



Australian Government

Australian Transport Safety Bureau



ATSB TRANSPORT SAFETY REPORT
Aviation Research and Analysis Report – AR-2008-018(2)
Final

Runway excursions

Part 2: Minimising the likelihood and consequences of runway excursions

An Australian perspective



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Runway excursions: Part 2 – Minimising the likelihood and consequences of runway excursions, An Australian perspective

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Abstract

While most runway excursions are relatively minor with no serious injuries or aircraft damage occurring, they do have the potential to pose a serious risk to public safety and infrastructure. This has been illustrated by several significant runway overruns around the world in 2007 and 2008, resulting in hundreds of on-board fatalities, as well as ground fatalities and significant property damage in communities adjacent to airports.

Further analysis of the Ascend World Aircraft Accident Summary set of 120 runway excursions on landing involving commercial jet aircraft between 1998 and 2007 (used in the first report in this series), was performed to map the distance that aircraft overran or veered off the runway. Most aircraft stopped within 1,000 ft of the runway end, and within the extended runway edges.

Preventative risk controls are the most important way to reduce the likelihood and consequences of runway excursions. These include reinforcement of safe approach techniques, pre-landing risk assessments, line-oriented flight training, clear policies on go-arounds, quality runway surfaces with safety features such as grooving and surface texturing, runway lighting, and indicators of remaining runway length through distance remaining signs and cockpit alert systems.

If these preventative risk controls fail, recovery risk controls are an important ‘last line of defence’ to mitigate severe consequences if a runway excursion does occur. Recovery risk controls include runway strips, runway end safety areas, soft ground arrestor beds, and public safety areas. Telephone surveys of 43 major airports found that runway end safety areas in Australia meet or will soon meet Civil Aviation Safety Authority requirements. A large majority of Australian airports had good quality runway surfaces that reduced the risk of a runway excursion occurring in the first place.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal bureau within the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. ATSB investigations are independent of regulatory, operator or other external organisations.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

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About ATSB investigation reports: How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site www.atsb.gov.au

EXECUTIVE SUMMARY

Runway excursion accidents are not an uncommon occurrence in commercial aviation. They account for a significant proportion of approach and landing accidents, and a quarter of all incidents and accidents in air transport (IFALPA, 2008). Between 1998 and 2007, there were 120 excursion accidents on landing worldwide. Over the same period, there were three excursions involving Australian-registered commercial jet aircraft, and two excursions of foreign-registered commercial jet aircraft in Australia. While this report focuses on commercial jet aircraft, 425 runway excursions of general aviation and low capacity aircraft were reported to the ATSB over this 10 year period. Those occurrences involved both Australian VH-registered aircraft and foreign-registered aircraft operating at Australian aerodromes.

Despite a continuing downwards trend in commercial aircraft hull loss accidents over the last decade, approach and landing accidents are one area which has shown little improvement in safety. The 2008 International Air Transport Association (IATA) Safety Report has shown that runway excursions were the most frequent type of accident in 2008, accounting for 25 per cent (IATA, 2009).

In Australia, previous runway excursions have led to little more than minor damage to the aircraft, with few (if any) injuries to passengers or crew. However, as runway excursions occur at airports (which are often located in built-up urban areas), a potential exists for injury to both people on board the aircraft and people who work, live or travel in close proximity to airports. Several significant runway excursion accidents occurred worldwide in 2007 and 2008 that resulted in over 300 on-board and ground fatalities. In 2008, IATA found that over half of all runway excursions globally in that year resulted in a hull loss, and 15 per cent involved fatalities (IATA, 2009).

The purpose of this study was to provide an overview of runway excursion accidents from both an international and Australian perspective. The study has been divided into two parts:

- Part 1 of the study (published in April 2009) examined worldwide trends in runway excursion accidents involving commercial jet aircraft over a 10-year period (1998 to 2007), and explored the types and prevalence of safety factors that contribute to runway excursions.
- Part 2 (this report) discusses the impact of runway excursion accidents on communities located near airports across the world, and the risk controls that have been or could be put in place to minimise this risk, or mitigate its effects if a serious excursion did occur in Australia or overseas.

Serious runway excursions, both overruns and veer-offs, can clearly pose risks to public safety and infrastructure. It is imperative that airlines, airport operators, and safety regulators have risk controls in place to manage the contributing factors that can lead to runway accidents (identified in Part 1 of this study).

Preventative risk controls are the most prudent way to minimise the chance of a runway excursion occurring. Good awareness of the factors that can contribute to runway excursions (and approach and landing accidents in general), in addition to safe approach and landing practices, is needed. Line operations flight training for flight crews focussed on approach and landing safety, firm standard operating

procedures for stabilised approaches, reinforcement of a clear and risk-averse operator policy on go-arounds, and limitations on contaminated runway operations are all important preventative risk measures that should be put in place to minimise the chance that an aircraft crew gets in a situation where the risk (likelihood and consequences) of an excursion occurring is increased. Preventative risk controls can also be used to make the flight crew aware of the length of the runway remaining through the use of runway distance remaining signs and cockpit alert systems such as the Honeywell Runway Awareness and Advisory System. Airport operators and aviation safety regulators also have a role to play in implementing preventative risk controls, such as quality runway design to reduce the effect or remove factors that could contribute to a runway excursion, for example, grooving and texturing, friction treatments, lighting, and rubber deposit removal.

Preventative risk controls are, and should always be, the primary protection against runway excursion accidents, as they remove or minimise the factors that increase the likelihood of an excursion occurring before one occurs.

A further level of protection to minimise the potential consequences of runway excursion accidents can be provided by recovery risk controls. These are physical, passive design features which act as a 'last line of defence' to prevent or reduce the seriousness of a runway excursion if preventative risk controls fail or are not in place. This report discusses recovery risk controls that can safely control and decelerate the aircraft if an excursion does occur including runway strips, runway end safety areas (RESAs), and soft ground arrestor beds. A further recovery risk control is the provision of public safety areas that minimise loss of life and property damage in areas surrounding airports if a significant approach and landing accident or runway excursion occurs by placing limits on development and land use.

While regulators generally have provisions for recovery risk controls at airports such as RESAs and graded runway strips, local issues and the physical environment can limit what safeguards can be put in place. The urban location of many major airports, including those in some Australian capital cities, reduces the ability of airport operators to provide RESAs that meet the International Civil Aviation Organization (ICAO) RESA standard of 90 m or the recommended length of 240 m.

A telephone survey was conducted of 43 airports in Australia capable of handling commercial jet aircraft services to determine the specifications of RESAs in use on their runways. All airports handling international jet aircraft that were surveyed, provided (or are in the process of providing) RESAs of at least 90 m in length from the runway strip that meet the Civil Aviation Safety Regulation (CASR) 139 *Manual of Standards – Aerodromes* and ICAO Annex 14 *Aerodrome Design and Requirements* standards. A minority of Australian international airports provided larger RESAs up to the 240 m recommended length for international airports by ICAO.

Internationally, programs such as the Federal Aviation Administration (FAA) *Runway Safety Area Improvement Program* have been highly successful in increasing the number of airports that are able to improve RESA areas to substantially meet regulatory requirements. However, some airports are unable to fully meet RESA dimensional requirements or recommendations due to terrain limitations. In these cases, regulators provide airport operators with alternative means to make their runways safer. Many of the recommended alternatives, such as reducing declared runway lengths, have negative operational and service impacts on airports and the communities that use them.

Runway surface improvements (grooving and texturing, friction treatments, rubber deposit removal) are the most important preventative risk controls at airports, as they provide better braking action for aircraft and reduce the likelihood of overruns and veer-offs occurring. Runway grooving has been widely adopted at Australian capital city and regional airports alike. By improving friction between the runway and the aircraft tyres, quality runway surfaces reduce the speed of aircraft that overrun or veer off a runway, reducing the need for an extended RESA.

Arresting technologies, such as soft ground arrestor beds, can provide airport operators with an alternative solution to meeting the full RESA requirements or extended RESA recommendations. They can also be used as an additional risk recovery control in their own right. These technologies generally have little to no operational impact on the airport, but do involve large capital infrastructure investment. Several types of foam and fuel ash-based arrestor beds were trialled at commercial airports in the United Kingdom between the 1960s and 1990s. Most recent research and development of soft ground arrestor beds has been done in the United States, with the FAA supporting commercial arresting technology development through its *Airport Cooperative Research Program*. This program has resulted in joint regulator-industry trials to evaluate arrestor systems. The Engineered Materials Arresting System (EMAS) has been the most successful system to date, and has been approved by the FAA as a runway safety alternative where full safety area requirements cannot be met. Since 1999, an EMAS bed installed at John F. Kennedy International Airport in New York has successfully arrested three commercial aircraft that have overrun the runway, and in each case with minimal damage to the aircraft and no injuries to the occupants.

While the CASR 139 *Manual of Standards* identified engineering solutions such as soft ground arrestor beds as an additional safety measure that could be used to supplement a RESA, the survey found that no major Australian airports are currently equipped with these beds.

It is important to note that airports are not safety deficient by not having all of these risk controls in place. This report is a review of all of the major preventative and recovery risk controls available that can be possible options for airport operators to help mitigate or avoid the serious consequences of runway excursions. Not all risk controls are necessary or appropriate for all airports. Due to the diverse Australian operating environment (in terms of movement activity, aircraft mix, approach terrain, environs, and climatic conditions), a risk management approach which adopts the best-fit preventative and recovery risk controls for each airport is the most appropriate way to minimise the risk of runway excursions.

At the time of writing (mid 2009), Australia has been fortunate in that it has not experienced a serious runway excursion accident as has occurred overseas. This can be attributed to the positive safety cultures of local aircraft operators, airport owners and managers, and regulators, investment in safety infrastructure and runway works at Australian airports, a smaller number of commercial jet aircraft movements than many overseas countries, and a lower prevalence of conditions such as ice and snow that can increase the both the likelihood and consequences of a serious runway overrun. However, Australia is not immune to runway accidents. Between 1998 and 2008, two excursions involving Australian-registered commercial jet aircraft have occurred in Australia, and another two excursions involving Australian-registered aircraft have occurred overseas. It is important to recognise that the risk of a runway excursion accident is ever present, and that aircraft operators and airport owners and managers should continue to focus their efforts on implementing risk controls to

ensure the risk remains at an acceptable level. Professional aviation forums such as the Australian Airports Association, the Regional Aviation Association of Australia, and the Air Transport Association in North America play an important role in allowing airline and airport operators to evaluate and discuss the benefits and challenges of implementing preventative and recovery risk controls, and for aviation safety regulators to gain a better awareness of the operational issues associated with different risk controls.

As the possibility that preventative and recovery risk controls could fail and a serious runway excursion occur cannot be eliminated entirely, governments at all levels need to be proactive in ensuring the damage to life, property and infrastructure is limited. For example, the Australian Government and some state governments are exploring the implementation of public safety areas as effective ways of controlling development of land in the airport environs where both the likelihood and consequences of approach and landing accidents is highest.

ABBREVIATIONS

A	Australian
AC	Advisory circular
ACI	Airports Council International
AFM	Aircraft Flight Manual
AIP	Aeronautical Information Publication (Airservices Australia)
ALAR	Flight Safety Foundation Approach and Landing Accident Reduction Study
ALPA	Air Line Pilots Association, Int'l
ANEF	Australian Noise Exposure Forecast (Airservices Australia)
ARC	Aviation Rulemaking Committee (FAA)
ARFF	Airport rescue and fire fighting
ASDA	Accelerate-stop distance available
ATC	Air traffic control
ATIS	Automatic terminal information service
ATSB	Australian Transport Safety Bureau
BITRE	Bureau of Infrastructure, Transport and Regional Economics
C	Centigrade
CAA	Civil Aviation Authority (United Kingdom)
CAP	Civil Aviation Publication (CAA)
CASA	Civil Aviation Safety Authority
CASR	Civil Aviation Safety Regulation (CASA)
CFIT	Controlled flight into terrain
CRM	Crew resource management
CWY	Clearway
DDG	Dispatch deviation guide
DGAC	Direction Générale de l'Aviation Civile (France)
EASA	European Aviation Safety Agency
E-GPWS	Enhanced ground proximity warning system
EMAS	Engineered Materials Arresting System

ERAS	Engineered Rootzone Arresting System (GridTech)
ERSA	En Route Supplement Australia (part of the AIP)
ESCO	Engineered Arresting Systems Corporation
FAA	Federal Aviation Administration (US)
FAR	Federal Aviation Regulation (FAA)
FDR	Flight data recorder
FOM	Flight Operations Manual
FSF	Flight Safety Foundation
ft	Feet
GA	General aviation
GPS	Global Positioning System
HUD	Head-up display
ICAO	International Civil Aviation Organization
IFALPA	International Federation of Air Line Pilots' Associations
IFR	Instrument flight rules
ILS	Instrument landing system
IMC	Instrument meteorological conditions
ISSG	ICAO Industry Safety Strategy Group
JAA	Joint Aviation Authorities (Europe)
kg	Kilograms
kts	Knots
L	Left, lift
lb	Pounds
LDA	Landing distance available
LOFT	Line oriented flight training
m	Metres
mm	Millimetres
MEL	Minimum equipment list
METAR	Aviation routine weather report
MFD	Multi function display
MLS	Microwave landing system
μ (Mu)	Friction coefficient

MTOW	Maximum takeoff weight
n	Number of occurrences
NM	Nautical miles
NDB	Non-directional beacon
NOTAM	Notice to airmen
NTSB	National Transportation Safety Board (US)
NTSC	National Transportation Safety Committee (Indonesia)
OAT	Outside air temperature
PFA	Pulverised fuel ash
PFC	Porous friction course concrete
PQC	Pavement quality concrete
PSA	Public safety area
R	Right
RAAF	Royal Australian Air Force
RAAS	Runway Awareness and Advisory System (Honeywell)
RDR	Runway distance remaining
RDRS	Runway distance remaining signs
RDS	Runway Distance Supplement (part of the ERSA)
RESA	Runway end safety area
RNAV(GNSS)	Area navigation Global Navigation Satellite System
ROFZ	Runway obstacle free zone (US)
RPA	Rules and Practices for Aerodromes (CASA)
RPT	Regular public transport
RSA	Runway safety area (US)
RVR	Runway visual range
SMA	Stone mastic asphalt
SOP	Standard operating procedure
SPECI	Special aviation weather report
SWSOOS	Sydney Water South and Western Suburbs Ocean Outfall Sewer
SWY	Stopway

TCH	Threshold crossing height
TODA	Takeoff distance available
TORA	Takeoff run available
TSB	Transportation Safety Board (Canada)
UK	United Kingdom
US	United States of America
V_p	Critical dynamic aquaplaning speed
V_{ref}	Aircraft approach and landing speed (reference)
VFR	Visual flight rules
VMC	Visual meteorological conditions
VOR	Very high frequency omni-directional range
WAAS	World Aircraft Accident Summary (Ascend)

1 INTRODUCTION

1.1 Background

Part 1¹ in this series showed that runway excursions comprise a significant proportion of commercial aviation accidents around the world each year. Runway excursion accidents are comprised of both runway overruns and veer-offs. The Flight Safety Foundation (FSF) defines a *runway overrun* as when an aircraft's landing or take-off rollout extends beyond the end of the runway. A *runway veer-off* is when the aircraft veers off the side of the runway during the landing roll, or veers off the side of the runway or taxiway when exiting the runway (Werfelman, 2008).

The International Federation of Airline Pilots Associations (IFALPA) claims that a quarter (24 per cent) of all incidents and accidents in air transport operations are runway overruns or veer-offs (IFALPA, 2008). This is supported by analysis of worldwide accidents by the International Air Transport Association (IATA), which in the 45th edition of the IATA Safety Review found that 25 per cent of all accidents in 2008 were runway excursions (IATA, 2009). In Europe, a 2007 report by the European Aviation Safety Agency (EASA) found that runway excursions were the third most common type of accident involving large commercial air transport aircraft in EASA member states² between 1998 and 2007. They were only surpassed in number by aircraft system and engine malfunctions, and abnormal ground contact accidents. The report also found that while controlled flight into terrain (CFIT) accidents, which have traditionally been one of 'aviation's historic killers' (ATSB, 2007), are declining overall, runway excursions showed an upward trend (EASA, 2008; Darby, 2008).

The review of worldwide runway excursion accidents between 1998 and 2007 covered in Part 1 identified some of the common threats to safe landings, and discussed how a range of flight crew technique, performance, weather and systems-related factors can contribute to sometimes catastrophic outcomes.

Unfortunately, a number of high-profile international fatal runway accidents in 2007 and 2008 have shown that runway excursion accidents continue to be a major hurdle to improving approach and landing safety, and have the potential to damage communities and infrastructure near airports.

Australia has not seen significant runway overruns to the extent of some other countries. This can be attributed to the positive safety cultures of local aircraft operators, airport owners and managers, and regulators, investment in safety infrastructure and runway works at Australian airports, a smaller number of commercial jet aircraft movements than many overseas countries, and a lower prevalence of conditions such as ice and snow that can increase the risk³ of a

¹ Taylor, R. P., Hughes, K., Godley, S. (2009). *Runway excursions. Part 1 – A worldwide review of commercial jet aircraft runway excursions* (Aviation Safety Research and Analysis Report AR-2008-018(1)). Canberra: Australian Transport Safety Bureau.

² At the time of writing (mid 2009), EASA member states were all of the 27 European Union states, plus Iceland, Norway, Liechtenstein, and Switzerland.

³ The term 'risk' combines both the likelihood of a runway excursion happening, and the consequences of a runway excursion if one does occur.

serious runway overrun. This does not mean that Australia is immune to runway accidents. Between 1998 and 2007, two notable excursions of commercial jet aircraft have occurred in Australia, and a serious overrun involving an Australian-registered aircraft occurred overseas. All three of these excursions were investigated by the Australian Transport Safety Bureau (ATSB). In 2008, another Australian-registered aircraft was involved in a runway veer-off in the Solomon Islands. While this report focuses on commercial jet aircraft, 425 runway excursions of general aviation and low capacity aircraft were reported to the ATSB over this 10 year period. Those occurrences involved both Australian VH-registered aircraft and foreign-registered aircraft operating at Australian aerodromes.

This report examines important risk controls that airlines, airport operators and safety regulators in Australia and worldwide may put in place to minimise the chance of a runway excursion occurring, and to reduce the consequences to life and property if such an accident does occur.

Airline operators, airport operators, aviation safety regulators, and aviation safety organisations can establish *preventative risk controls*⁴ to minimise the chance that aircraft will overrun or veer off a runway, and reduce the consequence to life and property if an excursion does occur through reducing the speed at which over-running aircraft exit the runway. Preventative risk controls include dedicated standard operating procedures (SOPs) for approaches and landings, crew simulator training, the promotion of awareness of approach and landing hazards, quality runway surfaces providing water drainage and friction, runway lighting, runway and cockpit indications of amount of runway remaining, and appropriate runway condition reporting procedures and tools. As preventative risk controls address factors that can contribute to a runway excursion before one occurs, their implementation and reinforcement should always be paramount.

Airport operators and regulators can complement these preventative controls by investing in *recovery risk controls*⁵ to minimise the injury and damage consequences for any aircraft that does overrun or veer off a runway. Recovery risk controls include runway strips, runway end safety areas (RESAs), soft ground arrestor beds, and defined public safety zones around runways.

While not all risk controls are necessary or appropriate for all airports, this report is a review of all of the major preventative and recovery risk controls available throughout the world that can be possible options for airport operators to help mitigate or avoid the serious consequences of runway excursions. In Australia, an array of both preventative and recovery risk controls are used by airport operators to reduce the likelihood of a runway excursion accident occurring. Professional aviation forums such as the Australian Airports Association, the Regional Aviation Association of Australia, and the Air Transport Association in North America play

⁴ Preventive risk controls are put in place to minimise the likelihood of undesirable local conditions, individual actions and occurrence events. These controls facilitate and guide performance at the operational level to ensure individual actions and technical events are conducted effectively, efficiently and safely. Such controls include procedures, training, equipment design and work rosters (Walker & Bills, 2008).

⁵ Recovery risk controls are put in place to detect and correct or otherwise minimise the adverse effects of local conditions, individual actions and occurrence events. Such 'last line' controls include warning systems, emergency equipment and emergency procedures. On rare occasions, these risk controls will be breached and an accident will result, or the consequences associated with an accident will become more severe (Walker & Bills, 2008).

an important role in allowing airline and airport operators to evaluate and discuss the benefits and challenges of implementing both preventative and recovery risk controls, and for aviation safety regulators to gain a better awareness of the operational issues associated with different risk controls.

1.2 Objectives

The purpose of this study was to provide an international and Australian perspective on runway excursion accidents involving commercial jet aircraft.

This study is divided into two parts, published as two separate reports:

- Part 1 of this study (Taylor et al, 2009), published in April 2009, explored the contributing factors associated with runway excursions of commercial jet aircraft through the analysis of accidents between 1998 and 2007.
- Part 2 (this report) discusses the impact of runway excursion accidents on communities located near airports across the world, and the risk controls that have been or could be put in place to minimise the likelihood of an excursion occurring, or mitigate its consequences if one did occur, with a particular focus on Australia.

Specifically, the objectives of this report (Part 2) were to:

- discuss the impact of serious runway excursion accidents in the Australian context;
- explore preventative risk controls that could assist airline operators to reduce the occurrence of runway overruns and veer-offs;
- explore recovery risk controls that could assist airport and airline operators to reduce the physical damage often associated with these accidents; and
- identify what recovery risk controls are provided at Australian airports to safely control a runway overrun if it does occur, by means of a survey of airport operators.

This report serves to provide a discussion of the prevalence, likelihood, and associated consequences of runway excursions of commercial jet aircraft both in Australia and internationally. It intends to identify current measures that regulators, aircraft manufacturers, airport and airline operators have in place internationally, and particularly in Australia, to minimise the likelihood and consequences of these accidents. The discussion extends to identifying additional preventative and recovery risk controls that can be implemented by actors to minimise runway excursions and their negative effects.

Not all risk controls are necessary or appropriate for all airports. Due to the diverse Australian operating environment (in terms of movement activity, aircraft mix, approach terrain, environs, and climatic conditions), a risk management approach which adopts the best-fit preventative and recovery risk controls for each airport is the most appropriate way to minimise the risk of runway excursions. In terms of recovery risk controls, it is important to note that airports are not safety deficient by not having all of these risk controls in place. This report reviews all of the important recovery risk controls available throughout the world that can be possible options for airport operators to help mitigate the serious consequences of runway excursions.

1.3

Scope

This report focused on runway excursion accidents (both runway overruns and runway veer-offs) for larger commercial jet aircraft, focusing on excursions during the landing phase.

Worldwide, runway excursion accidents have resulted in a large number of fatalities over the years. This has been particularly evident by the recent spate of accidents that have occurred internationally involving commercial jet aircraft. These include:

- an overrun of a Airbus A320 aircraft at Tegucigalpa, Honduras on 30 May 2008 that resulted in five fatalities;
- an overrun of a McDonnell Douglas MD-82 aircraft at Phuket, Thailand on 16 September 2007 that resulted in 90 fatalities;
- an overrun of a Airbus A320 aircraft at Sao Paulo, Brazil on 17 July 2007 that resulted in 199 fatalities; and
- an overrun of a Boeing 737-400 aircraft at Yogyakarta, Indonesia on 7 March 2007 that resulted in 22 fatalities.

Due to the sizable number of potential fatalities associated with runway excursions involving commercial airlines, this report focused on accidents involving commercial jet aircraft only.

Furthermore, previous research has indicated that 33 per cent of fatal accidents and 22 per cent of fatalities involving the worldwide commercial jet aircraft fleet occur during the final approach and landing phases of flight. Of these, 24 per cent of the fatal accidents occurred during landing, and 11 per cent of the fatalities (Boeing, 2008). Runway excursions during the take-off phase normally occur after high-speed rejected takeoffs, and while not uncommon, the majority happen at lower speeds than those during the landing phase, and hence present a lower risk of injury to occupants and damage to the aircraft or surrounding infrastructure (van Es, 2005). Consequently, this report predominately focused on runway excursion accidents that occurred during the landing phase of flight, rather than at takeoff.

This report excluded runway excursion accidents involving:

- smaller jet aircraft (International Civil Aviation Organization Aeroplane Design Group Code A and B or FAA Code I and II)⁶;
- reciprocating and turboprop-powered aircraft⁷;
- private and military aircraft;
- Eastern-built or Commonwealth of Independent States-built aircraft.⁸

⁶ These aircraft have a wingspan of less than 24 m, and have been excluded as the vast majority of commercial jet aircraft have a wingspan of greater than 24 m.

⁷ A September 2005 review by the Nationaal Lucht- en Ruimtevaartlaboratorium (Dutch National Aerospace Laboratory) of 400 runway excursion accidents that occurred worldwide between 1970 and 2004, determined that the difference in the landing runway excursion accident rate between jet-powered and turboprop-powered aircraft was not statistically significant at a 5 per cent confidence level (van Es, 2005).

⁸ Operational and accident data was limited for these aircraft types (Boeing, 2008).

- taxiway excursions, which occur at low speed and are unlikely to cause serious injury or significant aircraft damage.

In this report (Part 2), Australian airport operators were surveyed to identify what recovery risk controls were provided to safely control a runway overrun if one occurred. This survey was limited to:

- airports which received high-capacity jet regular public transport (RPT) or charter services in 2007, or had the capability to receive such services; and
- airports with Code 3 and 4 runways, as defined by International Civil Aviation Organization (ICAO) Annex 14 *Aerodrome Design and Operations*, and the Australian Civil Aviation Safety Regulation (CASR) 139 *Manual of Standards – Aerodromes*.

Code 3 and 4 runways are defined in ICAO Annex 14 as those runways which are 1,200 m (3,937 ft) or longer. Code 3 runways are between 1,200 and 1,799 m (5,902 ft) in length. Code 4 runways are all runways longer than 1,800 m (5,905 ft) (ICAO, 2004).

Code 1 and 2 runways (runways less than 1,200 m in length) were excluded from this survey as these runways generally are not serviced by high-capacity jet-powered aircraft.

2.1 Data sources

Runway excursion data, 1998 to 2007

The runway excursion accidents analysed in this series of reports involved commercial jet aircraft that were sourced from the Ascend⁹ *World Aircraft Accident Summary Issue 147* (WAAS) for the period 1 January 1998 to 31 December 2007. Researched and published on behalf of the United Kingdom Civil Aviation Authority (CAA), this data represents all known runway excursion accidents for commercial jet aircraft over this period.

Analysis of the Ascend data identified 141 runway excursion accidents over this period. Of those accidents, 120 were associated with the landing phase of flight and so form the primary focus for this report. The remaining 21 accidents occurred when the aircraft was in the take-off phase of flight. A full list of the 141 accidents can be found in Appendix B of Part 1 of this report series (Taylor et al, 2009).

Further details regarding each accident identified in the Ascend data were obtained from the following sources:

- the Australian Transport Safety Bureau (ATSB) aviation accident and incident database and safety investigation reports;
- accident investigation reports published by the United States National Transportation Safety Board (NTSB), the Transportation Safety Board of Canada (TSB), the National Transportation Safety Committee of Indonesia (NTSC), and other international aviation safety investigation bodies; and
- Ascend WAAS.

Hull loss and fatality rate data

Commercial aircraft hull loss data and fatality rates for all accident types between 1998 and 2007 were sourced from the International Air Transport Association (IATA), and from the Boeing *Statistical Summary of Commercial Jet Airplane Accidents, Worldwide Operations, 1959–2007*.

Movement data

Movement data for major Australian airports during 2007 was sourced from the Bureau of Infrastructure, Transport and Regional Economics (BITRE) publication *Aviation Statistics, Airport Traffic Data, 1997-98 to 2006-07*.

Airport runway and environment data

Runway declared distances for Australian Code 3 and 4 runways were sourced from the electronic edition of the En Route Supplement Australia (ERSA), which is maintained by Airservices Australia.

⁹ Ascend is a division of Airclaims.

Airport environment data, specifically the proximity of development to airports, was sourced from Google Earth satellite imagery. Distances are approximate only, and are measured from the end of each runway threshold and along the extended runway centreline.

Survey of Australian airport operators

A telephone survey was conducted of the operators of all Australian airports that had one or more Code 3 or 4 runways and received high-capacity jet regular public transport (RPT) or charter services in 2007, or had the capability to receive such services.¹⁰ A list of operators contacted is provided in Appendix A. A list of the 43 airports¹¹ involved appears in Appendix B.

Airport operators were asked to provide the measured length of the runway end safety areas (RESAs) at each Code 3 or 4 runway, as measured from the end of the 60 m runway strip which abuts the threshold end.

This data was collected between February 2008 and June 2008. Where airport operators indicated that construction works were currently underway to alter the RESA length, this was noted in Appendix B. Also noted were any obstacles reported by the airport operator that would be likely to limit further RESA improvement works in the future.

Prior to 2003, RESA requirements were governed by the Civil Aviation Safety Authority (CASA) Rules and Practices for Aerodromes (RPA) Chapter 7 – *Design Standards for Licensed Aerodromes*. Under the previous standard, the 90 m requirement for RESA length was measured from the end of the runway or any associated stopway. Under the new ICAO-based definitions where the RESA is measured from the end of the 60 m runway strip, this would make a RESA of only 30 m in length.

As a result, some airport operators quoted the RESA length as measured from the runway threshold or end of any associated stopway (previous standard). In cases where this was identified, the reported RESA length was adjusted to start from the end of the 60 m runway strip (current standard as of 2009).

While all efforts have been made to ensure this data is correct, the RESA lengths provided in this report should be taken as a guide only. For the most current RESA data, contact the airport operator directly.

Engineered Materials Arresting System (EMAS) performance

Actual and estimated performance data for the Engineered Materials Arresting System (EMAS) provided in this report was determined through simulated overrun trials conducted by the Federal Aviation Administration (FAA), and computer modelling by the manufacturer of the EMAS system (Engineered Arresting Systems Corporation of Logan Township, New Jersey).

¹⁰ Although the ATSB contacted the operators of all airports that were identified as meeting these criteria, it was unable to survey an appropriate representative of one airport operator: Hervey Bay.

¹¹ Data for Gladstone Airport is also included in Appendix B. It was not included in the 2008 survey of 43 airports, however, in 2009 Gladstone Airport is commencing runway works to allow jet RPT operations.

It is important to note that EMAS performance data was based on FAA requirements for runway safety areas (RSAs) in the United States. These requirements differ significantly from the Australian requirements for RESAs.

EMAS performance data has not been verified by the ATSB or CASA, and is presented in this report only as an example to illustrate the arresting capabilities of soft ground arrestor bed systems.

3

RISKS ASSOCIATED WITH RUNWAY EXCURSION ACCIDENTS

Runway excursion accidents may result in damage to aircraft and airport property. In some cases, they have also resulted in serious or fatal injuries to crew, passengers, airport workers, and people living, working or travelling near airports. Of the 141 worldwide commercial jet runway overruns and veer-offs recorded in the Ascend World Aircraft Accident Summary between 1998 and 2007, there were 550 fatalities, and many thousands of minor injuries (Ascend, 2007).

Previous runway excursion accidents, such as the overrun of a Boeing 737-700 at Chicago Midway Airport in 2005 (discussed in Part 1 of this series), have shown that these accidents can also have tragic and costly impacts on communities close to airports. This chapter will discuss the risks that runway overruns in particular can pose to people living, working and travelling beyond the end of runways.

3.1 Where do aircraft stop following a runway excursion?

The 120 runway excursion accidents between 1998 and 2007 identified in the Ascend World Aircraft Accident Summary that involved commercial jet aircraft on landing, were analysed to identify where aircraft stopped after the overrun or veer-off, the extent of damage to the aircraft, and the extent of damage on the ground. Aircraft damage ranged from minor scrapes and foreign object damage through to undercarriage collapses and post-impact fires. Ground damage included damage to antennas and nav aids, airport fences and lighting installations, through to collisions with buildings and vehicles.

The final position of the aircraft or wreckage after the excursion was available for 43 excursions: 35 overruns (out of 72) and eight veer-offs (out of 48). For overrun accidents, the approximate distance beyond the end of the runway (along the extended centreline) was recorded. In three overruns, both the lateral and longitudinal deviation from the end of the runway was known and recorded. For most of the overruns, however, the distance along the centreline was known but not the distance from the centreline. In these cases for the purposes of Figure 1 and Figure 2, only the overrun distance along the extended centreline was recorded. For veer-offs, the distance that the aircraft travelled to the left or the right of the runway centreline was recorded.

This analysis is limited by the paucity of the data on lateral location of the final position of the aircraft or wreckage after the excursion. Figure 1 and Figure 2 depict the final resting position (where known) of the aircraft along the extended runway centreline (longitudinal location), and present a simplified view of the lateral location of the final position from the extended centreline.

Some other studies of runway excursion data, particularly an analysis by Kirkland and Caves (2002) of 180 turboprop and jet aircraft overruns on takeoff and landing, provide a more complete analysis of lateral deviation of overrunning aircraft from the extended centreline (See *Other analyses* on page 14).

