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Bachelor's diploma thesis

in the field of study Aerospace Engineering
and specialisation Automatics and Aviation Systems

RISK AND RELIABILITY ANALYSIS BASED ON AIRBUS A319/320/321 FLEET

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Summary

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Abstract

Accidents are results of a sum of mishaps and unfortunate occurrences, and are defined as occurrences associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until all such persons have disembarked. We cannot know when are they going to happen, so we should be prepared for actuating correctly for these.

In this project, we are going to make an estimation of the probabilities and the risk of accident focusing in one aircraft, the Airbus 320 family, which includes A318, A319, A320 and A321.

We have divided it into four parts. The first part includes an introduction and a brief description of the Airbus company, and some specifications of each aircraft of the family with some main differences among them. The second part is a definitions section, in which we explain what is an accident and some key words to understand the project, and some concepts like definitions of phases of flight, undesirable events, natures of flight, categories of flight and airplane damages. The third part consist of an analysis of the database we have selected to study, also the analysis of an Airbus report of accidents between years 1958 and 2014, comparing the results of each range of dates. The last part consists on the calculation part, in which we obtain the probabilities of each accident occurred, the measure of the risk and the conclusions.

Introduction

Mainly, and before starting to carry out this project, it is very important to be aware of the development and the notable growth that such an important industry as aerospace has experimented.

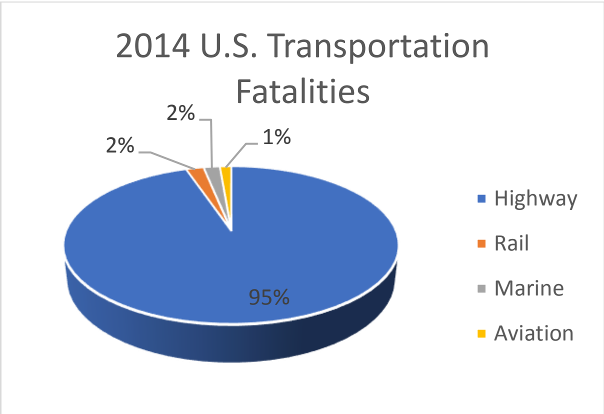
The aerospace industry has become, among other transports like the railway or automobile, one of the safest at the time of make a transportation, either of goods or people, either commercial or military.

The fact of this industry is considered one of the safest is due to all the effort and dedication of a group of organisations, whom are responsible of the regulation of the different laws and rules, as well as procedures, at the time of keep the security and make all the operations in this environment safer and avoiding any type of incident.

But, obviously, and as in any different type of transport, it is possible that some mishaps and unexpected situations could happen, which may imply difficulties at the time of the operations, even reach that point of having an accident.

Table 1 & Figure 1. 2014 U.S. Transportation Fatalities

2014 U.S. Transportation Fatalities	
Transport	Fatalities
Highway	32744
Rail	698
Marine	643
Aviation	454



If we access to the database of National Transportation Safety Board [1], which is an independent organization of the United States Government whose mission is investigate all different accidents referred to the aviation, automobile and marine fields, we can see some information about the accidents of each transport which have had any fatalities:

As we can check in the graphics above, in the United States, during the 2014, only one percent of the fatalities was resulted in the aviation industry.

The aviation field is very complex due to it is under so much rules and regulations, which ones must be obeyed, in order to all operations are performed as schematised and organised as possible, and avoid any type of incident.

But these accidents do not always depend on the compliance of rules, because there are much more factors what makes the operations safer or not. In this case, I allude to factors like adverse weather, human factors…

Due to this fact, studying carefully each accidents and occurrences which happen in aviation field is very important, because it involves analyse the failures occurred and the causes of them, which let us take some rules and measurements to avoid these accidents happening twice, and getting the accident risk lower at this industry. Also, is important to know that this measurement and rules changes involve economic outlay, therefore we can get an idea of the wealthy of this industry.

Then, anyone could be interested in the risk of accident during a flight, so this is the aim of this project, at which we will examine the risk of accident in particular aircraft. In our case, we have chosen the aerospace company of Airbus, and we will focus on the species A319/320/321 to realise the proper studies.

We will take one database of Airbus accidents found on internet [2], and we will compare it with reports done by Airbus of other years to evaluate the improvements of the security.

But first, we would like to introduce briefly in the history and the considered fleet of Airbus, we will explain some important characteristics of aircrafts under study, and also differentiate the subspecies of each aircraft.

Airbus' history

Airbus is one of the leaders in aviation field, and with such a high influence. This company, with headquarters on Toulouse, France, has such a wide catalogue of products, which comprise families with a high success.

For getting an idea of how this company works is important to know that it consists of over 55.000 employees around the world. The importance of this company is observed on countries it cooperates with, like United States, Japan, India… It relies with some formation and engineering centres, over 150 services offices around the world, and commercial relations with over 7.700 international suppliers.

The company was founded in 2001 in Toulouse, France, as a Society by Simplify Actions (Société par Actions Simplifiée), and working before as a company responsible for coordination of the assembling, design and sale process.

It started with a memorandum by United Kingdom, Germany and France with the objective of designing a 300 passenger aircraft. After some indecisions by United Kingdom, and the participation of Spanish company CASA, in 1971 it consolidated the committee composed by Aèrospatiale, CASA and Deutsche Aerospace to create EADS, closing the group the incursion of BAE Systems PLC (British Aerospace) in 1979.

The first model created by the committee was the A300 in 1972, which did not have the expected success, even it caused a critical stage in Airbus. Later the A310 was introduced, with smaller size.

In 80s, two more variants of created models were presented, but the most important fact was the appearance of A320 with the innovation of install electrics wires (fly-by-wire), doing it without hydraulic conductions. This model had great success, competing with B737 of Boeing.

Varieties of this model were designed: the A321, higher than A320, and later the A318 and A319, smaller.

In the following section, we are going to focus in this last family of aircrafts, what has been one of the most successful of the company and therefore it has been the objective of this projective.

Airbus 320 Family

This family comprise 4 types of aircrafts with different variants, depending on the size of the aircrafts, and provides sites for 100 until 240.

A318

This model offers the advantages which characterize the A320 family, and it is the smallest model, with high fuel efficiency, security and comfort.

We will not consider this model in the analysis of the accident risk because we do not have any signals nor information of accidents suffered by this airplane type.

Figure 2. Airbus 318

A319

It is a shorten version of A320, only with one aisle. Its transversal section is the same than the rest of the family and is the most width single aisle in the market, so it offers a very high comfort to the public. Moreover, it is the aircraft with more range of the family, due to the possession of the same fuel tanks with less passengers.

Figure 3. Airbus 319

It has 6 emergency exists, or 8 in the configuration with kitchen. The number of passengers varies depending on the selected configuration: 124 with two-classes system, or a maximum of 156 without kitchens and 2 more emergency exits.

We can distinguish three series of A319:

- A319-100: It is the standard model of A319, but differs with A320 because it is 3.73 meters shorter.

- A319-CJ: It is the executive version, with three additional fuel tanks, increasing its autonomy until 12.000 Km. Its capacity is over 39 passengers.
- A319-LR: This variety is the monoclass executive version, with an autonomy of 8300 Km.

A320

One of the main causes of this airplane has become one of the most successful in market is because be considered as one of the airplanes most comfortable in the short-medium range category. It consists of a wide cabin with one aisle.

Figure 4. Airbus 320

In this case, it has composed by 8 emergency exits, its maximum capacity is 220 passengers and the range goes from 3.100 to 12.000 Km, according to the variant.

We have two species of this type:

- A320-100: It is the original version, but the production of it was not very high because the later version was similar, but with reduced weights. Currently, there are no operative aircrafts of this specie due to they have been broken up or collected.
- A320-200: In this aircraft was introduced the modernization of the sharklets (tip device destined to improve the fixed wing airplane efficiency), and the increasing of fuel capacity.

A321

Figure 5. Airbus 321

We can characterize this model because of being the model with longest fuselage, with single aisle, and could take up to 185 passengers in two-classes configuration and a maximum capacity of 220. It has also 8 emergency exits.

The series of this model are:

- A321-100: It was the first variety of this type, so it was improved to reach the following innovation, the 200 serie.

- A321-200: This specie differs with 100 serie because it has higher range, higher power of the engines and an installation of one or two optional fuel tanks apart from the other two installed yet.

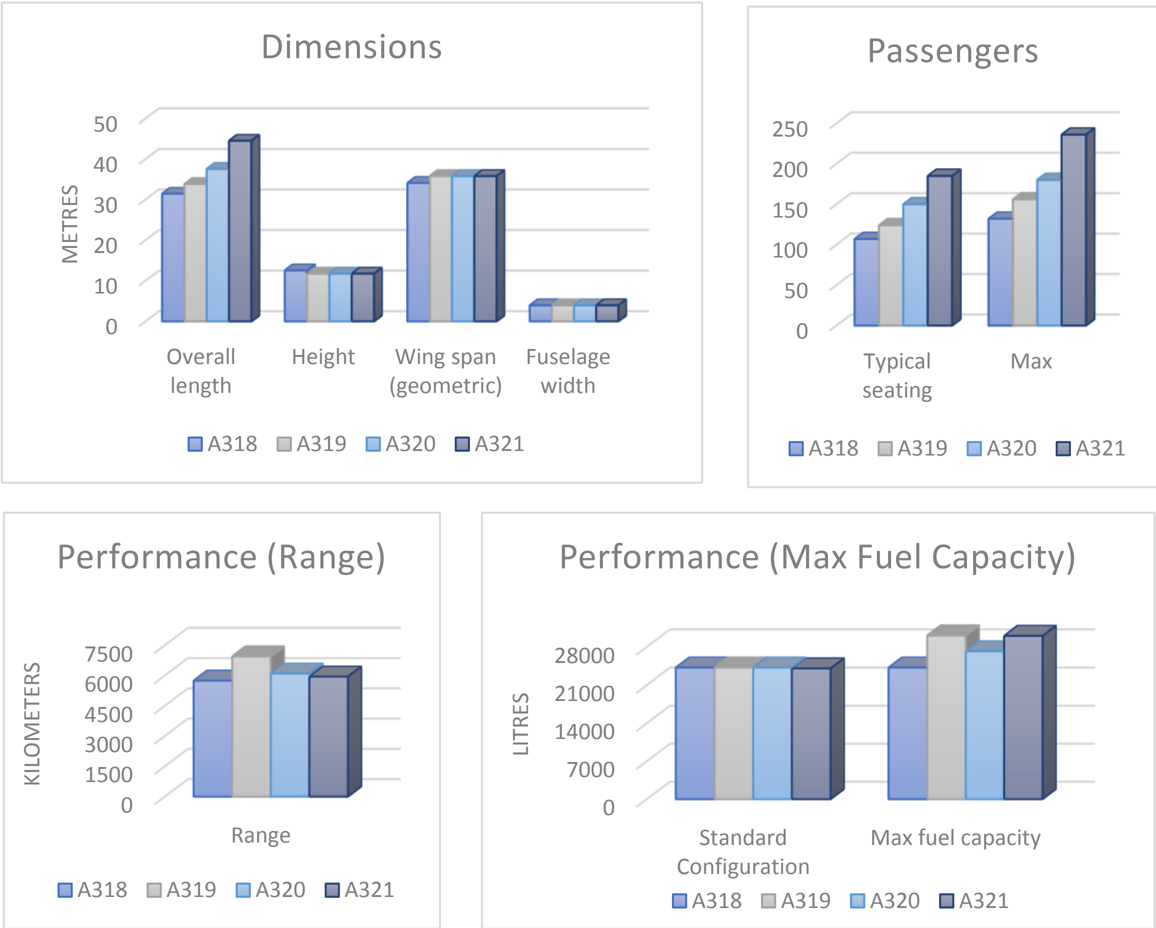
In the next table, we can see some specifications of each model in the family:

Table 2. Specifications of A320 Family

Models			A318	A319	A320	A321
Dimensions	Overall length		31.44 m	33.84 m	37.57 m	44.51 m
	Height		12.56 m	11.76 m		
	Wing span (geometric)		34.10 m	35.80 m	35.80 m with Sharklets	
	Fuselage width		3.95 m			
Capacity	Pax	Typical seating	107	124	150	185
		Max	132	156	180	236
Performance	Range		5 750 km	6 950 km with Sharklets	6 100 km with Sharklets	5 950 km with Sharklets
	Max fuel capacity		up to 24 210 litres	up to 24 210 (30 190) litres	up to 24 210 (27 200) litres	24 050 (30 030) litres

And in the diagrams below the evolution of some specifications according to development during the year:

Figure 6. Specifications of A320 Family



As we have said, the length of the aircrafts increases with the model, while the fuselage section is the same for all the models. About the height and the wing span, the A318 differs on a higher height and less wing span, but with minor differences.

Obviously, the capacity of the family gets higher with the model, the same as the size of the aircrafts.

The range, as we have mentioned, is higher for A319 model, and it is cause the higher fuel capacity and less weight than preview models.

It is important to explain why this family has been such a revolutionary and successfully. A great part of this is due to the use of the control system fly-by-wire. This control system is one of the main advantages of Airbus competitiveness. This system replaces conventional controls of manual flight with an electronic interface, so the flight movements are converted to electric signals, and the flight control devices (computers) determine the movements must be effectuated by the actuators of each control surface, resulting on the ordered response.

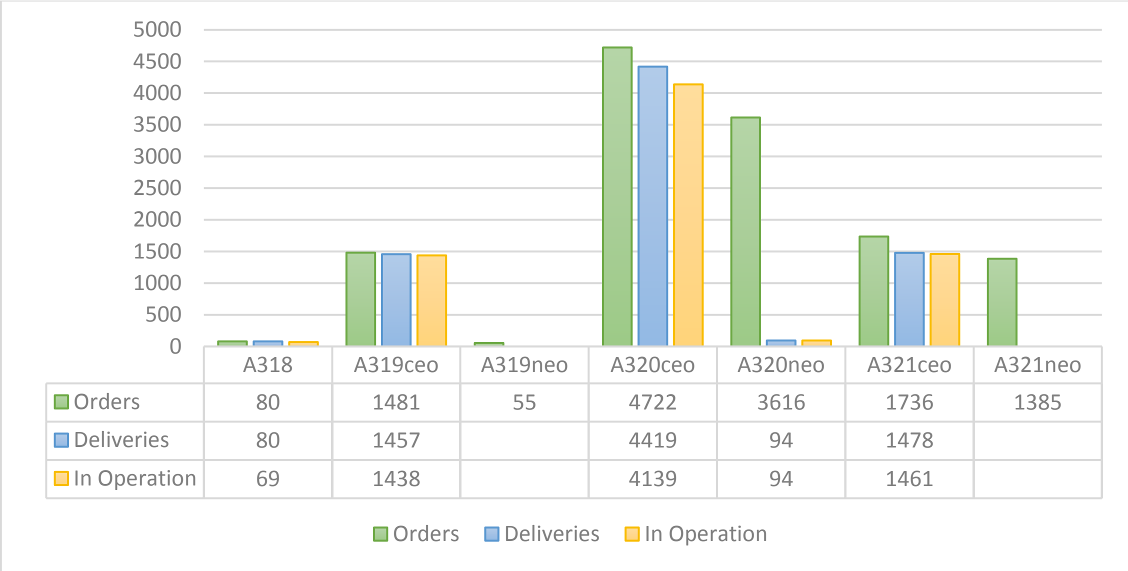
This control system has upgraded considerably the security in flight, it has reduced the load of pilot working and, mechanic parts…

Airbus 320neo

Airbus company is developing its last innovation: A320neo (New Engine Option). This new improvement is being applied to other models A319 and A321. The main idea of it is the change of aircraft engines, so aircrafts would reach less fuel consumption and also less impact in the environment.

We can see the demand of this family in the following graphics, using the source [3]:

Figure 7. Orders, deliveries and airplanes in operation

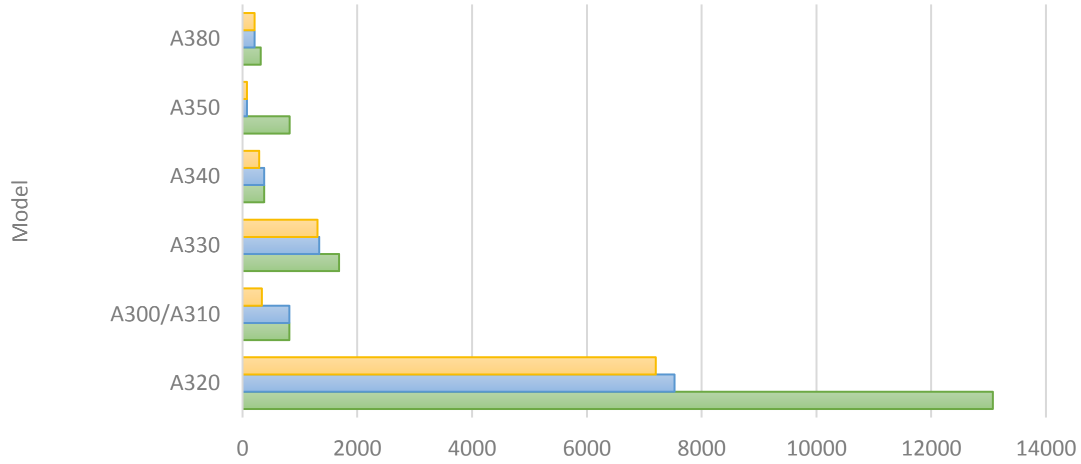


	A318	A319ceo	A319neo	A320ceo	A320neo	A321ceo	A321neo
Orders	80	1481	55	4722	3616	1736	1385
Deliveries	80	1457		4419	94	1478	
In Operation	69	1438		4139	94	1461	

The clear idea we could get from the drawings is the higher demand of the A320 model, and then the demands of the other species. We can also know that the innovation of the new aircrafts has made to the airliners to grow their interests in this new configuration aircrafts. Clearly, the lowest specie demanded of the family is the A318 due to the currently appearance of series A320 and their next innovations.

