



Aviation safety and accident survivability: Where is the need for aviation rescue fire fighting services greatest?

Samuel Woodman^{*}, Chris Bearman, Peter Hayes

Central Queensland University Australia, Appleton Institute, Australia

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ABSTRACT

Aircraft accidents are most likely to occur on or within the immediate vicinity of an aerodrome, however, only some aerodromes have a specialised onsite fire and rescue service (Aviation Rescue Fire Fighting Service or ARFFS). ARFFS exist to save life in the event of an aircraft accident, yet there is limited literature about assessing the need for ARFFS. This presents considerable challenges for aviation safety standard setting organisations and has resulted in global inconsistency and disparity relating to the ARFFS. This paper presents two studies that analyse aviation safety and accident data to start to establish an evidence base for decisions about where ARFFS should be located. The first study found that aerodromes with operations that were primarily general aviation had a higher rate of accidents and serious incidents than aerodromes with operations that were primarily commercial air transport. The second study found that narrow bodied aircraft present a greater probability of a fatal outcome (with or without fire) compared to wide-bodied aircraft. Passenger movement rates and the size of aircraft are the basis for many international ARFFS establishment criteria, but the findings in this paper suggests that alone they are not sufficient indicators of the need for an ARFFS.

1. Introduction

Aviation Rescue Fire Fighting Services (ARFFS) are a specialised on-aerodrome fire service which are also referred to as an Airport Fire Service or Rescue Fire Fighting Service. ARFFS are located at aerodromes to provide assistance during emergencies and generally seek to improve the safety of aviation (International Civil Aviation Organization, 2018). The primary role of ARFFS is to improve the chances of survival for passengers and crew in the event of an accident (Department of Infrastructure and Regional Development, 2015). ARFFS has been described as ‘a last line of defence’, that in an ideal world the aviation sector ‘would love to be able to do without’ (Braithwaite, 2001, p. 111). However, for passengers and crew to survive the most dangerous yet technically survivable accidents, the intervention of the ARFFS is essential (Braithwaite, 2001; Chang & Yang, 2010; Cherry and Associates, 2009).

For the ARFFS to intervene and enhance survivability during an aircraft accident; the service needs to be operational at the locations where such accidents are most likely to occur. One of the challenges for ensuring the appropriate provision of ARFFS at aerodromes globally is the lack of scholarly literature that examines the benefits ARFFS provide

and why they are located at some aerodromes and not others. In the absence of scholarly literature, globally, the approaches taken to which aerodromes require an ARFFS are disparate and relatively unexplained. This article presents the outcomes of two studies that examine aerodrome characteristics and accident scenarios to identify where the need for ARFFS is greatest. This evidence can then be considered to logically inform approaches taken to ARFFS establishment.

1.1. Background

The safety of aviation and the acceptability of the risk associated with air travel are fundamental to its broad public use as a reliable and effective method of transportation (Low & Yang, 2019; Sage & White, 1980). In 2019, globally there were 3.02 aircraft accidents per million departures resulting in 239 fatalities involving commercial flights above 5.7 t (International Civil Aviation Organization, 2020). The historical safety performance of aviation (as high as 40 accidents per million departures in 1959) combined with periodic contemporary major aircraft accidents (28 recorded between 1 Jan and 30 Aug 2020) continues to highlight the potential catastrophic outcomes that can be associated with aviation (Boeing, 2019; International Civil Aviation Organization,

^{*} Corresponding author at: 44 Greenhill Road, Wayville 5034 South Australia, Australia.
E-mail address: samuel.woodman@cquemail.com (S. Woodman).

2020). Although aviation maintains an exceptional safety record as the safest form of mass transportation, fear and apprehensiveness to flying continues, even if statistically irrational given the advancements made in aircraft accident survivability (Muir & Thomas, 2004; Oakes & Bor, 2010; Scheffey et al., 2012).

The existence of ARFFS is primarily based on the notion that certain aircraft accidents are survivable, and that a rescue and fire fighting capability can support survivability to preserve life. The phenomenon of a survivable aircraft accident implies that, at the time of the occurrence, persons involved remain alive and that survivability is a product of the resulting actions following the initial occurrence (Scheffey et al., 2011). The existence of a survivable aircraft accident also creates the concept of a non-survivable aircraft accident – being a situation whereby forces associated with the accident exceed human tolerances (Chang & Yang, 2010). In the event of fire threatening the fuselage and/or limiting the ability for evacuation to occur, the speed at which effective fire intervention can be established is critical (Scheffey et al., 2012). It is for this reason that the ARFFS must be designed to achieve rapid response times (three minutes or less) with the ability to apply large quantities of fire fighting agent (International Civil Aviation Organization, 2015, 2018).

There have been several examples where fire services not based on the aerodrome (in lieu of an ARFFS) were unable to achieve the required ARFFS response times and agent application requirements. For example, at Bankstown¹ in November 2003, a qualified pilot and flight instructor undertook multi-engine aircraft training in a Piper Aircraft Corp PA-34-200. Whilst on approach to runway 11R to perform a 'touch and go', the aircraft banked steeply to the right, then impacted the ground. The accident site was close to runway 11R/29L and on impact, the right fuel tank ruptured, spilling fuel which subsequently ignited. The pilot experienced fatal impact related chest injuries. The flight instructor was injured, yet able to vacate the aircraft, but due to the external fire, he suffered significant burns that resulted in his death three and a half weeks after the accident. The first arriving local fire service vehicle took 9 min to arrive (it is unknown if this was to the incident scene or to the aerodrome emergency gate). While a ten minute response time was deemed acceptable by a subsequent investigation report, it's not clear on what basis this determination was made as this is well outside the normal 3 min response target for ARFFS and the typical burn through times of most aircraft (International Civil Aviation Organization, 2015, 2018; Scheffey et al., 2012).

Analysis of aviation accidents conducted by Airbus and Boeing (Airbus, 2019; Boeing, 2019) indicates that the majority (circa 71 %) of accidents occur on or generally near an aerodrome with the most likely phase of flight (for an accident to occur) being landing. Thus, it appears that survivable accidents are most likely to occur in the vicinity of an aerodrome. In recognition of the concentration of risk associated at or near an aerodrome, the International Civil Aviation Organization (ICAO) requires a specialised emergency response capability in the form of an ARFFS be established in accordance with the promulgated standards and recommended practices (International Civil Aviation Organization, 2018). However, it is not realistic that every aerodrome can be allocated an ARFFS. Therefore, a determination must be made as to when such protection is warranted (Civil Aviation Safety Authority, 2021).

