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AIRCRAFT ACCIDENTS IN THE PORTUGUESE AIR FORCE – TRENDS IN PREVENTION AND CAUSES CHARACTERISATION

ACIDENTES COM AERONAVES NA FORÇA AÉREA PORTUGUESA – EVOLUÇÃO DA EFICÁCIA DA PREVENÇÃO E CARATERIZAÇÃO DE CAUSAS

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Abstract

The Portuguese Air Force (PtAF) has made great efforts towards accident prevention, but has it been successful in significantly reducing accidents in which the aircraft was destroyed? Is it on the same level as other Air Forces regarding number of accidents per 10.000 flight hours (FH)? What are the causes of these accidents? This research focused on the question "What are the causes of hull loss accidents and to what extent has accident prevention in the PtAF been effective, in absolute terms and when compared to other benchmark operators?"

The field of observation included the PtAF and the Spanish, Belgian and Swiss Air Forces. The time-frame analysed in the case of the PtAF was 30 years and in the other Air Forces that time-frame was 20 years.

This research concluded that, although human causes represent 41% of overall occurrences (incidents and accidents) in the PtAF, human causes of accidents involving hull loss have a weight of 60%. The latter causes have been effectively tackled, resulting in a decrease in the number of hull loss accidents per 10,000 flight hours over the last 30 years, which puts the PtAF on the same level as other European Air Forces, namely those from Spain and Belgium (and better than Switzerland's).

Keywords: Aircraft accidents, flight safety, accident prevention, aircraft loss.

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Resumo

A Força Aérea Portuguesa (FAP) tem colocado grande empenho na prevenção de acidentes, mas terá conseguido uma redução significativa de acidentes com destruição de aeronave? O número de acidentes, por cada 10.000 horas de voo (HV), será semelhante ao de outras Forças Aéreas? Quais as causas destes acidentes? Esta investigação centrou-se em torno da questão *"Quais as causas dos acidentes com perda de aeronave, e em que medida tem sido eficaz a prevenção destes acidentes na FAP, em termos absolutos e comparativamente com outros operadores de referência?"*.

O campo de observação abrangeu a FAP e as Forças Aéreas Espanhola, Belga e Suíça. O período temporal analisado foi de 30 anos no caso da FAP e de 20 nas restantes Forças Aéreas.

Nesta investigação conclui-se que embora na globalidade das ocorrências (incidentes e acidentes) na FAP, o fator humano contribua com um peso de 41%, verifica-se que no caso específico dos acidentes com perda de aeronave, os fatores humanos têm um peso de 60%. As causas dos acidentes com perda de aeronave têm sido combatidas eficazmente, resultando na diminuição nos últimos 30 anos do número de acidentes com perda de aeronave, por 10.000 HV, estando hoje a FAP, num nível de paridade (em número de acidentes por 10.000 HV) com Forças Aéreas de referência da Europa, nomeadamente as Forças Aéreas de Espanha e Bélgica (e melhor que a Suiça).

Palavras-chave: Acidentes com aeronaves, segurança de voo, prevenção de acidentes, perda de aeronave.

Introduction

On 11 July 2016, the news programmes opened with the report of an accident involving a Portuguese Air Force (PtAF) C-130H aircraft in Air Base 6, in Montijo, which resulted in three fatalities, as well as in the total loss of the aircraft. The PtAF had not recorded a fatal accident[1] for over a decade, and later clarified in a statement that the flight had included ground manoeuvres, aborted take-off, high-flying, and final approach. The crew lost control of the aircraft, which veered off the airstrip and came to an abrupt stop, triggering a fire that killed the crew (PtAF, 2016).

Unfortunately, accidents in which there is loss of life and in which the aircraft is destroyed still occur in the PtAF and in other Air Forces. Also in 2016, in September and August, respectively, the Swiss Air Force lost a Super Puma helicopter and an F/A-18C in the Alps, after having lost an F-5E in a collision with another aircraft during an air festival in the Netherlands early that same year (Lion, 2016). Other European Air Forces also recorded

[1] In the 2007 and 2008 crashes involving Alouette III and F-16 aircraft, the crew members were unharmed.

tragic accidents. Overall, in 2016, about 50 military aircraft were lost in accidents from India to the US (Financial Express, 2016) (Marine Corps Times, 2016).

Aviation accidents clearly remain a current reality that has repercussions for the armed forces in terms of human and material costs, and which they have long sought to avoid or at least minimise through prevention and through the promotion of flight safety.

The PtAF has a flight safety and accident prevention system in place that aims to "(...) safeguard the human and material resources of the Air Force" (FAP, 2009, pp. I-1-1). However, despite all the efforts made, about four dozen aircraft and a similar number of human lives have been lost over the last three decades (Marado, 2011).

It is therefore justified to continue to invest on improving flight safety, which can be described as the continued operation of aircraft over time without hull loss accidents"[2]. In order to successfully travel that path, it is important to understand "What are the causes of hull loss accidents and to what extent has accident prevention in the PtAF been effective, in absolute terms and when compared to other benchmark operators?"

The investigation carried out to answer this question used an inductive methodology to characterise and compare a small number of European air forces and to draw conclusions about the effectiveness of prevention in the PtAF, according to the scientific research phases proposed by Raymond Quivy and Luc Van Compenhoudt (Quivy, 2008).

Air forces from four European countries were chosen as the field of observation: Belgium, Switzerland and Spain, in addition to the PtAF. There were two selection criteria: they had to be small European air forces with 10,000 to 100,000 flight hours recorded per year, and they had to use western-designed and manufactured weapon systems[3]. The decision to survey four air forces (rather than a higher number) stemmed from the necessary compromise between the depth of analysis intended and a sample size that would allow it to be representative of small European air forces.

With regard to the research instruments, in addition to a literature review, technical reports, scientific papers, press releases, presentations in international *fora*, among others, on the topic at hand were also analysed. These research instruments were used to collect data that fed indicators such as number of annual flight hours, number of hull loss accidents, or percentage of accidents in which human factors were the main cause.

This paper is organised in four main chapters. The first chapter presents a brief overview of the history of flight safety and accident prevention and identifies the challenges that led to the central question. The second chapter presents the different data collected and the various indicators required for the model of analysis, namely the number of hull loss accidents per 10,000 FH in the PtAF and in the Spanish, Belgian and Swiss Air Forces. Next, in chapter

[2] Situations of loss due to enemy action are excluded.

[3] The standards used in the design, manufacture and maintenance of western aircraft are different than those used in other regions of the world, such as Russia, India, or China. The author opted for comparing only Air Forces operating aircraft designed, manufactured and maintained according to the same universe of (western) standards.

3, the causes of occurrences and the causes of hull loss accidents in the PtAF are examined and compared. In the fourth and final chapter an overall analysis is carried out, in absolute and comparative terms, of the effectiveness of prevention in the PtAF as well as of the main causes of hull loss accidents, which will provide an answer to the central question. Finally, the research findings are presented in a first section that provides a retrospective of the broad outlines of the procedures adopted, while the second section presents the conclusions, and the last section lists the paper's contributions to knowledge.

