculus	2	6
Weighted average			6,56

5. Aircraft Flight Dynamics

In this chapter one can find the analysis of the aircraft flight dynamics, the comparison between real flight data, simulated flight data and linearized calculus of the flight dynamics of the UAV.

As the test flight proved that the UAV was not properly built a new Merlin Simulator model was developed to make the proper changes to get the UAV ready for the mission flight. Therefore, the model used in the following analysis is not the one provided during the Detail Design Phase. This new model is described in the Appendix 1.

5.1. Drag Polar

The drag polar is a plot of drag coefficient versus lift coefficient (John D. Anderson, Fundamentals of Aerodynamics, 2011).

In this chapter one can find the comparison of the simulated drag polar versus the data extracted from flights and the drag polar calculated through the code developed by the group DBF-A.

The Glide Method (IIT Kanpur, n.d.) will be used for the determination of the Drag polar; this method is explained in the appendix Drag Polar determination method. The flights performed with the UAV don't match the conditions for a proper test flight to determinate the Drag polar so first the Drag polar will be extracted from the simulator model by means of the glide method and then will be compared with some of the data that can be extracted from the flights.

The drag polar equation is the one that represents the variation of CD with CL (John D. Anderson, Fundamentals of Aerodynamics, 2011), being "CD" drag coefficient and "CL" lift coefficient. The classic assumption is to take the drag polar as a parabolic curve and this assumption will be kept along this analysis. The drag polar equation can be described then as:

$$C_D = C_{D_0} + K * C_L^2$$

Equation 5.1-1

Being C_{D_0} the parasitic drag and K the induced drag factor, often approximated to:

$$K = \frac{1}{\pi * e * AR}$$

Equation 5.1-2

What means that is mostly dependent of the wing width to length relation (Aspect Ratio) and the lift force distribution of the wing (Oswald factor "e").

5.1.1. Simulated flight data

After analyzing the simulated flight data with the glide method, it presents the following drag polar equation:

$$C_D = 0.114 + 0.081 * C_L^2$$

Equation 5.1-3 Simulator Drag Polar equation

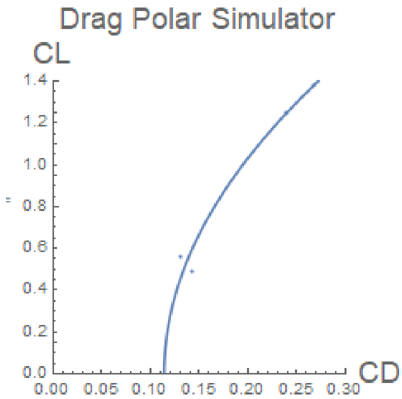


Figure 5.1-1 Drag Polar from Merlin Simulator

5.1.2. Flight data

During the test flight two main glides were conducted. They can be seen by the zones delimited by dashed lines with absence of throttle in the graph.

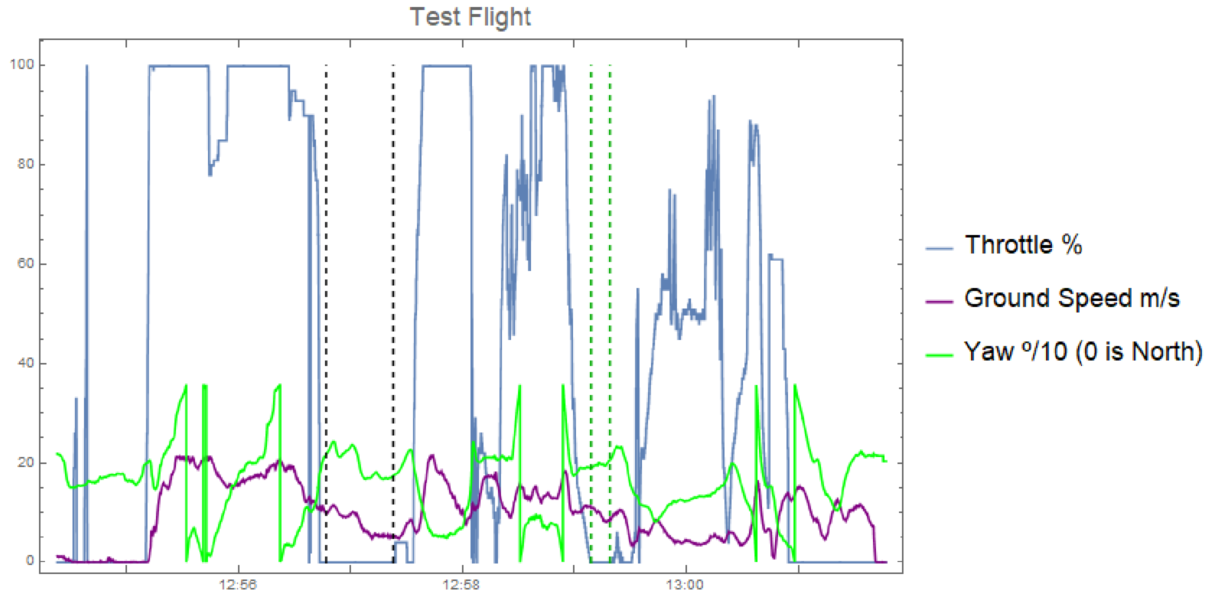


Figure 5.1-2 Test Flight glides with GPS and compass data

As explained in the Appendix 2 Drag Polar determination method the airspeed is needed to calculate the lift and drag coefficients, but during the flights the group already noticed that the airspeed sensor data seemed to be not reliable. This is confirmed by the readings of the airspeed sensor data on the Appendix 3 Proof of non-reliability of the Airspeed sensor.

Taking this into account a speed correction has been conducted using the GPS and compass data. The details and assumptions of this correction can be found in the Appendix 4 Airspeed correction of Real Flight Data.

Here one can see the results of the correction of the airspeed on both glides:

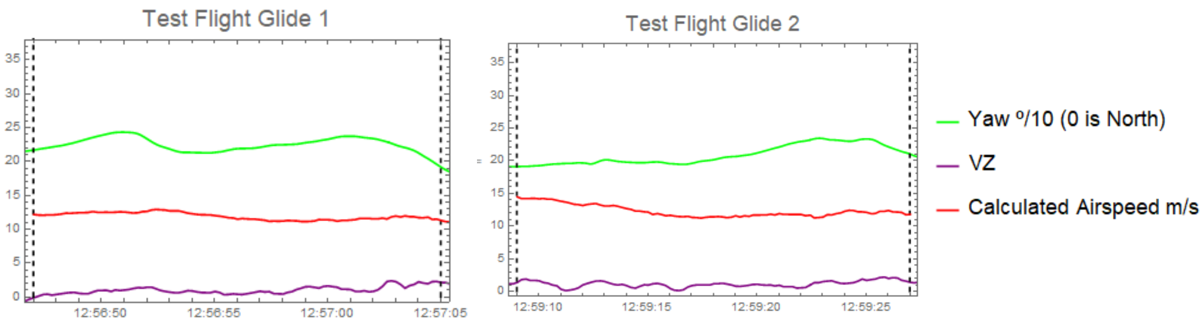


Figure 5.1-3 Test flight glides with corrected airspeed

Unfortunately, after the correction these two glides lie to near in the Drag Polar to fit any curve within them.

Table 5.1-1 Test Flight glides corrected airspeed

AIRSPEED CORRECTED	MEAN	STANDARD DEVIATION
GLIDE 1	11.92 m/s	±0.53
GLIDE 2	12.3 m/s	±0.93

Table 5.1-2 Test Flight glides corrected vertical speed

VERTICAL SINK SPEED	MEAN	STANDARD DEVIATION
GLIDE 1	1 m/s	±0.56
GLIDE 2	1.13 m/s	±0.49

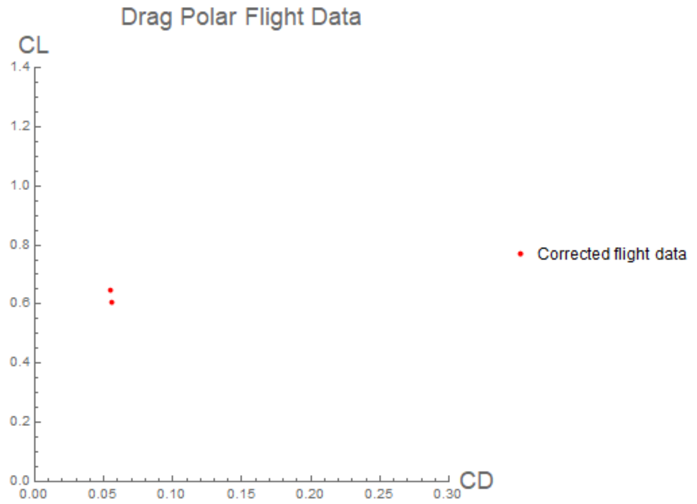


Figure 5.1-4 Test Flight, real flight data drag polar

5.1.3. Comparison

The two points from the real flight data are compared with the simulated drag polar and the drag polar calculated with the code developed by the group DBF-A that was presented on the Detail Design Report (DBF-A, 2019), the code is included in the Appendix 10.

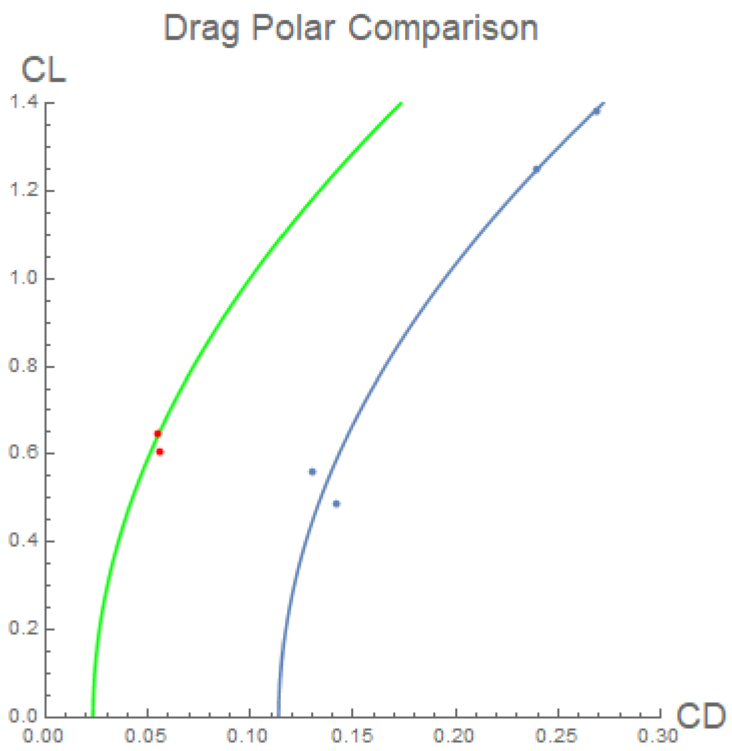


Figure 5.1-5 Drag polar comparison

Table 5.1-3 Drag Polar estimation comparison

DRAG POLAR	CD0	K
MERLIN MODEL	0.113	0.081
STUDENT CODE	0.023	0.077

It can be easily observed that the student developed code gives a result much more accurate than the merlin model. Nevertheless, the merlin model has deeper information about the wing shape than the linear theory code and the flight data is not enough to determinate any better value for the induced drag factor “K”. The drag polar proposed is therefore a combination of both:

$$C_D = 0.023 + 0.081 * C_L^2$$

Equation 5.1-4 Proposed drag polar

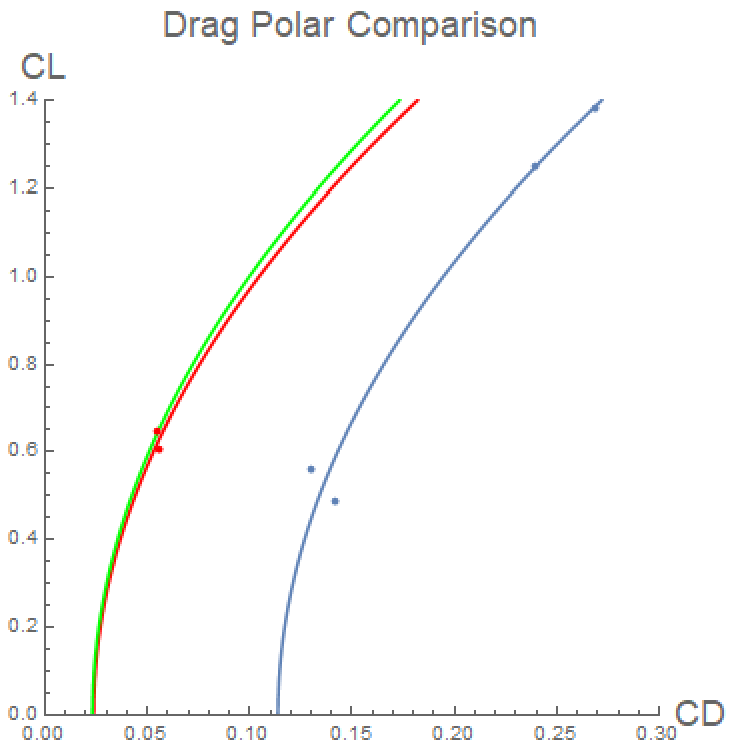


Figure 5.1-6 Drag Polar comparison with proposed Drag Polar

5.2. Power Curve

A graphical plot of power required versus airspeed for a given airplane at a given altitude is called the power required curve (John D. Anderson, Aircraft Performance and Design, 1999)

In this chapter one can find the comparison the power required curve obtained from the drag polar from Merlin Simulator with the student developed code and the proposed real drag polar.

The power required curve is easily obtained by multiplying the thrust required by velocity (John D. Anderson, Aircraft Performance and Design, 1999). The thrust required in steady flight is equal to the drag generated, therefore the power curve can be obtained from the drag polar calculated in 5.1 Drag Polar, a deeper description of the procedure can be found at Appendix 5.

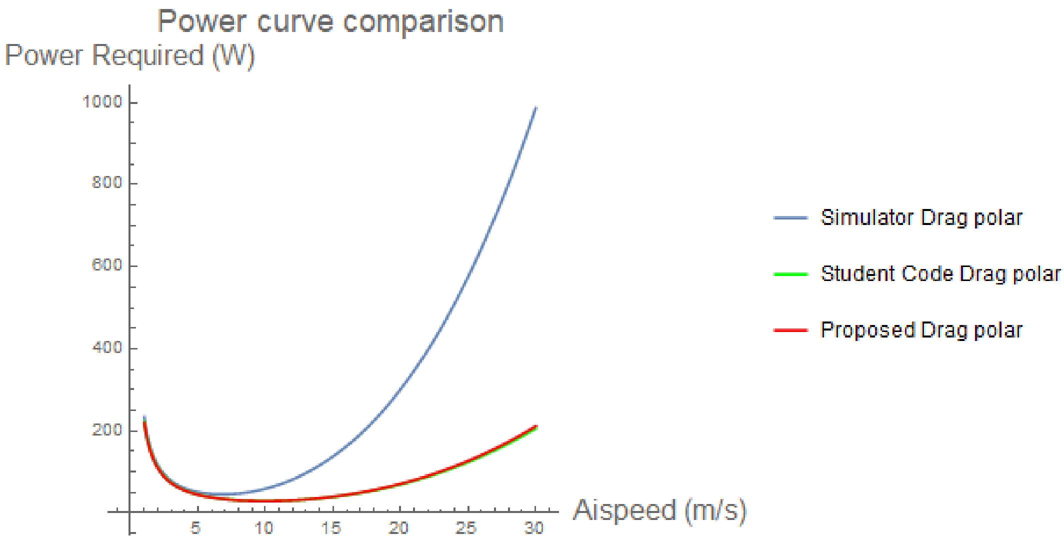


Figure 5.2-1 Power curve comparison

Considering that the proposed drag polar is very similar to the student developed code drag polar it's not surprising that the power curves are also very similar.

5.3. Maximum Speed in Level Flight

For an airplane cruising at steady level flight the lift is equal to the weight (John D. Anderson, Aircraft Performance and Design, 1999).

In this chapter one can find the estimation of the maximum speed in level flight using the flight data.

5.3.1. Merlin Simulator

One can easily set a maximum throttle steady level flight in the simulator and extract the data. With the model described in Appendix 1 the maximum airspeed was 29 knots.

Table 5.3-1 Simulator maximum airspeed

SIMULATOR MAXIMUM AIRSPEED
14.9 m/s

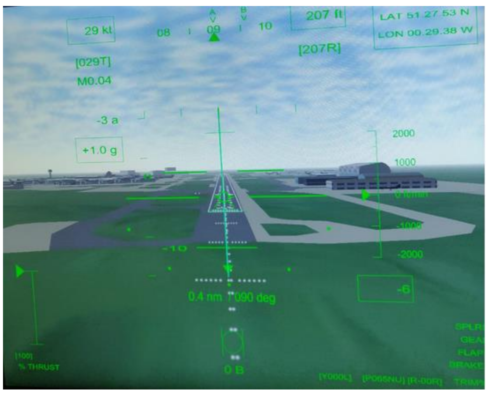


Figure 5.3-1 Simulator maximum airspeed

5.3.2. Flight Data

The flight data of the three flights done during mission day don't show any recording of level flight at maximum throttle so the maximum speed in level flight has to be estimated using the data available. Between the dashed lines of Figure 5.3-2 one can find a 10 seconds flight data that shows steady climb performance at full throttle, with nearly constant heading and corrected airspeed by the method explained in Appendix 4.

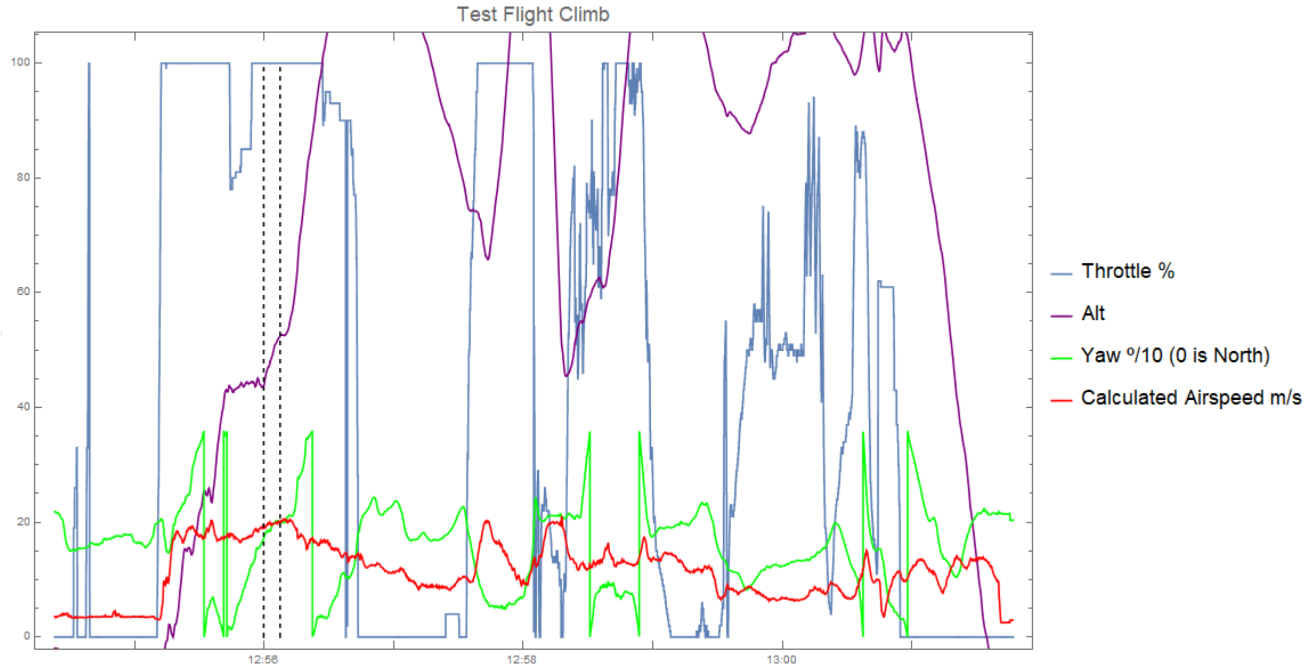


Figure 5.3-2 Test Flight steady climb

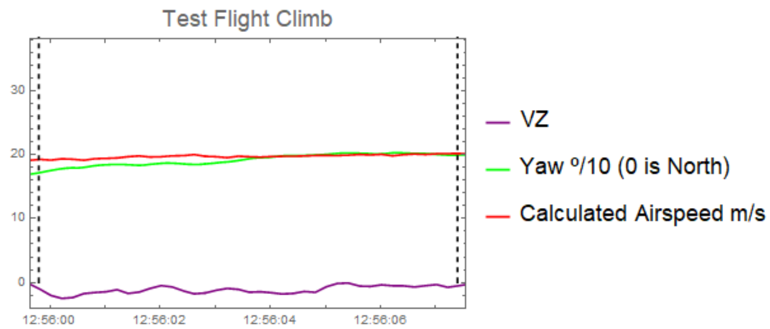


Figure 5.3-3 Test flight steady climb detail view

Using the method described in Appendix 6 the available power curve can be plotted with the required power curve; the maximum level flight can be found at the higher speed intersection of both.

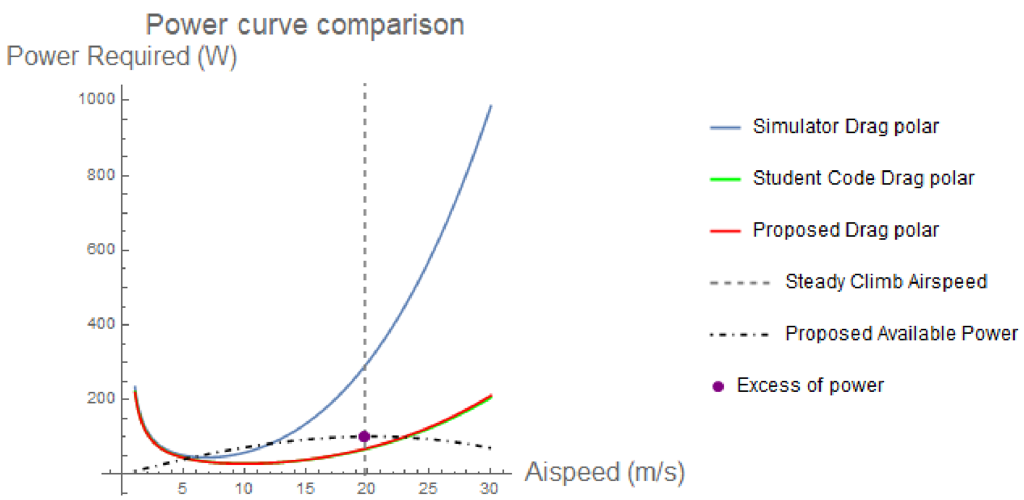


Figure 5.3-4 Power curve comparison with proposed available power

At first sight of Figure 5.3-4 it's easy to observe that the power curve extracted from the simulator model does not match the proposed available power, one can find the reason of that also in the Appendix 6. The intersections between the proposed available power and the proposed power required can be found in Table 5.3-2.

Table 5.3-2 Extreme steady level flight airspeeds

POWER AVAILABLE INTERSECTION WITH POWER REQUIRED	MINIMUM AIRSPEED	MAXIMUM AIRSPEED
	5 m/s	23 m/s

5.3.3. Comparison

The estimated maximum level speed from flight data match the fact that the maximum local calculated airspeed of the Test Flight shown in Figure 5.3-2 is 21.1 m/s far above the maximum level airspeed extracted from the simulator.

This result with the ones of sections 5.1 and 5.2 indicates that the drag model introduced to the simulator is not adequate. There is also the possibility that the Merlin Simulator has not been designed to simulate small size planes.

It is worth to say also that the thrust model estimated in the Detail Design Report (DBF-A, 2019) resulted to be very optimistic, being the maximum flight speed estimated with the student developed code 28 m/s, as one can extract from Figure Apx 6-1. This maximum speed is quite far from the speed range that the UAV resulted to fly.

5.4. Flight Envelope

The flight envelope of an aircraft refers to the capabilities of a design in terms of airspeed and load factor or altitude (Safety Flight Foundation, n.d.).

In this chapter one can find the flight envelope analysis.

The range of altitudes in which the UAV flew is very small and close to sea level altitude, therefore the flight envelope will be plotted as Load Factor versus Airspeed, and the assumption of sea level air density will be made

The flight envelope of the UAV is composed from of three limitations: Stall, structural limit and maximum speed. The stall load factor can be found IN, one can find the origin of this equation in the Chapter 6 of the Aircraft Performance and Design book (John D. Anderson, Aircraft Performance and Design, 1999). The structural limit is defined by the strength analysis that can be found in Appendix 9 (in the case of the group DBF-A UAV $n_{max\,Structural} = 5$). The different estimated maximum speeds and the proposed one can be found in Chapter 5.3.

The flight envelope can be extended also to negative load factors, but it is meaningless in the UAV context because it never flies in that conditions.

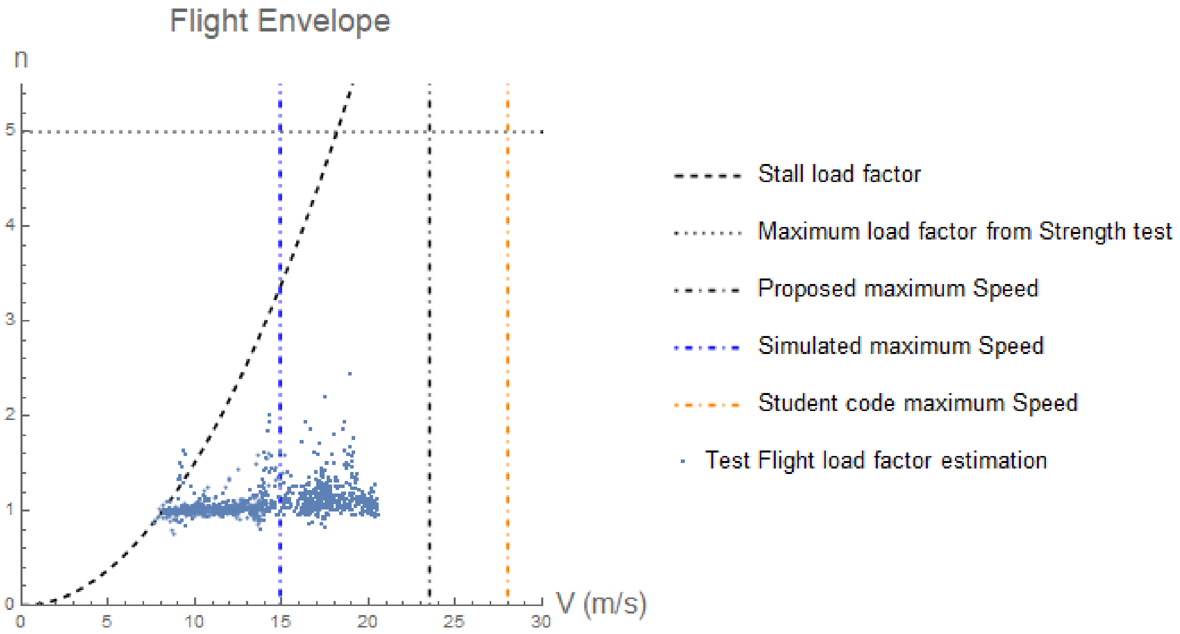


Figure 5.4-1 Flight envelope comparison

Now, the load factor that experiments the UAV during the test flight is estimated and plotted against the airspeed in order to check which flight envelope fits better. The estimation of the load factor is deeply explained in Appendix 7. Also, some flight data from the test flight has been excluded from the plot, further explanation can be found in Appendix 1. It can be seen in the plot that some points seem to lie outside the flight envelope but that points are also isolated from the points cloud so one can assume them to be outliers because of sensors noise in reading. They could be eliminated by means of a deeper statistical analysis that is outside the scope of this report.

It is not surprising that the best fit is the proposed flight envelope, as we have realized already in the previous sections. One can find that the simulated maximum speed limit is not consistent with the flight data, as it has been already stated and that the student code maximum speed limitation is far from the range that the aircraft flew in reality.

6. Conclusions

In this chapter the final evaluation of the project is presented, as well as the group's opinion about it. There are also presented a review of improvements applicable to the current UAV 6.1, changes that would be applied in the design with the knowledge acquired during the rest of the minor 6.2 and tips for the next groups 6.3.

The final evaluation of the project is calculated by averaging the grades of the different project phases. After all the work and the time spent in the project the group is satisfied with the result. Nevertheless the group agrees that the time consumed in the Build phase has been overwhelming, the record breaking size of the UAV had a complicated and stressful production.

Table 5.4-1 Final Evaluation

Phase	Mark
Design	8,16
Build	5,94
Fly	6,56
Average	6,89

Besides the difficulties the group is most satisfied with the acquired knowledge, not only the specific technical knowledge in terms of aerodynamics, flight mechanics, 3D design, structural strength and hazard and risk overview, but also in terms of project management and group work.

6.1. Recommendations for improvement

The current UAV has improvement margin, mainly in terms of controllability, automatic mission planning and visual finishing.

For a better controllability the ailerons shape should be improved in order to align better with the wing shape. The horizontal stabilizer should be changed as a hole with a review of the optimal mounting incidence and shape considering that the elevator chord percentage should be kept around the 20%.

The automatic mission planning needs to be improved, firstly by means of repairing and calibrating the airspeed sensor, secondly with a proper configuration to ensure the automatic payload drop and finally by testing and improving the configuration of the automatic land in order to achieve the automatic landing with front wind.

In terms of visual finishing the UAV should be painted or covered with plastic film in order to give it a better looking and an improved surface finishing.

6.2. Further design iterations ideas

The key feature that would be changed if a design review is applied is the deep camber airfoil. It resulted to be an overkill in terms of landing and take-off capabilities, where the UAV succeed fantastically but being able to fly very slow also means that the configuration is not adequate to fly fast which was a problem in the mission flight due to the long time needed in order to complete the mission, where the battery was heavily drained.

With more experience in the mission requirements the group thinks that a flapped wing would be a good option, and a rectangular wing shaped would halve the production times with a proper design, because the foam of the wing and its control surfaces could be laser cut and assembled fast and precisely as it was done with the fuselage middle.

In the same way the dihedral angle combination with the payload stored inside the fuselage resulted to be a problem because of the huge volume needed in the fuselage middle, that made the fuselage to have the biggest cross-section of all the UAVs built during the semester. In order to keep the payload inside the fuselage the dihedral mid-mounted configuration would be changed to a straight high-mounted wing.

After the NLR feedback during the mission flight[3] the payload would be mainly rice with a soft envelope instead the steel envelope used in the actual design, what means that in order to have the same weight it would be bigger. This encourages the dihedral configuration to a high-mounted wing change.

6.3. Tips for the next groups

From the group's actual experience, the key advice would be to not underestimate the time consumed during the build phase. A compromise between the group members at the beginning of the semester to do a schedule with the time that the group agrees to spend in the workshop would be useful in the design and production plan phases.

The detail design phase is very time consuming so another advice is that if there's desire for challenge and innovation the initial concept and configuration should be chosen as fast as possible and use the concept phase time to advance as much as possible with the design, even if it is not required. Covering all the possible details during this phase is very important, for example, is very common to need extension cables for the servos, define its length in advance is useful. Have production in mind during the detail design, it is very useful to test and estimate the crafting time required for the different parts in order to make a good production plan.

The Merlin Simulator model should be started soon to avoid rushing with it, because it is easy to mess up and introduce a model not consistent with the design. DBF-A found also useful to not base all the design only on the Merlin Simulator, the additional calculus performed with the Linear Theory student developed code and the XFLR5 proved to be useful.

Simplifying the structural strength calculus is also useful, but all assumptions should be clear, and a safety margin should be applied. This calculus can be time consuming too even if they are simplified so don't underestimate them.

As a final remark, use the consultants wisely. Ask for opinion or revision of your ideas but don't ask for solutions. Consultants can confirm or dismiss your worries about the design and find problems that are not found in calculations and simulations thanks to their experience.

[3] The payload is asked to be rice in order to not damage any other UAV or tool that is used in the flight field if the payload is lost after drop

Bibliography

Böing, B. (2019, February 6). *Design, Build and Fly guide book*. Retrieved from https://studiedelen.mijnhva.nl/studiedelen/ft-6000MDBF18/1819/Documents/Guidebook%20Aviation%20Minor%20DBF%202018-2019%20SEM2%202019-01-25.pdf

DBF-A. (2019). *Detail Design Report.*

Grit, R. (2015). *Project Management: A practical approach.* Groningen/Houten, the Netherlands: Noordhoff Uitgevers.