If we compare the information about the demands of the family with the other families, we can see the following drawing:

Figure 8. Orders, deliveries and airplanes in operation (Families)

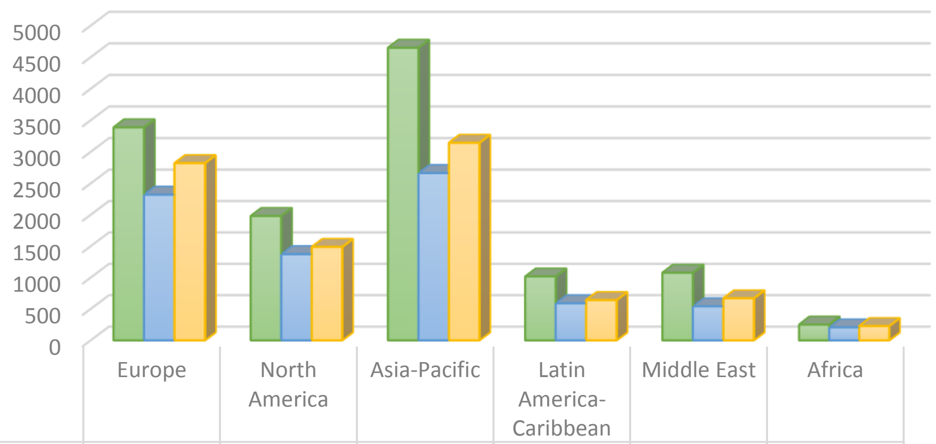


	A320	A300/A310	A330	A340	A350	A380
Aircrafts in operation	7201	337	1306	290	77	210
Total deliveries	7528	816	1336	377	77	210
Total orders	13075	816	1682	377	821	317

Then, with this we check that the family A320 has been the most successful and demanded over all designed and created aircrafts by Airbus.

Taking into account the origin of the different airliners, we could know what is the precedence of the airliners with more demand and operative aircrafts:

Figure 9. Orders, deliveries and airplanes in operation (Continents)

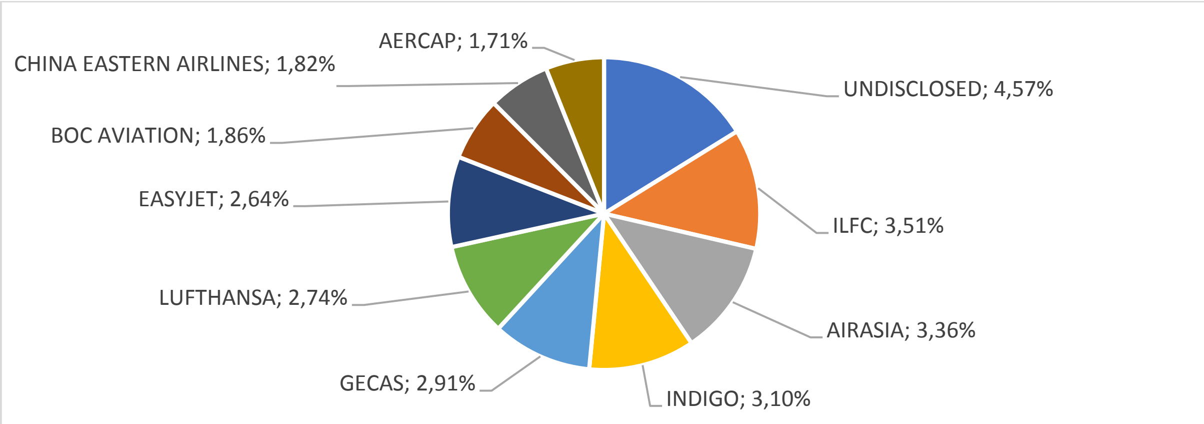


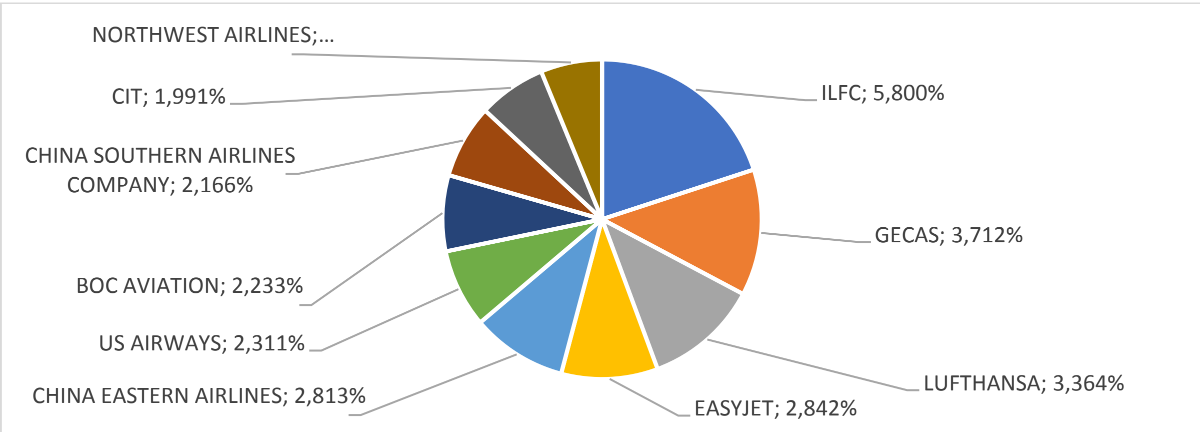
	Europe	North America	Asia-Pacific	Latin America-Caribbean	Middle East	Africa
Orders	3388	1981	4649	1017	1076	251
Deliveries	2321	1373	2664	590	542	206
In operation	2821	1488	3144	641	669	227

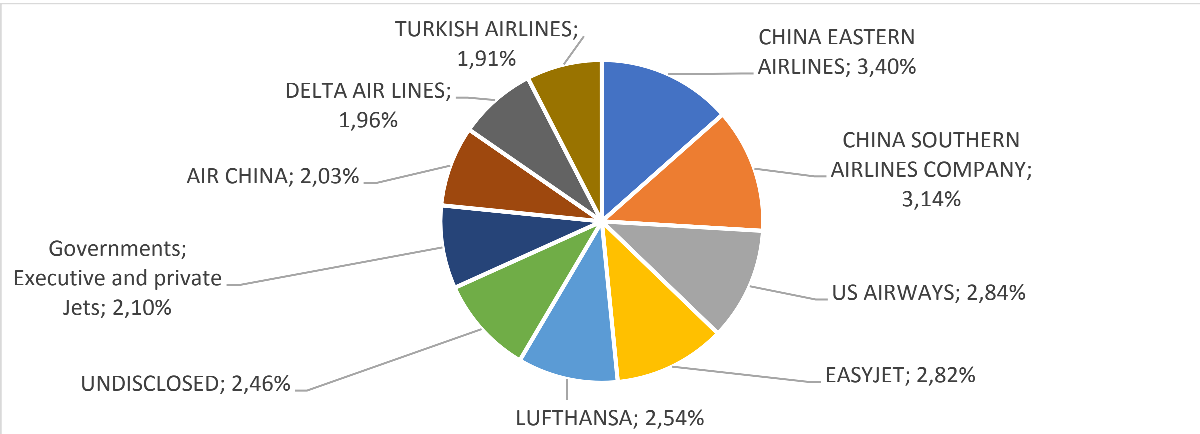
So, it is easy to see that the continents with higher demands are, from the most demanded, the Asiatic, European and North American companies. Under these three continents, we have the companies from Middle East, Latin-American and Africa.

Now, we can also know the airliners with more deliveries and with more active aircrafts until the present:

Figure 10. Orders, deliveries and airplanes in operation (Airliners)







It is possible to check that airliners with higher demand and higher number of operational aircrafts are those whose headquarter are in North America and European continents, and much more in Asia.

Basic definitions

Before focusing on the topic of the project, we should know some important concepts for well-understanding about we are talking.

In first place, the aim of the report is the study of the accident risk of one determined fleet, so we must know so well the concept of accident, what is no the same as incident.

According with International Civil Aviation Organization (ICAO) [4]:

Accident. An occurrence associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which:

a) a person is fatally or seriously injured as a result of: — being in the aircraft, or — direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or — direct exposure to jet blast, except when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew; or
b) the aircraft sustains damage or structural failure which: — adversely affects the structural strength, performance or flight characteristics of the aircraft, and — would normally require major repair or replacement of the affected component, except for engine failure or damage, when the damage is limited to the engine, its cowlings or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin; or
c) the aircraft is missing or is completely inaccessible.

Incident. An occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation.

It is important to say that the incidents are always a preview advise of an accident, so that is the importance of studying and prevent them in the future.

Then, it is possible to assume an accident as the transition between status of danger and loss, including human losses. An accident is considered as catastrophe when it carries remarkable losses, like so much fatalities.

About the risk, we could consider so many definitions such as:

- Likelihood that a harmful consequence (death, injury or illness) might result when exposed to the hazard.
- Probability of a future loss.
- Possibility of incurring specified loss (damage) in a definite period of life or during a particular activity due to various kinds of incidents or undesirable events, that may occur in the M-T-E system.

Said this, an accidents could be considered as an undesirable event, defined as an event whose occurrence in the M-T-E system could result in a exposure of danger for a propierty or a human. Then if we do not act correctly, it may carry any loss of damage.

We have talked about the M-T-E system but we have not commented anything about what it consists. This name comes from their three components: Man, Technology and Environment. It consists in a group whose elements may cause any type of undesirable event: by human errors, errors or system wrong performance of the airplane or by natural disasters like storms, hurricanes…

Once these concepts have been explained, we can conclude that for prevailing the security over the danger, we must decrease the risk of accident, and for getting it, the most important thing to do is study all the consequences and all factors which have had influenced in the accident, then we could avoid it in future occasions.

Doing this task is the objective of some organizations whose responsibilities are the reliability and the security in the aviation, so that it has a cooperation between them to establish rules and laws and maintain the security and make possible to avoid any mishap could happen during operation.

Some of these very important organizations are:

- International Civil Aviation Organization (ICAO) [5]: It consists on a specialized organism under ONU influence, created by United States in 1944. It works with 191 state members and with groups of the industry with the aim of reach the consensus about rules and recommended methods (SARPs) for the international aviation, so that the aviation sector was operationally safe, efficient and protected, economically sustainable and environmental responsible.
- Federal Aviation Administration (FAA) [6]: It is an agency of Transport Department of the United States with the authority of regulate and supervise all civil aviation aspects. It focuses basically on regulations in the United States. It was founded in 1958
- European Aviation Safety Agency (EASA) [7]: This organization consist of 32 countries, 4 of them non-belonging to European Union, and was created in 2002, and it has the objective of ensure the maximum security level for the citizens and the environment, make easier the internal market of the aviation…

These three organizations are the some of the most important and influential actually.

Now, we will try to explain the various categories in which we will be able to distinguish and classify the accidents, like the nature flight, the phase of flight in which the occurrence happens, the classification of the accident by the cause of it…

Nature flight

The first category to study is the nature of the flight. We can distinguish a lot of categories of the nature flights, but we are going to study only the categories which characterize our A-320 family accidents under study. So, we can define the following nature flights:

Domestic Scheduled Passenger: In these flights, the departure and the arrival occur in the same country, and it basically consist on the transport of people for different causes like business, holidays or short-term travels. These flights operate regularly and are planned a long time before.

Domestic Non-Scheduled Passenger: In this case, the flights are also considered to realise the departure and the arrival at the same country to transport passengers, but the difference is that they are not planned with so much time before. We can include in this group flights operated by tour companies, in which the flight ticket is usually included in the price of the package offer and are planned in a brief time, for example, for holiday periods.

International Scheduled Passenger: The definition of this nature type is the same as the domestic scheduled passenger, except that these flights take off and land in different countries.

International Non-Scheduled Passenger: As we can know intuitively, these are flights which departs in one country and land in other different country, and they are planned without so much time before, for example and as I have said before, planned holiday in other country by a company with all the trip organised.

Phase of flight [8]

If we take the report of the Airbus 320 family accidents between years 1958-2014, we can see the classification of the phases of flight considered by the Airbus company at the time of analyse the accidents, so we will take this classification to our analysis, with some modifications using the ICAO report of data definition standards. We can differentiate the following phases:

Standing (STD): The phase of flight prior to pushback or taxi, or after arrival, at the gate, ramp, or parking area, while the aircraft is stationary.

Taxi (TXI): The phase of flight in which movement of an aircraft on the surface of an aerodrome under its own power occurs, excluding take-off and landing (ICAO Annex 2). We include in this phase:

- → Pushback/ Towing (PBT): The phase of flight when an aircraft is moving in the gate, ramp, or parking area, not under its own power, but assisted by a tow vehicle.
- → Power back: The aircraft is reversing under its own power from the parking position.
- → Taxiing to/from runway: The phase of flight, after reaching the movement area, when the aircraft progresses under its own power to the departure runway, or post-flight moves under its own power after leaving the landing runway.

Take-off (TOF): The phase of flight from the application of take-off power until reaching the first prescribed power reduction, or until reaching the VFR pattern or 1000 feet (300 metres) above runway end elevation, whichever comes first or the termination (abort) of the take-off. We will consider in this section:

- → Take-off run: The phase of flight from the application of take-off power, through the take-off roll and rotation up to 35 feet [12 metres] above runway end elevation or until gear-up selection, whichever comes first.
- → Rejected take-off: The phase of flight in which any attempt is made to terminate a take-off between the application of take-off power, through rotation and up to 35 feet [or 12 metres] above the elevation of the runway end (from the point where the decision to abort has been taken until the aircraft begins to taxi from the runway).

- → Initial climb (ICL): From the end of the Take-off run sub-phase to the first prescribed power reduction, or until reaching 1000 feet above runway elevation or the VFR pattern, whichever comes first.

En-route (ENR):

Instrument Flight Rules (IFR): From completion of Initial Climb through cruise altitude and completion of controlled descent to the Initial Approach Fix (IAF).

Visual Flight Rules (VFR): From completion of Initial Climb through cruise and controlled descent to the VFR pattern altitude or 1000 feet above runway elevation, whichever comes first.

- → Climb to cruising level or altitude: Climb to Cruise:
  IFR: From completion of Initial Climb to arrival at initial assigned cruise altitude.
  VFR: From completion of Initial Climb to initial cruise altitude.
- → Cruise: The phase of flight from the top of climb to cruise altitude, or flight level, to the start of the descent toward the destination aerodrome or landing site. Any level flight segment after arrival at initial cruise altitude until the start of descent to the destination.
- → Initial descent:
  IFR: Descent from cruise to either Initial Approach Fix (IAF) or VFR pattern entry.
  VFR: Descent from cruise to the VFR pattern entry or 1000 feet above the runway elevation, whichever comes first.

Approach (APR): The phase of flight from the outer marker to the to the point of transition from nose-low to nose-high attitude immediately prior to the flare above the runway [IFR]; or [VFR] from 1000 feet (300 metres) above the runway end elevation or from the point of VFR pattern entry to the flare above the runway.

- → Initial Approach: From the Initial Approach Fix (IAF) to the Final Approach Fix (FAF).
- → Intermediate approach: The phase of flight between the middle approach fix and the final approach fix; or between the end of a reversal procedure or dead-reckoning track procedure and the final approach fix.
- → Final approach: that part of an instrument approach procedure which commences at the specified final approach fix or point
- → Missed approach or go-around: From the first application of power after the crew elects to execute a missed approach or go-around until the aircraft re-enters the sequence for a VFR pattern (go-around) or until the aircraft reaches the IAF for another approach (IFR).

Landing (LDG): The phase of flight from the point of transition from nose-low to nose-up attitude, immediately before landing (flare), through touchdown and until aircraft exits landing runway, comes to a stop or when power is applied for take-off in the case of a touch and-go landing, whichever occurs first.

- → Level off-touchdown: The phase of flight from the point of transition from nose-low to nose-up attitude, just before landing, until touchdown.
- → Landing roll: The phase of flight from touchdown until the aircraft exits the landing runway or comes to a stop, whichever occurs first.

Therefore, we have a classification above using the Airbus report [9] classification and the data standards of ICAO [10].