Globally, there is no consistency in the approach to ARFFS establishment and there is limited literature available to guide such policy

development. To date, ARFFS related research has primarily focused on technical and applied aspects of its operations, with much of this research instigated by the United States Federal Aviation Administration (Cherry and Associates, 1999, Cherry and Associates, 2009, Cherry and Associates, 2012, 2013, 2016; Scheffey et al., 2011, 2012). These technical papers focus on the efficacy of ARFFS operations by evaluating fire fighting foam performance, fuselage burn-through and associated survivability considerations. The International Civil Aviation Organization (2015) and United States National Fire Protection Association (2018) have also developed operational standards and guidance material relating to ARFFS vehicles, equipment and tactics. There has been extensive research into aircraft accident causation and survivability, but only limited consideration of the role and function of ARFFS in this literature (Ekman & Debacker, 2018; Grierson & Jones, 2001; Li & Baker, 1994; Li & Baker, 2007; Li et al., 2008; Valdes et al., 2011). Braithwaite (2001) provides a rare example of an ARFFS focused study that analysed public perceptions of ARFFS protection. This study identified a significant divergence between the perceptions of the travelling public and the actual availability of ARFFS, with 91.3 % of those surveyed overestimating the availability of ARFFS protection in Australia.

1.2. When is an ARFFS required?

There is no current ICAO guidance provided on when and where to establish an ARFFS (International Civil Aviation Organization, 2015, 2018). Thus, nations are required to devise their own approaches to when and where an ARFFS may or may not be required. Globally, there is considerable variation in the establishment requirements for an ARFFS (Table 1), with the obligation to set such requirements resting with individual nations who subscribe to the Convention on International Civil Aviation (International Civil Aviation Organization, 2018).

Table 1 highlights the globally inconsistent approach to establishment criteria. Although no two countries have the same criteria, themes can be identified which include the type of air transport operation (commercial), the number of annual passenger movements, the number of available seats and aircraft weight. These criteria are generally attempting to measure the same thing, but in slightly different ways. All countries have adopted criteria which (either directly or indirectly) seek to allocate an ARFFS based on the notion of passengers, that is, the greater number of passengers or capacity to move passengers, the greater the need for an ARFFS. This is important because this measures the magnitude of the emergency and the impact that it might have.

By focusing on passenger movement rates and therefore the magnitude of the emergency, other factors which may also provide meaningful indication as to the need for an ARFFS may be overlooked. Such factors may include historical rate of accidents² and incidents,³ the rate at which notifiable occurrences occur and an aerodrome's purpose and movement area design (Wilke et al., 2015). For example, Wilke et al. (2015) identified that airport (movement area⁴) complexity can be a causal factor in accidents/incidents, yet this is not considered in any current criteria for ARFFS establishment. Therefore, for ARFFS establishment criteria to ensure the service is located where the need is greatest, such need must be reliably indicated by an evidence base derived from research.

² An occurrence involving an aircraft where:

- A person is fatally or seriously injured
- The aircraft is destroyed or seriously damaged
- Any property is destroyed or seriously damaged.

³ An occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation.

⁴ Part of the aerodrome to be used for the takeoff, landing and taxiing of aircraft, consisting of the manoeuvring area and apron/s.

¹ Information for this case study was extracted from official accident investigation reports published by the Australian Transport Safety Bureau (2004). *The effectiveness of the fire fighting arrangements for Bankstown Airport, as they affected transport safety on 11 November 2003* (200305496). https://www.atsb.gov.au/media/24414/aafr200305496_001.pdf, Australian Transport Safety Bureau. (2005). *ATSB Investigation report Cessna 404, VH-ANV Jandakot Airport WA* (200303579). https://www.atsb.gov.au/media/4424572/aafr200303579_001.pdf.

Table 1
Comparison of ARFFS establishment requirements by location.

Country	Mandatory ARFFS establishment requirement/s
Australia	- An aerodrome from or to which an international passenger air service operates; and - Any domestic aerodrome through which more than 350,000 passengers passed through on air transport flights during the previous financial year. Source: Civil Aviation Safety Authority (2005)
United States of America	- Any aerodrome that is certificated under Federal Aviation Administration (FAA) Part 139, generally requiring the aerodrome to serve: - Scheduled passenger-carrying operations of an air carrier operating aircraft configured for more than 9 passenger seats. - Unscheduled passenger-carrying operations of an air carrier operating aircraft configured for at least 31 passenger seats. Source: Federal Aviation Administration US (2013)
United Kingdom	Condition 2 in the public use and ordinary aerodrome licences makes it mandatory for licence holders to provide an ARFFS appropriate to their aerodrome with a requirement that aircraft that meet the following particulars only use licenced or government aerodromes. - any aeroplane which has a maximum take-off mass of more than 5,700 kg flying on a flight— (a) for the purpose of the commercial air transport of passengers or the public transport of passengers; (b) for the purpose of instruction in flying given to any person for the purpose of becoming qualified for the grant of a pilot's licence or the inclusion of an aircraft rating, a night rating or a night qualification in a licence; or (c) for the purpose of carrying out flying examinations for the grant of a pilot's licence or the inclusion of an aircraft rating or a night rating in a licence. - any aeroplane which has a maximum take-off mass of not more than 5,700 kg flying on a flight which is— (a) a scheduled journey for the purpose of the commercial air transport of passengers or the public transport of passengers; (b) for the purpose of the commercial air transport of passengers or the public transport of passengers and which begins and ends at the same aerodrome; or (c) for the purpose of the commercial air transport of passengers or the public transport of passengers and which is at night. Source: Civil Aviation Authority UK (2016, 2019)
Canada	ARFFS is required at a designated airport, which is an airport at which, the total of the number of passengers that are embarked and the number of passengers that are disembarked is more than 180,000 per year. Source: Transport Canada Civil Aviation (2019)
New Zealand	- The holder of an aerodrome operator certificate must provide on the aerodrome, rescue and fire fighting capability (meeting the minimum requirements) during operations by— (1) an aeroplane having a certified seating capacity of more than 30 passengers that is engaged in a regular air transport operation for the carriage of passengers; or (2) an aeroplane that is engaged in regular air transport operations where— - the aeroplane's point of take-off that immediately precedes the aeroplane landing at the aerodrome, is an aerodrome outside New Zealand; or - the aeroplane's point of landing that immediately follows the aeroplane taking-off from the aerodrome, is an aerodrome outside New Zealand. - There is no passenger throughput criteria. Source: Civil Aviation Authority of New Zealand (2020)
European Union	- All aerodromes that: (i) are open to public use; (ii) serve commercial air transport; and (iii) have a paved instrument runway of 800 m or more, or exclusively serve helicopters using instrument approach or departure procedures; Source: European Aviation Safety Agency (2018)
Indonesia	Where international air transport operations take place, or;

