Development of an Aerodrome Risk Assessment Tool

António André Clemente Freitas
antonio.freitas@tecnico.ulisboa.pt

Instituto Superior Técnico, Universidade de Lisboa, Portugal

January 2021

Abstract

The complex world of commercial aviation is constantly subject to a considerably high pace of development where, every day, is required faster transport of passengers and goods, never relinquishing the high safety standards inherent to this type of activity. The airline operators' security department has the responsibility to carry out, in a completely impartial manner, the safety study in the sense of prevention, performing an activity independent of any other department, avoiding any management or commercial influence or pressure from the outside. An operator, operating in different destinations, requires the security department to continuously analyse its aerodromes of choice. This being an extremely multifaceted analysis, in addition to the safety scope, it is necessary to address all the characteristics of an aerodrome such as meteorology, performance, means of assistance, capacity, accommodations, specific licenses, distance to alternates, accessibility, among others. With this task in mind, the objective of this project was defined as the development and implementation of a tool that would allow to carry out, in a uniform way, a quantitative analysis of the risk of the operation at each aerodrome, in order to keep it within the limits defined as acceptable. This tool was implemented through a checklist where each item/question has an associated risk weighting factor calculated from a statistical analysis to past safety related occurrences, subsequently carrying out its implementation and validation in aerodromes of current and future operation. After the implementation of this tool, risk results were found to be consistent with the safety standards of the company to which it is intended, thus demonstrating the potential for integration into the safety department's operational routine, as well as potential support for the development of alternative tools for risk analysis of air routes, aircraft and crews.

Keywords: Safety, Aerodrome, Risk Assessment, Checklist, Impartiality.

1. Introduction

One of the key objectives pursued by airline companies is the reduction of the risks associated to the air transportation related operations. These risks encompass not only the safety of the aircraft but also safety factors external to the aircraft such as the safety of the operation in a specific aerodrome. Aerodromes are locations in which any type of aircraft flight operation takes place, regardless of whether it involves air cargo, passengers or neither. All airports are also aerodromes, with the particularity that these meet specific regulatory requirements.

Each company has defined its safety requirements and can decide whether to operate or not to a certain aerodrome. The focus of this project is the analysis of the aerodromes safety status, specifically the aerodromes with conditions to handle commercial flights (international and domestic airports), as well as the risk associated to the civil air transport operation in these locations.

All airline companies have a concept of safety and which risks are acceptable or not. However, there are situations when risk interpretation may become subjective. Generally, risk identification and interpretation is majorly performed by experienced safety department members of the airline companies which are aware of the relevance of subjectivity. Nonetheless, the best approach to risk interpretation is the mathematical form based on risk models and collected risk information and safety related occurrences. This involves the establishment of risk levels and risk acceptance criteria, completely eliminating the subjective interpretation of any safety department member. This is the objective seek by Portugália Airlines which proposed the development of an Aerodrome Risk Assessment Tool (ARAT) that, besides the qualitative assessments already performed by the company, also enables the determination of a quantitative risk value for each aerodrome operation and respective acceptance.

However, performing a complete analysis to the risk of operating an aerodrome surely becomes an embracing task due to the continuously increasing size and complexity of the aerodromes, which requires taking into account the safety concerns of all departments. This means that, in the day to day use of the tool, it will have to be shared with all the departments so it has to be enough elaborate, effective and accurate to validate the safety of the operation in an aerodrome but also concise, efficient and simple in order to be consistently handled by the safety delegates of all the involved departments consuming the possible least amount of their time.

There are three key objectives for this project that consist, primarily, in the development of an Aerodrome Risk Assessment Tool (ARAT) with questions related with safety concerns from each department in a checklist form, to be answered by the safety delegates in each department. This tool consists of an excel file and each aerodrome assessment should be performed individually in different versions of this file. The second key objective is the development of an Aerodrome Risk Assessment Summary (ARAS) that will be used to compile the risk results of each aerodrome ARAT file, thus, facilitating the comparison of the risk status of each aerodrome. The final major objective is to perform actual Aerodrome Validation analysis, obtaining risk results and compare this new developed risk assessment methodology and the obtained results with the previous ones obtained by Portugália Airlines. After these comparisons, optimisations can be performed depending on the feedback of the safety department members.