1. Flight safety and accident prevention

"The farther back you can look,
the farther forward you are likely to see."
Winston Churchill

1.1. Historical context

Man has been travelling across distances for a long time, and in doing so has designed different modes of transport throughout history. Although at first these travels were only made by land, sea travel quickly followed. More recently, in the early 20th century[4], it also became possible for humans to travel by air using airplanes and helicopters.

Although, in historical terms, air transport is very recent in comparison to land or sea transport, it is one of the safest modes of transport today, at the outset of the 21st century, especially when one considers fatalities per unit of distance travelled (Duarte et al., 2016, p. 87), as depicted in Table 1, which shows data collected in a survey on transport in the United Kingdom (Ford, 2010). Similar results were obtained in the US (Savage, 2013) and in Australia (Australian Transport Safety Bureau, 2002).

Table 1 – Deaths by distance travelled and travel time in different modes of transport in the United Kingdom.

Mortes por milhar de milhão de horas de viagem	Mortes por milhar de milhão de Km
Autocarro: 11.1	**Via Aérea**: 0.05
Comboio: 30	Autocarro: 0.4
Via Aérea: 30.8	Comboio: 0.6
Barco: 50	Barco: 2.6
Carro: 130	Carro: 3.1
A pé: 220	Bicicleta: 44.6
Bicicleta: 550	A pé: 54.2
Motociclo: 4840	Motociclo: 108.9

Source: Adapted from (Ford, 2010).

[4] Although the successful take-off of a hot air balloon with humans on board was conducted in the 18th century, it has never been used regularly with the primary mission of transporting people.

If one looks at Table 1 and considers the number of deaths per billion travel hours, this could lead to the conclusion that travelling by bus is safer than air travel. However, a deeper analysis shows that this is not the case. Let us imagine that two people wish to go from Lisbon to Porto, which are 300 km apart. The person who opts for a commercial flight will take an hour, so the risk[5] of death by accident in the plane will be 30.8×10^{-9}. As for the passenger who opted for the bus, if the journey is three and a half hours long, the risk of death by bus accident will be $3.5 \times 11.1 \times 10^{-9} = 38.85 \times 10^{-9}$. This demonstrates that the passenger who travelled by bus from Lisbon to Porto is at a higher risk of death due to a transport accident than the passenger who chose to make the same journey by airplane.

But this has not always been the case. Since the 1970s, there has been a remarkable decrease in aeronauticsrelated fatalities due to measures to improve flight safety that led to the reduction of hull loss accidents. This wide range of measures was largely based on the lessons learned from past accidents.

For example, the Air Force Safety Center of the United States Air Force (USAF) compiles and publishes the records of hull loss accidents for periods of over 40 years (AFSA, 2000, p. 2).

Even more comprehensive, the analyses of the two major world manufacturers - Boeing (Boeing, 2016) and Airbus (Airbus, p. 10, 2016) - as well as some speciality publications such as the Aviation Safety Network (Aviation Safety, 2016) systematically publish analyses of commercial airplanes with reaction engines for the previous 50 years, with indicators such as number of fatalities per year.

In addition to number of fatalities, another indicator that is commonly used is number of accidents per year. However, both show abrupt variations from year to year, so the moving average for each five or ten-year period is usually used as the indicator. This type of indicator attenuates the effect of the isolated peaks, ensuring that each value is drawn from a large sample, as can be seen in Chart 1 published by the European Aviation Safety Agency (EASA).

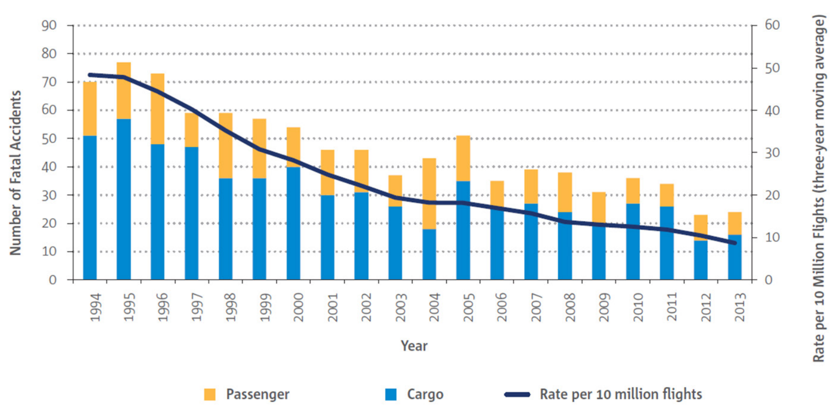

Chart 1 – Trend in fatal accidents in commercial aviation: discrete values and ten-year moving average - EASA.

Source: (EASA, 2014, p. 14).

[5] According to the definition of transportation fatality risk proposed by Savage (2013).

However, even when processed by the moving average method, if the exponential increase in number of flights over time is not taken into account both the number of fatalities per year and the number of annual accidents can lead to skewed conclusions. It could wrongly lead to the conclusion that a year with 29 recorded accidents would have been safer than a different year with 30 accidents (disregarding the fact that there were only 10 million flights in the former and 20 million in the latter). Chart 2 shows that the number of accidents stabilised from 1970-1990, but it also demonstrates that flight safety improved because there was an increase of more than 10 million flights!

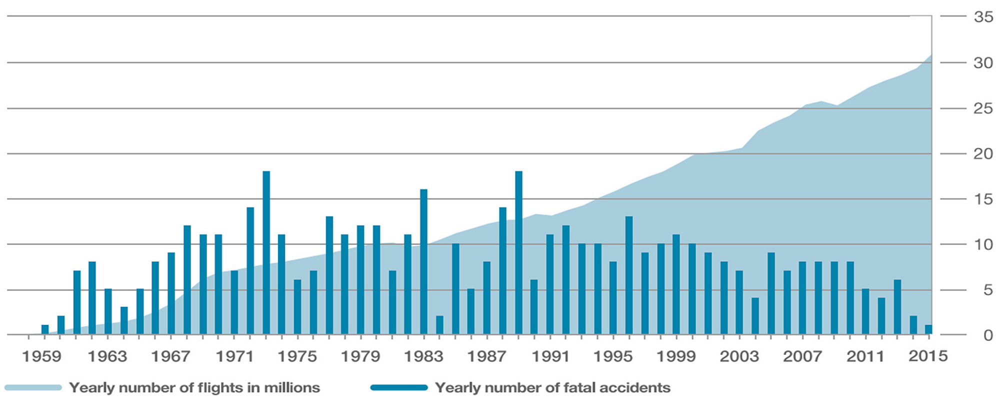

Chart 2 – Trend in number of fatalities *vs*. number of flights.