Table 1 (continued)

Country	Mandatory ARFFS establishment requirement/s
	Where specified levels of domestic air transport operations occur, (note – there is no domestic level specified in the regulation). Source: Republic Indonesia Ministry of Transportation (2009)
India	Landing and departure by a scheduled air transport service or for a series of landings and departures by any aircraft carrying passengers or cargo for hire or reward. Source: Government of India (2004)

1.3. Aim

The aim of these studies is to start to develop an evidence base that can be used to inform policy and decision making as to which aerodromes would most benefit from the establishment of ARFFS. This research is timely in that it uses data reflecting recent important improvements in aircraft crashworthiness and generally declining accident rates for scheduled commercial flights (e.g., 2010: 4.34 accidents per million departures and 2019: 3.02 accidents per million departures) ([International Civil Aviation Organization, 2020](#)).

The absence of contemporary literature and international standards relating to ARFFS establishment has resulted in different approaches being used globally. By understanding how the ARFFS can enhance survivability and where this service is of greatest need, aviation policy makers and standard setting organisations can focus ARFFS design and distribution to achieve the greatest safety benefit. This paper documents two studies that analyse aviation safety occurrence data and historical accident investigation records to provide an improved evidence base that:

- Compares accident and serious incident occurrence frequencies to identify if the nature of aerodrome operations (commercial air transport v general aviation) can be used to identify where the need for ARFFS is greatest.
- Analyses and compares aircraft accident characteristics to identify accident scenario types where the ARFFS can be of greatest benefit.

2. Study 1 - aviation safety occurrence data

2.1. Introduction

All nations that are signatories to the Convention on International Civil Aviation are required to establish aviation safety data collection and processing systems to capture, store, aggregate and enable the analysis of safety data and safety information, with the reporting of certain safety incidents being mandatory ([International Civil Aviation Organization, 2016](#)).

This study compares Australian accident and serious incident occurrence frequencies between two different types of aerodromes to identify if the nature of aerodrome operations has a relationship with the rate of occurrences. Two types of Australian aviation safety data managed by the Australian Transport Safety Bureau (ATSB) have been used in this study, these being, *accident data* and *serious incident data*. It is intended that the results of this study will assist in identifying if the nature of operations at an aerodrome (inclusive of movement rate) can be utilised in determining where the need for ARFFS is greatest and to provide further insight as to the most suitable measures to inform evidence based criteria for ARFFS establishment.

2.2. Method

Using quantitative frequency comparison, accident and serious incident data was compared between certain aerodromes pairings ([Table 2](#)). The Australian aerodrome pairings have been identified relative to the following criteria:

Table 2
Australian aerodrome pairings for occurrence data analysis.

Primary Aerodromes (Primarily commercial air transport operation – comparatively high rate of passenger aircraft movements and currently serviced by an ARFFS)		Secondary Aerodromes (Primarily general aviation – comparatively low rate of passenger movement and formerly serviced by an ARFFS which has been withdrawn)
Adelaide – South Australia	paired with	Parafield – South Australia
Melbourne (Tullamarine) – Victoria	paired with	Moorabbin – Victoria
Perth – Western Australia	paired with	Jandakot – Western Australia
Brisbane – Queensland	paired with	Archerfield – Queensland
Sydney – New South Wales	paired with	Bankstown – New South Wales

Geographic location (within the same state).

The nature of aviation operations that normally occur at that aerodrome (with one aerodrome primarily serving *commercial air transport operations* and the other primarily serving *general aviation*).

The current or historical presence of ARFFS at the aerodrome, that is, one aerodrome currently has an ARFFS and the other formerly had an ARFFS (which has subsequently been withdrawn due to a policy change).

Availability of annual aircraft movement data.

The following key term definitions were observed in this study.

An **accident** is defined as (Australian Transport Safety Bureau, 2021): An occurrence where:

- o a person dies or suffers serious injury
- o an aircraft is destroyed, or is seriously damaged
- o any property is destroyed or seriously damaged

A **serious incident** is defined as: An incident involving circumstances indicating that an accident nearly occurred (Australian Transport Safety Bureau, 2021).

Commercial air transport operation (CATO) is defined as: An aircraft operation involving the transport of passengers, cargo or mail for remuneration or hire (BITRE, 2021).

Table 3
Accident and Serious Incident Frequency Rates for Aerodrome Pairings.

Aerodrome	Accidents <i>n</i> = 108	Serious Incidents <i>n</i> = 226	Mean Annual Movements 2010–2019	Rate of occurrence (accident or serious incident to movements)
Sydney (primary)	6	15	327,589	1 per 15,599 movements
Bankstown (secondary)	17	36	246,135	1 per 4,644 movements
Perth (primary)	2	13	138,089	1 per 9,206 movements
Jandakot (secondary)	23	61	242,475	1 per 2,887 movements
Adelaide (primary)	2	3	104,760	1 per 20,952 movements
Parafield (secondary)	11	18	217,738	1 per 7,508 movements
Brisbane (primary)	4	11	213,124	1 per 14,208 movements
Archerfield (secondary)	12	11	145,769	1 per 6,338 movements
Melbourne (primary)	6	9	228,647	1 per 15,243 movements
Moorabbin (secondary)	25	49	248,772	1 per 3,362 movements
Total secondary	88	175		
Percentage Secondary	81.48 %	77.43 %		
Total primary	20	51		
Percentage Primary	18.52 %	22.57 %		

General aviation (GA) is defined as: An aircraft operation other than a commercial air transport operation (BITRE, 2021).

Occurrence data was extracted from the ATSB database using the following parameters:

Occurring between 01 January 2010 until 01 January 2020.

Occurring on or within 10 km of the aerodrome.

Categorised as an **accident** or **serious incident**.

Aircraft movement rates (landings and take-offs) were acquired and used to identify the mean rate of aircraft movement. The extracted data was categorised by year then analysed via cross tabular frequency comparison and rate of occurrence to aircraft movement frequency.

