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Topological risk mapping of runway overruns: A probabilistic approach

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ABSTRACT

The paper presents a topological risk mapping for aircraft overruns. The proposed procedure is based on the study published in 2008 by Hall et al. (Analysis of aircraft overruns and undershoots for runway safety areas. Airport Cooperative Research Program. Washington, DC: Transportation Research Board; 2008). In that study the authors performed an analysis of aircraft overruns and undershoots for runway safety areas proposing the ACRP hazard probability model. In the present study the model was integrated into a two-step Monte Carlo simulation procedure to assess the risk of overrun accidents and to provide a topological risk map for a specific airport area. The model was modified to utilize traffic-related and weather-related factors described by statistical distributions of historical data of the airport under analysis. The probability distribution of overrun events was then combined with the Longitudinal and Lateral Location models Hall et al. (Analysis of aircraft overruns and undershoots for runway safety areas. Airport Cooperative Research Program. Washington, DC: Transportation Research Board; 2008) to obtain a two-dimensional grid assessing the probability of each area to be the end point of a runway overrun. The expected kinetic energy of the aircraft in a given point of the grid is used as severity index. The procedure is suitable for generalisation and it allows a more detailed planning of Airport Safety Areas (ASA), improving the correct implementation of ICAO recommendations. Results are also useful for land planning and structural analyses in airport areas.

1. Introduction

Operations in the airport field are subjected to a number of different risks, both due to human action and to the intrinsic nature of the manoeuvres themselves. These events may have various characteristics and cover a wide range of events such as collisions between aircraft travelling on taxiways, terrorist strikes, bird strikes, undershoots and many others. This study focuses on runway related accidents and in particular on landing and takeoff overruns. Runway-related accidents represent a relevant fraction of the total number of recorded accidents leading to substantial damage: according to an investigation carried out by the Flight Safety Foundation and based on a data pool collected worldwide from1995 to 2008, 30% of the total number of accidents belong to the "runway related" category [2]. In particular, 97% of these are overruns. A runway overrun is an event where the aircraft running off the end or the side of the runway exceeding the runway limits during flight operation. This case can happen in three possible scenarios: landing overrun, takeoff overrun and landing undershoot. While undershoots affect the approach and landing phases of the flight, when it may happen that the aircraft touches the ground in a point before the beginning of the runway, overrun events may happen either during landing or during takeoff operations if the aircraft fails to come to a stop within the runway boundaries. Scenarios are reported in the statistical summary of commercial jet airline accidents for worldwide operations from 1959 to 2013 compiled by Boeing [3], a further analysis of 35 years of landing overrun accidents is discussed in the report compiled by Van Es [4]. Along those lines useful information is also to be found in a detailed analysis of an aircraft accident model for Taiwan performed by Shao et al. in 2009 [5]. The scenarios selected for the present study considering also the high number of observed occurrences, are those in which the aircraft departs from the runway following a longitudinal direction, therefore crossing its end [6].

Thanks to safety management practices it is possible to locate and estimate risks related to the different accident events, evaluate potential countermeasures and consequently plan the best allocation of resources to reduce risk while maximizing productivity. In particular, the International Civil Aviation Organization [7] issued regulations and procedures for the installation of structures with the aim of preventing and mitigating consequences of such events: despite containing useful guidelines for aerodrome design, they still lack the necessary topological contextualisation and thus may result in very different safety levels depending on the aerodrome characteristics. This leads to the need for a procedure able to evaluate the risk associated with overrun accidents, taking into

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account the specific characteristics of the airport under analysis, in terms of layout and operations, with the aim of identifying specific local critical situations.

The objective of the study is to develop and test a probabilistic model able to topologically characterize the risk of aircraft overruns in airports taking into consideration a wide set of uncertain factors, both traffic related and weather related. Starting from existing accident probability models, a Probabilistic Risk Analysis (PRA) procedure is proposed for the assessment of the risk level for infrastructure, buildings and generally obstacles surrounding the airport area, through the definition of a risk map to be superimposed on the airport layout. This will be useful for the identification of the most critical locations and infrastructure in the area, and subsequently for the definition of effective risk mitigation strategies and emergency plans.

The paper starts from a preliminary study already published in [8] and extends the theoretical and methodological background as well as the analysis of results. The paper is organised as follows: in the next section the overall proposed probabilistic approach to runway excursion risk analysis is described and justified in relation to existing contributions in the scientific literature. Section 3 provides an overview of the state of the art on aircraft overrun probability models and describes the selected reference model adopted in the proposed PRA procedure. Section 4 describes the reference deceleration model, while Section 5 is devoted to the detailed description of the proposed two-step PRA procedure able to return a topological risk mapping of the airport layout. Section 6 describes the consequence model by introducing the concept of Iso-Kinetic Energy Areas (KEA) as the main severity index. Finally, Section 7 reports the test case application, whereas conclusions and further research opportunities are drawn in Section 8.