In each figure, the dark grey box indicates the runway (a 45 m wide runway is shown as an example of a typical runway width used by commercial jet aircraft). The remaining boxes show the position of each aircraft relative to various

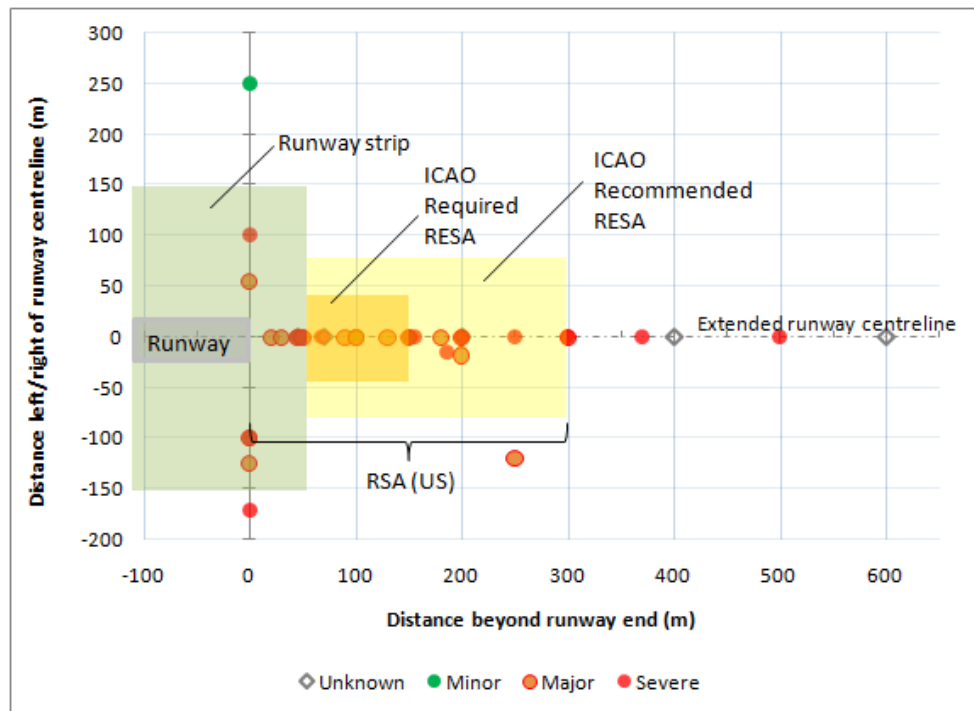
international standards for recovery risk controls that are used at many airports to limit damage and injury if a runway excursion does occur. The green box represents the runway strip and flyover area, which extends 60 m beyond the runway end. The dark yellow box represents the basic runway end safety area (RESA) mandated by the International Civil Aviation Organization (ICAO) and Civil Aviation Safety Authority (CASA), which extends for 90 m past the runway strip. The light yellow box indicates the ICAO-recommended RESA area, which extends 240 m beyond the end of the runway strip. Finally, the light grey box indicates the runway safety area (RSA) required by the FAA at airports in the United States. Chapter 5 discusses each of these areas in more detail, and their importance as runway excursion risk controls.

This analysis of final aircraft position shows that 90 per cent (n=39) of aircraft stopped within 300 m of the end of the runway, and that 81 per cent (n=35) stopped within 200 m of the end of the runway. Most aircraft also stopped within the bounds of the mandated or recommended safety areas. It should be noted that none of the accidents involved ice affected runways, and only four involved runways that were snow affected. The snow-related overrun distances ranged between 45 and 180 m.

Figure 1 shows final resting positions and the extent of damage to the aircraft in each of the 43 accidents analysed in this study. Aircraft damage was known for 38 excursions. Damage was coded (from either summary text accompanying each accident, or investigation reports where available) as:

- **Minor** – no structural damage to the airframe or landing gear was reported. Foreign object damage to the engines, undercarriage, and tyres were classed as minor damage;
- **Major** – partial undercarriage collapse, ground strike of wing or engine, minor structural damage to the fuselage; and
- **Severe** – complete collapse of the undercarriage, separation of engines, structural failure of the fuselage, post-impact fire.

Figure 1: Aircraft damage analysis and final stopping position from the runway end for 43 runway excursion accidents, 1998 to 2007

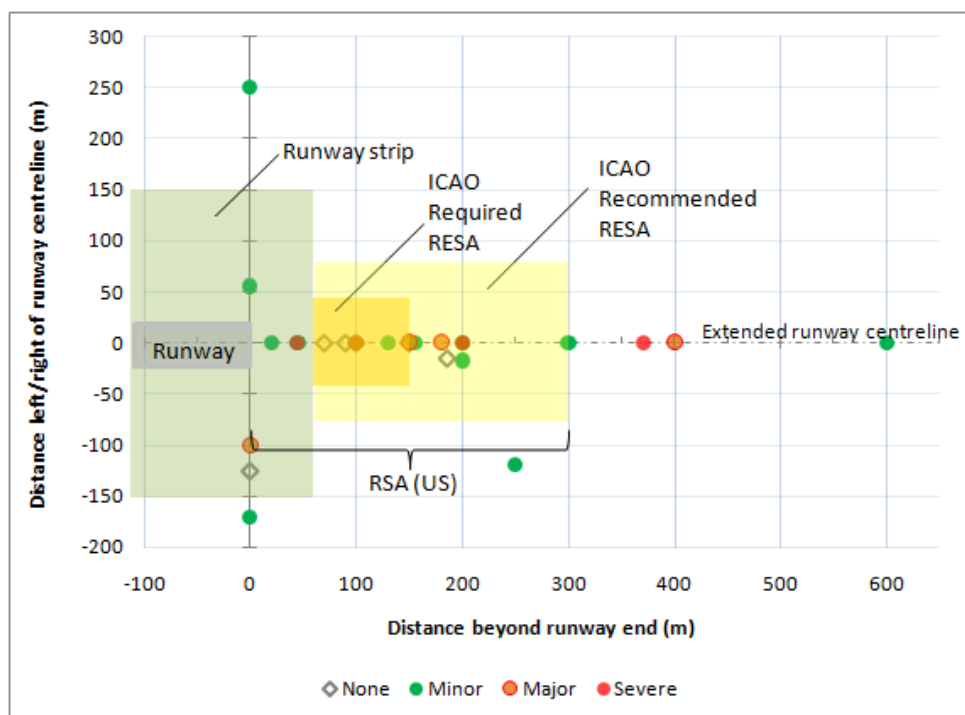


Due to the importance of aircraft damage assessment to determining insurance claims after an accident, Ascend also records the aircraft damage as a percentage. This information is useful in identifying how serious aircraft damage was in each accident, as it shows which aircraft were assessed as a hull loss. Half ($n = 64$) of the 120 runway excursion accidents recorded between 1998 and 2007 resulted in a damage rating by Ascend of 50 per cent or more. In 47 of these accidents, the aircraft was totally destroyed and assessed as a hull loss (Ascend, 2007).

Figure 2 shows the location and extent of ground damage caused for each accident where the ground damage was known (28 of the 43 accidents). The ground damage was coded from summary text accompanying each accident and investigation reports where available:

- **None** – no non-aircraft damage occurred/was reported;
- **Minor** – substantial damage to the runway strip, RESA or arrestor bed surfaces, and/or minor damage to airport infrastructure such as antennas, internal roads, or fences. Aircraft may impact and damage terrain obstacles such as ravines and drainage channels. No damage to airport perimeter fences or off-airport property;
- **Major** – aircraft impact with and significant damage to major airport infrastructure such as approach light stanchions, nav aids, instrument landing system (ILS) arrays, water tanks, buildings and hangars. No damage to airport perimeter fences or off-airport property; and
- **Severe** – aircraft overruns through airport perimeter fence and impacts off-airport property such as houses, warehouses, roads, vehicles and petrol stations.

Figure 2: Ground damage analysis and final aircraft stopping position from the runway end for 28 runway excursion accidents, 1998 to 2007



Other analyses

The analysis of the World Aircraft Accident Summary data agreed with several other recent studies of the distance travelled by aircraft that overrun or veer off the runway on takeoff and landing.

- Federal Aviation Administration (FAA) and National Transportation Safety Board (NTSB) studies of long-term runway excursion data have found that the overwhelming majority (90 per cent) of overrunning aircraft exit the end of the runway at 70 kts or less. Most aircraft come to rest within close proximity to the extended runway centreline, and within 1,000 ft (305 m) of the runway end (FAA, 2005).
- A 2003 analysis of 37 turboprop and jet aircraft runway overruns in the United States between 1982 and 1999, found that 31 came to rest within 1,000 ft (305 m) of the runway end. Most (29 aircraft) also stopped within the extended runway centrelines (JDA, 2003a).
- Several analyses by Kirkland et al from 2002 to 2004 of 180 turboprop and jet aircraft overruns that occurred on takeoff and landing in English-speaking countries between 1980 and 1998; found that 95 per cent of the aircraft (171) stopped within 1,000 ft (305 m) of the runway end. Only three aircraft veered more than 250 ft (75 m) left or right of the extended centreline.

For overruns where the aircraft also veered off the extended runway centreline, 95 per cent of these 180 aircraft (n=171) stopped within 1,000 ft (305 m) of the runway end. Of the 137 aircraft identified in that study that overran the end of the runway during landing, approximately 14 per cent (n=19) came to rest further to the left or right of the extended centreline

than the width of a typical runway¹² (more than 22.5 m to the left or right of the extended centreline). In these cases, recovery risk controls such as soft ground arrestor beds (discussed further in Chapter 5) would probably not be effective in decelerating these aircraft. Only three aircraft in that study veered more than 250 ft (75 m) left or right of the extended centreline, placing them outside of the bounds of the ICAO-recommended RESA area (Kirkland & Caves, 2002; Kirkland et al, 2003; Kirkland et al, 2004).

- A 2008 analysis of 257 overrun accidents and incidents in the United States, Canada, Western Europe, Oceania and selected Asian countries between 1982 and 1996 involving turboprop and jet aircraft, found that 95 per cent of aircraft stopped within 1,000 ft (305 m) of the runway end. Of the 141 accidents where the lateral deviation from the extended runway centreline was known, 94 per cent stopped within 250 ft to the left or right of the centreline (Hall et al, 2008).

3.2 Implications for communities and developments near airports

3.2.1 Risks to the public

Most runway excursions are relatively minor, involving little or no damage to the aircraft and no serious injuries to crew or passengers. In fact, all of the on-board fatalities that occurred in runway excursions between 1998 and 2007 involved just 13 of the 141 recorded accidents (Ascend, 2007). Experience has shown, however, that some runway excursions, and overruns in particular, can pose a great risk to communities surrounding airports, or people who travel in close proximity to airports.

- Impact damage will occur if the aircraft overruns the airport perimeter and into road traffic, houses, businesses or other infrastructure/built-up land. There are many major airports in the world where arterial roads, freeways or densely-populated urban areas lie within 300 m of the end of a runway.
- There is a risk of post-impact fire and associated hazardous fumes from burning fuel, structures, equipment and furnishings. The Flight Safety Foundation (FSF) Approach and Landing Accident Reduction (ALAR) Task Force found that post-impact fires occurred in 46 per cent of all approach and landing accidents (Khatwa & Helmreich, 1999).

For example, the 2005 overrun of a Boeing 737-700 aircraft at Chicago Midway Airport resulted in a child in a passing car being killed when the aircraft came to rest on a nearby road intersection and collided with several vehicles. Similarly, Figure 3 shows another excursion accident in which a Boeing 737 aircraft overran the runway at Burbank-Glendale-Pasadena Airport in 2000, passed through the airport perimeter fence and came to rest a few metres from a petrol station (USA Today, 2005).

¹² Based on a runway width of 45 m, which is typical for a Code 3 or 4 runway.

Figure 3: Boeing 737-300 overrun accident at Burbank-Glendale-Pasadena Airport, California, 5 March 2000



Source: Aviation Safety Network

3.2.2 Implications for development near airports

At many major airports worldwide, especially those in urban areas, space is at a premium. Land use pressures exist from nearby roads, building projects and urban expansion, and non-aeronautical business activities on airport land (such as shopping centres and business parks). The result of this pressure is often that the provision for clearways and RESAs is limited. These areas provide a flat, graded strip of land at the end and sides of the runway to decelerate an aircraft if it overruns or veers off. Less than adequate clearways and RESAs have been a latent failure point in numerous catastrophic runway overruns in particular, and have led to significant ground fatalities and damage to infrastructure. An example was the Airbus A320 overrun that occurred at Sao Paulo, Brazil in 2007, where the aircraft passed over a major road after overrunning the airport perimeter, and collided with a cargo warehouse causing a large fire. This accident was discussed in greater detail in the first report in this series.

The Civil Aviation Safety Authority (CASA), the FAA, and ICAO are among the regulatory authorities that have introduced regulations in recent decades that require airports to provide defined clearway and RESA areas¹³. Many airports worldwide were built prior to the existence of such regulations, and hence, in order to meet current standards, have needed additional construction works beyond the runway ends to provide the required grade of land.

In some cases, airports are unable to meet the RESA requirements due to the limitations of the surrounding built environment (as was the case in Sao Paulo). In these cases, other solutions need to be found to minimise the possible consequences of runway overruns (discussed in Sections 5.2 and 5.3.6).

¹³ In the United States, a RESA is called a runway safety area (RSA).

3.3 What about Australia?

3.3.1 Runway excursions

High capacity air transport

Australia has not yet experienced a serious runway excursion accident to the level of those that have occurred overseas (such as those highlighted in Section 1.3). This can be attributed to a number of factors, including the positive safety cultures of local aircraft operators, airport owners and managers, and regulators, investment in safety infrastructure and runway works at Australian airports, a smaller number of commercial jet aircraft movements than many overseas countries, and a lower prevalence of conditions such as ice and snow that can increase the likelihood and consequences of a serious runway overrun.

Australian high capacity operators, however, have not been immune from runway excursions.

In the 10 years between 1998 and 2007, there has been one accident¹⁴ and two serious incidents¹⁵ involving runway excursions of Australian-registered high-capacity regular public transport (RPT) aircraft. These occurrences were discussed in detail in Part 1 (Taylor et al, 2009). Briefly, these occurrences were:

- On 23 September 1999, a Boeing 747-400 aircraft overran runway 21L while landing at Bangkok International Airport, Thailand. The aircraft landed long and aquaplaned on a runway that was affected by water following very heavy rain, and was not stopped before the runway end. The runway was not grooved, was not equipped with centreline lighting, and was not coated with a high friction surface treatment (porous friction concrete). The aircraft suffered substantial damage after overrunning the runway at 96 kts, colliding with an instrument landing system (ILS) localiser antenna that initiated the collapse of the nose and right wing landing gear. This allowed the aircraft to adopt a slight right wing low attitude, resulting in the right inboard and outboard engine nacelles contacting the ground. The aircraft eventually came to rest on a road 220 m from the end of the stopway. No one on board reported any serious injuries (ATSB, 2001a).
- On 11 June 2002, a Boeing 737-800 aircraft overran runway 29 at Darwin International Airport at night following an unstabilised approach, and came to rest 44 m into the 90 m runway end safety area. There were no injuries, and the aircraft was not damaged. This serious incident was investigated by the ATSB (ATSB, 2004).

¹⁴ Accidents are defined by the International Civil Aviation Organization Annex 13 as occurrences where: a person is fatally or seriously injured; the aircraft sustains damage or structural failure (which affects structural strength, performance or flight characteristics, or requires major repair or replacement); or the aircraft is missing or inaccessible.

¹⁵ A serious incident is defined by the International Civil Aviation Organization Annex 13 as ‘an incident involving circumstances indicating that an accident nearly occurred.’ An incident is defined as an occurrence, other than an accident, associated with the operation of an aircraft that affects or could affect the safety of operation.

- On 19 February 2003, a Boeing 737-300 aircraft landed at night on runway 29 at Darwin International Airport following a normal, stabilised approach. The aircraft touched down close to the right edge of the runway and veered off the sealed runway surface. The captain returned the aircraft back to the runway during the landing roll. There were no reported injuries to the passengers or crew. The aircraft sustained minor damage from the ingestion of grass and fragments of the runway edge lights into the engines. The serious incident was investigated by the ATSB (ATSB, 2005a).

During the same 10-year period, there were also two runway excursions in Australia involving foreign-registered high capacity RPT aircraft (one serious incident and one incident¹⁵).¹⁶

- On 1 November 2000, a Chinese-registered Airbus A340-300 aircraft operating from Shanghai, China, to Sydney, experienced a loss of directional control on the runway after touchdown. Despite the captain applying full manual braking in addition to reverse thrust, the aircraft yawed rapidly to the right, coming to rest with the nose landing gear 16 m beyond the runway edge. None of the passengers or crew were injured (ATSB, 2001b).
- On 25 January 2005, a Sierra Leone registered Boeing 727-51C aircraft, operating as a cargo flight from Cairns to Brisbane, experienced a loss of directional control during the landing roll. Despite coordinated use of differential braking by the captain and first officer, the aircraft veered off the right edge of the runway at a speed of between 60 and 70 kts, coming to rest about 40 m from the runway edge. The aircraft was not damaged, and none of the crew were injured (ATSB, 2005b).

On 27 July 2008, a runway veer-off serious incident involving an Australian-registered Embraer ERJ170-100LR, operating as a high capacity RPT operation with 50 people on board, occurred at Honiara Henderson International Airport, Solomon Islands. Following a flight from Brisbane, the crew first attempted to land on runway 24 at Honiara, but conducted a missed approach due to an excessive tailwind. The second attempt at landing was on runway 06 during heavy rain and reduced visibility. The aircraft landed on the right edge of the 45 m wide runway with the outer wheels of the main right landing gear touching down off the paved runway. The captain reported that the aircraft then aquaplaned to the right on standing water on the runway. After 26 m, both of the main right wheels departed the paved surface for 700 m, striking and destroying two runway lights, before the aircraft was returned to the paved surface. The aircraft sustained damage to both of the main right landing gear tyres. Runway edge and threshold lighting was installed and operating at the time of the serious incident. The runway was not grooved (Solomon Islands Ministry of Culture, Tourism and Aviation, 2009).

While there have not been any catastrophic excursions of large jets in Australia and/or involving Australian aircraft, the prevalence of both relatively minor excursion incidents in Australia and more significant excursion accidents overseas in the last 10 years serves as a timely reminder there is always a risk that one could occur. This said, airline and airport operators in Australia provide measures to

¹⁶ From 1998 to 2007, there were also two taxiway excursions involving foreign-registered high capacity RPT aircraft at Melbourne Airport, and two taxiway excursions involving Australian-registered high capacity RPT aircraft at Christchurch Airport, New Zealand.

reduce the likelihood of an excursion occurring (such as go-around/missed approach procedures, runway grooving, centreline lighting, and high friction runway surface treatments), as well as risk controls for any aircraft that overrun or veer-off the runway (such as runway strips and runway end safety areas). These and other measures are discussed throughout this report.

Low capacity air transport and general aviation

While this report focuses on runway excursions of commercial jet aircraft, excursions involving general aviation (GA)¹⁷ and low-capacity passenger transport¹⁸ aircraft are a much more common safety occurrence in Australia. Over the same 1998 to 2007 period, 425 runway excursions were reported to the ATSB. Those incidents involved both Australian VH-registered aircraft and foreign-registered aircraft operating at Australian aerodromes.

- At least 30 per cent (n = 130) involved aircraft engaged in private operations.
- 27 per cent (n = 115) involved aircraft engaged in flying training operations.
- 19 per cent (n = 80) involved aircraft engaged in business and charter operations.
- Five per cent (n = 20) involved aircraft engaged in low-capacity RPT operations.
- Another five per cent (n = 18) involved aircraft engaged in aerial work.

Another 44 runway excursion occurrences (10 per cent) did not have the operation type recorded, but a review of the aircraft type involved strongly suggests that almost all these aircraft were engaged in private or flying training operations.

The remaining incidents were aircraft engaged in sport aviation, military, or other operations.

3.3.2 Australian airport environs

Table 1 summarises the proximity of the built environment surrounding major Australian airports to runway ends, as measured along the extended runway centrelines.

Airport environment data, specifically the proximity of development to airports, was sourced from Google Earth satellite imagery. Distances are approximate only, and are measured from the end of the threshold at each runway end, along the extended runway centreline. For the most up-to-date information on individual airports, contact airport operators directly.

¹⁷ GA aircraft are those involved in non-scheduled flying activity, such as charter, private, agriculture, flying training, and aerial work. Aircraft such as gliders, ultralights, gyroplanes and balloons are not included in GA, but form a separate category called sport aviation.

¹⁸ Low capacity passenger transport aircraft are those aircraft involved in scheduled transport of passengers or cargo with a maximum of 38 passenger seats and a maximum takeoff weight of no greater than 4,200 kg.

All airports in Australia that have Code 3 and 4 runways are equipped with controls to minimise the likelihood of a runway excursion occurring, and to reduce the likelihood of severe consequences if one did occur. The majority have grooved runway surfaces to assist drainage and reduce the risk of aquaplaning in wet weather. This includes at least the primary runway at all international airports and many domestic airports. All airport operators with Code 3 and 4 runways in Australia have undertaken (or are currently undertaking) construction works to ensure RESAs meet the requirements of CASR 139 *Manual of Standards* (discussed further in Section 5.2.3).

Full runway data for Australian airports with Code 3 and 4¹⁹ runways is provided in Appendix B. This list also identifies design features to minimise the likelihood of runway excursion accidents, such as runway surface grooving/texturing and RESAs.

¹⁹ Code 1 and 2 runways (runways less than 1,200 m in length) were excluded, as these runways generally are not serviced by high-capacity commercial jet aircraft.

Table 1: Built environment and movement data for major Australian airports

Airport (ICAO code)	Large jet landings (2007)	Number of Code 3/4 runways²⁰	Proximity of built-up urban areas to airport location²¹
Adelaide (YPAD)	22,646	4	Immediately adjacent to major arterial roads and inner residential suburbs (approximately 400 m from closest threshold)
Brisbane (YBBN)	57,990	4	Urban fringe/industrial area (approximately 2,350 m from a major arterial road)
Cairns (YBCS)	14,451	2	Immediately adjacent to major highway, dense mangroves and large creeks (approximately 130 m from closest threshold)
Canberra (YSCB)	9,360	2	Urban fringe area, adjacent to major roads (145 m from closest threshold)
Darwin (YPDN)	5,837	4	Immediately adjacent to major highway and light industrial suburbs (approximately 280 m from closest threshold)
Gold Coast (YBCG)	13,627	2	Immediately adjacent to major freeway, suburbs, and a desalination plant (approximately 250 m from closest threshold)
Hobart (YMHB)	6,160	2	Outer urban fringe, adjacent to major highway (approximately 450 m from closest threshold)
Melbourne (YMML)	70,895	4	Urban fringe area, adjacent to major freeway (approximately 590 m from closest threshold)
Perth (YPPH)	23,626	4	Adjacent to major freeways and outer suburbs (approximately 880 m from closest threshold)
Sydney (YSSY)	93,984	6	Immediately adjacent to major freeways, open water, residential and industrial suburbs (approximately 100 m from closest threshold)
Townsville (YBTL)	3,948	2	Adjacent to highway and industrial suburbs (approximately 500 m from closest threshold)

Source: Bureau of Infrastructure, Transport and Regional Economics (BTRE, 2007), Google Earth

Serious runway excursion accidents clearly have the potential to pose consequences to public safety and infrastructure if adequate and reliable risk controls are not in place. It is imperative that preventative risk controls are put in place by airline and airport operators to minimise the likelihood of an aircraft leaving the runway in the first place, through flight operations procedures and policies that reinforce safe approaches and landings, and high quality runway surfaces (see Chapter 4). Runway excursion risk has been reduced in Australia through the positive safety cultures of local aircraft operators, airport owners and managers, and regulators, government and private investment in safety infrastructure and runway works at

²⁰ Only ICAO Code 3/4 runways that usually handle commercial jet aircraft landings and takeoffs are listed.

²¹ Distances are approximate only, and are measured from the threshold end along the extended runway centreline.

Australian airports, and a lower prevalence of conditions such as ice and snow that can increase the likelihood and consequences of a serious runway overrun. Despite the strong preventative risk controls that are in place, the close proximity of suburbs and other infrastructure to some Australian airports, and the sheer number of landings at each, illustrates the potential for a serious runway overrun to cause major damage if such preventative risk controls were to fail. Sydney and Adelaide airports are located in particularly built-up urban areas. Operators of these and other airports should consider the cost versus the long-term safety benefit of recovery risk controls, considering the relative consequences of excursion accidents.

Taking Sydney International Airport as an example, there are between 300 and 3,000 people living in close proximity to the runway ends (within the Airservices Australia Australian Noise Exposure Forecast (ANEF²²) contour band of 30 or more ANEF units) (Airservices Australia, 2007a). In addition, there are tens of thousands of vehicles that travel every day on the M5 East, General Holmes Drive, and Princes Highway. These and other nearby arterials are adjacent to the airport boundary, or pass across the extended runway centreline.

In Australia, airport and airline operators, as well as regulators, are aware of the possible consequences of runway excursions, and as a result, numerous defences are in place to protect the Australian travelling public. Chapter 4 discusses a variety of preventative risk controls that are used to reduce the likelihood of factors that contribute to the frequency of runway overruns and veer-offs, and reduce the consequences if an excursion does occur. Chapter 5 identifies a number of recovery risk controls that are in place at airports in Australia and overseas to minimise the consequences to life and property if a serious runway excursion does occur. Additionally, an important safety mechanism exists in Australian aviation through professional industry forums and working groups, such as the Australian Airports Association and Regional Aviation Association of Australia, which provide an avenue for major airline, airport operator, and safety regulator representatives to maintain, evaluate, and improve risk controls and other safety standards. Professional forums such as these that allow frank and open discussion between regulators and operators do not always exist in other countries.

²² The ANEF system is an equal energy noise index, used to measure the relative noise around airports in Australia. The system, administered by Airservices Australia, is used as a land use planning tool to control encroachment on airports of noise-sensitive buildings (such as houses, schools and hospitals).

ANEF units are dimensionless numbers (not decibels). For example, areas near airports where the ANEF value is 20 or less are suitable for new residential dwellings (Department of Transport and Regional Services, 2000). Areas with ANEF values of 30 or higher generally describe airport land itself, land in the immediate vicinity of the airport perimeter, and land under the runway final approach paths.

The need to prevent runway excursions has led to the development of a number of safeguards to help minimise the likelihood of runway excursion accidents, and help reduce the consequences of excursions that do occur through minimising the speed at which aircraft exit the runway surface in cases when aircraft do overrun.

These preventative risk controls are the most important defence mechanisms against runway excursion accidents. Airline operators, flight crew, aviation safety regulators, and airport operators all have a role to play in implementing these risk controls.

The role of the airline and flight crew

For flight crew and airline operators, this chapter will discuss the importance of:

- Effective standard operating procedures – conducting threat and risk briefings prior to landing, reinforcing safe approach and landing techniques (including stabilised approaches), guidance on correct use of braking devices, and a firm ‘safety first’ operator policy on missed approaches and go-arounds.
- Effective flight crew training and risk awareness – dangers of unstabilised approaches, factors that increase the likelihood of a runway overrun or veer-off, identifying and managing safety risks, simulator training of missed approach and go-around procedures.
- Good operator risk awareness – ‘safety first’ focused review of policies affecting flight crew and maintenance personnel.

Improving awareness of the dangers, frequency and contributing factors behind runway excursions through preventative risk controls, will reduce the likelihood of excursion accidents occurring. The aim of preventative safeguards is to assist flight crew to *anticipate* safety risks, *recognise* risks when they occur, and *recover* from these risks to ensure a safe outcome. The first report in this series (Taylor et al, 2009) looked in detail at what safety risks contribute to both runway overruns and veer-offs, and their prevalence in 120 runway excursions on landing worldwide between 1998 and 2007.

The international aviation community is working to increase awareness of runway excursions, address the factors that contribute to them, and develop physical measures to reduce the consequences of excursion accidents that do happen. The Runway Safety Initiative (RSI) is a wider, international effort to improve runway excursion awareness, and is coordinated by the Flight Safety Foundation (FSF). A major task of the RSI is to support and promote existing and ongoing programs by governments, operators, and safety organisations to prevent runway incursions and excursions (Werfelman, 2008). One such program is the FSF Approach and Landing Accident Reduction (ALAR) Task Force, which has developed a series of briefing notes and risk identification and reduction tools aimed at instilling safer flight crew behaviours and clearly identifying safety risks that exist during the approach and landing phases of flight.

The FSF ALAR Task Force identified some of the key preventative risk controls that will control the flight crew performance, technique and decision, weather, and systems-related factors that contribute to runway excursion accidents (FSF, 2000a).

- A strong operator policy on stabilised approaches, with commitment from all levels of the organisation.
- A focus on establishing stable approach criteria as early as possible.
- Effective monitoring and challenging of approaches by other members of the flight crew.
- A willingness to say ‘no’ to air traffic control (ATC), where the flight crew considers their instructions are unsafe.
- Zero tolerance of deviations from the operator’s SOPs.
- Promotion of the use of precision approach and landings, such as instrument landing systems (ILS). A British study of 180 turbine-powered aircraft overruns between 1980 and 1998 found that the likelihood of an overrun following a precision approach was three times less than for other types of approaches (Kirkland et al, 2004).
- Careful monitoring of performance during visual approaches, and non-precision approaches, such as non-directional beacon (NDB), very high frequency omni-directional range (VOR), and area navigation global navigation satellite system (RNAV(GNSS)) approaches.

For preventative risk controls to provide their full safety benefit, dedicated approach and landing risk training and good flight crew awareness of the implications of runway accidents are needed. The RSI intends to do its part in this effort through ongoing development of its *Global Plan for the Prevention and Mitigation of Runway Excursions*. This document, when completed in 2009, will consist of 20 to 30 briefing notes and supporting data on these and other preventative risk controls, and a discussion of the contribution that constant-angle non-precision approaches, precision, and precision-like approaches can make towards achieving and maintaining a stabilised approach (Werfelman, 2008).

The role of the airport and the regulator

For airport operators, and aviation safety regulators, this chapter will discuss the importance of the following.

- Quality runway design – regular inspection, maintenance and treatment of runway surfaces, friction coatings and bearing strength, and improvement of surfaces through runway grooving or surface texturing.
- Accurate runway condition reporting – greater cooperation between the International Civil Aviation Organization (ICAO) and state civil aviation authorities to develop standards for reporting runway condition information.
- Aiding flight crew awareness of available runway length through runway distance remaining signs (RDRS) installed at regular intervals along the runway edge.
- Runway edge and centreline lighting.

Maintaining good runway friction is the most important preventative risk control that airport operators can put in place to reduce the likelihood of a runway excursion. Inspection and repair of depressions and cracks in the runway surface, and texturing of the runway surface through use of a bask brush/broom²³ or dragged burlap (for concrete runway surfaces), or chip and aggregate slurry seals (for temporary use on asphalt runway surfaces) improves the friction of pavement surfaces (FAA, 1997). Runway grooving is another simple, cost-effective and proven method to drain surface water and improve friction, and in most periods of heavy rain is able to prevent standing water accumulation that can lead to aquaplaning. Grooving and other surface texture treatments are in widespread use at airports in Australia and the United States.

The FSFs *Global Plan for the Prevention and Mitigation of Runway Excursions* will also direct airport operators via briefing notes on the types and roles of various recovery risk controls that can be used to control a runway excursion if one occurs (such as runway end safety areas and soft ground arrestor beds). Recovery risk controls are discussed in detail in Chapter 5. The FSF Plan will also highlight the importance of runway lighting, marking, and signage in assisting flight crews to maintain spatial awareness during approach and landing (Werfelman, 2008).

4.1 Effective standard operating procedures (SOPs)

Well-developed operator SOPs are an important preventative risk control to mitigate runway excursions. A detailed study of 76 approach and landing²⁴ occurrences by the FSF ALAR Task Force in 1998 found that 74 per cent involved poor professional judgement or airmanship, and 72 per cent involved a flight crew omission or inappropriate action. Deliberate non-adherence to SOPs was a contributing factor in 40 per cent of occurrences (Khatwa & Helmreich, 1999).

An analysis of 120 runway excursion accidents on landing between 1998 and 2007 from the Ascend World Aircraft Accident Summary, presented in the first report in this series (Taylor et al, 2009), found that a lack of awareness and compliance with SOPs was the leading flight crew performance factor that contributed to worldwide runway excursions. Also contributing significantly were SOPs that were less than adequate in terms of providing guidance to the flight crew for safe approach and landing techniques in typical weather, runway, and operational conditions. In total, SOP quality and compliance issues contributed to 16 accidents (13 per cent).

Non-compliance with SOPs can be reduced by ensuring they are relevant, provide adequate guidance (and any appropriate limitations) for operating in a range of weather conditions and aircraft configurations, and above all, be focused on the end user - the flight crew. The Federal Aviation Administration (FAA) stipulates that, at

²³ In the United States, the FAA also suggests the use of a wire comb or tine to texture concrete runway surfaces. In the 1970s, the Australian regulator (Department of Civil Aviation, now CASA) issued a safety directive to airport operators not to use wire brooms on runway surfaces, as the wires could let go from the broom and cause a tyre puncture or other foreign object damage.

²⁴ Of the 76 occurrences studied by the FSF, runway excursions were the second most common type of approach and landing accident (20 per cent), after controlled flight into terrain (37 per cent). Unstabilised approaches made up a further eight per cent of occurrences (Khatwa & Helmreich, 1999).

a minimum, operator SOPs should contain the following procedures directly related to runway excursion prevention:

- a requirement to fly stabilised approaches, including procedures for executing a go-around if the approach parameters are outside of the stabilised approach criteria;
- a requirement to conduct a landing distance reassessment at the time of arrival; and
- guidance on the correct use of brakes and other deceleration devices in different runway conditions (FAA, 2007a).