Source: (Airbus, p. 10, 2016)

Variations in air activity are taken into account by using indicators such as number of accidents per 100,000 flight hours (FH)[6] or number of accidents per million flights (Boeing, 2016, p. 17).

Models have also been created to explain why accidents occur, and that knowledge is used to devise actions for preventing them. About two and a half decades ago, Reason (1990) presented the "Swiss cheese" model, which explains the mechanism that leads to an accident through a chain of events similar to a chain composed of different links in which breaking one like would prevent the accident from happening. These links are different, and could be organisational factors, lack of supervision, preconditions for unsafe acts, and the unsafe acts themselves.

The interpretation of this "Swiss cheese" model allows us to state that a hull loss accident can be avoided by breaking one of the links in the chain of causes that led to that accident, which would instead result in a lower severity event, although the initial causes remain the same. However, this should not be extrapolated to the immediate conclusion that the causes of most occurrences are representative of the causes of hull loss accidents.

[6] If an analysis is carried out of an operator with an annual aerial activity below 100,000 FH (such as the PtAF), the indicator should be adjusted to accidents per 10,000 flight hours.

In this regard, it should be noted, for example, that in 1968, during a nine-month period, a USAF combat aircraft squadron reported 204 accidents that did not result in aircraft destruction. Six aircraft were destroyed in accidents over the same period. The analysis of 204 accidents in which the aircraft was not destroyed revealed that 9% were caused by pilot error, whereas 90% resulted from material failure and/or poor maintenance practices. However, pilot error was deemed to be the cause of five of the six hull loss accidents (83%), and only one case was attributed to material failure (Fair, 1968, p. 4).

This has cast doubts as to whether the causes ascertained for the majority of incidents and accidents are representative of the causes of accidents involving aircraft destruction.

1.2. Prevention in the PtAF

Accident prevention in the context of flight safety is an essential activity for the successful fulfilment of the PtAF mission, and therefore must encompass all areas associated with the aerial activity and allow them to be developed without incurring unnecessary risks7. The RFA 330-1 (FAP, 2009) currently in force sets forth procedures for the harmonious performance of all actions at various levels, defining the principles of accident prevention, the organisation created to respond to those requirements, and the definition of the responsibilities of each of the elements in that structure.

At the PtAF, accident prevention is a global task that is seen holistically, regardless of the wide range of areas and activities involved. As in any other area, a structure must exist that can respond to these requirements, to which are allocated human, material and financial resources. Through this organisation, concerted and complementary actions are developed at various levels, geared towards the goal of preventing accidents in the PtAF: "(...) safeguarding the human and material resources of the Air Force" (FAP, 2009, pp. I11).

Some of the different areas and activities carried out for prevention are, for example, periodic accident prevention/flight safety inspections, follow-up visits, flight safety courses, and training actions on "Crew Resource Management". There are frequent lectures and training activities integrated in the officers courses, in the courses administered at the Academy, and in the sergeants courses, depending on the subjects related to accident prevention covered in the different curricula. Several activities are developed at the Air Bases by the respective accident prevention offices, which will not be covered here due to their length. Mention should also be made of the annual accident prevention plans that endeavour to mitigate the causes of accidents by implementing the lessons learned from the most recent drills and accidents.

[7] Under certain circumstances, commander may agree to take a certain level of risk after a careful assessment where the importance of the mission is also taken into account.

1.3. Challenges

In aeronautics, a large portion of the processes to improve flight safety that have led to the decrease in the number of accidents was based on the lessons learned from past accidents, so the characterisation of hull loss accidents and their analysis over long periods, which serves to evaluate the effectiveness of accident prevention, is a concern of several operators and aeronautical authorities, as mentioned above.

In Portugal, the analysis of accidents with civil aircraft, as well as the analysis of the trend in hull loss accidents and their causes, is carried out by the Prevention and Investigation Office for Aircraft and Railway Accidents[8] (GIAAAF), established by Decree-Law No. 36/2017 of 28 March. In the case of military and state aircraft, the PtAF investigates the accidents through the Central Commission for Accident Investigation (which conducts research in the field of flight safety, investigating its causes and making recommendations with a view to eliminating or minimising accidents) (FAP, 2009, pp. I-5-4).

Despite all the efforts made, over the last three decades 36 PtAF aircraft and a similar number of human lives were lost in accidents, highlighting how important it is to embrace the challenge of achieving and maintaining an operation free of hull loss accidents, that is, to seek excellence in flight safety through prevention. To that end, it is imperative to begin by gauging the performance of the flight safety system implemented. If, as expected, the system has been leading to a consistent decrease in hull loss accidents and is found to be on the same level as other benchmark operators, proposing deep changes to the system is not a sensible course of action, rather the proven model should be maintained while making continuous improvements to specific aspects.

The preliminary research that preceded the formulation of the issues examined in this research paper identified human factors as the primary cause of 41%[9] of all occurrences[10]. However, the reference numbers accepted by the international community state that human causes are primarily responsible for 70% to 80% of cases involving aircraft loss (Kalpana, Chaturveda, 2009).

It is therefore relevant to clarify whether the causes leading to the loss of aircraft at the PtAF are similar (in terms of classification) to the causes of overall occurrences, or whether, on the contrary, human causes are more important, as reported in the international literature (Kalpana, Chaturveda, 2009). This could be a similar situation to the USAF case presented above, that is, the particular severity of hull loss accidents and the greater importance of some causes that can more easily lead to a catastrophic event have not been taken into account.

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[8] The GPIAAF was created out of the merger of the Aircraft Accident Prevention and Investigation Office (GPIAA) with the Safety and Accident Investigation Office (GISAF).

[9] Calculated from the data in (FAP, 2010, p. 1-III-4), (FAP, 2015, pp. 1-III-3) for causes determined between 2000 and 2014.

[10] Air Force Regulation (RFA) 330-1 (FAP, 2009), in the section on accident prevention, defines an "Occurrence" as an event involving an aircraft or its crew during the normal period of operation or in direct support of the flight activity, after the aircraft is considered ready to execute its mission. Occurrences that result in injuries to paratroopers after normal take-off are not considered accidents related to flight safety.

In fact, the analysis of occurrences as a whole has suffered from some limitations. If an analysis was conducted of the effectiveness of flight safety at the PtAF based on the total number of occurrences, it would find that there was an increase of about 500% between 2000 and 2014, which could lead one to conclude that flight safety has decreased dramatically over the last decade and a half. On the other hand, the only available data are those related to reported occurrences, and it is not possible to know or estimate the number of unreported occurrences (if there have been any), and whether they are associated with a specific set of causes. Furthermore, if this study had been based on the analysis of all occurrences (from the least severe to those that lead to the loss of the aircraft due to its destruction), it would be impossible to compare these figures with those from other benchmark operators because the criteria that define an occurrence, incident, or accident in the PtAF differ from the definitions used by other operators[11].