Category [11]

The following classification is made to distinguish the type of the occurrence. We will differ the occurrences with a letter and a number; the letter will indicate the type of the occurrence, and the number will mean the damages suffered depending on the consequences:

Accident, *A*: The definition is well explained in the section of basic aspects.

Incident, *I*: It is also explained in the section of basic aspects too.

Hijacking, *H*: Means the unlawful seizure or wrongful exercise or control of the aircraft (or the crew thereof).

Criminal occurrence, *C*: In this case, we can consider a criminal occurrence as an action in which a modification or irruption in external operations try to obtain a benefit for yourself. Examples of this occurrences could be a sabotage or a shot down.

Other occurrence, *O*: Safety occurrences that cannot be defined as 'accident', or 'incident'. Usually these cases involve aircraft being damaged (beyond repair) on the ground as a result of hurricanes, typhoons, sabotage, hangar fires etc.

Hull- loss, 1: Airplane damage that is beyond economic repair. Hull loss / write-off also include events in which:

- → Airplane is missing.
- → Search for the wreckage has been terminated without it being located.
- → Airplane is substantially damaged and inaccessible.

Repairable damage, 2: In this classification, we have the accidents which only need some repairs to make the aircraft available to continue its operations.

Airplane damage [12]

Now, we can classify the accidents by the amount of damage as a result of the occurrence. We should know:

None: This is the group of the aircrafts which did not suffer any type of damage in despite of the occurrence.

Substantial: Damage or failure that adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which would normally require major repair or replacement of the affected component. Not considered in substantial damage are; engine failure or damage limited to an engine only, bent or dented skin, damage to landing gear (to include wheels and tires), flaps, or wingtips.

Damaged beyond repair: This classification of the accidents involves the group of aircrafts which have not had the possibility of flight beyond repair.

Destroyed: In these accidents, the aircraft is not repairable, or, if repairable, the cost of repairs exceeds 50% of the cost of the aircraft when it was new.

Minor: Damage that neither destroys the aircraft nor causes substantial damage.

Classification by the cause (Undesirable events) [13]

Before explaining the last classification of the accidents, is important to know the meaning of a relevant concept: undesirable event, and it will be important in coming sections to study the risks of accidents. An undesirable event could be described as an event, which occurrence in a considered M-T-E system, could result in physical hazard to humans or other ecosystems, wherein these events can be observed with sense data [14].

We are going examine a group of undesirable events which could happen without notice, to know what are the most common undesirable events and which of that we should be awareness to avoid the consequences.

There are a lot of classifications of the accidents causes, or in other words, undesirable events but we have taken a similar classification to the applied in the Airbus accidents report. So, we can differ some events:

System/Component Failure or Malfunction (SCF): Failure or malfunction of an aircraft system or component.

Usage Notes:

- Includes errors or failures in software and database systems.
- Includes failures/malfunctions of ground-based launch or recovery systems equipment.
- Includes all failures/malfunctions, including those related to or caused by maintenance issues.

Abnormal Runway Contact (ARC): Any landing or take-off involving abnormal runway or landing surface contact.

Usage Notes:

- Events such as hard/heavy landings, long/fast landings, off centre landings, crabbed landings, nose wheel first touchdown, tail strikes, and wingtip/nacelle strikes are included in this category.
- Gear-up landings are also recorded here.
- Do not use this category for runway contacts after losing control.
- Occurrences in which the gear collapses during the take-off run or the landing roll are not included here except if a condition in the usage notes above has been met.

Runway Excursion (RE): A veer off or overrun off the runway surface.

Usage Notes:

- Only applicable during either the take-off or landing phase
- The excursion may be intentional or unintentional.

- Use RE in all cases where the aircraft left the runway/helipad/helideck regardless of whether the excursion was the consequence of another event or not.

Loss of Control in Flight (LOC-I): Loss of aircraft control while or deviation from intended flightpath inflight.

- Used only for airborne phases of flight in which aircraft control was lost.
- Loss of control can occur during either Instrument Meteorological Conditions (IMC) or Visual Meteorological Conditions (VMC).

Controlled Flight into Terrain (CFIT): Inflight collision or near collision with terrain, water, or obstacle without indication of loss of control.

Usage Notes:

- Use only for occurrences during airborne phases of flight.
- Includes collisions with those objects extending above the surface (for example, towers, trees, power lines, cable car support, transport wires, power cables, telephone lines and aerial masts).
- Can occur during either Instrument Meteorological Conditions (IMC) or Visual Meteorological Conditions (VMC).
- Includes instances when the cockpit crew is affected by visual illusions or degraded visual environment that result in the aircraft being flown under control into terrain, water, or obstacles.

Ground collision (GC): Collision while taxiing to or from a runway in use.

Usage Notes:

- Includes collisions with an aircraft, person, ground vehicle, obstacle, building, structure, etc. while on a surface other than the runway used for landing or intended for take-off.

Hijack / Terrorism (H): Actions associated with terrorism activities, sabotages…

Fire (FI): Fire or smoke in or on the aircraft, in flight or on the ground, which is not the result of impact.

Usage Notes:

- Includes fire due to a combustive explosion from an accidental ignition source.
- Includes fire and smoke from system/component failures/malfunctions in the cockpit, passenger cabin, or cargo area.

Birdstrike (BS): Occurrences involving collisions / near collisions with birds.

Midair collisions (MAC): Airprox, ACAS alerts, loss of separation as well as near collisions or collisions between aircraft in flight.

Usage Notes:

- Includes all collisions between aircraft while both aircraft are airborne.

- Both air traffic control and cockpit crew separation-related occurrences are included.

Turbulences (TURB): In-flight turbulence encounter.

Usage Notes:

- Includes encounters with turbulence in clear air, mountain wave, mechanical, and/or cloud associated turbulence.
- Wake vortex encounters are also included here.

Undershoot (USOS): A touchdown off the runway surface.

Usage Notes:

- An undershoot/overshoot of a runway/helipad/helideck occurs in close proximity to the runway/helipad/helideck and also includes offside touchdowns and any occurrence where the landing gear touches off the runway/helipad/helideck surface.

Fuel (F): One or more powerplants experienced reduced or no power output due to fuel exhaustion, fuel starvation/mismanagement, fuel contamination/wrong fuel, or carburetor and/or induction icing.

Explanations:

- Exhaustion: No usable fuel remains on the aircraft.
- Starvation/mismanagement: Usable fuel remains on the aircraft, but it is not available to the engines.
- Contamination: Any foreign substance (for example: water, oil, ice, dirt, sand, bugs) in the correct type of fuel for the given powerplant(s).
- Wrong fuel: Fuel supplied to the powerplant(s) is incorrect, for example: Jet A into a piston powerplant, 80 octanes into a powerplant requiring 100 octane.

Risk and reliability of Airbus 320 fleet family

Before doing the analysis of our data of the last 20 years, we can make an overview of the accidents data between the years 1958 to 2014, for which the statistical analysis of Airbus Commercial Aviation Accidents [9] between that years are going to be used.

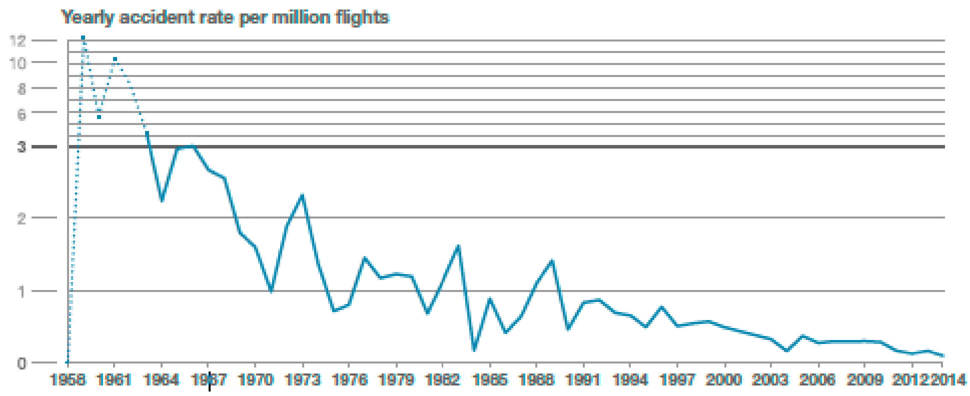
First, we can know by the report that, taking into account that tens of millions of flights each year are realised, the commercial aviation suffers the quantity between 2 and 13 fatal accidents depending on the year. For example, in the years of 2003, 20014 and 2005, the number of fatal accidents was 7, 4 and 9 respectively. From these data, we can conclude that the fatal accidents are occurred by many undesirable events, which some of them cannot be predicted.

In the case of the 2014, the number of flights reach 28.4 million, in which there have been 2 fatal accidents (0.07 accidents per million flights) and 9 hull-losses (0.32 accidents per million flights).

We can see the evolution of the accidents happened during the last years in the following graphs:

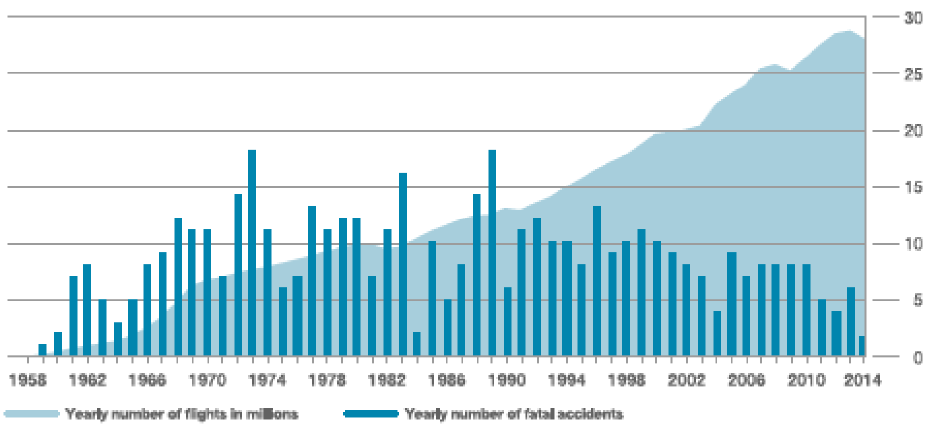
So, we can see the obvious idea of the accident rate per million flight decrease, what means that the air transport has become safer yearly.

Figure 11. Yearly accident rate per million flights (Fatal Accidents)



In the case of the fatal accidents per year, is easy to see the variability of the number of fatal accidents. It is due to what we have said before: these accidents are occurred by many undesirable events, so they could appear in any time. But it is important to look at the yearly number of flights: the number of it has increase a lot while the fatal accidents have experimented a decrease, what show the progress in the safety of the air transport.

Figure 12. Yearly accident rate per million flights (Hull losses)

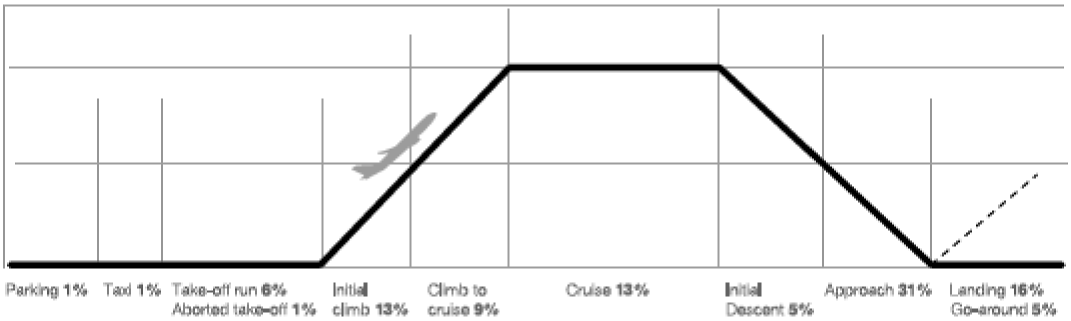


Regarding the hull losses in these years, the tendency of them are the same as the accidents: decreasing yearly and with perceptible changes on fatal accidents.

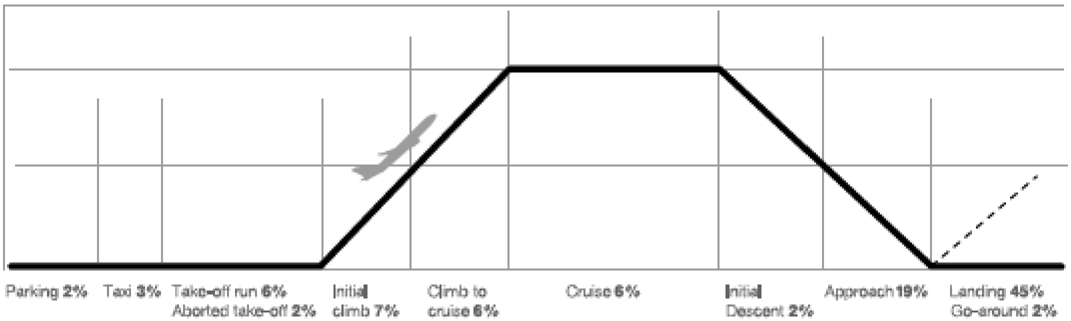
Considering the phase of flight, in Figure 13, there are also two graphs which show the percentage of fatal accidents and hull-losses respectively:

Figure 13. Accidents by phase of flight: a) Fatal accidents, b) Hull-losses

a)



b)

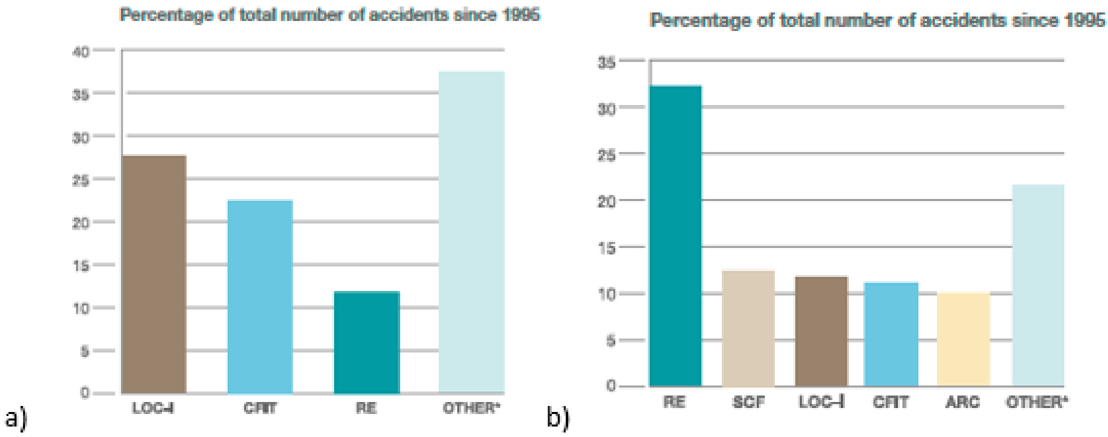


Both photos show basically the same percentages of the accidents with littles deviations, even if the most of hull-losses happen in the final phase of the flight, during landing, unlike the fatal accidents, where the most of them are occur in approach phase.

In conclusion, nearly 90% of the accidents in aviation are happened during the final phases of flight, as approach and landing are, also a significant percentage of the accidents are occurred during take-off and initial climb.

If we focus in the undesirable events, we have another two graphs which show the fatal accident (left) and the hull-losses (right):

Figure 14. Percentage of total accidents by undesirable event: a) Fatal accidents, b) Hull-losses



About the fatal accidents, most of the accidents are happened because of Loss of Control in Flight, followed by Controlled Flight into Terrain (CFIT) and the Runway Excursion (RE), while this cause of Runway Excursion (RE) is, in the most cases, the cause of a hull-loss, being the System/ Component Failure or Malfunction (SCF) the second most happened.

Checking these facts, is important to know what are the most repeated causes of the accidents: Loss of Control in Flight (LOC-I), Controlled Flight into Terrain (CFIT) and Runway Excursion (RE). During the last years, the data shows that the first two causes have decreased, however, the third cause keep around constant, with a slight decrease in the hull-loss accidents.

Database of A319/A320/A321

Now, it is the moment of the analysis of the Airbus Family A320. We are going to study only the accidents of the aircrafts A319/320/321 because of the lack of information of the A318 type. All the data has been got from the website Aviation Safety Network, whose aim is providing everyone with a (professional) interest in aviation with up-to-date, complete and reliable authoritative information on airliner accidents and safety issues [15].