4.1.1 Conducting pre-landing risk and threat briefings

A pre-landing risk and threat briefing can assist flight crew in assessing whether a landing attempt is safe in the prevailing weather and runway conditions, and provide a conservative estimate of landing rollout length prior to arrival that takes these conditions into account. Flight crews should conduct a pre-landing risk and threat briefing. The FSF has recommended that this briefing should take the following factors into consideration, based on the aircraft configuration and the runway condition:

- prevailing weather conditions (winds and gusts, wind shear etc.);
- runway conditions (water-affected, contaminated etc.);
- actual weight of the aircraft upon arrival, especially if fuel burn en route was higher or lower than normal;
- use of braking devices during the landing roll (autobrakes, reverse thrust etc.);
- airport elevation and runway slope; and
- minimum equipment list (MEL) items and dispatch deviation guide (DDG) conditions, or in-flight system failures (if any) (FSF, 2000b).

The pre-landing risk and threat briefing should also identify if conditions exist that might make a landing unsafe. The FSF recommends that SOPs require a diversion to an alternate airport where the runway conditions are more suitable, if:

- the runway is known to be contaminated or is affected by standing water;
- prevailing cross and tailwinds are beyond limits; or
- only one thrust reverser is operational, or an anti-skid system is not fitted to the aircraft (if the runway is wet) (FSF, 2000a; FSF, 2000c).

It is important for flight crews to remember that published landing lengths in aircraft flight manuals (AFMs) are based on flight test conditions, and are not accurate for most real-world operations. It is important for SOPs to provide specific landing distance factors for different operational conditions, and provide guidance so that flight crew know when and how to apply them to the dry runway landing distance published in the AFM (see the first report in this series, Taylor et al, 2009, for typical landing distance factors). The FAA and European Joint Aviation Authorities (JAA) require a minimum factor of 1.67 to be applied to landing distance in dry conditions, and 1.92 in wet conditions (FSF, 2000b).

The Civil Aviation Safety Authority (CASA) have indicated that they will also require similar factors to be applied under Civil Aviation Safety Regulation (CASR) Part 121 when this regulation comes into effect. Part 121 will require operator SOPs to mandate that if a runway is suspected to be wet, flight crews shall ensure that the landing distance available is at least 115 per cent of the required landing distance on a dry runway (and taking other factors that may increase landing distance into account – tailwinds, aircraft configuration and weight, aerodrome altitude etc.). The same factor will also apply for contaminated runway operations (CASA, 2002a).

There are a number of tools available to operators and flight crews that simplify landing distance calculations. The FAA Advisory Circular AC 91-79 *Runway Overrun Prevention* provides pilots and operators with ‘rules of thumb’ for calculating landing distance (Table 2). This includes a worksheet to evaluate the required landing distance (included in Appendix C). The worksheet allows pilots to easily factor in a range of operational and environmental conditions to compute a predicted rollout length prior to landing.

Table 2: FAA ‘rules of thumb’ for landing distance calculations

Condition	Possible effect on landing distance
Unstabilised approach	Unpredictable
Excess airspeed	
- <i>Dry runway</i>	Additional 300 ft per 10 kts
- <i>Wet runway</i>	Additional 500 ft per 10 kts
- <i>Extended flare (floating)</i>	Additional 2,500 ft per 10 kts
Normal airspeed	
- <i>Negative runway slope</i>	Additional 10 per cent of landing distance per one per cent of downhill slope
- <i>Delayed touchdown</i>	Additional 230 ft/sec
- <i>Excessive threshold crossing height (TCH)</i>	Additional 200 ft per 10 ft above TCH (usually 50 ft)
- <i>Delayed braking</i>	Additional 220 ft/sec

Source: FAA, 2007a

4.1.2 Correct approach and landing techniques

Standard operating procedures must reinforce the importance of flying safe, stabilised approaches. Flight crew need to be aware that unstabilised approaches increase the likelihood of approach and landing accidents such as runway excursions and controlled flight into terrain (CFIT).

All of the runway excursion accidents and serious incidents to date involving Australian-registered commercial jet aircraft (Section 3.3.1) have involved unstabilised approaches (and in some cases other contributing factors).

Unstabilised approaches were the leading contributor to runway excursion accidents in the analysis of 120 runway excursion accidents on landing between 1998 and 2007 from the Ascend World Aircraft Accident Summary presented in the first

report in this series. At least 55 of those accidents (46 per cent) involved elements of an unstabilised approach, and/or undesired states that can result from an unstabilised approach:

- 35 accidents (29 per cent) involved a reported ‘long’ landing or extended flare;
- 18 accidents (15 per cent) involved a reported ‘fast’ landing, and/or a loss of control after touchdown due to an excessive airspeed;
- 13 accidents (11 per cent) involved either a lateral (left/right) or vertical (too high/too low) deviation from the approach path or glideslope;
- 11 accidents (nine per cent) involved the flight crew having poor visual contact with the runway during the final approach; and
- Five accidents (four per cent) involved the aircraft bouncing on touchdown, due to an excessive descent rate.

As a result, correct approach and landing techniques are vital to making a safe landing. The Federal Aviation Administration (FAA, 2007a) and Flight Safety Foundation (FSF, 2000a; FSF, 2000d; FSF, 2000e) recommend the following approach and landing techniques.

Prior to approach

- Ensure flight crew are aware of any inoperative braking devices on the MEL or DDG.
- If landing in a crosswind, fly an appropriate approach – a wings-level touchdown (partial de-crab) is safer than a steady-sideslip touchdown with an excessive bank angle.
- Anticipate any crosswind or tailwind effects that might prevent normal braking or directional control on landing.
- Monitor ATC messages and automatic terminal information system (ATIS) broadcasts for changes in wind direction and velocity.

On approach

- The aircraft must be stabilised by 1,000 ft in instrument meteorological conditions (IMC), or 500 ft in visual meteorological conditions (VMC).
- If the aircraft is not stabilised, a go-around should be conducted in accordance with the operator’s procedures.

During pre-landing checklist

- Arm ground spoilers.
- Arm autobrakes to a setting appropriate for the prevailing runway conditions (such as a wet or contaminated runway).

Touchdown

- Ensure a positive touchdown in the touchdown zone²⁵ - do not conduct an extended flare or float to bleed off excessive airspeed, as this can use up hundreds or thousands of feet of runway.
- Conduct a firm touchdown to increase weight-on-wheels, and lower the nosewheel as quickly as possible – this activates deceleration systems (such as ground spoilers) on many aircraft.
- Do not touchdown outside the touchdown zone or significantly beyond the threshold – in this case conduct a missed approach and go-around in accordance with the operator's procedures.

Throughout the approach, it is important for the pilots to guard against visual illusions and spatial disorientation. Flight crew should make themselves aware of prevailing weather, the airport and approach path terrain. Cross-checking of visual references against instrument references should be performed regularly, by both the captain and first officer (FSF, 2000f).

4.1.3 Timely and effective braking

Timely and effective use of braking devices is critical in decelerating the aircraft in the minimum possible runway length.

Analysis of the Ascend World Aircraft Accident Summary in the first report in this series, found that of the 120 runway excursions that occurred on landing between 1998 and 2007, almost a third (n = 36) involved some form of delayed or incorrect use of braking devices by the flight crew, or inadequate identification of and response to a failure in the aircraft braking system.

The FAA and FSF recommend that standard operating procedures should require the following actions from flight crew during the landing rollout.

- Monitor and call extension of the ground spoilers immediately after touchdown – they are most effective in increasing drag at high speeds.
- Select maximum reverse thrust as soon as possible – this provides the maximum possible deceleration force at high speed.
- Monitor ground speed throughout landing roll, and reduce engines to idle reverse at the required speed (as per the AFM).
- Monitor the autobrakes to ensure the aircraft is decelerating as expected - use steady pedal braking to stop aircraft if necessary.
- Apply manual braking effectively – heavy braking at high speeds is ineffective, as it increases the likelihood of both aquaplaning and tyre blow-out (FAA, 2007a; FSF, 2000g).

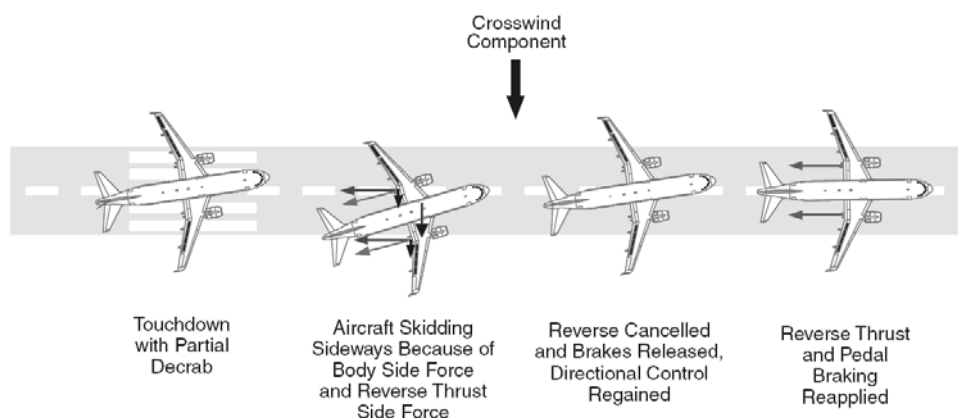
²⁵ The touchdown zone is defined by the FAA as a point 500 to 3,000 ft beyond the runway threshold, which does not exceed the first one-third of the runway length. The touchdown zone may be as short as 820 ft past the runway threshold (the point where a 3.5 degree glide path passing a TCH of 50 ft intercepts the runway surface).

The target touchdown point is 1,000 ft beyond the runway threshold, within the touchdown zone. After this point, maximum braking effort must be applied in order to stop the aircraft within the AFM predicted landing distance quoted by the aircraft manufacturer (FAA, 2007a).

As a general rule, flight crew should not stop braking until they are sure that the aircraft will stop in the available runway length. If the aircraft is fitted with anti-skid brakes, the pilot should apply firm brake pressure throughout the landing roll. If the aircraft is not fitted with anti-skid brakes, brake pressure should be applied until the wheel-skidding factor²⁶ approaches 100 and the wheel locks. At this point, brake pressure should be eased off (FSF, 2000g).

On a wet or contaminated runway, especially in crosswind conditions, the rudder and/or differential braking should be used to provide directional control. Use of the nosewheel may lead to loss of tyre cornering force and aquaplaning. If differential braking is required, braking should be applied on the required side and released on the other side. Use of reverse thrust should be carefully monitored in crosswind conditions, as the effect of the crosswind may cause the reverse thrust force to worsen sideways skidding. Differential reverse thrust may be required. Figure 4 shows the correct recovery procedure for a skid caused by crosswind and reverse thrust effect (FSF, 2000d).

Figure 4: Recovery from a skid caused by crosswind and reverse thrust side forces



Source: FSF, 2000e

The FSF recommends that throughout the landing roll, a flight crew member should monitor and callout the runway distance remaining at specific points during the rollout. Runway lighting colour changes, runway distance remaining signs (RDRS), or other visual references available to the flight crew such as runway/taxiway intersections, could serve as such points. Knowing where the end of the runway is will help reduce spatial disorientation, especially in poor visibility conditions (FSF, 2000f).

Autobrake and anti-skid systems

To protect against the risks of operating in less than adequate runway conditions, high capacity jet aircraft are often fitted with systems designed to enhance braking action (FSF, 2000g).

²⁶ The wheel-skidding factor, or slip ratio, is a measure of how much friction force is being applied to the wheels. It ranges between zero per cent (free rolling wheel) and 100 per cent (fully locked wheel). The ideal point is 10 per cent, which is the point where maximum braking action is available (FSF, 2000g).

- **Autobrake** – provides a selectable deceleration rate appropriate for prevailing runway conditions, usually between 3 and 6 knots per second.
- **Anti-skid** – adjusts braking on each wheel depending on the level of tyre-to-runway friction for the runway conditions. Anti-skid maintains the wheel-skidding factor (slip ratio) at 10 per cent, which is the point of maximum friction (where zero per cent is free-rolling and 100 per cent is full lock).

It cannot be assumed that such safety systems are fitted to all commercial aircraft. Pilots operating early generation commercial jet aircraft, general aviation, or low-capacity regular public transport (RPT) aircraft are less likely to have autobrake and anti-skid systems available to them when operating in potentially hazardous runway conditions. Systems such as autobrakes, spoilers and reverse thrust often deploy automatically, however, they may only operate fully if a positive ‘weight on wheels’ touchdown is made, and must be manually armed during the approach by the flight crew. If the flight crew does not complete these items on the approach checklist, these systems may not deploy as expected on touchdown. This can create confusion on the flight deck, delaying the application of these systems manually, and hence increasing landing rollout length. The limitations or non-fitment of such systems reinforces the need to provide quality runway surfaces, and for operators to have a firm policy limiting operations in potentially unsafe weather conditions.

4.1.4 Correct missed approach and go-around procedures

Unstabilised approaches have been a contributing factor in many approach and landing accidents, including runway excursions. Unstabilised approaches were a contributing factor in 66 per cent of approach and landing accidents studied by the FSF between 1984 and 1997 (FSF, 2000e), and in 46 per cent of the 120 runway excursions on landing recorded by Ascend between 1998 and 2007 (see the first report in this series).

The FAA, FSF, the French Directorate General of Civil Aviation (DGAC), and other aviation safety bodies often reinforce the message that stabilised approach criteria are a critical part of approach and landing safety, as are ‘no blame’ go-around policies. A non-blame go-around policy means that flight crew will never be penalised for conducting a go-around for safety reasons (for example, due to an unstabilised approach), no matter how the unsafe situation that led to the go-around arose. No-blame go-around policies lead to safer operations as flight crew can confidently make safety decisions (when required to ensure the safety of their aircraft) ahead of concerns about profitability, operator policies, or scheduling pressures without fear of reprimand.

Criteria for a stabilised approach were discussed in detail in the first report in this series, and include:

- adherence to intended or approved approach path for that airport;
- airspeed and power setting limits;
- minimum and maximum altitudes;
- attitude and sink rate limits;
- correct aircraft configuration; and

- flight crew readiness for the landing (FSF, 2000a; FSF, 2000e; Werfelman, 2008).

The last point above concerning flight crew readiness is crucial. Rushed approaches and ‘press-on-itis’²⁷ elevate the likelihood of an unstabilised approach. If the flight crew are not ready to conduct the landing, confusion, spatial disorientation, and cockpit resource management (CRM) problems could result, increasing risk and making a safe landing more difficult. Conducting a go-around or missed approach is usually the safest option in these cases. Of the 120 excursion accidents analysed in the Ascend World Aircraft Accident Summary, at least 16 involved a failure by the flight crew to divert or go around following unsafe landing conditions or an unstabilised approach.

Before descent, the FSF recommends that a checklist-triggered risk and threat briefing should be conducted by the flight crew for the upcoming approach. This will help to identify any serious risks that may jeopardise the safety of the landing, such as a contaminated runway, and give the flight crew the opportunity to monitor the stabilised approach criteria (FSF, 2000h). If any of these criteria cannot be achieved, SOPs and operator policy should state that a go-around is required. Flight crew training should reinforce this policy, and reaffirm a ‘no-blame’ approach to go-arounds (Khatwa & Helmreich, 1999).

4.2 Enhanced flight crew training and risk awareness

An effective training program is another preventative risk control that provides flight crews with an operationally-focused knowledge of factors that affect landing performance. Practical training, such as the use of flight simulators, reinforces the practical application of approach and landing SOPs in the cockpit.

To improve awareness and knowledge of approach and landing safety, the FAA recommends that operators’ training programs should include:

- coverage of operator-specific approach and landing SOPs;
- stabilised approaches, and stabilised approach criteria;
- good CRM principles, and their importance in preventing flight crew error and delayed flight crew actions;
- the source, and appropriate use of landing distance data contained in aircraft flight manuals (AFMs);
- calculation of required landing distance prior to arrival;
- the need to reassess landing distance calculations at the time of arrival (CASA (2002) has indicated that CASR Part 121 will require that this be done 30 minutes prior to landing);
- consequences of excess airspeed on landing rollout length;

²⁷ Press-on-itis is a term which is used to describe a decision by a flight crew to continue with their original landing plan, even though prevailing weather, runway, or other operational conditions suggest that another course of action would be more appropriate (i.e. deciding to ‘go’ in a ‘no-go’ situation) (Orasanu & Martin, 1998).

Press-on-itis and its role in runway excursion accidents is discussed further in the first report in this series (Taylor et al, 2009).

- consequences of long landings beyond the intended touchdown point;
- tail and crosswind limits specific to the operator's aircraft types, and the consequences of conducting a landing outside those limits;
- correct use of braking devices specific to the operator's aircraft types (autobrakes, ground spoilers, thrust reversers);
- the importance of being aware of inoperative equipment and systems on the MEL or DDG that might affect landing length;
- 'rules of thumb' to calculating required landing distance (such as the FAA '70 per cent' rule); and
- reasons to initiate a go-around, and how to execute a go-around. A policy of 'no-blame' for go-arounds should be reinforced throughout training (FAA, 2007a).

These principles can be reinforced by line oriented flight training (LOFT), where pilots can fly approach and landing profiles in a simulator that provide a practical appreciation of the consequences of flight crew decisions (such as flying an unstabilised approach), and their relationship to runway excursion accidents. In these LOFT sessions, instructors are able to demonstrate the indicators that were the precursors to the accident, so that pilots can recognise when a go-around is required. This is a similar model to the successful microburst and wind shear simulator training that has been commonplace in the airline industry since the 1980s (CAA, 2002; McKinney, 2006).

The FSF provides a thorough overview of the contributing factors to runway excursions through the freely available *Approach-and-Landing Accident Reduction (ALAR) Tool Kit*. The *ALAR Tool Kit* also includes a *Risk Awareness Tool* and *Risk Reduction Guide*, which are designed to assist flight crews conducting a pre-landing risk and threat briefing (FSF, 2000h; FSF, 2000i). The use of this tool kit has been recommended by the ICAO Industry Safety Strategy Group (ISSG) as part of their *Global Aviation Safety Roadmap*. The *Global Aviation Safety Roadmap* is a key part of the international effort to improve approach and landing safety (ISSG, 2006).

4.3 Organisational risk awareness and safety cultures

Management personnel also need to be aware of the safety factors that contribute to runway excursions. This includes taking an active role in implementing measures to mitigate the contributing factors. Investigations of some serious runway overruns have determined that less than adequate operator policies, organisational safety cultures and management oversight of safety training, are some of the higher-level organisational factors that contribute to these accidents.

4.3.1 Operator policies

For safety, financial, and operational reasons, as well as the importance of public reputation, it is in the best interests of operators to reduce the likelihood of their aircraft being involved in any form of accident. Runway excursions are no exception.

At the management level, operators can reduce the chance of safety threats and flight crew error leading to an approach and landing accident (such as a runway overrun or veer-off) by implementing policies that promote a culture of ‘safety first’ throughout all levels of their organisation.

A review of training and safety policies affecting both flight operations and maintenance support will assist operators to achieve a ‘safety first’ culture. Implementation of the policies recommended by FSF listed below (FSF, 2000a; FSF, 2000i) would ideally provide a clearer understanding across different business areas of the organisation of how individual actions can contribute to serious accidents.

Policies affecting flight crew

- Reinforcing a ‘no-blame’ missed approach policy to promote readiness and commitment to go-arounds, and discouraging any attempts to rescue an unstabilised approach or other situation that could possibly result in an unsafe landing.
- Providing SOPs that provide clear guidance to flight crews in:
 - conducting a pre-landing risk and threat briefing;
 - calculating required landing rollout distance prior to landing;
 - correct approach and landing procedures;
 - appropriate use of deceleration devices; and
 - the effect of different runway conditions on landing length.
- Providing appropriate CRM training to minimise the risk of incorrect flight crew action and coordination in poor weather conditions, through enhanced monitoring, deviation calls and cross-checking of actions.
- Providing a firm policy that prohibits landings in certain conditions (such as on contaminated runways).

Policies affecting both maintenance personnel and flight crew

- Providing practical and theoretical training that increases awareness of the serious safety implications of approach and landing accidents. The operational, human and environmental factors that can contribute to these accidents should be discussed.
- Requiring that all unserviceable equipment (such as brake units and thrust reversers) is reported in the aircraft logbook, and that they receive attention in accordance with the MEL or DDG.

4.3.2 Post-accident changes to operator procedures

When changes are made to SOPs and AFMs aiming to minimise the likelihood of overruns and veer-offs, it is often after an accident rather than before. Nevertheless, operators and regulators have learned from serious runway accidents, and improved approach and landing risk controls to protect against future accidents.

Below are two examples of runway excursion accidents that have occurred in the last 10 years which have led to important safety improvements to procedures and policies of the operators involved.

Learning from accidents: positive safety outcomes from serious runway overruns and excursions

Bangkok, Thailand – Boeing 747-400 overrun (1999)

Following both an internal investigation by the operator and an Australian Transport Safety Bureau (ATSB) investigation into the 1999 overrun of an Australian-registered Boeing 747 in Bangkok, the operator changed its approach and landing procedures to reduce operational risks on water-affected runways. This included the introduction of a landing configuration flowchart in the procedures manual, and a change in flap and reverse thrust configuration to increase braking effectiveness for all Boeing 747 landings.

The operator also introduced systemic changes at an organisational level to monitor and mitigate risks that could lead to an overrun. Key changes were quality assurance monitoring of long landings, and introduction of risk assessment methods for all new procedures and aircraft configurations. Crew training was enhanced, with a focus on simulator training for go-arounds and rejected landings, and incorporation of CRM principles into the training syllabus for both flight and cabin crew (ATSB, 2001; Williams, 2002).

Little Rock, Arkansas, United States – McDonnell Douglas MD-82 overrun (1999)

Following the investigation into the 1999 overrun of a McDonnell Douglas MD-82 at Little Rock, Arkansas, the operator revised its stabilised approach criteria to include altitude minima for instrument flight rules (IFR) and visual flight rules (VFR) flight. The operator changed its SOPs for approaches and landings to explicitly state that if an approach was unstabilised, a missed approach was to be declared and a 'no-blame' go-around was required. Spoiler extension calls by the copilot were also introduced at touchdown (NTSB, 2001).

4.4 Indicators of remaining runway distance

4.4.1 Runway distance remaining signs

Runway distance remaining signs (RDRS) are a simple and low cost measure to increase flight crew spatial awareness during the landing rollout. These are large, illuminated signboards on either side of the runway that indicate the distance remaining in thousands of feet during a takeoff or landing roll. The RDRS may be single-faced, or double-faced to provide runway distance information for operations in either direction.

FAA Advisory Circular AC 150/5340-18D, *Standards for Airport Sign Systems*, specifies the design and position tolerances for these signs.

While CASR 139 *Manual of Standards – Aerodromes* does not currently require the installation of runway distance remaining signs, they are useful to pilots both on takeoff and landing. On takeoff, pilots can use RDRS to check expected versus actual aircraft acceleration prior to rotation. These signs have several safety benefits for landing:

- if the aircraft lands long, they provide greater pilot awareness of remaining runway distance, allowing the pilots to make an informed decision about whether a go-around is warranted based on the risk of an overrun;
- they are visible in all conditions, and are not obscured by ice or snow (unlike standard runway distance markings painted on the runway surface); and
- the pilot is able to quickly realise if the aircraft is decelerating fast enough in the landing roll.

The FAA currently recommends that RDRS are installed on all runways used by jet aircraft (FAA, 2004a). Lobby groups such as the Airline Pilots Association (ALPA) and industry experts have urged the FAA to make RDRS compulsory for all airports in the United States that receive RPT services (Rogers & Cook, 2007).

Neither ICAO nor CASA require or recommend airport operators to install RDRS at the side of runways. Despite this, their potential safety benefits mean that they are installed at many airports (especially those owned by the Department of Defence which are leased by civilian operators).

4.4.2 Runway end lights

Runway end lights are another visual aid that can assist flight crews to judge the distance to the end of the runway during the landing rollout. In Australia, the CASR 139 *Manual of Standards* requires all runways which are equipped with edge lighting to also have six equally-spaced red lights marking the runway end. These runway end lights must be located perpendicular to the runway centreline, and be placed no more than 3 m outside or 1 m inside the runway extremity. The ICAO Annex 14 provides similar requirements for runway end lighting, but allows for a greater number of lights, and different ways of arranging lights. Both ICAO Annex 14 and the CASR 139 *Manual of Standards* provide further guidance to airport operators on the required intensity and directionality of runway end lighting.

4.4.3 Enhanced cockpit alert systems

Improved technology in cockpits could assist flight crews in determining whether enough rollout length exists for their aircraft prior to landing given the approach type, prevailing weather, and runway conditions.

The Honeywell Runway Awareness and Advisory System (RAAS) is an example of a cockpit-based warning system that is already in operational use. This system is a software add-on to the aircraft's existing enhanced ground proximity warning system (E-GPWS). The Honeywell RAAS uses Global Positioning System (GPS) data to determine the aircraft's position relative to the runway, removing the need for any specific airport infrastructure (such as distance measuring equipment) to be installed on the runway. Aural alerts of the remaining runway distance are provided to the flight crew after the aircraft has used up more than half of the available runway distance. The system operates when the radio altimeter indicates the aircraft is less than 100 ft (30 m) above the runway, and is travelling at a ground speed of 40 kts or more (Air Safety Week, 2004; Honeywell, 2007).

Federal Express was the first operator to install RAAS across its entire fleet. In September 2008, Alaska Airlines became the first United States airline to install Honeywell RAAS units across its entire fleet of 109 aircraft (Croft, 2008). Further commercial jet RPT aircraft in the United States are likely to be equipped with this system in the future, due to a July 2008 funding commitment by the FAA Office of Runway Safety to equip up to 20 aircraft with instrumentation to reduce the likelihood of runway incursions and excursions. Under this program, the FAA would provide up to US\$15,000 per electronic flight bag, and up to US\$4,000 for each aural alerting system (such as the Honeywell RAAS) (Aviation Week & Space Technology, 2008).

Outside of the United States, Air France has also installed Honeywell RAAS units into its fleet (Croft, 2008). In Australia, RAAS systems have been evaluated by major Australian airlines but are not currently used. However, some overseas airlines that operate to and from Australia (such as Emirates Airline) use aircraft fitted with RAAS.

McKinney (2006) suggests that future aircraft could incorporate a cockpit display of predicted rollout versus available runway, which would be visible to the pilot via the heads-up display (HUD) and multi-function display (MFD). Predicted rollout length would be recalculated from the start of the final approach (1,000 ft above ground level) throughout the rollout based on runway friction measurements, aircraft landing weight, and the approach configuration of the aircraft. Such a display would use simple colours to indicate to the pilot what action is required.

- **Green** – predicted rollout length is safely within the available runway length.
- **Amber** – predicted rollout length exceeds 80 per cent of available runway. This would indicate to the pilot that a firm landing at V_{ref} should be made near the touchdown zone, and that ground spoilers, reverse thrust and immediate braking is required after touchdown.
- **Red** – predicted rollout length exceeds 90 per cent of available runway, and a go-around or diversion is required.

Systems such as this hypothetical one may increase approach and landing safety in the future by improving pilot awareness of available runway remaining, especially

in poor visibility conditions and at unfamiliar airports. Challenges facing such a system would include ensuring the accuracy of the instrumentation, the expense of the system, and the ability to integrate it with existing aircraft and runways (McKinney, 2006). The safety potential in systems such as this and the Honeywell RAAS should be investigated further by airline operators as well as aircraft and avionics manufacturers as an aircraft-based preventative risk control for all types of approach and landing accidents.

4.5 Quality runway surfaces

Quality runway design and regular maintenance of runways are the most important preventative risk controls that airport operators can employ to reduce the likelihood of runway excursion accidents. A good runway surface can improve friction between the runway and aircraft tyres, reduce the likelihood of aquaplaning by improving drainage of surface water in heavy rain, and prevent build-up of rubber contamination in a cost-effective manner. Appropriate lighting of the runway centreline and edges has the potential to provide pilots with better spatial awareness at night or in poor visibility conditions, and may reduce the likelihood of veer-offs.

When a runway is water-affected or contaminated with standing water, quality runway surfaces with improved drainage and friction treatments will reduce the chance of aircraft exiting off a runway and minimise the overrun or veer-off distances when excursions do occur. The latter will reduce the importance for airport operators to provide an extended runway end safety area (RESA) (see Section 5.2).

4.5.1 Improved drainage

Good runway drainage is important to provide skid-resistance, improved runway friction, dissipate standing water, and prevent aquaplaning on water-affected runways. Drainage can be assisted by:

- runway cambering;
- provision of adequate runway surface macrotexture by means of a suitable friction treatment (such as runway grooving or porous asphalt); and
- maintaining a runway surface free of irregularities such as depressions.

As little as three millimetres of standing water on the runway surface can allow the aircraft to aquaplane. The analysis of 120 runway excursion accidents on landing between 1998 and 2007 presented in the first report in this series (Taylor et al, 2009) found that 64 per cent ($n = 77$) occurred on a wet or water-affected runway. Six of these accidents occurred on runways which had light to medium snow coverings, while the remaining 71 occurred on runways which were wet from rainfall. No accidents involved ice-affected runway surfaces. Aquaplaning was suspected as a contributing factor in 17 accidents.

Poor runway surface quality has played a contributing role in numerous accidents internationally that were analysed in this report, particularly those where local weather conditions meant that there was a higher likelihood of other risk factors (such as aquaplaning) contributing to the accident.

Runway camber and transverse slope

Runway cambering or transverse sloping allows water to drain to the side of the runway, which stops standing water pools from forming. CASR 139 *Manual of Standards* requires Australian Code 3 and 4 runways over 30 m in width to have a transverse slope between one and two per cent of the runway width.

Runway macrotexture

The provision of adequate runway surface macrotexture is a proven, cheap and effective way of reducing the likelihood of runway excursions. It improves the runoff of water and impedes the formation of standing water on the surface of the runway, which can increase the risk of aquaplaning.

International Civil Aviation Organization (ICAO) Annex 14, Attachment A, Section 7.8, states that among the factors affecting the friction coefficient between the aircraft tyres and the runway surface, texture is particularly important. If the runway has a good macrotexture that allows water the escape beneath the tyre, then the friction coefficient (μ^{28}) will be less affected by aircraft groundspeed. Conversely, a runway surface with low macrotexture will produce a larger drop in friction as groundspeed increases.

When normal asphalt and concrete mixes are used to surface runways, they do not have sufficient macrotexture as-is, and some form of texture treatment is required. The runway surface requirements in the CASR 139 *Manual of Standards – Aerodromes* are based on those in ICAO Annex 14. They both require that the surface of a bitumen seal, asphalt, or concrete runway must have an average surface texture depth of not less than one millimetre over the full length and width of the runway (CASA, 2008; ICAO, 2004). It states that the runway surface ‘shall be constructed without irregularities that would result in loss of friction characteristics’, and that the surface ‘shall be so constructed as to provide good friction characteristics when wet’ - and note that this normally requires some form of texture treatment (ICAO, 2004). However, there are different regulatory positions on runway texture around the world.

Figure 5 shows a commonly used type of runway surface texturing treatment, transverse grooving, which is widely used on Australian runways. Grooving is generally used at airports that record heavy rainfall or have drainage problems, and can be used on both concrete and asphalt runway surfaces (TSB, 2007). In other

²⁸ A μ value (sometimes denoted as μ , or runway friction coefficient) is a measurement of runway friction. It is the ratio of the tangential force needed to maintain uniform relative motion between two contacting surfaces (aircraft tyres to the pavement surface) to the perpendicular force holding them in contact (distributed aircraft weight to the aircraft tyre area). It is used as a simple way to quantify the relative slipperiness of pavement surfaces such as runways (FAA, 1997).

For example, a μ value of 0.5 would be measured on a dry runway. A μ value of 0.2 would be more likely on a water-affected runway. A μ value approaching zero would indicate that there is no friction between the tyres and the runway, for example, if the runway was covered by ice.

While μ values provide useful information to pilots to help judge the braking performance of their aircraft, they are estimates only. These values can vary significantly depending on measuring techniques, the time of measurement, and the material/s contaminating the runway. The FAA does not support the use of μ values alone in estimating an aircraft’s braking capability on wet and contaminated runways, as they may overstate braking potential (FAA, 2007a).

parts of the world, other types of runway surface macrotexture (such as porous asphalt) are more common.

Figure 5: Runway grooving at Congonhas International Airport, Sao Paulo, Brazil, July 2007



Source: Agência Brasil

In 1983, the National Aeronautics and Space Administration (NASA) studied the relative effect of factors influencing the aircraft braking performance of a medium sized commercial jet aircraft, including touchdown speed, tyre tread, and runway surface macrotexture. One of the areas of focus was the effectiveness of surface grooving on wet and dry runways. Through a series of landings by a Convair 990 Coronado²⁹ test aircraft on a burlap-drag finished concrete runway surface, it was shown that transverse runway grooving produced substantially greater aircraft braking friction levels with both rib-tread and smooth tyres than were shown by similar landings on wet ungrooved runways. At the test aircraft's critical dynamic aquaplaning speed (V_p) of 115 kts, the effective braking friction coefficient (μ) was 0.3/0.35 when the runway was wet and grooved, compared to 0.04/0.1 when the runway was wet and ungrooved (smooth tyres/rib-tread tyres).³⁰ While the runway grooves increased tyre tread wear (reducing braking friction), the study

²⁹ The Convair 990 Coronado was a first-generation commercial jet aircraft, and is no longer in airline service. The Convair 990 seated up to 121 passengers, and had a maximum takeoff weight of 246,200 lb (111,675 kg) (Jane's, 1964). This is similar in weight to a Boeing 757-300 aircraft. However, unlike the B757 and most modern commercial jet aircraft, the Convair 990 was not equipped with anti-skid brakes or other modern aircraft braking systems.

³⁰ In comparison, the same test achieved an effective braking friction coefficient (μ) of 0.41 for both tyre types on dry grooved and ungrooved runway surfaces (Yager, 1983). The actual landing rollout length of the aircraft would be also be affected by other factors, such as the use of reverse thrust and autobrake systems. Part 1 of this report series (Taylor et al, 2009) provides an example of the relative effect of μ values on landing rollout length for a Boeing 787-8 Dreamliner aircraft.

found that this friction loss was offset by the greatly enhanced pavement water drainage capability available on grooved runways (Yager, 1983).