In short, two major challenges have been identified: (i) Ascertaining the effectiveness of prevention for flight safety in relation to the trend observed in the last decades; (ii) Ascertaining whether in the PtAF prevention is now capable of generating a low number of hull loss accidents per 10,000 FH, or lower than other (small) benchmark European Air Forces; and (iii) Knowing to what extent the causes of hull loss accidents differ from the causes of most flight safety occurrences.

This is the only way to understand exactly what direction has been travelled over the last decades, where we are now, and what steps we must take to improve flight safety.

2. Accidents in the PtAF and other European Air Forces

"Facts are sacred,
Opinions are free"
Gabriel Galdón

A number of sources have been examined in the elaboration of this chapter, including reports, plans, and other unclassified official documents of the PtAF and of the Spanish, Belgian and Swiss air forces, as well as presentations at international conferences, press releases, and other open sources.

As for the relevance of assessing the trend in hull loss accidents in the PtAF over long periods, a first step was taken in 2010 with the 2009 annual report of the Accident Prevention Office of the Air Force General Inspection, which states that "having recognised the inconveniences that would reduce the accuracy of this report if it presented and

[11] For example, the United States Air Force categorises occurrences based essentially on economic criteria (AFSA, 2000:119): Mishap Class A is the classification given to damages in the amount of $ 1,000,000 or more, or fatalities, or permanent total disability, or destruction of Air Force aircraft; Mishap Class B is used for damages in the amount of $ 200,000 or more, or partial permanent disability, or the hospitalisation of five or more persons; Mishap Class C is used for damages in the amount of $ 10,000 or more, or injury/illness resulting in temporary incapacity for work, or other specific criteria based on the type of weapon system; HAP is the term used to describe other occurrences.

analysed only the figures for 2009, the timeframe was extended to the period from 2000 to 2009" (FAP, 2010). This statement illustrates that, in 2010, it was identified that it would be advantageous and necessary to analyse these accidents over longer periods rather than over a one-year period.

The aim is now to take a second step and to process the data for the 30-year period between 1986 and 2016. This is approximately the same time-frame as the one analysed by other operators and aeronautical authorities, which does not include periods of war, as this could influence the outcomes.

2.1. Hull loss accidents since 1986

An examination of several documents made it possible to elaborate the list of aircraft lost in accidents presented in Table 2. Two accidents that occurred in 1990 (C-212) and 2002 (ALIII) where there was loss of human life were omitted, since in these two cases the aircraft was not lost and continued to fly for several years. This is in keeping with the criterion initially defined, which was to analyse only hull loss accidents, either due to the total destruction of the aircraft or because the damages required repairs beyond what was economically feasible.

Table 2 – Hull loss accidents in the PtAF between 1986 and 2016

Year	Hull loss accidents	Aircraft:
1986	6	A7 (x2); G91 (x2); T37; SA330
1987	2	A7
1988	4	A7; FTB; ALIII; G91
1989	4	A7 (x2); T37; ALIII
1990	3	T37; ALIII; RF10
1991	1	TB30
1992	3	A7 (x2); ALIII
1993	1	TB30
1994	2	A7; TA7
1995	1	A7
1996-1997	0	---
1998	1	CHIPMUNK
1999	0	---

Table 2 – Hull loss accidents in the PtAF between 1986 and 2016 (cont.)

Year	Hull loss accidents	Aircraft:
2000	1	ALIII
2001	0	---
2002	1	F16A
2003	2	T6; AJET
2004	1	TIGER MOTH
2005-2006	0	---
2007	1	ALIII
2008	1	F16BM
2009-2015	0	---
2016	1	C130
TOTAL	36	

Key: A-7P Corsair II **(A7)**; FIAT G-91 **(G91)**; Cessna T-37 **(T37)**; Aérospatiale SA-330 Puma **(SA330)**; Reims-Cessna FTB-337G **(FTB)**; Sudaviation - SE 3160 Alouette III **(ALIII)**; Fournier RF-10 **(RF10)**; Aerospatiale TB-30 Epsilon **(TB30)**; De Havilland Chipmunk Mk20 **(CHIPMUNK)**; Lockheed Martin F-16 **(F16)**; North-American T-6 **(T6)**; Dassault-Dornier Alpha-Jet **(AJET)**; De Havilland DH-82 Tiger Moth **(Tiger Moth)**; Lockheed C-130 H Hercules **(C130)**.

Source: Prepared by author

Once the hull loss accidents in the PtAF between 1986 and 2016 had been identified, Chart 3 was elaborated showing the trend over the last three decades (blue line), where the red line represents the five-year moving average. The dots in the second line represent the mean values of the last five years, the use of moving averages being standard practice in aeronautical entities, as illustrated in the publications issued by GPIAA, EASA, or Airbus (GPIAA, 2010), (EASA, 2016, p. 14), (Airbus, 2016, p. 13). As mentioned in the previous chapter, the fiveyear moving average method attenuates the annual peaks that result from the low number of occurrences, allowing a more stable trend analysis. Additionally, the same chart also shows the annual flight hours in the axis of ordinates on the right-hand side, which corresponds to the green area (solid line).

There was a decrease in annual flight hours in the three-decade period under analysis, from 40,031 FH in 1986 to less than half in 2016 (Chart 3). This emphasises the need to take into account not only the absolute number of accidents, but also the number of accidents per 10,000 FH, allowing for the effect created by the decrease in aerial activity.

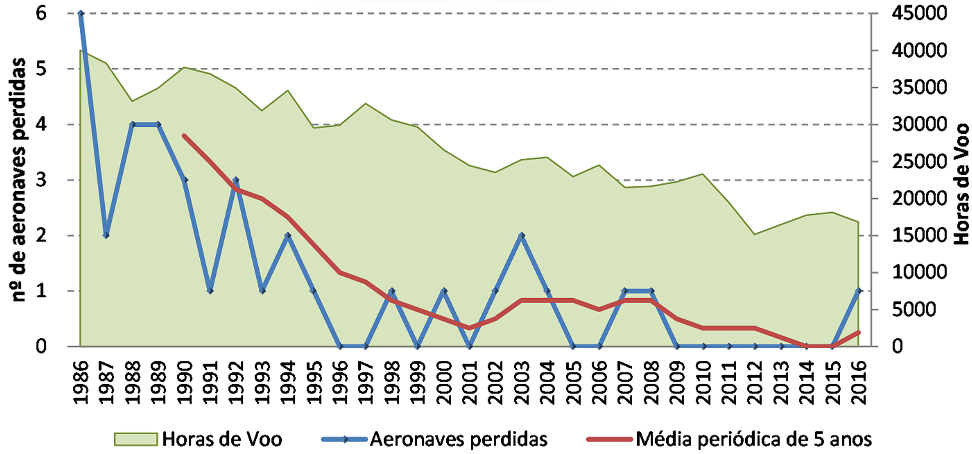

Chart 3 – Hull loss accidents in the PtAF since 1986.