The first task to do is collect all data of the accidents of the three aircrafts types, and classify them by different classifications as we have explained before. Then, we have got the table (It is possible to find it in Annex I), and we have the following categories:

- Date of the Accident
- First flight
- Airplane type and specie
- Occupants of the Aircraft
- Fatalities because of the accident
- Nature of the flight
- Phase of flight where the aircraft was at the during the accident
- Category of the accident
- Airplane Damage
- Undesirable event
- Total airframe hours

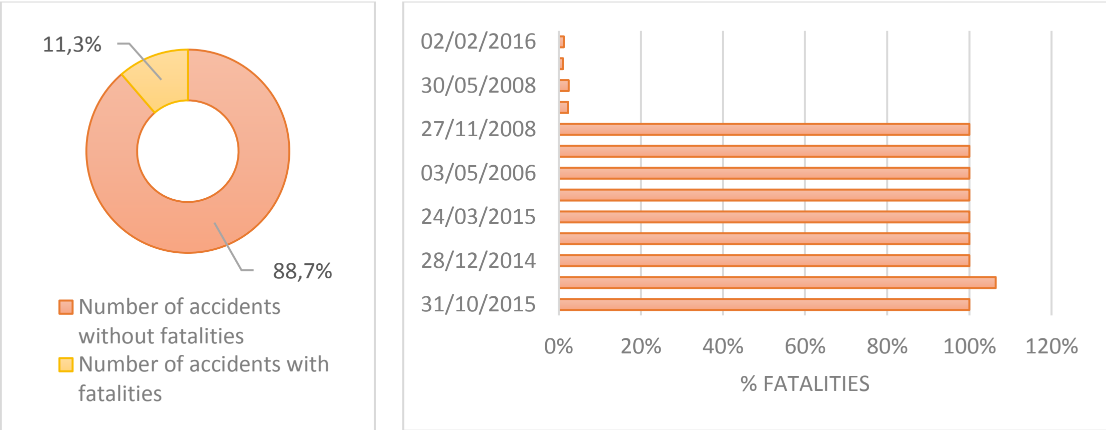
- Cycles
- Days flown

Our aim is study the different cases of accidents taken place during the last twenty years, so the first accident we have is in 1997. Until the present day, 106 accidents have been occurred, in which a little amount of that have had any fatality. In the following section, we could see the graph which shows the result.

Number of accidents

As we have said before, only 12 accidents of 106 have had fatalities, and in that accidents, there are different quantities of fatalities, what we can see in the following graphs:

Figure 15. Percentage of fatal accidents

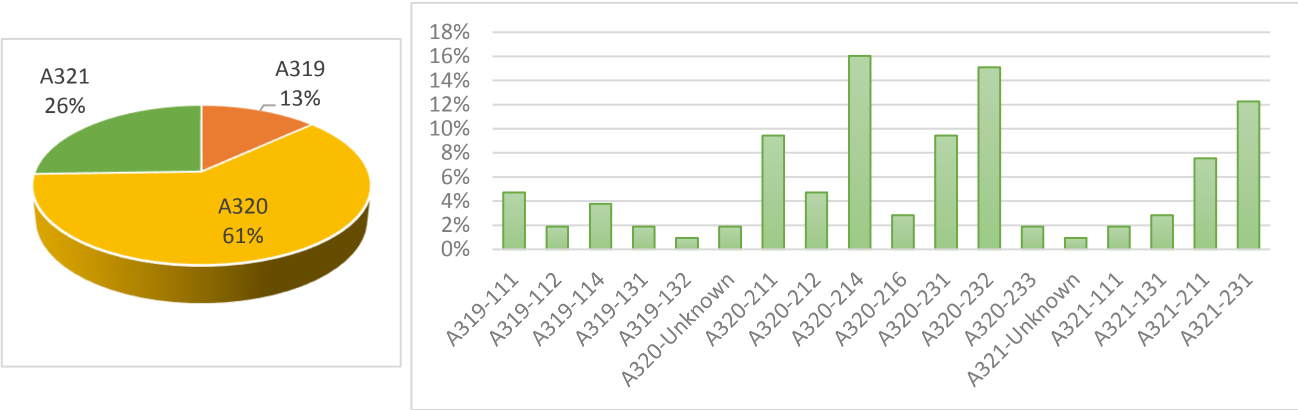


We have observed that most of the accidents don't have any fatalities, exactly the 88.7% of the total accidents. In the other hand, the 11.3% of the accidents have, at least, one fatality. In the diagram on the right, we could confirm that in most of the accidents, all people on board pass away: exactly in 9 accidents (in one of that, the accident caused fatalities also in the ground, that is why the percentage exceeds 100%), and in the rest of the accidents, only a quantity of people less than 3% passed away.

Accidents by the Aircraft type

We also know what species of the family suffered an accident. The following diagrams show the accidents of different varieties of each aircraft type:

Figure 16. Percentages of accidents by type

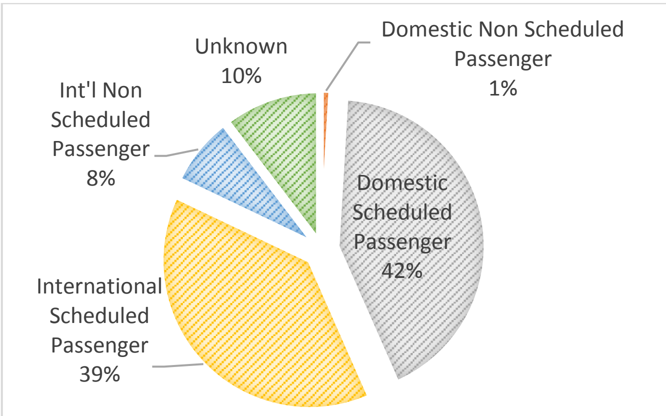


About the accidents depending on the aircraft type, the percentage of the A320 accidents is so much greater than the other, and it could be explained with the Airbus orders diagram shown in past sections. The orders of the A320 type are the highest contrasting with the other types, so the probability of having an accident with an A320 is higher if it is the type which operates more commonly.

Accidents by Nature of flight

The accidents distributed depending on the departure and arrival airport, if these are in the same country or not, or if these flights are planned with ahead of time, are presented in the following diagram:

Figure 17. Percentages of accidents by nature

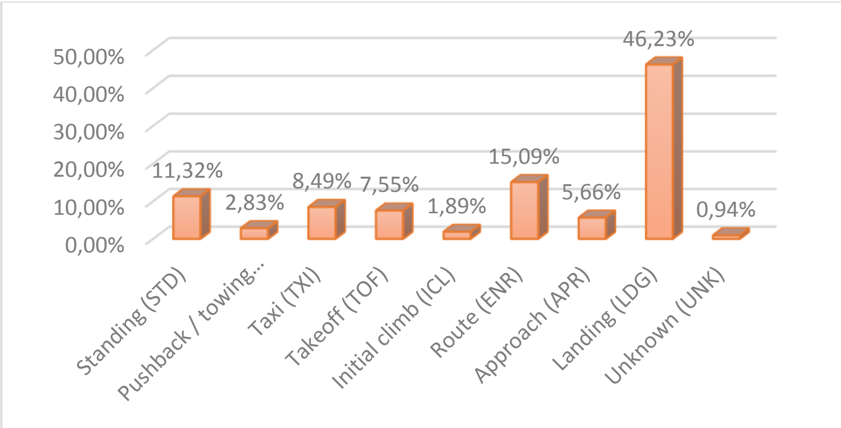


In this case, we have approximately the same accidents for international and domestic scheduled passenger flights. Most of the flights we take are scheduled in advance, either international or domestic flight. Consequently, the probability of having an accident of a scheduled flight will be higher than for non-scheduled, what are organised for special occasions.

Accidents by phase of flight

Now, we are going to contrast the accidents occurred in determinate phase of flight, and we could compare this results with the analysis made by Airbus report, mentioned in past sections. First, we should display the picture with phases of flight and their proper percentage:

Figure 18. Percentages of accidents by phase of flight



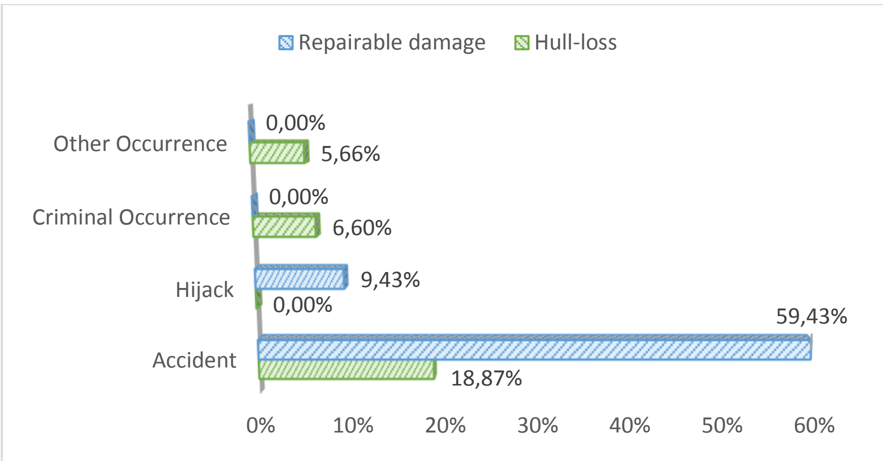
Clearly, landing is the phase with more problems at the time of realise it. Then, we have similar values of percentages for standing, route, taxi and take-off. In past sections, we observed that the most unfriendly phases to operate without problems were at the end of the flight, I mean, landing and approach, as the above diagram shows. There are also meaningful percentages of accidents during the initial phases.

In conclusion, during the years, the phase of flight which we should be more meticulous is, par excellence, the landing phase. It is possible that never changes, because most of the flight time may be operated with automatic pilot, and the moment when the pilot takes control could be the most probably accident time due to a human error, taking into account also the weather conditions, which could be adverse.

Accidents by category

In the present section, we will analyse the probability of suffer an accident by a hijack, an accident, an incident… and depending on the losses, if they are considered hull-losses or repairable damage. That being said, let's have a look to the diagram.

Figure 19. Percentages of accidents by category



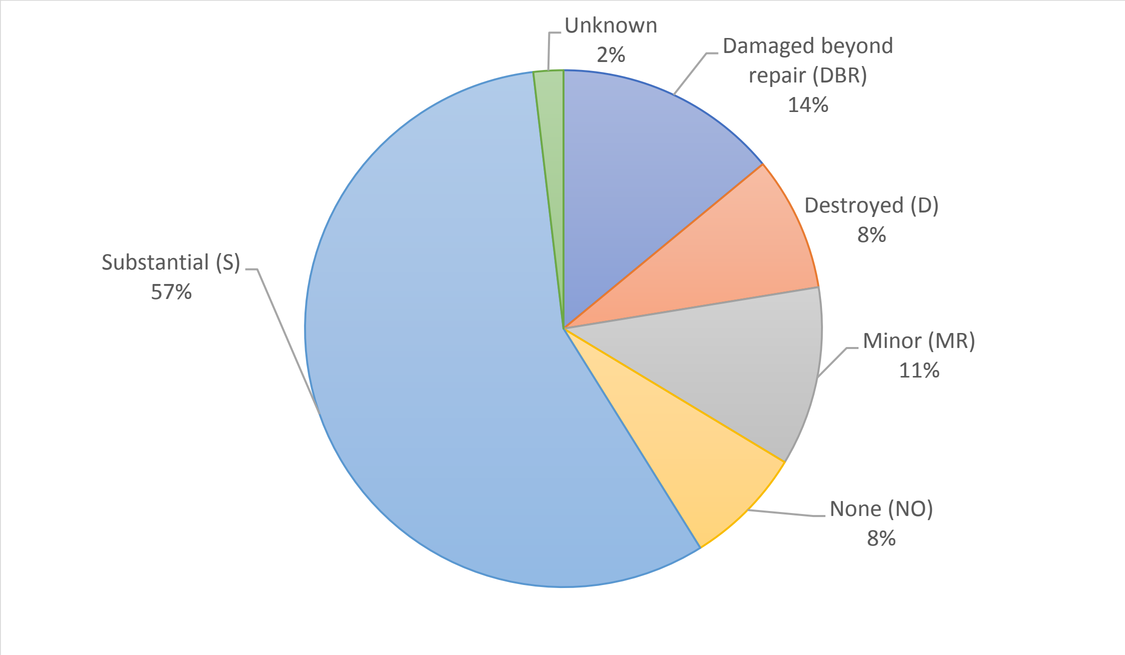
The greatest category of accident is the group of accidents, which are more common. Within this group, we have a clear vantage of repairable damage above the hull-loss.

Regarding the hijack, none of the accidents cause any hull-loss as contrast to repairable damage, and the criminal occurrences, fire and other situations only induced hull-losses.

Accidents by aircraft damage

Another way to classify the accidents, as we explained before, is by the damages as result of the accidents, depending on the aircraft conditions after the accident: if it is possible to make the aircraft operate again by reparations, or if the accident is named as hull-loss.

Figure 20. Percentages of accidents by aircraft damage



In this category, the aircrafts which have experienced substantial damages are predominant. We can support this result using the diagram of accidents by category. Most of the aircraft damaged are classify as repairable damage aircraft, it means the aircraft would be prepared to operate again after some reparations or renovations of appropriate pieces, what comes to be a substantial damage.

The following most popular damage is that one that after it the aircraft is recognised as inoperative, followed by minor damages and with equal percentages of destroyed and none damaged.

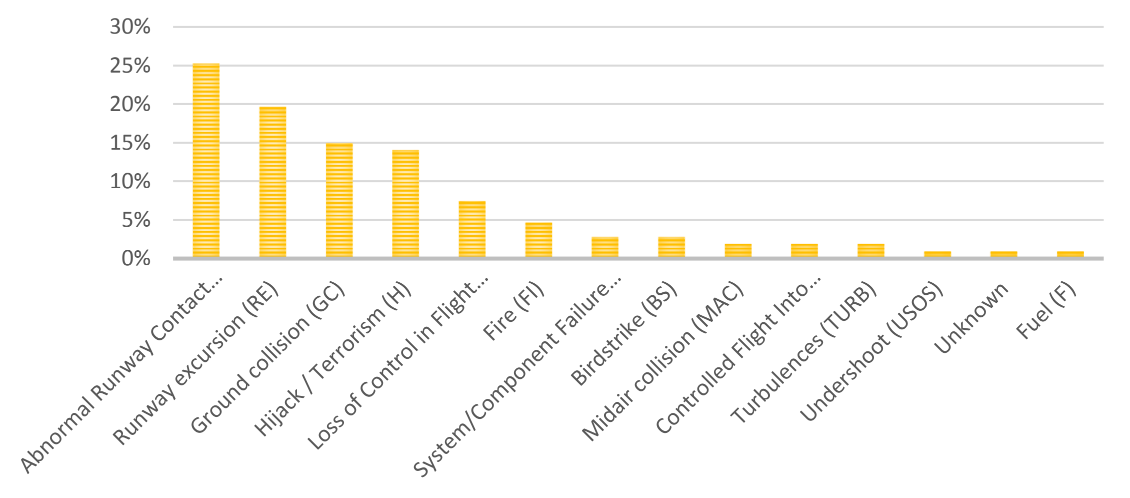
Concluding, the results say that if the aircraft experienced an accident, probably it suffers substantial damages, or could become inoperative.

Undesirable events

It is the moment to analyse the undesirable events the aircraft could suffer at any instant of flight. The result if an undesirable event take place could be very dangerous, from beat the adversities to experience a hull-loss, and they appear without any previous notify.

According to the classification taken after, we have the obtained diagram below:

Figure 21. Percentages of accidents by undesirable event



Majority of the accidents are produced by abnormal runway contact, runway excursion or ground collision. Comparing with the information from the Airbus report, the similarity between years 1958-2014 and the last 20 years is the predominant undesirable event of runway excursion.

If we contrast with the report effectuated by Airbus, we can conclude that the accidents due to abnormal runway contact, ground collision, hijack or terrorism have increased, while the cause of loss of control in flight has decreased, which was the predominant between years 1958 to 2014.

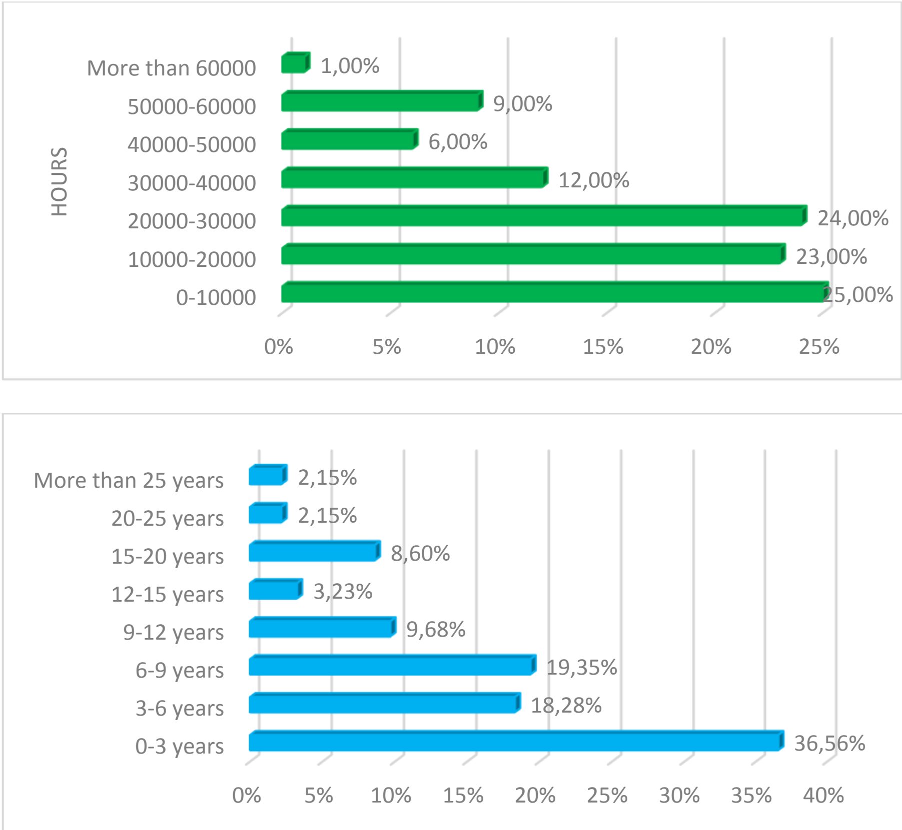
If we consider the same categories as Airbus report, which they call it *Others*, it exceeds the percentage of abnormal runway contact, which is the predominant, with a value of 43.4%. In the category of *Others* we would include: Ground collision, Hijack/ Terrorism, Fire, Bird, Air collision, Turbulences, Undershoot, Fuel and Unknown categories.