In order to accomplish these objectives it was necessary to study the Safety Management Systems (SMS) of airline companies and then focus specifically on Portugália Airlines. The Safety Management System is an organisational function subdivided in the components of Safety Policy and Objectives, Safety Risk Management, Safety Assurance and Safety Promotion that merely consists of principles, processes and measures to identify and decrease risks. It can be applied to any type of organisation but requires adaptation to the type of operation of each one. In the case of the safety management in aviation operations, the main focus is the safety of flights and all other services like air navigation services and aerodrome operations management that support this activity. Naturally, being this project focused in analysing the risk of operation in an aerodrome, major relevance will be given to the aerodrome safety management and to its component of Safety Risk Management (SRM). The documents that provided the most complete information about the SMS of airline companies and the SRM process were ICAO's Doc 9859: Safety Management Manual [3] and ICAO's Annex 19: Safety Management [2]. When it became necessary to focus specifically on the SMS of Portugália Airlines, the Safety Management Manual [5] was very relevant. Additionally, documents such as the "Safety Management and the Concept of Dynamic Risk Management Dashboards" [4] and "ADREP 2000 Taxonomy" [1] made available the basic tools to start the development of the ARAT.

2. Aerodrome Safety Background

The initial focus, in this section, is to briefly present the safety theory that is behind the daily operation of aircraft in aerodromes, describing the major components of the Safety Management System (SMS) of the aerodromes. Then, it is presented the greater significance of one of these components, the Safety Risk Management, for the goal set for this project of developing an Aerodrome Risk Assessment Tool. Finally, because safety related occurrences are the direct consequence of accepting risks, it is presented an accident causation theory and the methodologies already in implementation on how to prevent this type of occurrences.

2.1. Aviation Safety Management System

Safety, as defined in ICAO Annex 19 [2] is " the state in which risks associated with aviation activities are reduced and controlled to an acceptable level". Thus, when the expression "completely safe" is used to characterize an activity, it is usually misunderstood as not having any risks associated to it, which is not entirely truthful. Safety consists of nothing more than the definition of a risk boundary (acceptable level) where anything above it is considered unsafe and, inversely, below it considered safe.

In aviation, Safety Management Systems (SMS) and State Safety Programmes (SSP) are mandated by Member States and Service Providers in order to achieve an acceptable level of safety (ALoS). The main modules of the SMS consist in Safety Policy and Objectives, Safety Risk Management, Safety Assurance and Safety Promotion.

Safety Management itself is an organizational function with focus on applying principles, processes and measures to identify, assess and mitigate risks to an acceptable level preventing human injury, property and/or environment damage or any other adverse consequence that may be caused by making use of a service or product. For a successful safety management, a systematic approach has to be defined, including the necessary organizational structure, accountabilities, policies and procedures. Safety management has shown huge importance for aviation safety, sustainable business management and operational growth which led to the progressive implementation of these systems by aviation service providers.

The following sub-sections provide a brief description of the components that constitute the SMS. It was decided to leave the component Safety Risk Management for last to present a more in depth description due to its major importance for the development of the ARAT.

2.2. Safety Policy and Objectives

This is the first component of the SMS framework of a company and its focus is on the creation of an environment that enables an effective safety management and the management's commitment to safety, to its goals and the supporting organizational structure.

The safety objectives of a company should be concise and statements of the organization's safety priorities while addressing its most significant safety risks.

2.3. Safety Assurance

Safety assurance is the formal management component process of the SMS that continuously monitors its operation, assuring the meet of expectations and requirements. Additionally, safety assurance must identify the need of new safety risk controls and develop and implement corrective actions as a response to the system's deficiencies. Put in practice, it consists of reviews, evaluations, inspections and, most importantly, internal and external audits, and it is recommended that these actions are an intrusive and enquiring exercise to ensure its effectiveness.

2.4. Safety Promotion

Safety promotion is another major component of the SMS and has the role of assisting in the achievement of effective control of safety risks during service delivery, through the combination of technical competence continuously enhanced through training and education, effective communications and information sharing, constituting the safety culture of the organization. Safety promotion affects both individual and organizational behaviour and is the mean that enables organizations to adopt a culture that goes beyond merely avoiding accidents or incidents and pursuits doing the right interventions at the right time. According to ICAO, safety training and education and safety communication are the two important processes supporting safety promotion.

2.5. Safety Risk Management

This is the component of the Safety Management System of most interest for this project. This process is mainly composed by the identification of the hazards associated to the product or service provided, the assessment of the risk associated to the hazards and, lastly, either the acceptance or mitigation of this risk.

Three techniques are involved in the Risk Management process: reactive, proactive and predictive. These consist of different methods of identifying hazards and assessing risks and the major difference that distinguishes them is the focus on hazards that already resulted (reactive), are resulting (proactive) or may result (predictive) in safety related occurrences. In an "ideal world" all these methods should be constantly explored. However, each particular method requires availability of resources that can go from historical data to computational power. The available resources decide which method can be explored in each specific situation.

Independently of the method selected for the risk management process, it always starts with the hazard identification. Hazards consist of any condition, event or circumstance with potential to cause harm to a person or organization, so it becomes noticeable the wide scope of this process in an industry as developed as commercial aviation.