Source: Prepared by author

2.2. Aircraft lost per 10,000 FH since 1986

Once the annual FH data and number of accidents were obtained, it was possible to calculate the annual rate of hull loss accidents per 10,000 FH since 1986, as shown in Chart 4. It was also decided to include the five-year moving average, for the reasons mentioned above.

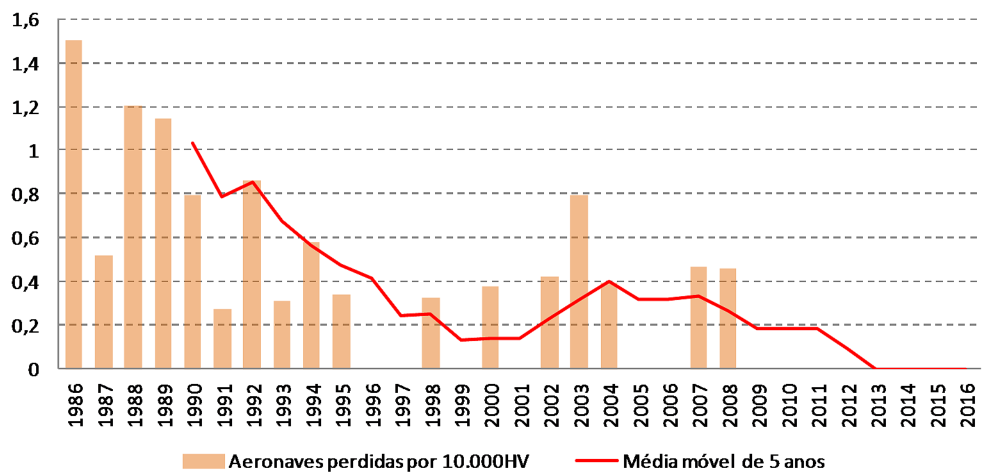

Chart 4 – Hull loss accidents per 10,000 FH in the PtAF since 1986.

Source: Prepared by author.

2.3. Accidents in other operators

In order to verify whether or not there is a relation of parity between the PtAF and other benchmark operators regarding hull loss accidents, it was first necessary to define and identify those benchmark operators.

The author opted for considering as benchmark operators those that met the following criteria: (i) Being a military operator; (ii) Having a similar number of annual flight hours to the PtAF, and (iii) Operating western-designed and manufactured aircraft.

Three operators were then identified that met the criteria defined above, on which it was possible to obtain the necessary data, namely number of accidents over the last 20 years and number of flight hours[12]: (i) the Spanish Air Force; (ii) the Belgian Air Force; and (iii) the Swiss Air Force. Most of these values were obtained from presentations at international conferences, specifically through the Air Forces Flight Safety Committee Europe, as well as through open sources (Colles, 2010), (Sendin, 2010), (Kobert, 2010), (Marado, 2011), (Fiorenza, 2012), (Estrella digital, 2015), (FAP, 2016), (Lion, 2016).

Chart 5 shows the desired indicators (aircraft lost per 10,000 FH) for the PtAF and for the three benchmark operators (dashed line). UAV/UAS/RPAS losses and flight hours were excluded for all operators. The fiveyear moving average (solid line) was also included, for the reasons explained above.

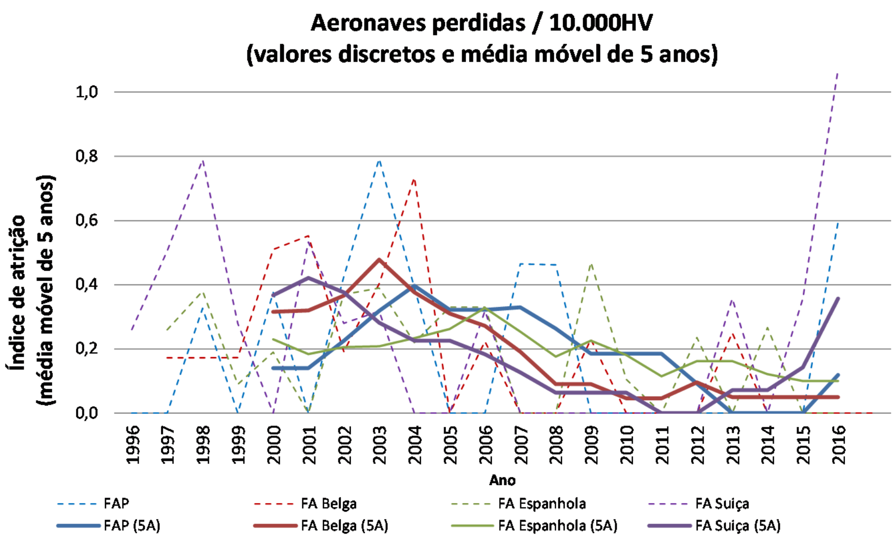

Chart 5 – Number of hull loss accidents (per 10,000 FH) in the various Air Forces from 1996-2016.

Source: Prepared by author.

[12] Only manned aerial vehicles were considered, since unmanned aircraft (Unmanned Aerial Vehicle - UAV; Unmanned Aircraft System - UAS; Remotely Piloted Aircraft System - RPAS) have a set of specificities that lead to significantly higher numbers of accidents per FH than those recorded with manned aircraft (this is the main reason why they cannot, as a rule, fly over densely populated areas).

After comparing the trend in number of annual hull loss accidents per 10,000 FH in the four Air Forces under study, the global mean values for the period under analysis were calculated. The analysis of Chart 6 reveals that these four operators obtained values between 0.17 and 0.24 accidents per 10,000 FH in the time-frame analysed, whereas the PtAF obtained a value of 0.18, that is, in the last two decades an average of one hull loss accident occurred every 55,000 FH. It should be noted, however, that this is the average, and Charts 4 and 5 already showed that an effective decrease was recorded in the last decades.

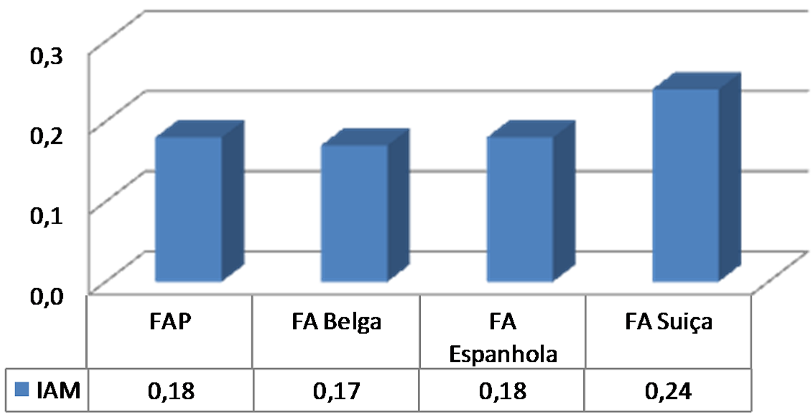

Chart 6 – Aircraft lost in accidents (per 10,000 FH) in several Air Forces (1996-2016)

Source: Prepared by author.