Lifetime until accident

The last probabilities we are going to calculate are depending on the flight time until the accident. The first task we have done for this category is to estimate the flight hours per day with the accidents we have their flight hours.

To estimate the flight hours per day of the accidents we do not have it, we only should make an average with the flight hours we have. Then, we calculate the operative days of the aircraft, subtracting the date of first flight to the date of the accident. Done it, we would have the lifetime of most of the aircrafts and the total airframe hours. Finally, we have collected all data in two diagrams: one of total airframe hours, and another one with the lifetime until the accident; for this second diagram, we have assumed months with 30 days.

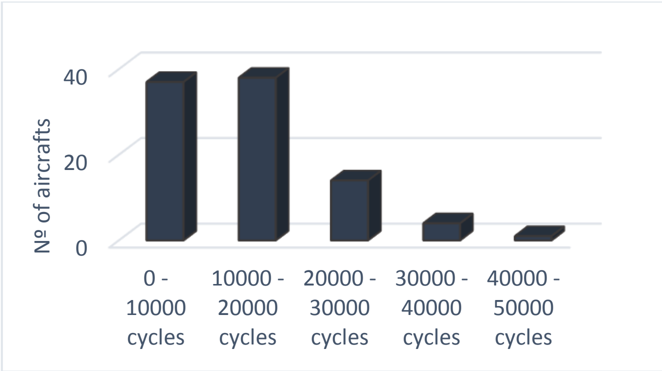
Figure 22. Percentages of accidents by lifetime



Obviously, the results are as we expected. Logically, the probability of having an accident increase with the antiquity of the aircraft and increase as much as airframe hours do. A little quantity of aircrafts exceeds 20 years of life, and the most of them have an accident during their three first years of operation.

It is possible to present a third diagram which shows the number of cycles realized by the aircraft until the accident. We can characterize a cycle as the total number of take-offs and landings at the time of the accident, so we could treat this category as the number of flights. Then, the following picture present the number of aircrafts classify by cycle interval until the accident:

Figure 23. Percentages of accidents by cycles



As we waited for, in most of cases, the aircrafts suffer accidents in their first years of operation, most common between 0 and 20000 flights, while a very little quantity of airplanes reach a high number of flights. Despite this, generally we could consider that these airplanes keep in operation for a long time.

Analysis of results

In this section, we are going to analyse the probabilities of the accidents, depending on the phase where the aircraft is operating and the undesirable event which excites the accident among others.

It is important to have some assumptions before doing all the calculations, because we are working with so much information and the clarifying of them will be so good for our understanding.

One of the most important task in this project is to know: the total number of flights operated and the number of the accidents happened between two dates. As we have known before, we have taken the information of 20 years, but it is not so right. We started to analyse the data from 1/1/1997, that is clear, but we took the data until the last accident, which was in 2/4/2017. So, we do not have only 20 years, but we have some days more. The program used is the Microsoft Excel and when we are working with dates, all functions of it treats years of 360 (in our case, we will use 360 days), and months of 30 days. So:

First Date Considered: 1/1/1997 Last Date Considered: 2/4/2017

Using the function *DIAS* (*DAYS* in English), the program gives back the dates between that dates, and if we take this days and divide them by 365 (days in one year) we have:

Days Considered: 7396 Years Considered: 20.263

Another task we will need in the future calculations is the obtaining of the average airframe hours per day and cycles per day, and with them, we will be able to estimate the total flights in the considered time. This calculation was explained briefly in the section *Lifetime until accident*: it is simply to take the difference dates of first flight and the accident to obtain the operation dates, and then divide total airframe hours these operation days to obtain the average airframe hours per day. About the average of cycles per day, we will take the cycles and the operation days, and following the same process as before, we obtain the cycles per day. Done it, we have got these values:

Average Airframe Hours per Day: 7.2 Average Cycles per Day: 4.2

The next step is to obtain the total number of flights, but first we need the aircrafts which have operated during the last 20 years. Because knowing the number of active aircrafts is a very hard task, and probably we will not get the true amount, we have made our own assumption.

We have consult in so much websites looking for the number of flights of the A-320 Family, and we found one of them, where there was a list with the different A-320 varieties, and their status [16]. So we considered all the aircrafts which were frame between years 1997 and 2017, and whose status was active. Then, we collected the following data:

Table 3. Built and operative airplanes

	Built airplanes between 1997 and 2017	**Operative airplanes**
A319	1488	1406
A320	4669	4190
A321	1537	1473
Total	7694	7069

Finally, the number of total flights will be:

$$Total\ flights = Operative\ Airplanes * Days\ considered * Average \frac{Cycles}{Day}$$

$$Total\ flights = 7069 * 7396 * 4.217 = 220519022$$

Thus, the number of total flights will be over 220 million, bringing to mind that it is only an approximation, assuming the same number of flights each year, with the same number of active aircrafts.

The last task to start the calculation of probabilities is estimate the number of hours per flight, and the easier way is to divide the averages got before (airframe hours per day and cycles per day), and we would obtain the number of hours per cycle:

Nº of hours per Flight/Cycle: 1.740

If we multiply this value with the total number of flights, we could get the total number of flight hours:

Total flight hours: 1.740

That said, we can begin to determine the probabilities of each category.

Probability of accident

Before start collecting all the probabilities, we need to get the main probability, which one is of having an accident. As we know, we can obtain this probability as:

$$P(Accident) = {}^{Total\ accidents}/_{Total\ flights}$$

And remembering that the number of accident was 107:

$$P(Accident) = {}^{107}/_{220519022} = 4{,}85219 * 10^{-7}\ {}^{1}/_{Flight}$$

And calculating it with flight hours:

$$P(Accident) = {}^{Total\ accidents}/_{Total\ flights\ Hours}$$

$$P(Accident) = {}^{107}/_{383732498{,}4} = 2.7884 * 10^{-7}\ {}^{1}/_{Flight\ Hour}$$

And with these probabilities, we can calculate the rest. The calculations of probability will be computed with both units: 1/Flight and 1/Flight Hour.

Probability of accident during each phase of flight

The expression we should apply is the following:

$$P(Phase\ of\ flight) = \%\ of\ phase\ of\ flight\ with\ accidents * P(Accident)$$

Now, we apply the formula above for each phase of flight. The percentage of accidents in each phase of flight are shown in the table below:

Table 4. Probability of accident during each phase of flight

Phase of flight	**Accidents (%)**
Approach (APR)	6,54%
Initial climb (ICL)	1,87%
Landing (LDG)	45,79%
Pushback / towing (PBT)	2,80%
Route (ENR)	14,95%
Standing (STD)	11,21%
Take-off (TOF)	7,48%
Taxi (TXI)	8,41%
Unknown (UNK)	0,93%

Probability of having an accident during Standing (STD)

$$P(STD) = 11.21\% * 4{,}85219 * 10^{-7} = 4.53476 * 10^{-9} \frac{1}{Flight}$$

$$P(STD) = 11.21\% * 2.7884 * 10^{-7} = 2.60598 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of having an accident during Pushback / towing (PBT)

$$P(PBT) = 2.8\% * 4{,}85219 * 10^{-7} = 1.36043 * 10^{-8} \frac{1}{Flight}$$

$$P(PBT) = 2.8\% * 2.7884 * 10^{-7} = 7.81795 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of having an accident during Taxi (TXI)

$$P(TXI) = 8.41\% * 4{,}85219 * 10^{-7} = 4.08128 * 10^{-8} \frac{1}{Flight}$$

$$P(TXI) = 8.41\% * 2.7884 * 10^{-7} = 2.34538 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of having an accident during Take-Off (TOF)

$$P(TOF) = 7.48\% * 4{,}85219 * 10^{-7} = 3.6278 * 10^{-8} \frac{1}{Flight}$$

$$P(TOF) = 7.48\% * 2.7884 * 10^{-7} = 2.08479 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of having an accident during Initial Climb (ICL)

$$P(ICL) = 1.87\% * 4{,}85219 * 10^{-7} = 9.06951 * 10^{-9} \frac{1}{Flight}$$

$$P(ICL) = 1.87\% * 2.7884 * 10^{-7} = 5.21196 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of having an accident during Route (ENR)

$$P(ENR) = 14.95\% * 4{,}85219 * 10^{-7} = 7.25561 * 10^{-8} \frac{1}{Flight}$$

$$P(ENR) = 14.95\% * 2.7884 * 10^{-7} = 4.16957 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of having an accident during Approach (APR)

$$P(ICL) = 6.54\% * 4{,}85219 * 10^{-7} = 3.17433 * 10^{-8} \frac{1}{Flight}$$

$$P(ICL) = 6.54\% * 2.7884 * 10^{-7} = 1.82419 * 10^{-8} \frac{1}{Flight\ Hour}$$

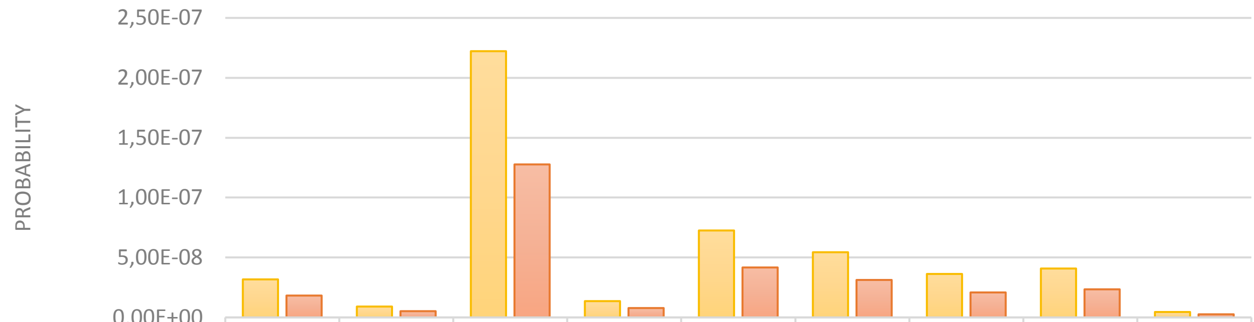
Probability of having an accident during Landing (LDG)

$$P(ICL) = 45.79\% * 4{,}85219 * 10^{-7} = 2.22203 * 10^{-7} \frac{1}{Flight}$$

$$P(ICL) = 45.79\% * 2.7884 * 10^{-7} = 1.27693 * 10^{-7} \frac{1}{Flight\ Hour}$$

Done it, we can represent the results above with a diagram:

Figure 24. Probability of accident during each phase of flight



	Approach (APR)	Initial climb (ICL)	Landing (LDG)	Pushback / towing (PBT)	Route (ENR)	Standing (STD)	Takeoff (TOF)	Taxi (TXI)	Unknown (UNK)
P (1/Flight)	3,174E-08	9,07E-09	2,222E-07	1,36E-08	7,256E-08	5,442E-08	3,628E-08	4,081E-08	4,535E-09
P (1/Flight Hours)	1,824E-08	5,212E-09	1,277E-07	7,818E-09	4,17E-08	3,127E-08	2,085E-08	2,345E-08	2,606E-09

PHASE OF FLIGHT

In the representation above, we can check the percentages we obtained in last sections: the highest probability to suffer an accident in a flight, is during the landing phase, which one have probability values of 2.222E-07 (1/Flight) and 1.277E-07 (1/Flight Hours). Then the probabilities are more or less the same, being the second highest value in route phase (7.256E-08 1/Flight and 4.17E-08 1/Flight Hours), followed by standing, taxi and approach. At present, he largest problems come at landing phase, and is rarely to have accidents during in route phase due to it is a phase commonly operated by automatic pilot. If we check the data table in Annex I, we could conclude to say that most of the accidents produced in this phase are because of hijacking or terrorist activities.

About the phases we have less probabilities of having an accident are in the initial climb (9.07E-09 1/Flight and 5.21E-09 1/Flight Hours) and in the pushback/ towing (1.36E-08 1/Flight and 7.818E-09 1/Flight Hours). The rest of the probabilities are in the table below the diagram.

Probability of accident by the nature of flight

In this case, we are going to use the following expression:

$$P(Nature) = \%\ of\ accidents\ with\ each\ nature * P(Accident)$$

Then, we apply it to each case.

Table 5. Probability of accident by nature of flight

Nature of flight	**Accidents (%)**
Domestic Non Scheduled Passenger	0,93%
Domestic Scheduled Passenger	42,06%
International Scheduled Passenger	38,32%
Int'l Non Scheduled Passenger	7,48%
Unknown	10,28%
Test	0,93%

Probability of having an accident with Domestic Non-Scheduled Passenger flight (DNS)

$$P(DNS) = 0.93\% * 4{,}85219 * 10^{-7} = 4.53476 * 10^{-9}\frac{1}{Flight}$$

$$P(DNS) = 0.93\% * 2.7884 * 10^{-7} = 2.60598 * 10^{-9}\frac{1}{Flight\ Hour}$$

Probability of having an accident with Domestic Scheduled Passenger flight (DS)

$$P(DS) = 42.06\% * 4{,}85219 * 10^{-7} = 2.04064 * 10^{-7}\frac{1}{Flight}$$

$$P(DS) = 42.06\% * 2.7884 * 10^{-7} = 1.17269 * 10^{-7}\frac{1}{Flight\ Hour}$$

Probability of having an accident with International Scheduled Passenger flight (IS)

$$P(IS) = 38.32\% * 4{,}85219 * 10^{-7} = 1.85925 * 10^{-7}\frac{1}{Flight}$$

$$P(IS) = 38.32\% * 2.7884 * 10^{-7} = 1.06845 * 10^{-7}\frac{1}{Flight\ Hour}$$

Probability of having an accident with International Non-Scheduled Passenger flight (INS)

$$P(INS) = 7.48\% * 4{,}85219 * 10^{-7} = 3.6278 * 10^{-8}\frac{1}{Flight}$$

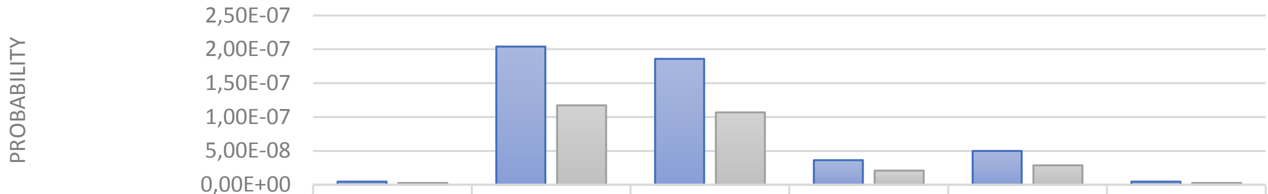
$$P(INS) = 7.48\% * 2.7884 * 10^{-7} = 2.08479 * 10^{-8}\frac{1}{Flight\ Hour}$$

Probability of having an accident with International Test (T)

$$P(T) = 0.93\% * 4{,}85219 * 10^{-7} = 4.53476 * 10^{-9}\,\frac{1}{Flight}$$

$$P(T) = 0.93\% * 2.7884 * 10^{-7} = 2.60598 * 10^{-9}\,\frac{1}{Flight\ Hour}$$

Figure 25. Probability of accident by nature of flight



	Domestic Non Scheduled Passenger	Domestic Scheduled Passenger	International Scheduled Passenger	Int'l Non Scheduled Passenger	Unknown	Test
Probability (1/Flight)	4,53476E-09	2,04064E-07	1,85925E-07	3,6278E-08	4,98823E-08	4,53476E-09
Probability (1/Flight Hours)	2,60598E-09	1,17269E-07	1,06845E-07	2,08479E-08	2,86658E-08	2,60598E-09

NATURE OF FLIGHT

In the category of nature of flight, we see that the highest probabilities of having accidents are in flights of domestic and international scheduled passenger, being the highest for domestic scheduled flights (2.04064E-07 1/Flight and 1.17269E-07 1/Flight Hours) while international flights have a bit less probability (1.85925E-07 1/Flight and 1.06845E-07 1/Flight Hours). It is because we said in the analysis done in last sections: the most of Airbus aircrafts flights are planned with enough time, and they are not used for charter flights, for example.

The following highest probability by nature is for international flights, but non-scheduled (3.6278E-08 1/Flight and 2.08479E-08 1/Flight Hours). We have also a percentage a bit higher than international non-scheduled flights, but this category consists of unknown nature accidents. For test and domestic non-scheduled, the probabilities are so much low than the highest values.