IIT Kanpur. (n.d.). *Flight Determination of the Drag Polar*. Retrieved February 22th, 2019, from http://www.iitk.ac.in/aero/fltlab/flight.html

John D. Anderson, J. (1999). *Aircraft Performance and Design.* McGraw-Hill.

John D. Anderson, J. (2011). *Fundamentals of Aerodynamics.* Mcgraw-Hill Education - Europe.

Safety Flight Foundation. (n.d.). *Skybrary*. Retrieved June 27th, 2019, from Flight Envelope: https://www.skybrary.aero/index.php/Flight_Envelope

Appendices

Appendix 1 Merlin model according mission flight UAV

The produced UAV for the test flight was slightly different from the designed one during the Detail Design phase, mainly concerning to the position of the tail and electronics:

- Vertical stabilizer and horizontal stabilizer root longitudinal distance to the tip increased 10cm, and therefore the overall length of the UAV
- Center of gravity longitudinal distance to the tip increased 4cm

After the test flight several modifications were applied in order to improve the performance. These modifications afect mainly the control surfaces:

- Doubled surface of ailerons and rudder
- Increased elevator surface
- Reduced horizontal stabilizer mounting incidence to 0 degrees

A new Merlin Model was developed between test and mission flight in order to determine the necessary horizontal stabilizer changes and the aileron and rudder modifications were modeled after the mission flight in order to do the necessary analysis for this Project Evaluation.

Figure Apx 1-1 New merlin model panel drawings is a group of drawings that correspond to the modeled panels, it's easy to see the increased aileron surface.

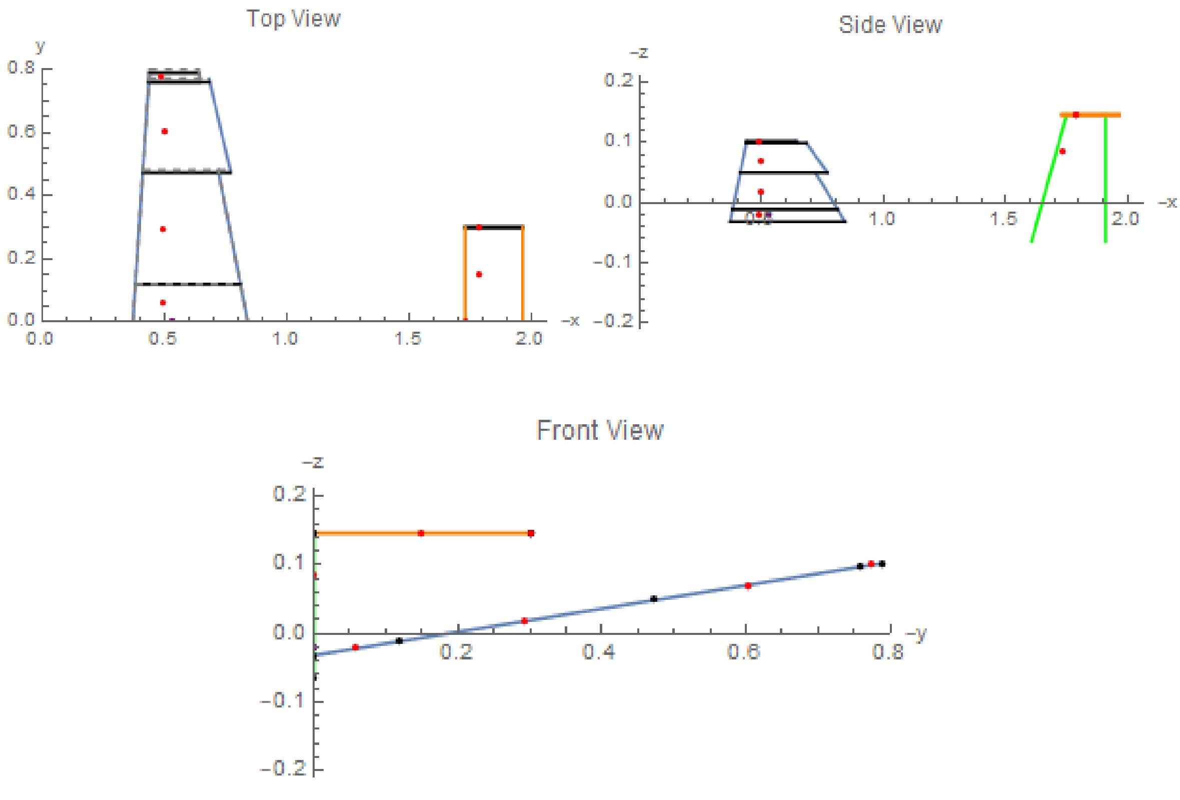


Figure Apx 1-1 New merlin model panel drawings

One can find the Merlin model file here:

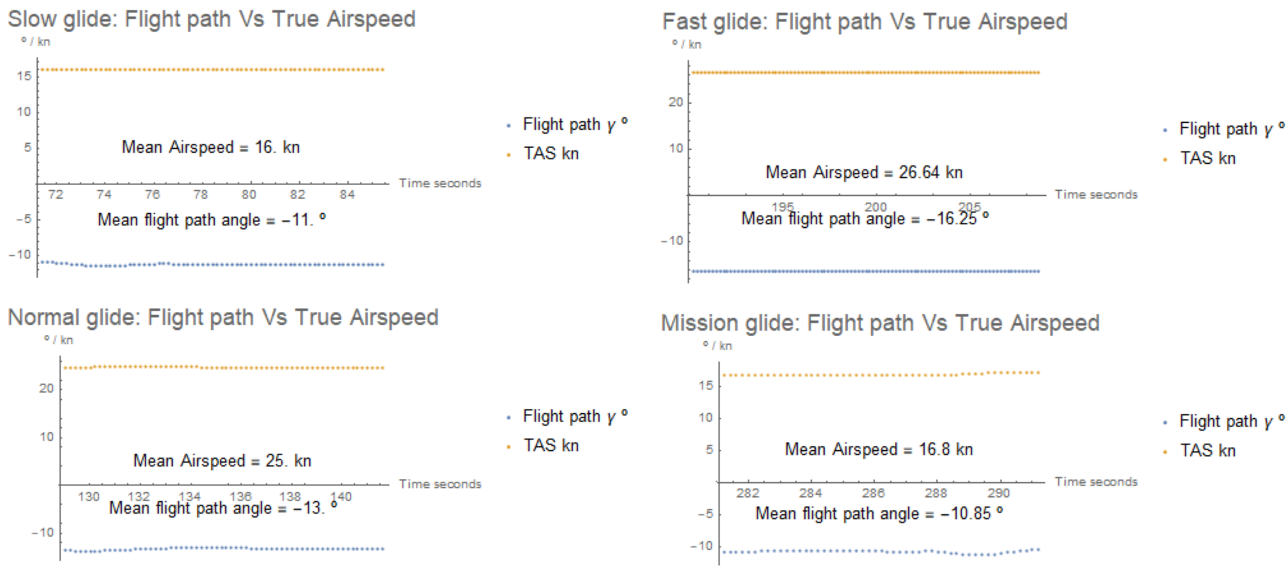
https://drive.google.com/open?id=1ejPqUWcjLJPKcD2Yx6yleeRGZ471330Z

Appendix 2 Drag Polar determination method

The Glide Method (IIT Kanpur, n.d.) is based on the use of steady glide performance to calculate the Drag Polar.

First of all, the glides must be performed at different speeds, being the needed amount of different speeds up to three to be able to determinate the Drag Polar.

In our case we will use 4 glides from the simulator, being one of them the one that matches the angle of attack with the a glide we can extract from the mission flight of the real UAV.



Equation Apx 2-1 Glide data from simulator model

Secondly the different Drag Polar (C_L vs C_D) points are calculated using the path angle "γ", airspeed "V", weight "W" and wing surface of the UAV "S". As the UAV flights at low altitudes, sea level air density "ρ" is assumed.

$$C_L = \frac{W * Cos(\gamma)}{\frac{1}{2} * V^2 * \rho * S} \qquad C_D = \frac{W * Sin(\gamma)}{\frac{1}{2} * V^2 * \rho * S}$$

Equation Apx 2-2

Appendix 3 Proof of non-reliability of the Airspeed sensor

From the first flight (Test Flight) performed with the UAV on the mission day is easy to identify two main glides, marked with the dashed lines:

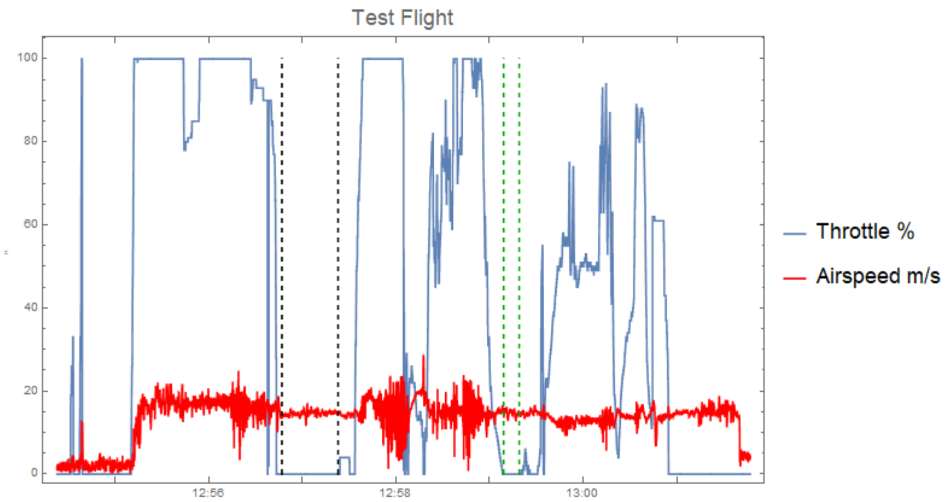


Figure Apx 3-1 Flight Test glides

These glides have almost constant airspeed registered by the airspeed sensor:

Table Apx 3-1 Glide airspeed registered by sensor

AIRSPEED	MEAN	STANDARD DEVIATION
GLIDE 1	14.63 m/s	±0.63
GLIDE 2	14.69 m/s	±0.76

Both speeds are very similar, the difference is negligible considering its standard deviation, but this is not all, once the UAV is flying the airspeed sensor registers almost the same mean value at any time. Assuming the flight time the one between the black dashed lines:

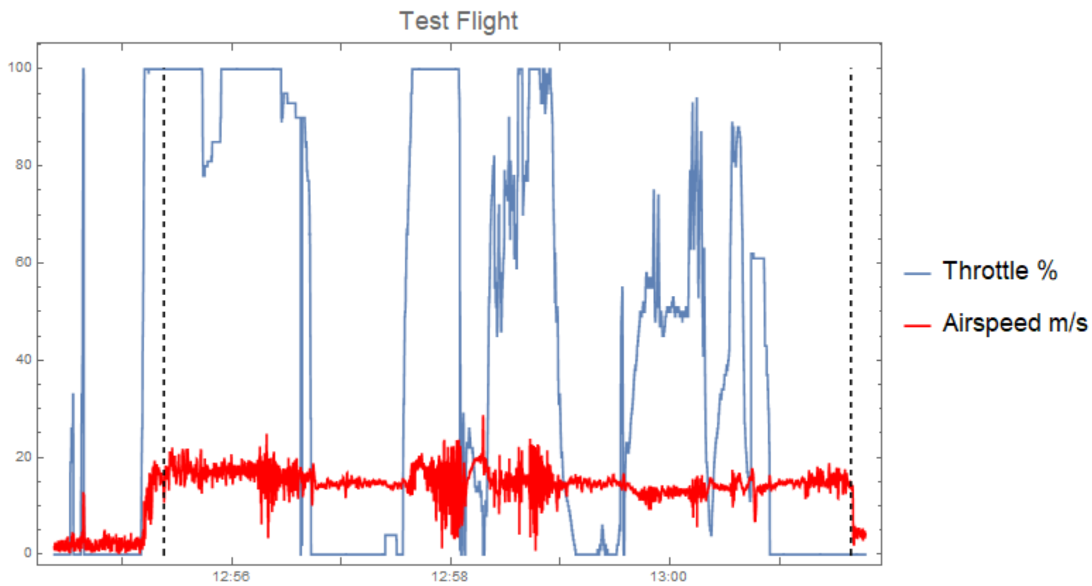


Figure Apx 3-2 Flight Test total flight time

Table Apx 3-2 Flight test total flight time airspeed

AIRSPEED	MEAN	STANDARD DEVIATION
FLIGHT TIME	15.05 m/s	±2.47

These results indicate that airspeed almost didn't change during the flight, the mean keeps almost constant and one can see in the graphs that variation of airspeed seems to be noise in the reading. This means that the airspeed sensor data is not reliable, it might not be proper calibrated or there was an initialization error with it.

Appendix 4 Airspeed correction of Real Flight Data

Once it's demonstrated that the airspeed sensor is not fully trustable the next step is to retrieve the airspeed from ground speed and compass data using some assumptions:

- Wind speed is constant in the analyzed time interval
- Wind direction is constant from launch to glide
- Airspeed is nearly constant

These assumptions are consistent because it's easy to see that in the time intervals selected the ground speed is directly related with the heading:

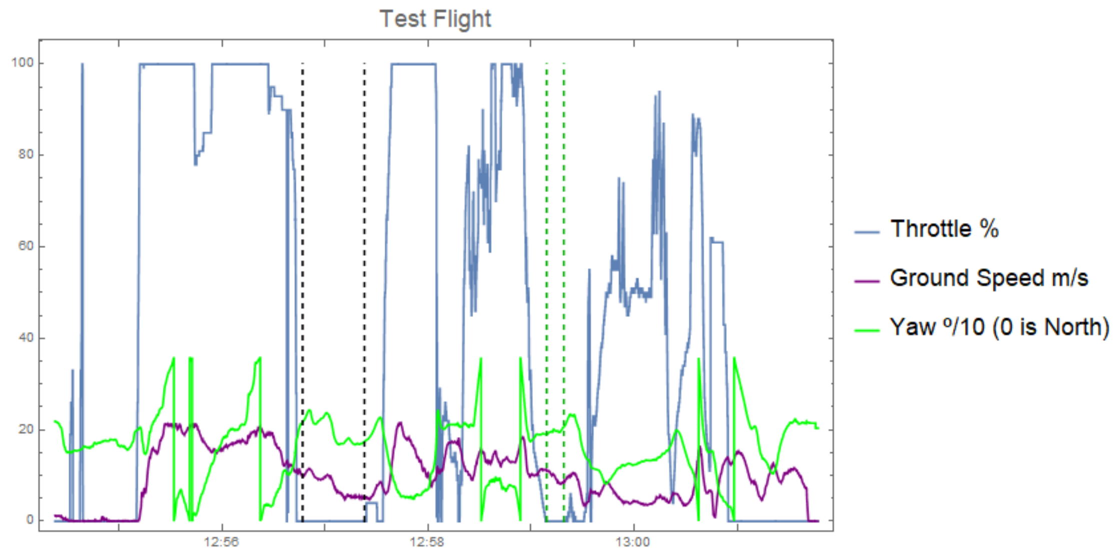


Figure Apx 4-1 Test Flight glides with GPS and compass data for airspeed correction

The airspeed correction will be fully detailed for the first glide. This glide has two main orientations, marked in red in the map. The wind direction can be extracted from the beginning of the flight, when the aircraft is aligned against the wind for the launch:

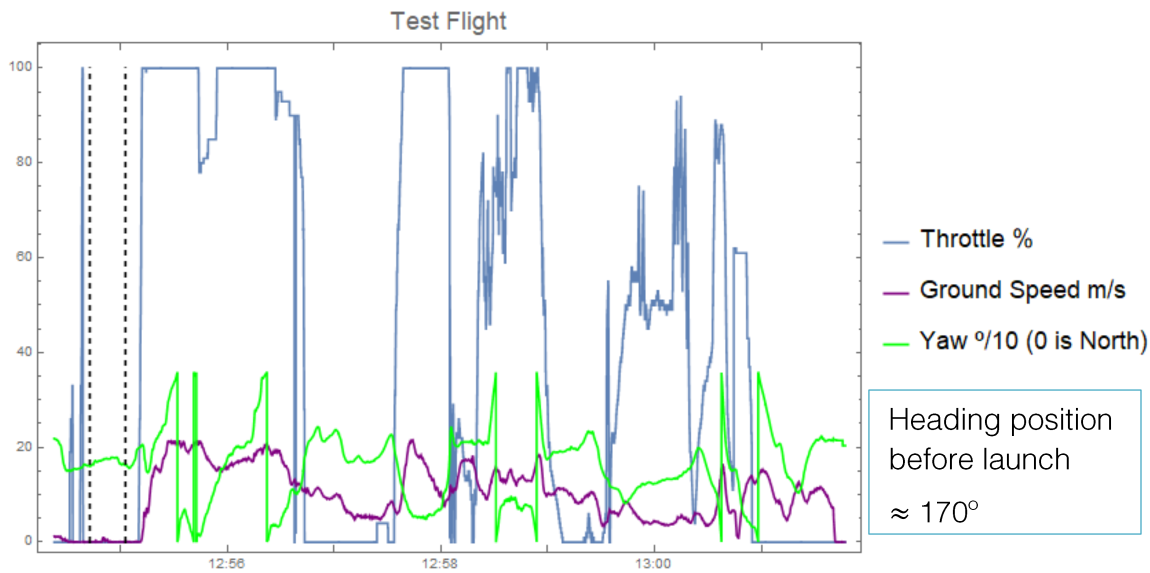


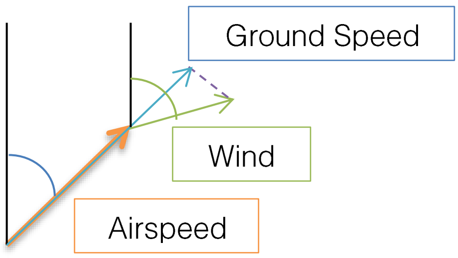
Figure Apx 4-2 Flight Test launch heading

Therefore, the wind direction can be calculated from the launch direction with the assumption that it will remain constant from the launch until the end of the glide. Then, we can tune the wind speed to get the assumed nearly constant airspeed in the two main different headings that the glide takes place and that are marked in red in the map.

Figure Apx 4-3 Glide map with wind direction and speed

The corrected airspeed is calculated with the following formula:

$$AirSpeed = GroundSpeed - Cos(Wind\ direction - heading) * Wind\ Speed$$



Equation Apx 4-1

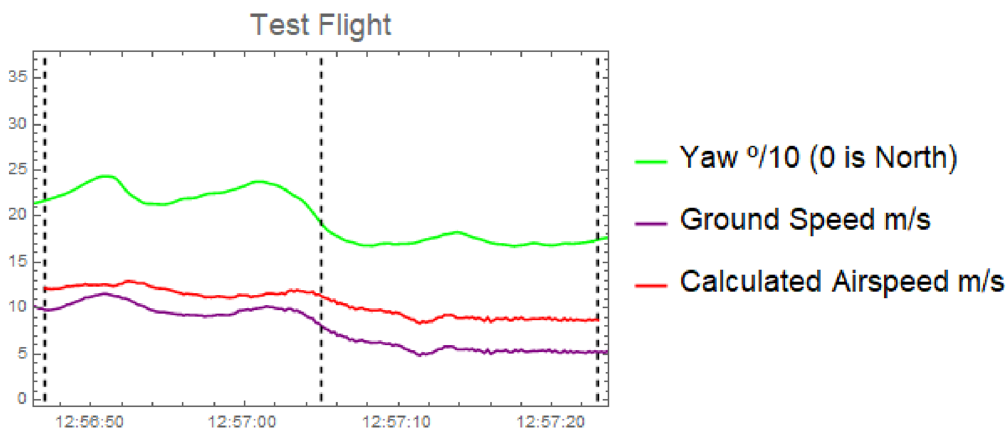


Figure Apx 4-4 Glide 1 corrected airspeed

AIRSPEED CORRECTED	MEAN	STANDARD DEVIATION
GLIDE 1 FIRST PART	11.92 m/s	±0.53

Table Apx 4-1 Airspeed corrected in glide 1

Appendix 5 Power required curve calculation from Drag Polar

As stated in Equation 5.1-1 the drag polar relates drag with lift coefficient.

Assuming steady leveled flight the lift coefficient can be described as in Equation Apx 5-1.

$$C_L = \frac{W}{\frac{1}{2} * V^2 * \rho * S}$$

Equation Apx 5-1

Assuming sea level air density the only unknown that remains is airspeed "V", therefore with the drag polar we have a relation of drag coefficient with airspeed. With the definition of drag coefficient in steady leveled flight shown in Equation Apx 5-2 one can relate thrust "T" with airspeed.

$$C_D = \frac{T}{\frac{1}{2} * V^2 * \rho * S}$$

Equation Apx 5-2

Now from the definition of the power required "Pr" shown in Equation Apx 5-3 one can find the relation "Pr" versus "V" that describes the power curve.

$$Pr = T * V$$

Equation Apx 5-3

Appendix 6 Power available curve calculation from Power required and steady climb data

From the longitudinal equation of motion described in Equation Apx 6-1 one can extract the steady case described in Equation Apx 6-2. From that point it is easy to reach a relation of the power available ($T * D$), power required, weight and vertical speed shown in

$$T - D - W * Sin(\gamma) = m\frac{dV}{dt}$$

Equation Apx 6-1

$$T - D = W * Sin(\gamma)$$

Equation Apx 6-2

$$T * V - Pr = W * V_z$$

Equation Apx 6-3

A thrust model was presented in the Detail Design Report (DBF-A, 2019) if we take that as an optimistic thrust model and represent it as a power available curve with the power required curves shown in Chapter 5.2. The airspeed observed in the steady climb that Figure 5.3-2 shows is already not consistent with the merlin simulated data.

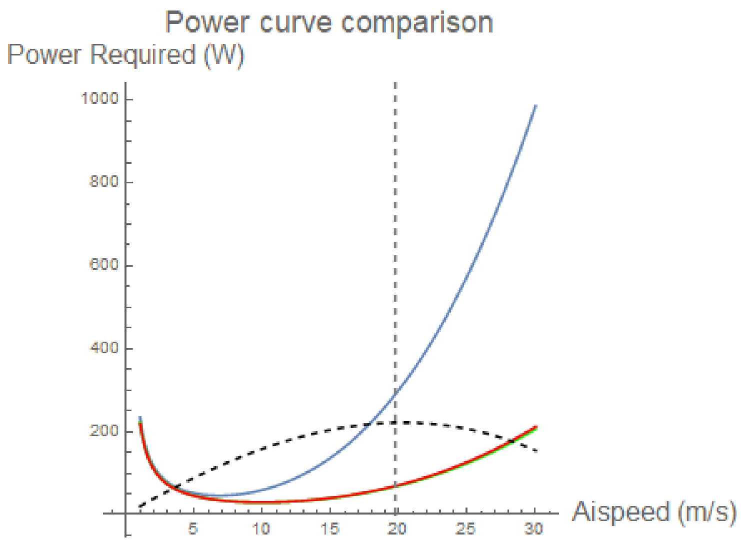


Figure Apx 6-1 Power curve comparison with steady climb airspeed

Therefore, the simulated power curve will be discarded for the estimation of the power available curve, instead the power curve calculated by means of the proposed Drag Polar will be used. One can add the excess of power to the required power to find one of the points that define the power available curve. Then a power available curve would be fitted by means of reducing the maximum thrust available of the thrust model presented in the Detail Design Report (DBF-A, 2019).

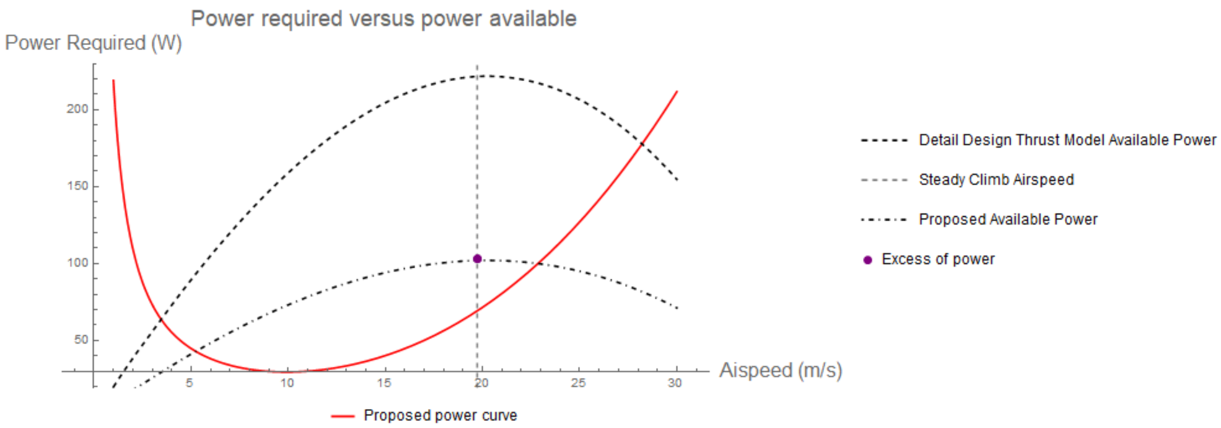


Figure Apx 6-2 Proposed Available Power

Appendix 7 In flight Load factor estimation

The load factor is described by Equation Apx 7-1. By using the tangential equation of motion (Equation Apx 7-2 aligned with axes "Zw" of Figure Apx 7-2) we can describe the load factor as it is in Equation Apx 7-3.

ε is the angle that exists between the aircraft longitudinal axis ("Xb" Figure Apx 7-3) and the thrust generation axis, it's usual to assume that this angle is negligible or to set the longitudinal axis of the plane in the thrust axis, as the group DBF-A did.

Another usual assumption is to neglect the influence of the angle of attack ("α") in the Equation Apx 7-2because the thrust influence in the tangential equation during cruise, but as our plane takes off at high angles of attack this assumption is a priori not consistent. Nevertheless, the results after the calculus show that the influence is indeed really small and depreciable.

$$n = \frac{L}{W}$$

Equation Apx 7-1

$$\big(L + T * Sin(\alpha + \varepsilon)\big) * Cos(\mu) - W * Cos(\gamma) = m * V * \frac{\delta V}{\delta t}$$

Equation Apx 7-2

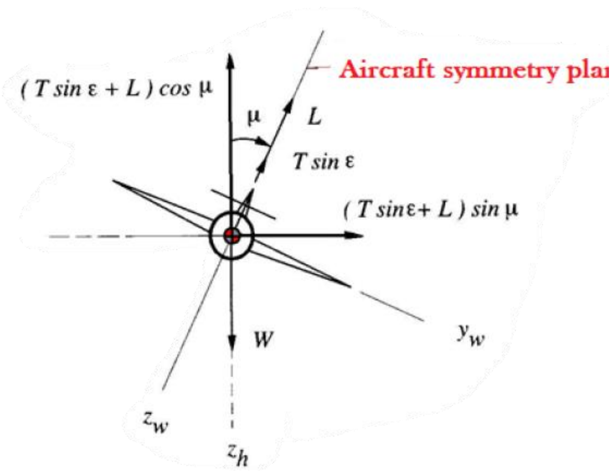


Figure Apx 7-1 Horizontal plane turn sketch

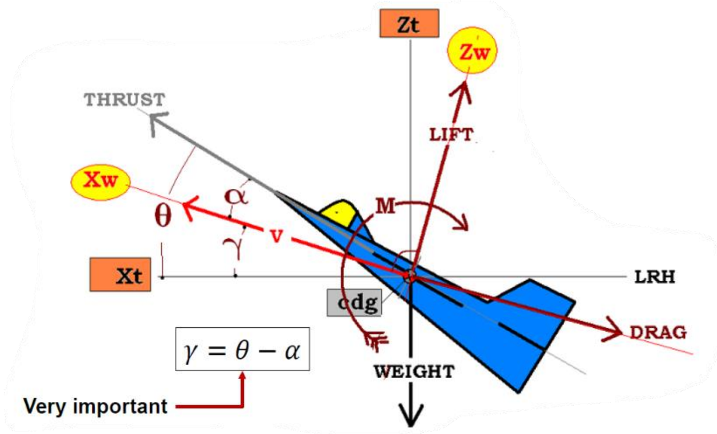


Figure Apx 7-2 Wind axes visualization

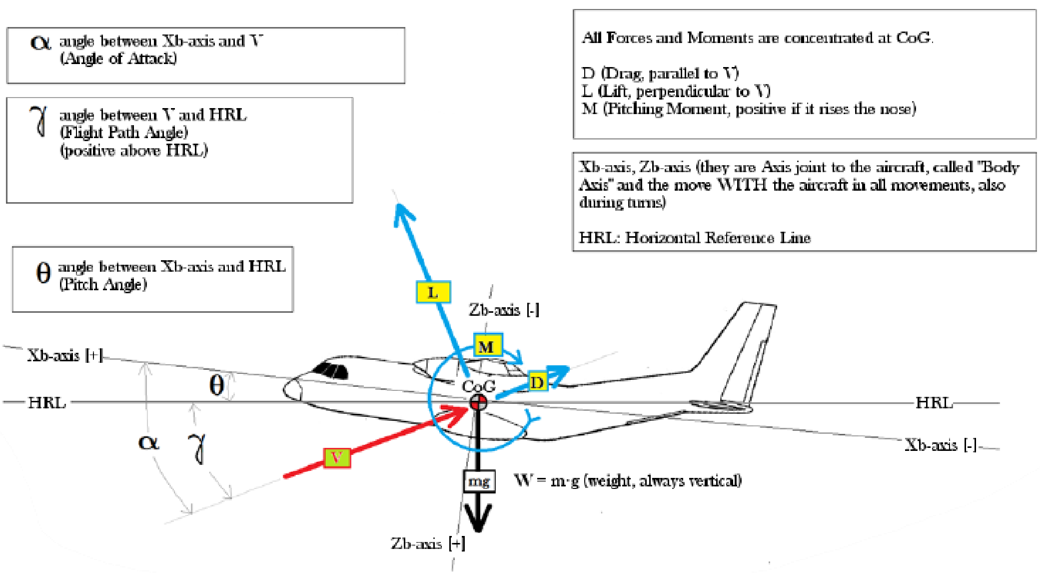


Figure Apx 7-3 Body axes visualization

$$n = \frac{-T * Sin(\alpha + \varepsilon) * Cos(\mu) + W * Cos(\gamma) + m * V * \frac{\delta V}{\delta t}}{W * Cos(\mu)}$$

Equation Apx 7-3

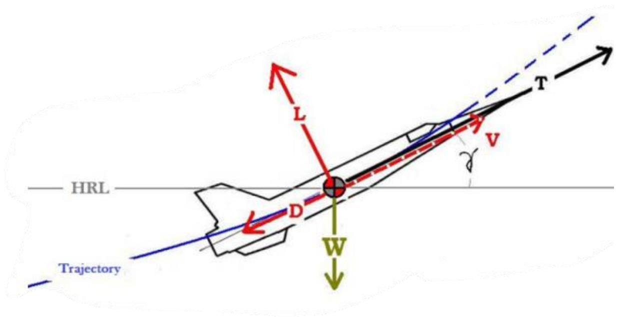


Figure Apx 7-4 Vertical plane turn sketch

All the terms that appear in Equation Apx 7-3 can be extracted from the flight data, derived from flight data or estimated. Thrust has been estimated using the proposed available curve described in Appendix 6, but the results show that its influence is negligible.

Appendix 8 Eliminated data in the flight envelope check

For the flight envelope check the only the Test Flight has been considered, due that the other flights lack from a proper steady glide that allows us to estimate the wind speed and therefore estimate the UAV airspeed because the airspeed sensor data is not reliable as explained in Appendix 3.

The data from the Test Flight that is useful is the one when the aircraft is actually flying (Marked between black dashed lines in the Figure Apx 8-1). One of the most important assumptions is that the wind direction and speed remains unchanged during the hole flight to calculate the airspeed. As this assumption is not consistent in the hole flight the data extracted during the Return to Launch mode is excluded from the analysis because it presents abnormally low calculated airspeeds around 13:00 (as one can see in Figure Apx 8-1) that does not match with the flight envelope (as one can see in Figure Apx 8-2).