Following the hazard identification process is the risk assessment process that includes the hazard severity and probability classification. ICAO already developed, in Doc 9859 [3], a severity and probability criteria based on aviation's historical safety data and with the aim to better adapt to the majority of airline companies, so it makes sense to use these criteria in the development of this project (summarized criteria available in tables 1 and 2).

The severity classification is based on a qualitative analysis of the chain of events and possible consequences that can follow from an hazard and is defined by the worst possible outcome. The probability classification might be based on either a qualitative or quantitative analysis but, in order to eliminate the majority of the subjectivity of the risk management process, the quantitative approach should have priority which requires data study and statistical analysis. These classifications enable the identification of the risk level of each hazard that, lastly, should be subjected to acceptance or mitigation.

A risk is only acceptable if it meets the company's predefined Acceptable Level of Safety (ALoS). If not, it can be decided to mitigate the risk to an acceptable level or define it as unacceptable.

Risk mitigation consists of the process of defining and implementing the necessary measures that are able to reduce the risk level and preventing hazards resulting in harm. This is performed through the implementation of the aviation safety defences that are technology, training and regulations, reducing the severity of the potential consequences of an hazard, the probability of occurrence harmful effects and the exposure to that risk, this way concluding the risk management process.

2.6. Accident Causation

The "Swiss cheese" Model is an accident causation model, proposed by Professor James Reason (ICAO Doc 9859 [3]) that consists of a comparison of the human system defences to a series of randomly-holed Swiss Cheese slices arranged in an uni-axial stack like demonstrated in the left side of figure 1.

The application of this method to the aviation safety has gained widespread acceptance within the aviation safety community. Performing the translation of the model to aviation terms, the cheese slices consist of the multiple organisation's defences against failure at all levels and the holes represent the weaknesses in each system defence layer, randomly distributed in each slice. The goal is to prevent the alignment of the weaknesses (holes) in the system's different barriers (slices) leading to a breach that penetrates all the defensive barriers and may result in a catastrophic outcome.

Although fairly simple, this model is commonly used by service providers as a guide that helps overcoming the urge to analyse the identified hazards and the individuals involved in the incidents and focus on the organizational circumstances which may have allowed the harmful occurrence.

2.7. Dynamic Risk Management Dashboards (DRMDs)

The Dynamic Risk Management Dashboards emerged in recent years as a powerful risk management tool. They combine the efforts of different departments to identify hazards and to real-time assess risks, while examining the current state of aircraft, aircrews, aerodromes and air traffic routes (DRMD for the fleet, DRMD for the aircrew, DRMD for aerodromes and DRMD for the air traffic routes, respectively). Its main application is to enable operators to assess the overall risk state of an operation by cumulatively considering factors affecting critical system components which must perform within standards. This task involves knowing all the conditions that affect aerodromes, aircraft, aircrews and traffic routes and that together and successively lead to a high, medium or low risk state.

Having all types of DRMDs, an operator can apply the "Red2Red" concept. This concept can and should be applied even if not all four types of DRMDs are available. It consists of avoiding dispatching a "red" aircrew to a "red" aircraft for flying to a "red" aerodrome through a "red" route. The "red" concept has the meaning that the aircrew, aircraft, aerodrome or route that it is characterizing is still operational but far from its best state. Thus, the DRMDs represent the most approximate implementation in aviation operation of the "Swiss cheese" model of Prof. James Reason (figure 1).

One fault that can be recognized in the DRMDs is the fact that these are a semi-linear approach that do not include weighting factors for each system components, neither for the risk factors. Despite this, even in this current form, the DRMDs were able to practically assist the risk management processes of not only aviation organisations but also other industry sectors, which proves that the development of a risk assessment tool with proper weighting factors developed for each specific hazard would reveal to be an important aid to the safety department of any airline company. This is the aim of the development of the ARAT, that is not meant to fully replace the DRMDs but, instead, to act as an improvement of the "DRMD of the aerodromes".

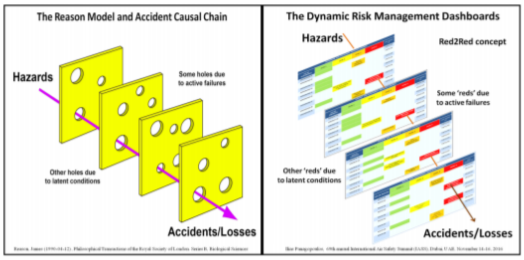

Figure 1: Comparison between Swiss Cheese Model and Red2Red Concept.