Probability of accident by airplane damage

Another analysis of the probability will be done considering the damages suffered by the airplane if it has had an accident. The calculations are going to be done by:

$$P(Airplane\ Damage) = \%\ of\ accidents\ which\ cause\ each\ damage * P(Accident)$$

Table 6. Probability of accident by airplane damage

Aircraft Damage	**Accidents**
Damaged beyond repair (DBR)	14,02%
Destroyed (D)	8,41%
Minor (MR)	11,21%
None (NO)	7,48%
Substantial (S)	57,01%
Unknown	1,87%

Probability of having a Damaged Beyond Repair accident (DBR)

$$P(DBR) = 14.02\% * 4{,}85219 * 10^{-7} = 6.80213 * 10^{-8} \frac{1}{Flight}$$

$$P(DBR) = 14.02\% * 2.7884 * 10^{-7} = 3.90897 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of having a Destroyed accident (D)

$$P(D) = 8.41\% * 4{,}85219 * 10^{-7} = 4.08128 * 10^{-8} \frac{1}{Flight}$$

$$P(D) = 8.41\% * 2.7884 * 10^{-7} = 2.34538 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of having a Minor accident (MR)

$$P(MR) = 11.21\% * 4{,}85219 * 10^{-7} = 5.44171 * 10^{-8} \frac{1}{Flight}$$

$$P(MR) = 11.21\% * 2.7884 * 10^{-7} = 3.12718 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of having a None accident (NO)

$$P(NO) = 7.48\% * 4{,}85219 * 10^{-7} = 3.6278 * 10^{-8} \frac{1}{Flight}$$

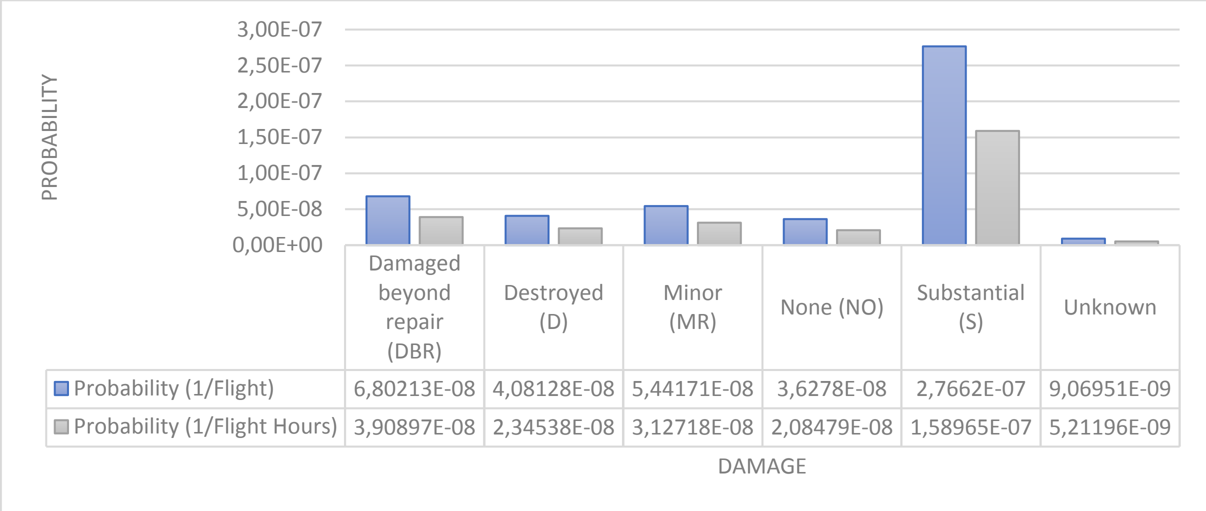
$$P(NO) = 7.48\% * 2.7884 * 10^{-7} = 2.08479 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of having a Substantial accident (S)

$$P(S) = 57.01\% * 4{,}85219 * 10^{-7} = 2.7662 * 10^{-7} \frac{1}{Flight}$$

$$P(S) = 57.01\% * 2.7884 * 10^{-7} = 1.58965 * 10^{-7} \frac{1}{Flight\ Hour}$$

Figure 26. Probability of accident by airplane damage



In case of accident, as we see in the diagram above, it is easy to say that most of the accidents only cause substantial damages (2.7662E-07 1/Flight and 1.58965E-07 1/Flight Hour). The other damages have similar probabilities between them, for example, aircrafts considered damaged beyond repair (6.80213E-08 1/Flight and 3.90897E-08 1/Flight Hour) and Minor damages (5.44171E-08 1/Flight and 3.12718E-08 1/Flight Hours). It means that majority of the aircrafts which got hurt, would need any repair or aircraft pieces replacement to continue its operations, and a little amount of that would be considered inoperative or got destroyed, or only suffer minor damages.

The probability of not having any damage is the lowest if we have an accident (3.6278E-08 1/Flight and 2.08479E-08 1/Flight Hours).

Probability of accident caused by each undesirable event

And the last probabilities to obtain is those what indicates it of an accident caused by an undesirable event. In this section, we will do:

$$P(Undesirable\ Event) = \%\ of\ accidents\ cause\ by\ Undesirable\ Event * P(Accident)$$

The percentages of them are presented on table 7:

Table 7. Probability of accident by undesirable event

Undesirable Event	**Accidents**
Abnormal Runway Contact (ARC)	25,23%
Birdstrike (BS)	2,80%
Controlled Flight Into Terrain (CFIT)	1,87%
Fire (FI)	4,67%
Fuel (F)	0,93%
Ground collision (GC)	14,95%
Hijack / Terrorism (H)	14,02%
Loss of Control in Flight (LOC-I)	7,48%
Midair collision (MAC)	1,87%
Runway excursion (RE)	19,63%
System/Component Failure or Malfunction (SCF)	2,80%
Turbulences (TURB)	1,87%
Undershoot (USOS)	0,93%
Unknown	0,93%

Probability of Abnormal Runway Contact (ARC)

$$P(ARC) = 25.23\% * 4{,}85219 * 10^{-7} = 1.22438 * 10^{-7} \frac{1}{Flight}$$

$$P(ARC) = 25.23\% * 2.7884 * 10^{-7} = 7.03615 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of Birdstrike (BS)

$$P(BS) = 2.8\% * 4{,}85219 * 10^{-7} = 1.36043 * 10^{-8} \frac{1}{Flight}$$

$$P(BS) = 2.8\% * 2.7884 * 10^{-7} = 7.81795 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of Controlled Flight into Terrain (CFIT)

$$P(CFIT) = 1.87\% * 4{,}85219 * 10^{-7} = 9.06951 * 10^{-9} \frac{1}{Flight}$$

$$P(CFIT) = 1.87\% * 2.7884 * 10^{-7} = 5.21196 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of Fire (FI)

$$P(FI) = 4.67\% * 4{,}85219 * 10^{-7} = 2.26738 * 10^{-8} \frac{1}{Flight}$$

$$P(FI) = 4.67\% * 2.7884 * 10^{-7} = 1.30299 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of Fuel (F)

$$P(F) = 0.93\% * 4{,}85219 * 10^{-7} = 4.53476 * 10^{-9} \frac{1}{Flight}$$

$$P(F) = 0.93\% * 2.7884 * 10^{-7} = 2.60598 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of Ground Collision (GC)

$$P(GC) = 14.95\% * 4{,}85219 * 10^{-7} = 7.25561 * 10^{-8} \frac{1}{Flight}$$

$$P(GC) = 14.95\% * 2.7884 * 10^{-7} = 4.16957 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of Hijack / Terrorism (H)

$$P(H) = 14.02\% * 4{,}85219 * 10^{-7} = 6.80213 * 10^{-8} \frac{1}{Flight}$$

$$P(H) = 14.02\% * 2.7884 * 10^{-7} = 3.90897 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of Loss of Control in Flight (LOC-I)

$$P(LOC - I) = 7.48\% * 4{,}85219 * 10^{-7} = 3.6278 * 10^{-8} \frac{1}{Flight}$$

$$P(LOC - I) = 7.48\% * 2.7884 * 10^{-7} = 2.08479 * 10^{-8} \frac{1}{Flight\ Hour}$$

Probability of Midair Collision (MAC)

$$P(MAC) = 1.87\% * 4{,}85219 * 10^{-7} = 9.06951 * 10^{-9} \frac{1}{Flight}$$

$$P(MAC) = 1.87\% * 2.7884 * 10^{-7} = 5.21196 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of Runway Excursion (RE)

$$P(RE) = 19.63\% * 4{,}85219 * 10^{-7} = 9.52299 * 10^{-8} \frac{1}{Flight}$$

$$P(RE) = 19.63\% * 2.7884 * 10^{-7} = 547256 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of System/Component Failure or Malfunction (SCF)

$$P(SCF) = 2.8\% * 4{,}85219 * 10^{-7} = 1.3604 * 10^{-8} \frac{1}{Flight}$$

$$P(SCF) = 2.8\% * 2.7884 * 10^{-7} = 7.81795 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of Turbulences (TURB)

$$P(TURB) = 1.87\% * 4{,}85219 * 10^{-7} = 9.06951 * 10^{-9} \frac{1}{Flight}$$

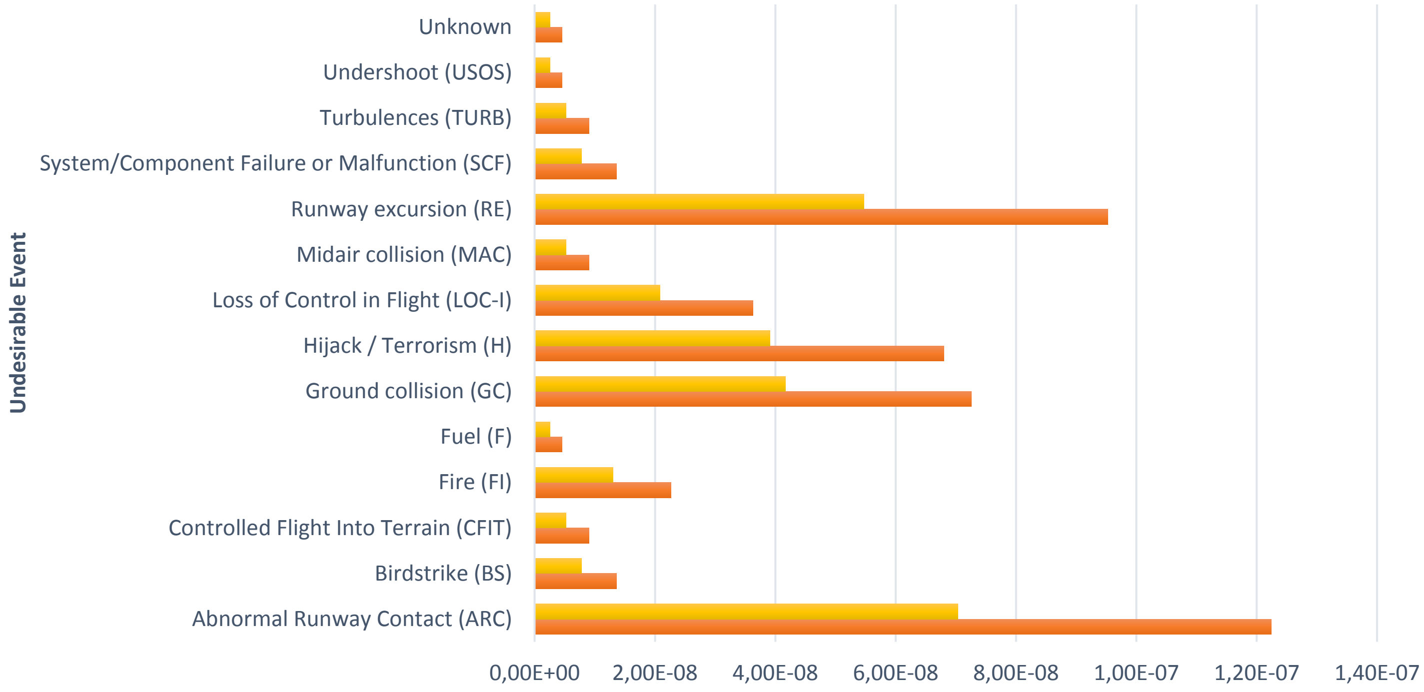
$$P(TURB) = 1.87\% * 2.7884 * 10^{-7} = 5.21196 * 10^{-9} \frac{1}{Flight\ Hour}$$

Probability of Undershoot (USOS)

$$P(USOS) = 0.93\% * 4{,}85219 * 10^{-7} = 4.53476 * 10^{-9} \frac{1}{Flight}$$

$$P(USOS) = 0.93\% * 2.7884 * 10^{-7} = 2.60598 * 10^{-9} \frac{1}{Flight\ Hour}$$

Figure 27. Probability of accident by undesirable event



	Abnormal Runway Contact (ARC)	Birdstrike (BS)	Controlled Flight Into Terrain (CFIT)	Fire (FI)	Fuel (F)	Ground collision (GC)	Hijack / Terrorism (H)	Loss of Control in Flight (LOC-I)	Midair collision (MAC)	Runway excursion (RE)	System/ Component Failure or Malfunction (SCF)	Turbulences (TURB)	Undershoot (USOS)	Unknown
P (1/Flight Hour)	7,04E-08	7,82E-09	5,21E-09	1,3E-08	2,61E-09	4,17E-08	3,91E-08	2,08E-08	5,21E-09	5,47E-08	7,82E-09	5,21E-09	2,61E-09	2,61E-09
P (1/Flight)	1,22E-07	1,36E-08	9,07E-09	2,27E-08	4,53E-09	7,26E-08	6,8E-08	3,63E-08	9,07E-09	9,52E-08	1,36E-08	9,07E-09	4,53E-09	4,53E-09

Probability

First of all, the undesirable event which is most common to happen is the abnormal runway contact (7.04E-08 1/Flight and 1.22E-07 1/Flight Hour), which is related with the phase where most of the accidents occur: landing. The other undesirable event related with the landing is the runway excursion (5.47E-08 1/Flight and 9.52E-08 1/Flight Hour). Then, the most probably undesirable events to happen are the abnormal runway contact and runway excursion, what occur in landing phase of flight (phase with most probability of accident).

The second most accidental phase was the route, where most of the accidents have a common cause or undesirable event: hijack or terrorism activity (3.91E-08 1/Flight and 6.8E08 1/Flight Hour).

Other undesirable event which has a high probability of occurrence is ground collision (4.17E-08 1/Flight and 7.26E-08 1/Flight Hour), which one is could happen in phases of standing, pushback or taxi (all probabilities together sum a high probability).

With less probabilities, we have others undesirable events like loss of control in flight (2.08E-08 1/Flight and 3.63E-08 1/Flight Hours), fire (1.3E-08 1/Flight and 2.27E-08 1/Flight Hours), which one were produce while airplanes were in the hangar, and system/component failure or malfunction (7.82E-09 1/Flight and 1.36E-08 1/Flight Hours).

Risk analysis

Before, we have already said something about the risk, but we are going to go over it.

As we said, Risk is a possibility of incurring specified loss (damage) in a definite period of life or during a particular activity due to various kinds of incidents or undesirable events, that may occur in the M-T-E system, or what is easier, the probability of a future loss.

The risk is calculated to know the probability of having losses by the M-T-E, this is:

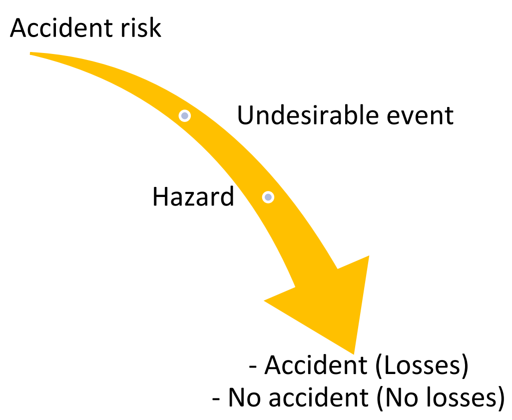
- Losses due to human errors, like wrong pilot decisions or failures in the airplane technology system because of bad treatments of technicians or pre-flight inspectors.
- Losses caused by a technologic failure, life engine failures, design errors or airframe errors.
- Losses caused by the environment and by some occurrences which happen without advertisement, like birdstrikes, turbulences or adverse weather conditions.

But, before suffering an accident and its respective losses, we are warned by another important concept: hazard.

What is the hazard? It is a condition, associated with design, operation or environment of a system that has the potential for harmful consequences or, explained with other words, a possibility of making specified loss, assigned to a situation developed after occurrence of an undesirable event in the man-technology-environment system.

So the hazard emerges when an undesirable event appears, this is when an event in the considered M-T-E system could result in hazard exposure for humans or property. If the undesirable event is not correctly responded to, may lead to loss or injury.

Then, we have the following process:



Hence, the importance of risk study comes: try to know the appearance probability of undesirable events to avoid the hazard and, in case it emerges, act with correct procedures to keep away from any accident or loss.