2.3. Study 1 - results

There were 108 accidents and 226 serious incidents between 1 January 2010 and 1 January 2020 related to the ten aerodromes analysed. 81.48 % (88 of 108) of accidents occurred at secondary aerodromes and 18.52 % at primary aerodromes. 77.43 % (175 of 226) of serious incidents occurred at secondary aerodromes and 22.57 % at primary aerodromes.

Table 3 details the frequencies of accidents and serious incidents relative to the primary and secondary aerodrome pairings.

By averaging the frequency data in Table 3, occurrence ratios can be determined:

1. For every accident at a primary aerodrome there is 4.4 accidents at secondary aerodromes.

2. For every serious incident at a primary aerodrome there is 3.4 serious incidents at secondary aerodromes.

An examination of the rates of on aerodrome injuries and fatalities also shows that:

- For the five primary aerodromes – 0 fatalities, 4 serious injuries and 3 minor injuries.
- For the five secondary aerodromes – 3 fatalities, 5 serious injuries and 21 minor injuries.

Fig. 1 provides a graphical representation of the occurrence data set out in Table 3, highlighting the elevated levels of accidents and serious incidents at secondary aerodromes.

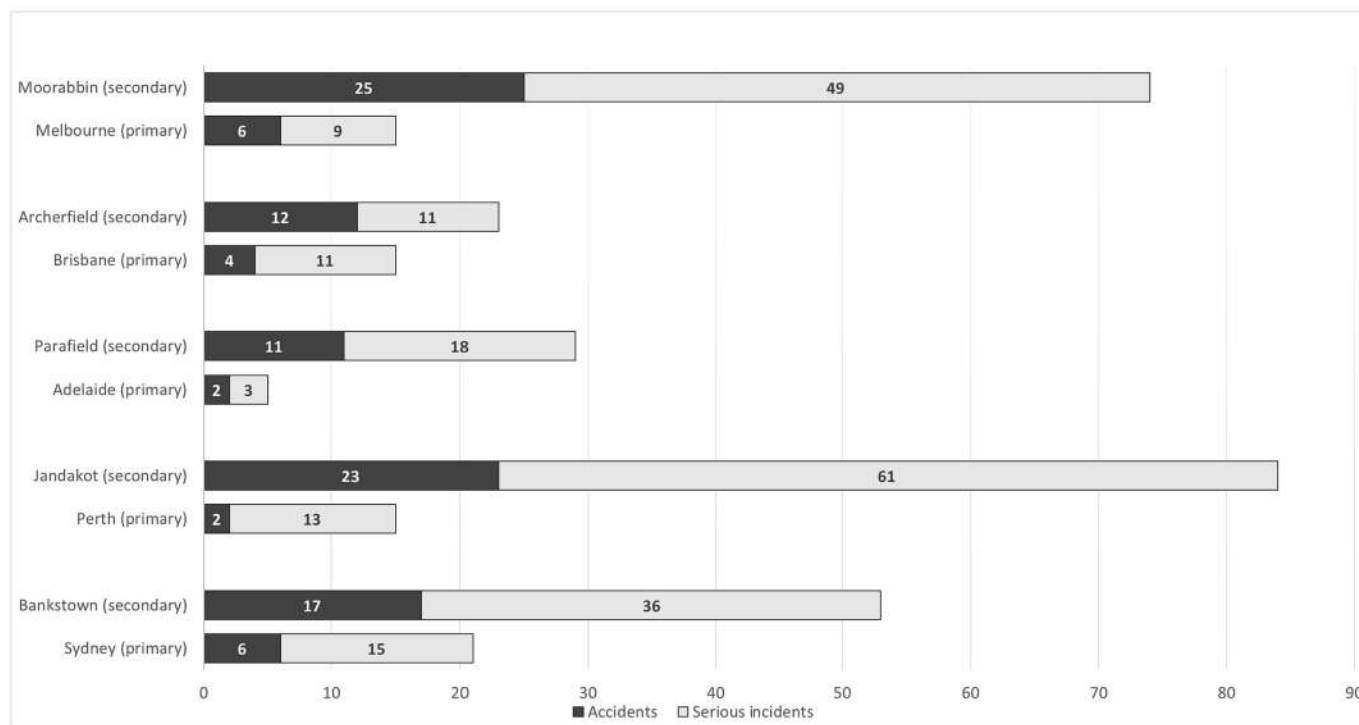


Fig. 1. Accident and serious incident frequency comparison bar chart.

2.4. Discussion

This study compared five primarily commercial air transport aerodromes (which have ARFFSs) and five primarily general aviation aerodromes (which do not have ARFFSs). The results show that over a 10 year period the rate of accidents and serious incidents are greater at primarily general aviation aerodromes than primarily commercial air transport aerodromes. This finding cannot be accounted for by greater aircraft movements at general aviation aerodromes than commercial air transport aerodromes. While Table 3 shows that aircraft movement is generally greater at secondary aerodromes, when averaged, it is only 8.76 % greater than the mean primary aerodrome aircraft movements. This suggests that greater aircraft movements alone is not a plausible explanation for the higher levels of accidents and serious incidents.

This finding is important because it shows that there is a compelling case for establishing ARFFS at general aviation aerodromes. Also, many countries currently utilise criteria for the establishment of ARFFS that are largely based on accident magnitude (such as annual passenger movement rates or aircraft size criteria). Focusing on accident magnitude means that ARFFS may be established at aerodromes where the potential size and scale of an incident is greatest but not at aerodromes where there is a much higher frequency of accidents and serious incidents. Clearly then, measures of potential accident magnitude need to be supplemented with other measures that include the historical accident and incident rate at an aerodrome. Study 2 further investigates this issue.

3. Study 2 - Aviation Safety Network accident data

3.1. Introduction

Study 2 seeks to analyse and compare aircraft accident characteristics to identify accident scenario types where the ARFFS can be of greatest benefit. As part of this analysis we will again consider the issue of accident magnitude as the focus for ARFFS establishment criteria. This study uses a scenario-based event modelling technique known as event tree analysis to identify the probabilities of certain aircraft

accident scenarios. By analysing the probabilities of different accident scenarios, insight can be gained into the types of scenarios that have the greatest potential to benefit from an ARFFS, how probable they are and the likely rate of survivability. Identifying scenario characteristics in the event tree that are most common informs us about the basic need for ARFFS and where the need for ARFFS is greatest.