2.8. ICAO ADREP

Since the objective of this project is the development of an Aerodrome Risk Assessment Tool it became necessary to perform an analysis to the past safety related occurrences in the various aerodromes around the world. This required understanding the already established standards and definitions to categorize and describe safety related occurrences in aviation. These standards and definitions are contained in a system that was established in 1976 but that has evolved to meet the changes in information, technology and in the aviation industry. It is known as the Accident/Incident Data Reporting (ADREP) system and is operated and maintained by ICAO. The ADREP reporting system is based on the use of a common reporting standard, also known as taxonomy, which operates using a software platform developed by ECCAIRS.

This extensive taxonomy, available in [1], is divided in various lists of attributes but not all of these lists will be relevant for the development of the ARAT. The ones that contain crucial information for this project are the Occurrence category, Damage aircraft, Event phases, Occurrence classes and Injury level.

3. Formulation of the Aerodrome Risk Assessment Tool

The idea for the aerodrome risk assessment tool being developed for Portugália Airlines, consists of developing a safety checklist that can be used by the Safety Department to evaluate the safety status of the current operation in an aerodrome already operated by the company or in a new aerodrome. It was intended for the checklist to have safety related questions distributed through different Parts, each containing Sections that correspond to the different categories of concerns that should be considered while conducting a safety assessment to an aerodrome. For each Part of this checklist, a list of suitable questions and respective answer options had to be developed in association with the safety department of Portugália Airlines and distributed through the appropriate Sections in these Parts. Thereafter, these questions and respective answers had to be adapted through a series of standard type questions purposely developed consisting of 4 types of questions, from questions with 2 answer options to 5 answer options.

3.1. Questions, Sections and Parts Formulation

Seven of the created Parts correspond to the different Departments of the company while two other Parts were created to address specific hazards of greater importance (CFIT and Environmental Hazards). The list of the created Parts for this checklist is the following: Part 1 - CFIT Risk Analysis; Part 2 - Operations Engineering Department; Part 3 - Flight Operations Department; Part 4 - Training Department; Part 5 - Security Department; Part 6 - Ground Operations Department; Part 7 - Maintenance and Engineering Department; Part 8 - Environmental Hazards; and Part 9 - Safety Department. Each of the previously mentioned Parts was subdivided in sections according to the subjects of the hazards that the respective questions represent. The process for the formulation of the questions was based on the study of the major safety concerns of the company through search on the company's documentation, interviews to the managers of each department and study of the safety analysis methods currently in use.

3.2. Hazards Identification Process

The following task was to translate the concern addressed in each question to the hazard that each represents. The hazard identification process was divided in three separate steps. These are the identification of the hazard, the potential outcome and the possible occurrences outcome, which will then enable the calculation of the weighting factor to attribute to each question. This process was mainly reactive and proactive, being a combination of studying the concerns addressed in each question and identifying the dangerous aspects that, in the past, already led to safety related occurrences or that have substantial potentiality to jeopardize the safety of the operation.

3.3. Potential Outcome Identification Process

The identification of the potential outcome consists of assessing the most probable consequences that can result from an hazard in the eventuality that it actually causes harm to the safety of the operation. It consists of the description of the potential safety related occurrences, from damage to aircraft and infrastructures to injuries or fatalities, that can result from the hazard in each question, and this description is what enables the following task of identifying the potential occurrence outcome.

3.4. Occurrence Category Determination Process

This process is done with help of the thorough description of the usage of each occurrence categorization taxonomy present in the ECCAIRS / ICAO documents [1]. The process for attributing one or more occurrence categories to a certain question is to analyse the already identified potential outcome attributed to that question and search, in the usage description of each occurrence category, the one(s) that better applies to that specific outcome. With each question having one or more occurrence categories attributed, it is possible to move on to attributing a severity and probability of occurrence level to each occurrence category. This way, the occurrence categorization acts as a "bridge" that connects each question and its related hazard to a severity and probability of occurrence level enabling the posterior development of the weighting factors that determine the relevance of each question for the final risk assessment result.

3.5. Severity and Probability of Occurrence Determination Process

ICAO provides a criteria of severity and probability of occurrence levels, in Doc 9859 [3] (simplified criteria in tables 1 and 2), that companies can adopt and refine to their benefit.