3. Occurrences and causes

In order to verify whether there is a direct relation between the trend in numbers of hull loss accidents and the trend in overall (reported) occurrences, an exhaustive survey has been carried out for the data available from 2000 to 2014[13], a period that was considered acceptable as the sample includes a total 1,533 events (red columns in Chart 7).

As mentioned above, the analysis of occurrences (whether or not they result in aircraft loss) should take into account the aerial activity measured in flight numbers or flight hours. The number of occurrences per 10,000 FH (occurrence rates) was then calculated, as presented in Chart 7 (green columns), to which was added a trend line obtained by linear regression to better show the trend since 2000.

[13] The data for 2015/2016 were not available at the time the research was conducted.

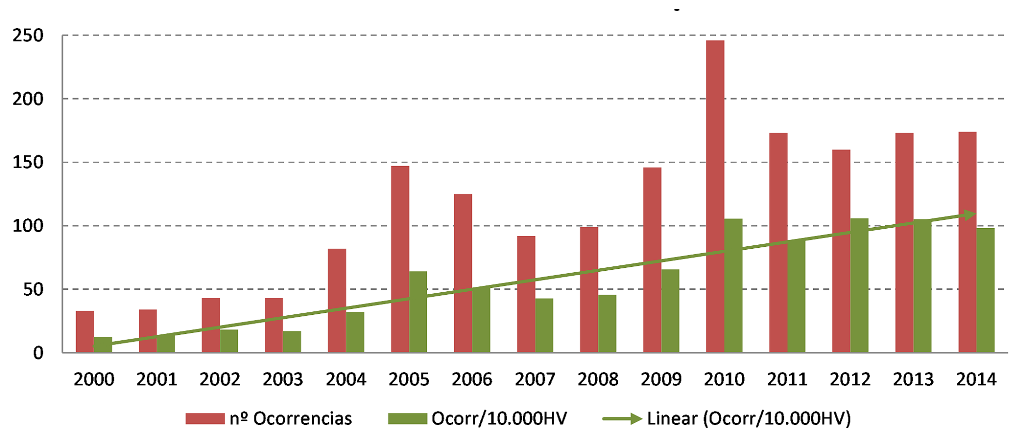

Chart 7 – Total annual occurrences in the PtAF and occurrences per 10,000 FH

Source: Adapted from (FAP, 2010, p. 1-III-4) (FAP, 2015, p. 1-III-3)

According to the Accident Prevention Office report for 2009, the significant increase in the number of occurrence reports since 2004 is the result of the introduction of a computerised accident prevention reporting system (SIPA) as well as of greater awareness of the importance of reporting all occurrences, regardless of their relevance or severity. This increase in occurrences in the PtAF is not an isolated phenomenon, and has also been recorded in the Belgian Air Force, where "since 2007, a steady increase of about 17% a year has been verified, primarily caused by the increase in the number of Cat C (minor accidents)" (Colles, 2010, p. 4).

3.1. Categorisation of Causes

In order to determine whether the causes of overall occurrences are representative of the causes of hull loss accidents compared to their prevalence, the causes must be examined and their prevalence quantified, which will be expressed as a percentage of the total number of causes ascertained.

As for the causes, it should be noted that the categorisation used here has been defined in Air Force Regulation 330-1. The causes are divided into three large sets, as shown below, to which are associated failures that are described in detail in the above regulation, as follows:

- SET OF HUMAN CAUSES, which includes the following situations:
  - Crew/Operator Failure;
  - Maintenance Failure;
  - Organisation Failure.

- SET OF MATERIAL CAUSES, which includes situations of:
    - Material failure;
    - Unsatisfactory Equipment[14].
- SET OF VARIED/DIVERSE CAUSES (OTHERS), which includes situations of:
    - Support Service Failure;
    - Unknown perrson related Failure[15];
    - Natural, Operational, or Health Causes;
    - Unknown[16];
    - Others[17].

3.2. Causes of occurrences

The analysis of the causes of occurrences was based on the data available prior to the beginning of this investigation. Figure 8 shows the causes of about 1500 occurrences from 2000-2014 (not including a small number of cases where the investigation has not yet been closed, specifically regarding nonoperational fleets such as SA-330 Puma and C-212 Aviocar). The figures presented for each year refer to the causes determined in the investigations completed during that same year, since investigation processes can be closed in the year following the occurrences.

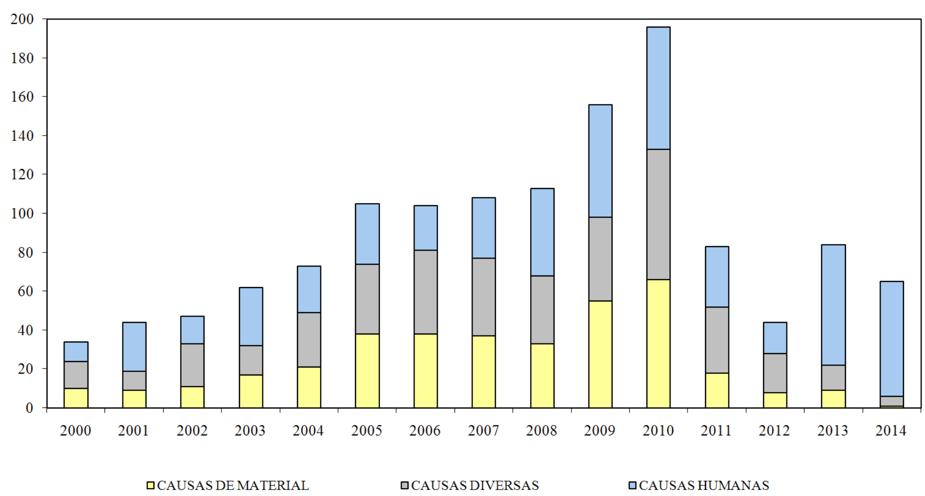

Chart 8 – Sets of causes of occurrences in the PtAF over the last decade

Source: Adapted from (FAP, 2010, p. 1-III-4) (FAP, 2015, p. 1-III-3).

[14] This includes: equipment that, despite complying with the parameters for which it was designed, does not meet the operational requirements; requirements that have not been met (for example, warning lights, poor signalling, lack of protective equipment, etc.); equipment designed in such a way as to lead to human error or material failure (FAP, 2009, p. F-1).

[15] Failure related to the performance of persons or collective entities external to the Air Force (FAP, 2009, p. F-2).

[16] Causes that could not be positively identified (FAP, 2009, p. F-2).

[17] Causes not covered by any of the above definitions (FAP, 2009, p. F-2).