The event tree analysis technique described by Ericson (2005) was used in this study. Scenarios are developed with an initiating event (IE) and associated progressive pivotal events (PE). Event trees are inductive logic methods capable of analysing various accident sequences from an initiating event and contain elements of qualitative interpretation of the data (aligned with the scenario events) as well as quantitative statistical analysis via the calculation of the consequence probabilities (Zio, 2007). The technique is frequently utilised within high reliability system safety domains and produces outputs which allow for comparison-based probability analysis of the consequence scenarios (Dowie et al., 2003; Lower et al., 2016; Rosqvist et al., 2013).

Recent international accident and incident reports contain information from actual emergencies around the world that can be used to construct the event tree. Contemporary records from the Aviation Safety Network (ASN) database were subjected to analysis by pivotal events (or key events). These pivotal events reflect the key stages of an aviation accident development aligned with ARFFS operational performance expectations (Civil Aviation Safety Authority, 1998; International Civil Aviation Organization, 2015, 2018; Cherry and Associates, 2013). Thus, the pivotal events reflect the progression of an aircraft accident that the ARFFS is designed to manage.

3.2. Method

Data was extracted from the ASN database, coded relevant to the following events, and then entered into the event tree to support scenario-based probability analysis. Missing parent record data is recorded in the corresponding event tree data field as unavailable.

Initiating event (IE) – aircraft emergency occurrence.

- Pivotal event 1 (PE1)** – Location of the accident or incident.

- Pivotal event 2 (PE) – Presence of fire.**

- o The incident record, inclusive of official investigation reports and/or incident photographs are reviewed to identify the presence of fire – internal or external.

- o The presence of fire is not always immediately identifiable via the ASN database records. In some instances, review of the associated official investigation report and/or site/incident photographs (if available) is required to confirm the presence of fire.

Relative to the 1,472 accidents/incidents on or within the vicinity of an aerodrome, 1,465 records had sufficient information to assess the presence of fire with 252 involving fire (17.2 %) and 1,213 with no indication of fire (82.8 %).

Pivotal event 3 (PE) – Aircraft type – wide-bodied or narrow-bodied.

- o Aircraft type is categorised as wide-bodied if there is more than one aisle (passenger aircraft) or fuselage diameter is greater than 5 m (non-passenger aircraft). All aircraft that are not wide-bodied are categorised as narrow-bodied.

Consequence – Fatal or non-fatal

- o The probability of a fatal or non-fatal outcome of accidents that align with the associated event sequence is determined by analysing the rate of fatality relative to the total passengers involved.

Scenario probability

- o The probability of scenario event sequence occurrence, inclusive of consequence outcome (fatal/non-fatal) represented as a percentage relative to the 10 scenario event sequence outcomes.

3.3. Results

2,012 aircraft accidents and incident records were extracted from the ASN database between 1 January 2010 and 1 January 2020 and coded into an event tree (Fig. 2).

Accidents or incidents categorised as *parked* (236), *taxiing* (164), *take-off* (192) and *landing* (787) were deemed 'on or within the vicinity of an aerodrome' (PE1), with *manoeuvring* (13) and *en-route* (323) not considered 'on or within the vicinity of an aerodrome' due to the definition of these categories. *Approach* (163) and *initial climb* (88) required

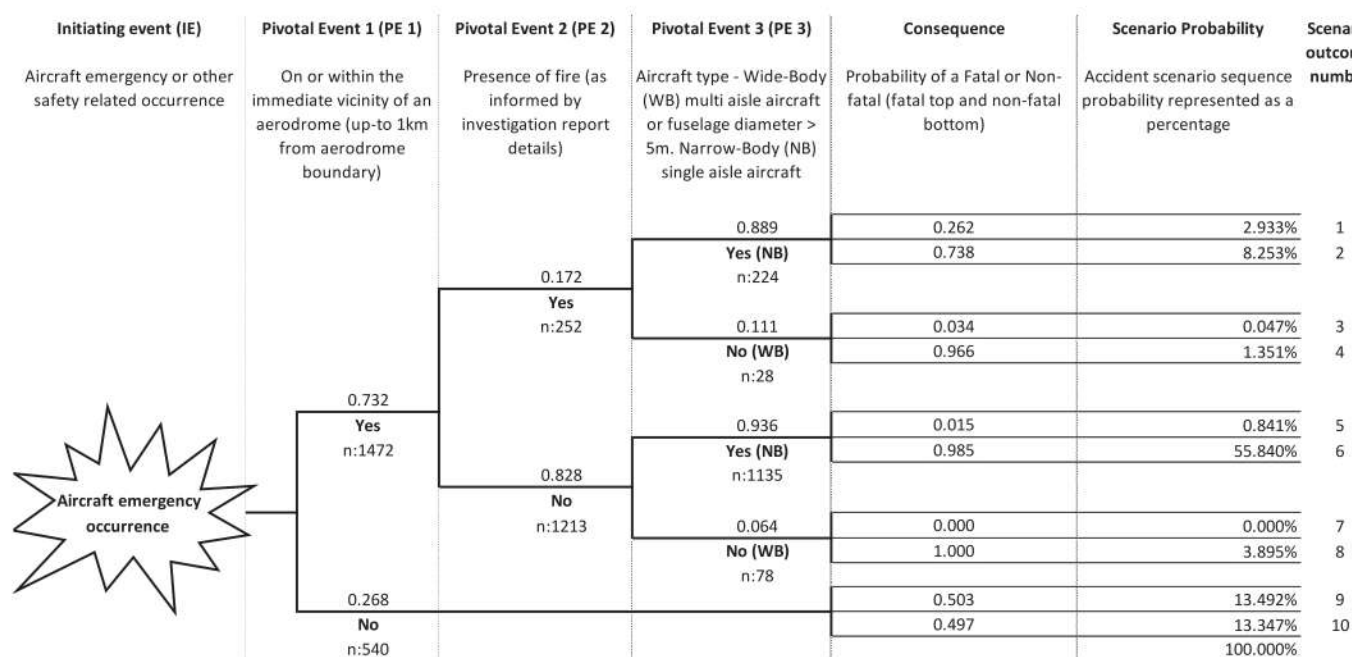


Fig. 2. Event tree for 2,012 aircraft accidents recorded in the Aviation Safety Network accident database between 1 January 2010 and 1 January 2020.

Table 4
Frequency of Accident/Incident by Phase of Flight.