Table 1: ICAO's Severity Criteria

Severity Classification	Value	Numeric Value
Catastrophic	A	5
Hazardous	B	4
Major	C	3
Minor	D	2
Negligible	E	1

This criteria is the basis of the levels adopted for the development of the ARAT due to its general similarity to most of companies standards. Each of the occurrence category, previously attributed to the questions, has an associated level of severity and probability. The determination of these levels was achieved through a reactive approach method that consisted of a statistical analysis to the safety related occurrences in all aerodromes members of

Table 2: ICAO's Probability Criteria

Probability Classification	**Prob. Value**	**Value**
Frequent	$>10^{-3}$	5
Occasional	$<10^{-3}$	4
Remote	$<10^{-5}$	3
Improbable	$<10^{-7}$	2
Extremely improbable	$<10^{-9}$	1

ICAO (section 4). Having each occurrence category its specific severity and probability level, it is possible to attribute these levels to the questions in the checklist. The occurrence categories act as a bridge between questions and their risk's severity and probability levels and, consequently, their weighting factor. Additionally, as a safer approach, it was decided that, if a question has more than one potential occurrence category attributed, the selected severity and probability levels are the highest of the set.

3.6. Risk Level and Risk Number Determination

The Risk Level (R_L) attributed to each question is composed by one letter and one number (e.g level 3E). The letter, comprised between A and E, corresponds to the level of severity attributed to the question in descending order of severity and the number, comprised between 1 and 5, corresponds to the probability of occurrence level, this time in ascending order of probability.

The Risk Number (R_N) consists of the multiplication of the severity level by the probability of occurrence level. However, in order to get this value, the severity levels are translated from the letters A to E to numbers from 1 to 5 (third column of table 1), similarly to the probability of occurrence levels. This way, the risk level is a number comprised between the lowest value 1 and the most critical value 25.

3.7. Weighting Factor

For the calculation of the weighting factor attributed to a specific question, it was decided to take into account the risk number of the hazard represented in that question due to the fact that an hazard that represents a greater danger must have greater influence in the risk score of its section. This way, as expected, an hazard with a high risk number and low exposure can have the same influence in the risk score as an hazard with low risk number and higher exposure.

The weighting factor calculation consists of the division of the risk number attributed to the question by the highest possible risk number (25), as shown in equation 1.

$$Weighting\ Factor\ (WF) = \frac{Risk\ Number\ (R_N)}{Max\ Risk\ Number\ (25)} \quad (1)$$

This way, for every question, this value is comprised between 0,04 (1/25) and 1 (25/25). The combination of this value and the exposure level (answer), selected by the user, results in the initial risk score of the question.

3.8. Aerodrome Category Increased Weighting Factor (ACIWF)

Before companies establish a continuous operation to a specific aerodrome, it has to be classified as an aerodrome of category A, B or C, proportional to the predetermined risk of its operation and the safety requirements established by the company. With this in mind, it was decided to create the Aerodrome Category Increased Weighting Factor (ACIWF) besides the normal Weighting Factor (WF) attributed to all the questions. This factor consists of the sum of the normal Weighting Factor (WF) with an Increment Factor (IF) based on the aerodrome category (table 3). This increment factor was determined through a statistical analysis to past safety related occurrences.

Table 3: Aerodrome Category Increment Factors

Aerodrome Category	**Increment Factor**
A	0
B	0,1
C	0,2

3.9. Exposure to Occurrences

For the calculation of the risk score of each question (risk after exposure is taken into account) the following model is used (equation 2).

$$SEP\ Model:\ Risk\ Score\ (R_S) = Severity\ (S) \times Probability\ (P) \times Exposure\ (E) \quad (2)$$

The Severity and Probability of occurrence are the parameters which are predefined for each question present in the ARAT and contribute to the weighting factor (ACIWF) that will determine the influence of each question in the final risk score. On the other hand, Exposure is the parameter which is inserted by the user when answering the checklist's questions. As mentioned before, the types of questions go from having 2 answer options to 5 answer options. These options go from the best case, where there is a minimum exposure to that specific hazard, to the worst case, where there is maximum exposure. Exposure is divided in levels and, in the case of this checklist, 5 exposure levels where defined from "very low" to "very high" (from 1 to 5), as shown in table 4.

Table 4: Exposure levels for the ARAT.

Exposure	Level
Very Low	1
Low	2
Medium	3
High	4
Very High	5

3.10. Initial Risk Score

The initial risk score is the risk value determined for each question after the levels of severity, probability of occurrence and exposure have been attributed. This value's calculation consists of the multiplication of the weighting factor (value between 0,04 and 1) by the exposure level (value between 1 and 5), as shown in equation 3.

$$Risk\ Score\ (R_S) = Weighting\ Factor\ (ACIWF)\ \times Exposure\ (E) \quad (3)$$

The sum of the initial risk score of each question in a section divided by the worst case scenario (all question's scores in that section having maximum risk level and exposure) results in the initial risk score of that section, in percentage. The "initial" denomination comes from the fact that this value results from the user selection of the initial options that correspond to the state of the aerodrome in the current conditions, without any intervention of the company to minimize the risk of operation. The same method is used to determine the initial risk score of each Part, this time considering the risk scores of all the questions in each Part. For the Initial Global Risk Score, it was adopted the value of the Part of the assessment with maximum risk score.