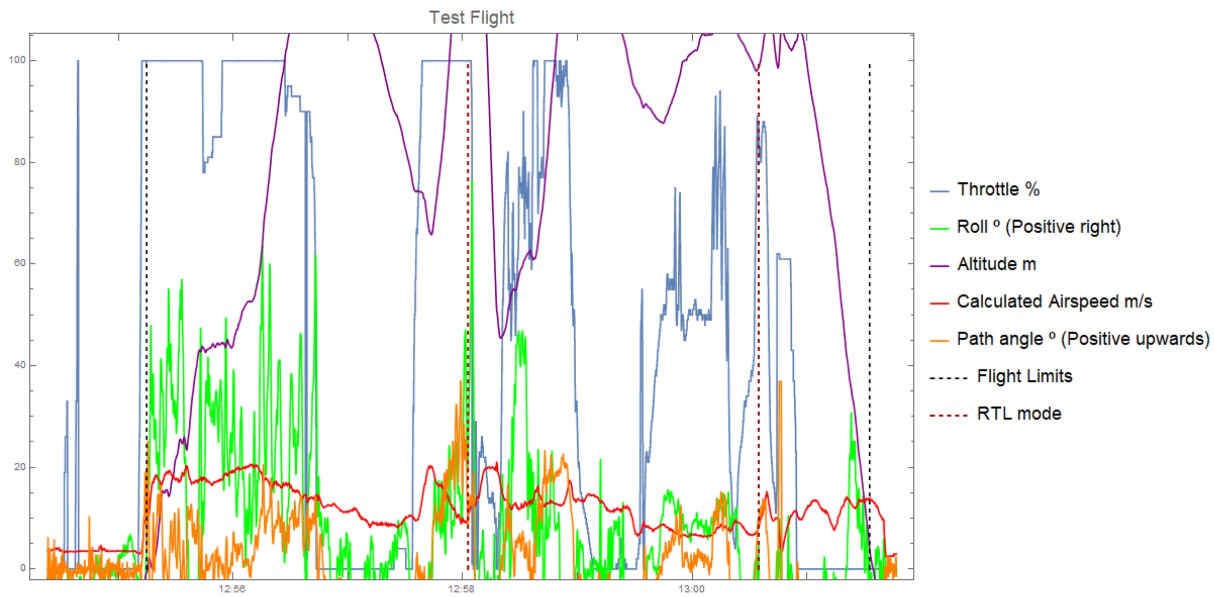


Figure Apx 8-1 Flight envelope check data origin

On the mission day this mode also coincides with the observation of a strange behavior of the UAV where it seemed to hover in the air without moving. One can think that that behavior was caused because of an increase of the wind speed, what would make the calculated airspeed assumptions false. The flight data that is kept in the analysis is then the launch, initial climb, first glide (Where the wind speed is estimated as shown in Appendix 4), second climb and landing.

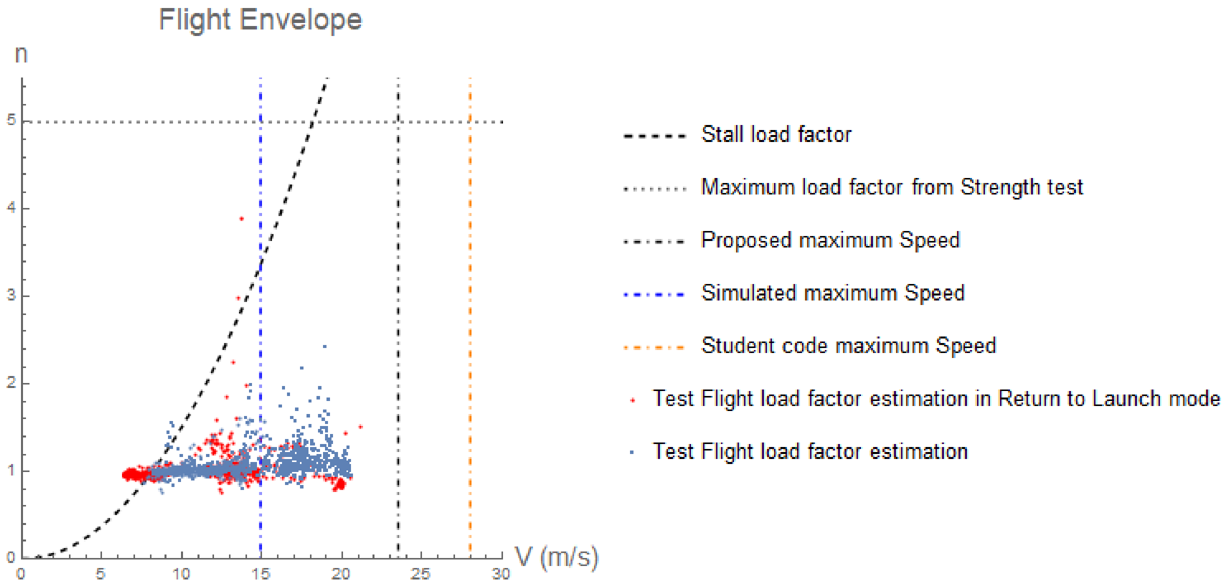


Figure Apx 8-2 All Test Flight data in flight envelope

Appendix 9 Strength Test

Strength test description can be found in this here:

https://drive.google.com/file/d/1vOjJs8KGT7VKFRlVb5Yt-99rnmfT5j3S/view?usp=sharing

Appendix 10 Mathematica Linear Theory code

The Mathematica code developed can be found here:

https://drive.google.com/file/d/1WS_fYIe49e-S_BJuAMjLHYGNoyJZI5m8/view?usp=sharing

Appendix 11 Mission plan

The mission planner waypoints file can be found here:

https://drive.google.com/open?id=1XClZNLHhdFbexyoouikhDtS5aGHsCnMoOFSp-8DvzkY

While in the following document one can find the comments about the different waypoints and important information about the configuration parameters of the mission planner:

https://drive.google.com/open?id=1XClZNLHhdFbexyoouikhDtS5aGHsCnMoOFSp-8DvzkY

Appendix 12 Logbook

Table Apx 12-1 Logbook

Phase	*Approximate Date*	*Decision*
Project Plan	02/04/2019	Meetings scheduled at the beginning of each week
Project Plan	11/02/2019	Stefan is assigned as Treasurer and Leandra the Controller
Concept	26/02/2019	Dihedral mid-mounted wing with T-Tail configuration chosen Carbon fiber rod along the foam fuselage Payload stored inside the fuselage
Concept	28/02/2019	Cruise design speed set between 15-50 m/s Maximum payload weight of 200g Aim for a 3kg UAV Leandra is assigned as the Hazard Analysis responsible
Concept	07/03/2019	Deep camber airfoil selected CH-10-48-13 Wing strength test must be performed including the fuselage middle
Detail	19/03/2019	Wing connection by means of 3D printed parts and small carbon fiber rods inserted on the wing Andreu assigned as Weight and balance keeper Fahad assigned as responsible of ordering the materials
Detail	21/03/2019	Fahad assigned as electronics responsible Fuselage parts divided considering the production method Motor support made by means of 3D printed parts
Detail	28/03/2019	Wing connection composite skin reinforcement in top of fuselage middle Composite skin reinforcement in vertical stabilizer
Detail	02//04/2019	Fuselage middle produced by laser cut pieces glued together Wood reinforcement in the connection between fuselage middle and fuselage front Dropping system consisting of two servos, one for the door opening and the other for the payload drop. One hinge door opened against the airflow
Detail	04/04/2019	Downwards wing mounting incidence and upwards horizontal stabilizer mounting incidence
Production Plan	16/04/2019	Wood heat shield in the motor support to avoid overheating of the plastic Wood spikes reinforcement in the connection of the vertical stabilizer to the main carbon fiber rod Electronics access hinges by means of 3D printing
Production	23/04/2019	Wood reinforcement in the horizontal stabilizer to vertical stabilizer connection

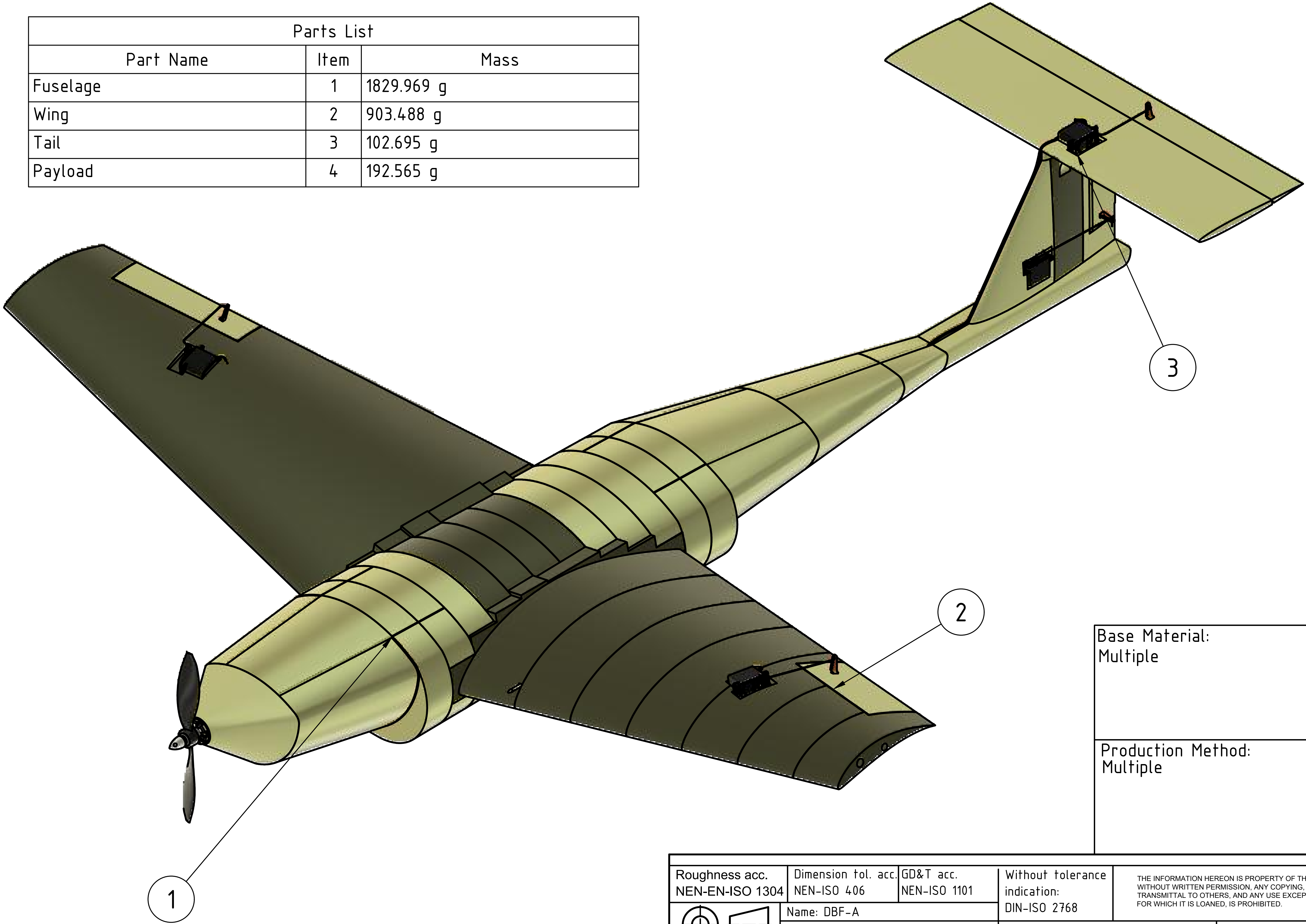
		Aluminum reinforcement in the motor support
		Wood reinforcement in the connection between fuselage middle and fuselage rear
		Tail shifted 10 cm backwards due to production error
Production	09/05/2019	Composite skin reinforcement applied to the elevator
Before Flight Test		Composite strips reinforcement applied to the fuselage belly
		Payload reduced to 100g
		Wood reinforcement in the horizontal stabilizer
		Re positioning of electronics
		Motor support re-design
		Removed wood reinforcement in the connection between fuselage middle and fuselage rear
		Added weight to one of the wings to balance the weight asymmetry
Production	22/05/2019	Removed horizontal stabilizer mounting incidence
After Flight Test		Doubled ailerons and rudder surface
		Extended elevator

-PARTS CATALOG-

The following technical drawings were an appendix in the Detail Design Report, and they were the content of the “Technical Drawings” chapter of the Production Plan but they have been added at the end of this compilatory document due to their extension and format.

As already stated in the Production Plan contributions, these drawings have been made entirely by the author of the thesis, Andreu Giménez Bolinches.

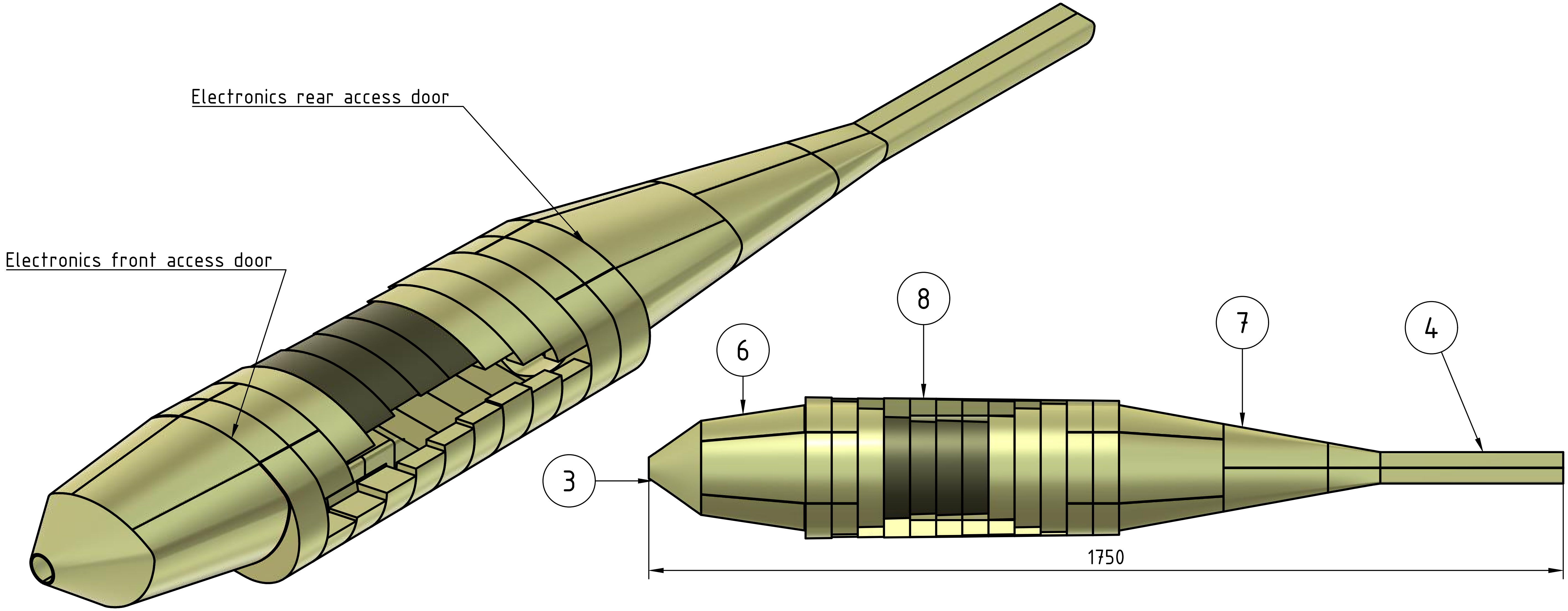
Parts List		
Part Name	Item	Mass
Fuselage	1	1829.969 g
Wing	2	903.488 g
Tail	3	102.695 g
Payload	4	192.565 g



Base Material:
Multiple

Production Method:
Multiple

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:5
	Education: Design, Build and Fly minor			Sheet: 1/35
Amsterdam University of Applied Sciences	Part: Aircraft		Number:	Format: A3



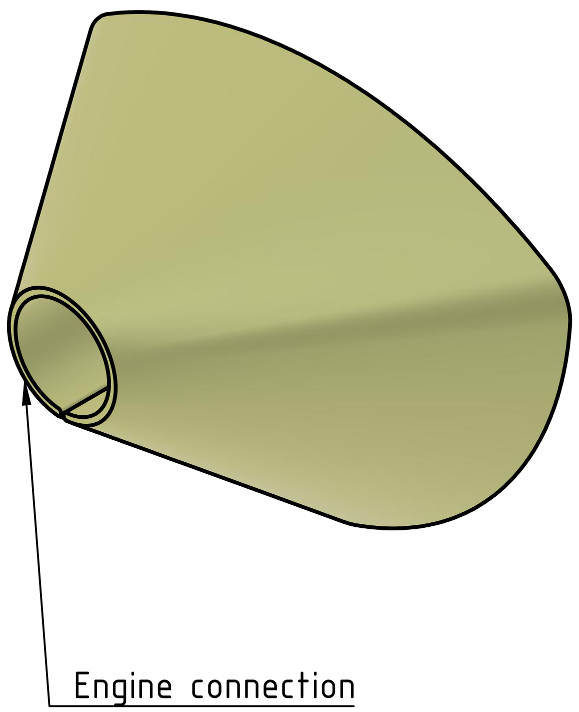
Part Name	Item	Mass
Fuselage Middle	8	296.872 g
Fuselage Rear	7	118.696 g
Fuselage Front	6	98.108 g
Fuselage Carbon Fiber rod	5	175.709 g
Fuselage Tail	4	25.056 g
Fuselage Tip	3	27.503 g

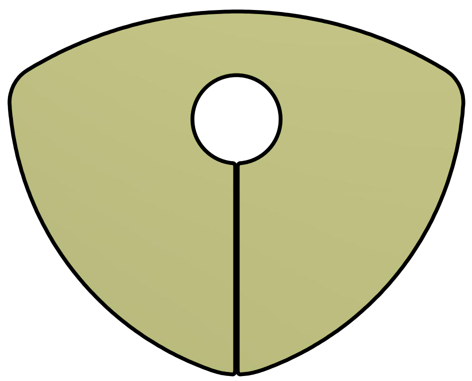
Parts List

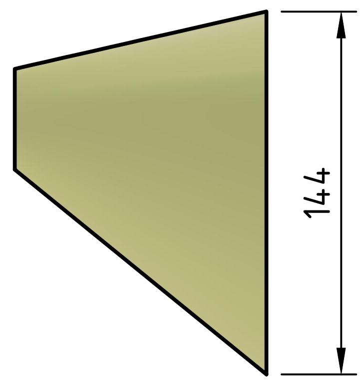
Base Material:
Foam
Composite Skin Reinforcement
Wood Beam Reinforcement

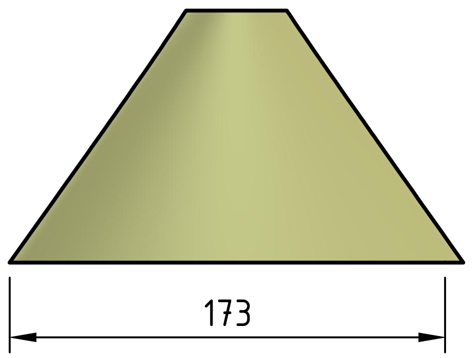
Production Method:
Multiple

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:5
	Education: Design, Build and Fly minor			Sheet: 2/35
Amsterdam University of Applied Sciences	Part: Fuselage		Number:	Format: A3









Base Material:
10 cm thickness Foam
Minimum Base Block: 10x18x15 cm

Production Method:
Hot wire cut
Laser cut wood templates
Aligned by drilled hole
in the engine section

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
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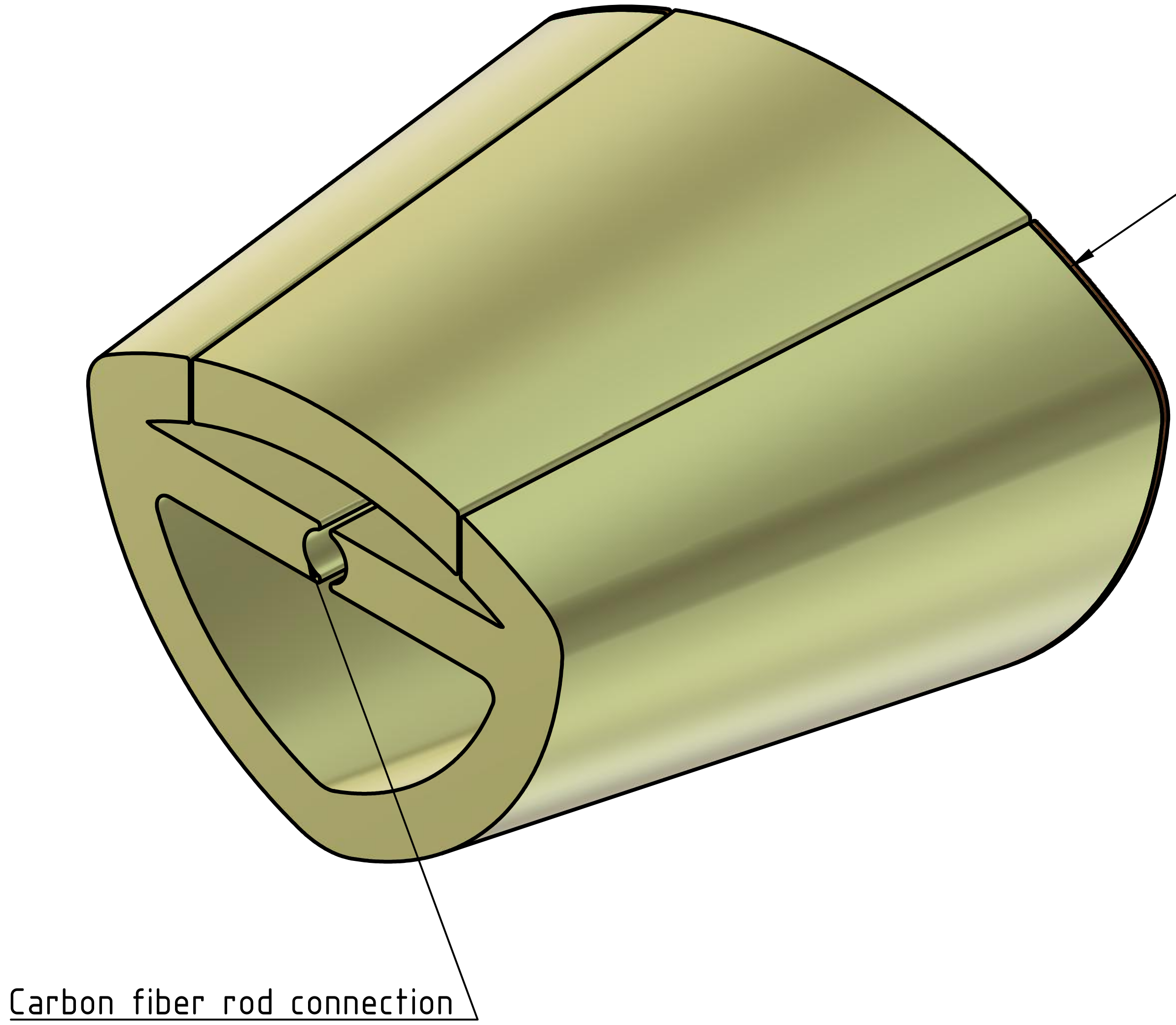
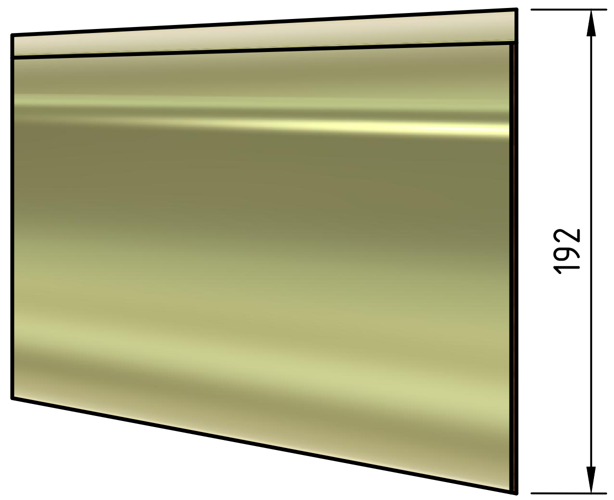
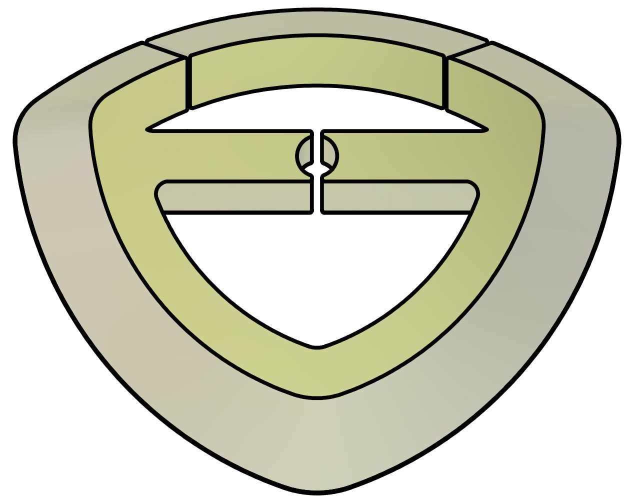
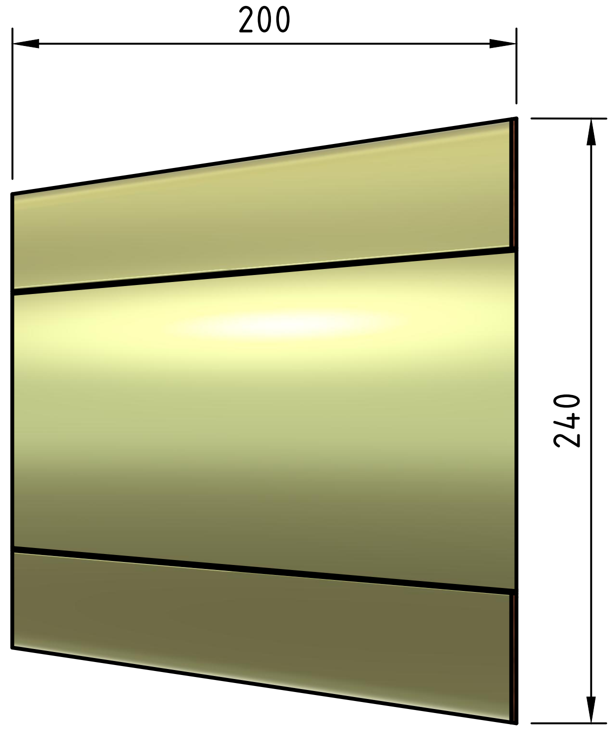
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:5
	Education: Design, Build and Fly minor			Sheet: 3/35
Amsterdam University of Applied Sciences	Part: Fuselage Tip		Number:	Format: A3









Base Material:
20 cm thick Foam Block
Made from 2 10 cm thick boards
Minimum Base Block: 20x25x20 cm

Production Method:
Hot wire cut
Laser cut wood templates
Aligned by reference measures

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
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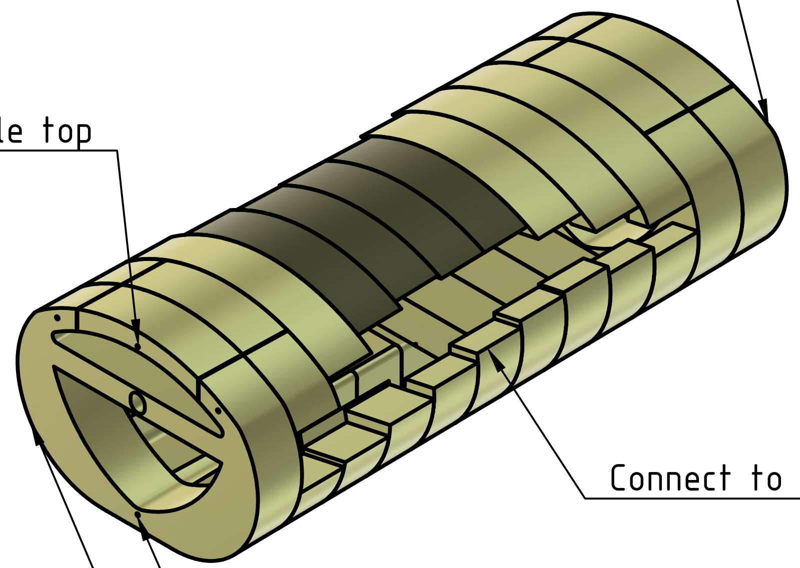
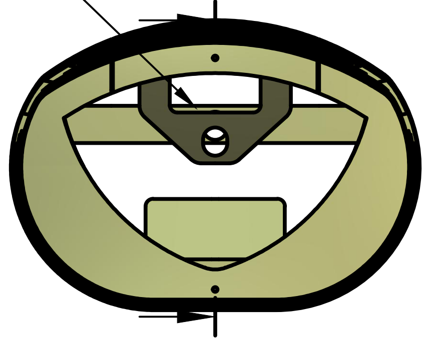
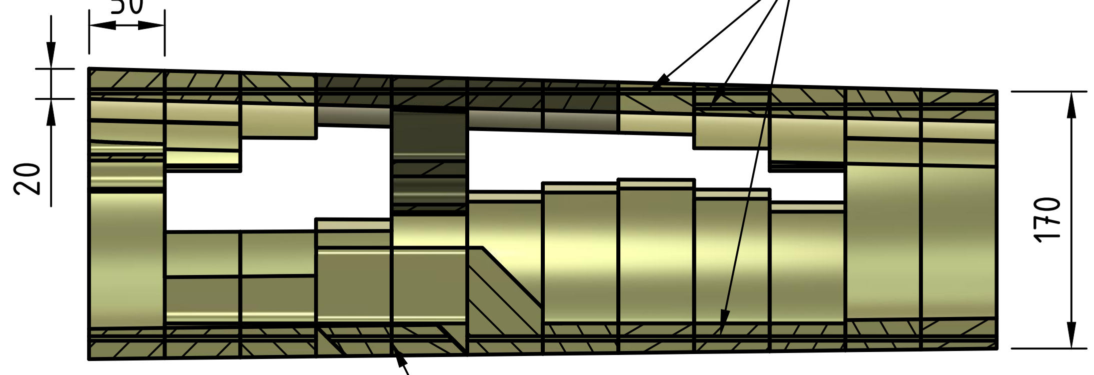
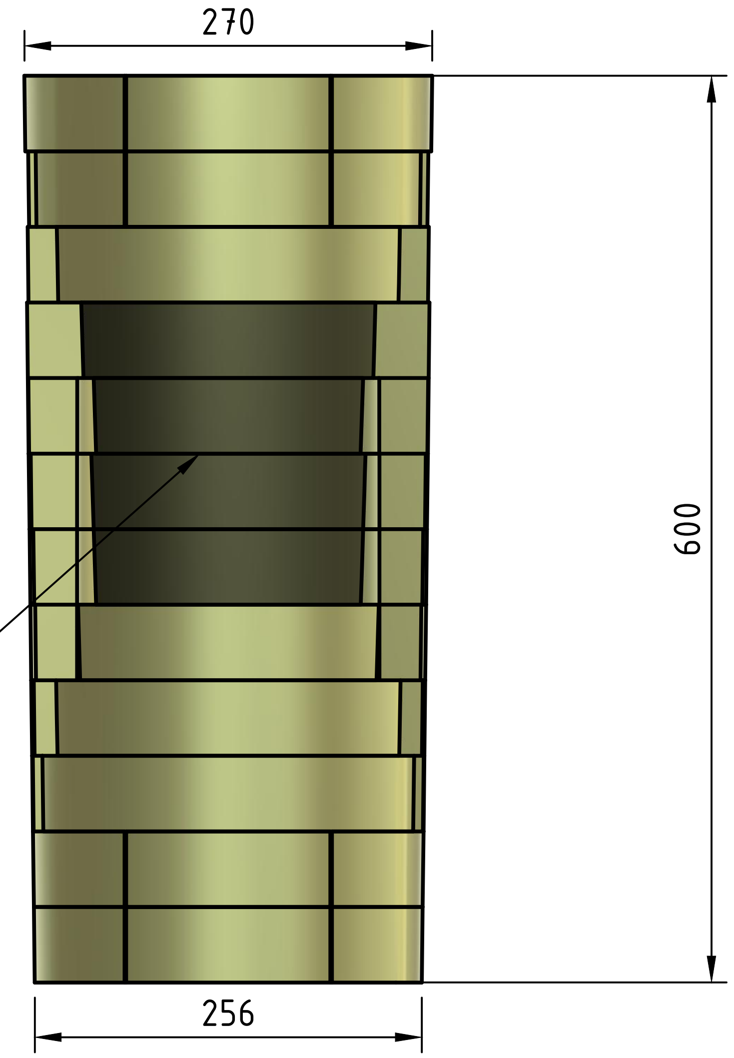
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:3
	Education: Design, Build and Fly minor			Sheet: 4/35
Amsterdam University of Applied Sciences	Part: Fuselage Front		Number: Section 1	Format: A3