Phase of flight	Frequency	Percentage
Parked	236	12.00 %
Taxiing	164	8.34 %
Take-off	192	9.77 %
Initial climb	88	4.48 %
En-route	323	16.43 %
Manoeuvring	13	0.66 %
Approach	163	8.29 %
Landing	787	40.03 %
Total	1,966¹	100 %

¹ Note: 46 records (of the total 2,012) were unable to be coded for phase of flight due to insufficient information within the parent record.

analysis to determine the proximity of the incident to the aerodrome. For records where it could be determined that the incident was within 1,000 m of the aerodrome boundary, such accidents or incidents were determined as 'on or within the vicinity of an aerodrome'. Table 4 defines the distribution of frequency by phase of flight.

1,472 (73.2 %) of accidents or incidents occurred on or within the immediate vicinity of an aerodrome. There were 540 (26.8 %) incidents that were not on or within the immediate vicinity of an aerodrome. Accidents on the aerodrome presented a mean survivability rate of 92 %, with accident off aerodrome having a 50 % survivability rate.

For the 252 accidents/incidents where fire is present in an aircraft on or within the vicinity of an aerodrome, 88.9 % ($n = 224$) involved a narrow-bodied aircraft and 11.1 % ($n = 28$) involved wide-bodied aircraft. For the 1,213 accidents/incidents where fire is not present on or within the vicinity of an aerodrome, 93.6 % ($n = 1,135$) involved a narrow-bodied aircraft and 6.4 % ($n = 78$) involved wide-bodied aircraft.

In the presence of fire, a narrow-bodied aircraft experienced a 26.2 % fatality rate, significantly greater than the 0.015 % fatality rate for a narrow-bodied aircraft without the presence of fire on or within the vicinity of an aerodrome. Wide-bodied aircraft, in the presence of fire, experienced a 3.4 % fatality rate, greater than the 0 % fatality rate for wide-bodied aircraft accidents without the presence of fire on or within the vicinity of an aerodrome.

3.4. Discussion

The event tree analysis conducted in this study allowed us to model scenario-based events to identify the probabilities of certain aircraft accident scenarios and the likely rate of survivability. This analysis showed that the majority of aircraft accidents (73.2 %) do occur on or within the immediate vicinity of an aerodrome. This is broadly consistent with Boeing phase of flight analysis which indicates approximately 71 % of commercial aircraft accidents/incidents occur on or within the general vicinity of an aerodrome (Boeing, 2019). Survivability is greater for accidents on or within the immediate vicinity of an aerodrome compared to incidents off aerodrome and the presence of fire increases the probability of fatality, which is consistent with literature published by Ekman and Debacker (2018) and Cherry and Associates (2013). This establishes the basic need for an on-aerodrome ARFFS.

In relation to ARFFS establishment criteria one of the most important findings from this study is the higher rate of survival associated with wide-bodied aircraft, with and without the presence of fire. Although the rate of wide-bodied aircraft accidents is lower than that for narrow-bodied aircraft due to the respective rate of movements, when compared by presence of fire, 26.4 % of the wide-bodied aircraft accidents involved fire, greater than the 16.4 % associated with narrow-bodied aircraft, yet the rate of survivability was considerably higher for wide-bodied aircraft. A closer examination of the 106 wide-bodied aircraft incidents analysed has identified that in many instances, despite a concurrent fire, all or close-to-all passengers have been able to rapidly

evacuate the aircraft.

One example of this is the 2016 American Airlines Boeing 767 accident at Chicago-O'Hare International Airport. The Boeing 767 (wide-bodied aircraft) had commenced its takeoff ground roll when it experienced an uncontrolled engine failure, which led to a significant fire on the right side of the aircraft impacting the wing and fuselage. The crew aborted takeoff and commenced emergency evacuation when the aircraft came to a stop on the runway. The aircraft fire was eventually controlled and extinguished by the ARFFS (National Transport Safety Bureau, 2018). Irrespective of the presence of fire, rapid evacuation occurred; taking two minutes and twenty-one seconds for the 170 crew and passengers. There were no fatalities, although as a result of the evacuation, there were two serious injuries and 19 minor injuries.

Rapid evacuation of wide-bodied aircraft is supported by analysis undertaken by the United Kingdom Royal Aeronautical Society which attributes advancements in evacuation, flight-crew training and aircraft design resulting in survivable outcomes in otherwise clearly catastrophic circumstances (Butcher et al., 2018).

The higher survivability of wide-bodied aircraft results in a paradox whereby the ARFFS may be arriving on-scene to commence actions to save life, however, persons associated with the accident may have already commenced evacuation and be moving away from the accident, reducing the threat to life. In 2015, a British Airways 777 commenced takeoff ground roll at McCarran International Airport Las Vegas, and during acceleration, experienced a loud bang with the aircraft veering to the left. A rejected takeoff maneuver was initiated and the aircraft came to a stop on the runway. A significant fire developed due to a failure of the left engine, with the fire damaging the left wing and sections left and right of the fuselage. Emergency evacuation commenced 55 s prior to the arrival of the first ARFFS vehicle with the fire being extinguished (by the ARFFS) after evacuation ended (National Transport Safety Bureau, 2018a). This paradox is further compounded by the reality that, in some circumstances, the presence of ARFFS may introduce hazards. For example, the 2016 Emirates Boeing 777 accident at Dubai Airport resulted in the death of one ARFFS fire fighter and injuries to seven other fire fighters during an accident that had no other fatalities (General Civil Aviation Authority, 2020). ARFFS vehicles may also pose a hazard during evacuation, as shown in the 2013 Asiana Airlines 777 accident at San Francisco International Airport, when a casualty was driven over twice by ARFFS vehicles during fire fighting operations (although this casualty may have already succumbed to previously acquired injuries) (National Transport Safety Bureau, 2013).

Narrow-bodied aircraft experiencing an accident on aerodrome present the greatest probability of a fatal outcome (with or without fire), and therefore generate the greatest need for an ARFFS. Wide-bodied aircraft demonstrate a much higher level of survivability, and whilst they will still benefit from ARFFS assistance, the risk associated with very large aircraft appears to be lower than its single-aisle alternative. Like Study 1, this challenges the notion that establishment criteria for ARFFS can be largely based on accident magnitude. In contrast this study shows that the size of an aircraft and the number of passengers being carried does not directly inform the level of risk associated with its operation and thus could be a misleading indicator as to the need for an ARFFS at an aerodrome. Given all the countries listed in Table 1 (except India) utilise criteria that either directly or indirectly measure incident magnitude this is an important finding indicating the need for more appropriate ARFFS establishment criteria.