The FAA regards surface texturing of all runways serving (or expected to serve) jet aircraft as high priority safety work, and in 1997 recommended that all existing non-grooved runways should be grooved as soon as practicable. Where existing runway pavement is not suitable for cutting grooves (due to the material used), or surface anomalies exist (e.g. cracks, bumps, depressions or faulted joins), the FAA recommended that the runway should be resurfaced with porous friction course (PFC) concrete³¹ and then grooved (FAA, 1997). Most airport runways in the United States now have surface texture treatments in place.

In Australia, runway grooving is the primary preventative risk control implemented by airport operators to reduce the likelihood of runway excursions. Most airports that receive high capacity RPT jet services have grooved runways. All major capital city airports (and many regional airports) have at least the primary runway grooved (a full list is included in Appendix B). This includes airports in northern Australia which are subject to heavy monsoonal rainfall, such as Darwin, Townsville and Cairns. In these locations, runway resurfacing and grooving activities are undertaken in the dry season to limit risks to aircraft from surface water accretion (such as aquaplaning).

Elsewhere in the world, other types of surface texturing are more common. In the United Kingdom and South Africa, the majority of runways are textured using either porous asphalt or grooving. In France, specialised asphalt surfacings with improved texture are used. In some colder climates, grooving is only used where unusual drainage problems exist. For example, Canada only has four grooved runways. This is because in cold climatic conditions the grooves allow the accumulation of ice and snow, resulting in a reduction in runway friction as well as the deterioration of the runway surface through the freeze/thaw cycle. This type of pavement degradation also has the unwanted effect of increasing formation of foreign objects on the runway (TSB, 2007). In hotter climates, such as the Middle East, most runways do not have any texture treatments due to the low average rainfall level, and concerns regarding the structural stability of runway grooves during periods of sustained high temperatures.

Of the 120 runway excursions that occurred worldwide between 1998 and 2007, 77 followed a landing on a wet or water-affected runway. Sufficient data was generally not available from the Ascend WAAS or investigation reports (where available) to determine whether or not the runway used for landing was grooved or otherwise textured at the time of the accident.

³¹ Porous friction concrete (PFC) is a course, gap-graded asphaltic concrete mixture with a high (80-88 per cent by weight) proportion of aggregate larger than a No. 8 sieve.

The coarse surface texture of PFC allows surface flow of water, plus pressure relief channels and pavement tyre contact above any film of surface water. Its structure has a high proportion of void space to solid particles (25 to 45 per cent), allowing water to permeate instead of collecting on the surface (Johnson & White, 1976).

4.5.2 Improved friction and macrotexture

Surface treatments

To improve surface friction and increase skid-resistance on runway surfaces, airport operators can apply a number of surface texture treatments when runways are resurfaced or being constructed.

Surface treatments do not prevent aircraft from aquaplaning, but serve to provide better friction between the runway and the aircraft tyres in normal operational conditions.

Concrete runway surfaces can be treated with a textural finish when still in the plastic condition after being laid. This texture treatment is usually applied before the runway is grooved, and puts corrugations in the runway surface that provide improved contact with aircraft tyres. Common methods of texturing a concrete runway surface are through use of a brush or broom, sheets of burlap, or a wire tine made of flexible steel bands dragged across the runway surface.

Asphalt runway surfaces are generally smooth when laid, due to rolling work done to compact the surface and achieve the required density. The texture can be increased by cutting or forming grooves into the runway surface, by applying a thin overlay (25 to 40 mm thick) of porous asphalt, surfacing with a special bitumen seal, or by overlay with specialised asphalt. Testing of PFC overlays by the FAA has shown that the overlay can last longer and provide better adhesion if rubber particles are added to the mix. However, PFC overlays are highly susceptible to rubber build-up, and can be severely damaged by removal activities. For this reason, the FAA does not recommend their use on runways which have a high number of heavy jet aircraft landings (over 91 per day) (FAA, 1997). Specialised asphalt surfacings have been developed which provide good macrotexture, including gap-related mixes such as stone mastic asphalt (SMA) and proprietary ultra-thin asphalts such as Novachip™ and ULM™. These seals are somewhat different to those used on highways. Friction on asphalt runways can be temporarily improved by constructing a chip seal³² with a fog seal³³ overlay, or an aggregate slurry seal (Emery, 2008).

While the construction and maintenance of bitumen (chip) seals is fairly similar to those applied to roads, greater care in design/construction and a preventative maintenance program is needed to avoid loose stones which could be a hazard to aircraft operations by increasing the risk of foreign object damage (particularly to aircraft tyres, engines, propellers and windshields). Chip seals are a cost-effective runway surfacing method for airports servicing smaller aircraft, and are widely used on runways at rural Australian airports (over 200 regional airports in Australia have sealed runways) (Emery, 2008).

³² A chip seal is a pavement surface treatment that combines a layer of bitumen/asphalt with a layer of fine aggregate, which is laid over the existing pavement or runway surface to provide a rougher surface. It is also often used on roads as a low cost method of resurfacing, and is commonly referred to as a sprayed or tar seal.

³³ A fog seal is an additional layer of bitumen/asphalt that is laid over the top of a chip seal to keep the aggregate component of the chip seal in place, preventing premature erosion and loss of stones from the pavement or runway surface.

Rubber deposit removal

Rubber from aircraft tyres is deposited on all runways as part of normal operations, particularly in the touchdown zone and along the centreline. These deposits can build up to several millimetres in thickness, decreasing runway friction (μ) to a point where safety may be diminished (FAA, 1997). Thick rubber deposits can disperse rain into pools of standing water at varying depths, which increases the likelihood of aquaplaning (Ranganathan, 2006).

To ensure that runway friction is maintained, regular removal of rubber deposits is needed. Pavement surfaces which are formed from PFC are particularly susceptible to dense build-up of rubber during normal operations (FAA, 1997). The frequency of removal may depend on the number of daily landings on the runway or on regular assessment by the airport operator of the runway surface friction level. In these cases, rubber removal activities are conducted if the μ value reaches a minimum at which it is considered contaminated. At some Australian airports (such as Perth), favourable climatic conditions assist in preventing rubber deposit build-up, and scheduled rubber removal maintenance by the airport operators is not necessary.

For airports where rubber deposit removal activity is based on the number of landings, Table 3 gives the rubber deposit removal frequencies recommended by the FAA in Advisory Circular AC 150/5320-12C, *Measurement, Construction and Maintenance of Skid-Resistant Airport Pavement Surfaces*.

Table 3: FAA-recommended intervals between rubber deposit removal activities

Number of daily jet aircraft landings per runway end	Suggested rubber deposit removal frequency
Less than 15	2 years
16 to 30	1year
31 to 90	6 months
91 to 150	4 months
151 to 210	3 months
Greater than 210	2 months

Source: FAA, 1997

A number of methods are available for removing rubber deposits, such as high pressure water, chemical treatments (Figure 6), high velocity impact (sandblasting), and mechanical grinding. Following removal, the FAA recommends that the airport operator conduct runway friction measurements and ensure that the μ value is within 10 per cent of that of the uncontaminated portions of the runway. Both measurements should be within the acceptable friction levels for safe aircraft operations (FAA, 1997).

Figure 6: Chemical removal of rubber deposits from a runway



Source: Vital Chemical Pty Ltd

Standing water depth measurement

Measurement of standing water depth has been touted as a possible means of replacing runway friction measurements, as it would provide both airport operators and pilots with a quantitative means of determining aquaplaning risk. Some airport operators make manual measurements of standing water depth at isolated locations on the runway during periods of intense or sustained rainfall, and report this information to pilots via NOTAM.

One difficulty with reporting friction results to flight crews is that the measured value is only valid at the time it is taken. The friction level reported to a pilot even 15 minutes after the completion of a manual friction test could have changed, as the runway conditions can change considerably in short periods of time.

A study has been undertaken by ICAO to determine and document the design requirements for the development of standing water measurement devices that can estimate depth (and respective μ reduction) across the whole runway surface. This study determined that it is not currently practical to develop a standing water measurement device that can meet all the necessary design requirements prescribed by ICAO. The major limitation is the sheer number and location of the devices that would need to be installed on a runway to provide an accurate picture of friction across the entire surface (TSB, 2007).

4.6 Runway lighting

At night or in poor visibility conditions, runway lighting is an important safety measure to maintain pilot spatial awareness and assist maintaining a stabilised approach.

Both ICAO Annex 14 and the Australian CASR 139 *Manual of Standards* require airports to provide the following types of runway lighting:

- runway edge lights for runways that are intended for precision approaches or for use at night;

- touchdown zone lighting for Cat II³⁴ and III³⁵ precision runways; and
- centreline lighting for Cat II and III precision runways, or runways to be used for takeoff with an operating minimum runway visual range (RVR) below 400 m (1,312 ft).

Annex 14 and CASR 139 *Manual of Standards* also recommend that runway centreline lighting be provided on wide runways (greater than 50 m) which are Cat I³⁶ precision (ICAO, 2004).

The 2003 veer-off of a Boeing 737-300 aircraft in Darwin (described in Part 1) illustrates how landing on a runway of non-standard dimensions with unusual lighting at night and in instrument (IMC) conditions can lead to a runway excursion. In that incident, the aircraft touched down close to the right edge of runway 29 and veered off the sealed runway surface.

Runway 29 was 60 m (197 ft) wide, which was significantly wider than other Australian runways used by the operator's Boeing 737 fleet. This meant that the visual cues and runway perspective available to the flight crew were different from those normally experienced. Both ICAO and CASA had recommended that centreline lighting be provided on runways where the width between the runway edge lights was greater than 50 m. However, the runway was not required to be equipped with centreline or touchdown zone lighting and these were not present.

4.7 Runway condition reporting procedures and tools

As discussed in the first report in this series (Taylor et al, 2009), there is little standardisation in runway condition reporting between state and international aviation safety regulators, air traffic management system operators, and airline operators. As discussed in that report, there are many different methods to report both braking action and runway friction, including μ ²⁸ values, ICAO runway condition codes, and generic terms such as 'good', 'medium' and 'poor'. The lack of a universal reporting practice makes it difficult for flight crews to judge whether it is safe to commit to a landing on a particular runway.

³⁴ ICAO Annex 14 defines a Cat II runway as an instrument runway served by instrument landing system (ILS) and/or microwave landing system (MLS) and visual aids intended for operations with a decision height lower than 60 m (200 ft) but not lower than 30 m (100 ft), and with a runway visual range (RVR) of not less than 350 m.

³⁵ ICAO Annex 14 defines a Cat III runway as an instrument runway served by ILS and/or MLS to and along the surface of the runway, with a decision height lower than 30 m (100 ft). There are three types of Cat III runway defined by ICAO:

- Cat IIIa – intended for operations with a decision height lower than 30 m (100 ft), or no decision height and a RVR not less than 200 m;
- Cat IIIb – intended for operations with a decision height lower than 15 m (50 ft), or no decision height and a RVR less than 200 m but not less than 50 m;
- Cat IIIc – intended for operations with no decision height and no RVR limitations.

³⁶ ICAO Annex 14 defines a Cat I runway as an instrument runway served by ILS and/or MLS and visual aids intended for operations with a decision height not lower than 60 m (200 ft), and either a visibility not less than 800 m or a RVR of not less than 500 m.

The FAA has published a tool that provides estimated correlations between FAA, ICAO, and industry-agreed friction definitions. These correlations allow flight crews to better judge actual runway conditions where the flight crew is presented with several conflicting runway condition reports. This tool, included in FAA AC 91-79 *Runway Overrun Prevention*, is reproduced in Appendix D.

Providing accurate measurements of runway friction is important to help reduce the ambiguity of runway condition information. A requirement of ICAO Annex 14 is that airports in member states take friction measurements along each third of the runway using an approved device. The member state is required by ICAO to define minimum acceptable friction values before a runway is declared water-affected or contaminated, and publish these in the Aeronautical Information Publication (AIP).

Prior to the introduction of CASR 139, Australian airport operators used several different methods to periodically check runway friction. Visual inspections were made daily, and application of an empirical testing method followed by testing with a Mu meter was required by the Department of Civil Aviation from the 1970s until the establishment of the Federal Airports Corporation in 1988. From January 2006, CASR 139 required that the ICAO standard for runway friction measurements is used on all Australian Code 4 runways being used for international operations, meaning that an ICAO-accepted continuous friction measuring device with self-wetting features must be installed (CASA, 2008).

As of 2008, progress is being made toward establishing standards for runway condition reporting in the United States. Following the National Transportation Safety Board (NTSB) investigation into the December 2005 overrun of a Boeing 737 at Chicago Midway Airport in the United States, the FAA convened an Aviation Rulemaking Committee (ARC). The role of this ARC was to review and establish minimum acceptable lengths for takeoff or landing on snow, slush or standing water-affected runways. The ARC will also establish standards for runway condition reporting, and provide minimum acceptable friction levels in the US AIP for continued flight operations from water, slush, snow or ice-affected runways (Croft, 2007).

Inclusion of runway condition information in meteorological reports (e.g. METAR/SPECI) would also serve to improve safety. A recommendation of ICAO Annex 3, which governs meteorological services for international air navigation, is that runway condition information be provided by the appropriate airport authority to the meteorological service provider for the inclusion in METAR/SPECI³⁷ meteorological reports (ICAO, 2007a). Since this is a recommendation only and subject to regional air navigation agreements and multi-agency cooperation, such information may not be available globally. The World Meteorological Organization (WMO) is responsible for regulating codes used in METAR and SPECI reports in accordance with WMO Document 306, *Manual on Codes, International Codes*, and specifies the format as **RD_RDR_RER_Cre_RBR_B**, where:

- **RD_RDR_R** gives the runway designator (e.g. 'R27' for runway 27/27L, 'R77' for runway 27R, 'R88' for all runways);

³⁷ METAR is an internationally recognised format for reporting meteorological information at regular intervals (in Australia this is usually every 30 minutes). METAR reports are generated by permanent weather observation stations or airport operators, and are received by flight crew as part of a pre-flight weather briefing. A SPECI is an additional weather report alerting users to the fact that specific criteria have been met.

- **E_R** gives the type of runway deposit (e.g. '0' for clear/dry, '2' for wet, '3' for frost, '7' for ice);
- **C_R** gives the extent of contamination, as a percentage ('1' is 10 per cent or less, '2' is 11 to 25 per cent, '5' is 26 to 50 per cent, '9' is 51 per cent or more);
- **e_Re_R** gives the depth of the deposit in millimetres (e.g. '00' is less than one millimetre, '05' is five millimetres, '33' is 33 millimetres). If the designator is '92' or greater, the depth of the contamination is more than 10 cm. A designator of '99' indicates the readings are unreliable, and '/' indicates the runway is non-operational;
- **B_RB_R** gives either the runway friction (Mu) coefficient, or a braking action report. Values from '00' to '90' indicate the Mu value of the runway. Values from '91' (poor) to '95' (good) indicate braking action. A value of '99' indicates no reliable report of runway friction or braking action is available (METAR runway state group coding, 2008).

Countries such as the US and Canada use a modified version of the WMO coding system, the Federal Meteorological Handbook FMH-1, which does not have METAR codes allocated to runway surface information (with the exception of water and snow depth reports at some airports) (OFCM, 2005).

As of March 2009, the Australian Bureau of Meteorology did not include runway friction values in the METAR or SPECI reports for Australia (Bureau of Meteorology, 2009).

In terms of accident investigation and reporting of runway excursions, greater standardisation of runway condition reporting through such systems and procedures would assist aviation safety investigators to gain a clearer picture of any role the runway surface may have played in contributing to runway excursions. Information that should be collected at the time of the excursion (both by investigators and the airport operator/runway specialist) includes:

- the runway length and width;
- an assessment of the age and condition of the runway surface and any friction treatments;
- the date when the runway was last resurfaced;
- whether the runway was grooved, and the spacing and location of the grooves;
- if any runway works were underway;
- if the runway threshold was temporarily displaced;
- whether the runway affected by water, ice, slush, snow, or other contaminants, and if so what was the estimated depth of the contaminant on the runway surface; and
- the temperature of both the runway surface and the aircraft tyres at the time of the excursion.

The ATSB and other international aviation safety investigation bodies collect evidence such as this during the course of investigations where the runway surface may possibly have contributed to the accident or incident.

As outlined in Chapter 4, preventative risk controls put into place by operators minimise the likelihood of local conditions and individual actions impacting on the safety of the aircraft. Preventative risk controls are the most important way in which the likelihood of a runway excursion accident can be reduced. The primary focus of runway safety initiatives by airline operators and flight crews, aviation safety regulators, and airport operators should always be on minimising the chance that an aircraft will overrun or veer off a runway. Should a runway excursion still occur, measures to reduce the severity of the consequences of runway excursions by minimising the speed that an aircraft will be moving when it overruns the runway should also be implemented.

Implementation and use of preventative risk controls is not only a responsibility for airline operators and flight crews. Airport operators also have a duty to prevent runway accidents by maintaining runways to a high safety standard - through regular maintenance of runway surfaces (to ensure they are free from cracks and depressions, rubber deposits and other contamination), friction testing and treatment renewal, and through improvement works such as grooving/surface texturing that can enhance safety (discussed in Chapter 4). While the likelihood of an excursion is greatly reduced through the use of the preventative risk controls discussed in Chapter 4, preventative risk controls cannot be relied upon to always be in place or always be effective in avoiding an excursion accident in all conditions. If a runway excursion occurs, recovery risk controls are needed to safely control and stop the aircraft with minimal injury and damage. These are design features which act as ‘last line of defence’ mechanisms to prevent or reduce the seriousness of a runway overrun or veer-off.

Recovery risk controls for runway excursion accidents are employed at airports to reduce the severity to the crew and passengers, bystanders, and aircraft, if a runway excursion does occur. They can include the following controls:

- Runway strips; which are cleared, graded areas that surround the area immediately around the runway to reduce the risk (likelihood and consequences) of an aircraft that has veered off or overrun from colliding with any objects or terrain.
- Runway end safety areas (RESAs); which provide a further area of clear, graded ground beyond the runway end to assist aircraft deceleration in the event of an overrun.
- Soft ground arrestor beds fitted beyond the runway end; which quickly decelerate aircraft in a controlled manner as they cross a bed of specially-engineered material.
- Arrestor cables, barriers and nets at the runway ends; which physically restrain overrunning aircraft.
- Zoning and development limitations near airports; which limit development and commercial activities that could increase the risk to the public if placed near runway ends, such as hazardous material storage and manufacturing, schools, hospitals, and new residential development.

It is important to note that airports are not safety deficient by not having all of these recovery risk controls in place. This chapter reviews all of the important recovery risk controls available that can be possible options for airport operators to help mitigate the serious consequences of runway excursions. Not all risk controls are necessary or appropriate for all airports. Due to the diverse Australian operating environment (in terms of movement activity, aircraft mix, approach terrain, environs, and climatic conditions), a risk management approach which adopts the best-fit preventative and recovery risk controls for each airport is the most appropriate way to minimise the likelihood and consequences of runway excursions.

5.1 Runway strips

Runway strips are a key recovery risk control when runway excursions do occur, especially for veer-offs. They consist of a fully graded area surrounding the runway at both ends and beyond the side of the runway. The aim of this area is to reduce the risk of damage to aircraft running off the ends or sides of the runway.

Annex 14 specifies the ICAO requirements and recommendations for runway strips. For Code 3 and 4 runways with precision approaches, ICAO requires runway strips to extend for at least 60 m in length from each runway end, and for at least 150 m in width on both sides of the runway centreline and extended centreline for the entire length of the runway. For non-precision and non-instrument runways, a 60 m long runway strip must still be provided; however, ICAO does not specify a requirement for runway strip width. However, Annex 14 recommends that Code 3 and 4 runways without precision approaches have a runway strip at least 150 m wide on both sides of the centreline and extended centreline for the entire length of the runway, and a width of at least 75 m for runways without an instrument approach. Full international requirements for runway strips can be found in Annex 14 (ICAO, 2004).

The CASR 139 *Manual of Standards* specifies the requirements for runway strips at Australian airports. It requires runway strips to be free of all fixed objects and potential obstructions, other than visual aids for guiding aircraft or vehicles. These objects must be of low mass and frangible.

At Australian Code 3 and 4 runways³⁸ - those served by commercial jet aircraft - the runway strip must extend at least 60 m beyond the end of the runway and any associated stopway³⁹. The width of the runway strip varies according to the width and type of runway. For runways without an instrument approach:

- Code 3 runways with a width of 30 m must have a runway strip at least 90 m wide (45 m either side of the runway centreline); and
- All Code 4 runways and Code 3 runways which are 45 m or wider must have a runway strip at least 150 m wide (75 m either side of the runway centreline) (Figure 7) (CASA, 2008).

³⁸ See Section 1.3 for the definition of Code 3 and Code 4 runways.

³⁹ A stopway is an extension of the runway designed to stop an aeroplane in the event of an aborted takeoff. Stopways are not required, and the provision and length of a stopway is an economic decision made by the airport operator.

Figure 7: Required runway strip dimensions for non-instrument runways in Australia (fully graded area only)



Source: CASA, 2008

For precision approach (ILS-equipped) runways, the runway strip is wider, and includes an additional flyover area to protect aircraft transiting across the aerodrome (Figure 8). All Code 3 and 4 instrument runways in Australia must have a runway strip at least 300 m wide (150 m either side of the runway centreline). This includes the graded area plus the flyover area.

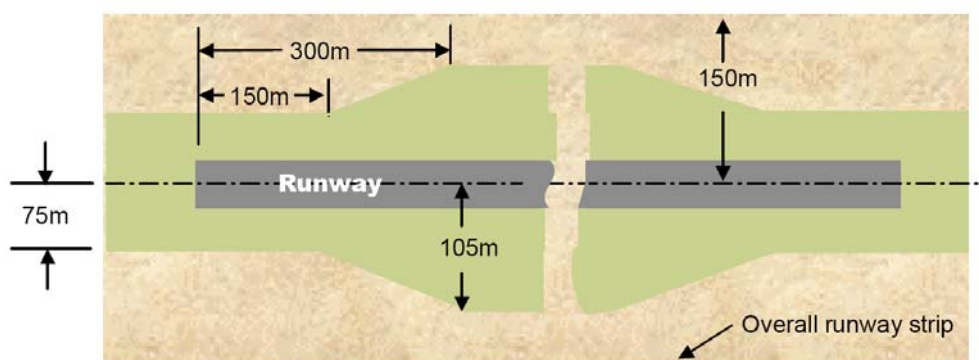
Figure 8: Required runway strip dimensions for instrument runways in Australia (both graded and flyover area)



Source: CASA, 2008

CASA also recommends that an additional width of graded runway strip should be provided for runways with precision approaches, offering an additional level of safety if a runway veer-off occurs, or if an aircraft touches down beyond the runway edges. In this case, the graded width extends to a distance of 105 m on both sides of the runway centreline, except that the width is gradually reduced (over a distance of 150 m) to a width of 75 m from both sides of the centreline at both ends of the strip for a length of 150 m from the runway ends (Figure 9) (CASA, 2008).

Figure 9: CASA-recommended runway strip design for ICAO Code 3 and 4 precision approach runways in Australia



Source: CASA, 2008

Annex 14 notes that transverse (lateral) slopes on the portion of a runway strip to be graded should be adequate to prevent the accumulation of water on the surface, but should not exceed certain limits. For Code 3 and 4 runways in Australia, the CASR

139 *Manual of Standards* requires the lateral slope to be no more than 2.5 per cent. The longitudinal slope must be no more than 1.75 per cent for Code 3 runways, and no more than 1.5 per cent for Code 4 runways. Full slope requirements for both the graded and flyover areas are specified in the *Manual of Standards* (CASA, 2008).

5.2 Runway end safety areas (RESAs)

Civil Aviation Safety Regulation 139 *Manual of Standards* defines runway end safety areas (RESAs) as areas of graded, flat ground beyond the end of a runway and any associated stopway³⁹, and beyond the runway strip, designed to enhance aircraft deceleration. RESAs may lie within any clearway area⁴⁰ that exists beyond the runway end. These areas are symmetrical about the extended runway centreline, and are free from any non-frangible obstacles or obstructions.

Runway end safety areas are designed to reduce the risk of damage to an aircraft that:

- undershoots the runway (touches down before the runway threshold);
- aborts a takeoff and overruns the runway end; or
- cannot stop following a landing and overruns the runway end.

A RESA achieves this by assisting aircraft to decelerate in a controlled manner.

Surface materials used for RESAs vary widely, from natural surfaces to pavement. Common RESA surface materials include compact gravel pavement, pulverised fuel ash (PFA), grass, pavement quality concrete (PQC), compacted earth, or a combination of these. In all cases, the bearing strength of the RESA must be able to support movement of airport rescue and fire fighting (ARFF) vehicles, and be resistant to blast erosion from jet engine exhaust from aircraft in day-to-day operations.

The RESA area is not included in the declared distances of a runway.⁴⁰

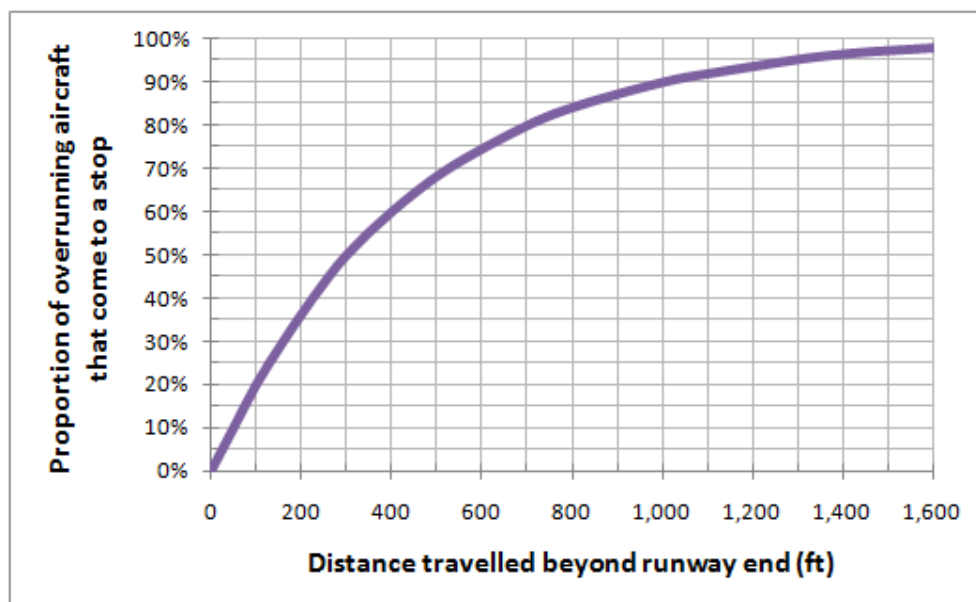
5.2.1 Safety benefits of RESAs

The provision of RESAs at airports was initiated by an FAA study of overrun and undershoot accidents between 1975 and 1987. This study showed that approximately 90 per cent of aircraft that overrun stop within 1,000 ft (approximately 330 m) of the runway end. Half of overrunning aircraft stopped within 300 ft (90 m), and 80 per cent stopped within 700 ft (approximately 210 m) (Figure 10). It also found that most overrunning aircraft do not deviate very far from the extended runway centreline (FAA, 2005). As detailed in Section 3.1, analysis of the 43 known resting positions of the 120 landing runway excursion

⁴⁰ Runway end safety areas may be included in the clearway area. A clearway is an obstruction-free rectangular area that must be long enough to allow an aeroplane to climb to 35 ft (10 m) after takeoff. In Australia, clearways extend from the runway or stopway end, and include the portion of land between the end of the runway and runway strip (60 m). Clearways are included in one measure of declared distance used in Australia, the take off distance available (TODA). However, since RESAs are located beyond the end of the runway strip, they are not included in the TODA (CASA, 2008).

accidents examined in this report series and analysis by others have confirmed this conclusion.

Figure 10: Distribution of stopping distance of aircraft that overrun the runway end



Source: adapted from FAA, 1989

Several recent runway overruns have had catastrophic outcomes because of a combination of the insufficient size of overrun areas, and the close proximity of urban development to runway ends. In the US alone, four serious overrun accidents since 1999 occurred on runways which had runway safety areas⁴¹ that were not of a sufficient size, resulting in 12 fatalities and 185 injuries (OIG, 2009). In recent years, ground fatalities and significant damage to property and public infrastructure resulted from aircraft overrunning the airport boundary in the 2003 Chicago Midway and 2007 Congonhas accidents.

More recently, the May 2008 overrun of an Airbus A320 in Honduras killed five people (including two on the ground) when the aircraft overran the end of runway 02 at Toncontin International Airport in Tegucigalpa and ploughed into a road, striking several vehicles. The runway, which was water-affected at the time of the accident, has a landing distance available (LDA) of 1,649 m. The aircraft touched down 400 m from the runway end threshold, overrunning at a speed of 54 kts and falling down a 20 m embankment beyond the runway end prior to impacting the road (AAC, 2008). The RESA beyond the end of the runway was only 15 m (50 ft) long (Lacagnina, 2008b). A larger safety area beyond the runway end which was free of steep terrain and obstacles could have reduced the consequences of this accident. Take-off accidents such as the tailstrike of an Airbus A340 aircraft at Melbourne Airport in March 2009 also show the usefulness of large, clear, graded areas beyond the end of runways to minimise the safety consequences to passengers and the public if an aircraft does not achieve expected take-off performance.

⁴¹ In the United States, RESAs are known as runway safety areas (RSAs). See Section 5.2.2.

5.2.2 RESA requirements

International RESA requirements

International Civil Aviation Organization Annex 14 provides the international standard for RESAs. RESAs must be provided for all Code 3 and 4 runways, and all Code 1 and 2 runways with instrument approaches. For Code 3 and 4 runways, the RESA must extend at least 90 m beyond the end of the runway strip (which extends 60 m beyond the runway threshold or associated stopway – see Figure 11).

Based on the results of the FAA study presented in Figure 10, a 90 m long RESA in addition to the 60 m long runway strip should contain about 70 per cent of runway overruns.

The width of the ICAO required RESA is twice the width of the runway.

Furthermore, for Code 3 and 4 runways, ICAO recommends that the RESA should extend (as far as is practicable) to a length of at least 240 m (787 ft) beyond the end of the runway strip. The International Federation of Airline Pilots (IFALPA) has lobbied for the 240 m long RESA recommendation to be upgraded to an ICAO standard (IFALPA, 2008). Figure 10 suggests that 90 per cent of runway overruns would be contained within a 240 m RESA (approximately 790 ft).

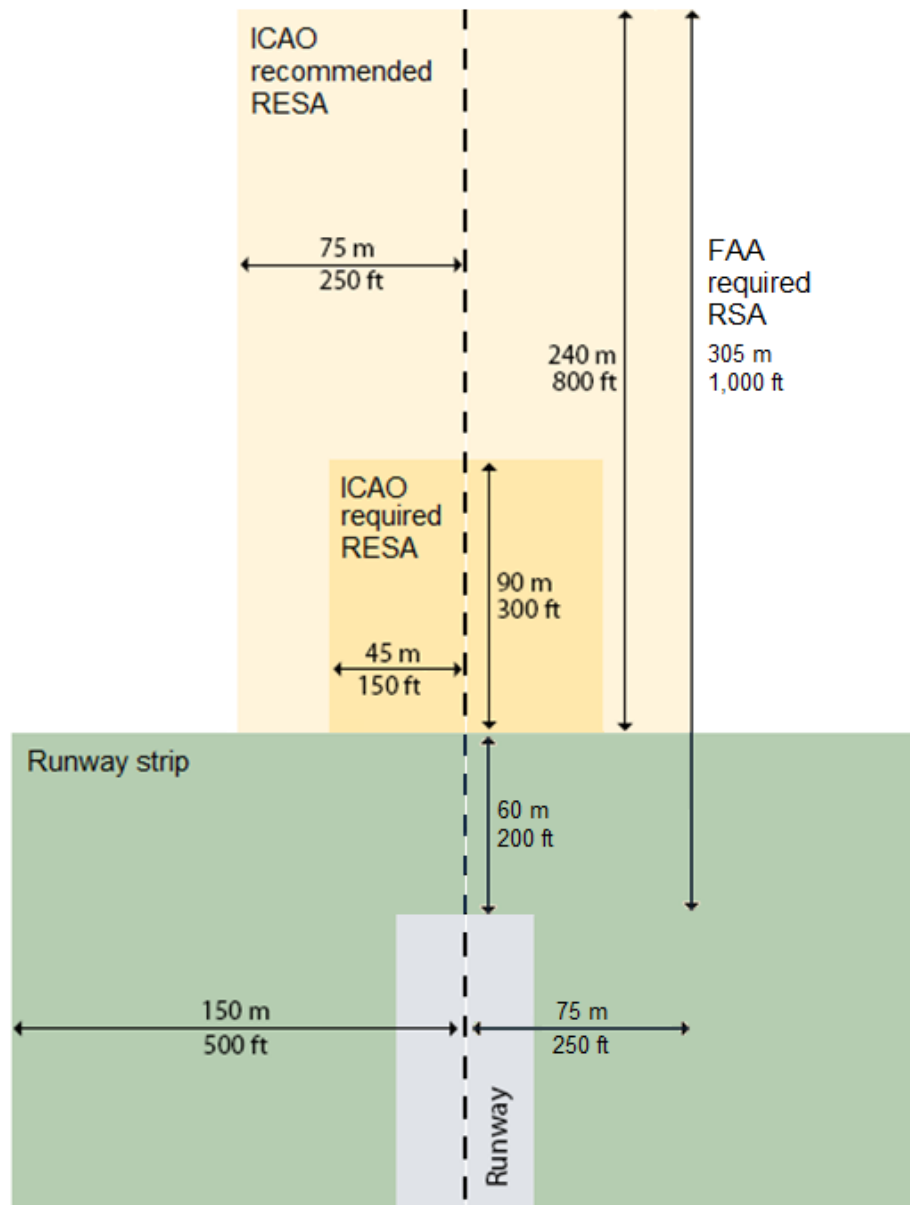
The width of the ICAO recommended RESA is equal to the width of the graded portion of the runway strip.

