Journal of Air Transport Management 65 (2017) 1–10

Contents lists available at ScienceDirect

Journal of Air Transport Management

journal homepage: www.elsevier.com/locate/jairtraman

Risk analysis of the EASA minimum fuel requirements considering the ACARE-defined safety target

Ludwig Drees [a, *, 1], Manfred Mueller [b, 1], Carsten Schmidt-Moll [c], Patrick Gontar [d], Kilian Zwirglmaier [e], Chong Wang [a], Klaus Bengler [d], Florian Holzapfel [a], Daniel Straub [e]

[a] Institute of Flight System Dynamics, Technical University of Munich, Germany
[b] Captain Airbus A330/A340 and Type Rating Examiner, Member of the Advisory Council of Aviation Research & Innovation in Europe (ACARE) and OPTICS Advisory Committee, Germany
[c] Captain Embraer 195, Accident and Incident Investigator, Germany
[d] Chair of Ergonomics, Technical University of Munich, Germany
[e] Engineering Risk Analysis Group, Technical University of Munich, Germany

ARTICLE INFO

Article history:
Received 14 November 2016
Received in revised form
8 May 2017
Accepted 13 July 2017

Keywords:
Final reserve fuel
Accident probability
Aviation safety
Safety management
Procedure handling
Crew performance

ABSTRACT

We present the results of flight simulator experiments (60 runs) with randomly selected airline pilots under realistic operational conditions and discuss them in light of current fuel regulations and potential fuel starvation. The experiments were conducted to assess flight crew performance in handling complex technical malfunctions including decision-making in fourth-generation jet aircraft. Our analysis shows that the current fuel requirements of the European Aviation Safety Agency (EASA) are not sufficient to guarantee the safety target of the Advisory Council for Aviation Research and Innovation in Europe (ACARE), which is less than one accident in 10 million flights. To comply with this safety target, we recommend increasing the Final Reserve Fuel from 30 min to 45 min for jet aircraft. The minimum dispatched fuel upon landing should be at least 1 h.

1. Introduction

1.1. Background

On behalf of the European Commission, the Advisory Council for Aviation Research and Innovation in Europe (ACARE) recommends various research activities including a strategic path towards increased flight safety (ACARE, 2011; 2012). ACARE aims to keep the average number of accidents in Europe below a maximum of 20 per year, taking into account the growth in air transport until the year 2050 (ACARE, 2002). ACARE also defines a safety target for airline passenger transport, a so-called Acceptable Level of Safety Performance (ALoSP), such that "the European air transport system should have less than one accident [as defined by ICAO] per ten million commercial aircraft flights", which translates into a target accident probability for a single flight of $p_{target} = 1\cdot10^{-7}$ (ACARE, 2011). $P(Accident)$ denotes the accident probability for an average single flight and it should be:

$$P(Accident) \leq p_{target} = 1\cdot10^{-7} \tag{1}$$

Given the current European accident rate of 1.5 accidents per 1 million flights (IATA, 2016), which corresponds to $P(Accident) = 1.5\cdot10^{-6}$, this ALoSP requires a reduction in the accident rate of approx. 90%. In comparison, the global accident rate was 1.81 accidents per 1 million flights in 2015, i.e. $P(Accident) = 1.8\cdot10^{-6}$ (IATA, 2016). Therefore, improvements and mitigation strategies, so-called corrective actions, are necessary and must be implemented to achieve a significant reduction in the accident rate. The objective of this paper is to quantify the impact of a change in the current fuel regulations for jet aircraft as a major corrective action.

To identify suitable and effective corrective actions, one has to identify the causes of an accident first and then quantify their contribution and dependencies. Ale et al. (2005) developed a model of the whole air transport system, termed Causal Model for Air

* Corresponding author. Institute of Flight System Dynamics, Technical University of Munich, Boltzmannstr. 15, 85748 Garching, Germany.
E-mail address: ludwig.drees@tum.de (L. Drees).
[1] Co-first author.

http://dx.doi.org/10.1016/j.jairtraman.2017.07.003
0969-6997/

Transport Safety (CATS), which includes the causal chain of accident sequences (Ale et al., 2005, 2009; CATS Consortium, 2008). In total, the model represents 35 accident categories that are described by event-sequence diagrams as well as fault and decision-trees. The CATS model is integrated into a Bayesian belief network that allows for the quantification of the overall level of safety and accounting for dependencies between causal factors.

In Drees and Holzapfel (2011), Drees et al. (2014), Wang et al. (2014), and Zwirglmaier et al. (2014), Drees (2017), a physics-based approach is presented in which accidents are modeled by taking the known physical relationships between factors that contribute to an accident into account. Similar to the CATS approach, sensitivities are quantified that describe the individual contribution of each factor to the accident probability.

One factor that relates to aviation safety is the amount of fuel. Due to the large proportion of fuel costs on the total airline costs, airlines are interested in finding the optimal/minimum amount of fuel for their operation. Ayra et al. (2014) present a Bayesian decision model to assess the optimal amount of fuel to be able to cope with holdings at the destination airport and to avoid unnecessary diversions due to fuel. They develop a decision tree that is fed with operational data from a major airline. The aim of the model is to support airlines in reducing their operational (fuel) costs by adapting the amount of fuel for holdings due to air traffic. The model does not account for the reduction in safety due to reduced fuel reserves.