A-A (1:5)



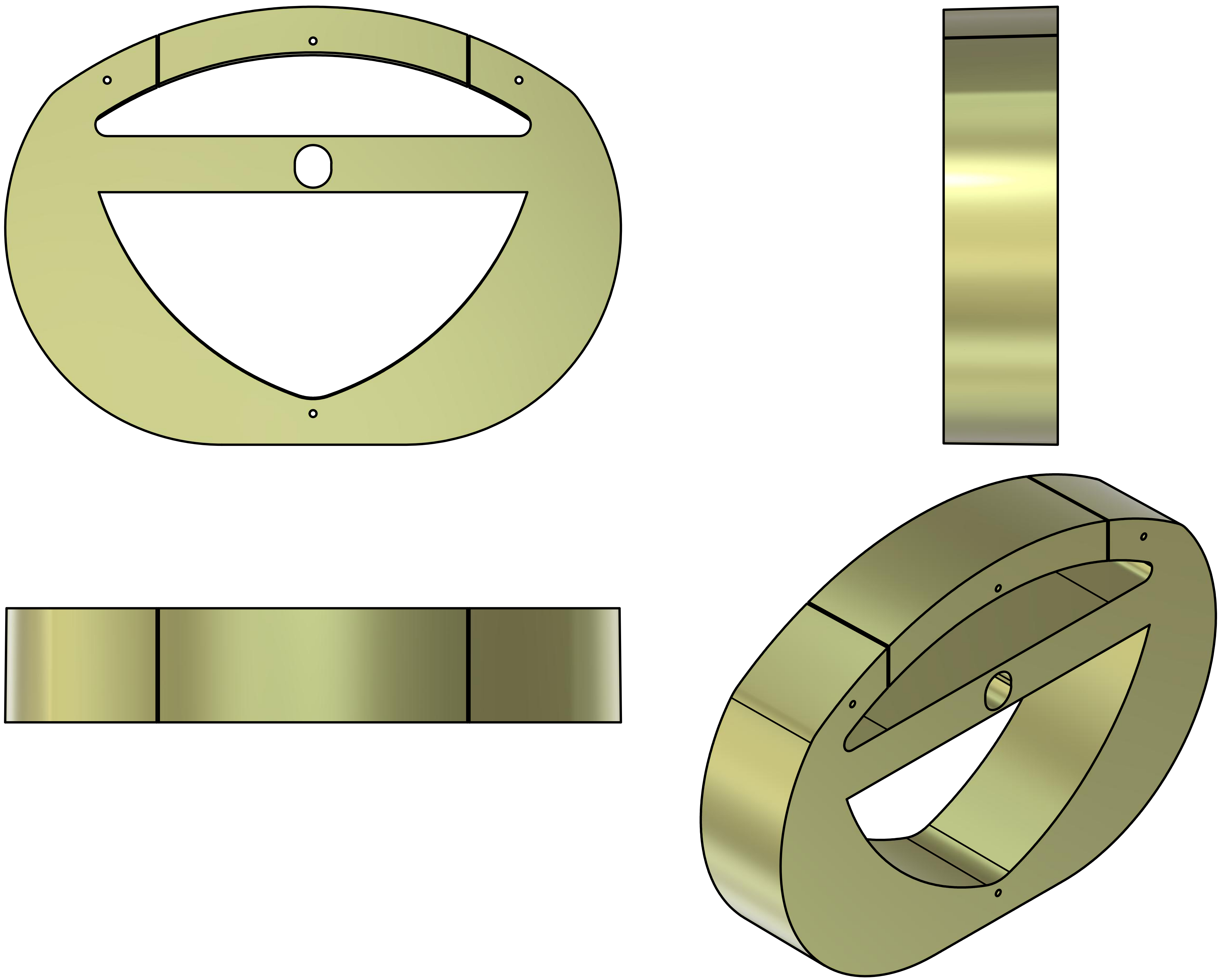


Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:5
	Education: Design, Build and Fly minor			Sheet: 5/35
Amsterdam University of Applied Sciences	Part: Fuselage Middle		Number: Section 2	Format: A3

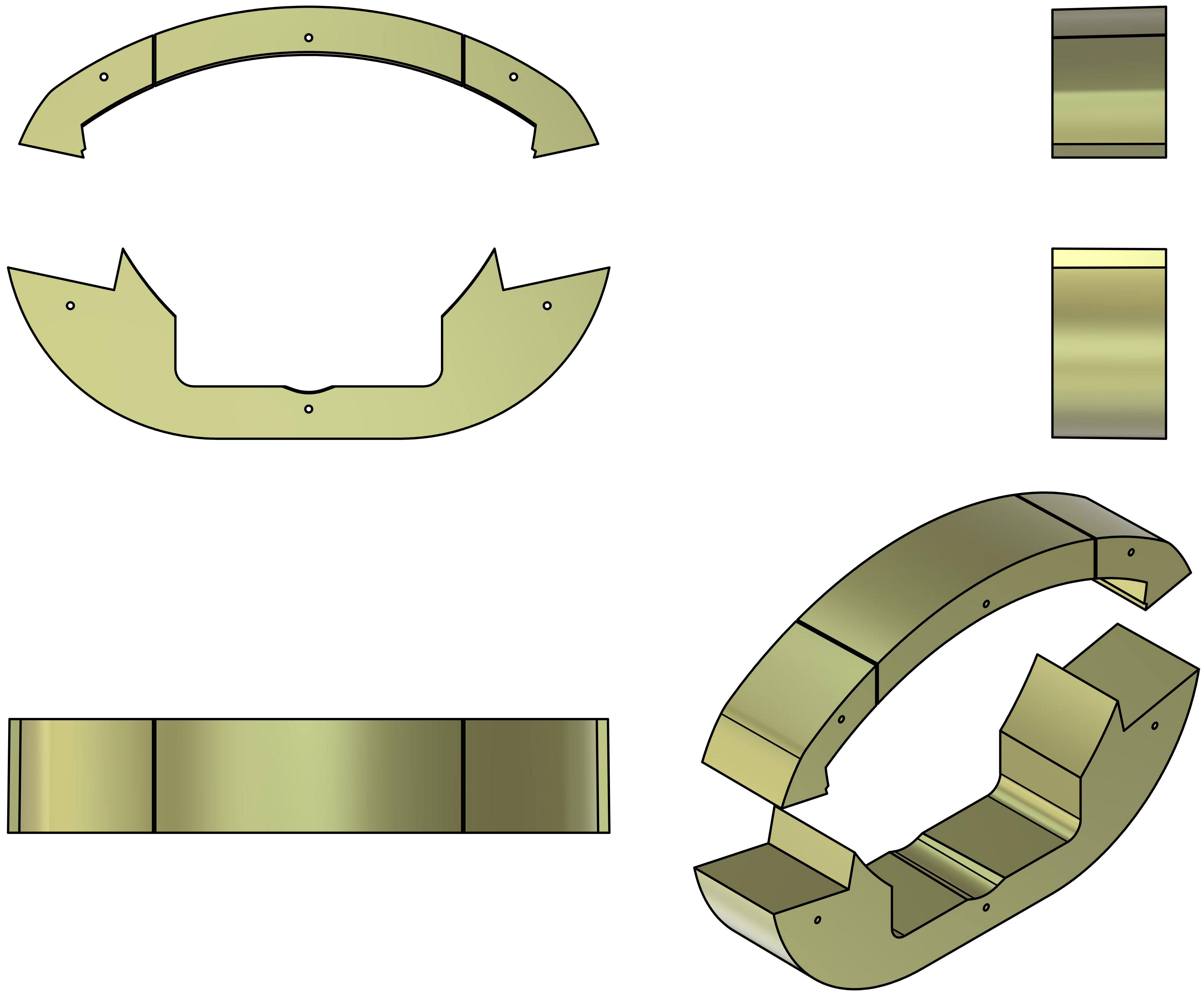


Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by
reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 6/35
Amsterdam University of Applied Sciences	Part: F Cut 1		Number:	Format: A3

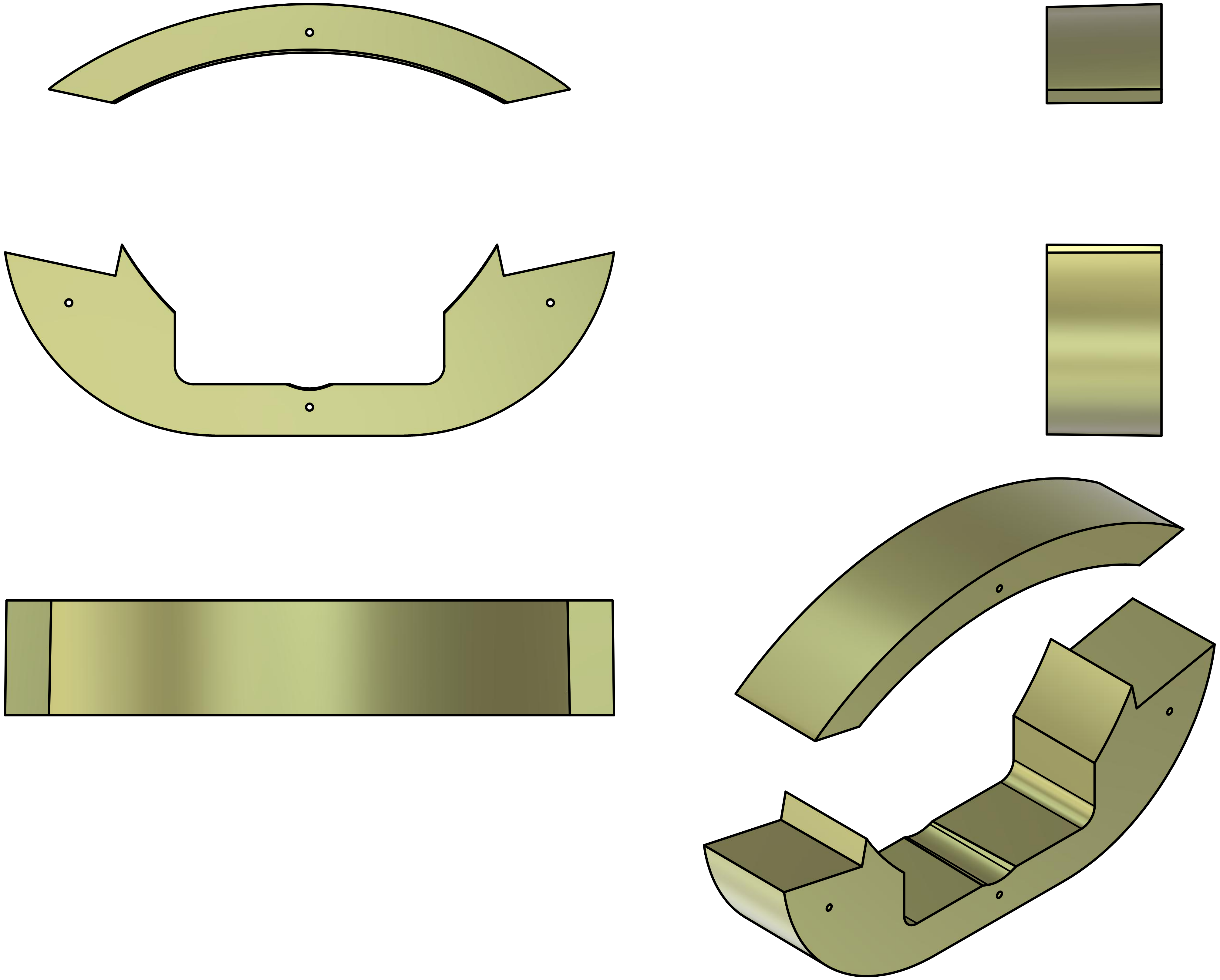


Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:1
	Education: Design, Build and Fly minor			Sheet: 7/35
Amsterdam University of Applied Sciences	Part: F Cut 2		Number:	Format: A3

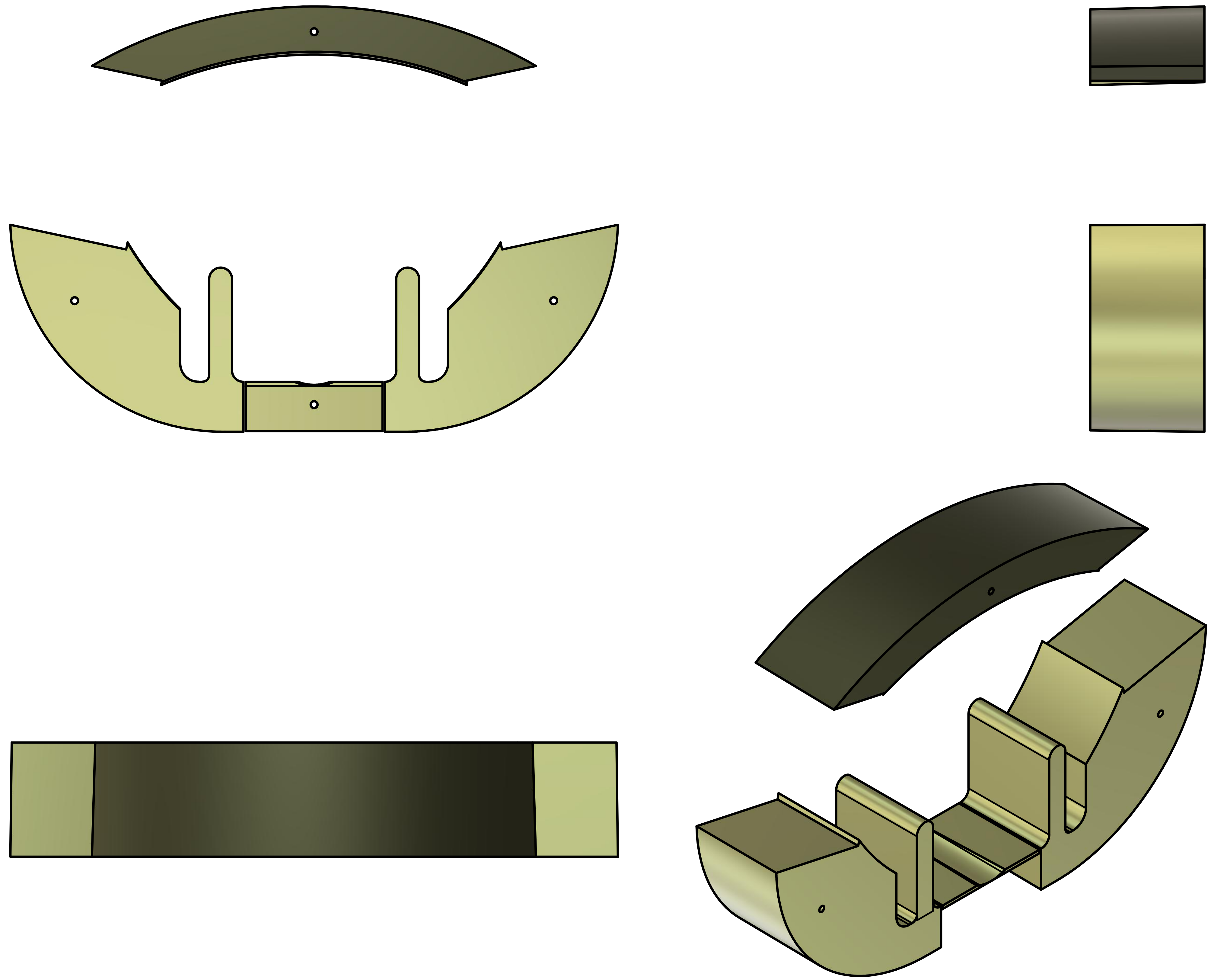


Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by
reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 8/35
Amsterdam University of Applied Sciences	Part: F Cut 3		Number:	Format: A3

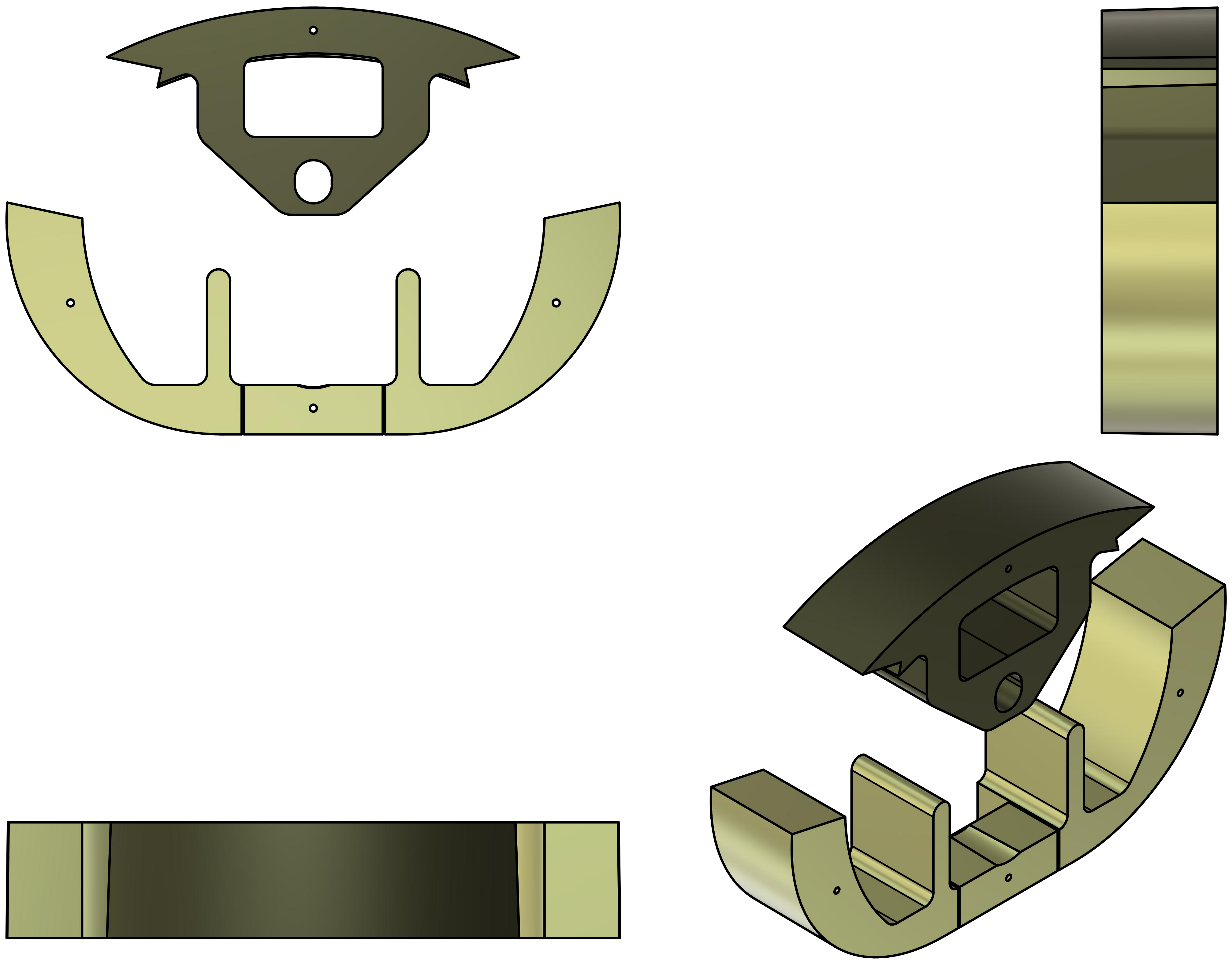


Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 9/35
Amsterdam University of Applied Sciences	Part: F Cut 4		Number:	Format: A3

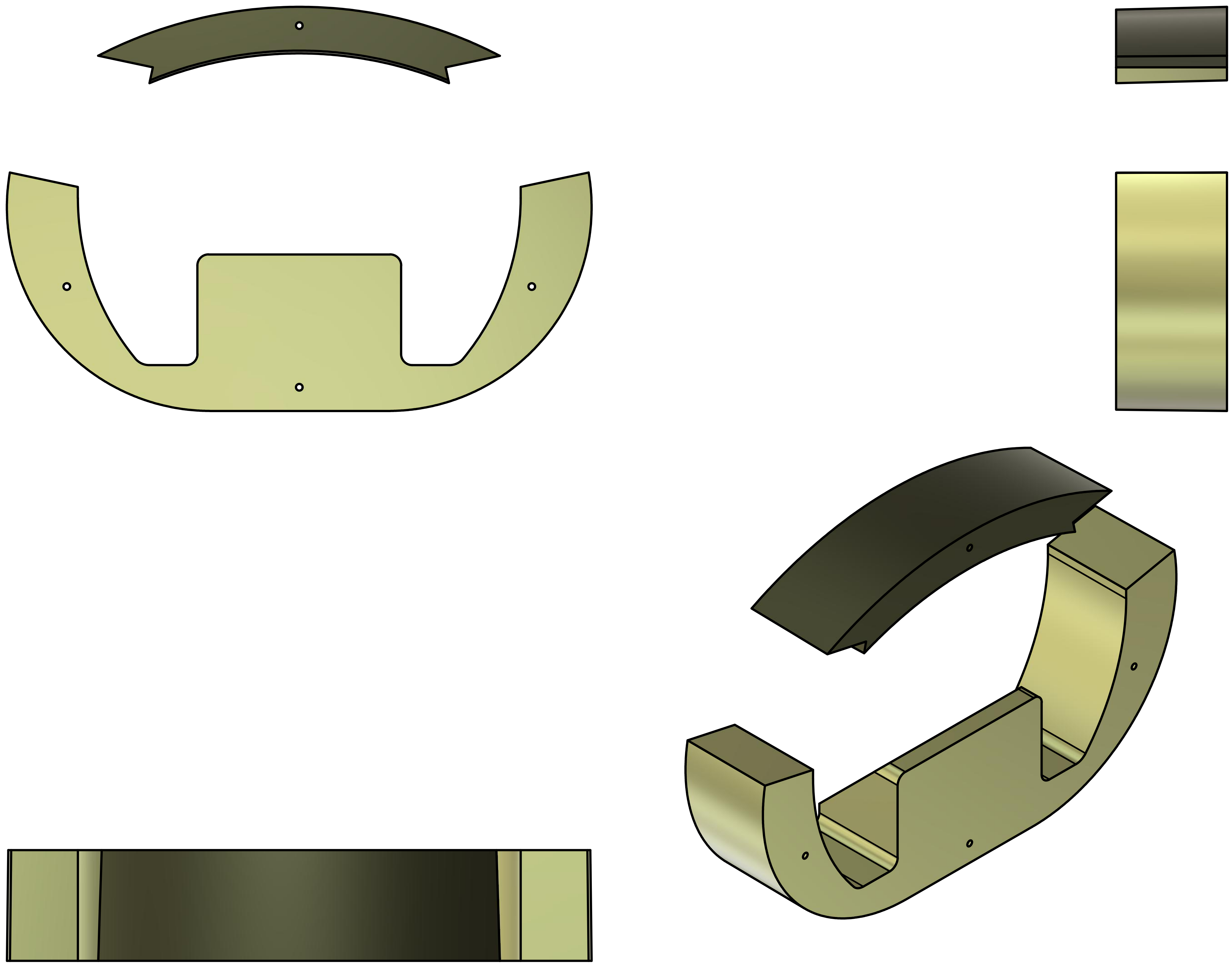


Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by
reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 10/35
Amsterdam University of Applied Sciences	Part: F Cut 5		Number:	Format: A3

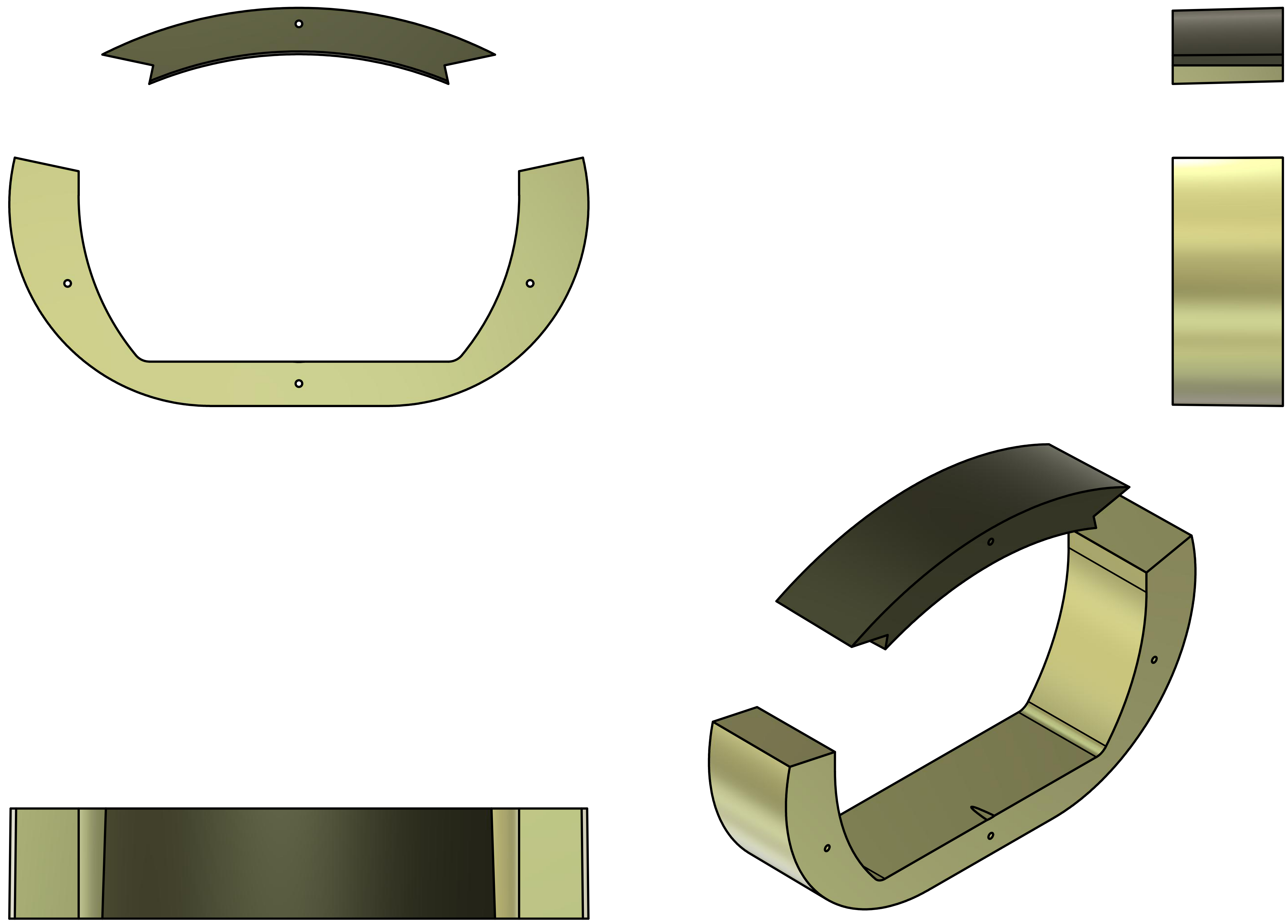


Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by
reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 11/35
Amsterdam University of Applied Sciences	Part: F Cut 6		Number:	Format: A3

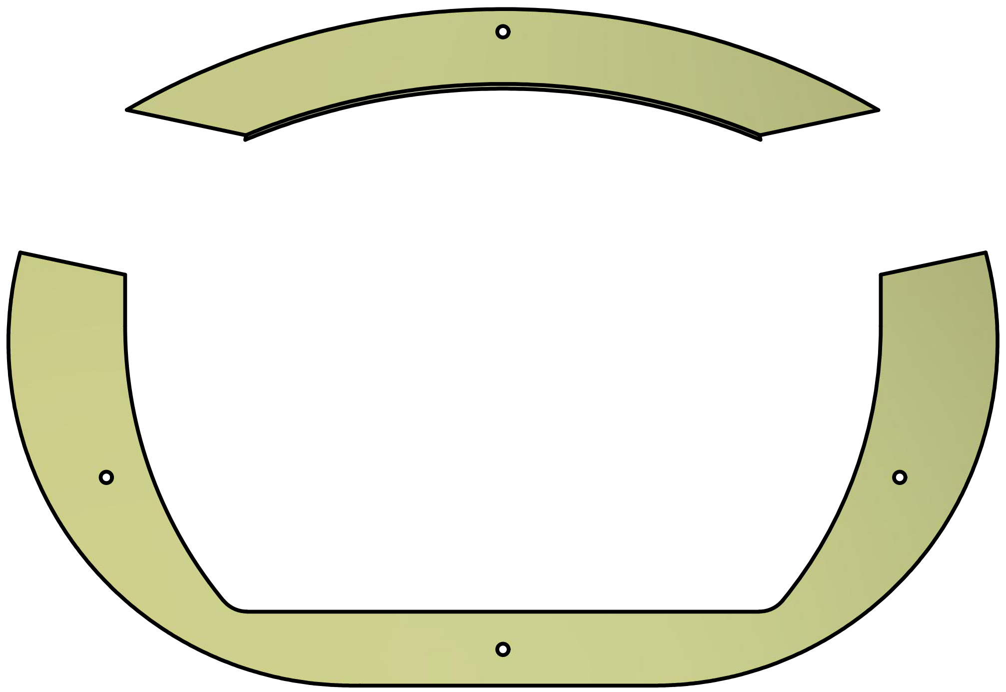


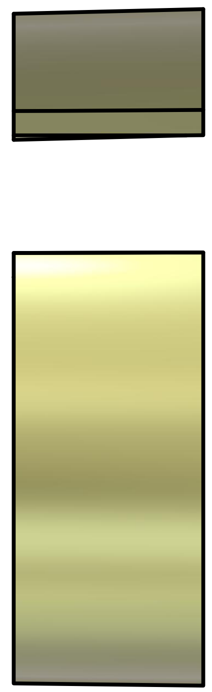
Base Material:
5 cm thick Foam plate

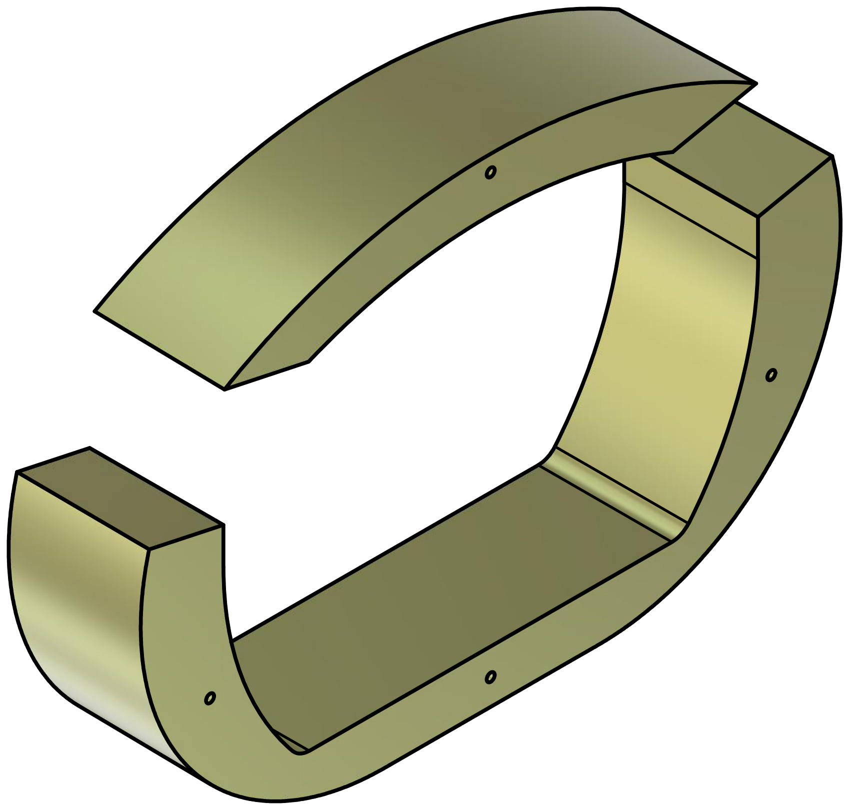
Production Method:
Laser cut

Assembly alignement by
reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 12/35
Amsterdam University of Applied Sciences	Part: F Cut 7		Number:	Format: A3