The European Aviation Safety Agency (EASA) does not publish specific RESA requirements beyond those set by ICAO. The ICAO 90 m requirement and 240 m recommendation are explicitly endorsed by the Airports Council International (ACI) following an October 2008 revision to the *ACI Policy and Recommended Practices Handbook (Sixth Edition)*.

The US has adopted its own requirements for RESAs which are different to the ICAO Annex 14 standard. In the US, RESAs are called runway safety areas (RSAs).

Although mostly consistent with the ICAO requirements, Australian RESA requirements have some differences from those prescribed by ICAO. The US and Australian standards are discussed below.

Figure 11: Standard and recommended dimensions for RESAs (ICAO) and RSAs (FAA)



Source: adapted from Lacagnina, 2008b

United States RESA requirements

In the US, RESAs are known as RSAs. The FAA standard is to measure RSA lengths from the end of the runway or any associated stopway, as opposed to from the end of the runway strip (which is the ICAO and CASA standard).

Prior to the late-1980s, the FAA standard for RSA length was 200 ft (90 m) (ICAO, 2007b). This is equivalent to a 30 m RESA under the ICAO measurement method. The RSA length requirement in the US was increased with the introduction of FAA Advisory Circular AC 150/5300-13, *Airport Design*, in 1989.

- A runway obstacle free zone (ROFZ) (equivalent to a runway strip) 60 m in length is required beyond the end of the runway.

- RSA lengths range from 240 ft (73 m) to 1,000 ft (305 m) beyond the end of the runway (not the runway strip), depending on the aircraft and approach minimums associated with the runway. Generally, runways used by aircraft with approach speeds higher than 121 kts require a 1,000 ft long RSA. This requirement encompasses all commercial jet aircraft, and many propeller-driven aircraft that are used for low capacity RPT services (such as the Piper PA-31 Navajo).
- RSA width ranges from 60 ft (18 m) to 250 ft (75 m) on either side of the runway centreline depending on the width of the runway, and the aircraft and approach minimums associated with the runway. Generally, runways used by commercial jet aircraft will have a 500 ft (152 m) wide RSA.

The FAA requirement for a RSA length of 1,000 ft (305 m) for runways supporting commercial jet aircraft operations is substantially longer than the ICAO 90 m RESA requirement and equates to the ICAO RESA recommendation of 240 m (Figure 11). The 500 ft width of the FAA-required RSA for runways supporting commercial jet aircraft operations is substantially wider than the ICAO 90 m RESA requirement and equates to the ICAO RESA recommendation of 150 m.

In 2000, the FAA instituted a program to review RSA requirements, improve RSAs at commercial airports to meet standards, and to work with airport operators to find alternative solutions where it was not possible to fully meet the RSA standards. As a result, over 72 per cent of commercial runways in the US now substantially meet RSA standards (up from 46 per cent in 1990), and only three per cent of runways will not be improved (down from 36 per cent in 1996) (ICAO, 2007b). The FAA has already spent US\$2 billion on the RSA Improvement Program, with the goal of achieving substantial compliance with RSA requirements at 87 per cent of the 1,020 runways in the US that are used by aeroplanes with approach speeds greater than 120 kts. The United States Congress has budgeted approximately US\$300 million per year to allow the FAA to complete these works by 2015 (OIG, 2009; Lacagnina, 2008b).

In 2009, the US Department of Transportation Office of the Inspector General completed an audit into the FAA's RSA Improvement Program, and the progress in RSA improvement works at the 11 most significant airports in the US.⁴² While the Inspector General found that the FAA and airport operators had made significant progress in bringing RSAs at these airports up to the AC 150/5300-13 standard, non-frangible structures (particularly nav aids) remained in over 40 per cent of RSAs, increasing the likelihood of major aircraft damage and potential loss of life if a runway excursion occurred (OIG, 2009).⁴³

⁴² Baltimore/Washington-Thurgood Marshall, Boston-Logan, Charlotte-Douglas, Fort Lauderdale/Hollywood, New York-John F. Kennedy, New York-LaGuardia, Los Angeles, Philadelphia, Phoenix-Sky Harbor, Washington D.C.-Reagan National, San Francisco (OIG, 2009).

⁴³ Non-frangible structures in RESAs, RSAs and other clearway areas can pose a risk to aircraft. In 1975 for example, a Boeing 727 aircraft on final approach to John F. Kennedy International Airport, New York collided with a non-frangible approach lighting system (ALS) array. The aircraft was significantly damaged, and 113 passengers were fatally injured (OIG, 2009).

Australian RESA requirements

Since 2003, CASR 139 *Manual of Standards* has specified the requirements for RESAs at Australian aerodromes.

- A 60 m long runway strip must be provided after the end of the runway (and any associated stopway).
- For Code 3 and 4 runways, a 90 m long RESA must be provided beyond the end of the runway strip.
- The width of the RESA must be no less than twice the runway width.
- A 240 m long RESA is recommended for Code 3 and 4 runways, especially at international aerodromes (CASA, 2008).

Other requirements for these areas (such as bearing strength and obstacle limitations) are also defined in CASR 139 *Manual of Standards*.

Figure 11 depicts the Australian standard RESA dimensions compared with the ICAO and FAA requirements and recommendations.

Prior to 2003, Australian RESA requirements were governed by the CASA *Rules and Practices for Aerodromes* Chapter 7 – *Design Standards for Licensed Aerodromes*. Under this old standard, the 90 m requirement for RESA length was measured from the end of the runway or any associated stopway, rather than from the end of the 60 m long runway strip (CASA, 2002b). Under the new ICAO-based definitions where the RESA is measured from the end of the runway strip, the *Rules and Practices for Aerodromes* requirements would make a RESA of only 30 m in length for Code 3 and 4 runways. Based on the FAA analysis presented in Figure 10, such a short RESA would decelerate and stop only 50 per cent of aircraft overrunning the runway.

The CASR 139 requirements for RESAs at Australian airports are now in line with ICAO standards (as of March 2009). The CASR 139 Regulation Impact Statement stated that all Code 4 runways being used for international jet operations must have met the new RESA standards within five years of promulgation of CASR 139 (by January 2008⁴⁴). However, apart from Code 4 runways being used by international jet operations, the CASR 139 standard applies only to new runways and existing runways when they are lengthened, meaning that existing RESAs that were built under the previous *Rules and Practices for Aerodromes* legislation do not have to meet the CASR 139 *Manual of Standards* length requirements.

As a result of these changes to the CASA standards for RESAs, a number of Australian airport operators have been required to make their runway RESAs longer. CASR 139 *Manual of Standards* provides several options to do this:

- provide additional land to meet the specified RESA requirement;
- reduce runway operating length to cater for the RESA requirement; or
- where it is not practicable to provide the full required RESA length, use an engineering solution to prepare the RESA surface such that it will assist effectively in aircraft deceleration, for example, through use of a soft ground arresting system (see Section 5.3) (CASA, 2008).

⁴⁴ The CASR Part 139 Regulation Impact Statement was approved by CASA on 16 December 2002. The CASR Part 139 rules were promulgated in January 2003.

At aerodromes owned by the Department of Defence which have civilian operations (Darwin/RAAF Darwin, Derby/RAAF Curtin, Exmouth/RAAF Learmonth, Newcastle/RAAF Williamstown, and Townsville/RAAF Garbutt), aerodrome design standards are specified in the Defence publication ADFP602 *Joint Services Works Administration Aerodrome Design Criteria*. This publication does not define or use the term RESA. It does however use the term ‘stopway’, which is defined as a paved or stabilised rectangular area at the end of the runway in which an aircraft can be stopped in the case of an aborted take-off. ADFP602 specifies that the stopway distance should normally extend 305 m beyond the end of the runway for the width of the combined runway and shoulders. The first 60 m is normally paved to at least the same strength as the runway shoulder pavement, with the remainder to be stabilised to cause minimal damage to overrunning aircraft.

It is important to note that the definition of a ‘stopway’ as per ADFP602 is significantly different from that used by CASA in CASR 139 *Manual of Standards – Aerodromes*.

5.2.3 RESAs at Australian airports

There is a lack of published RESA information in the Australian Aeronautical Information Publication (AIP). Dimensions of RESAs are not easily calculable from declared distance data in the En Route Supplement Australia (ERSA), because RESAs and clearways may overlap under the CASR 139 regulations. The lengths of RESAs are not the same on all runways, and it is important that pilots be aware of this before assuming that their destination runway has a RESA of the standard size.

As a central record of Australian RESAs was not available, the ATSB conducted a telephone survey of Australian airport operators with Code 3 and 4 runways to determine what RESAs were installed. Airport operators were asked:

- if they had implemented a 90 m long RESA, measured from the end of the 60 m runway strip;
- the actual dimensions and surface type of the RESAs provided;
- if they had provided the CASA and ICAO-recommended 240 m long RESA (required for runways with international operations); and
- if they had considered a RESA extension beyond the 90 m requirement, were there any limitations that prevented an extension to the recommended 240 m.

The 43 airports surveyed included all primary capital city airports, all international airports, mining charter airports with jet services, and airports in major regional centres that had scheduled high-capacity RPT operations. The responses were generally provided by the airport operations manager or by the airport engineer. A full list of airports surveyed is included in Appendix B.

Standard 90 m RESAs

At the time of writing (mid 2009), all Australian airport operators with Code 4 runways handling international jet RPT and charter services (except Sydney Airport) had undertaken works to meet the new CASR 139 *Manual of Standards* requirements of a 90 m RESA measured from the end of the runway strip. Sydney Airport is scheduled to finish these works before the end of 2009.

Some regional airports still provide the 90 m RESA measured from the runway end, as specified by the earlier *CASA Rules and Practices for Aerodromes* requirements. This specification provides a RESA which extends 30 m from the runway strip end under the current CASR 139 *Manual of Standards* requirements. The CASR 139 *Manual of Standards* allows for runways built under the previous requirements to not meet the new 90 m RESA length requirement as long as the runway is not lengthened, upgraded, or used for international jet operations.

A very high number of Code 3 runways and non-international Code 4 runways surveyed had a RESA at least 90 m long as measured from the end of the runway strip. This is despite the fact that it is unlikely that most Australian airports have built new runways or undertaken runway lengthening programs since CASR 139 was promulgated in 2003.

The majority of the airports surveyed (70 per cent) provided 90 m or longer RESAs on all the Code 3 and 4 runways from the end of the runway strip. Seven per cent of airports provided at least one RESA of 90 m or longer length; several of these airports (such as Sydney) were in the process of upgrading all RESAs to the full 90 m dimensional standard. At 18 per cent of airports surveyed, the RESA was less than 90 m in length as per the previous *Rules and Practices for Aerodromes* requirements. The remaining two airports (5 per cent) did not provide data.

Gravel, or a natural grassed or dirt surface (or a combination of both) were the most common RESA surface materials.

The challenges of improving runway safety – Sydney Airport runway 07/25 RESA extension

Following the new RESA requirements introduced by CASR 139 in 2003, all international Australian airports with Code 4 runways were required to provide 90 m long RESA areas by 2008.

In 2008, construction works began on a RESA extension to the western end of the cross-runway at Sydney Airport (runway 25 end). This is the last of the runways at Sydney Airport to be extended to the new requirements, with the other five runways having their RESA extensions completed in 2006.

The RESA extension at the end of runway 25 is no easy task. Compared with other runways at the airport which had areas of vacant land beyond their ends, there is a raft of major infrastructure beyond this end of the runway 25. This includes (Figure 12):

- an airport perimeter road;
- the heritage-listed Sydney Water South and Western Suburbs Ocean Outfall Sewer (SWSOOS), which is the largest sewer in Greater Sydney;
- the M5 East freeway, and its associated tunnel beneath the Cooks River;
- high-voltage electricity transmission cables; and
- the Cooks River.

Complex engineering works to a value of A\$85 million will be conducted to extend the runway around this major infrastructure, and extend the RESA to the required 90 m length. This is a large cost compared with the other five RESA extensions already completed, which cost just A\$3 million in total.

During the construction works, the cross-runway will have limited operations, and noise sharing arrangements will be in place. The project is expected to be complete by the end of 2009.

Figure 12: Sydney Airport cross-runway RESA extension, runway 07 end



Source: Sydney Airport Corporation Limited (SACL, 2007; SACL, 2008a; SACL, 2008b)

Extending RESAs to the 240 m recommendation

Some airports provided RESAs longer than the CASA requirement of 90 m. Some of these were to the 240 m length recommended by ICAO.

- Alice Springs (all runway ends)
- Avalon (all runway ends)
- Canberra (one runway end)
- Darwin (three runway ends)
- Derby (RAAF Curtin) (all runway ends)
- Exmouth (RAAF Learmonth) (all runway ends)
- Melbourne (all runway ends)
- Mildura (all runway ends)
- Newcastle (RAAF Williamtown) (all runway ends)

Melbourne and Darwin were the only international airports in Australia to provide RESAs close or equal to the 240 m ICAO recommendation. It is important to note though that these airports are located in urban fringe areas. Most other Australian international airports are located in built-up areas with limited available land (see Table 1 in Section 3.3.2). Runways at land-constrained airports, such as Sydney, have required major engineering works to meet the new *CASR 139 Manual of Standards* RESA length requirement of 90 m from the end of the runway strip.

The Australian Airports Association reported to the ATSB that the Association does not believe a safety case for extending RESAs beyond 90 m in length can be mounted or sustained.

A number of airport operators indicated that they had conducted studies of RESA extensions in light of the ICAO Annex 14 recommendation that all Code 3 and 4 runways should extend to at least 240 m if practicable, but determined that an extension to the recommended 240 m was impractical. Common reasons cited for this were:

- houses, roads and other public infrastructure lay within 240 m of the runway strip end, which would have to be resumed to create an extended RESA;
- sensitive habitats (such as wetlands, and sites sacred to Indigenous Australians) lay within 240 m of the runway strip end, which might be damaged or require relocation by the construction of an extended RESA; or
- large terrain obstacles lay within 240 m of the runway strip end, such as ocean, cliffs, coral reefs, ravines and creeks.

At remote airports (such as Moomba in the far-north of South Australia and Ballera in far-western Queensland), overrunning aircraft could be decelerated by large areas of existing flat land that extend well beyond the runway strip end, to a distance of over 240 m.

The cost impact of a large RESA extension would impact on regional airport operators if the 240 m ICAO recommendation became a requirement for those airports. This is especially the case when major earthworks would be required to provide a larger RESA at an airport. From a cost-benefit perspective, most regional

airports run on small operating margins, and handle an insufficient number of large aircraft operations for a 240 m RESA to necessarily provide a significant safety benefit.

5.3 Soft ground arrestor beds

Soft ground arrestor beds are used at some space-confined airports as an additional measure to increase runway safety. In the same way that highway safety ramps work for trucks, soft ground arrestor beds are made of a material that will deform readily and predictably when an aircraft overruns onto it. As the aircraft tyres crush the material, the increased drag forces decelerate the aircraft (NTSB, 1998). As a result, overrunning aircraft will stop in a considerably shorter distance than they could on a standard RESA alone.

Soft ground arrestor beds are placed within the airport boundaries, usually beyond the length of RESA or RSA that is available. They are constructed from materials that may include (but are not limited to) gravel beds and collapsible concrete.

Soft ground arrestor beds are not designed to replace RESAs. They exist to complement RESAs or RSAs if the full dimensional requirements cannot be provided. They also provide an additional level of protection against runway overruns for airport operators, nearby communities and infrastructure. Not all runway excursions can be controlled by a soft ground arrestor bed. For approximately half of runway excursions, the final position of the aircraft or wreckage is likely to be outside the boundaries of a standard bed beyond the runway end. This shortcoming reinforces the need to have clear, graded RESA and runway strip areas, even if a soft ground arresting system is fitted.

Some types of soft ground arrestor beds involve large capital infrastructure investment, and hence their installation should be supported by an assessment of their safety benefit in each specific location compared to improving other risk controls (such as runway grooving/surface texturing, lighting, signage, or extending RESA lengths).

5.3.1 What is the need?

Most runways worldwide were built during an era when aircraft landing speeds were considerably slower than they now are in modern jet aircraft, before the existence of regulations requiring RESAs, or under earlier standards which recommended shorter RESA lengths. Aviation safety regulators, such as CASA and the FAA, actively work to ensure that these airports can provide RESA areas that meet legislative requirements.

Sometimes, airport operators around the world cannot fully meet RESA requirements. Common limitations for meeting these requirements are the location of runways adjacent to urban development, highways, wetlands, waterways, or sharp terrain drop-offs that do not allow a standard safety area to be provided (NTSB, 1998). In these cases, construction and/or environmental costs would be exceedingly high to allow the RESA to meet full dimensional standards (ICAO, 2007b). The FAA, CASA, the Civil Aviation Authority of the United Kingdom (CAA), and other regulators provide two preferred alternatives to allow these runways to meet the RESA standards: shortening or relocation of the runway, or reduction of the declared runway length (TORA).

Projects such as relocating runways can be impractical, or exceedingly expensive (in the order of US\$10-30 million). Shortening runways or reducing declared runway distances may have a negative impact on airport operations (JDA, 2003b). In the US, FAA policy on RSAs does not allow a reduction of runway length or use of declared distances if there would be an operational impact on aircraft that currently or are planned to use the airport (FAA, 2005).

In these cases, some regulators recommend installation of a soft ground arrestor bed as a cost-effective and practical alternative to a full dimensional RESA or RSA. A standard soft ground arrestor bed is designed to provide a level of overrun and undershoot safety which is equivalent to a full RESA or RSA (FAA, 2005).

5.3.2 Types of soft ground arrestor systems

Several types of soft ground arrestor system have been installed at selected commercial airports across the world:

- Engineered Materials Arresting System (EMAS);
- Lytag, which is a type of pulverised fuel ash;
- Engineered Rootzone Arresting System (ERAS);
- air-entrained concrete; and
- pavement quality concrete (PQC).

Use of soft ground arrestor systems result in minimal or no damage to the aircraft, dramatically reducing the risk of a post-crash fire.

Engineered Materials Arresting System (EMAS)

The Engineered Materials Arresting System (EMAS) is the most widely employed type of soft ground arrestor system. It is currently the only FAA-approved system (as of 2008), and hence is focused on in this report. The EMAS is developed by New Jersey-based Engineered Arresting Systems Organization (ESCO).

The EMAS soft ground arrestor bed is a surface of cellular, aerated concrete blocks that collapse under heavy load. They are able to support the weight of airport and airport rescue and fire fighting (ARFF) vehicles with none to minimal deformation, but collapse under the weight of an aircraft. An EMAS bed works by transferring the kinetic energy of the overrunning aircraft into the action of crushing the concrete blocks, creating drag at the leading edge of the wheel and decelerating the aircraft (ESCO, 2008a). Figure 13 shows an EMAS bed installed beyond the end of a runway.

Figure 13: An EMAS bed installed at Minneapolis-St Paul International Airport (KMSP), runway 12R end



Source: Engineered Arresting Systems Corporation (Peters, 2007)

The EMAS beds are usually designed with a short entry ramp to give the overrunning aircraft a smooth transition from the RESA or RSA surface (Figure 14). To protect the EMAS bed from damaging jet blast, they must be set back a minimum of 75 ft (23 m) from the end of the runway surface, irrespective of the length of RESA or RSA provided. The surface is also coated with a special jet blast resistant coating by the manufacturer, which is designed to last between 5 and 10 years in service (Rosenkrans, 2006).

Figure 14: An EMAS transition ramp at San Diego International Airport (KSAN), runway 09 end



Source: San Diego County Regional Airport Authority (Peters, 2007)

An EMAS bed requires minimal maintenance, with most work involving protection of surface coatings (painting and caulking). Repainting of the entire bed may be required every 3 to 5 years (ESCO, 2009). Runway maintenance personnel are recommended by the manufacturer (ESCO) to conduct weekly to monthly inspections to remove foreign objects and reseal joints between individual cells as required (Peters, 2007).

If an aircraft overruns the runway and is stopped or decelerated by the EMAS bed, the bed can be restored back to its original condition by replacing only the concrete cells that were damaged by the aircraft. This significantly reduces the replacement cost to airport operators following a runway overrun, and minimises the operational impact on that runway for other aircraft movements.

Based on operational experience of three major runway excursions at John F. Kennedy International Airport in New York where EMAS stopped the aircraft (Section 5.3.4), the aircraft can be removed in a few hours using several tugs towing the aircraft back out onto the runway. Repair timeframes depend on the amount of EMAS cells damaged, however, the maximum allowable time for repairs mandated by the FAA is 45 days. In one of these three overruns, involving a Saab 340 aircraft, the EMAS bed was repaired within 12 days. During the period of the repair work, the FAA allows airport operators to reopen runways if a notice to airmen (NOTAM) is issued stating that the EMAS is out of service (ESCO, 2009).

Alternatives to EMAS

The US is leading research into soft ground arrestor beds, with the FAA continuing to examine alternative arrestor bed materials through the *Airport Cooperative Research Program Project 07-03*. This US\$500,000 project is operated through the Transportation Research Board of the US national Academy of Sciences, with research and trials being conducted by a non-government consultant (Protection Engineering Consultants, LLC of Dripping Springs, Texas). The results of this project are expected in mid-2009 (TRB, 2009; FAA, 2007b).

Lyttag arrestor beds were fitted to a number of RESAs in the UK during the 1990s, including runways at Southampton, London City and Gloucestershire Airports (TSB, 2007). Lytag is a product based on pulverised fuel ash (PFA), which is waste material produced by coal-fired power stations. Due to some safety concerns, Lytag beds have been removed from most of these airports, and replaced with pavement quality concrete (PQC). The CAA recommended the removal of the Lytag beds as they ‘presented a considerable hazard from the possibility of fire from pooled fuel following a tank rupture’ (Transport Research Laboratory, 2004).

Urea formaldehyde foam arresting beds were also trialled in the UK in the 1960s and 1970s to arrest commercial aircraft, and provided significant data towards developing soft ground arrestor bed performance models (ICAO, 2005). Today, fuel ash or concrete-based materials (such as EMAS) are more commonly used in soft ground arresting beds.

Engineered Rootzone Arresting System (ERAS) is an arresting system developed in the US by Rhode Island-based GridTech, and is being trialled as part of the FAA *Airport Cooperative Research Program*. It comprises a layered arrestor bed of Lytag and an aggregate base material. The Lytag layer is protected from jet blast by a surface layer of Netlon™ artificial grass (GridTech, 2004).

5.3.3 Requirements for soft ground arresting systems

The requirements for RESAs in ICAO Annex 14 not identify or prescribe any alternative to a full dimensional RESA, and do not specify any requirements or recommendations for soft ground arresting systems.

As a result, FAA Advisory Circular AC 150/5220-22A, *Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns*, is the international standard by proxy on the requirements of soft ground arresting systems, in particular EMAS.

If an EMAS bed is provided, the total RSA length requirement (including the EMAS bed) is reduced from 1,000 ft (305 m) to 600 ft (183 m) from the end of the runway surface (see Figure 15 for an example of a normal RSA compared to an RSA with an EMAS bed installed).

The FAA specifies the following requirements for EMAS systems installed at airports in the US (FAA, 2005):

- EMAS beds can vary in length, depending on the aircraft types that typically use the runway. The ‘critical’ or design aircraft may not always be the heaviest aircraft to use the runway; it is the heaviest aircraft that is operated at least 500 times a year on that runway (Lacagnina, 2008b).
- The EMAS bed should be placed on the extended runway centreline, and be as least as wide as the runway.
- The EMAS bed should be placed as far back from the runway end as practicable.
- The EMAS bed should be designed to stop an aircraft with no reverse thrust and a poor braking coefficient (μ of 0.25), which overruns the runway end at:
 - 70 kts if the far end of the EMAS bed is set back 600 ft (183 m) from the end of runway end (a ‘standard’ EMAS bed); or
 - 40 kts if the far end of the EMAS bed is set back less than 600 ft (183 m) from the runway end (a ‘non-standard’ EMAS bed).
- It must be able to withstand (without deformation) the load of regular pedestrian traffic, runway inspection and maintenance vehicles, and fully loaded ARFF vehicles.
- It must be resistant to fire, water, ice, aircraft fuel, ultraviolet radiation, and other types of deformation.
- It must be designed to facilitate safe passenger egress from both the aircraft and the EMAS bed in the event of an overrun.
- It must be designed to minimise the potential for structural damage to the aircraft, as such damage could result in injuries to passengers.

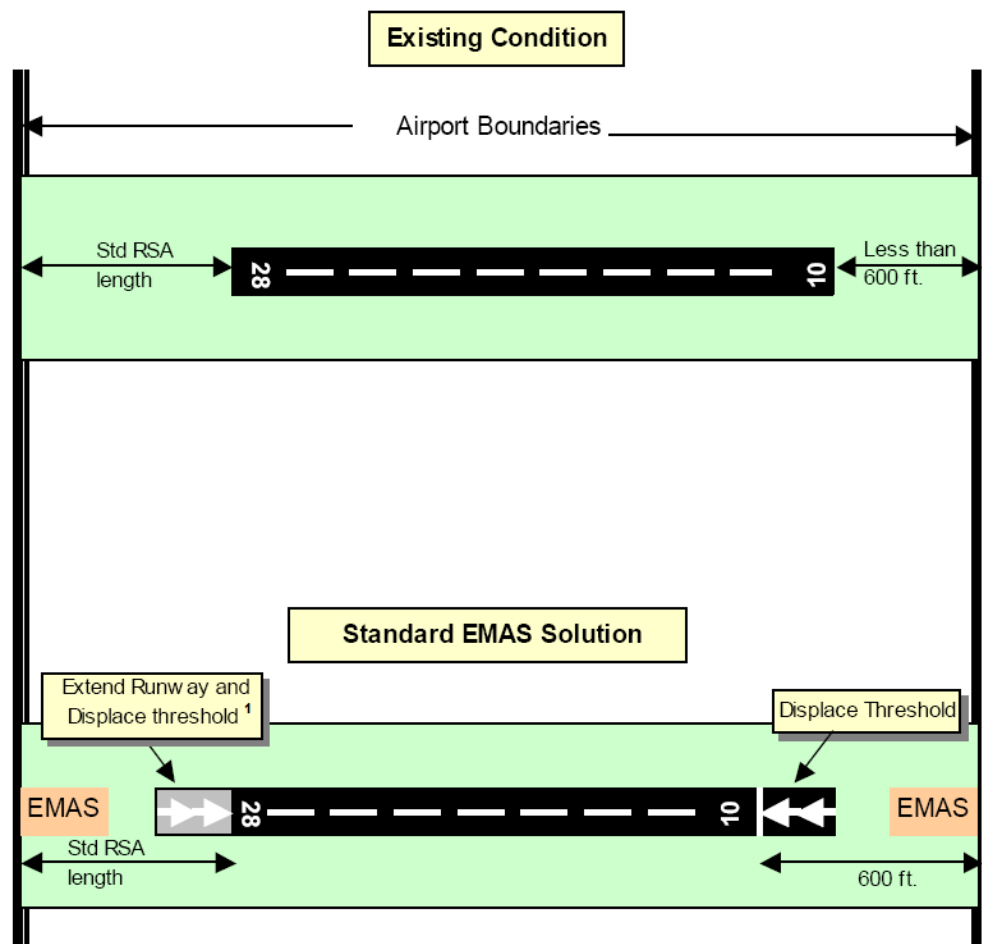
Federal Aviation Administration Order 5200.9, *Financial Feasibility and Equivalency of Runway Safety Area Improvements and Engineered Material Arresting Systems*, is used by the FAA and US airport operators to determine the best practicable and financially feasible alternative to improve an RSA. This determination is based on construction and ongoing maintenance costs over a predicted 20 year design life. An EMAS is one option.

Figure 15 depicts a standard EMAS installation, as per the FAA requirements. It shows how an EMAS system can be used with a shorter RSA (600 ft instead of 1,000 ft) to provide the equivalent level of overrun safety of a full dimensional RSA, and alleviate the need to reduce declared distances.

Even if a standard length EMAS arrestor bed cannot be installed due to limited land beyond the runway end, a non-standard shorter bed will help to slow an aircraft that overruns the runway, reducing the consequences of a runway overrun to life and property (FAA, 2007b). Non-standard EMAS beds have been installed at inner urban airports in the US where space is limited, such as Chicago Midway Airport.

Most other national aviation safety regulators that authorise the use of soft ground arresting systems as partial RESA alternatives base their requirements on the FAA standard, with some differences. In the United Kingdom, where RESA regulations are based on the 90 m ICAO requirement, the CAA regulation CAP 168, *Licensing of Aerodromes*, allows for the installation of soft ground arrestor beds beyond the required RESA length (CAA, 2007).

Figure 15: Example of an FAA-approved EMAS (standard installation)⁴⁵



Source: FAA, 2004b

⁴⁵ Figure notes:

1. The runway extension and EMAS beyond the end of runway 10 could be eliminated if sufficient landing distance remained after displacing the runway 10 threshold.

5.3.4 EMAS performance

Ability to decelerate aircraft

Studies by the FAA have shown that a standard EMAS installation at an airport with a full dimensional RSA will arrest 90 per cent of runway overruns, and accommodate 90 per cent of undershoots. For example, a standard EMAS bed of 400 ft (122 m) in length installed in a 600 ft (183 m) full dimensional RSA is able to stop a Boeing 737-class aircraft overrunning the runway end at 70 kts (FAA, 2004b) (Figure 16).

Appendix F provides the FAA and manufacturer-estimated EMAS bed length required to stop a Boeing 737-400, Boeing 747, Douglas DC-9, McDonnell Douglas DC-10, and Bombardier CRJ-200 aircraft. These aircraft represent a range of narrowbody and widebody aircraft. In 2009, the Boeing 747 and numerous models of the Boeing 737 were utilised in a significant portion of jet RPT services in Australia. Aircraft of equivalent size and weight in service of the DC-9, DC-10 and CRJ-200 aircraft were also common with Australian RPT and charter operators.

Figure 16: FAA performance trials of the EMAS system, simulating a runway overrun of a Boeing 727-200 aircraft



Source: Engineered Arresting Systems Corporation (ESCO)

Unlike RESAs, the performance of soft ground arrestor beds such as EMAS are not influenced by surface friction. The presence of standing water, snow, ice or other contaminants that decrease the friction of the runway and the RESA surface, have no effect on aircraft deceleration across the bed.

One limitation of the EMAS system is that it is unable to stop aircraft that veer-off the side of the runway, and may be unable to fully stop an overrunning aircraft that also veers left or right of the extended runway centreline beyond the end of the runway. This is because a standard EMAS installation is the same width as the runway (JDA, 2003a). Of the 120 runway excursions that occurred on landing

between 1998 and 2007, 48 were veer-offs. From the remaining 72 overruns, analysis by Kirkland and Caves (2002) indicates that approximately 10 per cent of these aircraft would have come to rest outside the 45 m width of a typical Code 3 or 4 runway (i.e. more than 22.5 m left or right of the extended centreline). Thus, for approximately half of runway excursions, the final position of the aircraft or wreckage is likely to be outside the boundaries of a standard EMAS bed.

This shortcoming reinforces the need to have clear, graded RESA and runway strip areas, even if a soft ground arresting system is fitted.

In-service performance

At some airports, arrestor systems have been installed only after a severe runway excursion accident has happened. For example, an EMAS bed was installed beyond the runway ends at Little Rock National and Chicago Midway Airports in the US after two fatal overruns in 1999 and 2003 respectively. At both of these airports, the need for an alternative aircraft arrestor system existed prior to those accidents occurring as unfavourable terrain and urban development restricted the ability to provide room for a full dimensional RSA/RESA.

Following these and other overrun accidents, the FAA has been promoting the installation of standard and non-standard EMAS beds at space-limited airports in the US. As of December 2007, 30 EMAS beds had been installed at 21 airports. Another 21 EMAS beds are currently under contract (as of December 2007), with eight to be installed in 2008. Outside of the US, two airports in China and Spain have EMAS systems installed. At both of those airports, terrain or urban development prevent a full 90 m RESA from being provided (ESCO, 2007).

Arrestor beds have minimised the consequences of some overruns in recent years. In the US alone, EMAS beds have been credited with five overrun 'saves' at major airports (Lacagnina, 2008b), involving a range of aircraft types.

A full list of airports with existing and planned EMAS installations (as of November 2007) is provided in Appendix E.

EMAS 'saves' at John F. Kennedy International Airport, New York

2005

A 610,000 lb (276,694 kg) Boeing 747 freighter aircraft landed long, and overran the end of the runway at 70 kts. The aircraft was stopped by the EMAS bed, with no injuries to the flight crew. Damage to the aircraft was limited to the replacement of nine tyres, and it was returned to service within a few days.

2003

A 470,000 lb (213,191 kg) McDonnell Douglas MD-11freighter aircraft landed long, and overran the end of the runway at low speed. The aircraft was stopped by the EMAS bed, with no injuries to the flight crew and no major aircraft damage. The aircraft was extracted from the EMAS bed within a few hours, and the runway returned to service (Figure 17).