2. A probabilistic approach to runway overrun risk analysis

While the risk of an aircraft overrunning a runway depends on many factors, like for instance the aircraft weight, weather conditions, presence of contamination on runway surface and many others, in safety regulations and airport operations it is very hard to keep track of all these contributions. Only very generic indexes are widely considered: ICAO recommendations in Annex 14 give very broad directions, in which the aircraft reference field length is the only discriminating variable [7].

Indeed, the problem of developing a customized and consistent risk evaluation methodology on which safety management actions can be based is therefore not a new topic; current models [1] often take a number of factors into consideration to estimate the probability of a certain operation to end up in an overrun incident.

In a study published in 2008 by Hall, Wong, & Ayres titled ACRP (Airport Cooperative Research Program) the authors performed an analysis of aircraft overruns and undershoots for runway safety areas [1]. An accident probability model was then used in combination with a location model, which in turn gives a cumulative probability distribution of the overrunning aircraft to end up its run at a certain distance from the runway end; through the use of both of these models it is possible to assign a probability and a severity value to every considered operation, but it is not possible to characterize the entire airport. This method is very useful when one wants to rank a set of operations by their risk coefficients, which allows to spot critical ones and help deciding where intervention is needed and where resources should be concentrated.

The method discussed in this paper is based on the ACRP model. Unlike former models the ACRP hazard probability model [1] uses normal operational data along with accident data: this allows quantifying the importance of every factor and the way it influences the final accident probability. The model is reported in the form of a logistic regression, and takes into account many different factors both from the traffic and weather conditions point of view, for a total of fourteen and eleven regression parameters for landing and takeoff overruns, respectively. The logistic regression technique was chosen because it was deemed suitable to model phenomena with a dichotomous outcome like incident or non-incident, and to take into account a high number of variables including a mixture of continuous and categorical parameters. This kind of approach does not only take into account the particular conditions of one single operation, but allows to describe in a statistical way the traffic and weather conditions a particular runway undergoes throughout the year, thus making possible to obtain a more general result which is valid for all operations carried out on the runway in a specific time window.

Once a “portrait” of the considered runway is obtained, which is independent from any of its particular operations, it is possible to associate it with a distribution, which points out the probability of having a takeoff or landing overrun for that runway. Furthermore, by integrating the location model it is also possible to characterize each point beyond the runway end with the probability distribution of the aircraft kinetic energy, measuring the intensity of the potential impact with an obstacle located in the same point of the grid.

The final step of the proposed methodology is to match these two results – overrun probability and kinetic energy probability for each point of the grid – to assign every point of the terrain surrounding the runway a probability distribution of the expected aircraft kinetic energy for a single movement; since kinetic energy is an index of the damage occurring to possible obstacles in case of crash, the final result is a risk grid around the airport, which can be superimposed on a map of the airport area in order to assign each building a risk value. This is particularly useful in the case of airports close to large and critical infrastructure, generally lacking space for increasing safety areas.

3. Overrun probability models

3.1. Literature review and selection of reference models

In order to assess risk values, tools were needed to assign probability values associated with overrun accidents, as well as models able to estimate consequences of such events. A literature review revealed that several accident probability models have been published in the last decade, starting from Eddowes and Handcox [9], in a report produced by the Norwegian Civil Aviation Authority concerning risk analysis in support of aerodrome design rules. I was followed by Kirkland et al. [10] with studies on data collection and normalization that led to development of models allowing the estimation of probability, location of wreckage and an assessment of the consequences. The models performance was measured with Hosmer–Lemeshow coefficients: for landing models, when using excess distance available as input, it accounts for 11% of the determinants of overrun. If fed with weight-related data the model explains 2.4% and 4.8% of landing and takeoff overrun occurrences, respectively. These models had a major limitation as data was only collected for overrun accidents and not for normal operation data (due to the lack of availability of the latter): this led to the impossibility to demonstrate that possible influencing variables have higher frequency in correspondence to incidents than in correspondence of non overrunning flights.

In 2008 the ACRP report “Analysis of Aircraft Overruns and Undershoots for Runway Safety Areas” was published [1]: it faced the problem of assessing overrun probability values for landing and takeoff operations in a more accurate way, accounting for several causal factors and using a model based on a large database of