Based on the data available (FAP, 2010, p. 1-III-4) (FAP, 2015, pp. 1-III-3), it was found that, of the investigations completed between 2000 and 2014, 41% were attributed to human causes, 27% to material causes, and the remaining 32% to varied causes.

3.3. Causes of hull loss accidents

In order to compare the causes and underlying factors of accidents (in which the aircraft was destroyed) and PtAF occurrences, Chart 9 was elaborated with the causes ascertained since 2000.

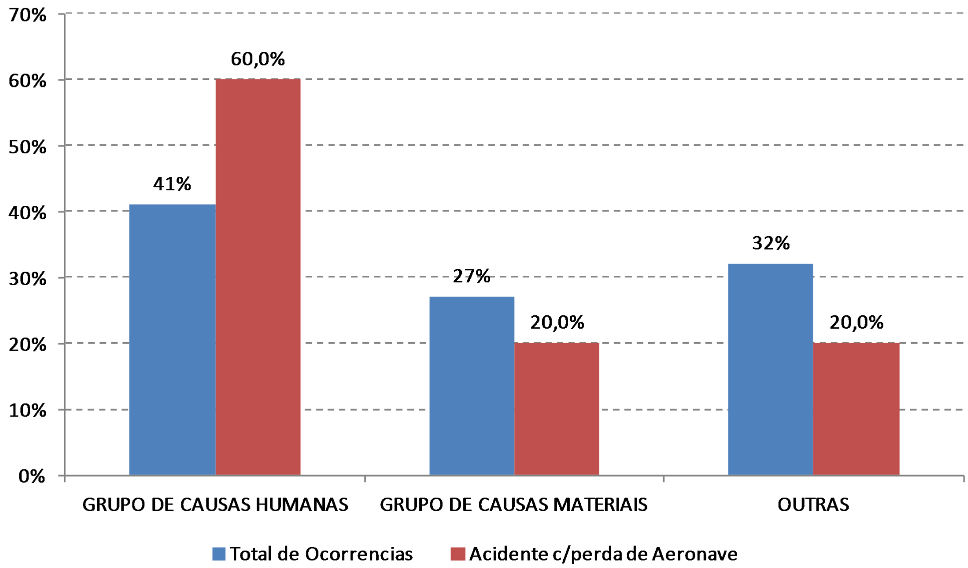

Chart 9 – Sets of causes of hull loss accidents and causes of overall occurrences (prevalence)

Source: Prepared by author.

It was found that 41% of overall occurrences were primarily caused[18] by human factors, but that those causes have a substantially higher weight, specifically 60%, in hull loss accidents. These figures are close to the reference values accepted by the international community: human causes are primarily responsible for 70% to 80% of aircraft loss cases (Kalpana, Chaturveda, 2009). These human causes include not only failure on the part of the human element of the crew, but also maintenance failure (which in turn can be quite varied and can include fatigue, error of judgement, deficient training, among others).

[18] It was found that a large portion of the accidents had not been caused by a single cause, but by a primary cause (that contributed decisively and that would prevent the accident should it be eliminated) and by contributing causes (that contribute to the accident by acting in tandem with the primary cause, or by amplifying its effects; however, eliminating them would not be enough to prevent the accident).

4. Information analysis

> "Speaking or writing without thinking is like shooting without aiming."
>
> Arnold Glasow

This chapter will present a comparison of the findings and provide an answer to the central question that guided the research.

4.1. Trend in hull loss accidents in the PtAF

The analysis of Figure 4, which shows hull loss accidents (per 10,000 FH) over the last three decades, reveals a continuous decrease of the fiveyear moving average, with the exception of 2016, with the loss of a C-130H in Montijo after eight years without accidents, and also of a short period between 2002 and 2004. The increase in the period from 2002 to 2004 resulted from the loss of five aircraft in only three years, whereas only one aircraft was lost in the previous three years (1999 to 2001). A closer analysis of the triennium (2002 to 2004) found that 40% of all accidents, namely the loss of one T6 and one Tiger Moth aircraft, involved Air Museum aircraft. It was also ascertained that once the circumstances under which these accidents occurred had been discovered, the Chief of General Staff of the Air Force made the decision to suspend the aerial activity of the Air Museum squadron until a number of changes and actions had been carried out to improve flight safety.

Of the remaining aircraft lost in the three-year period (2002 to 2004), the first F-16 aircraft loss was also recorded during a training mission for a performance test, which constituted a high risk mission as the flight profile was designed to push the limits of both aircraft and pilot.

The trend analysis confirms that (despite the isolated peak in the above triennium, as well as in 2016 with the first accident in eight years) **a consistent decrease in hull loss accidents was recorded over the last three decades**.

4.2. Relation between hull loss accidents in the PtAF and other benchmark operators

Analysing the accidents in the PtAF over the last two decades and comparing them to those in the Belgian, Spanish and Swiss Air Forces revealed that all air forces show an overall decrease trend (see Chart 5), except for the Swiss Air Force, which has seen an increase in the five-year moving average accident rate (with loss of aircraft) per 10,000 FH since 2012, with three accidents recorded in 2016, the worst year of the last decade for that Air Force. The latter example shows that flight safety requires a continuous and intense commitment, otherwise the trend will revert. As for the total value of the average of hull loss accidents per 10,000 FH over the last 20 years, the values obtained by the Portuguese, Belgian and Spanish Air Forces were quite close, between 0.17 and 0.18. As for the Swiss

Air Force, although the value obtained is within the same order of magnitude, it stands out with a significantly higher value, 0.24, as shown in Figure 6.

Thus, it was found that, in terms of hull loss accidents, there is a relation of parity between the PtAF and the Spanish and Belgian Air Forces, all of which obtained better values than the Swiss Air Force.

4.3. Relation between the trend in hull loss accidents and frequency of occurrences

The trend in occurrence rates was also examined and compared to the number of hull loss accidents per 10,000 FH.

Between 2000 and 2014, investigations on 1,533 occurrences were completed, of which only seven resulted in aircraft loss (<1%).

If the number of hull loss accidents dropped in recent years, the number of accidents showed the opposite trend, increasing up to five times between 2000 and 2014 (due to a stronger reporting culture); therefore, it is not possible to establish a relation between the trend in overall occurrences and the trend in hull loss accidents. In this respect, it should be noted that the increase in number of occurrences in recent years is also a trend in other air forces, such as the Belgian Air Force.

It was thus demonstrated that **there is no direct relation between the trend in number of hull loss accidents per 10,000 FH and the trend in occurrence rates.**

4.4. Relation between the causes of hull loss accidents and the causes of overall occurrences

As for the causes of overall occurrences in the last decade, it was verified that human causes had a weight of 41%, material causes of 27%, and other causes, 32%. However, an analysis of the weights of the various causes that led to hull loss accidents revealed very different figures, with human causes weighting 60%, material causes weighing 20%, and other causes, 20%.