4. General discussion

Aviation Rescue Fire Fighting Services (ARFFSs) are designed to respond to aerodrome aviation emergencies and they make an important contribution to safety and public confidence in aviation. However, there is currently little or no published academic research on ARFFS and no evidence base to support decisions about which aerodromes need to have an ARFFS. There is also a lack of international standards or

recommended practices from the International Civil Aviation Organization (ICAO) which has contributed to considerable variation internationally in the establishment requirements for an ARFFS and a focus on the magnitude of a potential aircraft accident (such as annual passenger movement rates or aircraft size criteria).

The first study in this paper shows that over a 10 year period the rate of accidents, serious incidents, fatalities and injuries are greater (on or within the vicinity) of five Australian primarily general aviation aerodromes (that do not have ARFFS) than five primarily commercial air transport aerodromes (that do have ARFFS). This firstly demonstrates a compelling case for establishing ARFFS at general aviation aerodromes and secondly that the historical rate of accidents and serious incidents needs to be taken into account in ARFFS establishment criteria in addition to measures of potential accident magnitude.

The second study uses an event tree to explore 10 years of international accident and incident data. This study shows that wide-bodied aircraft present a lower probability of a fatal outcome (with or without fire) compared to narrow-bodied aircraft. This again challenges the notion that establishment criteria for ARFFS can be largely based on accident magnitude. Whilst wide-bodied aircraft can hold the greatest number of passengers of any aircraft type, this study has shown they result in significantly better rates of survivability (with or without fire) when compared to narrow-bodied aircraft. That is, the level of risk is not simply related to the passenger capacity of the aircraft.

These results are important for ARFFS as they start to provide an evidence base for a fuller consideration of factors that should form the establishment criteria for ARFFS. Passenger movement rates and accident magnitude are important considerations, but should not be relied upon as the sole indicator of the risk associated with aviation. The results of this study have shown that such an approach could result in some aerodromes that would benefit from an ARFFS being overlooked. Ultimately, the ARFFS should be located at aerodromes where the risk is greatest, and for this to be effectively determined, criteria should consider both the magnitude of potential accidents (e.g. aircraft size and passenger movement rates) and the likelihood of occurrence (e.g. rate of accidents and serious incidents). This approach results in ARFFS establishment being proportionate to the level of risk and highlights the importance of evidence-based criteria to guide the establishment requirements of an ARFFS.

In this paper we argue that there is a case for greater presence of ARFFS at general aviation aerodromes, however, we acknowledge that geographical location and funding are important considerations that may influence the establishment and service provision of ARFFS. Funding in particular presents both a challenge and an opportunity for ARFFS service providers and researchers. For aerodromes with less commercial activity (such as general aviation and regional/remote aerodromes) the challenge is to identify cost effective methods to provide the safety benefits associated with an ARFFS in a way that meets the financial capacity to support such a service. Further research needs to be conducted into these issues and into the development of new technologies that provide innovative solutions to the provision of ARFFS at smaller general aviation aerodromes. Emerging technologies such as video cameras, remote sensing and drones can all potentially be developed to supplement existing ARFFS technology. This acts to enhance the accessibility and long-term sustainability of an ARFFS by reducing barriers to establishment and improving access to this critical safety support system, which ultimately improves aviation safety. This also ultimately points to the evolving nature of aviation and the need for ARFFS to leverage technology to best support current and emerging aviation safety needs.

The research in this paper has a number of practical applications. In the short term there is a need for aviation policy makers and standard setting organisations to review their ARFFS establishment criteria. In particular, there is a need to supplement current ARFFS establishment criteria with 1) an analysis of historical accident and serious incident data and 2) an analysis of the crashworthiness of the aircraft that use the

aerodrome. In the longer term a risk based model for ARFFS establishment that includes a variety of risk-based characteristics needs to be developed. While, further research needs to be conducted into the specific characteristics that form the model, candidates for inclusion include: the aerodrome safety performance, rate of movements, the nature and purpose of aircraft operations, aircraft safety performance, etc. The model needs to be transparent and easily applied in a clear and practical way (following a reasonable amount of training) by aviation policy makers and standard setting organisations to provide a reliable evidence-based assessment of the need for ARFFS at an aerodrome. By understanding how the ARFFS can enhance survivability and where this service is of greatest need, aviation policy makers and standard setting organisations can focus ARFFS design and distribution to achieve the greatest safety benefit.

The absence of guidance from the International Civil Aviation Organization (ICAO) on ARFFS establishment requirements has likely contributed to global inconsistency. This research suggests that (ICAO) needs to both prompt a review of current ARFFS establishment criteria and provide better information and guidance on ARFFS establishment. This material needs to help aviation policy makers and standard setting organisations to determine the level of risk associated with aerodromes and support individual nations to set a more consistent set of standards. Following the development of a risk based model for ARFFS establishment ICAO would be able to provide international standards and recommended practices on the establishment of ARFFS.

The research in this paper has a number of limitations that should be acknowledged. In Study 1, the use of Australian aviation safety occurrence database may limit the applicability of this information to international contexts. However, there are international standards for aviation safety occurrence data management, so the generalised concepts identified by the analysis are likely to be applicable beyond the Australian context. Another limitation is acknowledged in relation to the completeness of the international repository or database for aircraft accidents used in Study 2. Whilst there is no single database which contains every aircraft accident that has occurred globally, the ASN database was selected as providing a comprehensive database for this research.

5. Conclusion

For passengers and crew to survive the most dangerous yet technically survivable aircraft accidents, the intervention of an ARFFS is essential. To be able to intervene and enhance survivability in such situations ARFFS needs to be operational at the locations where accidents are most likely to occur. To date most of the criteria for establishing ARFFS are based on the magnitude of a potential aircraft accident. As the research in this paper shows, while this criterion is important it should not be used as the sole method for determining whether an aerodrome should have an ARFFS. The first study found that primarily general aviation aerodromes (without an ARFFS) had a higher rate of accidents, serious incidents, fatalities and injuries than primarily commercial air transport aerodromes (with an ARFFS). The second study showed that wide-bodied aircraft present a lower probability of a fatal outcome (with or without fire) compared to narrow-bodied aircraft. Indeed, there are several examples where all passengers and crew were able to evacuate wide-bodied aircraft with evacuation being underway before the arrival of the ARFFS. The insights provided by these studies highlight the need for ARFFS service providers, policy makers and standard setting organisations to review their establishment criteria in terms of both the historical accident/serious incident data and the crashworthiness of the aircraft that use the aerodrome. In the longer term this research identifies the need for a risk model of ARFFS establishment criteria that can help determine the need for ARFFS at an aerodrome. In this way a defensible evidence based approach to establishing ARFFS can be determined so that the ARFFS is available where it is needed most.