Measure of categories probabilities

In this project, we are going to calculate the risk of some categories of loss. These categories could be established with so much parameters, but we have chosen the classification shown below:

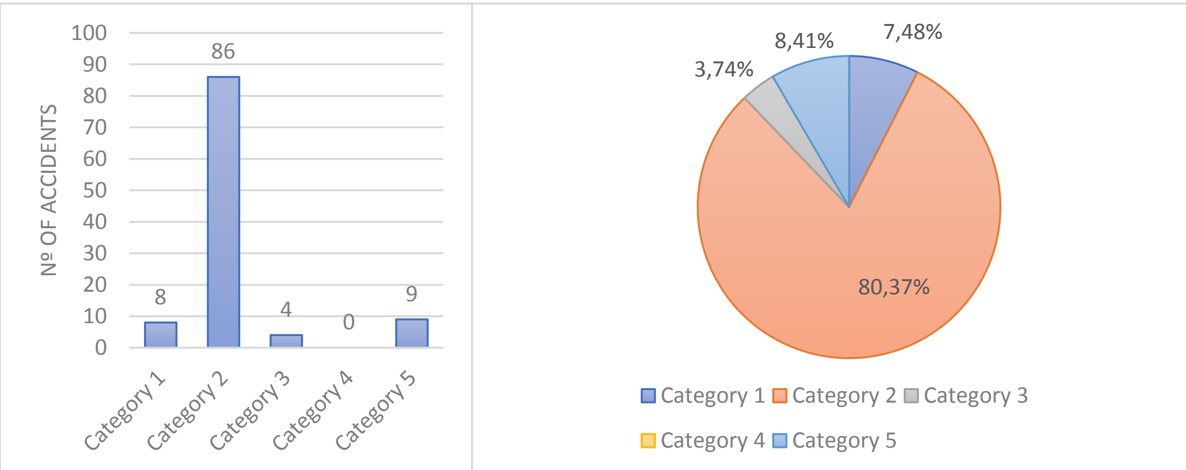
Table 8. Categories of loss

Category 1	0% Fatalities, None Damage
Category 2	0% Fatalities, Any Damage
Category 3	1 - 50% Fatalities
Category 4	51 - 99% Fatalities
Category 5	100% Fatalities

The first category includes all accidents without fatalities nor airplane damages, while the second includes also accidents without fatalities, but with the condition of have suffered any type of damage. About the categories 3, 4 and 5, they include accidents what have a quantity of 1 – 50%, 51 – 99% and 100% of occupants respectively.

In the following diagrams, we can see number of accidents of each category and the percentage over the total of accidents:

Figure 28. Accidents by category of loss



Analysing the graphics, we could conclude that most of the accidents, exactly 86, or 80.37% of all the accidents occurred during the last 20 years. It means that a great amount of accidents only has caused damages to the aircraft, and no fatalities. The quantity of accidents without any type of consequence is 8 or 7.48% of the total accidents.

Attending to the accidents with at least one fatality, 3.74% of the total accidents (4 accidents) induced fatalities between 1 – 50% of the occupants, while we do not have any information about accidents from fourth category. The last category, which one is based on accidents that reach 100% occupants fatalities, is characterized by 9 accidents over the total, what means the 7.48% of total accidents.

This is, assuming the total number accidents for last 20 years, the mayor quantity of them only required a reparation to continue active, then we have almost equal number of accidents for accidents without any type of loss and for destructive accidents.

The aim of classify the losses by categories is to obtain a representative value of risk: risk of the undesirable event appearance which induce any category of loss. First of all is to collect all the accidents in a conditional table so that we can identify the number of accidents due to each undesirable event which has caused one of the categories. Our collection is below:

Table 9. Categories of loss vs. undesirable events

Number of accidents per category of loss	Category 1	Category 2	Category 3	Category 4	Category 5	**Total**
Abnormal Runway Contact	0	27	0	0	0	27
Runway excursion	0	18	2	0	1	21
Ground collision	0	16	0	0	0	16
Hijack / Terrorism	8	2	2	0	3	15
Loss of Control in Flight	0	5	0	0	3	8
Fire	0	5	0	0	0	5
System/Component Failure or Malfunction	0	3	0	0	0	3
Birdstrike	0	3	0	0	0	3
Midair collision	0	2	0	0	0	2
Controlled Flight Into Terrain	0	0	0	0	2	2
Turbulences	0	2	0	0	0	2
Undershoot	0	1	0	0	0	1
Unknown	0	1	0	0	0	1
Fuel	0	1	0	0	0	1
Total	8	86	4	0	9	

And then, we calculate the probabilities of having an accident which involves each category of loss due to the occurrence of an undesirable event. It is done by:

$$P_i = \frac{Number\ of\ accidents\ by\ the\ category\ caused\ by\ the\ undesirable\ event}{Total\ number\ of\ accidents\ caused\ by\ the\ undesirable\ event}$$

We have made the calculations and we have got the following results:

Table 10. Probabilities of categories of loss vs. undesirable events

Occurrence of category per undesirable event	Category 1	Category 2	Category 3	Category 4	Category 5
Abnormal Runway Contact	0	1	0	0	0
Runway excursion	0	0,857142857	0,095238095	0	0,047619048
Ground collision	0	1	0	0	0
Hijack / Terrorism	0,533333333	0,133333333	0,133333333	0	0,2
Loss of Control in Flight	0	0,625	0	0	0,375
Fire	0	1	0	0	0
System/Component Failure or Malfunction	0	1	0	0	0
Birdstrike	0	1	0	0	0
Midair collision	0	1	0	0	0
Controlled Flight Into Terrain	0	0	0	0	1
Turbulences	0	1	0	0	0
Undershoot	0	1	0	0	0
Unknown	0	1	0	0	0
Fuel	0	1	0	0	0

For the safest category, which does not include any fatality or damage, we only have information about hijacks or terrorism activities, which represents a probability of 0.533, this is the half of accidents caused by this undesirable event. The hijacking of these accidents only caused chaos and fear, but after taking the situation under control, the aircraft arrives to the airport and nobody resulted hurt.

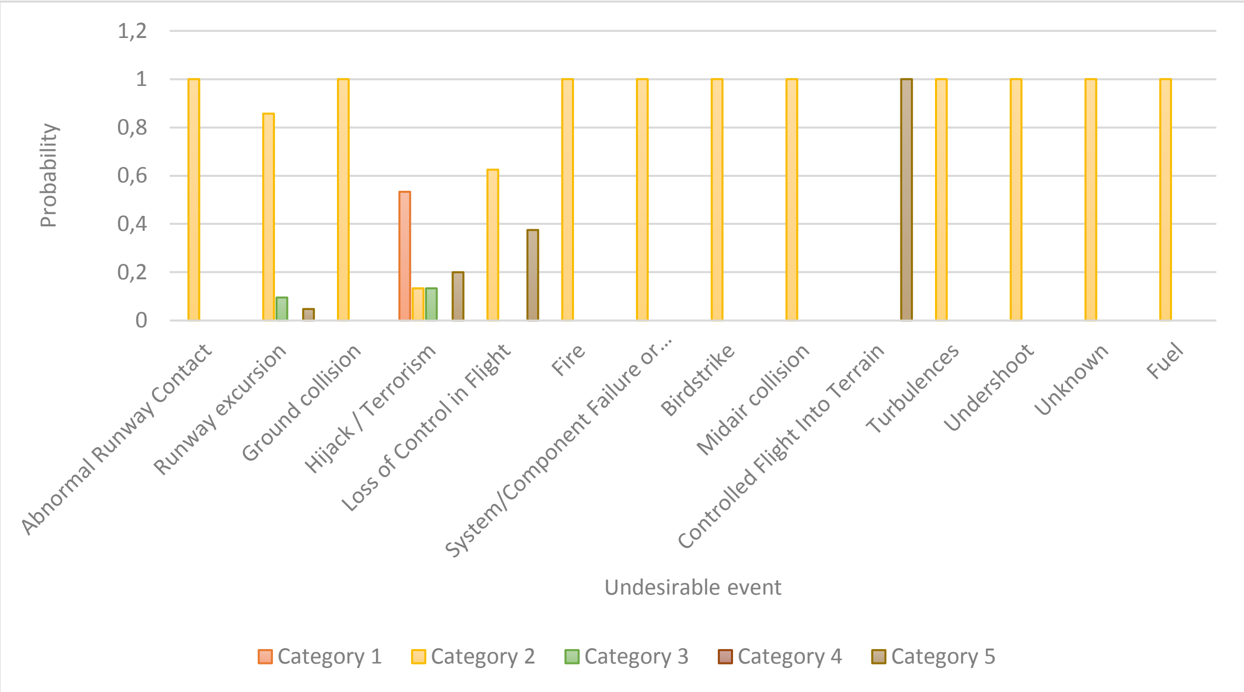
About the second category, which one does not have fatalities but any damage, is occurred in the 100% of the accidents caused by the following undesirable events: fuel, undershoot, turbulences, midair collision, birdstrike, system/component failure or malfunction, fire, ground collision and abnormal runway excursion. We have a little probability of having a category 2 accident by hijack (0.133), and higher in cases of loss of control in flight and runway excursion.

The third category is the lowest involved (excluding the fourth category, which is not involved by accident), with low values in runway excursion (0.095) and hijack (0.133).

The last and the most several categories, the number 5, is involved all times controlled flight into terrain has occurred. The others undesirable events which cause this category are runway excursion (0.047), hijack (0.2) and loss of control in flight (0.375).

We can review the results in the figure below:

Figure 29. Probabilities of categories of loss vs. undesirable events



Hazard measure

At this point is necessary to explain how to do the hazard measure.

How can we get the numerical estimation of the hazard? The best way to explain it is with the following expression:

$$Z(c) = P\{C_1 \geq c|A\}$$

The meaning of the coefficients is: Z(c) – Hazard of having losses include in one category c and C_1 is the loss caused by occurrence of the event A.

Then, the hazard of suffer one category of loss is the sum of all the probabilities that, happening an occurrence A, it has had losses of higher or equal categories than the considered category. We can express it with the following sequence:

$$Z(c_1) = p_1 + p_2 + p_3 + p_4 + p_5 = 1$$

$$Z(c_2) = p_2 + p_3 + p_4 + p_5$$

$$Z(c_3) = p_3 + p_4 + p_5$$

$$Z(c_4) = p_4 + p_5$$

$$Z(c_5) = p_5$$

Where the p are the probabilities of occurrence.

Risk measure

The last step to obtain the risk of the undesirable event appearance which induce any category of loss is to apply the expression of the risk measure, which one could be written by:

$$(Risk\ measure) = (Unreliability\ measure) * (Hazard\ measure)$$

The unreliability measure is basically the likelihood of undesirable event, and the hazard measure, as we have explained before, is the probability of loss. We could also express the formula like:

$$\Lambda_{c_i}(t) = Q(t) * Z(c_i)$$

Where

$$Q(t) = \frac{W_j(\Delta\tau)}{\Delta\tau * Z(c_i)}$$

The coefficients are:

$$W_j(\Delta\tau) \rightarrow Numberof\ accidents\ due\ to\ occurrence$$

$$\Delta\tau \rightarrow Number\ of\ data\ collection\ years$$

However, if we want to calculate the risk (1/flight), it is simply applying the expression below, due to we have the probabilities of each undesirable event defined by 1/Flight:

$$\Lambda_{Undesirable\ Event}\left(\frac{1}{flight}\right) = P(Undesirable\ event) * Z(c_i)$$

These probabilities are in the section *Probability of accident caused by each undesirable event*. It is important to use the probability with the units 1/Flight to collect the right value.

To obtain the risk with the other units (1/Flight Hours), we would have to do the following estimation:

$$\Lambda_{Undesirable\ Event}\left(\frac{1}{Flight\ Hours}\right) = \frac{h * d}{\Delta\tau} * P(Undesirable\ event) * Z(c_i)$$

Where:

$$h \rightarrow Average\ of\ flight\ hours\ per\ day\ by\ one\ plane \rightarrow 7.23537$$

$$d \rightarrow Number\ of\ days\ under\ study \rightarrow 7396$$

$$\Delta\tau \rightarrow Years\ under\ study \rightarrow 20.263$$

And using also the probability in 1/Flight, we can know this risk.

We have collected both of risks and the hazard measures in one table, which we can see here:

Table 11. Hazard and risk of categories of loss

Abnormal Runway Contact					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0
Risk (1/Flight)	1,22438E-07	1,22438E-07	0	0	0
Risk (1/year)	0,000323349	0,000323349	0	0	0
Runway excursion					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0,142857143	0,047619048	0,047619048
Risk (1/Flight)	9,52299E-08	9,52299E-08	1,36043E-08	4,53476E-09	4,53476E-09
Risk (1/year)	0,000251494	0,000251494	3,59277E-05	1,19759E-05	1,19759E-05
Ground collision					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0
Risk (1/Flight)	7,25561E-08	7,25561E-08	0	0	0
Risk (1/year)	0,000191614	0,000191614	0	0	0
Hijack / Terrorism					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	0,466666667	0,333333333	0,2	0,2
Risk (1/Flight)	6,80213E-08	3,17433E-08	2,26738E-08	1,36043E-08	1,36043E-08

Risk (1/year)	0,000179638	8,38312E-05	5,98794E-05	3,59277E-05	3,59277E-05
Loss of Control in Flight					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0,375	0,375	0,375
Risk (1/Flight)	3,6278E-08	3,6278E-08	1,36043E-08	1,36043E-08	1,36043E-08
Risk (1/year)	9,58071E-05	9,58071E-05	3,59277E-05	3,59277E-05	3,59277E-05
Fire					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0
Risk (1/Flight)	2,26738E-08	2,26738E-08	0	0	0
Risk (1/year)	5,98794E-05	5,98794E-05	0	0	0
System/Component Failure or Malfunction					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0
Risk (1/Flight)	1,36043E-08	1,36043E-08	0	0	0
Risk (1/year)	3,59277E-05	3,59277E-05	0	0	0
Birdstrike					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0
Risk (1/Flight)	1,36043E-08	1,36043E-08	0	0	0
Risk (1/year)	3,59277E-05	3,59277E-05	0	0	0
Midair collision					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0

Risk (1/Flight)	9,06951E-09	9,06951E-09	0	0	0
Risk (1/year)	2,39518E-05	2,39518E-05	0	0	0
Controlled Flight Into Terrain					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	1	1	1
Risk (1/Flight)	9,06951E-09	9,06951E-09	9,06951E-09	9,06951E-09	9,06951E-09
Risk (1/year)	2,39518E-05	2,39518E-05	2,39518E-05	2,39518E-05	2,39518E-05
Turbulences					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0
Risk (1/Flight)	9,06951E-09	9,06951E-09	0	0	0
Risk (1/year)	2,39518E-05	2,39518E-05	0	0	0
Undershoot					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0
Risk (1/Flight)	4,53476E-09	4,53476E-09	0	0	0
Risk (1/year)	1,19759E-05	1,19759E-05	0	0	0
Unknown					
	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0
Risk (1/Flight)	4,53476E-09	4,53476E-09	0	0	0
Risk (1/year)	1,19759E-05	1,19759E-05	0	0	0
Fuel					

	C1	C2	C3	C4	C5
Hazard (Z(Cj))	1	1	0	0	0
Risk (1/Flight)	4,53476E-09	4,53476E-09	0	0	0
Risk (1/year)	1,19759E-05	1,19759E-05	0	0	0

And according to:

$$\Lambda_{c_i}(1) = \sum_{i=1}^{i=m} \Lambda_{c_i}(i)$$

We fulfilled the table of total risk:

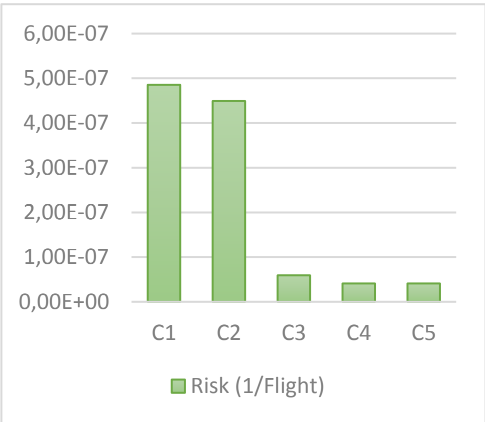
Table 12. Total risk of categories of loss

Total	**C1**	**C2**	**C3**	**C4**	**C5**
Risk (1/Flight)	4,85219E-07	4,48941E-07	5,89518E-08	4,08128E-08	4,08128E-08
Risk (1/year)	1,28E-03	1,19E-03	1,56E-04	1,08E-04	1,08E-04

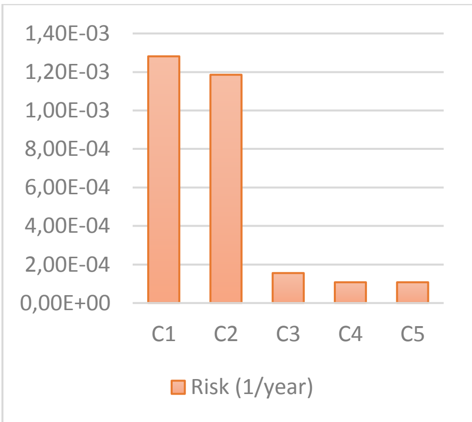
If we represent the obtained results:

Figure 30. Total risk of categories of loss: a) Risk (1/Flight), b) Risk (1/Year)

a)



b)



Obviously, the pattern of the diagrams is the similar, the only difference is the time considered (one of the risk shows the risk in one year and the other in one flight). The aim of the representation of them is to assimilate that the most probably result, in case of an undesirable event happens, is to have no fatalities, and in any case, some damages in the aircraft but without influence over the occupants of its.