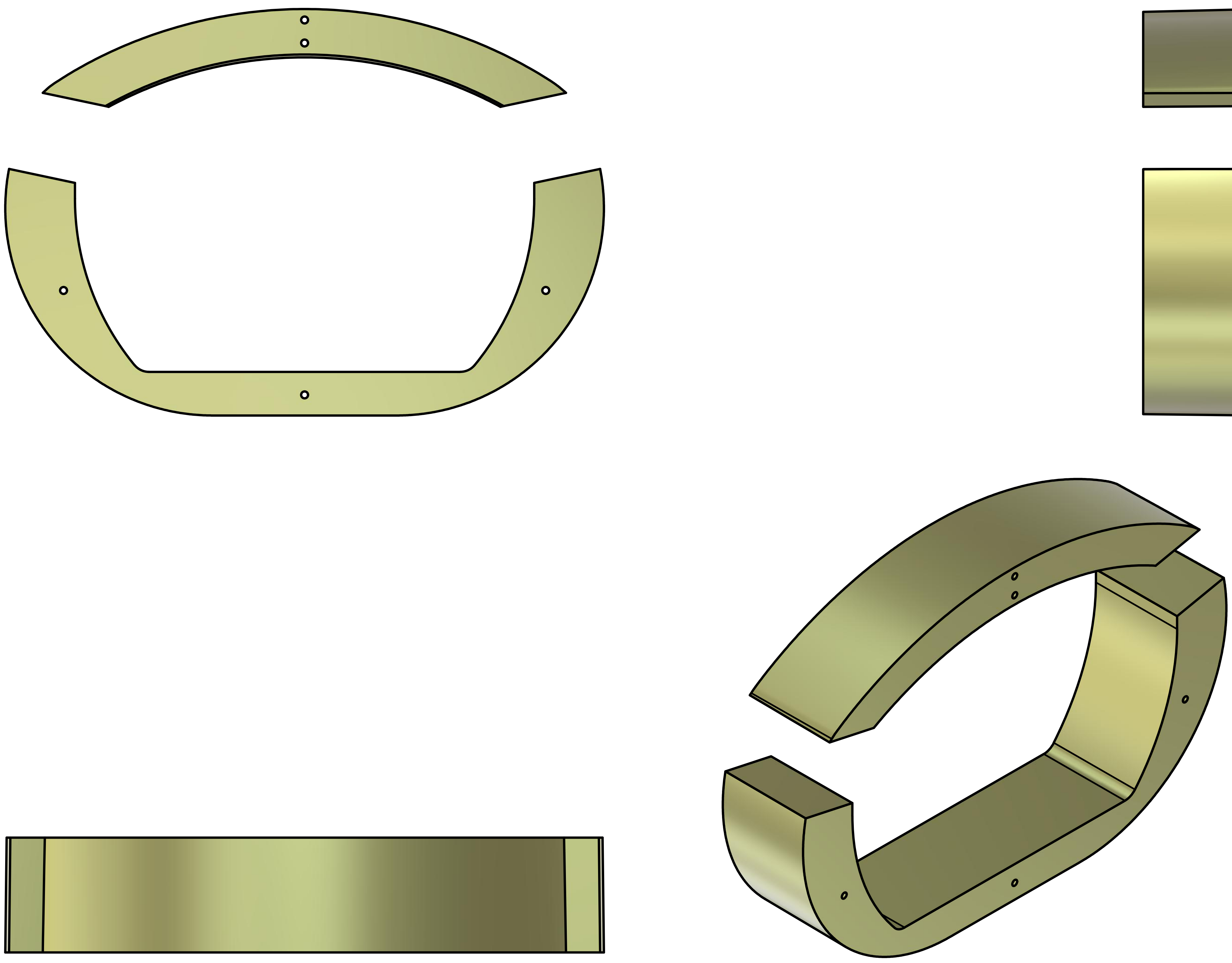


Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by
reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 13/35
Amsterdam University of Applied Sciences	Part: F Cut 8		Number:	Format: A3

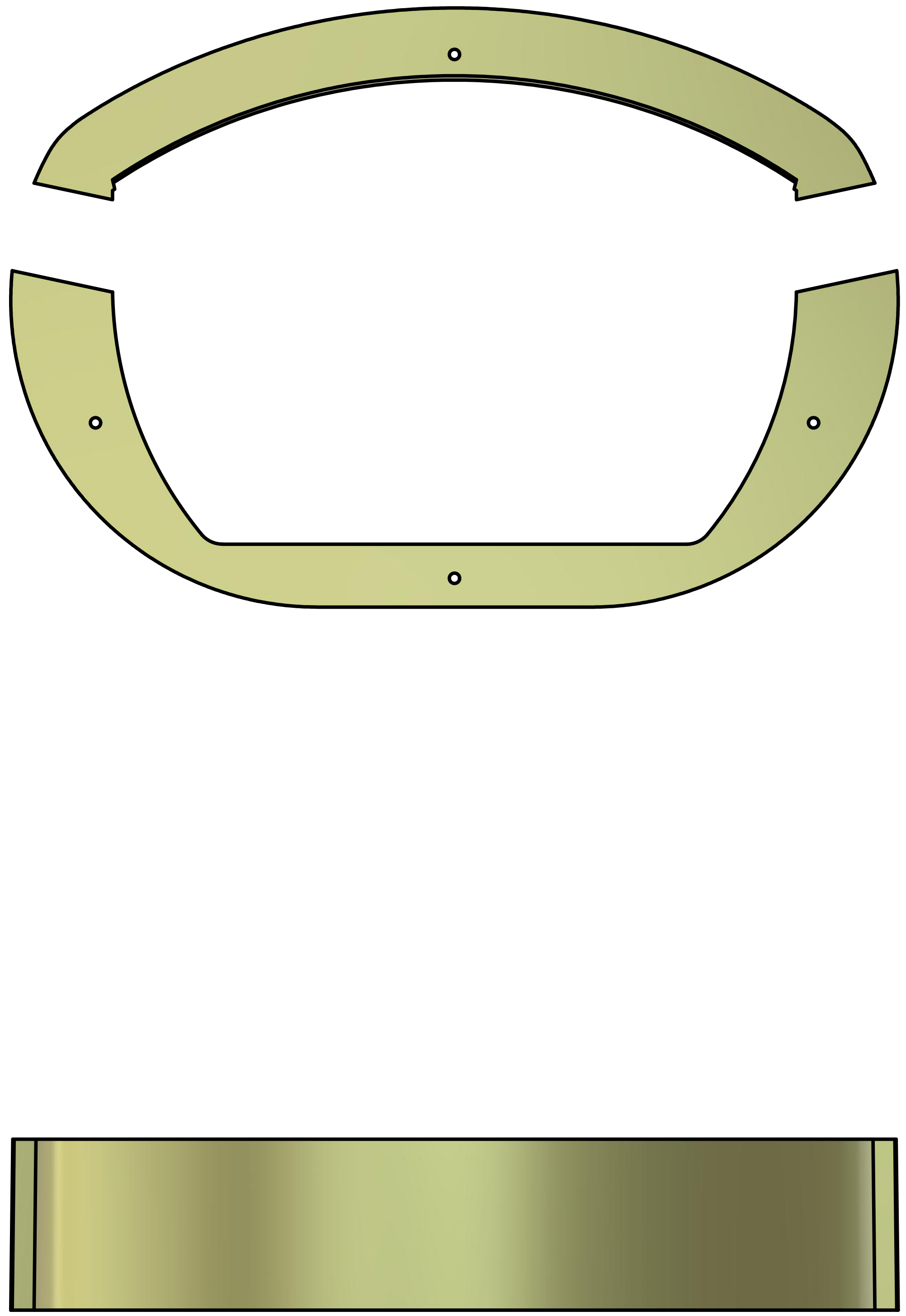


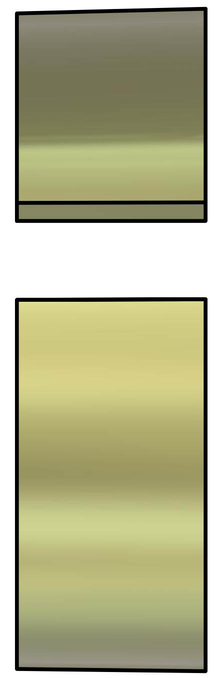
Base Material:
5 cm thick Foam plate

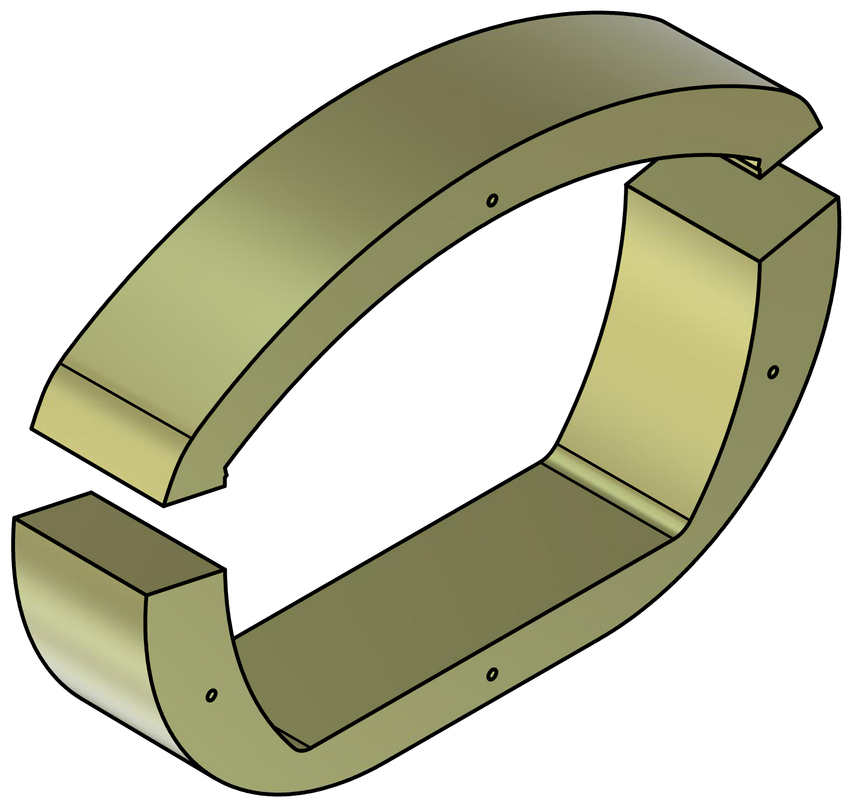
Production Method:
Laser cut

Assembly alignement by
reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 14/35
Amsterdam University of Applied Sciences	Part: F Cut 9		Number:	Format: A3





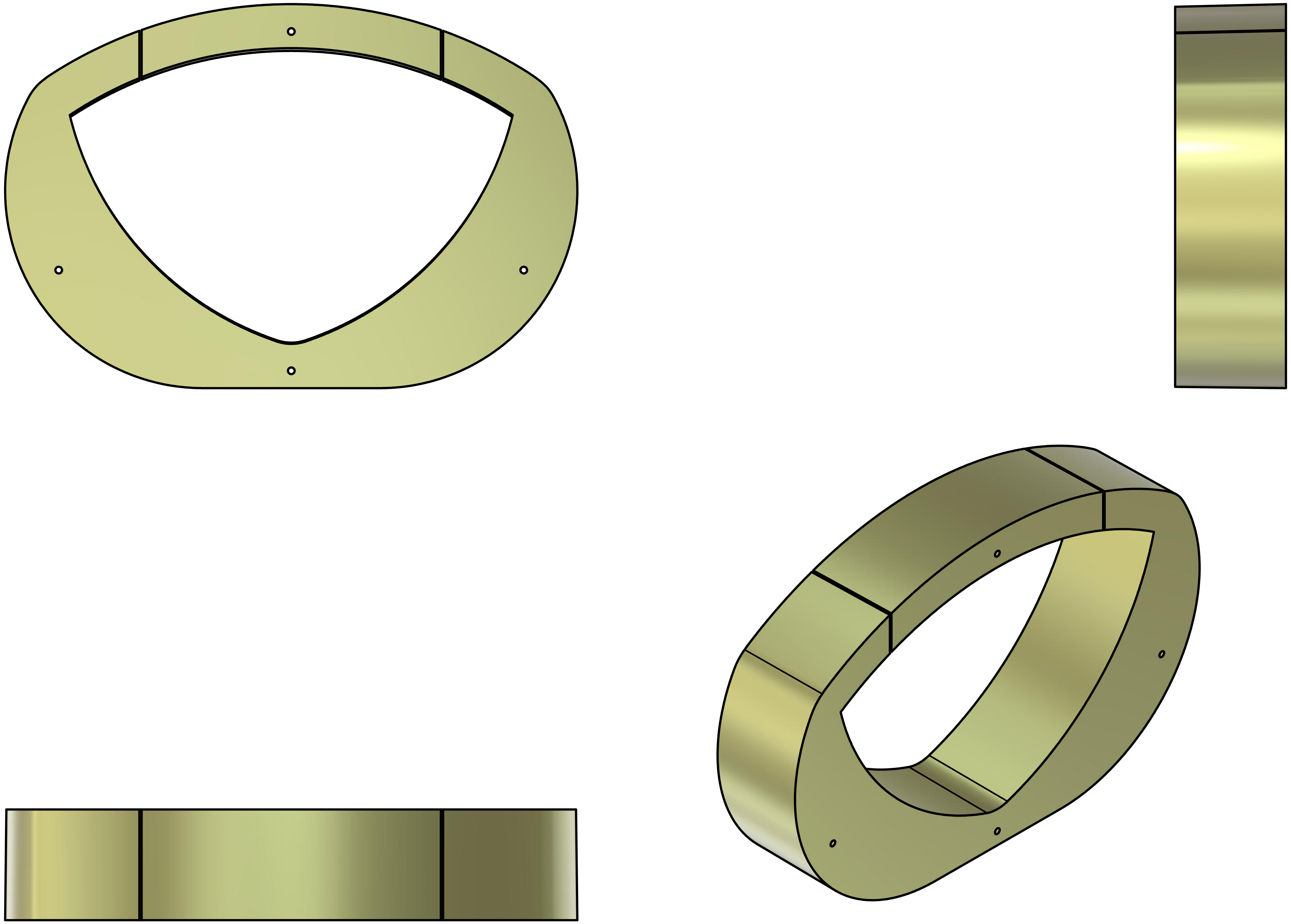


Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 15/35
Amsterdam University of Applied Sciences	Part: F Cut 10		Number:	Format: A3

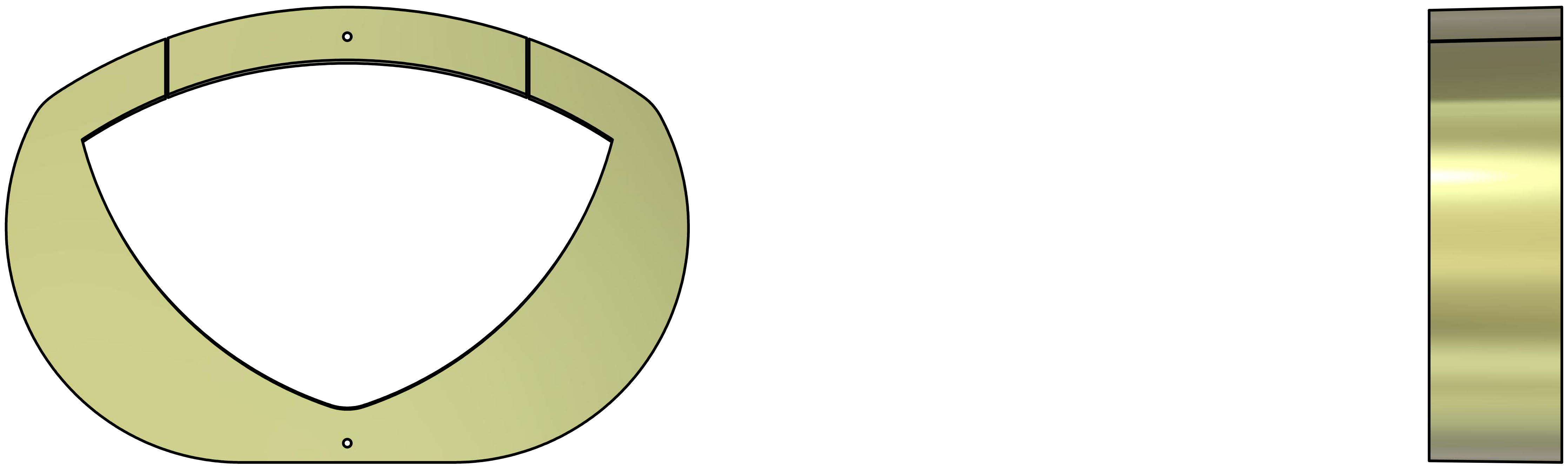


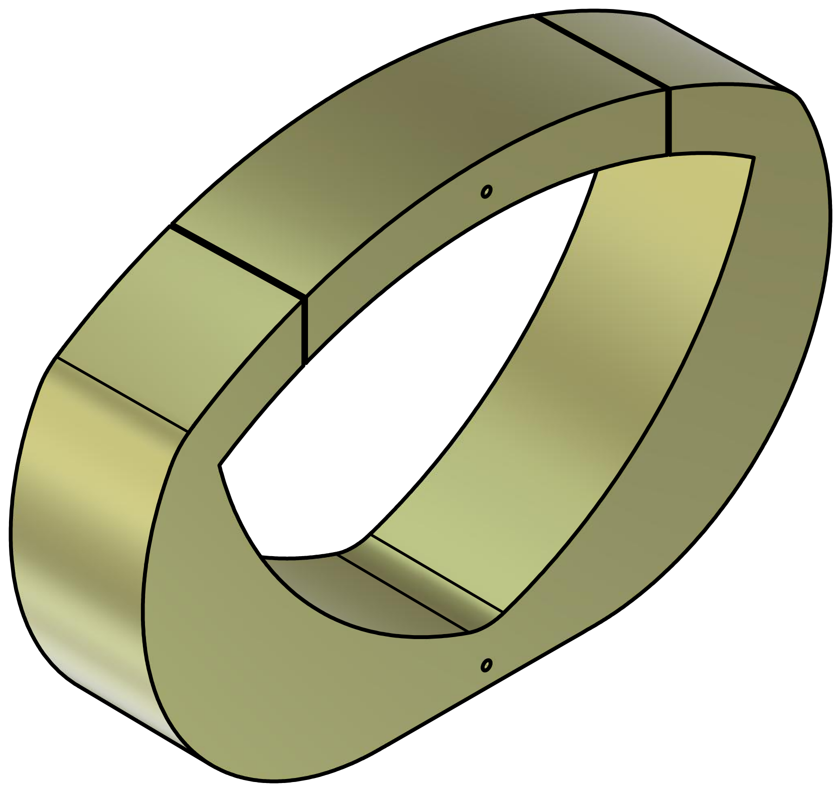
Base Material:
5 cm thick Foam plate

Production Method:
Laser cut

Assembly alignement by
reference holes

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 16/35
Amsterdam University of Applied Sciences	Part: F Cut 11		Number:	Format: A3





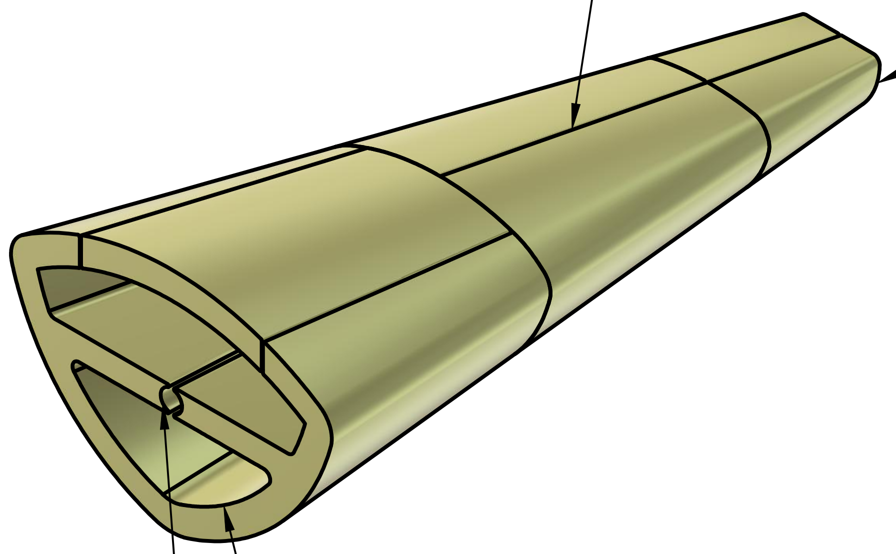
Base Material:
5 cm thick Foam plate

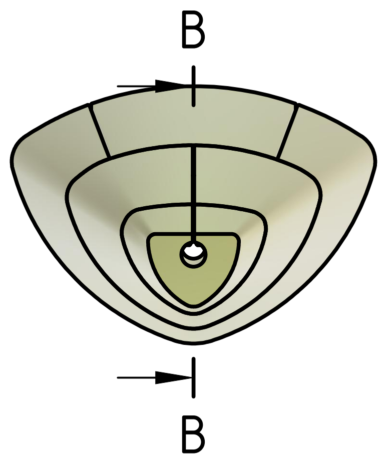
Production Method:
Laser cut

Assembly alignement by
reference holes

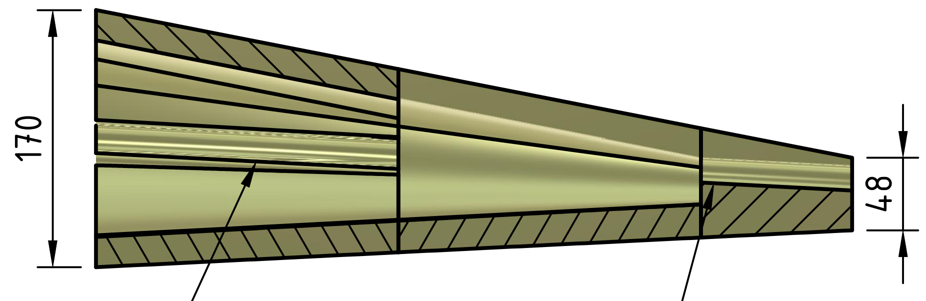
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 17/35
Amsterdam University of Applied Sciences	Part: F Cut 12		Number:	Format: A3

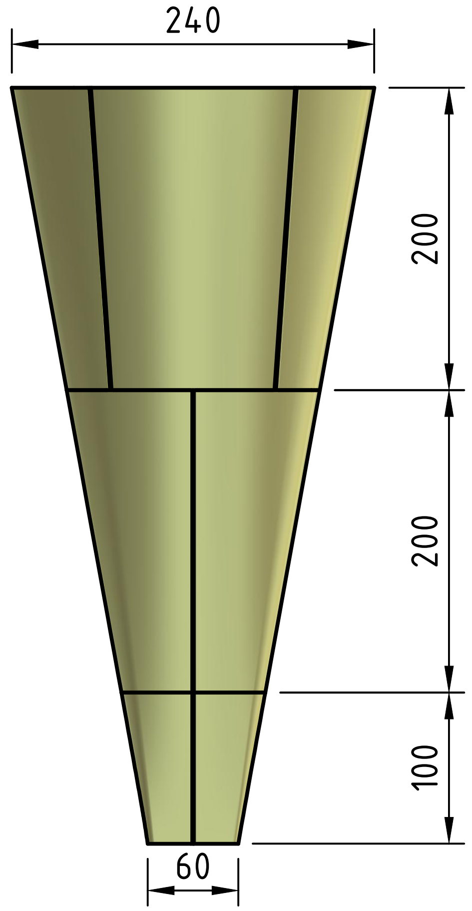
To carve the interior of the foam we need to take into account an exit path for the hot wire





B-B (1:5)

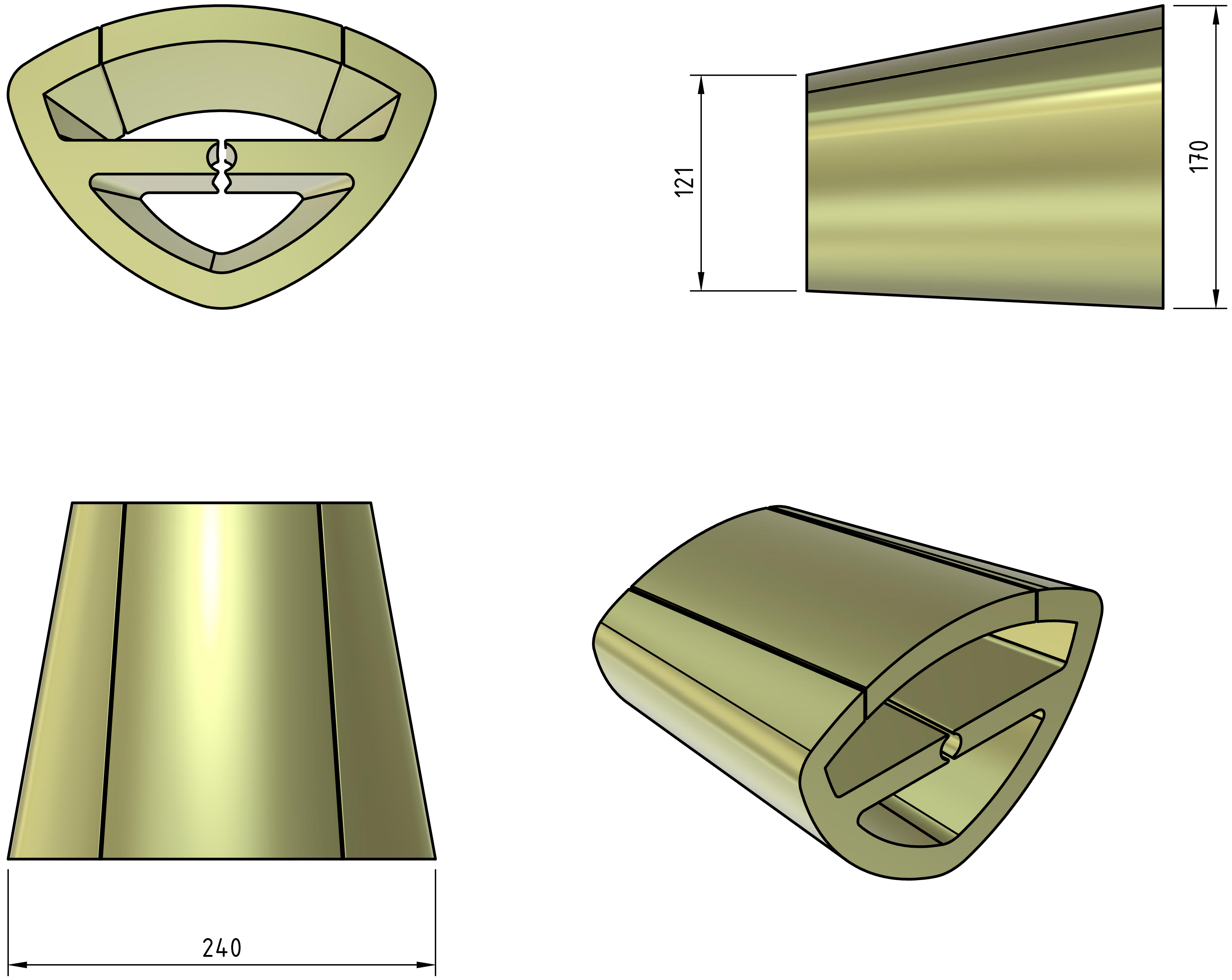




Base Material:
20cm thick foam block
10cm thick foam board

Production Method:
Hot wire cut
Laser cut wood templates
Aligned by reference measures

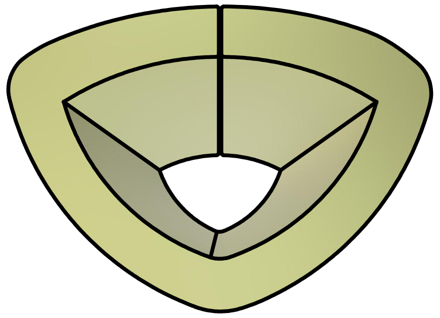
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:4
	Education: Design, Build and Fly minor			Sheet: 18/35
Amsterdam University of Applied Sciences	Part: Fuselage Rear		Number:	Format: A3

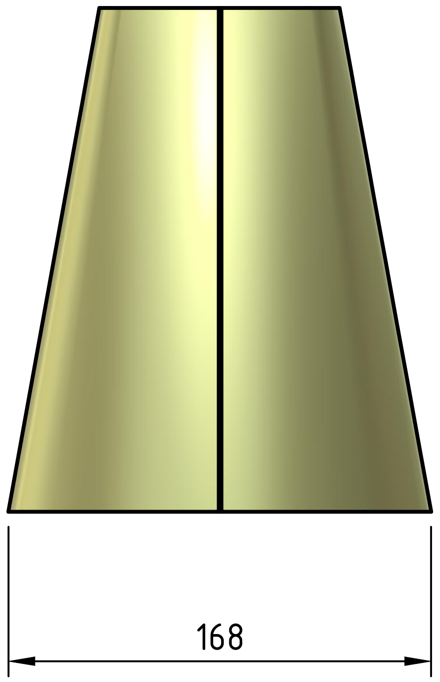


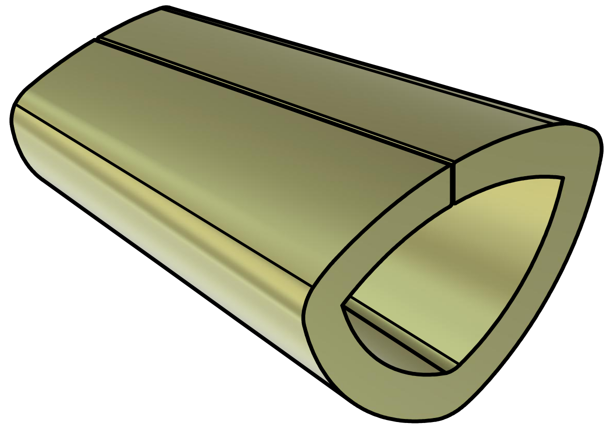
Base Material:
20cm thick foam block

Production Method:
Hot wire cut
Laser cut wood templates
Aligned by reference measures

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:3
	Education: Design, Build and Fly minor			Sheet: 19/35
Amsterdam University of Applied Sciences	Part: Fuselage Rear 1		Number:	Format: A3



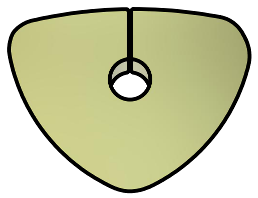


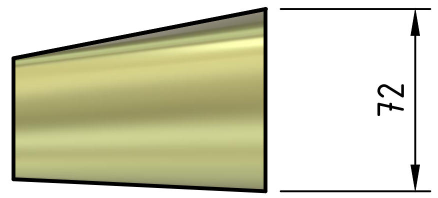


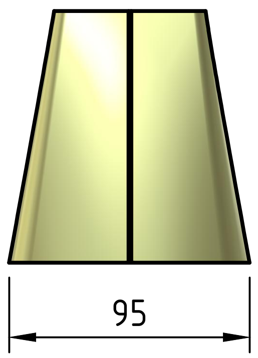
Base Material:
20cm thick foam block

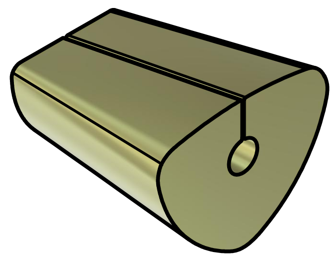
Production Method:
Hot wire cut
Laser cut wood templates
Aligned by reference measures

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:3
	Education: Design, Build and Fly minor			Sheet: 20/35
Amsterdam University of Applied Sciences	Part: Fuselage Rear 2		Number:	Format: A3