Iniciado em sexta-feira, 21 jun. 2024, 16:30**Estado** Finalizada**Concluída em** sexta-feira, 21 jun. 2024, 16:31**Tempo
empregado** 10 segundos**Questão 1**

Não respondido

Vale 1,00 ponto(s).

v10 (mais recente)

Woodman, Berman e Hayes (2024) discorrem sobre os Serviços de Combate a Incêndios em Aeroportos, conhecidos pela sigla ARFFS. Qual das assertivas a seguir está INCORRETA em relação ao conceito e às características de um ARFFS?

Escolha uma opção:

- ☐ O ARFFS é um espaço obrigatório em aeroportos porque acidentes com aeronaves ocorrem majoritariamente em ou nas mediações de um aeroporto.
- ☐ A maioria dos critérios para estabelecer ARFFS, até a data, baseia-se na magnitude de um potencial acidente aéreo.
- ☐ O objetivo principal de um ARFFS é prestar assistência em caso de emergências e melhorar as chances de sobrevivência de passageiros e tripulação.
- ☐ A intervenção dos ARFFS é essencial no caso de acidentes mais perigosos, mas tecnicamente passíveis de sobrevivência.

Questão 2

Não respondido

Vale 1,00 ponto(s).

v10 (mais recente)



Para conduzir a análise dos dados de acidentes e segurança da aviação no intuito de estabelecer uma base de evidências para decisões sobre ARFFS, os autores partem de alguns pressupostos. Nesse enfoque, analise as assertivas a seguir e identifique quais são pressupostos que foram considerados pelos autores:

I – Dois aspectos fundamentais para a utilização pública da aviação como método de transporte confiável e eficaz são sua segurança e a aceitabilidade do risco associado às viagens aéreas.

II – Historicamente, o baixo desempenho da aviação se destacou pelos resultados catastróficos de grandes acidentes com alta frequência de ocorrência em partidas de viagens aéreas no ano de 1959.

III – O medo e a apreensão em voar continuam devido às estatísticas mantidas pela aviação como transporte de massa sem melhoria na capacidade de sobrevivência em casos de acidentes.

IV – Para que um acidente aéreo seja compreendido como passível de sobrevivência, considera-se que a capacidade de sobrevivência é um produto das ações resultantes após a ocorrência inicial.

V – A velocidade com que uma intervenção eficaz contra incêndio pode ser estabelecida é crítica no caso de um incêndio ameaçar a fuselagem e/ou limitar a capacidade de evacuação.

Escolha uma opção:

- ☐ As assertivas II, III e V são pressupostos corretos mobilizados pelos pesquisadores.
- ☐ As assertivas III, IV e V são pressupostos corretos mobilizados pelos pesquisadores.
- ☐ As assertivas I, II e III são pressupostos corretos mobilizados pelos pesquisadores.
- ☐ As assertivas I, IV e V são pressupostos corretos mobilizados pelos pesquisadores.

Questão 3

Não respondido

Vale 1,00 ponto(s).

v15 (mais recente)

Globalmente, há uma variação considerável nos requisitos de estabelecimento para um ARFFS, cabendo às nações individuais que subscrevem a Convenção sobre Aviação Civil Internacional estabelecerem tais requisitos. Nesse enfoque, analise as afirmativas a seguir

I – Enquanto a Austrália e o Canadá estabelecem critérios embasados no número médio anual de passageiros, os Estados Unidos consideram o número de assentos de passageiros operados por aeronave.

II – Os Estados Unidos, assim como o Reino Unido e a Nova Zelândia, requerem uma certificação de operação fornecida pela Administração Federal de Aviação.

III – Tanto a Austrália como a Indonésia consideram algumas especificações do serviço aéreo internacional e de operações domésticas para o estabelecimento de seus requisitos.

IV – A Índia e a União Europeia partem de dados relacionados ao fato de os voos serem regulares ou esporádicos, como a condição de pavimentação da pista para estabelecerem seus requisitos.

V – Os temas em comum identificados como critérios dos diferentes países incluem o tipo de operação de transporte aéreo, o número de movimentos anuais de passageiros, o número de lugares disponíveis e o peso da aeronave.

Selecione a alternativa que apresenta a avaliação correta das afirmativas anteriores em Verdadeiras (V) ou Falsas (F):

Escolha uma opção:

- ☐ V – F – V – F - V
- ☐ V – V – F – F - V
- ☐ F – V – F – V - V
- ☐ V – F – V – V - F

Questão 4

Não respondido

Vale 1,00 ponto(s).

v2 (mais recente)



Considerando a discussão geral de Woodman, Berman e Hayes (2024), qual das alternativas a seguir se constitui uma limitação da pesquisa conduzida pelos pesquisadores?

- ☐ No estudo 1, a utilização da base de dados australiana de ocorrência de segurança da aviação pode limitar a aplicabilidade desta informação a contextos internacionais.
- ☐ Existem normas internacionais para a gestão de dados de ocorrências de segurança da aviação, o que pode levar à provável aplicação dos resultados do Estudo 1 para além do contexto australiano.
- ☐ Para o Estudo 2, embora não exista uma base de dados única que contenham todos os acidentes aeronáuticos ocorridos globalmente, a base de dados selecionada fornece uma base abrangente.
- ☐ A ausência de orientação da Organização Civil internacional sobre os requisitos para estabelecimento de ARFFS contribuiu para a inconsistência global.

Questão 5

Não respondido

Vale 3,00 ponto(s).

v9 (mais recente)

Redija uma comparação entre o Estudo 1, Dados de ocorrências de segurança aeronáutica, e o Estudo 2, Dados de acidentes da Rede de Segurança da Aviação, tendo como foco: (i) o desenho metodológico e (ii) os tipos de dados estatísticos gerados como resultados desses estudos.

Questão 6

Não respondido

Vale 3,00 ponto(s).

v9 (mais recente)



Discorra sobre como os dois estudos se complementam e sobre o que sugerem para práticas e pesquisas futuras.