Rarely, if an undesirable event occurs, the consequences imply us any fatalities, which are represented by 3, 4 and 5 categories, and have the smallest value of probability.

Conclusions and remarks

Firstly, the most important fact we should have clear is that we are studying a system composed by three elements: Man – Technology – Environment. Possibly, the technology is only the element we could improve to avoid the major quantity of accidents as possible.

Obviously, in the other elements we could find problems and adversities, but they are difficult to solve, basically because the problems would be, for example, pilot errors or dangerous weather. All people could cause problems or make mistakes, and we could find some adverse conditions of flight without a preview advise. This is the reason of that we only can improve some aspects about aircraft design or software.

Said that, during our project we have checked some aspects: most of the accidents do not involve fatalities, and in that case, major part of the occupants passed away. The accidents are caused, overall, in the phase of landing, where the pilot activity is crucial and any error could take place.

Depending on the nature of flight, we could conclude that the accidents are usually produced in flights which are scheduled, domestic flights as much as international.

We have discovered also what is the aircraft variety which has most risk at the time of flight: the A320. This observation is clear, only because the number of flights of this variety is so much higher than the others two species.

In case of having an accident, we could suffer some types of damages, depending on the status of the aircraft. In our case, almost the Airbus airplanes suffer substantial damages, which means the replacement of damaged pieces or reparations.

About the undesirable events, most of the accidents have been caused by abnormal runway contact, runway excursion, also in minor quantity by hijack or ground collision.

Finally, with the analysis of the hazard and the risk, we have been able to know what would be the consequences (fatalities and damages) classified by categories depending on the undesirable event. In case we would suffer a hijack, the probability of survive without any damages in the aircraft is near to 50%. In most of undesirable events, only some damages in the aircraft and no fatalities would be the result. About the worst category, or catastrophe, would be almost secure if a controlled flight into terrain happens, and less probability for loss of control in flight or hijack.

These calculations have been a demonstration of why the aviation is considered as the safest transport in present, and it will be much safer if they continue taking regulations and rules to avoid any type of problem, as it has done until present. At any time, it is possible an occurrence happens, but in other transports too, but it is merely fate.

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Tables

Figures

Appendix I

Date	Serie	Fatal.	Pax.	Phase of flight	Cat	Damage	Airframe Hours	Cycles	Undesirable Event	First Flight	Days Flown
10/03/1997	A320-212	0	115	TOF	A1	Damaged beyond repair	4640	4024	Runway excursion	01/07/1995	618
22/03/1998	A320-214	3	130	LDG	A1	Damaged beyond repair	1224	1070	Runway excursion	01/07/1997	264
12/05/1998	A320-231	0	54	TXI	A2	Substantial	18139,08252	10574,15099	Unknown	01/07/1991	2507
21/05/1998	A320-212	0	187	LDG	A2	Substantial	22265	10612,11164	Runway excursion	01/07/1991	2516
12/02/1999	A320-211	0	169	ENR	A2	Minor	14425	11164,65004	Midair collision	14/11/1991	2647
02/03/1999	A320	0	82	UNK	H2	Unknown			Hijack / Terrorism		
15/10/1999	A320-231	0	94	TXI	A2	Substantial	32206		Ground collision		
26/10/1999	A320-231	0	92	LDG	A2	Substantial	14058,3316	8195,283353	Abnormal Runway Contact	01/07/1994	1943
20/01/2000	A320-231	0	152	TOF	A2	Substantial	22350,07016	13028,93993	System/Component Failure or Malfunction	06/08/1991	3089
11/04/2000	A320-231	0	0	STD	O1	Damaged beyond repair	15273,87443	8903,882222	Fire	01/07/1994	2111

11/05/2000	A321-231	0	19	ENR	H2	None			Hijack / Terrorism		
12/06/2000	A320-232	0	152	TOF	A2	Substantial	3012		System/Component Failure or Malfunction		
05/07/2000	A320	1	96	ENR	H2	Minor			Hijack / Terrorism		
23/08/2000	A320-212	143	143	APR	A1	Destroyed	17370	13990	Loss of Control in Flight	16/05/1994	2291
07/02/2001	A320-214	0	143	LDG	A1	Damaged beyond repair	1149	869	Turbulences	01/07/2000	221
17/03/2001	A320-212	0	151	TOF	A2	Substantial	9346	4175,671909	Fuel	01/07/1998	990
24/07/2001	A320-231	0	0	STD	C1	Damaged beyond repair	23949,0878	13961,08487	Hijack / Terrorism	01/07/1992	3310
01/09/2001	A321	0		ENR	H2	None			Hijack / Terrorism		
16/11/2001	A321-231	0	88	LDG	A2	Substantial	11952,83778	6967,888882	Abnormal Runway Contact	09/05/1997	1652
21/01/2002	A321-131	0	93	APR	A2	Substantial	6140	3943,690136	Turbulences	01/07/1999	935
28/08/2002	A320-231	0	159	LDG	A1	Substantial	40084	18530	Loss of Control in Flight	01/07/1990	4441

19/01/2003	A319-114	0	2	TXI	A1	Damaged beyond repair	6743,36853	3931,036585	Loss of Control in Flight	01/07/2000	932
21/03/2003	A321-131	0	175	LDG	A1	Damaged beyond repair	13516	18580	Abnormal Runway Contact	01/07/1996	2454
16/06/2003	A320-231	0	185	LDG	A2	Substantial	29223,67542	17035,89782	Abnormal Runway Contact	25/05/1992	4039
06/11/2003	A320-232	0	128	LDG	A2	Substantial	7741,850136	4513,099942	Runway excursion	01/12/2000	1070
23/03/2004	A321-211	0	194	TXI	A2	Minor	14108,97922	8224,808305	Ground collision	20/11/1998	1950
18/10/2004	A320-232	0	106	LDG	A2	Substantial	12124	16248	Loss of Control in Flight	01/07/1998	2301
15/01/2005	A320-214	0	184	TOF	A2	Unknown	19318,44847	11261,6606	Abnormal Runway Contact	24/09/1997	2670
10/05/2005	A319-114	0	43	TXI	A2	Substantial	4912,818918	2863,92043	Ground collision	01/07/2003	679
18/05/2005	A320-211	0	178	LDG	A2	Minor	28957	16321	Runway excursion	12/07/1991	5059
18/09/2005	A321-231	0	197	LDG	A2	Substantial	16473		Loss of Control in Flight		
03/05/2006	A320-211	113	113	APR	A1	Destroyed	28234	14376	Controlled Flight Into Terrain	28/06/1995	3962

05/05/2006	A320-211	0	0	STD	O1	Damaged beyond repair	35330,33104	20595,76357	Fire	21/12/1992	4883
05/05/2006	A320-211	0	0	STD	O1	Damaged beyond repair	24824,56805	14471,44477	Fire	12/12/1996	3431
05/05/2006	A320-232	0	0	STD	O1	Damaged beyond repair	8270,032435	4821,003022	Fire	19/03/2003	1143
08/09/2006	A319-112	0	109	TXI	A2	Minor	13215		Ground collision		
28/12/2006	A321-211	0	168	ENR	H2	None	1302,367313	759,2130743	Hijack / Terrorism	01/07/2006	180
17/07/2007	A320-233	199	187	LDG	A1	Destroyed	20000	9300	Runway excursion	13/02/1998	3441
27/07/2007	A321-231	0	111	STD	A2	Minor	8110,854208	4728,210313	Ground collision	01/07/2004	1121
26/10/2007	A320-214	0	154	LDG	A1	Substantial	26394,6442	15386,71831	Runway excursion	30/10/1997	3648
09/01/2008	A319-114	0	73	APR	A2	Substantial	15029		Abnormal Runway Contact		
17/02/2008	A319-111	0	51	TXI	A2	Substantial	16587		Ground collision		
04/05/2008	A321-231	0		LDG	A2	Substantial			Abnormal Runway Contact		
30/05/2008	A320-233	3	124	LDG	A1	Damaged beyond repair	21957	9992	Runway excursion	29/11/2000	2739

18/07/2008	A321-211	0	228	LDG	A2	Substantial	24737,74357	14420,83056	Abnormal Runway Contact	09/03/1999	3419
28/07/2008	A321-231	0	167	LDG	A2	Substantial	24810,09731	14463,00907	Abnormal Runway Contact	09/03/1999	3429
20/10/2008	A320-232	0	163	LDG	A2	Substantial	34617		Abnormal Runway Contact		
27/11/2008	A320-232	7	7	APR	A1	Destroyed	10124	3931	Loss of Control in Flight	30/06/2005	1246
15/01/2009	A320-214	0	155	ICL	A1	Damaged beyond repair	25338,2796	14770,91215	Birdstrike	15/06/1999	3502
01/02/2009	A320-232	0	169	ENR	H2	None			Hijack / Terrorism		
09/02/2009	A321-211	0	229	LDG	A2	Minor	11482	3542	Runway excursion	27/02/2006	1078
04/05/2009	A320-211	0	154	LDG	A2	Substantial	57600	29027,24654	Abnormal Runway Contact	01/07/1990	6882
28/10/2009	A321-231	0	147	LDG	A2	Substantial	6150,067865	3585,172851	Abnormal Runway Contact	01/07/2007	850
10/01/2010	A319-131	0	53	LDG	A2	Substantial	39679	17634,83258	Abnormal Runway Contact	31/07/1998	4181
18/06/2010	A321-131	0	151	TXI	A2	Substantial	32967	20549,36721	Ground collision	14/02/1997	4872

28/07/2010	A321-231	152	152	APR	A1	Destroyed	34018	13566	Controlled Flight Into Terrain	14/04/2000	3757
12/08/2010	A319-111	0	127	LDG	A2	Substantial	12763,19966	7440,288129	Runway excursion	13/10/2005	1764
24/09/2010	A319-132	0	129	LDG	A1	Damaged beyond repair	15763	8936	Loss of Control in Flight	04/03/2005	2030
10/01/2011	A320-216	0	129	LDG	A2	Substantial	7676,73177	4475,139288	Runway excursion	14/02/2008	1061
25/08/2011	A320-214	0	0	STD	C1	Substantial	3255,918282	1898,032686	Ground collision	01/06/2010	450
29/08/2011	A320-214	0	143	LDG	A2	Minor	4758	2301	Runway excursion	19/01/2010	587
12/09/2011	A321-211	0		LDG	A2	Substantial	9261,278667	5398,848529	Abnormal Runway Contact	11/03/2008	1280
13/12/2011	A319-111	0	119	LDG	A2	Substantial	28615,90401	16681,59838	Abnormal Runway Contact	13/02/2001	3955
05/02/2012	A320-211	0	166	LDG	A1	Substantial	43423	32544,93379	Abnormal Runway Contact	21/12/1990	7716
12/02/2012	A320-232	0		ENR	H2	None	24708,80207	14403,95916	Hijack / Terrorism	07/10/2002	3415
13/02/2012	A320-214	0	142	LDG	A2	Minor	20997,05523	12240,2019	Runway excursion	04/03/2004	2902
14/02/2012	A319-111	0	148	LDG	A2	Minor	4290,576758	2501,185295	Abnormal Runway Contact	01/07/2010	593

20/09/2012	A320-232	0		ENR	A2	Substantial	34208,84808	19941,99675	Midair collision	11/10/1999	4728
06/02/2013	A320-211	0	83	LDG	A1	Substantial	59395,18483	34624,33404	Runway excursion	17/08/1990	8209
16/03/2013	A320-214	0	0	STD	O1	Damaged beyond repair	44584,37434	25990,39425	Ground collision	02/05/1996	6162
29/03/2013	A321-111	0	181	LDG	A2	Minor	37757	22420	Runway excursion	06/01/1997	5926
16/04/2013	A321-231	0	139	LDG	A2	Substantial	30268	13619	Abnormal Runway Contact	20/04/2004	3283
24/05/2013	A319-131	0	80	TOF	A2	Substantial	28362	18157,84603	Abnormal Runway Contact	10/08/2001	4305
24/05/2013	A320-232	0	178	LDG	A2	Substantial	3164	1330	Runway excursion	10/05/2012	379
02/06/2013	A320-214	0	171	LDG	A2	Substantial	4428,048863	2581,324453	Runway excursion	29/09/2011	612
08/06/2013	A320-232	0	171	LDG	A2	Substantial	3545,33324	2066,746702	Abnormal Runway Contact	04/02/2012	490
13/06/2013	A319-111	0	101	LDG	A2	Minor	18146,31789	10578,36884	Runway excursion	01/08/2006	2508
03/07/2013	A320-212	0	1	STD	O1	Substantial	51045,56328	29756,93466	Fire	10/03/1994	7055
10/08/2013	A320-232	0		STD	A2	Substantial	8928,451465	5204,82741	Ground collision	25/03/2010	1234
29/09/2013	A320-216	0	157	LDG	A2	Substantial	7974	6010	Abnormal Runway Contact	16/03/2010	1293

03/12/2013	A320-214	0	64	LDG	A2	Substantial	48773,65586	28432,52963	Abnormal Runway Contact	20/06/1995	6741
05/01/2014	A320-231	0	179	LDG	A1	Substantial	55705	30655,3368	Undershoot	11/02/1994	7268
02/02/2014	A320-231	0	192	LDG	A2	Substantial	54604	23974	Runway excursion	04/01/1994	7334
13/03/2014	A320-214	0	154	TOF	A2	Substantial	44230	22038,26841	Runway excursion	22/11/1999	5225
01/04/2014	A321-231	0	82	ENR	H2	None	12755,96429	7436,070278	Hijack / Terrorism	03/06/2009	1763
04/07/2014	A320-232	0	155	LDG	A2	Substantial	19144,7995	11160,43219	Abnormal Runway Contact	06/04/2007	2646
27/07/2014	A320-214	0	0	STD	C1	Damaged beyond repair	10100,58205	5888,119177	Ground collision	30/09/2010	1396
28/12/2014	A320-216	162	162	ENR	A1	Destroyed	23039	13610	Loss of Control in Flight	25/09/2008	2285
24/03/2015	A320-211	150	150	ENR	C1	Destroyed	58313	46748	Hijack / Terrorism	29/11/1990	8881
29/03/2015	A320-211	0	138	LDG	A1	Substantial	62680,04461	36539,23813	Abnormal Runway Contact	10/07/1991	8663
14/04/2015	A320-232	0	82	LDG	A1	Substantial	23595	11742,49555	Abnormal Runway Contact	30/08/2007	2784
25/04/2015	A320-232	0		LDG	A2	Substantial	22509,24839	13121,73263	Runway excursion	18/10/2006	3111

19/07/2015	A321-231	0	175	LDG	A2	Substantial	28449,49041	16584,58782	Abnormal Runway Contact	12/10/2004	3932
15/08/2015	A321-231	0	159	LDG	A2	Substantial	7358,375316	4289,55387	Abnormal Runway Contact	01/11/2012	1017
19/09/2015	A321-211	0	175	TOF	A2	Substantial	10720	4722	System/Component Failure or Malfunction	23/04/2012	1244
31/10/2015	A321-231	224	224	ENR	C1	Destroyed	56000	21000	Hijack / Terrorism	09/05/1997	6749
02/12/2015	A321-211	0	0	PBT	A2	Substantial	2214,024431	1290,662226	Ground collision	30/01/2015	306
14/01/2016	A319-112	0	110	APR	A2	Substantial	21387,76542	12467,96582	Birdstrike	11/12/2007	2956
02/02/2016	A321-111	1	81	ENR	C1	Substantial	50401,615	29381,54598	Hijack / Terrorism	06/01/1997	6966
29/03/2016	A320-232	0	64	ENR	H2	None	33630,01816	19604,56872	Hijack / Terrorism	08/07/2003	4648
10/05/2016	A321-211	0		ICL	A2	Substantial	40445,74043	23577,78381	Birdstrike	19/01/2001	5590
11/05/2016	A320-214	0	64	TXI	A2	Substantial	35713,80586	20819,30964	Ground collision	05/11/2002	4936
19/05/2016	A320-232	66	66	ENR	C1	Destroyed	33876,02088	19747,97563	Hijack / Terrorism	25/07/2003	4682
28/05/2016	A320-214	0		PBT	A2	Substantial	29607,15024	17259,44389	Ground collision	15/03/2005	4092
23/12/2016	A320-214	0	118	ENR	H2	None	24629,21296	14357,56281	Hijack / Terrorism	29/08/2007	3404

03/03/2017	A320-214	0		PBT	A2	Substantial	18616,6172	10852,52911	Ground collision	15/02/2010	2573
02/04/2017	A319-114	0		STD	A2	Substantial	50835,73744	29634,617	Ground collision	06/01/1998	7026