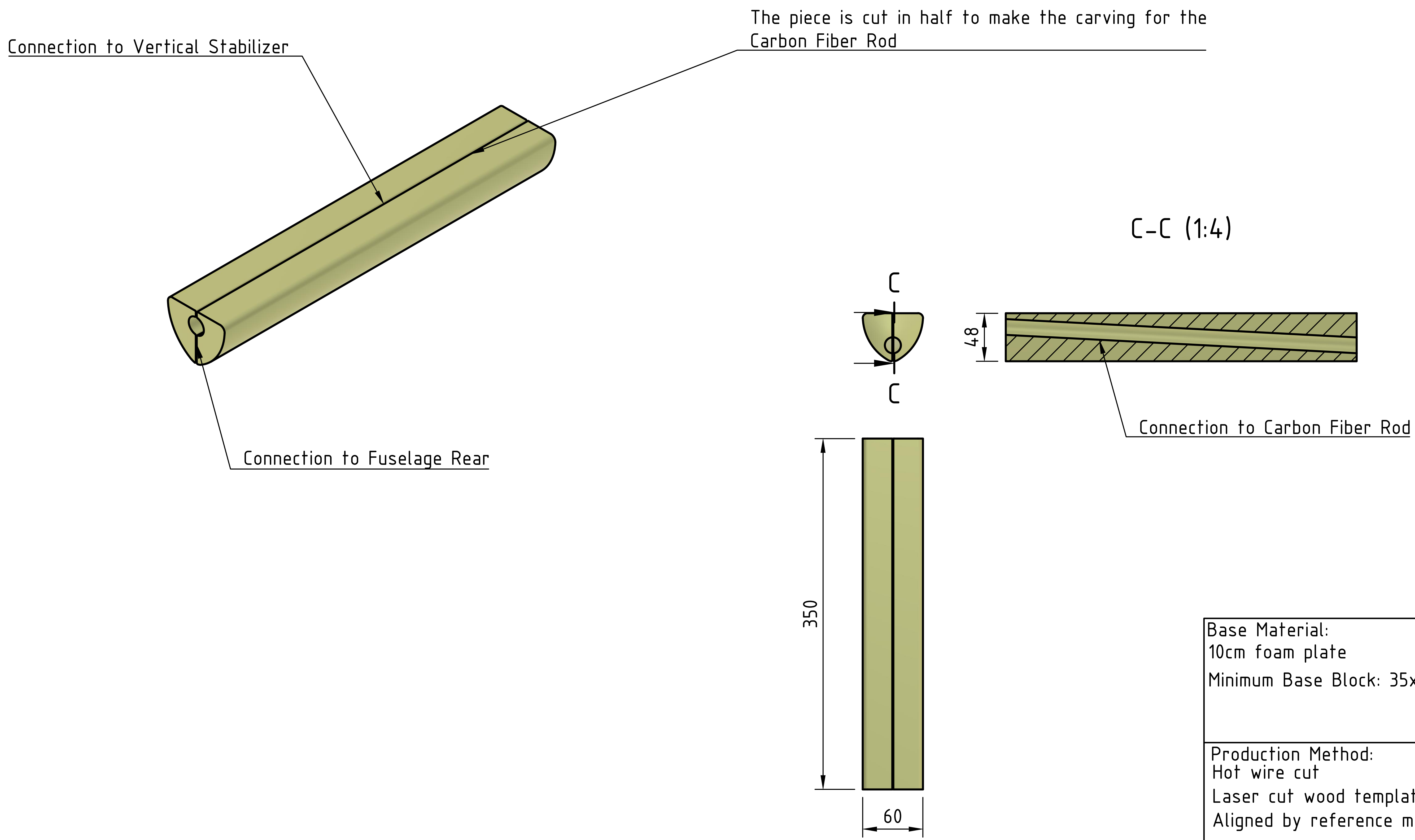




Base Material:
10cm thick foam plate

Production Method:
Hot wire cut
Laser cut wood templates
Aligned by reference measures

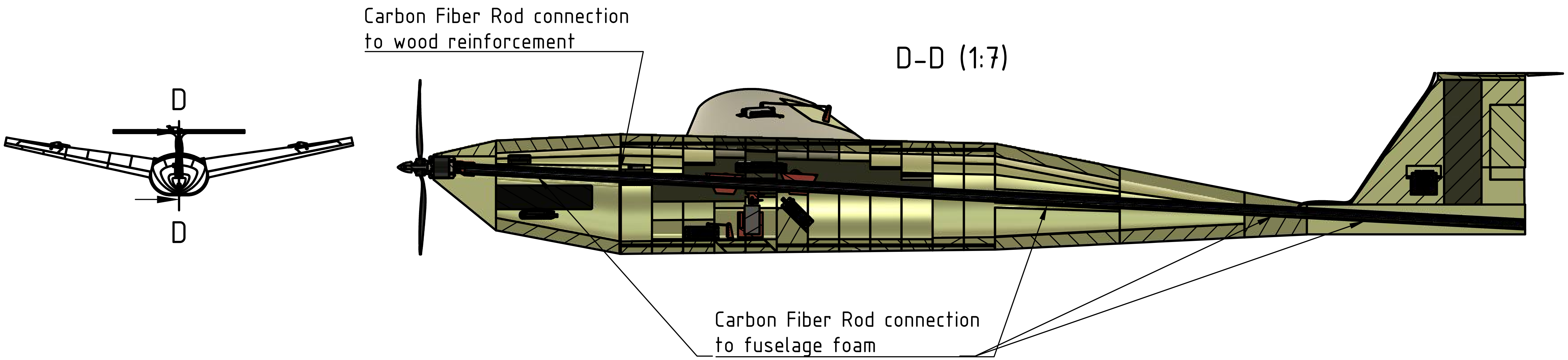
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:3
	Education: Design, Build and Fly minor			Sheet: 21/35
Amsterdam University of Applied Sciences	Part: Fuselage Rear 3		Number:	Format: A3

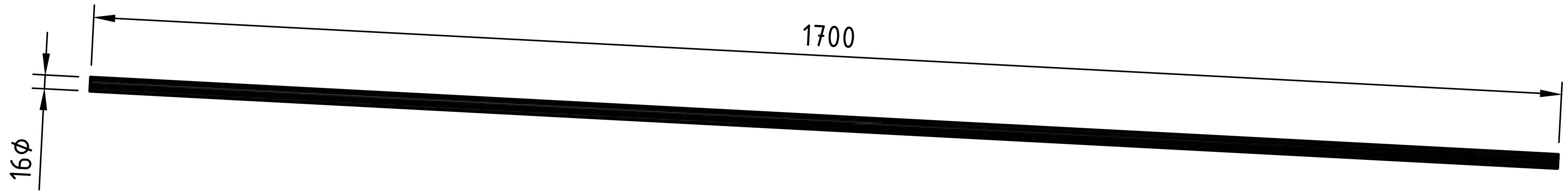


Base Material:
10cm foam plate
Minimum Base Block: 35x7x10cm

Production Method:
Hot wire cut
Laser cut wood templates
Aligned by reference measures

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:20
	Education: Design, Build and Fly minor			Sheet: 22/35
Amsterdam University of Applied Sciences	Part: Fuselage Tail		Number:	Format: A3

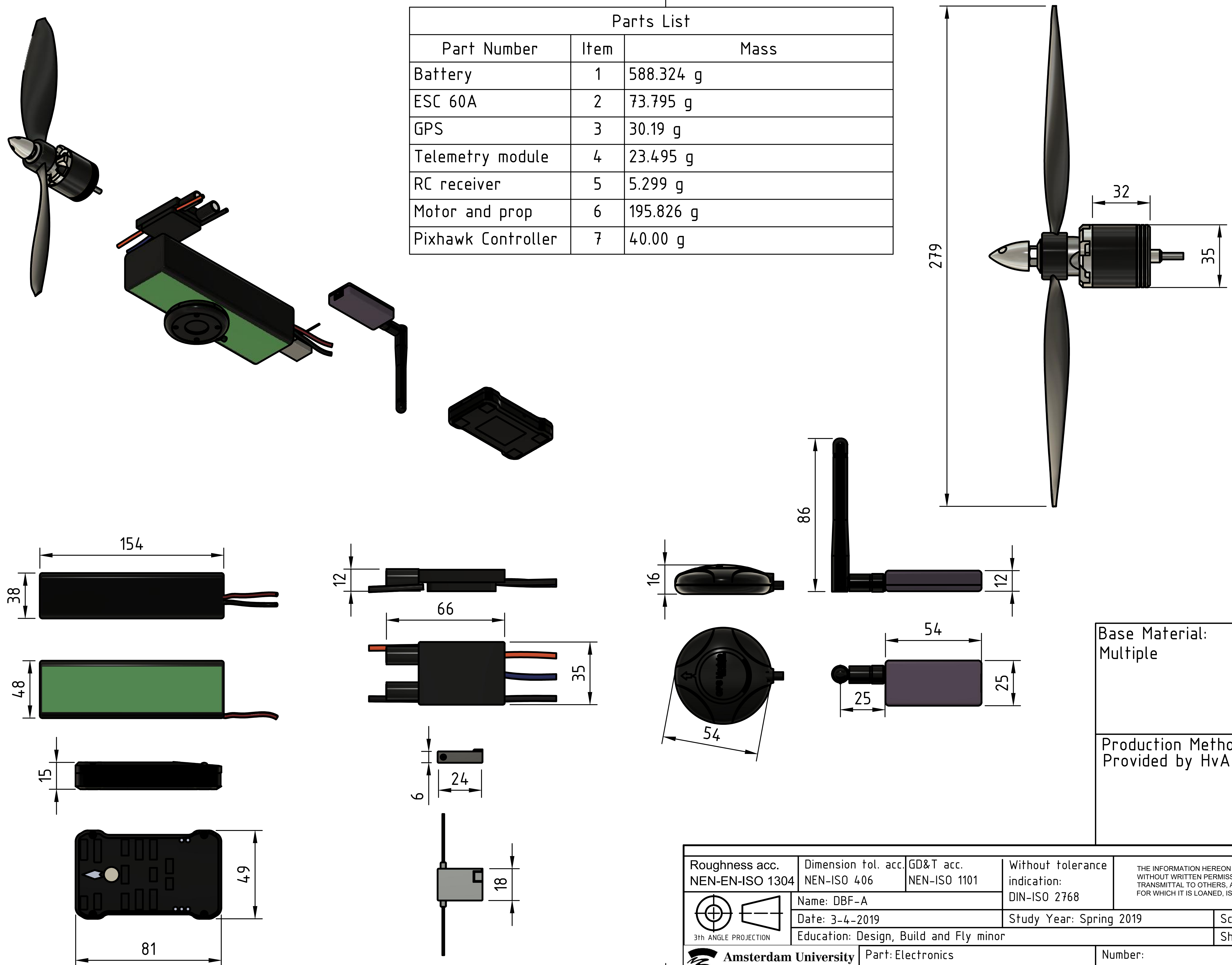




Base Material:
Carbon Fiber

Production Method:
Vendor reached trough HvA
Glued to fuselage
Assembly alignement in
fuselage shape

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:7
	Education: Design, Build and Fly minor			Sheet: 23/35
Amsterdam University of Applied Sciences	Part: Fuselage Carbon Fiber Rod		Number:	Format: A3

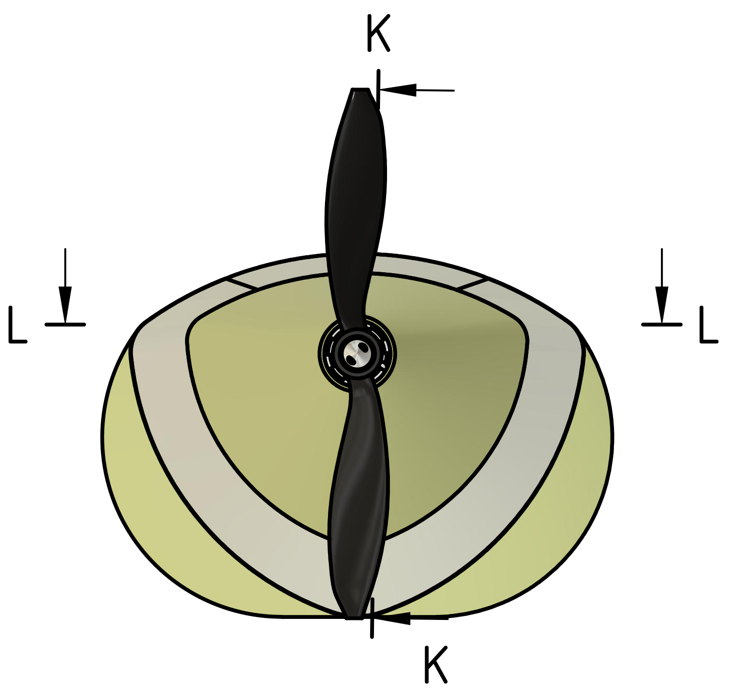


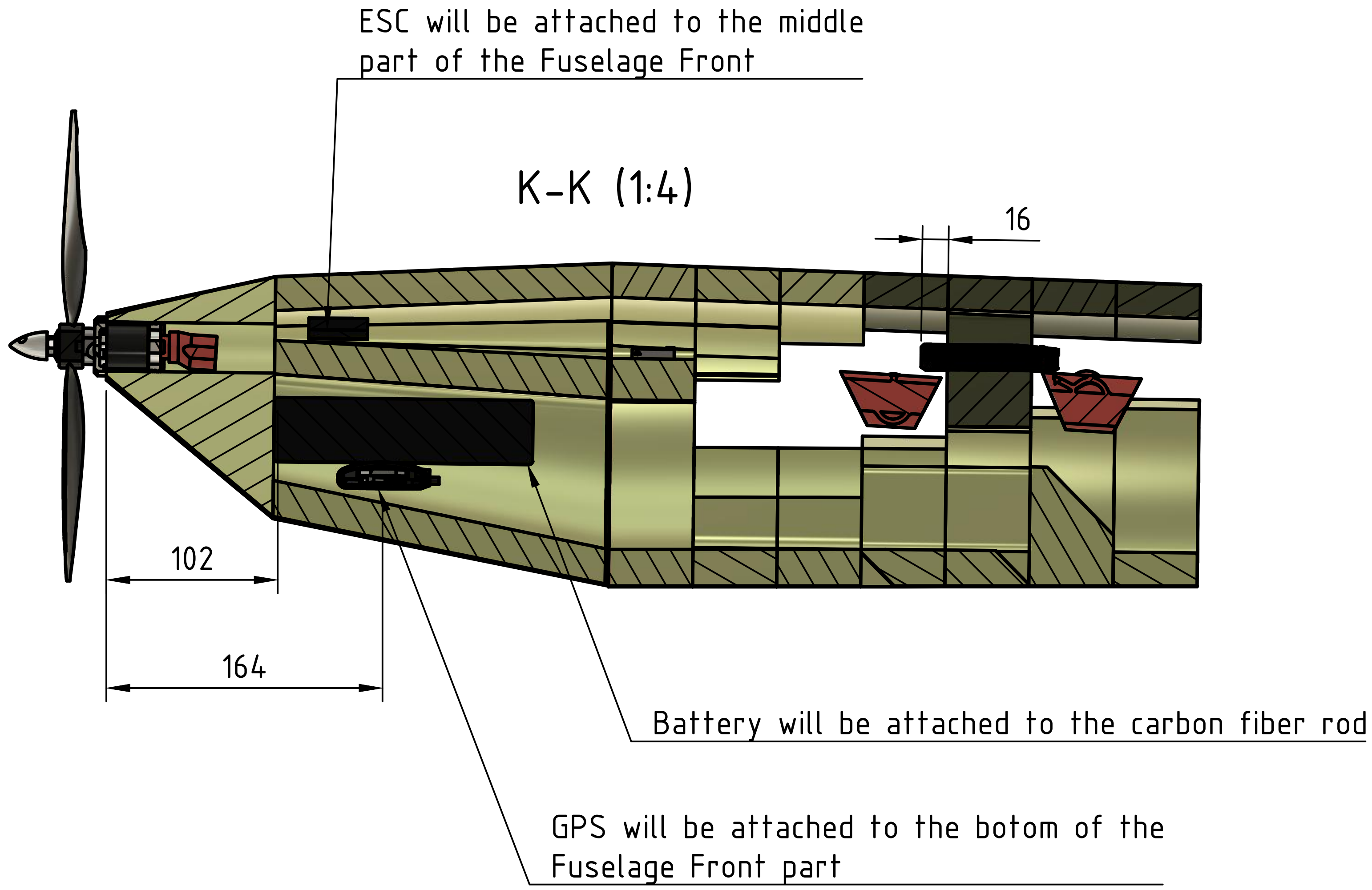
Parts List		
Part Number	Item	Mass
Battery	1	588.324 g
ESC 60A	2	73.795 g
GPS	3	30.19 g
Telemetry module	4	23.495 g
RC receiver	5	5.299 g
Motor and prop	6	195.826 g
Pixhawk Controller	7	40.00 g

Base Material:
Multiple

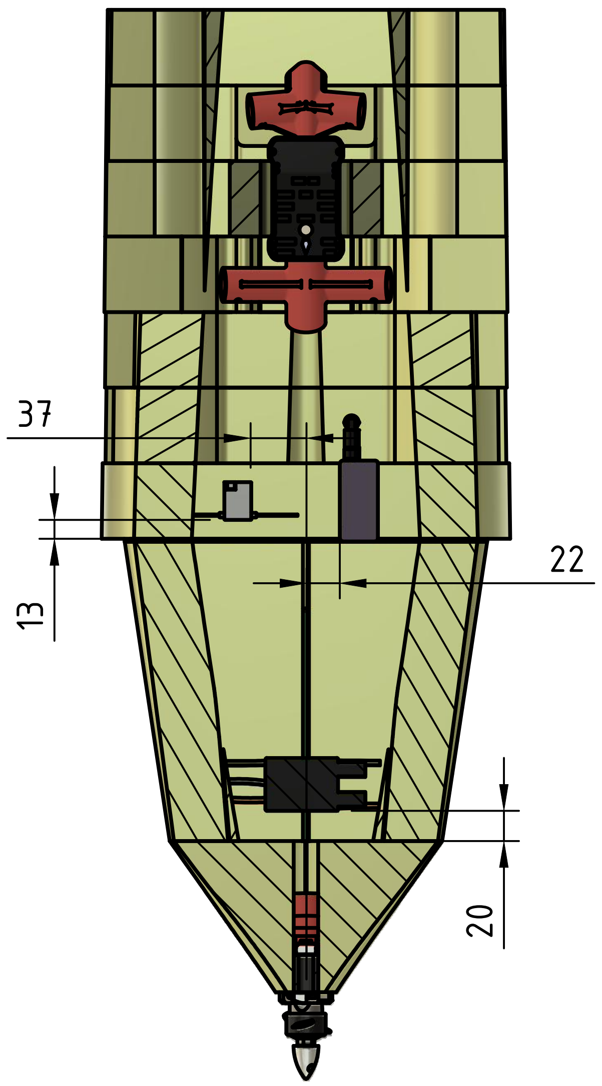
Production Method:
Provided by HvA

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 24/35
Amsterdam University of Applied Sciences	Part: Electronics		Number:	Format: A3





L-L (1:5)

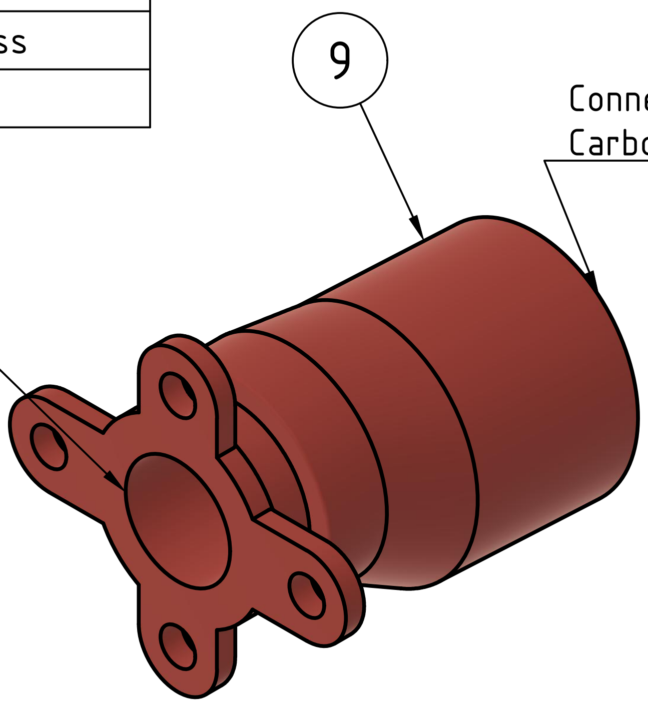


Base Material:
Multiple

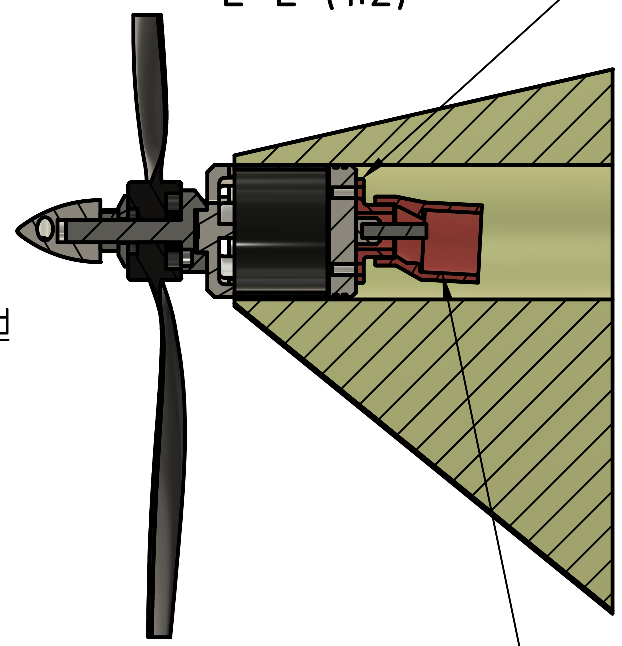
Production Method:
Provided by HvA

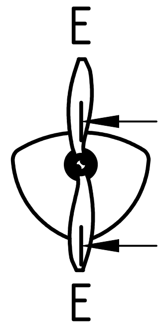
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:5
	Education: Design, Build and Fly minor			Sheet: 25/35
Amsterdam University of Applied Sciences	Part: Electronics position		Number:	Format: A3

Parts List		
Part Name	Item	Mass
Motor support	9	6.082 g

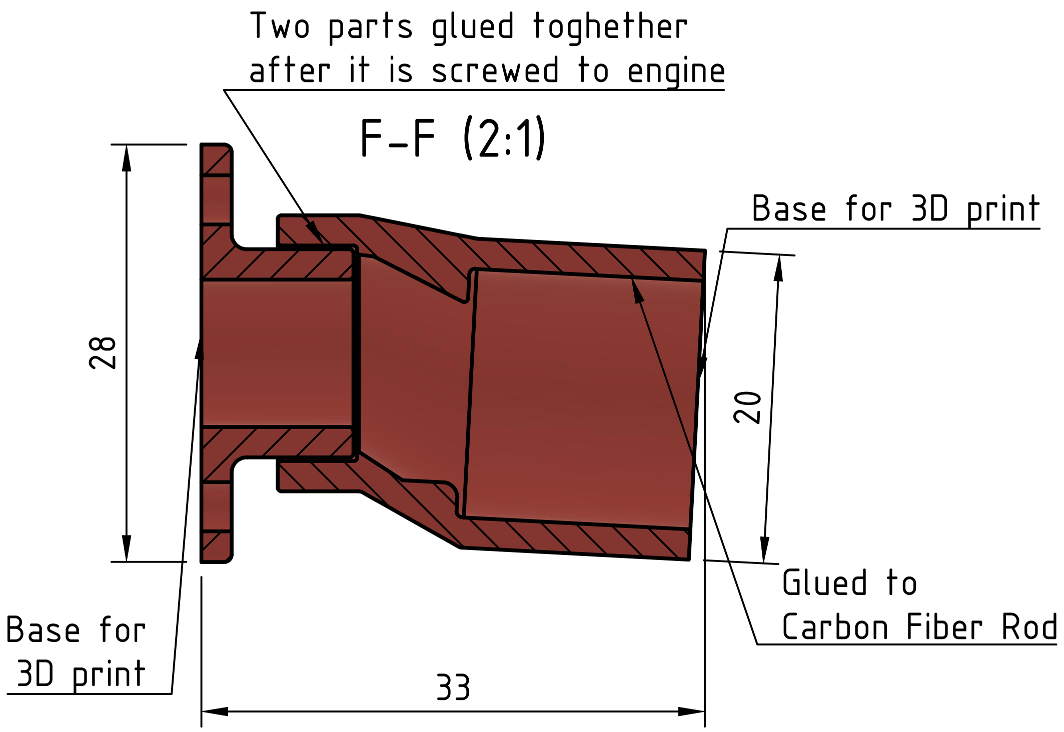


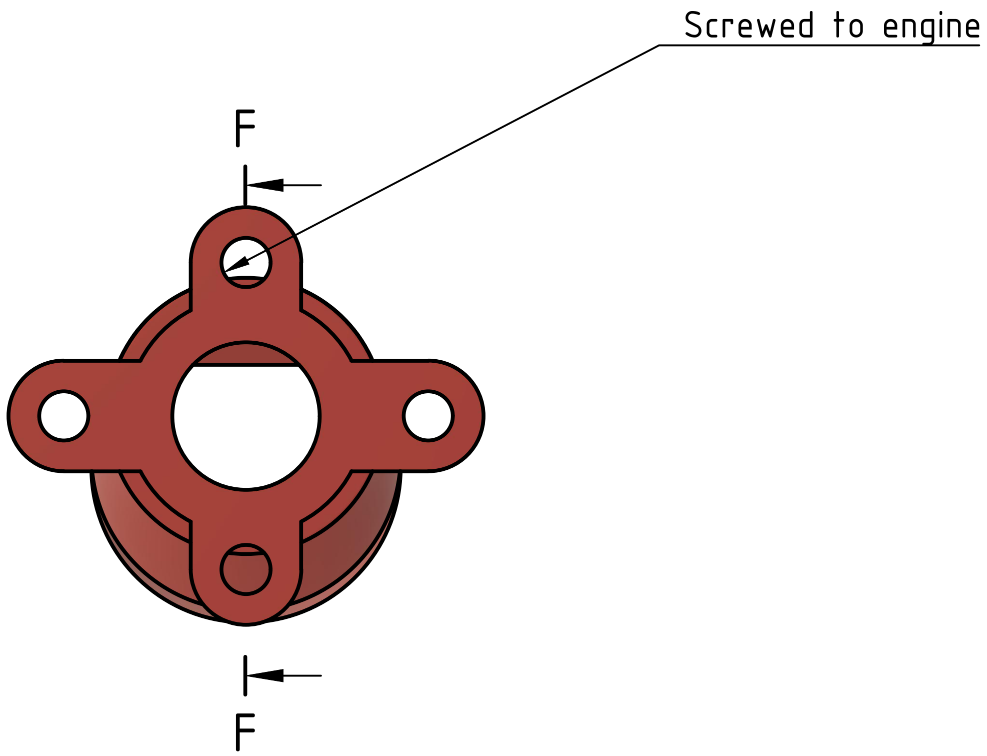
E-E (1:2)





F-F (2:1)

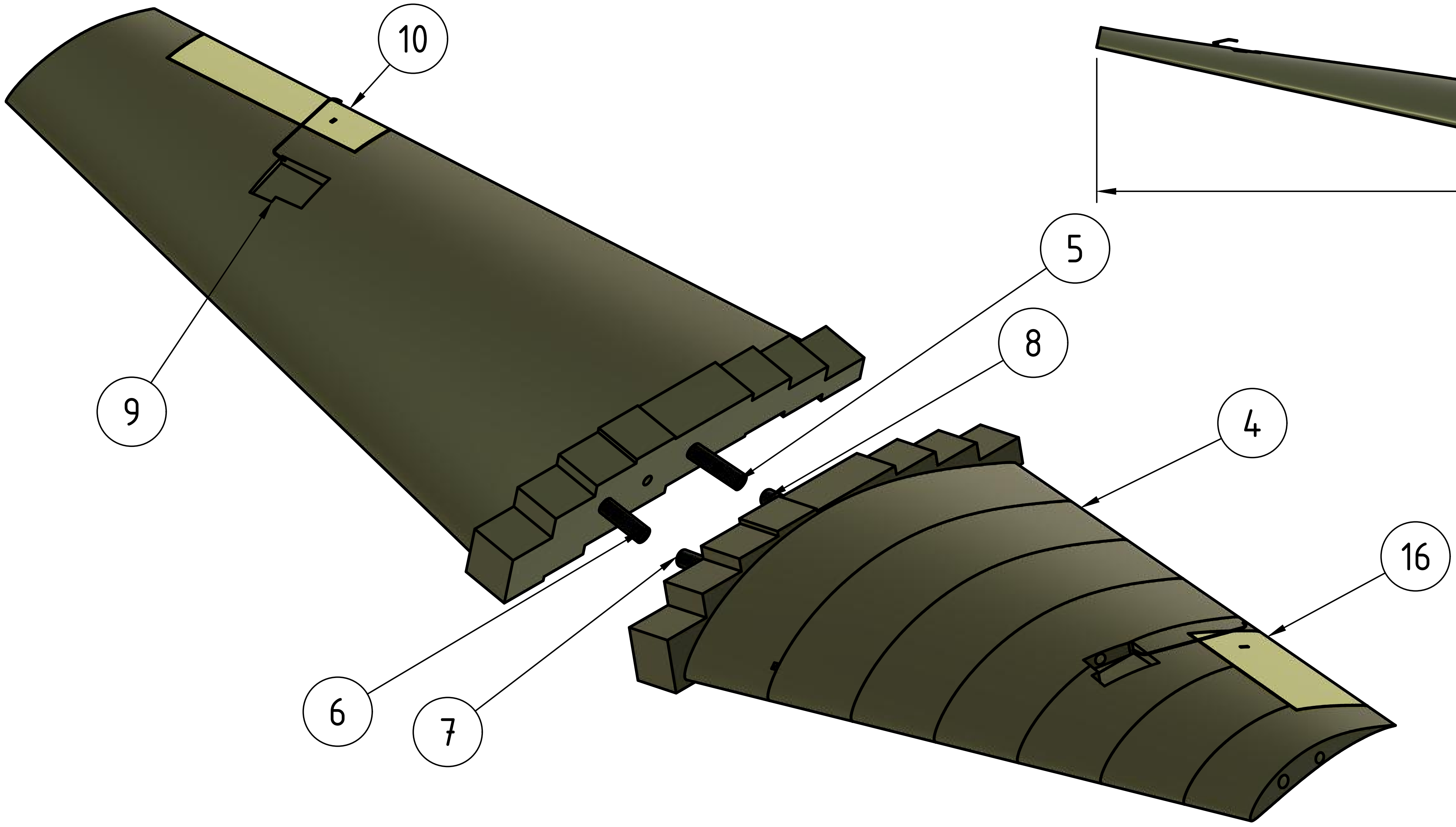


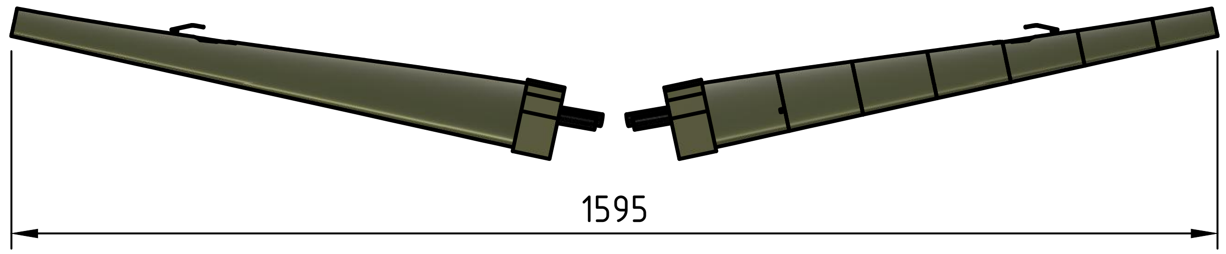


Base Material:
PLA

Production Method:
3D printing

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:2
	Education: Design, Build and Fly minor			Sheet: 26/35
Amsterdam University of Applied Sciences	Part: Motor support		Number:	Format: A3