3.11. Observations and Notes

For every question present in the ARAT, there is a dedicated column for the user to insert observations or notes to provide explanation and reasoning behind the answer selected or even for the developer of the checklist to leave information that one might find useful to the user of the tool while responding to a specific question, e.g, provide links to databases containing information that could help the user to choose the most appropriate answer.

3.12. Mitigation Measures and Risk Score After Mitigation

Besides the initial state assessment, the ARAT has also an assessment that corresponds to the analysis of the risk of the aerodrome's operation after the implementation of certain mitigation measures targeted to decrease the exposure to the risks represented by the hazards in each question. Concretely, this means that the user performing the initial state assessment can also introduce, in the questions deemed necessary, one or more mitigation measures in order to control the risk represented in those specific questions, enabling the reduction of the exposure to that risk and, consequently, selecting a lower exposure option that will result in a lower after mitigation risk score.

The calculation of the after mitigation risk score follows the same process of the initial risk score, this time taking into account the exposure level after applied the mitigation measures.

3.13. Acceptance Criteria

The acceptance criteria for this risk assessment tool was develop in a way that it defines the acceptance in the same manner for the whole assessment, not only the risk score of each question, Section or Part, but also the acceptance of the risk level/number, represented by the hazard present in each question. Because, since the beginning of its development, the ARAT was oriented to the safety requirements of Portugália Airlines, it only made sense to develop the acceptance criteria according to the specifications of this company and its limit of tolerance to risk while operating in an aerodrome. Thus, the process for the development of the acceptance criteria (figure 2) was based on an analysis to the SMM of Portugália Airlines, trying to understand this company's defined limits of tolerance to certain risks.

General Acceptance Criteria		
Acceptable	<=	24,0%
Caution	<=	48,0%
Dangerous	<=	64,0%
Unacceptable	>	64,0%

Figure 2: ARAT acceptance criteria.

4. Aerodrome Safety Occurrences Statistical Analysis

In order to define the severity level and probability of occurrence associated with each occurrence category, a statistical analysis was performed to the Safety Occurrences database from ICAO containing safety related events from every aerodrome in all the 192 ICAO member sates through all continents, since the start of the year 2008 until the December, 1^{st} 2019.

4.1. Probability Analysis

The probability level of each occurrence category was quantified in number of occurrences per flight hour. However, the number of flight hours of all aircraft in world in the studied time interval is not an accessible value but can be estimated through the number of departures, which is available. The number of occurrences consists of the number of times each occurrence category was associated to a safety related event. In order to determine the probability level to attribute to each occurrence category it was calculated the probability value of each occurrence category in each year of the time interval and studied its evolution in order to extrapolate the probability value for the year 2020. The probability value obtained for 2020 was then compared to the ICAO Probability criteria in Doc 9859 [3] and the most applicable level out of the 5, from "Extremely Improbable" to "Frequent", was selected.

4.2. Severity Analysis

Severity consists of the extent of harm that might reasonably be expected to occur as a consequence or outcome of an identified hazard and it is categorized in different classification levels that should take into account the extent of damage to people's health, including those on board of the aircraft and common citizens on the ground that may contact with detached aircraft parts and also the damage to the aircraft and/or infrastructures either belonging to an aerodrome or outside of it. However, in the studied database, there was no information about the extent of damage to aircraft or infrastructures. Thus, the severity level of each occurrence could only be analysed in 3 points of view: occurrence class (accident, serious/major/significant incident, incident and no safety effect); injury level (fatal, serious, minor and none); and the number of fatalities. For each occurrence category, it was attributed the highest severity level obtained from these 3 points of view. Similarly to the study of the probability level, for the occurrence class and injury type points of view, it was performed a study over the years to determine, in 2020, which occurrence class and injury type would be most frequently attributed to each occurrence category and that would correspond to a certain severity level. The point of view of number of fatalities was used to distinguish "hazardous" occurrences from "catastrophic" ones.

5. Controlled Flight Into Terrain (CFIT) Analysis

The Safety Department of Portugália expressed some specific concern about studying the CFIT occurrence possibility and, after performing the Aerodrome Occurrences Statistical Analysis in the section 4, this type of occurrence revealed to be major concern due to its high "Fatality/Number of Occurrences" rate. This justified the introduction of the CFIT sub-checklist inside this ARAT. This checklist is a modified version of the one developed by the Flight Safety Foundation that is already used by the safety department of Portugália Airlines to perform safety assessments that are only related with the risk associated with the possibility of CFIT occurrences in each aerodrome operated by the company and the acceptance of this risk. This checklist has already its own acceptance criteria developed and tested by the FSF but, in this case, it was adapted to the criteria and the risk score calculations of the ARAT, making it part of a much more extensive safety assessment.