1999

A 22,000 lb (9,979 kg) Saab 340B commuter aircraft overran the end of the runway at 75 kts. The aircraft was stopped by the EMAS bed. Damage to the aircraft was minor, and the only injury was a twisted ankle sustained by a passenger during evacuation. The aircraft was extracted from the EMAS bed within four hours.

Source: Aviation Safety Network Database; FAA, 2007b; JDA, 2003a

Figure 17: McDonnell Douglas MD-11 runway overrun, John F. Kennedy International Airport, New York, 2003



Source: Port Authority of New York and New Jersey

5.3.5

Australian use of soft ground arresting systems

Under the requirements for RESAs in CASR 139 *Manual of Standards*, airport operators may include an ‘engineering solution’ as a supplementary measure if the full dimensional requirements of a RESA cannot be met. In this case, the operator must liaise with CASA to determine the best solution to enhance aircraft deceleration (CASA, 2008).

At the time of writing (mid 2009), there were no Australian airports equipped with soft ground arrestor beds.

There are some fundamental differences between the FAA requirements for RSAs and the CASA requirements for RESAs which would affect the in-service performance of an EMAS bed and its ability to completely stop an overrunning aircraft. The FAA requires a 1,000 ft long (305 m) RSA, or 600 ft long (183 m) RSA if a standard EMAS is installed within the RSA (as measured beyond the end of the runway surface). In comparison, CASA requires a 90 m (295 ft) RESA beyond the runway strip which extends 60 m (197 ft) beyond the runway. This total distance of 150 m (492 ft) is about half of the FAA length requirement for RSAs if an EMAS was not installed.

Actual performance trials (Figure 16) and mathematical modelling of EMAS beds by the FAA established that a 400 ft (122 m) long EMAS bed was able to stop a Boeing 737 departing the runway end at 70 kts (Appendix F). This assumed that a 200 ft (61 m) setback area existed between the runway end and the start of the EMAS bed (i.e. the total RSA length including the EMAS bed is 600 ft). This is approximately equivalent to the length of the ICAO-required runway strip.

Using the Boeing 737 as an example, if the same 400 ft (122 m) long EMAS bed was installed at an Australian airport because it could not meet the 90 m RESA requirement (ending 150 m beyond the runway end), the EMAS would have to be located within the runway strip area under 30 m from the end of the runway. This would be impractical and would not stop an aircraft leaving the runway at 70 kts as modelled.

If an Australian airport operator chose to install a 400 ft EMAS after the required 90 m RESA area due to an inability to provide the full 240 m RESA that is recommended by CASA and ICAO, then it should perform as modelled.

Given that a number of airport operators surveyed indicated that it was impractical to extend their RESAs much beyond 90 m, EMAS could be an option to consider to provide a similar level of protection from overruns to that which would be provided by the 240 m recommended RESA. For runways where Boeing 737-sized aircraft are the largest aircraft operating from the runway, the total RESA area would have to be approximately 210 m in length (if the EMAS was placed beyond the 90 m RESA), or 120 m in length (if the EMAS was allowed to overlap the 90 m RESA). For runways where large aircraft operate (such as the Boeing 747), a 600 ft long EMAS would be needed. This would result in a total RESA area of approximately 330 m (if the EMAS was placed beyond the 90 m RESA), or 240 m (if the EMAS overlapped the 90 m RESA). This is the more distance than the 240 m RESA length as recommended by ICAO.

If an airport did not have enough land to provide these distances, the EMAS would have to be a shorter, non-standard bed, and would only be able to stop aircraft overrunning the runway end at speeds lower than 70 kts.

Therefore, it is unlikely that a standard EMAS could be fitted to an Australian runway unless airport operators acquired more land at the runway end to allow RESA extensions, especially if the EMAS bed was required to be placed beyond the end of the 90 m RESA. Irrespective of the large costs involved in significantly extending RESAs, significant RESA extensions at urban airports such as Adelaide and Sydney would also require acquisition of homes, businesses and public infrastructure to provide the necessary land.

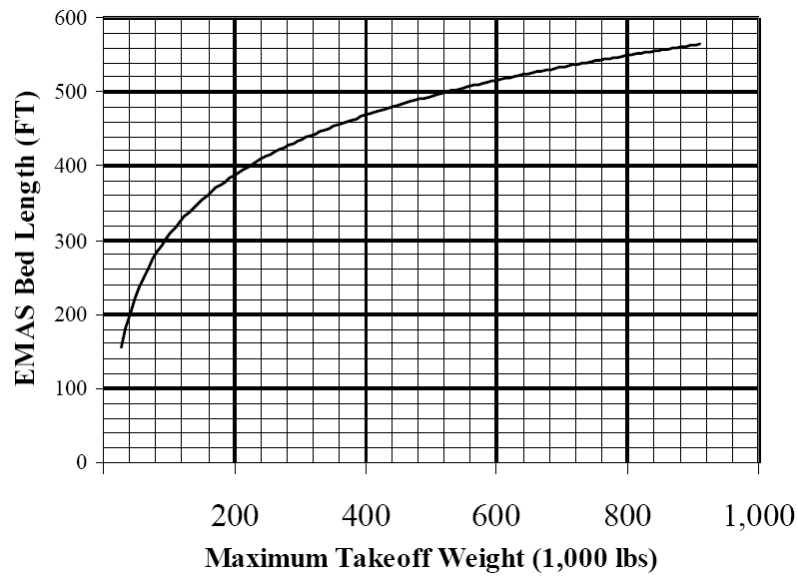
One possible option for these airports might be to employ non-standard length EMAS or other soft ground arrestor beds. Non-standard EMAS beds (closer to the runway and/or a shorter bed length) would not perform as modelled by the FAA, but would still assist in aircraft deceleration. Non-standard EMAS beds are designed for slower aircraft entry speeds, but require less RESA length between the end of the runway strip and the far end of the arrestor bed. Due to limitations in terrain or acquiring land beyond the runway ends, more than half of the EMAS systems in service worldwide are non-standard (Rosenkrans, 2006).

5.3.6 EMAS cost and installation challenges

While they are the most effective way to decelerate overrunning aircraft, soft ground arrestor beds are significantly more of a cost burden on airport operators than other risk controls such as RESA improvements, runway grooving and surface texturing, and other runway surface friction treatments. They have a high installation cost, a limited life, and require ongoing maintenance and inspection works.

For installations in the US, FAA Order 5200.9, *Financial Feasibility and Equivalency of Runway Safety Area Improvements and Engineered Material Arresting Systems*, provides airport operators with an estimation of the difference between the costs of installing an EMAS and improving an RSA to meet FAA standards. Installation costs for an EMAS depend on the length of the EMAS bed that is required for the aircraft that typically service that runway (i.e. the critical/design aircraft). Figure 18 shows the relationship between the maximum takeoff weight (MTOW) of the design aircraft, and the required EMAS bed length. Figure 19 shows the maximum feasible cost of improving an RSA to meet FAA standards in US dollars, based on EMAS bed length. Costs for other works that may be required to extend a RESA or RSA (such as acquisition of real estate, filling of watercourses, or realignment of roads and highways) are supplementary to these estimates.

Figure 18: FAA-estimated EMAS length requirements versus design/critical aircraft MTOW⁴⁶

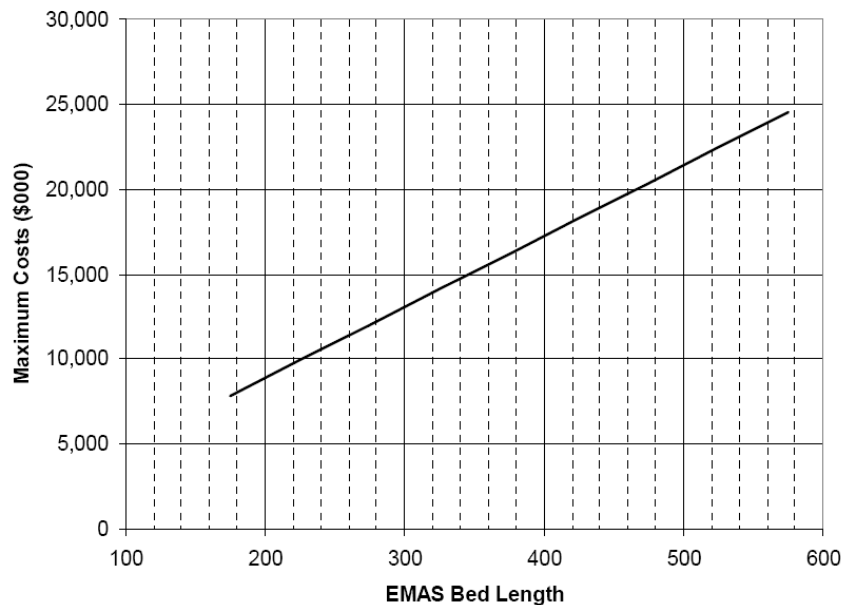


Source: FAA, 2004b

⁴⁶ Figure notes:

1. EMAS bed length does not include the setback from the runway.
2. This figure is conservative for aircraft with an MTOW less than 50,000 lb. The FAA recommends contacting the EMAS manufacturer for a more accurate EMAS bed length estimate for specific aircraft models.
3. The EMAS bed length is based on aircraft leaving the end of the runway at a groundspeed of 70 kts, with a runway setback distance of 75 ft.

Figure 19: FAA-estimated RSA improvement cost compared to EMAS bed length⁴⁷



Source: FAA, 2004b

If the actual costs of improving the RSA exceed those in Figure 19, then the FAA recommends that the best safety alternative be implemented (such as a non-standard EMAS) up to the feasible cost. The cost of the EMAS installation itself varies depending on site preparation required, and the required bed length (Figure 18). Based on existing EMAS installations and a 20 year lifecycle where the EMAS material is replaced every 10 years, the FAA suggests that the costs of installing an EMAS are approximately:

- **Site preparation** (including relocation of utilities and runway approach lighting) – US\$14.00 per square foot
- **EMAS bed material and installation** – US\$78.00 per square foot
- **Maintenance** – US\$1.00 per square foot, every three years
- **Periodic inspection** – variable (in the case of the EMAS system provided by ESCO, the manufacturer provides quarterly inspections at no cost to the airport operator in the first year of installation).

For example, including the EMAS bed setback of 75 ft, an EMAS bed 400 ft in length beyond the end of a 100 ft wide runway is estimated by the FAA to cost US\$3,785,000 (FAA, 2004b).

⁴⁷ Figure notes:

1. Maximum feasible cost applies to both runway ends and the full width of the RSA.
2. This figure assumes the runway is 150 ft wide. For narrower runways, multiply the maximum cost by 0.67. For runways 200 ft in width, multiply by 1.33.
3. EMAS bed length does not include the setback from the runway end.
4. When calculating EMAS bed length in this figure, use the EMAS bed length for one end of the runway only (not the total length for both ends).

Repair costs to the EMAS bed following damage from a runway excursion are usually borne by the aircraft operator's insurer (ESCO, 2009).

As of April 2009, there is only one manufacturer that is approved by the FAA to supply and install EMAS systems (ESCO). For such systems to be installed in Australia, CASA would be required to honour the FAA certification, or more appropriately evaluate EMAS systems locally so that any beds installed in Australia would provide an equivalent level of performance considering Australian requirements for RESAs and runway strips (which differ from those in the US). In addition, local representation from the EMAS manufacturer would be required to ensure that EMAS beds are correctly installed and that adequate post-installation support and repair services are available to Australian airport operators.

Due to the large capital infrastructure investment involved in some soft ground arrestor bed systems, their installation should be supported by an assessment of their safety benefit at that particular location compared to that of improving other risk controls (such as runway grooving/surface texturing, lighting, signage/RDRS, or by extending RESA lengths where this is realistically achievable).

5.4 Other arresting technologies

Aircraft arresting systems have traditionally been the domain of military aviation, and are used at many Department of Defence airfields in Australia for deliberately stopping military aircraft to provide a shorter landing rollout. Joint user or lease operations occur at some of these airfields (see Appendix B for a full list). As military arresting systems are designed for use with fighter aircraft, they do not necessarily have the capability to decelerate larger transport aircraft, military or commercial.

Arresting technologies in use (besides soft ground arrestor beds) include:

- foam arresting beds;
- arrestor nets; and
- arrestor hooks/cables.

Arrestor nets are raised by a stanchion system activated by the on-duty air traffic controller if emergency arresting of an aircraft is required. As the arrestor net envelopes the aircraft, rotary hydraulic brakes activate to provide a uniform braking force, and smoothly decelerate the aircraft without damage (AmSafe, 2008). Arrestor nets at Defence airfields in Australia are provided specifically for aircraft that are not fitted with arrestor hooks (primarily the BAE Systems Hawk aircraft, which has an MTOW of 9,100 kg).

Some arrestor net systems produced today around the world have the capability to arrest military aircraft in the 20,000-40,000 kg range that exit the runway end at 160 kts (in comparison, an Embraer E-170 aircraft has a maximum landing weight of approximately 33,000 kg, and an approach reference speed of 140 kts). Using such systems, the aircraft comes to a stop after the nets reach their full run-out distance of 240 m from the runway end (DRDO, 2005; Jane's, 2008). The Department of Defence has advised that arrestor net systems used at Defence airfields in Australia do not have the capability to arrest aircraft in this weight range.

Arrestor hook systems work in a similar way to arrestor nets, using a cable that is remotely raised by the tower air traffic controller when required to stop aircraft

immediately on landing (at the arrival end of the runway), or at the end of the aircraft's landing rollout (at the departure end of the runway). At Defence airfields in Australia, arrestor cables are positioned approximately 450 m from the runway end to allow safe extension of the cable before the aircraft reaches the end of the runway. Water or friction brake units mounted at the runway edge provide a uniform braking force against the arrestor cable, which automatically adjusts depending on aircraft weight, position and velocity. The arrestor cable is raised to a height of 100 mm above the runway surface. The cable cannot be engaged by an aircraft landing gear at this height; moreover it is designed to be trampled by an aircraft landing gear if required. Arrestor cables can only be used by selected aircraft which are fitted with a special hook which is able to engage the arrestor cable (such as the Boeing/McDonnell Douglas F/A-18 and General Dynamics F-111 aircraft). Arrestor hook systems that are installed at military-commercial joint-use airfields are approved by the FAA and other regulators to ensure that they can be lowered beyond the runway surface to prevent damage to normal commercial aircraft operations (ESCO, 2008b).

The Department of Defence has advised the ATSB that they do not provide arresting technologies such as nets and cables for larger aircraft on its airfields as these aircraft are ill-equipped and inappropriate for net and cable arresting technologies. Defence does, however, groove runways used by larger aircraft, and provides other preventative risk controls such as runway distance remaining markers, airfield lighting, airfield marking, and comprehensive maintenance programs on its airfields.

5.5 Public safety areas/zones

In Queensland, State Planning Policy 1/02, *Development in the Vicinity of Certain Airports and Aviation Facilities*, has required public safety areas (PSAs) to be provided beyond runway ends at major airports⁴⁸ in that state since 2002.

Public safety areas limit development and commercial activities that could increase the safety risk to the public if placed near runway ends, including:

- residential development;
- the manufacture, or bulk storage of flammable, explosive or noxious materials;
- commercial developments that attract large numbers of people (e.g. shopping centres, stadiums, or industrial/commercial developments that involve a large number of workers or customers); and
- institutional developments (e.g. hospitals, schools, universities) (Queensland Department of Local Government and Planning, 2002).

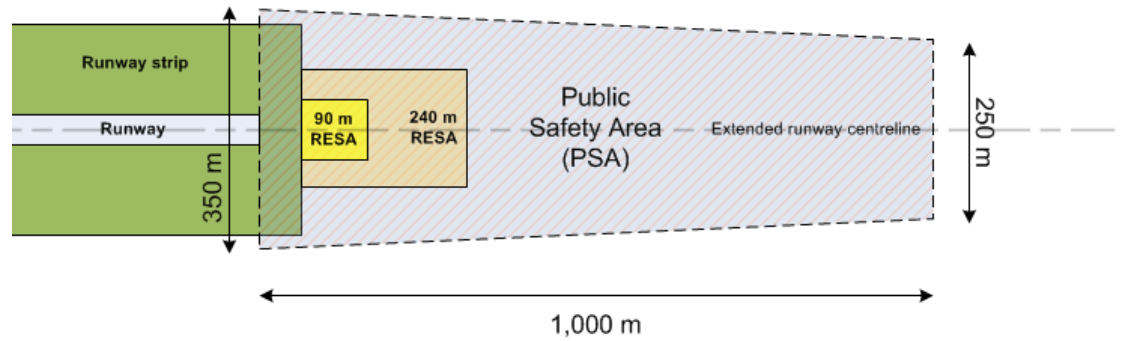
The PSA is trapezoidal in shape, with a base of 350 m (1,148 ft) at the runway end (around the runway centreline). The PSA extends for 1,000 m (3,281 ft) beyond the

⁴⁸ Queensland State Planning Policy 1/02 defines a 'major airport' as one where RPT services are provided, or where a high level of aircraft movements exists (i.e. greater than 10,000 non-general aviation movements).

Major airports in Queensland include (but are not limited to) Brisbane, Cairns, Gold Coast, Hamilton Island, Hervey Bay, Mackay, Maroochydore, Rockhampton and Townsville Airports.

runway end, and tapers to 250 m (820 ft) in width. These dimensions enclose the full area where the safety risk to an individual resulting from an aircraft undershoot or overrun is in the order of one in 10,000 or higher (Figure 20).

Figure 20: Public safety area (PSA) dimensions relative to the RESA and runway strip⁴⁹



Queensland state planning policy allows existing developments within the PSA to remain, but limits or prevents future developments. Planning policies in other states limit development near airports based on the Airservices Australia Australian Noise Exposure Forecast (ANEF), especially in areas below 20 ANEF units.

While PSAs are only mandated in Queensland at the time of writing (mid 2009), they have been identified by the Australian Government in the *National Aviation Policy Green Paper – Flight Path to the Future* as one of a potential range of airport and aviation infrastructure hazard risk mitigation strategies that could be considered for Australian airports. A discussion paper on PSAs and other safeguards developed by the Department of Infrastructure, Transport, Regional Development and Local Government in response to the recommendations of the Green Paper will be published in mid 2009.

⁴⁹ The runway depicted in this figure is 45 m in width.

Despite a downwards trend in commercial aircraft hull loss accidents over the last decade, approach and landing accidents are one area which has shown little improvement in safety. Runway excursion accidents are a leading type of approach and landing accident, accounting for a quarter of all incidents and accidents in commercial air transport operations (IFALPA, 2008). Several catastrophic runway overruns occurred in 2007 and 2008, resulting in hundreds of fatalities and attracting significant public and media attention.

Fortunately, Australia has not yet experienced a fatal runway excursion accident as has occurred in some other countries. This can be attributed to the positive safety cultures of local aircraft operators, airport owners and managers, and regulators, investment in safety infrastructure and runway works at Australian airports, a smaller number of commercial jet aircraft movements than many overseas countries, and a lower prevalence of conditions such as ice and snow that can increase the likelihood of a serious runway overrun. However, in the last decade, there have been four notable runway excursion events involving commercial jet aircraft operated by Australian airlines. Furthermore, numerous runway excursions involving general aviation and lower-capacity aircraft have occurred in Australia. These excursions are generally less serious due to the lower speeds and energy involved in these aircraft compared to a commercial jet aircraft. Between 1998 and 2007, 425 runway overrun and excursion occurrences were reported to the ATSB involving these smaller aircraft.

The need to minimise the risk (likelihood and consequences) of runway excursions is a high priority worldwide, because:

- airlines and manufacturers are utilising higher-capacity commercial aircraft, which carry more people and require more runway length to land;
- population pressure around airports, and non-aviation development on airport land are reducing the safety margin between aircraft and people if a runway excursion occurs; and
- there is a very real potential for an overrunning aircraft to collide with houses, cars, roads and other public infrastructure beyond runway ends if adequate runway end safety areas (RESAs) or other arresting measures do not exist.

The first report in this series (Taylor et al, 2009) provided a statistical picture of runway excursion accidents (overruns and veer-offs) involving commercial jet aircraft, through an analysis of 120 excursions on landing between 1998 and 2007. A range of flight crew technique/decision, weather, flight crew performance, and systems-related factors were identified as contributing to runway excursion accidents.

The purpose of this report was to discuss the risk controls that airline operators, aircraft manufacturers, airport operators, and safety regulators both in Australia and internationally can utilise to reduce the likelihood of a runway excursion occurring. Preventative risk controls are the first defence against runway excursions, and are critically important as they reduce or remove the factors that can contribute to runway excursions. For airline operators and flight crews, preventative risk controls include reinforcement of safe and stabilised approach techniques in standard operating procedures, line oriented flight training, the completion of pre-landing

risk assessments, and clear policies on when go-arounds must be conducted. For airport operators, preventative risk controls include runway design and maintenance procedures that reduce the effect or remove factors that could contribute to a runway excursion (such as runway grooving and surface texturing, friction treatments, lighting, and ongoing repair/maintenance including rubber deposit removal). Preventative risk controls can also be used to make the flight crew aware of the length of the runway remaining through the use of runway distance remaining signs and cockpit alert systems such as the Honeywell Runway Awareness and Advisory System.

Greater international agreement between aviation regulators to standardise requirements, definitions and terms for reporting runway contamination levels, runway friction coefficients, and estimated braking action levels would also assist in developing effective preventative risk controls.

This report also discussed the role of recovery risk controls in minimising the consequences if a runway excursion does occur. Recovery risk controls are 'last line of defence' measures if preventative risk controls fail or are non-existent. They aim to safely control and decelerate the aircraft if an excursion does occur. They include runway strips, runway end safety areas (RESAs), and soft ground arrestor beds such as the Engineered Materials Arresting System (EMAS), and other military-oriented arrestor systems.

The dimensional and bearing strength information for RESAs is currently not easily available to pilots and operators in the En Route Supplement Australia (ERSA) or other publications. As part of this report, a survey was conducted between February 2008 and June 2008 of airport operators in Australia to determine what recovery risk controls were in place at their airport to minimise the consequences of a serious runway excursion accident. Airport managers at all airports that handled (or were capable of handling) commercial jet services were surveyed. The survey found that all airports provide (or are in the process of providing) adequate runway strip and RESA areas to meet CASA and ICAO requirements. Few airports provided additional risk recovery controls against runway overruns. No Australian airports surveyed were fitted with soft ground arrestor beds (such as the EMAS).

A further recovery risk control involved the protection of life and property for members of the public in areas surrounding airports if a catastrophic approach and landing accident or runway excursion occurs. In Queensland, public safety areas define exclusion zones for such protection.

It is important to recognise that the risk of a runway excursion accident is ever present and that a range of safety measures should be utilised by aircraft operators and airport owners and managers to ensure the risk remains at an acceptable level. Reducing this risk in the first place using preventative risk controls should always be the focus of runway safety initiatives, however, recovery risk controls are also necessary to safely control aircraft that do overrun or veer off a runway when preventative risk controls fail or are not in place. Professional aviation forums such as the Australian Airports Association, the Regional Aviation Association of Australia, and the Air Transport Association in North America play an important role in allowing airline and airport operators to evaluate and discuss the benefits and challenges of implementing both preventative and recovery risk controls, and for aviation safety regulators to gain a better awareness of the operational issues associated with different risk controls.

Not all risk controls are necessary or appropriate for all airports. Due to the diverse Australian operating environment (in terms of movement activity, aircraft mix, approach terrain, environs, and climatic conditions), a risk management approach which adopts the best-fit preventative and recovery risk controls for each airport is the most appropriate way to minimise both the likelihood and consequences of runway excursions.

However, accepting that the possibility of a runway excursion accident is ever present, the aviation industry as a whole must continue to reduce the likelihood of these accidents through a focus on improved preventative risk controls (particularly stabilised approach criteria, firm procedures for limiting operations on wet and contaminated runways, and through appropriate go-around/missed approach policies). There is further work required by aviation safety regulators worldwide to standardise runway friction and condition reporting, and allow its clear conveyance to flight crew through air traffic control, METAR reports, and NOTAMS.

Preventative risk controls are also important considerations for airport operators, as runway grooving/surface texturing, pavement surface quality, and runway lighting/signage/markings (such as RDRS) are the most important airport infrastructure defences to prevent excursions once the aircraft has touched down. They have been proven to be effective and are relatively low in cost. Furthermore, analysis of runway excursion accident data between 1998 and 2007 has shown that runway surface quality has played a contributing role in numerous accidents, particularly those where local weather conditions meant a higher likelihood of other risk factors (such as aquaplaning or standing water) contributing to the accident. Runway grooving/surface texturing is an important preventative risk control used at Australian airports, and is also considered high priority safety work by the FAA in the United States. Airport operators and owners in Australia need to continue to focus their efforts in regularly inspecting, maintaining, testing, and restoring their runway surfaces to ensure they are maintained to the specified friction and maintenance levels. Grooving and correct cambering are important components of this work. Runway resurfacing works should be conducted at times of the year where rainfall is less frequent, and re-grooving/texturing be completed as soon as possible to minimise risks to aircraft from standing water accumulation. Runway end, edge, centreline and touchdown zone lighting; and runway distance signs and line markings are key to improving the positional awareness of pilots both on approach and on the runway, and should be installed, maintained, and upgraded with new developments in lighting technology.

Continued investment by airport operators and owners in existing recovery risk controls, such as RESAs and runway strips, is needed to minimise the consequences of runway excursions and other types of approach and landing accidents that do occur. Some types of soft ground arrestor beds (such as the EMAS system) involve large capital infrastructure investment, and hence their installation should be supported by an assessment of their safety benefit in each specific location compared to improving other recovery risk controls (such as runway grooving/surface texturing or extending RESA lengths). Further research, such as that being undertaken by the FAA Airport Cooperative Research Program, is required to develop soft ground arrestor beds that are cheaper yet can reliably and safely decelerate aircraft that leave the runway surface in a range of prevailing weather conditions.

As the possibility that preventative and recovery risk controls could fail and a serious runway excursion occur cannot be eliminated entirely, governments at all

levels need to be proactive in ensuring the damage to life, property and infrastructure is limited. For example, the Australian Government and some state governments are exploring the implementation of public safety areas as effective ways of controlling development of land in the airport environs where both the likelihood and consequences of approach and landing accidents is highest.

- Air Safety Week. (2004). RAAS to the rescue? *Air Safety Week*, October 18. Retrieved 26 March 2008 from http://findarticles.com/p/articles/mi_m0UBT/is_40_18/ai_n6283704.
- Airports Council International. (2008). *ACI Policy and Recommended Practices Handbook* (6th edition). Geneva: ACI.
- Airservices Australia. (2007a). *Sydney Airport, N451 Australian Noise Exposure Index, 1 January to 31 December 2006* (EO 07-179). Canberra: Airservices Australia.
- Airservices Australia. (2007b). *Aeronautical Information Publication (AIP)*. Canberra: Airservices Australia.
- AmSafe. (2008). *Aircraft Arrestor Barrier Nets*. Retrieved 27 March 2008, from <http://www.amsafe.com/products/detail.php?id=44&type=categories>.
- Ascend. (2007). *World Aircraft Accident Summary, 1990-2007*, London: Airclaims.
- Australian Transport Safety Bureau. (2001a). *Boeing 747-438 VH-OJH, Bangkok, Thailand, 23 September 1999* (Aviation Safety Investigation Report 199904538). Canberra: Australian Transport Safety Bureau.
- Australian Transport Safety Bureau. (2001b). *Airbus A340-300, B-2380, Sydney, NSW, 1 November 2000* (Aviation Safety Investigation Report 200005030). Canberra: Australian Transport Safety Bureau.
- Australian Transport Safety Bureau. (2004). *Runway overrun at Darwin International Airport, Boeing 737-800 VH-VOE, 11 June 2002* (Aviation Safety Investigation Report 200202710). Canberra: Australian Transport Safety Bureau.
- Australian Transport Safety Bureau. (2005a). *Boeing Co 737-376, VH-TJB, 19 February 2003* (Aviation Safety Investigation Report 200300418). Canberra: Australian Transport Safety Bureau.
- Australian Transport Safety Bureau. (2005b). *Boeing Co 727, 9L-LEK, Brisbane Airport, 25 January 2005* (Aviation Safety Investigation Report 200500302). Canberra: Australian Transport Safety Bureau.
- Australian Transport Safety Bureau. (2007). *CFIT: Australia in context, 1996 to 2005* (Aviation Research and Analysis Report B2006/0352). Canberra: Australian Transport Safety Bureau.
- Autoridad de Aviacion Civil El Salvador (AAC). (2008). *Preliminary report, TACA International Airlines Flight 390, Airbus A320-233, Register no. EI-TAF, Toncontin International Airport (MHTG/TGU), Tegucigalpa, Honduras, May 30th, 2008*. San Salvador: AAC.
- Aviation Week & Space Technology. (2008). FAA To Subsidize Some Electronic Flight Bag Installations. *Aviation Week & Space Technology*, 11 August. Retrieved 13 August 2008, from http://www.aviationweek.com.ezproxy.libproxy.db.erau.edu/publication/awst/loggedin/AvnowStoryDisplay.do?fromChannel=mro&pubKey=awst&issueDate=2008-08-11&story=xml/awst_xml/2008/08/11/AW_08_11_2008_p51-

71829.xml&headline=FAA+To+Subsidize+Some+Electronic+Flight+Bag+Installations.

Boeing. (2008). *Statistical Summary of Commercial Jet Airplane Accidents, Worldwide Operations, 1959-2007*. Seattle, WA: Boeing Commercial Airplanes.

Bureau of Meteorology. (2008). *Aeronautical Services Handbook – Operations Manual for the Provision of Aviation Services in Australia*. Melbourne: Bureau of Meteorology.

Bureau of Meteorology. (2009). *METAR/SPECI Format Explanation, METAR and SPECI Examples*. Retrieved 14 March 2009, from http://www.bom.gov.au/general/reg/aviation_ehelp/explanmetar.shtml.

Bureau of Transport and Regional Economics. (2007). *Aviation Statistics, Airport Traffic Data, 1997-98 to 2006-07*. Canberra: BTRE, Department of Infrastructure, Transport, Regional Development and Local Government.

Civil Aviation Authority (United Kingdom). (2002). *Flight Crew Training: Cockpit Resource Management (CRM) and Line-Oriented Flight Training (LOFT)* (Civil Aviation Publication CAP 720). Gatwick Airport South, West Sussex: Safety Regulation Group, CAA.

Civil Aviation Authority (United Kingdom). (2007). *Licensing of Aerodromes* (Civil Aviation Publication CAP 168). Gatwick Airport South, West Sussex: Safety Regulation Group, CAA.

Civil Aviation Safety Authority. (2002a). *Notice of Proposed Rule Making, Air Transport Operations – Large Aeroplanes, Proposed Part 121A of the Civil Aviation Safety Regulations (CASRs)* (Document NPRM 0211OS). Canberra: CASA.

Civil Aviation Safety Authority. (2002b). *Rules and Practices for Aerodromes (RPA), Chapter 7, Design standards for licensed aerodromes*. Canberra: CASA.

Civil Aviation Safety Authority. (2008). *Manual of Standards Part 139 – Aerodromes* (v. 1.4). Canberra: CASA.

Croft, J. (2007). FAA to study bad weather landing and take-off margins. *Flight International*, 18-31 December, 12.

Croft, J. (2008). Alaska equipping entire fleet with Honeywell anti-incursion tool. *Air Transport Intelligence*, 11 September. Retrieved 15 March 2009, from <http://www.flightglobal.com/articles/2008/09/11/315842/alaska-equipping-entire-fleet-with-honeywell-anti-incursion.html>.

Darby, R. (2008). 2007 Accident Totals Improve for EASA Member State Aircraft. *AeroSafety World*, December, 50-53.

Defence Research & Development Organisation of India (DRDO). (2005). Arrestor Barrier System. *Technology Focus* (online edition), v. 13, no. 6. Retrieved 27 March 2008, from <http://drdo.gov.in/pub/techfocus/dec05/arrestor.htm>.

Department of Transport and Regional Services. (2000). *Expanding Ways to Describe and Assess Aircraft Noise* (Discussion paper). Canberra: Department of Transport and Regional Services.

Emery, S. (2008). *Seals for Heavy Duty Airport Pavements*. Paper presented at the 1st International Sprayed Sealing Conference, Adelaide, 27-28 July.

Engineered Arresting Systems Corporation (ESCO). (2007). *EMAS Installation List*. Logan Township, NJ: ESCO, Zodiac S.A.

Engineered Arresting Systems Corporation (ESCO). (2008a). *Theory of Operation (EMAS)*. Retrieved 27 March, 2008, from <http://www.esco.zodiac.com/index.cfm/navid-45>.

Engineered Arresting Systems Corporation (ESCO). (2008b). BAK-14 Retractable HC. Retrieved 27 March 2008, from <http://www.esco.zodiac.com/index.cfm/navid-92>.

Engineered Arresting Systems Corporation (ESCO). (2009). *FAQ (EMAS)*. Retrieved 31 March, 2009, from <http://www.esco.zodiac.com/index.cfm/navid-54>.

European Aviation Safety Agency. (2008). *Annual Safety Review 2007* (TO-AA-08-001-EN-C). Cologne: EASA.

Federal Aviation Administration. (1989). *Airport Design* (Advisory Circular AC 150/5300-13). Washington, DC: FAA, United States Department of Transportation.

Federal Aviation Administration. (1997). *Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces* (Advisory Circular AC 150/5320-12C). Washington, DC: FAA, United States Department of Transportation.

Federal Aviation Administration. (2004a). *Standards for Airport Sign Systems* (Advisory Circular AC 150/5340-18D). Washington, DC: FAA, United States Department of Transportation.