Therefore, there are significant differences in the weight of the various sets of causes, depending on whether they refer to overall occurrences or specifically to hull loss accidents, **which shows that the causes of occurrences are not representative and are not directly related to the causes of hull loss accidents with regard to their prevalence**.

This aspect merits a more detailed analysis, which falls beyond the scope of this investigation. However, the high percentage of material causes (27%) expected in overall occurrences stems from the fact that some causes are attributed to material factors as a result of superficial investigations. That is, when there is a lack of (technical and financial) resources to conduct specialised expert assessments, material failure is assumed. Should there be (more) specialised expert assessments, it would be found that many of these cases involved human error at some point of the design, manufacture, maintenance, or operation process.

As for the high percentage of other causes (32%) of overall occurrences, these result from the prevalence of occurrences involving birds (about 160 in ten years) and also from the (technical and financial) difficulties in conducting specialised expert assessments. Thus, when expert assessments cannot be conducted and there is no apparent reason for the failure, the unknown cause category is used.

In the case of hull loss accidents, the investigations are more thorough and more (human, financial, and material) resources are allocated, resulting in the increase of causes attributed to human failure (maintenance, operation, or otherwise).

Conclusions

In aeronautics, a large portion of the flight safety improvement processes that have led to the reduction of accidents was based on lessons learned from past accidents; thus, the characterisation of hull loss accidents and their analysis over long periods is a concern for operators, manufacturers, and aeronautical authorities. On the one hand, developing specific aspects of flight safety and prevention is a concern, but on the other it is important to have a global view of the whole system, particularly with regard to the ultimate goal of flight safety and accident prevention, which is to prevent the loss of human life and aircraft.

This research focused on the question "What are the causes of hull loss accidents and to what extent has accident prevention in the PtAF been effective, in absolute terms and when compared to other benchmark operators?", beginning by conducting an extensive literature review, summarised in Chapter 1, which included magazine and newspaper articles, as well as articles issued by aeronautical authorities, manufacturers, and military operators.

An analysis model was created based on the concepts of hull loss accident, occurrence, and cause, using indicators such as number of hull loss accidents per 10,000 FH, occurrence rates, and prevalence of causes to scientifically determine (i) What is the trend in number of hull loss accidents in the PtAF over the last three decades; (ii) How does the PtAF compare to other benchmark operators; (iii) What is the relation between the trend in number of hull loss accidents per 10,000 FH, and the trend in occurrence rates in the PtAF, and (iv) What is the relation between the causes of occurrences and the causes of hull loss accidents with regard to the prevalence of different sets of causes.

Once the analysis model had been consolidated, the findings were presented in the second chapter. The field of observation included accidents involving hull loss and/or loss of human life in the PtAF and in the Spanish, Belgian and Swiss Air Forces. The object of observation for hull loss accidents was a 30-year time-frame in the case of the PtAF, and a time-frame of about two decades (due to the impossibility of obtaining previous data) in the other Air Forces. Chapter 3 presents an analysis of overall occurrences in the PtAF since

2000, a timeframe that was considered sufficiently long to obtain a sample with about 1500 events. After looking at the data to test the analysis model, the indicators were measured.

Chapter 4 presented an analysis of the various indicators, and the first conclusions were drawn, allowing the central question to be fully answered. It was found that if an analysis was carried out of the effectiveness of flight safety based on overall occurrences, it would reveal a fivefold increase since 2000, which could lead to the conclusion that flight safety decreased dramatically over the last decade and a half. However, this is not the case, and the phenomenon is associated with greater awareness and ease of reporting resulting from the entry into operation (in 2005) of computerised reporting tools, and from a stronger safety and prevention culture, which also occurs in other air forces. In fact, the continued increase in flight safety in the PtAF over the last 30 years has been demonstrated by the consistent decrease of the five-year moving average for hull loss accidents. It has been shown that over the last three decades there has been a consistent decrease not only in the number of hull loss accidents in absolute terms, but also in the number of aircraft lost per 10,000 FH.

The number of hull loss accidents per 10,000 FH in the PtAF over the last two decades was also analysed and compared with the figures from the Belgian, Spanish and Swiss Air Forces, and it was verified that the Portuguese, Belgian and Spanish Air Forces obtained very similar values between 0.17 and 0.18. As for the Swiss Air Force, despite remaining within the same order of magnitude, it obtained a significantly higher value, 0.24. Thus, it was found that, in terms of hull loss accidents, there is a relation of parity between the PtAF and the Spanish and Belgian Air Forces, all of which obtained better values than the Swiss Air Force.

As for the trend in causes of occurrences and number of hull loss accidents per 10,000 FH, investigations on about 1500 occurrences were completed since 2000, of which only eight involved hull loss. In that period, while the (reported) occurrence rates increased fivefold, the number of hull loss accidents per 10,000 FH decreased, and no direct relation was found between these indicators. It was thus demonstrated that there is no direct relation between the trend in number of hull loss accidents per 10,000 FH and the trend in occurrence rates.

As for causes, it was ascertained that, with regard to overall occurrences, human causes have a weight of 41%, material causes of 27%, and other causes, 32%. However, the analysis of the weights of the various causes that led to hull loss accidents (which represent less than 1% of overall occurrences) obtained rather different results, with human causes weighing 60%, material causes, 20%, and other causes, 20%. Therefore, highly significant differences have been found between the weight of the various sets of causes, depending on whether they refer to overall occurrences or to the specific case of hull loss accidents, which shows that the prevalent causes of most occurrences are not representative, nor are they directly related to the prevalent causes of hull loss accidents. This occurs because in most cases, there are limitations in terms of carrying out indepth investigations by conducting specialised expert assessments, and because more human, material and financial resources are allocated in the case of hull loss accidents.

In answer to the central question, this research has found that **although it was determined that human causes have a weight of 41% for overall occurrences (incidents and accidents), in the specific case of more serious accidents (involving hull loss) human causes have a weight of 60%. These causes have been effectively tackled, which resulted in a consistent decrease in the number of hull loss accidents per 10,000 FH over the last 30 years, and today the PtAF is on equal footing with other benchmark European Air Forces**.

It is only by knowing and assessing that one can evolve. Thus, the aim of this research is to contribute to "accident prevention culture".

As for new contributions to knowledge, it should be noted that while it was already known that the number of hull loss accidents in the PtAF has been decreasing, this research also revealed that, over the last 30 years, this was not only caused by a reduction in annual flight hours but to a consistent decrease in the number of hull loss accidents per 10,000 FH. It was also discovered that, in this respect, the PtAF is on the same level as other European operators such as the Spanish and Belgian Air Force, and on a level higher than the Swiss Air Force. Finally, it was found that there is no direct relation between the trend in number of hull loss accidents per 10,000 FH and the trend in accident rates or cause rates, that the causes of occurrences ascertained are not representative, and that they do not directly relate to the causes of hull loss accidents regarding their prevalence.

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