However, in the FSF checklist there was a concern related with the original risk multiplier factors attributed to the location (continent) of the aerodromes, which were believed to be inaccurate to nowadays operations. This motivated a statistical analysis to the same ICAO database used for the determination of the severity and probability of occurrence level of all occurrence categories, focused on selecting only the CFIT occurrences. This way, as expected, were verified considerable discrepancies between the values obtained for the current location risk multiplier factors and the original ones, so these were updated.

6. Results

The developed ARAT was tested with a total of eight aerodromes operated by Portugália Airlines. The key objective was to select a considerable variety of aerodromes from those which tend to have associated a lower risk of operation to the ones that have an higher one, also taking into account the necessity of choosing aerodromes from different countries to cover aspects such as the country's safety and security beyond the aerodrome's border. Besides this, there was the intention of selecting aerodromes with different characteristics that would explore the different Parts of the tool, i.e, aerodromes that stand out from the remaining due to either a more complex approach, specific training required, high intensity traffic, common hazardous meteorological conditions, topography hazards, concerning historical data, etc. On the other hand, in order to have a reference of the usual risk result of the operation in aerodromes who are known to be "safer", some aerodromes that do not possess the previous characteristics were also selected.

6.1. ARAT Results

Table 5 presents a simplified version of these results which are presented in percentage. Keep in mind that the full version of the ARAT results is much more complete, presenting the risk scores of each Part and Section, which despite not being shown in this table due to space restrictions, will be mentioned in the following paragraphs.

Starting with the category C aerodromes, LPMA and EGLC, these are known for presenting very rel-

Table 5: Results of the assessments performed with the ARAT.

Aerodrome	Category	Global Risk Score	Acceptance
LFPG	A	21,1%	Acceptable
GMMX	A	22,1%	Acceptable
LPPR	A	19,6%	Acceptable
LPPT	B	23,7%	Acceptable
LEMD	B	28,1%	Caution
LIRQ	B	33,6%	Caution
EGLC	C	52,0%	Dangerous
LPMA	C	52,0%	Dangerous

evant unusual characteristics. In this case, the concern is these aerodrome's locations which result in obstacles and/or mountainous terrain close to the normal approach paths demanding more strict flight procedures and training from crews. This fact also results in turbulence and windshear near the final approach. Additionally, LPMA has no precision landing systems and EGLC has a medium length and width runway. These factors combined should translate in risk assessments with increased global risk scores when compared to other aerodromes and, specifically, increased risk scores in the following Parts: Part 1 - CFIT Risk Analysis; Part 2 - Operations Engineering Department; Part 3 - Flight Operations Department; Part 4 - Crew Training Department; and Part 8 - Environmental Hazards. In fact, this was verified and these aerodromes presented the highest risk values of all the aerodromes analysed in these Parts, some reaching inside the "Dangerous" zone. An exception was the risk score of Part 3 of LPMA which was slightly lower due to the low traffic intensity of this aerodrome.

Moving to the category B aerodromes, LEMD, LIRQ and LPPT, these are known for also presenting relevant unusual characteristics that are not as concerning as the category C ones. In the case of LEMD, the unusual characteristics are the extremely high traffic intensity and high elevation with high reference temperature which, in fact, translated in an increased risk score in Part 3 - Flight Operations Department, inside the "caution" zone, as expected. In the case of LIRQ, the unusual characteristic is its location, similarly to the category C aerodromes. The mountainous terrain close to the normal approach paths demands more strict flight procedures and training from crews and also results in common turbulence and windshear, which, as expected, translated in increased risk scores in Part 1 - CFIT Risk Analysis; Part 2 - Operations Engineering Department; Part 3 - Flight Operations Department; Part 4 - Crew Training Department; and Part 8 - Environmental Hazards, some well inside the "caution" zone. In the case of LPPT, the unusual characteristics are the Winter fog and the medium/high traffic intensity, not only caused by this aerodrome but also three military facilities (Montijo, Sintra and Alverca) and one civil airport (Tires) within 15NM, which translated in increased risk score in Part 3 - Flight Operations Department and Part 8 - Environmental Hazards but still inside the acceptable zone.

Finally considering the category A aerodromes, LFPG, GMMX and LPPR, these are known for not presenting major unusual characteristics which should translate in lower global risk scores. This is, in fact, what was verified in the results of the risk assessments of these aerodromes, which, for all Parts, were inside the acceptable range and, for the most part, were the lowest risk scores obtained in all the assessments performed.