Federal Aviation Administration. (2004b). *Financial Feasibility and Equivalency of Runway Safety Area Improvements and Engineered Material Arresting Systems* (Order 5200. Washington, DC: FAA, United States Department of Transportation.

Federal Aviation Administration. (2005). *Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns* (Advisory Circular AC 150/5220-22A). Washington, DC: FAA, United States Department of Transportation.

Federal Aviation Administration. (2007a). *Runway Overrun Prevention* (Advisory Circular AC 91-79). Washington, DC: FAA, United States Department of Transportation.

Federal Aviation Administration. (2007b). *Fact Sheet: Engineered Materials Arresting System (EMAS)*, media release, 27 October. Washington, DC: FAA, United States Department of Transportation.

Flight International. (2007). Life-or-death decisions, *Flight International*, 18-31 December.

Flight Safety Foundation. (2000a). FSF ALAR Briefing Note 8.1 – Runway Overruns and Runway Excursions (ALAR Tool Kit). *Flight Safety Digest*, August-November, 159-162.

Flight Safety Foundation. (2000b). FSF ALAR Briefing Note 8.3 – Landing Distances (ALAR Tool Kit). *Flight Safety Digest*, August-November, 167-171.

- Flight Safety Foundation. (2000c). FSF ALAR Briefing Note 8.5 – Wet or Contaminated Runways (ALAR Tool Kit). *Flight Safety Digest*, August-November, 179-184.
- Flight Safety Foundation. (2000d). FSF ALAR Briefing Note 8.7 – Crosswind Landings (ALAR Tool Kit). *Flight Safety Digest*, August-November, 189-196.
- Flight Safety Foundation. (2000e). FSF ALAR Briefing Note 7.1 – Stabilized Approach (ALAR Tool Kit). *Flight Safety Digest*, August-November, 133-138.
- Flight Safety Foundation. (2000f). FSF ALAR Briefing Note 5.3 – Visual Illusions (ALAR Tool Kit). *Flight Safety Digest*, August-November, 103-109.
- Flight Safety Foundation. (2000g). FSF ALAR Briefing Note 8.4 – Braking Devices (ALAR Tool Kit). *Flight Safety Digest*, August-November, 173-177.
- Flight Safety Foundation. (2000h). *FSF ALAR Tool Kit – Approach-and-landing Risk Awareness Tool* (rev. 1.1). Alexandria, VA: FSF.
- Flight Safety Foundation. (2000i). *FSF ALAR Tool Kit – Approach-and-landing Risk Reduction Guide* (rev. 1.1). Alexandria, VA: FSF.
- Gladstone Regional Council. (2009). *Council opts for lowest tender submission for airport project* (Media release). March 24. Gladstone, QLD: Gladstone Regional Council.
- Grid Technologies (GridTech). (2004). *Goals & Objectives* (Engineered Rootzone Arrestor System) [Presentation]. Retrieved 27 March 2008, from <http://gridtech.com/ERAS.pdf>.
- Hall, J., Ayres, M., Jr., Wong, D., Appleyard, A., Eddowes, M., Shirazi, H., Speir, R., Pitfield, D., Caves, R., Selezneva, O. & Puzin, T. (2008). *Analysis of Aircraft Overruns and Undershoots for Runway Safety Areas* (Airport Cooperative Research Program (ACRP) Report 3). Washington, DC: Transportation Research Board of the National Academies.
- Honeywell. (2007). *Runway Awareness and Advisory System (RAAS)* (DWG 060-4404-000). Redmond, WA: Honeywell International, Inc.
- Industry Safety Strategy Group (ISSG). (2006). *Implementing the Global Aviation Safety Roadmap*. Montreal: ICAO.
- International Air Transport Association (IATA). (2009). *Safety Report 2009* (45th edition). Montreal: IATA.
- International Civil Aviation Organization. (2004). *Annex 14 to the Convention on International Civil Aviation, Aerodromes, Volume 1, Aerodrome Design and Operations* (4th edition). Montreal: ICAO.
- International Civil Aviation Organization. (2005). *Runway Safety Areas/Engineered Materials Arresting Systems*. Paper presented at the second meeting of the North American, Central American and Caribbean Directors of Civil Aviation (NACC/DCA/2), Tegucigalpa, Honduras.
- International Civil Aviation Organization. (2007a). *Annex 3 to the Convention on International Civil Aviation, Meteorological Service for International Air Navigation* (16th edition). Montreal: ICAO.

- International Civil Aviation Organization. (2007b). *Runway Safety Area Improvements in the United States*. Paper presented at the ninth meeting of Directors of Civil Aviation of the Central Caribbean (C/CAR/DCA/9), Oranjestad, Aruba, Netherlands Antilles.
- International Federation of Air Line Pilots' Associations. (2008). *Runway End Safety Areas (RESAs)* (08POS01) (Position statement). Chertsey, Surrey: IFALPA.
- Jane's All the World's Aircraft. (1964). *Aircraft: General Dynamics – USA, The Convair 990A*. Coulsdon, Surrey: Jane's Information Group Ltd., 213-214.
- Jane's All the World's Aircraft. (2008). Empresa Brasileira de Aeronáutica SA – Embraer 170 and 190. Retrieved 27 March 2008, from <http://www.janes.com>.
- JDA Aviation Technology Solutions. (2003a). *An Analysis to Demonstrate EMAS Equivalency to a Standard Runway Safety Area* (v. 1). Washington, DC: JDA Aviation Technology Solutions.
- JDA Aviation Technology Solutions. (2003b). *Is EMAS equivalent to a standard runway safety area?* (Information Letter no. 10). Washington, DC: JDA Aviation Technology Solutions.
- Johnson, E. & White, T. (1976). Porous Friction Course Solves Airport Hydroplaning Problem [Abstract]. *Civil Engineering – American Society of Civil Engineers* (ASCE), 46 (no. 4), 90-92.
- Khatwa, R. & Helmreich, R. (1999). Analysis of Critical Factors During Approach and Landing in Accidents and Normal Flight – Data Acquisition and Analysis Working Group Final Report. *Flight Safety Digest*, November-December, 1-77.
- Kirkland, I. & Caves, R. E. (2002). *A New Aircraft Overrun Database, 1980-1998*. Paper presented at the 81st annual meeting of the Transportation Research Board of the National Academies, Washington, DC.
- Kirkland, I., Caves, R., Hirst, M. & Pitfield, D. (2003). The normalisation of aircraft overrun accident data. *Journal of Air Transport Management*, 9, 333-341.
- Kirkland, I., Caves, R., Humphreys, I. & Pitfield, D. (2004). An improved methodology for assessing risk in aircraft operations at airports, applied to runway overruns. *Safety Science*, 42, 891-905.
- Lacagnina, M. (2008a). High, Hot and Fixated. *AeroSafety World*, January, 42-46.
- Lacagnina, M. (2008b). Margin for Error. *AeroSafety World*, August, 22-26.
- McKinney, D. (2006). *Preventing Runway Overruns or Excursions*. Paper presented at the 18th European Aviation Safety Seminar (EASS), Flight Safety Foundation, Athens.
- National Transportation Safety Board. (1998). *We Are All Safer: NTSB-Inspired Improvements in Transportation Safety* (2nd edition). Washington, DC: NTSB.
- National Transportation Safety Board. (2001). *Runway Overrun During Landing, American Airlines Flight 1420, McDonnell Douglas MD-82, N215AA, Little Rock, Arkansas, June 1, 1999* (Aircraft Accident Report NTSB/AAR-01/02). Washington, DC: NTSB.
- National Transportation Safety Committee (Indonesia). (2007). *Boeing 737-497, PK-GZC, Adisucipto Airport, Yogyakarta, Indonesia, 7 March 2007* (Aircraft

Accident Investigation Report KNKT/07.06/07.02.35). Jakarta: NTSC, Indonesian Ministry of Transportation.

Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM). (2005). *Federal Meteorological Handbook No. 1 – Surface Weather Observations and Reports* (FCM-H1-2005). Washington, DC: United States Department of Commerce.

Office of the Inspector General (OIG). (2009). *Actions Taken and Needed To Improve FAA's Runway Safety Area Program, Federal Aviation Administration* (Report AV-2009-039). Washington, DC: OIG, Office of the Secretary of Transportation, United States Department of Transportation.

Orasanu, J. & Martin, L. (1998). *Errors in Aviation Decision Making: A Factor in Accidents and Incidents*. Paper presented at the first annual workshop on Human Error, Safety, and System Development (HESSD), Glasgow.

Peters, H. (2007). *EMAS at San Diego International Airport*. Paper presented at the 2007 Airport Conference, Airports – Western-Pacific Region, FAA, San Diego, CA.

Queensland Department of Local Government and Planning. (2002). *Development in the Vicinity of Certain Airports and Aviation Facilities* (State Planning Policy 1/02), Brisbane: Department of Local Government and Planning, Queensland Government.

Ranganathan, A. (2006). Wet Runway Overruns: Pilot Error? System Deficiency? *ISASI Forum* (International Society of Air Safety Investigators), 39(1), January-March, 6-8.

Rogers, R. & Cook, T. (2007). *The Case for Runway Distance Remaining Signs*. Rio de Janeiro: Instituto CEPTA (Brazilian Institute of Strategic Studies and Public Policies in Air Transport).

Rosenkrans, W. (2006). Rethinking Overrun Protection. *AviationSafety World*, August, 13-18.

Solomon Islands Ministry of Culture, Tourism and Aviation, Civil Aviation Division. (2009). *Report on Aviation Incident Involving Embraer E-170 Aircraft, VH-SWO, 8:00 p.m. (local time) 27th July 2008, Honiara Henderson International Airport*. Honiara: Ministry of Culture, Tourism and Aviation.

Sullivan, R. (2008). *Gladstone Airport Development Plan* (Draft Plan V2, April 2008). Gladstone, QLD: Gladstone Regional Council.

Sydney Airport Corporation Limited (SACL). (2007). *Runway safety enhancement project to commence*, media release, 27 November. Sydney: SACL.

Sydney Airport Corporation Limited (SACL). (2008a). *Draft Major Development Plan, Runway Safety Enhancement, Runway 25 – Runway End Safety Area, Sydney Airport*. Sydney: SACL.

Sydney Airport Corporation Limited (SACL). (2008b). *Sydney Airport Runway Safety Enhancement Project – Public Exhibition of Draft Major Development Plan* [n.d.]. Retrieved 31 March 2008, from <http://www.sydneyairport.com.au/SACL/Corporate+Information/Runway+Safety/default.htm>.

Taylor, R. P., Hughes, K., & Godley, S. (2009). *Runway excursions. Part 1 – A worldwide review of commercial jet aircraft runway excursions* (Aviation Safety Research and Analysis Report AR-2008-018(1)). Canberra: Australian Transport Safety Bureau.

Transport Research Laboratory. (2004). *Gloucestershire First: The Present and Future Role of Gloucestershire Airport, Final Report*. Crowthorne, Berks: Transport Research Laboratory.

Transportation Research Board of the National Academies (TRB). (2009). *Developing Improved Civil Aircraft Arresting Systems* (Airport Cooperative Research Program (ACRP) 07-03 [Active]). Retrieved 15 March 2009, from <http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=152>.

Transportation Safety Board of Canada. (2007). *Runway overrun and fire: Air France Airbus A340-313 F-GLZQ, Toronto/Lester B. Pearson International Airport, Ontario, 02 August 2005* (Aviation Investigation Report A05H0002). Gatineau, Quebec: TSB.

USA Today. (2005). New technology can prevent runway overruns. *USA Today* (online edition), 9 December. Retrieved 25 March 2008, from http://www.usatoday.com/news/washington/2005-12-09-runwaytech_x.htm.

van Es, G. (2005). *Running out of runway: Analysis of 35 years of landing overrun accidents*. Amsterdam: Nationaal Lucht-en Ruimtevaartlaboratorium (NLR).

Walker, M. & Bills, K. (2008). *Analysis, Causality and Proof in Safety Investigations* (Aviation Research and Analysis Report AR-2007-053). Canberra: ATSB, Department of Infrastructure, Transport, Regional Development and Local Government.

Werfelman, L. (2008). Safety on the Straight and Narrow. *AeroSafety World*, August, 12-17.

Williams, M. (2002). Runway overrun. *Flight Safety Australia*, November-December, 24-31.

World Meteorological Organization. (2007). *Manual on Codes, International Codes, Vol. 1, Part A – Alphanumeric Codes* (Document no. 306) (1995 ed., updated 2007). Geneva: WMO.

Yager, T. (1983). *Factors influencing aircraft ground handling performance* (NASA Technical Memorandum 85652). Langley Research Center, Hampton, VA: National Aeronautics and Space Administration.

8.1 Appendix A – Sources and submissions

8.1.1 Sources of information

The primary sources of information used during this investigation were:

- the Ascend World Aircraft Accident Summary (WAAS)
- Australian airport operators
- Civil Aviation Safety Authority publications
- Airservices Australia En Route Supplement Australia (ERSA) and Aeronautical Information Publication (AIP)
- Federal Aviation Administration publications
- Engineered Arresting Systems Corporation (ESCO) test data for the Engineered Materials Arresting System (EMAS)
- accident investigation reports published by the Australian Transport Safety Bureau (ATSB), Autoridad de Aviacion Civil El Salvador (AAC), and Solomon Islands Ministry of Culture, Tourism and Aviation, Civil Aviation Division

Runway end safety area (RESA) data was also sourced from the following airport operators:

- Adelaide Airport Ltd (Adelaide Airport)
- Administration of Norfolk Island (Norfolk Island Airport)
- Albury City Council (Albury Airport)
- Australia Pacific Airports Pty Ltd (Launceston Airport, Melbourne Airport)
- Avalon Airport Australia Pty Ltd (Avalon Airport)
- Ballina Shire Council (Ballina/Byron Gateway Airport)
- Brisbane Airports Corporation Ltd (Brisbane Airport)
- Broome International Airport (Broome Airport)
- Cairns Port Authority (Cairns Airport)
- Canberra International Airport Pty Ltd (Canberra Airport)
- City of Albany (Albany Airport)
- City of Kalgoorlie-Boulder (Kalgoorlie-Boulder Airport)
- Cloncurry Shire Council (Cloncurry Airport)
- Coffs Harbour City Council (Coffs Harbour Airport)
- the Department of Defence (owner of Darwin Airport/RAAF Darwin, Derby Airport/RAAF Curtin, Exmouth Airport/RAAF Learmonth, Newcastle Airport/RAAF Williamtown, Townsville Airport/RAAF Garbutt)

- Great Barrier Reef Airport Pty Ltd (Hamilton Island Airport)
- Hervey Bay City Council (Hervey Bay Airport)
- Hobart International Airport Pty Ltd (Hobart Airport)
- Mackay Port Authority (Mackay Airport)
- Mildura Rural City Council (Mildura Airport)
- Mount Hotham Skiing Company Transportation Services (Mount Hotham Airport)
- Newcastle Airport Ltd (Newcastle Airport/RAAF Williamtown)
- Northern Territory Airports Pty Ltd (Alice Springs Airport, Darwin Airport)
- Nhulunbuy Corporation (Gove Airport)
- Port Macquarie-Hastings Council (Port Macquarie Airport)
- Queensland Airports Ltd (Cairns Airport, Mount Isa Airport, Townsville Airport)
- Rockhampton Regional Council (Rockhampton Airport)
- Santos Ltd (Ballera Airport, Moomba Airport)
- Shire of Derby/West Kimberley (Derby/Curtin Airport)
- Shire of East Pilbara (Newman Airport)
- Shire of Exmouth (Exmouth/Learmonth Airport)
- Shire of Roebourne (Karratha Airport)
- Sunshine Coast Regional Council (Sunshine Coast-Maroochydore Airport)
- Sydney Airport Corporation Ltd (Sydney Airport)
- Town of Port Hedland (Port Hedland Airport)
- Voyager Resorts & Hotels Pty Ltd (Ayers Rock Airport)
- Wagga Wagga City Council (Wagga Wagga Airport)
- Westralia Airports Corporation (Perth Airport)
- Whitsunday Regional Council (Proserpine/Whitsunday Coast Airport)

A full list of data sources is provided in the Methodology (Chapter 0) and References (Chapter 7).

8.1.2 Submissions

A draft of this report was provided to the Civil Aviation Safety Authority (CASA), Airservices Australia, the Department of Infrastructure, Transport, Regional Development and Local Government, the Department of Defence, the Australian Airports Association, the Bureau of Meteorology, all major high capacity commercial jet aircraft operators, and the 43 operators of Australian airports with a Code 3 or 4 runway that received high-capacity jet regular public transport (RPT) or charter services in 2007 that were contacted or attempted to be contacted for the telephone survey.

Submissions were received from the following parties:

- Adelaide Airport Ltd (Adelaide Airport)
- Airservices Australia
- Albury City Council (Albury Airport)
- the Australian Airports Association
- Ballina Shire Council (Ballina/Byron Gateway Airport)
- Brisbane Airports Corporation Ltd (Brisbane Airport)
- Broome International Airport (Broome Airport)
- the Bureau of Meteorology
- Cairns Port Authority (Cairns Airport)
- the Civil Aviation Safety Authority (CASA)
- Coffs Harbour City Council (Coffs Harbour Airport)
- the Department of Defence
- the Department of Infrastructure, Transport, Regional Development and Local Government
- Port Macquarie-Hastings Council (Port Macquarie Airport)
- Sunshine Coast Regional Council (Sunshine Coast-Maroochydore Airport)
- Virgin Blue Airlines Pty Ltd
- Westralia Airports Corporation (Perth Airport)

The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

8.2

Appendix B - Australian runway data

Table B.1 provides runway data for major Australian airports with Code 3 and 4 runways. As of March 2009, these airports currently, have previously, are planned to, or have future potential to receive jet regular public transport (RPT) and charter operations. This data includes declared distances for these runways, whether a surface texture treatment was applied to the runway⁵⁰, and an indication of the built environment surrounding these airports.

Runway declared distances for Australian Code 3 and 4 runways were sourced from the electronic edition of the En Route Supplement Australia (ERSA), which is maintained by Airservices Australia. They are defined in CASR 139 *Manual of Standards – Aerodromes*.

As part of the telephone survey of Australian airport operators, 43 airport operators⁵¹ were asked to provide the measured length of the runway end safety areas (RESAs) of each Code 3 or 4 runway, as measured from the end of the 60 m runway strip which abuts the threshold end.

This data was collected between February 2008 and June 2008. Where airport operators indicated that construction works were currently underway to alter the RESA length, this was noted in Table B.1. Also noted were any obstacles reported by the airport operator that would likely limit further RESA improvement works in the future.

Prior to 2003, RESA requirements were governed by the *CASA Rules and Practices for Aerodromes* Chapter 7 – *Design Standards for Licensed Aerodromes*. Under the previous standard, the 90 m requirement for RESA length was measured from the end of the runway or any associated stopway. Under the present ICAO-based CASR 139 definitions where the RESA is measured from the end of the 60 m runway strip, this would make a RESA of only 30 m in length.

As a result, some airport operators quoted the RESA length as measured from the runway threshold or end of any associated stopway (as per the previous *Rules and Practices for Aerodromes* standard). In cases where this was identified, the reported RESA length was adjusted to start from the end of the 60 m runway strip (current CASR 139 standard).

Gladstone Airport was not included in the survey, but data for this airport is also included in Table B.1. In 2009, Gladstone Airport is commencing a \$45 million upgrade to runway 10/28 that will allow it to receive Boeing 737-class aircraft (it is currently suitable only for Bombardier Dash 8 Series Q400-class and smaller aircraft). A standard 90 m long RESA will be provided at both runway ends. On the

⁵⁰ Data collected in the telephone survey focused on runway grooving only. Information on other types of runway surface texture treatments (such as bitumen chip seals) has been made available for airports in Western Australia only. Such treatments may also be applied to other runways in Australia that are noted in Table B.1 as being ungrooved. Airport operators should be contacted directly for further information on runway surface treatments at individual airports.

⁵¹ Although the ATSB contacted the operators of all airports that were identified as meeting this criteria, it was unable to survey an appropriate representative of one of the airport operators (Hervey Bay).

end of runway 10, this will involve relocation of a minor road, and bridging of a creek (Sullivan, 2008; Gladstone Regional Council, 2009).

While all efforts have been made to ensure this data is correct, the RESA lengths provided in this report should be taken as a guide only. For the most current RESA data, contact the airport operator directly.

Table B.1: Data for selected Australian Code 3 and 4 runways used for RPT operations

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Adelaide ⁽ⁱ⁾	YPAD	05 (4)	Yes	3100	3204	3160	2950	60	44	90 (N)	Inner urban (480m to residential development)	RESA 05 end cannot be extended further due to physical limitations (residential development and roads surrounding the airport).
		23 (4)	Yes	3100	3204	3160	3100	60	44	90 (N)	Inner urban (400m to blast fence, major road and river)	
		12 (3)	Yes	1652	1832	1652	1652	-	180	90 (N)	Inner urban (630m to creek and residential development)	
		30 (3)	Yes	1652	1832	1652	1652	-	180	90 (N)	Inner urban (500m to major road)	
Albany	YABA	14 (4)	No (sealed)	1800	1860	1800	1800	-	60	90 (S)	Farmland (>1,000m to nearest obstacle)	
		32 (4)	No (sealed)	1800	1860	1800	1800	-	60	90 (S)	Farmland (>1,000m to nearest obstacle)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Albury	YMAY	07 (4)	Yes	1900	1990	1900	1900	-	90	30 (N)	Flat, urban fringe (500m to major road)	RESAs meet previous RPA requirements only, as rwy has not been lengthened or upgraded. RESA 25 end cannot be extended beyond 200m due to a large, open drain.
		25 (4)	Yes	1900	1990	1900	1900	-	90	30 (N)	Flat, urban fringe (200m to large open drain, 320m to industrial development)	
Alice Springs ⁽ⁱ⁾	YBAS	12 (4)	Yes	2438	2738	2438	2438	-	300	300 (D)	Flat, rural land (>1,000m to nearest obstacle)	
		30 (4)	Yes	2438	2738	2438	2438	-	300	300 (D)	Flat, rural land (>1,000m to nearest obstacle)	
Avalon ⁽ⁱ⁾	YMAV	18 (4)	No	3048	3353	3108	3048	60	245	240 (N)	Flat, rural land (600m to minor road)	
		36 (4)	No	3048	3291	3108	3048	60	183	240 (N)	Flat, rural land (>1,000m to nearest obstacle)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Ayers Rock	YAYE	13 (4)	No	2599	2659	2599	2599	-	60	30 (S)	Flat, rural land (>1,000m to nearest obstacle)	RESA length meets previous RPA requirements only, as rwy has not been lengthened or upgraded. Additional flat natural surface exists beyond RESAs.
		31 (4)	No	2599	2659	2599	2599	-	60	30 (S)	Flat, rural land (>1,000m to nearest obstacle)	
Ballera	YLLE	03 (4)	No	1800	1860	1800	1800	-	60	90 (S)	Flat, rural land (300m to minor road)	
		21 (4)	No	1800	1860	1800	1800	-	60	90 (S)	Flat, rural land (>1,000m to nearest obstacle)	
Ballina/Byron Gateway	YBNA	06 (4)	No	1900	1960	1900	1900	-	60	30 (N)	Flat, riverbank (140m to tidal estuary)	RESA length meets previous RPA requirements only, as rwy has not been lengthened or upgraded. RESA 06 end cannot be extended significantly to a tidal estuary.
		24 (4)	No	1900	1960	1900	1900	-	60	30 (N)	Farmland (800m to minor road)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Brisbane ⁽ⁱ⁾	YBBN	01 (4)	Yes	3500	3620	3560	3500	60	60	90 (D)	Flat, urban fringe (1,000m to dense mangroves)	RESA could be extended to 240m if required (space is available). New parallel runway will have a 90m RESA installed.
		19 (4)	Yes	3560	3620	3560	3560	-	60	90 (D)	Flat, urban fringe (>1,000m to nearest obstacle)	
		14 (3)	No	1700	1760	1700	1700	-	60	90 (D)	Flat, urban fringe (900m to creek)	
		32 (3)	No	1700	1760	1700	1700	-	60	90 (D)	Flat, urban fringe (460m to ocean)	
Broome ⁽ⁱ⁾	YBRM	10 (4)	No (sealed)	2458	2518	2458	2368	-	60	90 (S)	Urban (340m to major road)	RESA cannot be extended significantly due to nearby development and terrain. Reduction of declared distance to provide a 240 m RESA would have operational impacts on the airport
		28 (4)	No (sealed)	2368	2428	2368	2248	-	60	90 (S)	Urban (350m to major road)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Cairns ⁽ⁱ⁾	YBCS	15 (4)	Yes	3196	3257	3197	3197	1	60	60 (S)	Urban (130m to creek, 500m to major road)	RESA 15 end cannot be extended beyond 60m due to a creek.
		33 (4)	Yes	3196	3257	3197	3197	1	60	90 (S)	Urban fringe (340m to dense mangroves, 440m to river)	A 90m RESA on rwy 15 end will be effective from October 2009 ⁵² .
Canberra ⁽ⁱ⁾	YSCB	12 (3)	No	1679	1739	1679	1679	-	60	15 (N)	Farmland (145m to major road)	RESA 12 end cannot be extended significantly due to a major road.
		30 (3)	No	1679	1739	1679	1614	-	60	90 (N)	Urban fringe and airport development (280m to major road)	
		17 (4)	Yes	2683	3273	2983	2683	300	290	240 (S)	Flat, urban fringe (660m to major road)	
		35 (4)	Yes	3283	3343	3283	2683	-	60	90 (N)	Adjacent to major road (500m to minor road)	

⁵² Cairns Airport has advised the ATSB in June 2009 that a RESA extension to 90 m on runway 15 will come into effect following a runway lighting upgrade in October 2009. This is to be achieved through a 40 m reduction in the declared distance of runway 33. As a result, the runway 15 TORA/TODA/LDA distances and runway 33 LDA distance will reduce by 40 m. The ASDA distances for both runways will remain unchanged. New figures will be issued by Airservices Australia in the ERSAs when the new 90 m RESA comes into effect.

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Cloncurry	YCCY	12 (4)	No	2000	2060	2000	2000	-	60	90 (N)	Flat, rural land (270m to minor road)	
		30 (4)	No	2000	2060	2000	2000	-	60	90 (N)	Flat, rural land (400m to dry river bed)	
Coffs Harbour ⁽ⁱ⁾	YCFS	03 (4)	Yes	2080	2140	2080	2080	-	60	90 (N)	Flat, urban fringe (800m to nearest obstacle)	RESA dimensions following completion of current extension works. Further extensions limited by Indigenous heritage site.
		21 (4)	Yes	2080	2140	2080	2080	-	60	90 (N)	Forested, urban fringe (300m to scrub, 1,200m to creek)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Darwin ^{(i)(j)}	YPDN	11 (4)(H)	Yes ⁵³	3354	3444	3354	3354	-	90	210 (N)	Flat, urban fringe (>1,000m to nearest obstacle)	
		29 (4)(H)	Yes ⁵³	3354	3444	3354	3354	-	90	210 (N)	Flat, urban fringe (900m to golf course and major road)	
		18 (3)	No	1524	1584	1524	1524	-	60	90 (N)	Urban (280m to highway and residential development)	
		36 (3)	No	1524	1584	1524	1524	-	60	200 (N)	Flat, urban fringe (>1,000m to nearest obstacle)	
Derby (Curtin) ^(j)	YCIN	11 (4)	No	3049	3354	3111	3049	62	243	250 (G) + additional 1,490m grassed area	Flat, rural land (>1,000m to nearest obstacle)	
		29 (4)	No	3049	3354	3110	3049	62	244	250 (G) + additional 690m grassed area	Flat, rural land (1,000m to scrub)	

⁵³ Runway 11/29 at Darwin is grooved only for the central 45 m of the runway, not the full 60 m width.

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Exmouth (Learmonth) ^{(i)(J)}	YPLM	18 (4)	No	3047	3352	3107	3047	60	245	220 (N)	Flat, rural land (>1,000m to major road)	
		36 (4)	No	3047	3352	3137	3047	90	215	200 (N)	Flat, rural land (>1,000m to nearest obstacle)	
Gladstone	YGLA	10 (3)	No	1635	1695	1635	1635	-	60	90 (N)	Adjacent to forest and railway trunk line (160m to trees, 350m to railway)	N/A – Airport was not surveyed In 2009, works commence on a rwy extension to 1,915 m (ICAO Code 4). This will require the bridging of Briffney Creek and the realignment of Callemondah Drive.
		28 (3)	No	1635	1695	1635	1535	-	60	90 (N)	Adjacent to creek and minor road (230m to creek)	
Gold Coast (Coolangatta) ⁽ⁱ⁾	YBCG	14 (4)	Yes	2342	2402	2342	2342	-	60	90 (N)	Adjacent to freeway (400m to freeway tunnel, 570m to scrub and creek)	
		32 (4)	Yes	2492	2552	2492	2042	-	60	90 (S)	Urban (250m to desalination plant, 550m to residential development)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Gove	YPGV	13 (4)	No	2208	2268	2208	2208	-	60	90 (G)	Flat, rural land (>1,000m to nearest obstacle)	
		31 (4)	No	2208	2268	2208	2208	-	60	90 (S)	Flat, rural land (>1,000m to nearest obstacle)	
Hamilton Island	YBHM	14 (3)	Yes	1764	1839	1764	1704	-	75	60 (S) + 30 (G)	Flat coastline (110m to ocean)	RESA extensions limited by ocean and environmental issues.
		32 (3)	Yes	1764	1824	1764	1704	-	60	60 (S) + 30 (G)	Flat coastline (110m to ocean)	
Hervey Bay	YHBA	11 (4)	Yes	2000	2060	2000	2000	-	60	<i>No data provided</i>	Flat, urban fringe (380m to minor road)	Unknown
		29 (4)	Yes	2000	2060	2000	2000	-	60	<i>No data provided</i>	Flat, urban fringe (800m to major road)	
Hobart ^(l)	YMHB	12 (4)	Yes	2251	2451	2311	2251	60	140	90 (N)	Flat coastline (500m to minor road, 750m to ocean)	
		30 (4)	Yes	2251	2461	2311	2251	60	150	90 (N)	Farmland (450m to highway)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Kalgoorlie-Boulder ⁽ⁱ⁾	YPKG	11 (4)	No (sealed)	2000	2060	2000	2000	-	60	90 (S)	Flat, rural land (220m to scrub)	
		29 (4)	No (sealed)	2000	2060	2000	2000	-	60	90 (S)	Urban fringe (>1,000m to industrial area)	
Karratha	YPKA	08 (4)	Yes	1850	2200	1940	1850	90	260	90 (N)	Tidal flats (700m to minor road)	RESA extensions are limited by terrain.
		26 (4)	Yes	1850	2150	1940	1850	90	210	90 (N)	Flat, rural land (900m to major road)	
Launceston ⁽ⁱ⁾	YMLT	14R (4)	Yes	1981	2041	1981	1981	-	60	90 (S)	Farmland (115m to railway cutting)	Small impairment to RESA 14R end due to a railway cutting.
		32L (4)	Yes	1981	2041	1981	1981	-	60	90 (N)	Farmland (450m to minor road)	
Mackay	YBMK	14 (4)	Yes	1981	2041	1981	1981	-	60	90 (S)	Tidal flats (175m to mangroves, 370m to creek)	RESA dimensions following completion of current extension works. Currently RESA only meets previous RPA requirements.
		32 (4)	Yes	1981	2041	1981	1981	-	60	90 (S)	Urban (180m to major road)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Maroochydore (Sunshine Coast)	YBMC	18 (3)	Yes	1797	1857	1797	1797	-	60	30 (D)	Urban (130m to major road)	RESA length meets previous RPA requirements only, as rwy has not been lengthened or upgraded. RESA extension at 18 end is limited by terrain and a major road.
		36 (3)	Yes	1797	1857	1797	1797	-	60	30 (D)	Flat coastline (325m to scrub, 530m to major road and residential development)	
Melbourne ⁽ⁱ⁾	YMLL	09 (4)	Yes	2286	2436	2346	2286	60	90	240 (D)	Farmland (590m to freeway)	
		27 (4)	Yes	2286	2436	2346	2286	60	90	240 (D)	Farmland (>1,000m to trees and creek)	
		16 (4)	Yes	3657	3777	3717	3657	60	60	240 (D)	Farmland (540m to golf course)	
		34 (4)	Yes	3657	3837	3717	3657	60	120	240 (D)	Farmland (1,000m to highway)	
Mildura	YMIA	09 (4)	Yes	1830	1950	1860	1830	30	90	100 (G)	Farmland (380m to highway junction)	
		27 (4)	Yes	1830	1980	1890	1830	60	90	100 (G)	Farmland (230m to minor road)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Moomba	YOOM	12 (3)	No	1718	1778	1718	1718	-	60	90 (S)	Flat, rural land (260m to minor road)	Significant flat natural surface exists beyond RESAs for at least 240m.
		30 (3)	No	1718	1778	1718	1718	-	60	90 (S)	Flat, rural land (>1,000m to nearest obstacle)	
Mount Hotham	YHOT	11 (3)	No	1460	1520	1460	1460	-	60	30 (N)	Forested, mountainous (400m to terrain drop)	RESA length meets previous RPA requirements only, as rwy has not been lengthened or upgraded. Major terrain drop-offs at both runway ends would limit significant RESA extensions.
		29 (3)	No	1460	1520	1460	1460	-	60	30 (N)	Forested, mountainous (200m to terrain drop)	
Mount Isa	YBMA	16 (4)	Yes	2560	2620	2560	2560	-	60	60 (S) + 30 (G)	Undulating rural land (970m to highway)	RESA extensions are limited by terrain (embankment) at 16 end, and a creek at 34 end.
		34 (4)	Yes	2560	2650	2560	2560	-	90	60 (S) + 30 (G)	Flat, rural land (160m to dry creek bed)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Newcastle (Williamstown) ^{(i)(j)}	YWLM	12 (4)(H)	Yes	2438	2498	2498	2438	60	-	55.5 m rwy strip (S) + additional 240m grassed area ⁵⁴	Farmland (670m to major road junction)	Being a Defence-managed aerodrome, Rwy 12/30 is maintained under Defence publication ADFP602 <i>Joint Services Works Administration Aerodrome Design Criteria</i> ⁵⁴ .
		30 (4)(H)	Yes	2438	2498	2498	2438	60	-	55.5 m rwy strip (S) + additional 240m grassed area ⁵⁴	Forest and scrub (1,000m to forest)	

⁵⁴ ADFP602 *Joint Services Works Administration Aerodrome Design Criteria* does not define or use the term RESA. It does however use the term ‘stopway’, which is defined as a paved or stabilised rectangular area at the end of the runway in which an aircraft can be stopped in the case of an aborted take-off. The stopway distance should normally extend 305 m beyond the end of the runway for the width of the combined runway and shoulders. The first 60 m is normally paved to at least the same strength as the runway shoulder pavement, with the remainder to be stabilised to cause minimal damage to overrunning aircraft.