Fuel consumption models are also available for the taxi phase (Nikoleris et al., 2011; Khadilkar and Balakrishnan, 2012). For example, Khadilkar and Balakrishnan present a regression model to quantify the amount of fuel during the taxi-out phase. Here, the model parameters are based on flight operation data from various aircraft types, such as the Airbus A320 or the A340.

In Wang, Drees & Holzapfel (2016), a method for quantifying the probability of fuel starvation caused by hub closure is presented. Here, an air traffic scenario model is described in which a hub airport closes and the approaching aircraft have to divert to a smaller airport nearby, which may not have the capacity to cope with all aircraft simultaneously. Therefore, aircraft may have to fly multiple holding patterns, and some aircraft may have to use their reserve fuel.

1.2. Current fuel regulations

The minimum fuel quantities required for passenger transportation in jet aircraft are defined by the International Civil Aviation Organization (ICAO) and are adopted by the European Aviation Safety Agency (EASA). They comprise the following components (ICAO, 2010):

- *Taxi Fuel* (the amount of fuel consumed on ground before take-off)
- *Trip Fuel* (fuel from departure to destination airport).
- *Contingency Fuel* (additional fuel for an unexpected fuel consumption)
- *Alternate Fuel* (fuel for the flight to an alternate airport)
- *Final Reserve Fuel* (minimum fuel upon landing)
- *Extra Fuel* (additional fuel at the pilot's discretion to cover delays or re-routings)

Fuel values are typically expressed in minutes of flight time. For jet aircraft, the *Final Reserve Fuel* should be sufficient for 30 min of flight time at 1,500 ft above the airport elevation at holding speed (ICAO, 2010). One has to keep in mind that these fuel regulations were defined when jet aircraft came into service more than 50 years ago, many of which have remained unchanged. Moreover, technical failures were not taken into account (EASA, 2016b; ICAO, 2010). Given the relatively low complexity of first and second[2] generation jet aircraft compared to today's aircraft[3], ensuring that additional time is available to handle a technical problem was considered less important. At that point in time (50 years ago), the complexity levels of abnormal or emergency procedures were relatively small. Also, the total number of flights only amounted to 5% of today's traffic (ICAO, 2016a). Therefore, severe traffic congestion at airports was nonexistent. The question now arises as to whether the requirement on *Final Reserve Fuel* is still up to date, or whether the complexity and length of abnormal procedures, the traffic volume and today's safety targets requires a modification.

EASA's fueling policy was modified in 2012 (EASA, 2012). At destination airports where more than one suitable runway is available and if the weather fulfills certain requirements regarding cloud base and visibility, *Alternate Fuel* can be substituted by an additional 15 min of fuel according to the new regulations CAT.OP.MPA.150 (b) (EASA, 2016a). Those 15 min of additional flight time can be used to cover possible unexpected delays, ensuring a landing with at least 30 min of *Final Reserve Fuel*.

2. ICAO safety management

The Safety Management Manual published by the ICAO requires airlines to identify hazards and unsafe conditions, so-called emerging risks, that have not yet caused an incident or accident (ICAO, 2013a; 2013b). Emerging risks should be reviewed and, if necessary, corrective actions have to be defined to take control of these emerging risks (ICAO, 2013b). This is achieved by performing quantitative risk assessments, including studies and experiments (ICAO, 2013b). The risk assessments must demonstrate that a proposed change in the aviation system does not increase the probability of an accident.

2.1. Safety requirements

The event 'accident' can be broken down into n subtypes AT_1, AT_2, …, AT_n, e.g., *runway excursion* or *loss of control in flight*. The overall probability of an accident $P(Accident)$ is the probability that at least one of the n accident types occurs:

$$P(Accident) \; = P(AT_1 \cup AT_2 \cup \ldots \cup AT_n) \tag{2}$$

An upper bound to $P(Accident)$ is the sum of the probabilities of the different accident types $P(AT_i)$. Because some accident types are correlated, the actual value of $P(Accident)$ will be lower; nevertheless, due to the overall very small probability of an accident, the approximation error when using the upper bound will be typically small. Hence, to comply with the ALoSP (Eq. (1)), the sum of probabilities of all different accident types $P(AT_i)$ has to be roughly equal to or less than the safety target of $p_{target} = 10^{-7}$ per flight. In line with the certification standards of the European Aviation Safety Agency (EASA) for large aircraft (EASA, 2007), we consider $n = 100$ (failure) conditions that could potentially be catastrophic and result in an accident. The overall ALoSP of $p_{target} = 10^{-7}$ can thus only be met if the average probability of individual accident types is in the order of $10^{-7}/_n = 10^{-9}$ per flight. It is not necessarily optimal or desirable to require the same safety level for all accident types, but we shall assume here that it is safe to state that the safety requirement for an individual accident type AT_i must be at *least* 10^{-8} per flight in order to meet the overall ALoSP. This means,

[2] E.g. Airbus A300, Boeing B737–100/200 (Airbus, 2016b).

[3] E.g. Airbus A320 Family, Boeing 777, Embraer E-Series (Airbus, 2016b).