6.2. Company's Previous Method Description and Results

For the Safety Department, this process consisted, for each aerodrome, of filling the FSF CFIT Checklist and searching for past safety related occurrences and common issues in the aerodrome. Every other department should also perform a similar analysis to identify the aerodrome's common issues related with their scope of the operation. All this information should be compiled in the MoC Operation document, resuming all risks identified in the operation and the proposed mitigation measures. A conclusion in this document would resume the most critical risks and the appropriate mitigation measures while also providing an estimated (qualitative analysis) risk level/number for the before and after mitigation conditions and the respective acceptance levels. Table 6 presents a simplified version of these results which are presented in risk number. Besides this, the full version presents the severity level, probability level and acceptance of the risk.

Table 6: Risk results obtained with the company's previous method.

Aerodrome	Category	Risk Number
GMMX	A	9
LPPR	A	9
LFPG	A	12
LEMD	B	12
LIRQ	B	12
LPPT	B	8
LPMA	C	12
EGLC	C	12

6.3. Results Comparison and Conclusion

Overall, it can be concluded that the ARAT provided appropriate and trustworthy risk scores for each aerodrome while integrating successfully the safety standards of the company, which was confirmed by two Captains and all the Safety Department members involved in the project. Comparing these results with the previous method of the company, it is noticeable that the previous method was a very simplified analysis, which lacked the specification of the risk associated to the operation of each department (as it is performed with the ARAT) only presenting a global risk value. Besides this, the risk number obtained with the previous method resulted from a qualitative analysis which is highly dependent on the subjectivity of the person making the assessment, which is supported by the fact that the obtained results of this method are not coherent, in some occasions presenting higher risk values for category A over category B aerodromes and, sometimes, the same risk values for category A and category C aerodromes. A situation like this should not occur and is never observed in the risk assessments performed with the ARAT.

Taking into account the previous points, it can be concluded that besides giving more complete and coherent risk results, the ARAT also takes away the majority of the subjectivity introduced by the user performing the assessment (major source of incoherence) and also has the potential to standardize and speed up the aerodrome risk assessment process of this company.

7. Conclusions

It can be affirmed that the key objective of this project of developing an Aerodrome Risk Assessment Tool (ARAT) for Portugália Airlines was successfully achieved.

As promised, this tool addresses the major safety concerns of all departments of the company, presenting an approachable design with helpful instructions that are able to guide the common user that only intends to perform an assessment but as no knowledge of the overall method of operation of the tool.

Additionally, the tool evidences a successful integration of the company's safety standards and acceptance criteria, as well as, good integration of ICAO's risk management process, criteria and taxonomy (ADREP) which is a big achievement given that this is one of the most important organizations in aviation.

It was also achieved with success the development of a mathematical model behind every classification attributed, majorly eliminating the subjectivity present in the previous risk assessments of Portugália and enabling the achievement of trustworthy risk scores for the evaluated aerodromes.

Finally, this tool can be majorly editable to keep up with the evolution of the company's safety requirements and can act as a foundation for the development of the remaining DRMDs mentioned in chapter 2.

Despite all the work achievements previously mentioned, there are also certain aspects that can be improved.

Firstly, the severity and probability classifications for each question in the ARAT depend on a statistical analysis that was performed manually. An huge improvement for this tool could be the development of an automated process to perform this analysis and, the automation of the database with monthly updated information and the development of an automated process that could automatically identify the hazards in each question and link them to the possible occurrence outcomes and respective ADREP codes.

In terms of the data support of this project, an important improvement would be getting access to a more complete and detailed database, thus improving the accuracy of the obtained severity and probability classifications.

Another way to improve the accuracy of the obtained severity and probability classifications could be the development or adoption of new severity and probability criteria, besides the ICAO one, with more classification levels, enabling to better pinpoint the exact severity and probability classifications for each question and allowing more accurate risk scores.

Finally, in section 2, it was mentioned that this Aerodrome Risk Assessment Tool would be only one of the four risk assessment tools that should be developed in order to complete all types of DRMDs, enabling the use the Red2Red concept. Thus, the main future work for this project is the development of the remaining types of DRMDs based on the ARAT method, completing all the "barriers" that can avoid future significant safety related occurrences.

References

[1] ICAO - International Civil Aviation Organization. *ADREP 2000 Taxonomy*, 2010.

[2] ICAO - International Civil Aviation Organization. *Annex 19: Safety management*, 1^{st} edition, 2013.

[3] ICAO - International Civil Aviation Organization. *Doc 9859: Safety Management Manual*, 4^{th} edition, 2018.

[4] I. Panagopoulos and N. Karanikas. Safety management and the concept of dynamic risk management dashboards. *AUP Advances*, 1(1):58–74, 2018.

[5] Portugália Airlines. *Safety Management Manual*, 2017.