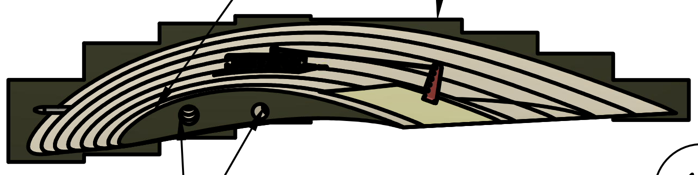


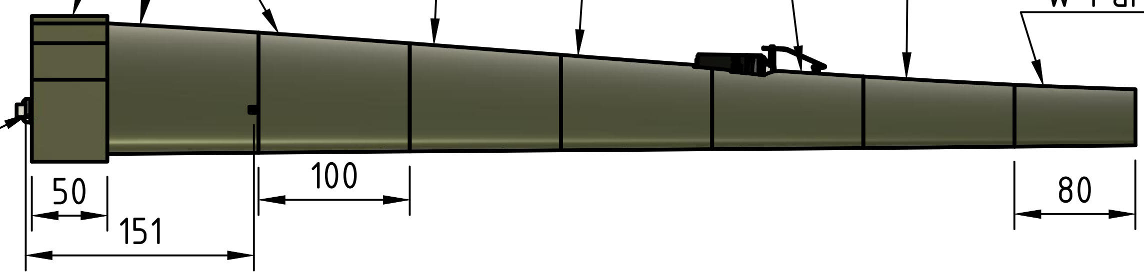
Wire left	18	0.797 g
Wire right	17	0.797 g
Aileron Right	16	4.236 g
Aileron Left	10	4.236 g
Wing Left	9	381.859 g
Carbon Rod c/2 Right	8	21.705 g
Carbon Rod AC Right	7	20.672 g
Carbon Rod AC Left	6	20.672 g
Carbon Rod c/2 Left	5	21.705 g
Wing right	4	380.628 g
Part Name	Item	Mass
Parts List		

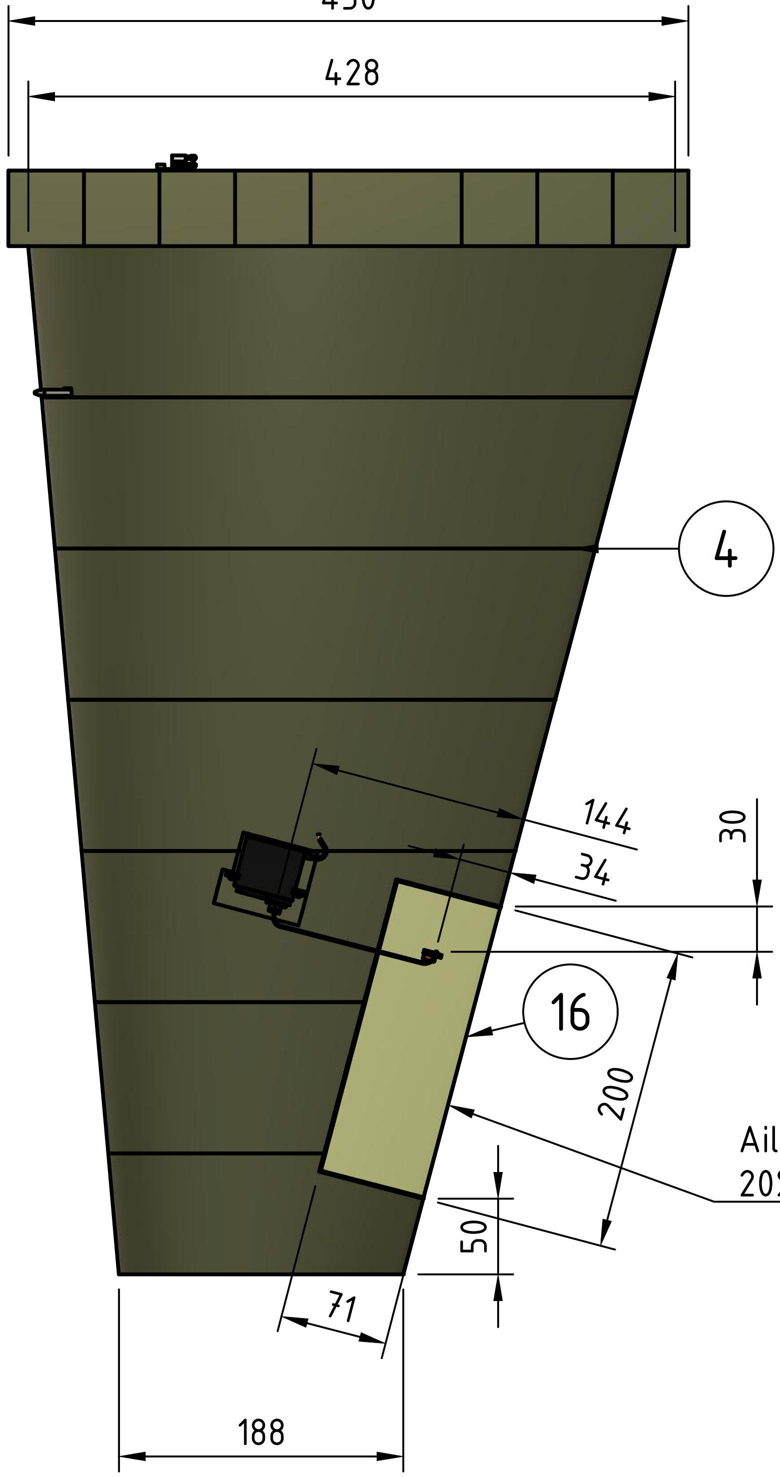
Base Material:
Foam
Compopsite Skin
Carbon Fiber rods

Production Method:
Multiple

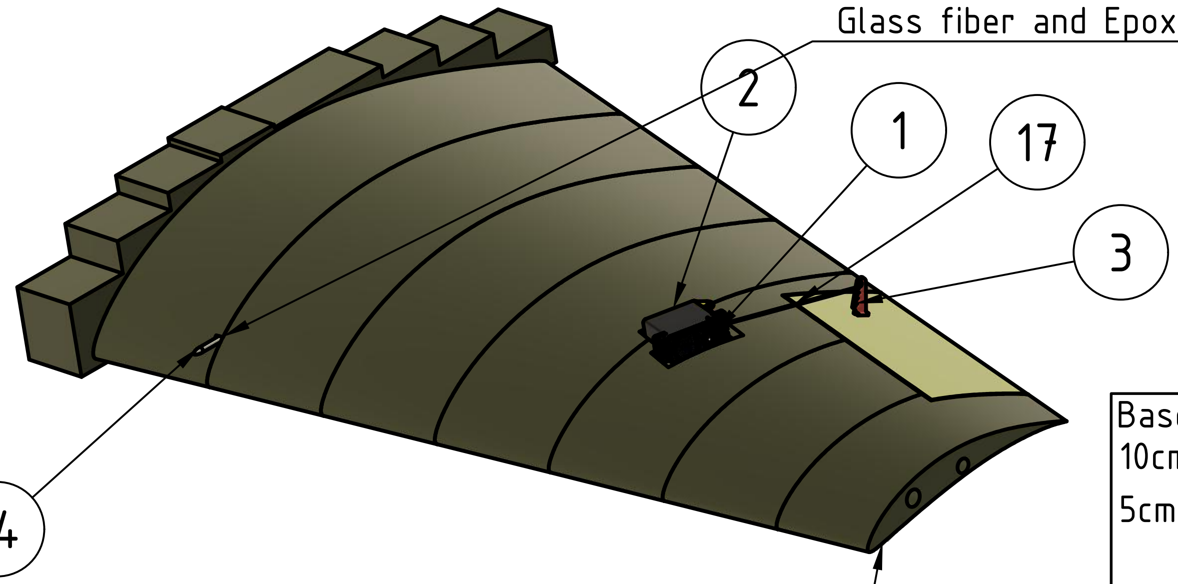
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:5
	Education: Design, Build and Fly minor			Sheet: 27/35
Amsterdam University of Applied Sciences	Part: Wing		Number:	Format: A3







Dimensions of this part can be
mirrored to get the left wing
(except for the speed sensor)



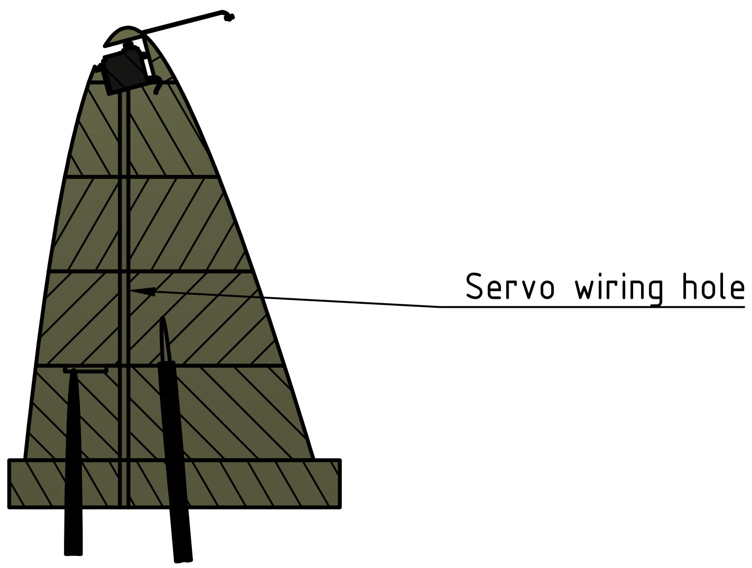
Parts List

Item	Part Number	Mass
1	Microservo horn	0.239 g
2	Servo	14.698 g
3	Horn	0.604 g
4	Wing right	380.628 g
14	Pitot Sensor	5.50 g
15	Pitot Electronics	9.599 g
16	Aileron Right	4.236 g
17	Wire right	0.797 g

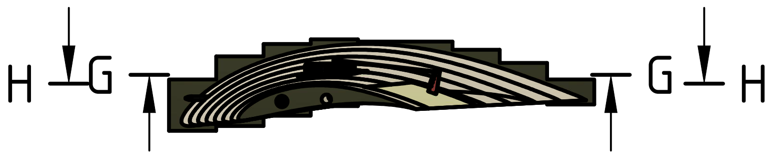
Base Material:
10cm thick foam plate
5cm thick foam plate

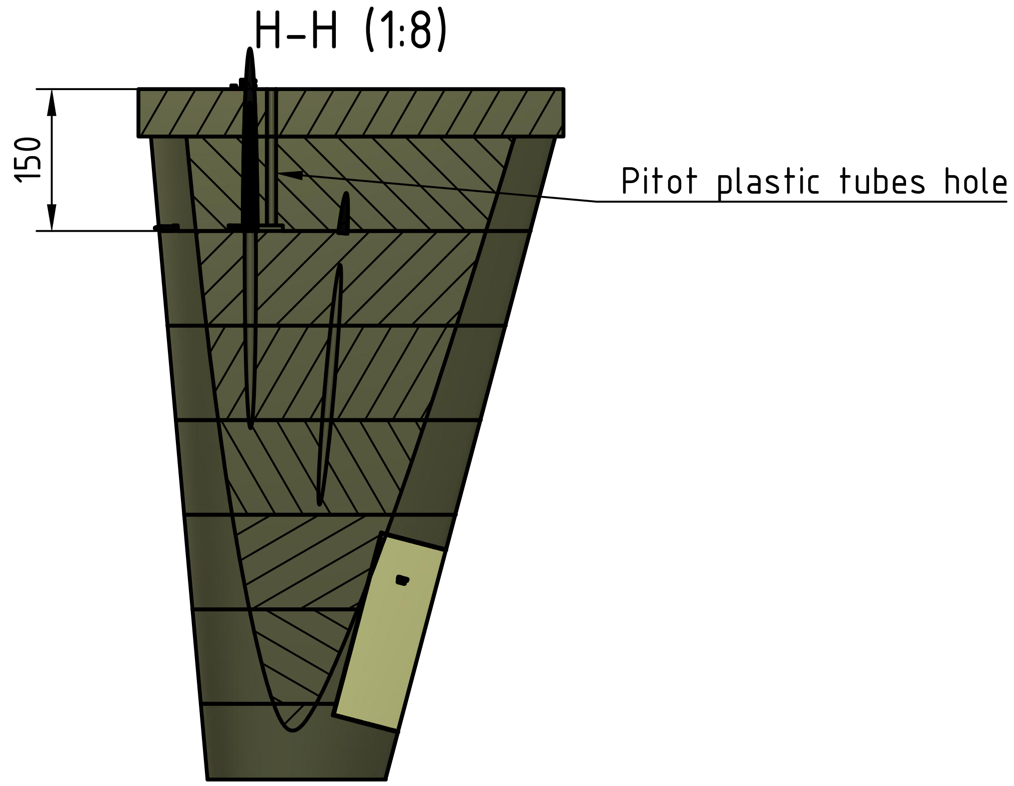
Production Method:
Hot wire cut
Laser cut wood templates
Aligned by drilling reference
holes using the templates

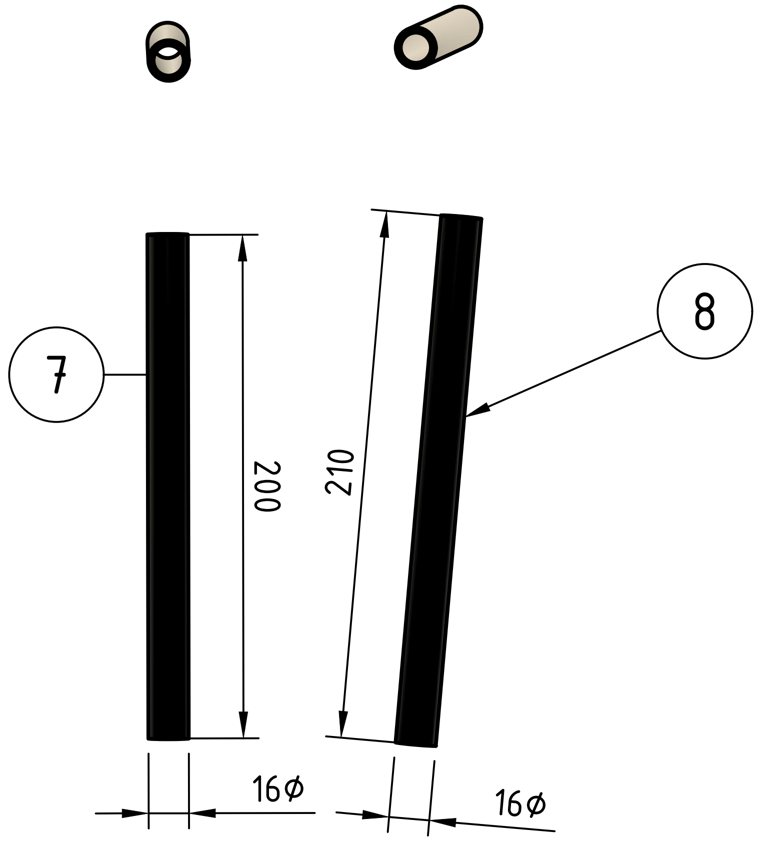
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768
3th ANGLE PROJECTION	Name: DBF-A		
	Date: 3-4-2019	Study Year: Spring 2019	Scale: 1:20
	Education: Design, Build and Fly minor		Sheet: 28/35
Amsterdam University of Applied Sciences	Part: Wing Right	Number:	Format: A3



Parts List		
Part Name	Item	Mass
Carbon Rod AC Right	7	20.672 g
Carbon Rod c/2 Right	8	21.705 g



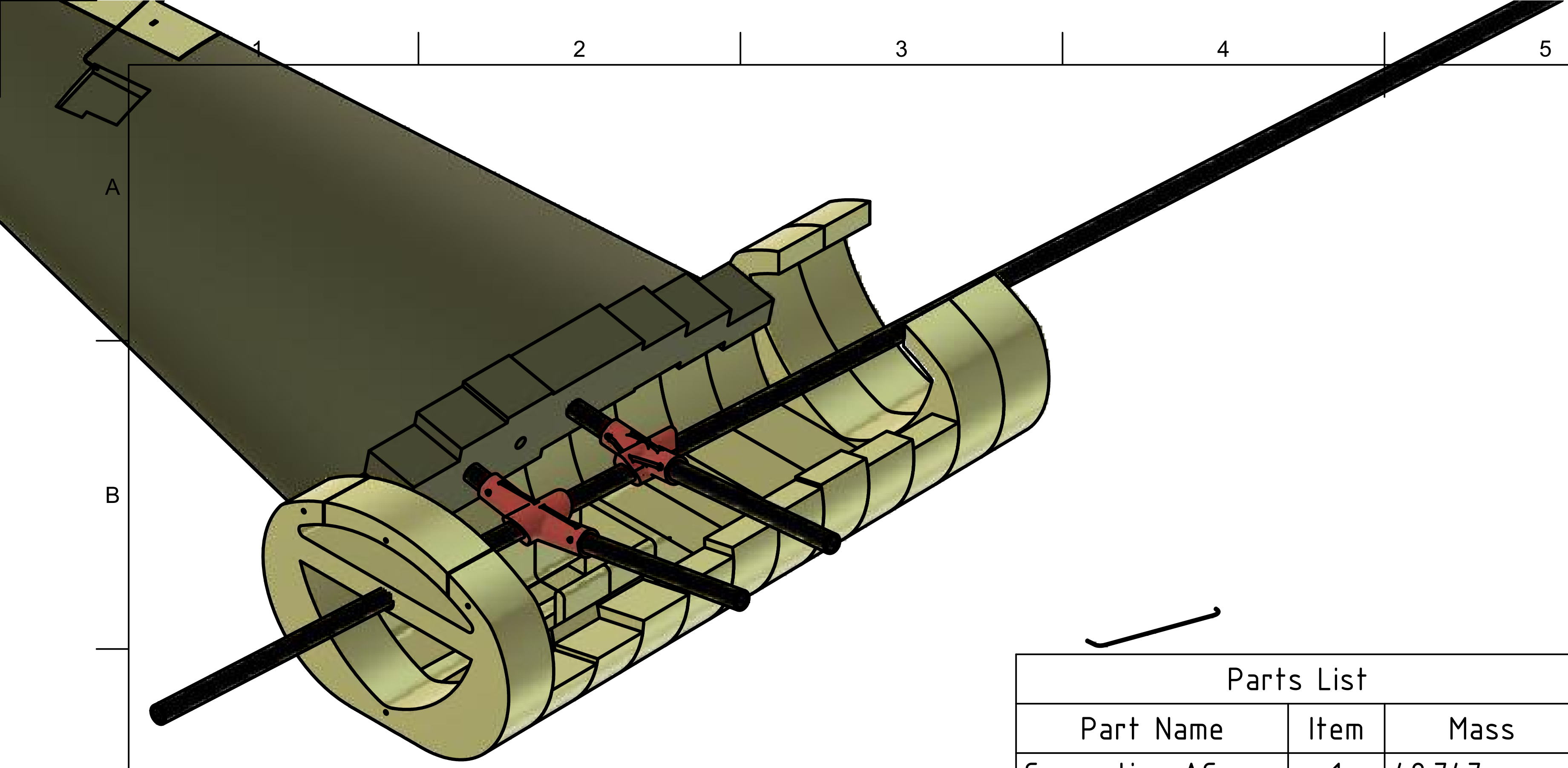


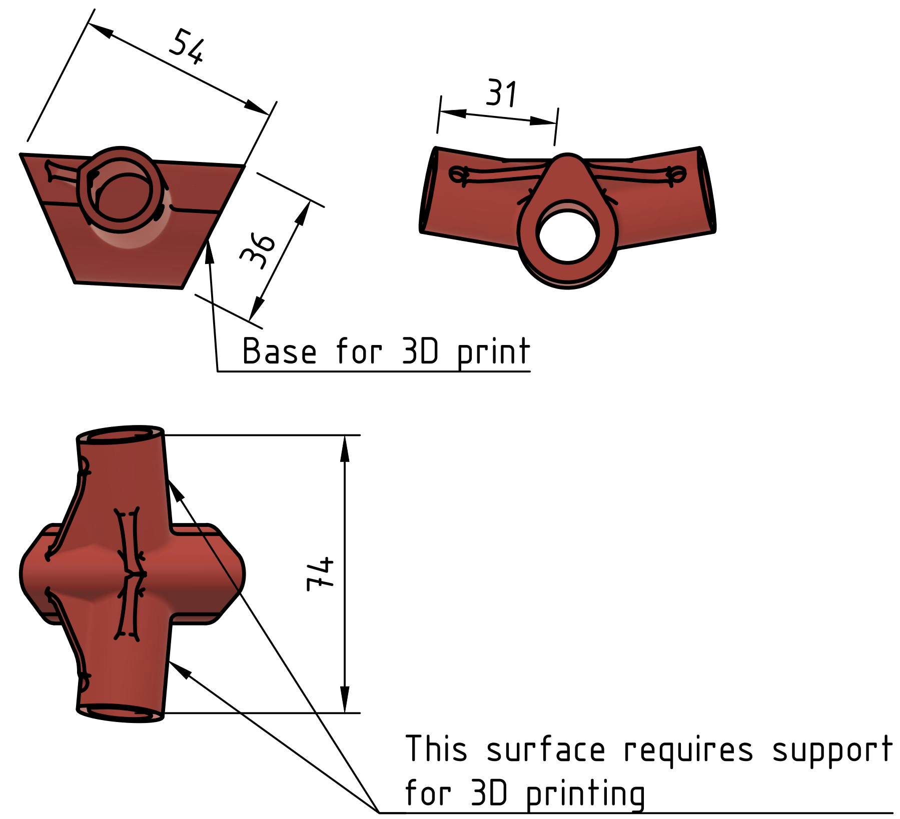


Base Material:
Carbon fiber

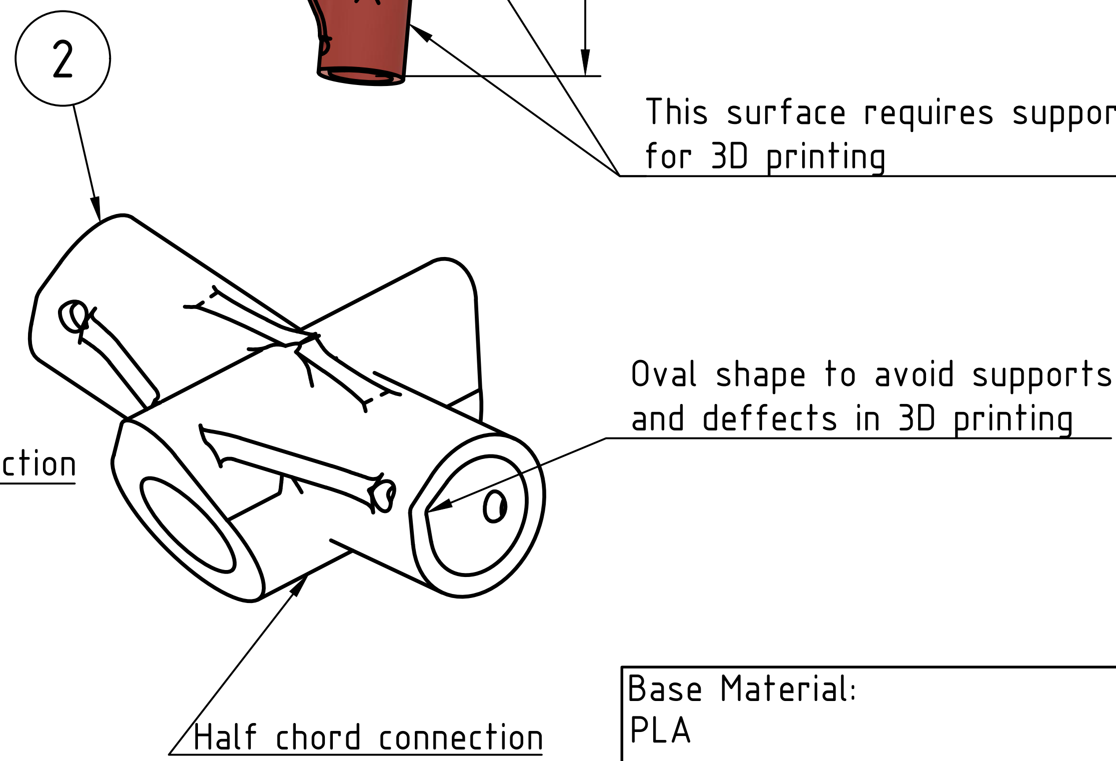
Production Method:
Vendor reached trough HvA
Glued to wing foam

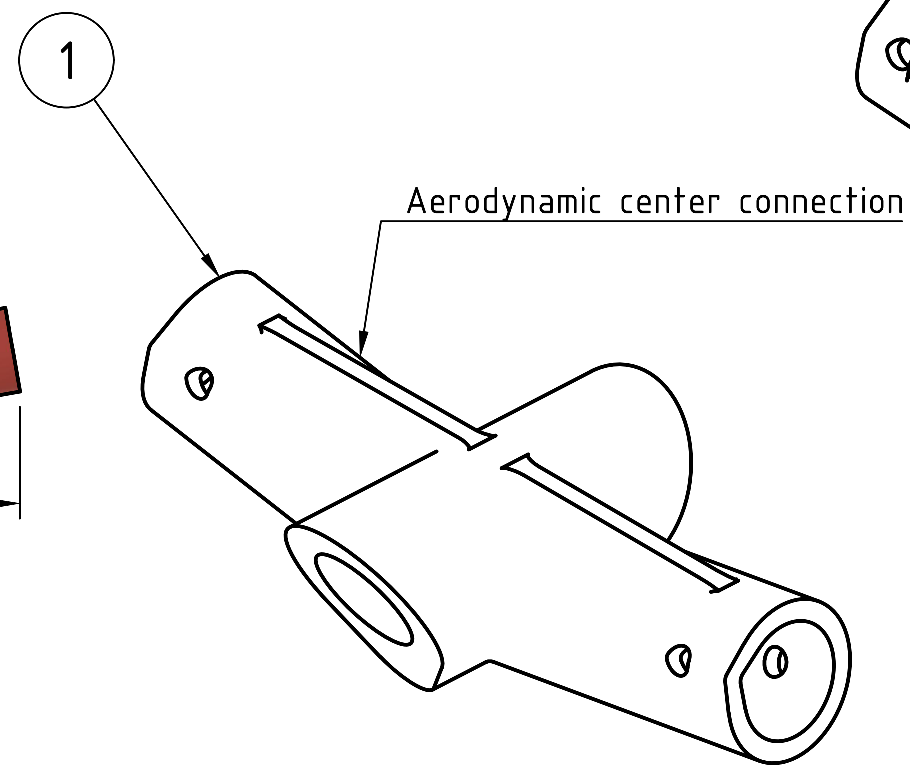
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:8 (From parent)
	Education: Design, Build and Fly minor			Sheet: 29/35
Amsterdam University of Applied Sciences	Part: Carbon Rods		Number:	Format: A3

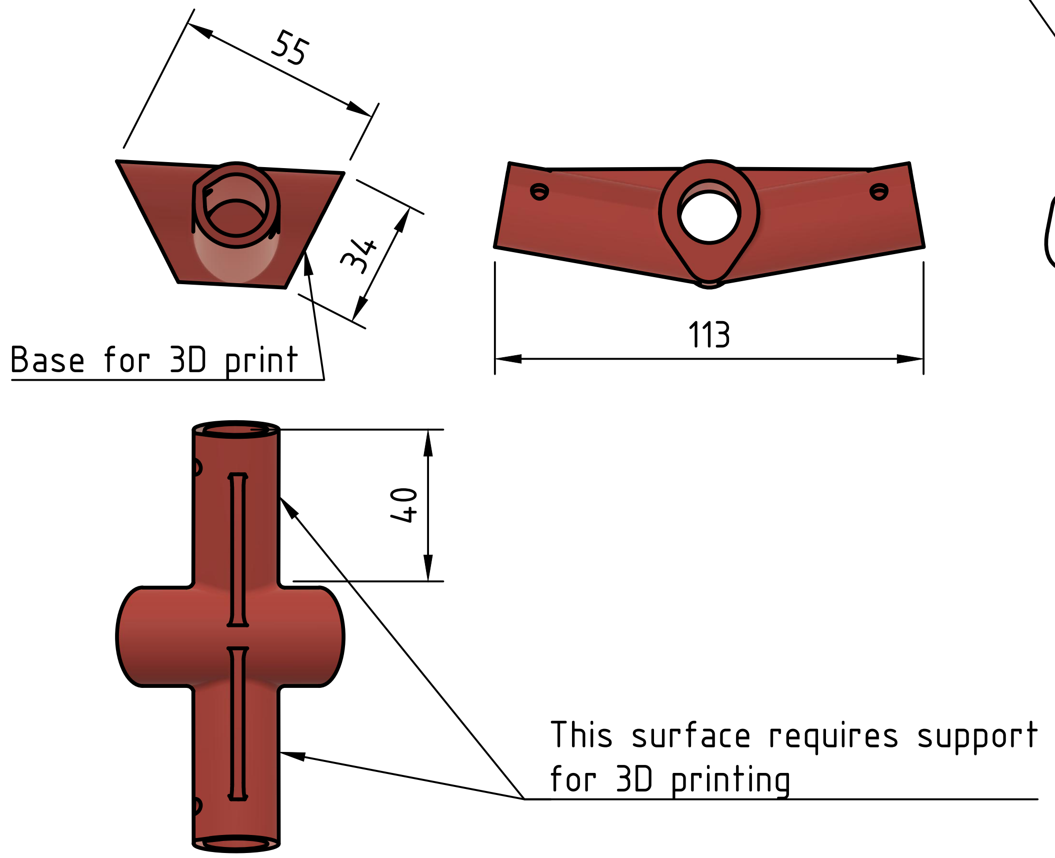




Parts List		
Part Name	Item	Mass
Connection AC	1	49.747 g
Connection c/2	2	40.893 g



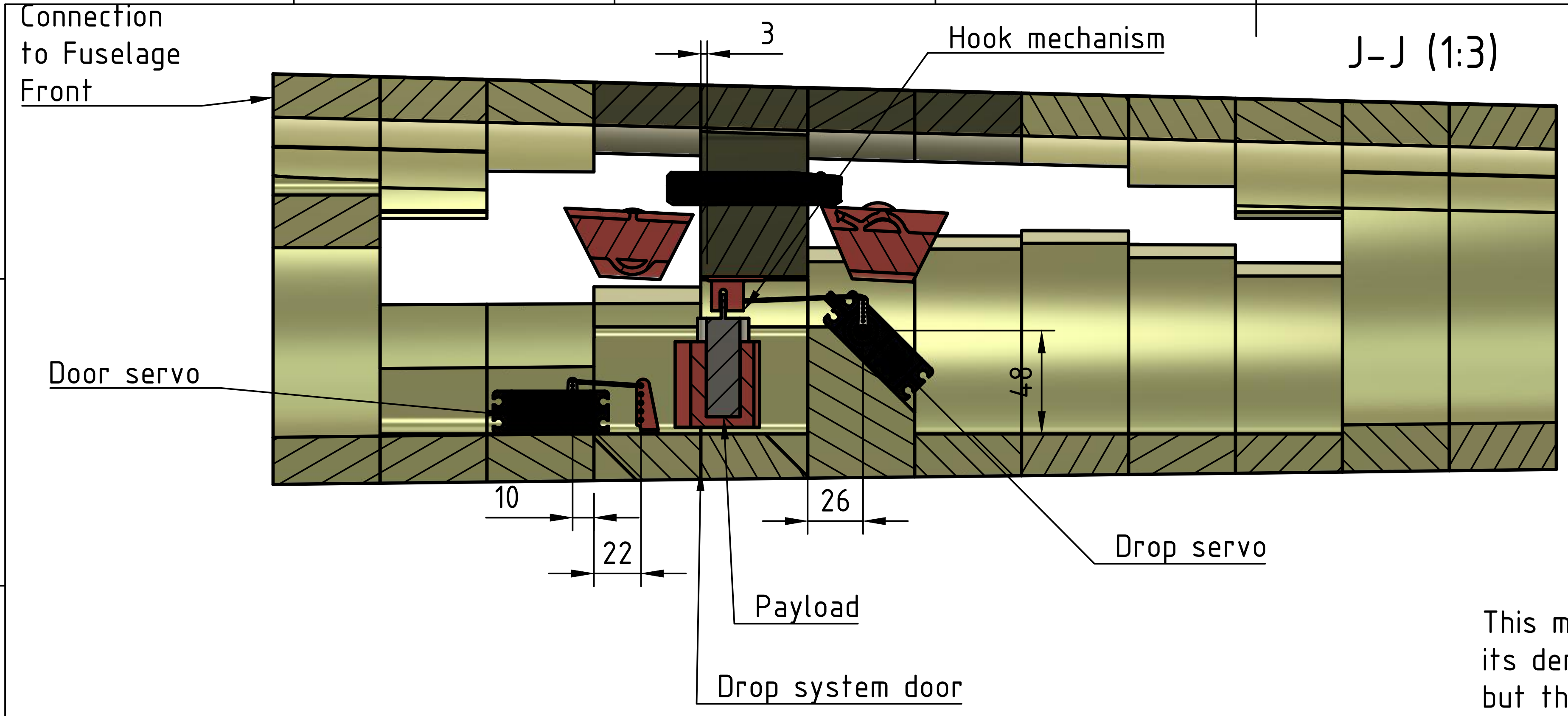




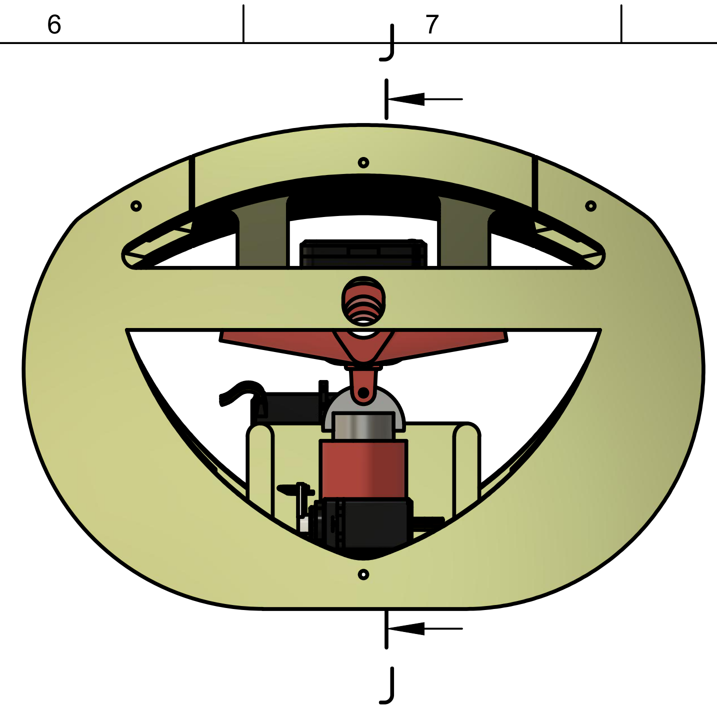
Base Material:
PLA

Production Method:
3D printing

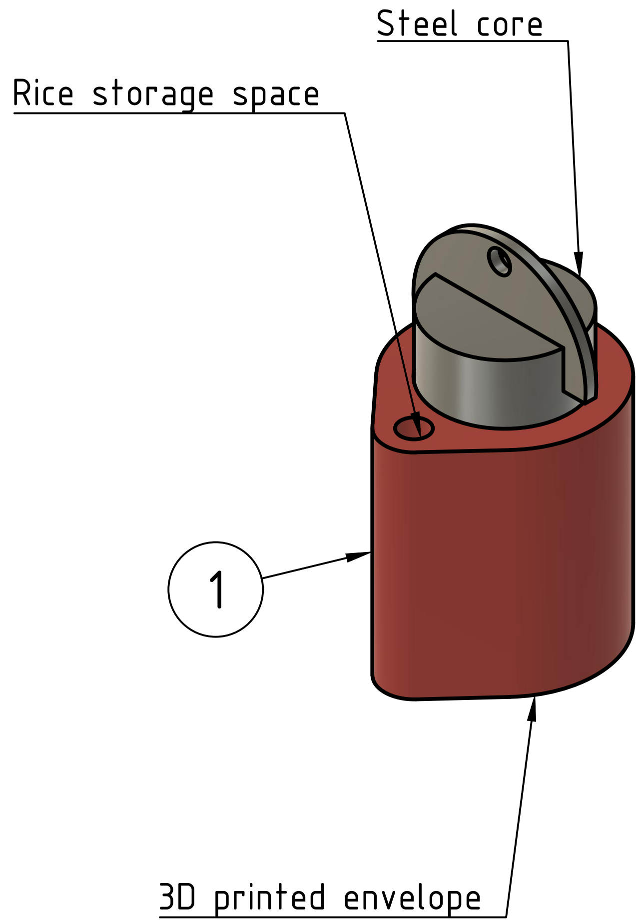
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:3
	Education: Design, Build and Fly minor			Sheet: 30/35
Amsterdam University of Applied Sciences	Part: 3D print connection Wing-Fuselage		Number:	Format: A3

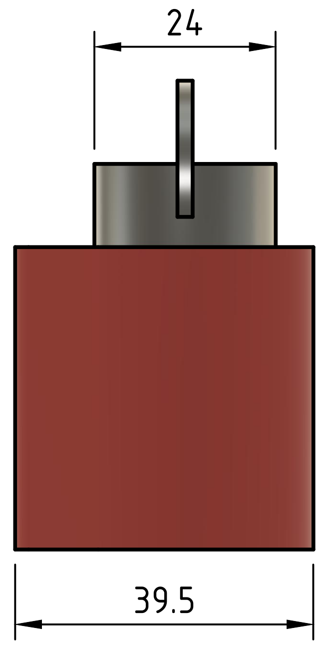


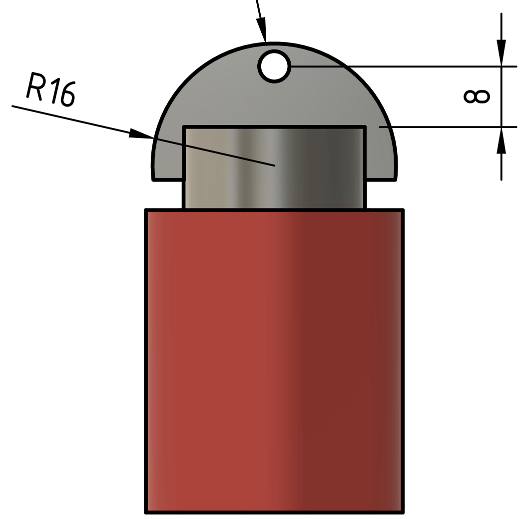
J-J (1:3)

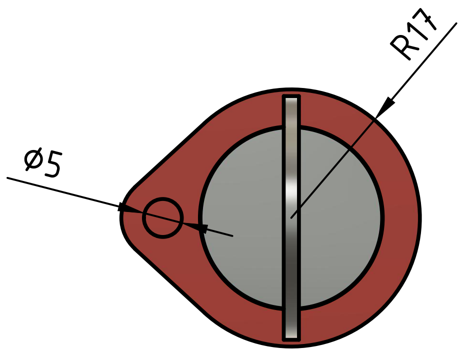


This model is an approximation of the real payload, its density has been modified to match the real weight but the hook attachment is a geometrical simplification of reality





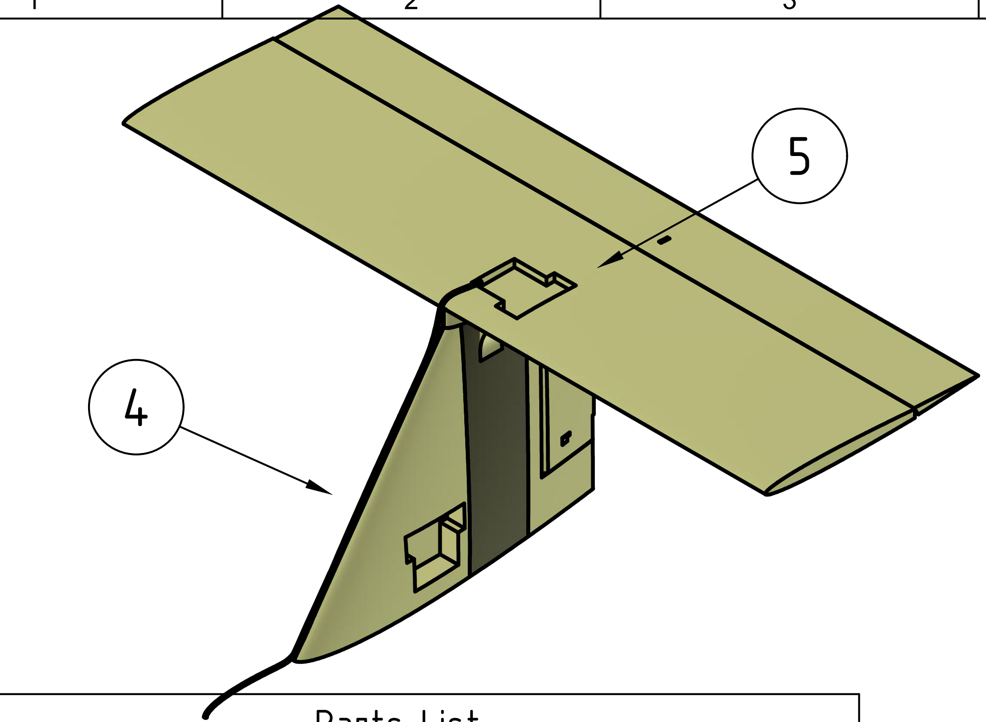




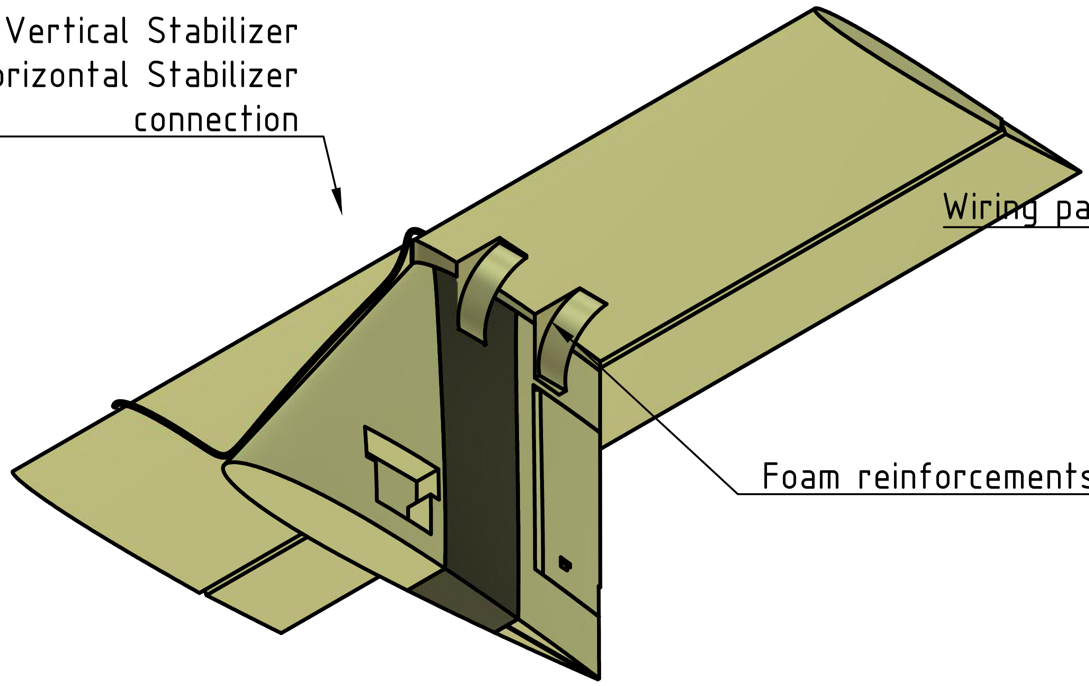
Base Material:
Steel and PLA

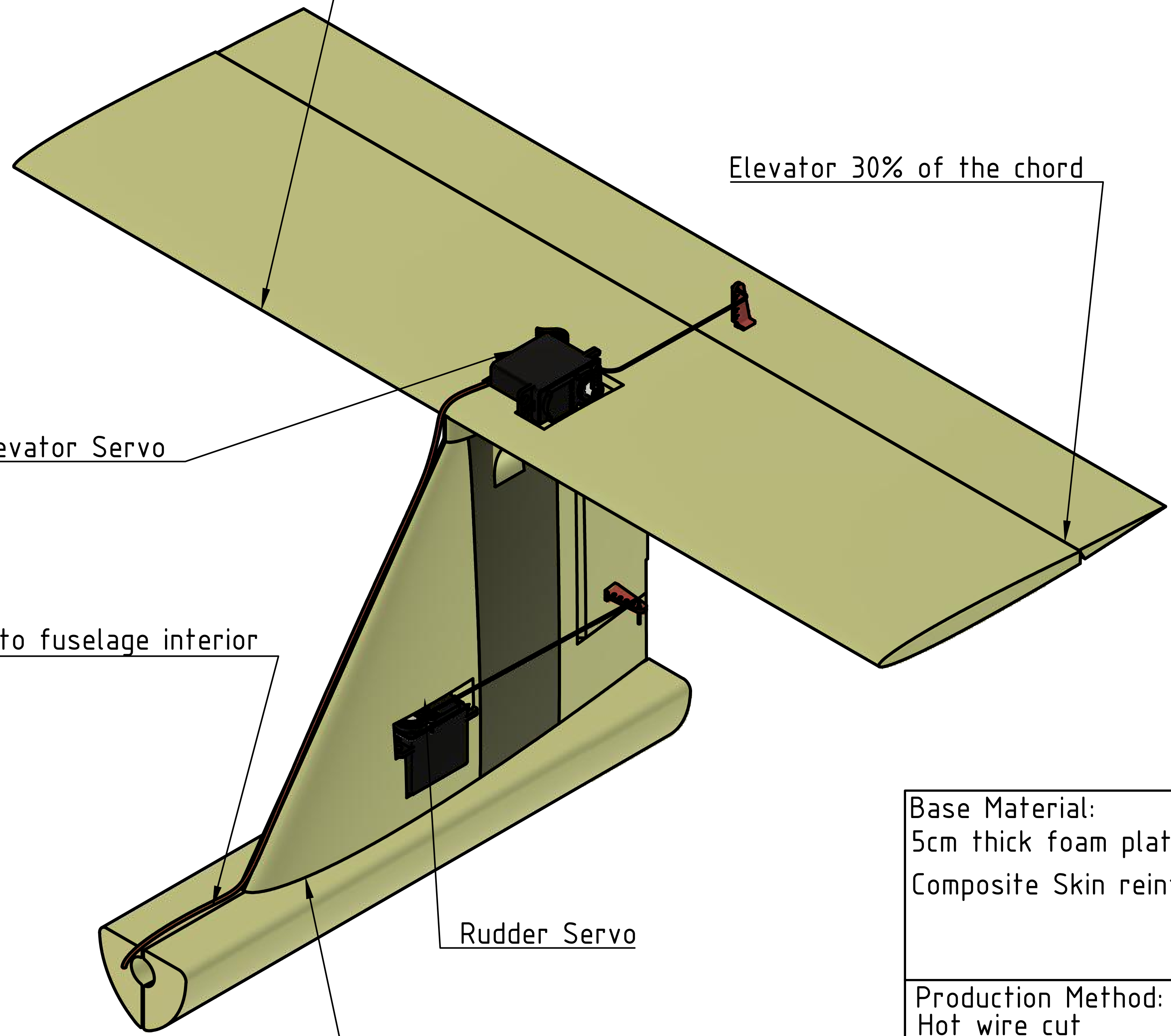
Production Method:
Steel cylinder cut and drill
Lead welding
3D printing

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:3
	Education: Design, Build and Fly minor			Sheet: 31/35
Amsterdam University of Applied Sciences	Part: Payload		Number:	Format: A3



Parts List		
Part Name	Item	Mass
Vertical Stabilizer	4	31.433 g
Horizontal Stabilizer	5	35.524 g

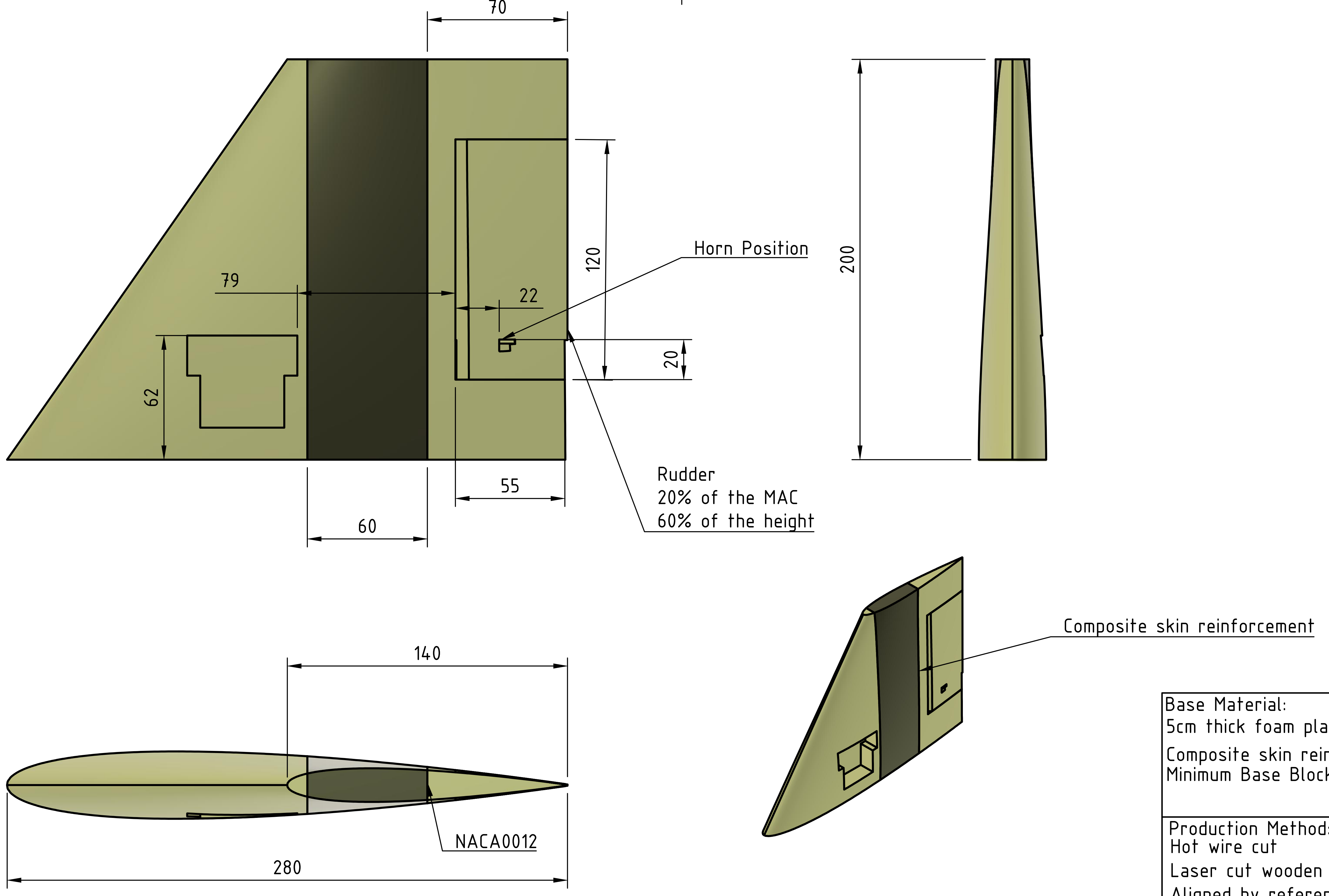




Base Material:
5cm thick foam plate
Composite Skin reinforcement

Production Method:
Hot wire cut
Laser cut wood templates
Aligned by reference measures

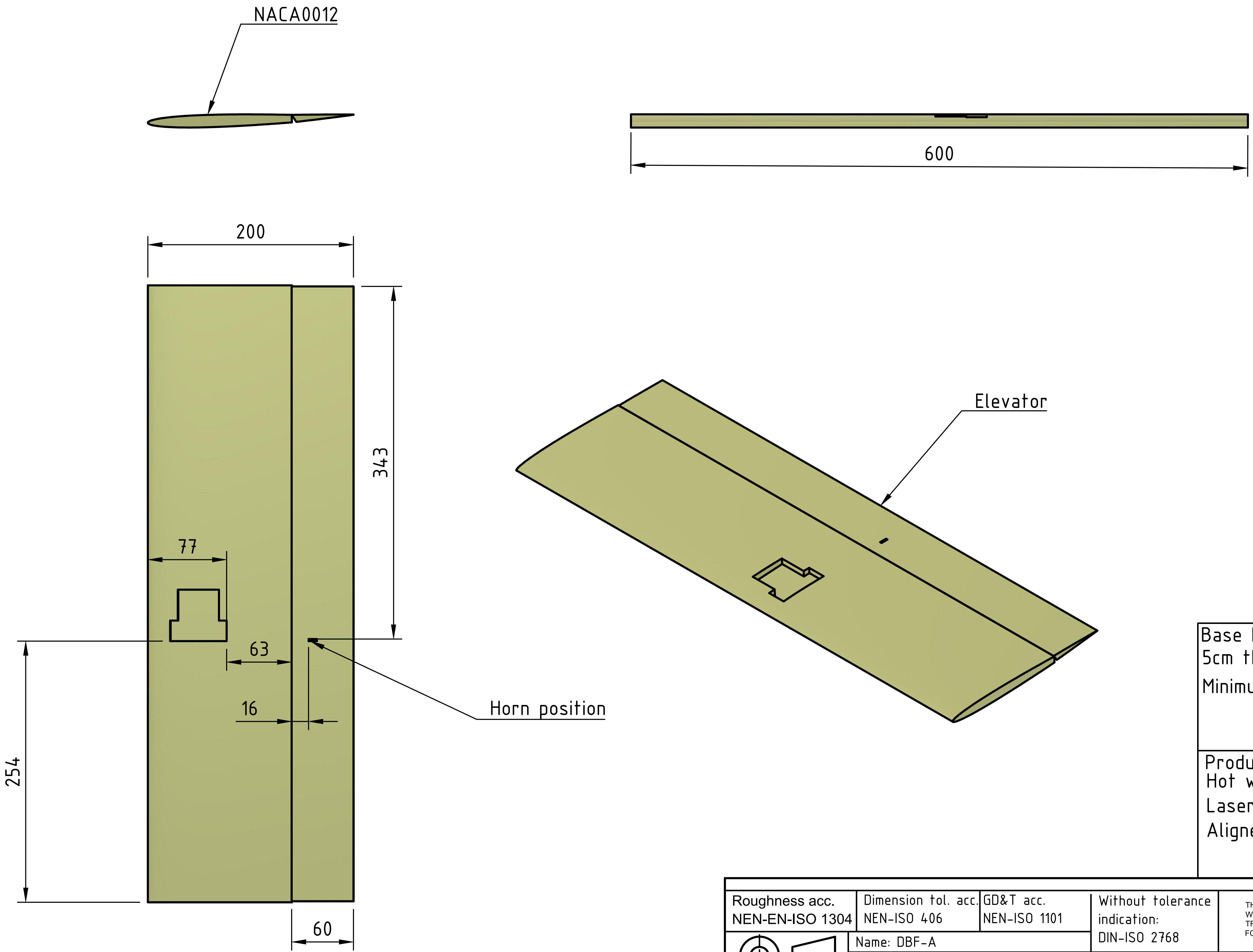
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:5
	Education: Design, Build and Fly minor			Sheet: 32/35
Amsterdam University of Applied Sciences	Part: Tail		Number:	Format: A3



Base Material:
5cm thick foam plate
Composite skin reinforcement
Minimum Base Block: 20x30x5

Production Method:
Hot wire cut
Laser cut wooden templates
Aligned by reference measures

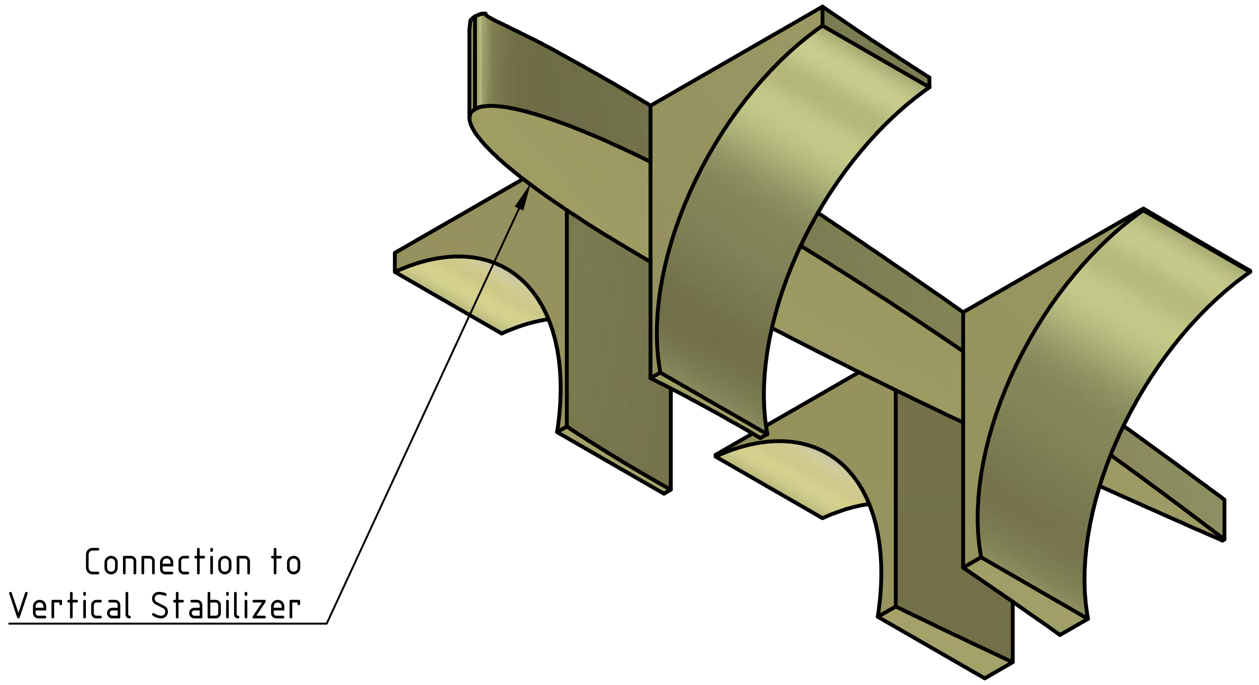
Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:4
	Education: Design, Build and Fly minor			Sheet: 33/35
Amsterdam University of Applied Sciences	Part: Vertical Stabilizer		Number:	Format: A3

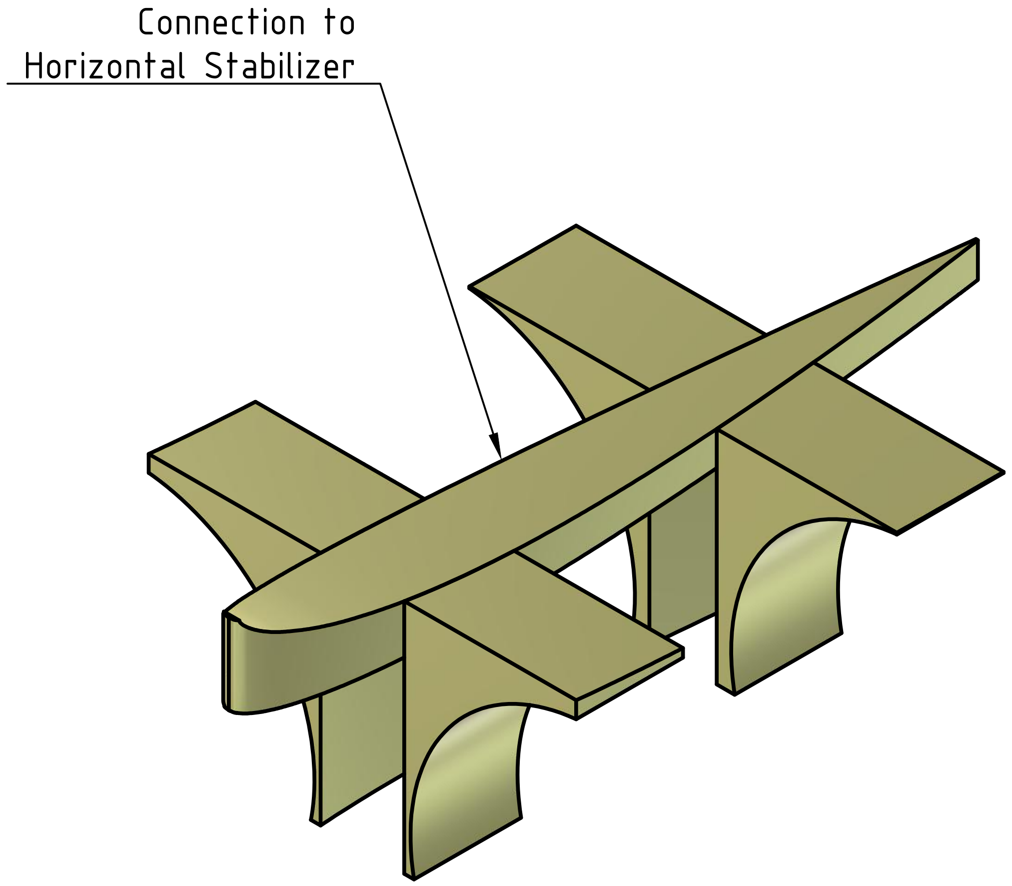


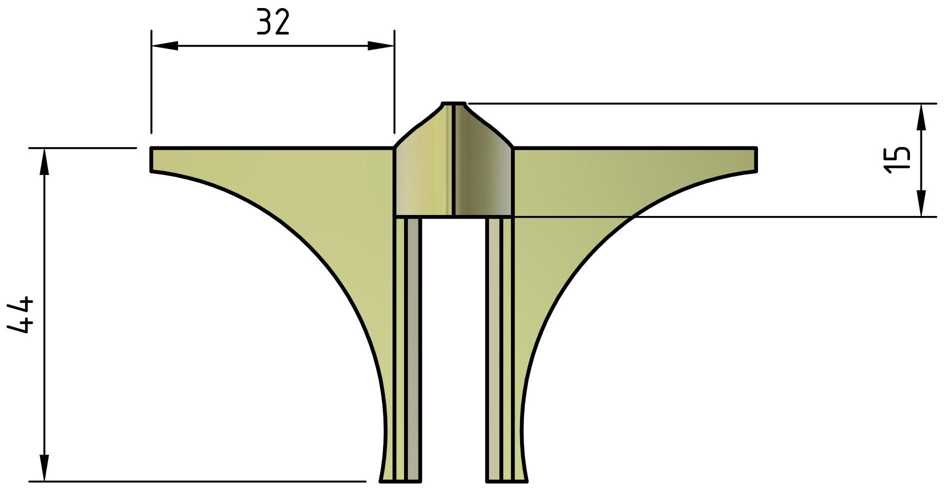
Base Material:
5cm thick foam plate
Minimum Base Block: 60x22x5 cm

Production Method:
Hot wire cut
Laser cut wood template
Aligned by reference measures

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.	
3th ANGLE PROJECTION	Name: DBF-A				
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:4	
	Education: Design, Build and Fly minor			Sheet: 34/35	
Amsterdam University of Applied Sciences	Part: Horizontal Stabilizer		Number:		Format: A3







Base Material:
5cm thick foam plate
Minimum Base Block: 15x8x5 cm

Production Method:
Hot wire cut
Laser cut wood template
Aligned by reference measures

Roughness acc. NEN-EN-ISO 1304	Dimension tol. acc. NEN-ISO 406	GD&T acc. NEN-ISO 1101	Without tolerance indication: DIN-ISO 2768	THE INFORMATION HEREON IS PROPERTY OF THE HvA. WITHOUT WRITTEN PERMISSION, ANY COPYING, TRANSMITTAL TO OTHERS, AND ANY USE EXCEPT THAT FOR WHICH IT IS LOANED, IS PROHIBITED.
3th ANGLE PROJECTION	Name: DBF-A			
	Date: 3-4-2019		Study Year: Spring 2019	Scale: 1:1
	Education: Design, Build and Fly minor			Sheet: 35/35
Amsterdam University of Applied Sciences	Part: Taiil reinforcements		Number:	Format: A3