In comparison, at civilian aerodromes, the CASR 139 *Manual of Standards – Aerodromes* provides for a minimum of 150 m beyond the runway end (60 m runway strip + 90 m RESA) for Code 3 and 4 runways.

It is important to note that the definition of a ‘stopway’ as per ADFP602 is significantly different from that used by CASA in the CASR 139 *Manual of Standards – Aerodromes*.

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Newman	YNWN	05 (4)	No (sealed)	2072	2132	2072	2072	-	60	90 (G&N)	Flat, rural land (>1,000m to nearest obstacle)	
		23 (4)	No (sealed)	2072	2132	2072	2072	-	60	20 (S) + 70 (N)	Flat, rural land (580m to highway)	
Norfolk Island ⁽ⁱ⁾	YSNF	04 (3)	No	1435	1495	1435	1435	-	60	90 (N)	Urban fringe and escarpment (70m to minor road, 90m to dense forest)	RESA extensions are limited by terrain (steep valleys).
		22 (3)	No	1435	1495	1435	1435	-	60	90 (N)	Undulating farmland (130m to VOR antenna)	
		11 (4)	No	1950	2010	1950	1890	-	60	90 (N)	Undulating farmland (380m to forest and minor road)	
		29 (4)	No	1950	2010	1950	1890	-	60	90 (N)	Undulating farmland (180m to trees and farmhouses)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Perth ⁽ⁱ⁾	YPPH	03 (4)	Yes	3444	3690	3444	3444	-	246	90 (N)	Flat, rural land (570m to creek)	Perth Airport advises that RESA extensions to the 240 m recommendation have been assessed; however, internal airport roads prevent the provision of such a RESA extension in some cases.
		21 (4)	Yes	3444	3644	3444	3444	-	200	90 (N)	Flat, urban fringe (550m to forest)	
		06 (4)	Yes	2163	2224	2163	2163	-	61	90 (N)	Flat, rural land (450m to creek and scrub)	
		24 (4)	Yes	2163	2224	2163	2163	-	61	90 (N)	Flat, urban fringe (880m to highway and residential development)	
Port Hedland ⁽ⁱ⁾	YPPD	14 (4)	No	2500	2560	2500	2500	-	60	30 (G)	Flat, rural land (470m to railway junction)	RESA length meets previous RPA requirements only, as neither rwy has been lengthened or upgraded. Rwy 14/22 RESAs will be 90m long following planned extension works.
		32 (4)	No	2500	2560	2500	2500	-	60	30 (D)	Flat, rural land (1,000m to highway)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Port Macquarie	YPMQ	03 (3)	Yes	1586	1646	1586	1586	-	60	30 (S) + 60 (N)	Flat, farmland and urban fringe (90m to minor road)	RESA extension at 21 end is limited by terrain (wetlands), and at 3 end by a road easement. Note that the RESA at 3 end as noted is currently under construction, with the removal of trees required to meet RESA grade and dimension requirements. Port Macquarie Airport advised that these works will be completed by the end of 2009.
		21 (3)	Yes	1586	1646	1586	1586	-	60	90 (D)	Flat and forested (380m to dense forest)	
Proserpine/ Whitsunday Coast	YBPN	11 (4)	No	2073	2133	2073	2073	-	60	60 (S) + 30 (N)	Flat, rural land (400m to creek and trees)	
		29 (4)	No	2073	2133	2073	2073	-	60	60 (S) + 30 (N)	Flat, rural land (200m to scrub)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Rockhampton ⁽ⁱ⁾	YBRK	04 (3)	No	1645	1705	1645	1645	-	60	30 (N)	Flat, urban fringe (220m to a minor road)	RESA length meets previous RPA requirements only, as neither rwy has been lengthened or upgraded. Rwy 15/33 RESAs will be 90m long following completion of current extension works. Terrain issues and the presence of a road prevent the rwy 04 and 33 end RESAs to be extended significantly without reducing the declared runway length.
		22 (3)	No	1645	1705	1645	1645	-	60	30 (N)	Flat, rural land (460m to a minor road)	
		15 (4)	Yes	2628	2928	2628	2628	-	300	30 (S)	River floodplain with complex drainage channels (800m to oxbow lake)	
		33 (4)	Yes	2628	2688	2628	2628	-	60	30 (S)	River floodplain with complex drainage channels (170m to oxbow lake)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Sydney ⁽ⁱ⁾	YSSY	07 (4)	Yes	2530	2620	2560	2530	30	60	90 (D)	Urban (340m to freeway)	RESA 25 end will be 90m long following completion of current extension works. Position of the parallel runways on reclaimed land in Botany Bay would require major works to significantly extend the RESA by extending the seawall (with likely environmental impact). An alternative may be a small reduction in the declared runway length. Major roads at the runways 07 and 34L ends would limit a large RESA extension.
		25 (4)	Yes	2530	2590	2530	2429	-	60	30 (S)	Urban, abuts freeway tunnel and river (100m to electricity trunk line freeway, 200m to river)	
		16L (4)	Yes	2438	2528	2438	2207	-	90	90 (D)	Flat coastline (340m to ocean)	
		34R (4)	Yes	2438	2498	2438	2400	-	60	90 (D)	Urban, adjacent to canal (740m to freeway)	
		16R (4)	Yes	3962	4052	3992	3877	30	60	90 (S)	Flat coastline (370m to sea wall, 400m to ocean)	
		34L (4)	Yes	3962	4053	3962	3962	-	91	90 (S)	Urban (320m to major road, 370m to canal)	
Townsville ^{(i)(j)}	YBTL	01 (4)(H)	Yes	2438	2640	2438	2438	-	202	90 (N)	Flat coastline (>1,000m to nearest obstacle)	
		19 (4)(H)	Yes	2438	2640	2438	2438	-	202	90 (N)	Flat, urban fringe (500m from highway)	

Airport ⁽ⁱ⁾	ICAO airport code	Rwy end, ICAO code ^{(ii) (iii)}	Grooved?	TORA (m) ^(iv)	TODA (m) ^(v)	ASDA (m) ^(vi)	LDA (m) ^(vii)	SWY length (m) ^(viii)	CWY length (m) ^(ix)	RESA length (m) ^(x)	Surrounding environment ^{(xi) (xii)}	RESA limitations ^(xiii)
Wagga Wagga ^(J)	YSWG	05 (3)	No	1768	1828	1768	1768	-	60	60 (N)	Farmland (860m to highway)	RESA length meets previous RPA requirements only, as neither rwy has been lengthened or upgraded.
		23 (3)	No	1768	1828	1768	1768	-	60	60 (N)	Farmland (760m to minor road)	

Source: Airservices Australia, 2007b; Google Earth; individual airport operators

Table notes

- (i) 'I' indicates that the airport is designated for international operations by the Department of Infrastructure, Transport, Regional Development and Local Government. 'J' indicates that the airport is owned by the Department of Defence, however, lease arrangements are used for civilian operators.
- (ii) The 'runway end' is defined as the threshold at the opposite end of the runway being used for operations (e.g. 'runway 18 end' is actually describing the threshold where the numbers '36' are painted on the runway surface).
- (iii) The numbers '3' or '4' indicate the ICAO runway code. 'H' denotes that a tensioned hook/cable arresting system is installed at the runway end. 'N' denotes that an arrestor net system is installed.
- (iv) Take-off run available (TORA) = length available for takeoff, normally includes entire runway length (excludes stopways and clearways).
- (v) Take-off distance available (TODA) = length available for ground run, lift off and initial climb to 35 ft (includes clearways, excludes stopways).
- (vi) Accelerate-stop distance available (ASDA) = length available for takeoff run, plus any stopways (includes stopways, excludes clearways).
- (vii) Landing distance available (LDA) = length available for ground run (excludes stopways, clearways and displaced thresholds).

- (viii) Stopway length calculated from ERSA data where applicable (stopway length = ASDA – TORA).
- (ix) Clearway length calculated from ERSA data where applicable (clearway length = TODA – ASDA). In Australia, CASA treats the 60 m portion between the runway end and the end of the runway strip as part of the clearway. The clearway may also include the RESA.
- (x) RESA lengths are reported as quoted by individual airport operators between February 2008 and June 2008. The distance reported is measured from the end of the 60 m runway strip as required by CASA and ICAO. ‘S’ denotes sealed, paved or bitumen surface, ‘G’ denotes gravel surface, ‘N’ denotes natural grass or dirt surface, ‘D’ denotes rock/sand/gravel and topsoil/turf aggregate surface.
- (xi) Approximate distances measured from runway end, along the extended runway centreline.
- (xii) An ‘obstacle’ is defined as an object that would likely cause significant damage to an aircraft upon impact (e.g. a major road, highway, houses, body of water).
- (xiii) As raised in discussions with airport operators.

8.3

Appendix C - FAA sample worksheet for calculating landing length

Table C.1 replicates a sample worksheet provided by the Federal Aviation Administration (FAA) for calculating landing length. It is sourced from FAA Advisory Circular AC 91-79 *Runway Overrun Prevention*. It is intended to be used by flight crew as a tool when calculating actual landing rollout length as part of a pre-landing risk and threat briefing. To provide a safe and conservative estimate of actual required rollout length, this worksheet applies factors of safety for various local conditions at the time of landing.

The sample landing rollout length estimate below is based on an aircraft intending to land at night on a wet, windy runway, with some unserviceable aircraft systems. The baseline unfactored dry landing length for the aircraft (as provided by the manufacturer in the Aircraft Flight Manual (AFM)) is 3,000 ft (914 m).

Table C.1: FAA sample worksheet for calculating landing length

1. Un-factored AFM landing distance (baseline data for a dry runway)	3,000 ft (914 m)
2. Airspeed additive to be held to the landing threshold (e.g. all of the gust). Max additive of 20kts. Landing distance increase: - Dry runway: 20-30 ft per knot - Wet runway: 40-50 ft per knot - Extended flare: 250 ft per knot	(5 kt additive) 250 ft (76 m) (wet rwy) 1,250 ft (381 m) (extended flare)
3. Add 2 seconds flare time due to gusty winds (results in a 230 ft/sec additive)	460 ft (140 m)
4. Night – no glide path: assume a 10 ft error (add 200 ft to the landing distance)	200 ft (61 m)
5. Any additions caused by minimum equipment list (MEL) or dispatch deviation guide (DDG) requirements	500 ft (152 m)
6. <i>Subtotal (1+2+3+4+5)</i>	<i>5,660 ft (1,725 m)</i>
7. Runway condition – if wet, add 15 per cent of line 6, or use AFM data if available	850 ft (259 m)
8. Contaminated runway adjustment to line 6, as per AFM and standard operating procedures	0 ft (0 m)
9. Less than maximum braking – add 20 per cent of line 6, or use AFM data if available	1,130 ft (344 m)
10. Total (6+7+8+9)	7,640 ft (2,329 m)

Source: FAA, 2007a

8.4

Appendix D - FAA/Industry Agreed Braking Action Definitions

The following table (Table D.1) of Federal Aviation Administration (FAA) and industry-agreed braking action definitions is reproduced from FAA Advisory Circular AC 91-79 *Runway Overrun Prevention*.

Table D.1: FAA/industry-agreed braking action definitions

Braking action		Estimated correlations		
Term	Definition	Runway surface condition	ICAO	
			Code	Mu
<i>Good</i>	Braking deceleration is normal for the wheel braking effort applied. Directional control is normal.	- water depth of 1/8" (3 mm) or less - dry snow less than 3/4" (20 mm) in depth - compacted snow with OAT at or below 15 °C	5	40 and above
<i>Good to medium</i>			4	39-36
<i>Medium (fair)</i>	Braking deceleration is noticeably reduced for the wheel braking effort applied. Directional control may be slightly reduced.	- dry snow 3/4" (20 mm) or greater in depth - sanded snow - sanded ice - compacted snow with OAT above 15 °C	3	35-30
<i>Medium to poor</i>			2	29-26
<i>Poor</i>	Braking deceleration is significantly reduced for the wheel braking effort applied. Potential for aquaplaning exists. Directional control may be significantly reduced.	- wet snow - slush - water depth more than 1/8" (3 mm) - ice (not melting)	1	25-21
<i>Nil</i>	Braking deceleration is minimal to nonexistent for the wheel braking effort applied. Directional control may be uncertain. NOTE: The FAA prohibits taxi, takeoff and landing operations in 'nil' conditions.	- ice (melting) - wet ice	9	20 and below

Source: FAA, 2007a

8.5

Appendix E - Airports worldwide with approved EMAS installations

Tables E.1 and E.2 list all airports in the United States and worldwide (at November 2007) that had Engineered Arresting Systems Corporation (ESCO) Engineered Materials Arresting System (EMAS) installations, and the number of EMAS beds at those airports.

Table E.3 lists EMAS installations currently under contract, or with EMAS contracts pending, as quoted by ESCO as of November 2007.

As of March 2009, no airports in Australia had EMAS or other soft ground arrestor beds installed at the end of runways.

This list is current as of November 2007. At the time of writing (mid 2009), ESCO was the only FAA-approved manufacturer of EMAS systems. For the most recent data, contact the manufacturer directly⁵⁵.

Table E.1: Airports in the United States with FAA-approved EMAS beds installed (at November 2007)

Airport	Location	Number of EMAS beds	Departure end of runway/s	Installation date
New York (John F. Kennedy Intl)	Jamaica, NY	2	4R, 22L	1996, 2007
Minneapolis/St. Paul Intl	Minneapolis, MN	1	12R	1999
Little Rock National	Little Rock, AR	2	4R, 22R	2000, 2003
Rochester Intl	Rochester, NY	1	28	2001
Burbank-Glendale-Pasadena (Bob Hope)	Burbank, CA	1	8	2002
Baton Rouge Metropolitan	Baton Rouge, LA	1	13	2002
Greater Binghamton	Binghamton, NY	2	16, 34	2002
Greenville Downtown	Greenville, SC	1	1	2003
Barnstable Municipal	Hyannis, MA	1	24	2003
Roanoke Regional	Roanoke, VA	1	33	2004
Fort Lauderdale Intl	Fort Lauderdale, FL	2	27R, 9L	2004
Dutchess County	Poughkeepsie, NY	1	6	2004

⁵⁵ Engineered Arresting Systems Corporation

2239 High Hill Road
Logan Township, NJ 08085
United States of America

Phone: +1 (856) 241 8620
Fax: +1 (856) 241 8621
Internet: <http://www.esco.zodiac.com>

Airport	Location	Number of EMAS beds	Departure end of runway/s	Installation date
New York (LaGuardia)	Flushing, NY	2	22, 13	2005
Boston (General Logan Intl)	Boston, MA	2	4L, 15R	2005, 2006
Laredo Intl	Laredo, TX	1	35L	2006
San Diego Intl (Lindbergh Field)	San Diego, CA	1	27	2006
New York (Teterboro)	Teterboro, NJ	1	6	2006
Chicago (Midway Intl)	Chicago, IL	4	31C, 4R, 22L, 13C	2006, 2007
Charleston Yeager	Charleston, WV	1	23	2007
Manchester	Manchester, NH	1	6	2007
Cordova	Cordova, AK	1	27	2007

Source: ESCO, 2007

Table E.2: Airports worldwide with EMAS beds installed (at November 2007)

Airport	Location	Number of EMAS beds	Departure end of runway/s	Installation date
Jiuzhai-Huanglong	Sichuan Province, China	2	2, 20	2006
Madrid-Barajas Intl	Madrid, Spain	2	33L, 33R	2007

Source: ESCO, 2007

Table E.3: Airports with EMAS beds under contract (at November 2007)

Airport	Location	Number of EMAS beds	Expected installation date
Chicago (O'Hare Intl)	Chicago, IL	2	2008 (northern spring)
Wilkes-Barre/Scranton Intl	Scranton, PA	1	2008 (northern spring)
Newark Liberty Intl	Newark, NJ	1	2008 (northern spring)
San Luis Obispo County	San Luis Obispo, CA	2	2008 (northern spring)
Minneapolis/St. Paul Intl	Minneapolis, MN	2 (+ 1 existing)	2008 (northern spring)
Telluride Regional	Telluride, CO	2	TBD
Groton-New London	Groton, CT	2	TBD
Lafayette Regional	Lafayette, LA	2	TBD
New York (Teterboro)	Teterboro, NJ	1 (+1 existing)	TBD

Airport	Location	Number of EMAS beds	Expected installation date
Key West Intl	Key West, FL	1	TBD
New York (Farmingdale Republic)	Farmingdale, NY	1	TBD
Smith Reynolds	Winston-Salem, NC	1	TBD
Worcester Regional	Worcester, MA	2	TBD
Charlotte-Douglas Intl	Charlotte, NC	1	TBD

Source: ESCO, 2007

8.6 **Appendix F - Estimated EMAS performance for selected narrow and widebody aircraft**

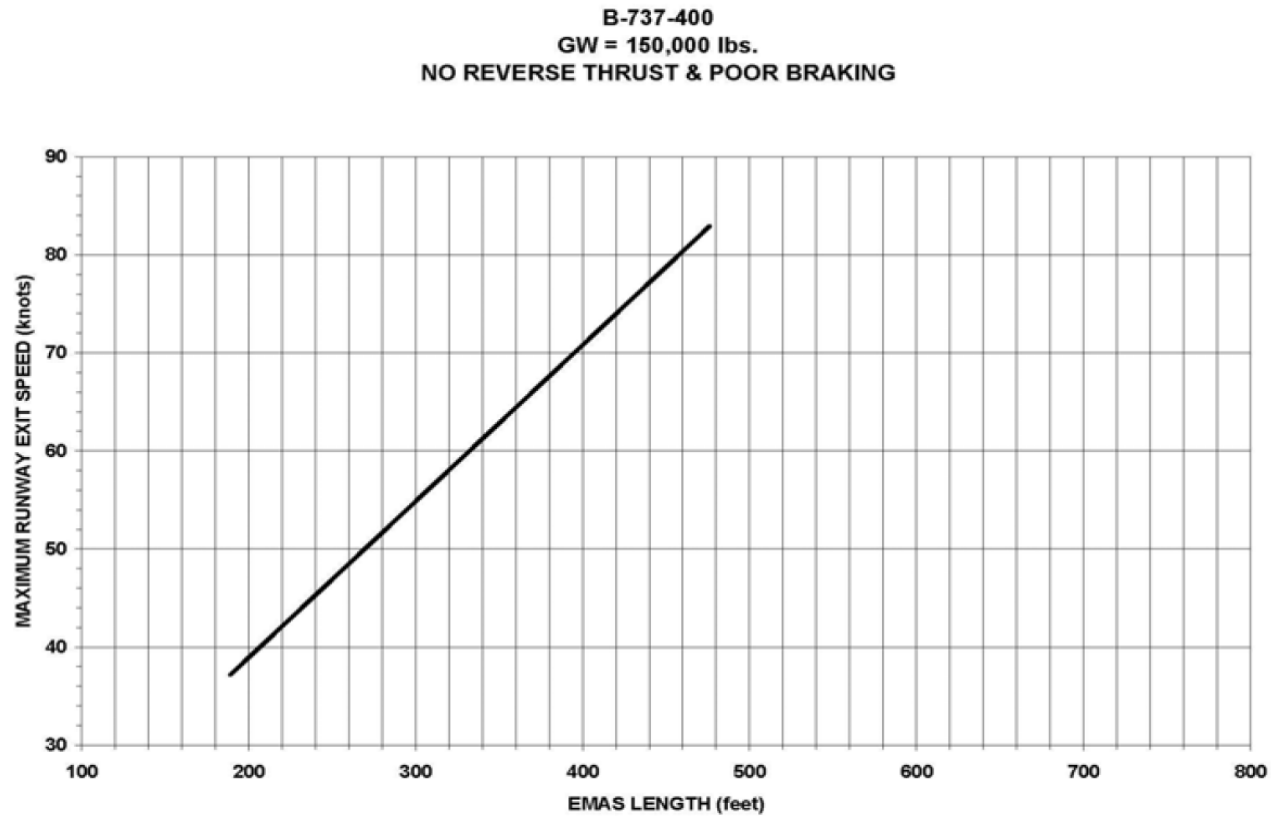
This appendix gives the Federal Aviation Administration (FAA) and Engineered Arresting Systems Corporation (ESCO)-estimated Engineered Materials Arresting System (EMAS) bed length required to stop Boeing 737-400, Boeing 747, Douglas DC-9, McDonnell Douglas DC-10, and Bombardier CRJ aircraft.

These aircraft represent a range of narrowbody and widebody aircraft, which are in Australian RPT and charter service. In the case of the DC-9, DC-10 and CRJ-200 aircraft, there are aircraft of equivalent size in service with Australian operators.

- A Douglas DC-9 is comparable to the Boeing 717 or Fokker F100 aircraft.
- A McDonnell Douglas DC-10 is comparable to the Boeing 767, Boeing 777 or Airbus A330 aircraft.
- A Bombardier CRJ is comparable to an Embraer E-Jet (E-170 and E-190 aircraft).

In all cases, the modelled performance assumes the EMAS is set back 75 ft from the end of the runway, the flight crew is not using reverse thrust to decelerate the aircraft, and that the braking action is poor (Mu value of 0.25).

Figure F.1: Estimated EMAS stopping capability for a Boeing 737-400 aircraft (narrowbody)⁵⁶

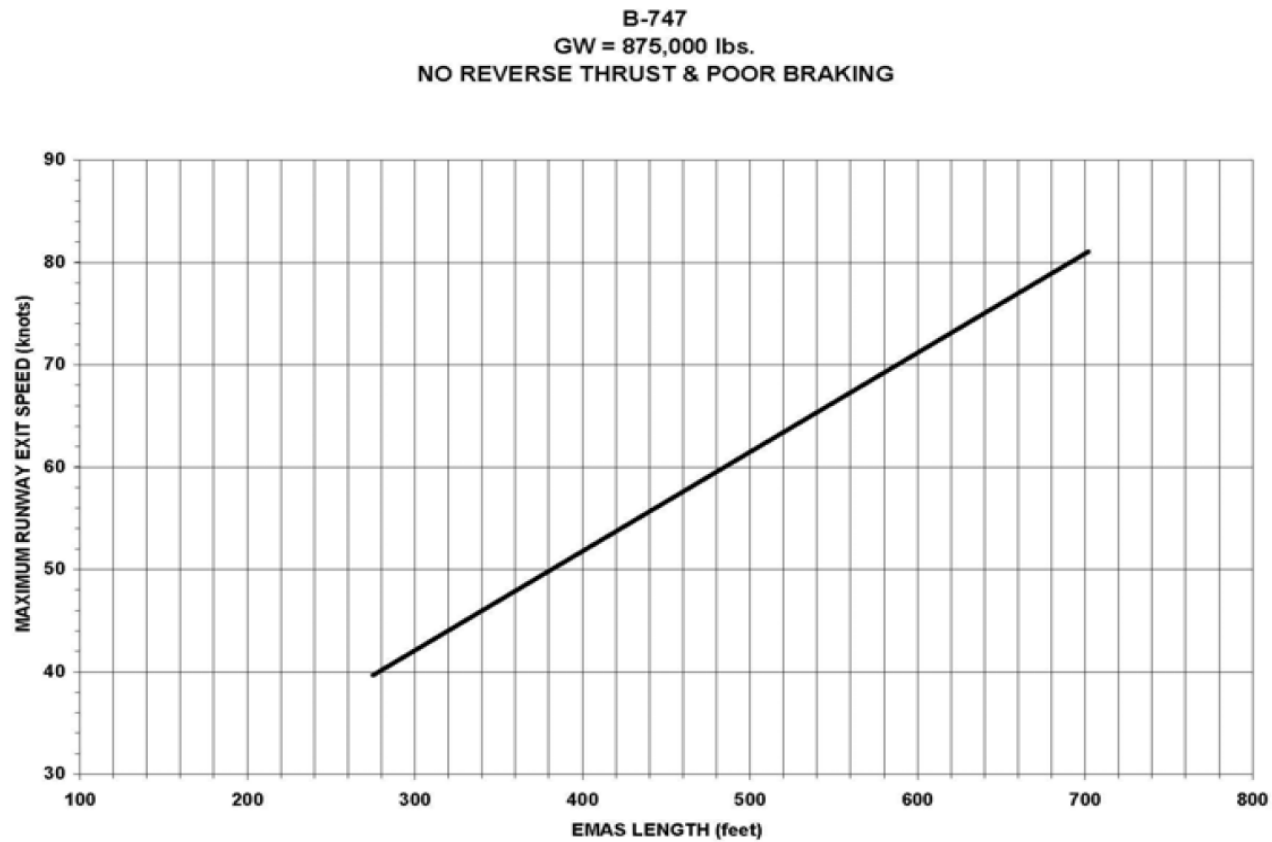


Source: FAA, 2005

⁵⁶ Figure notes:

1. EMAS includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas.
2. Poor braking simulated using a braking friction coefficient ($\mu = 0.25$).

Figure F.2: Estimated EMAS stopping capability for a Boeing 747 aircraft (widebody)⁵⁷

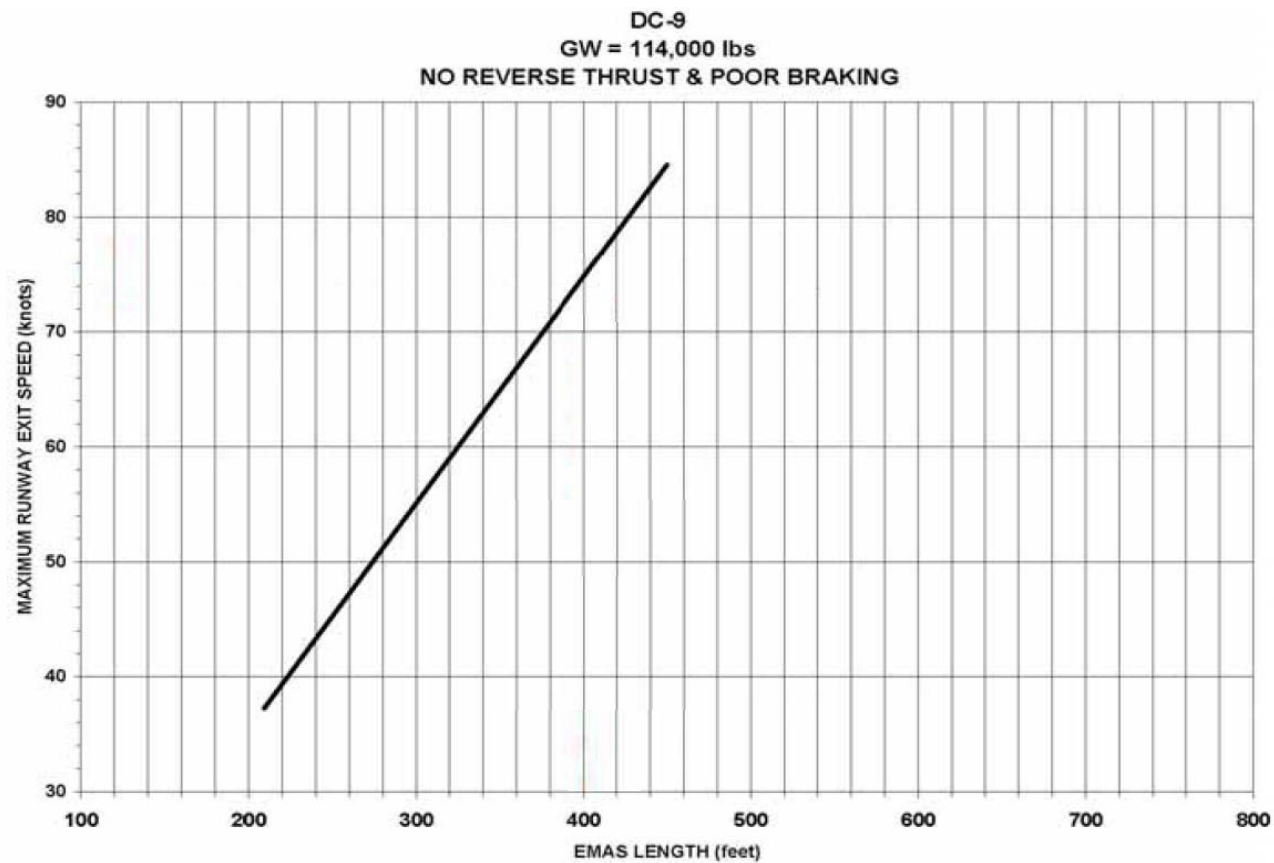


Source: FAA, 2005

⁵⁷ Figure notes:

1. EMAS includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas.
2. Poor braking simulated using a braking friction coefficient ($\mu = 0.25$).

Figure F.3: Estimated EMAS stopping capability for a Douglas DC-9 aircraft (narrowbody)⁵⁸

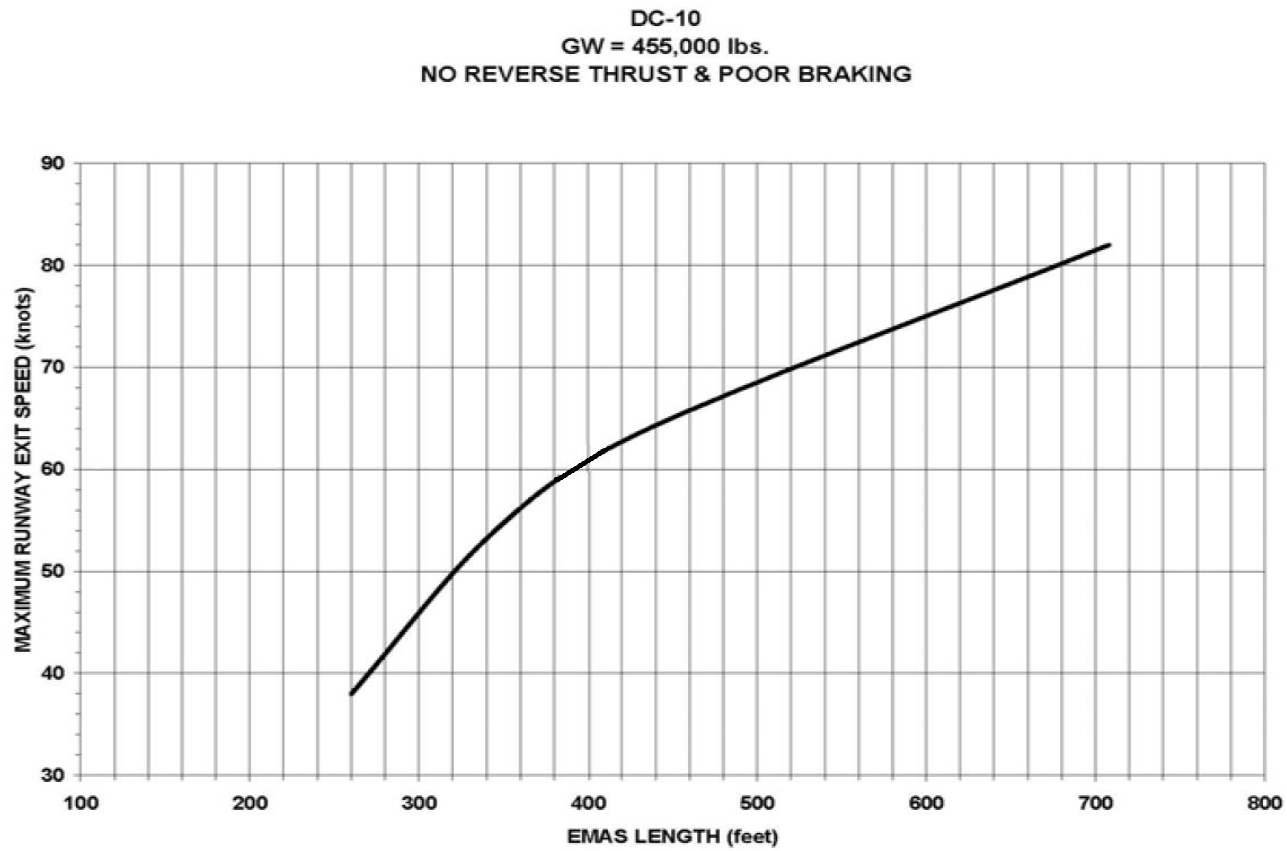


Source: FAA, 2005

⁵⁸ Figure notes:

1. EMAS includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas.
2. Poor braking simulated using a braking friction coefficient ($\mu = 0.25$).

Figure F.4: Estimated EMAS stopping capability for a McDonnell Douglas DC-10 aircraft (widebody)⁵⁹

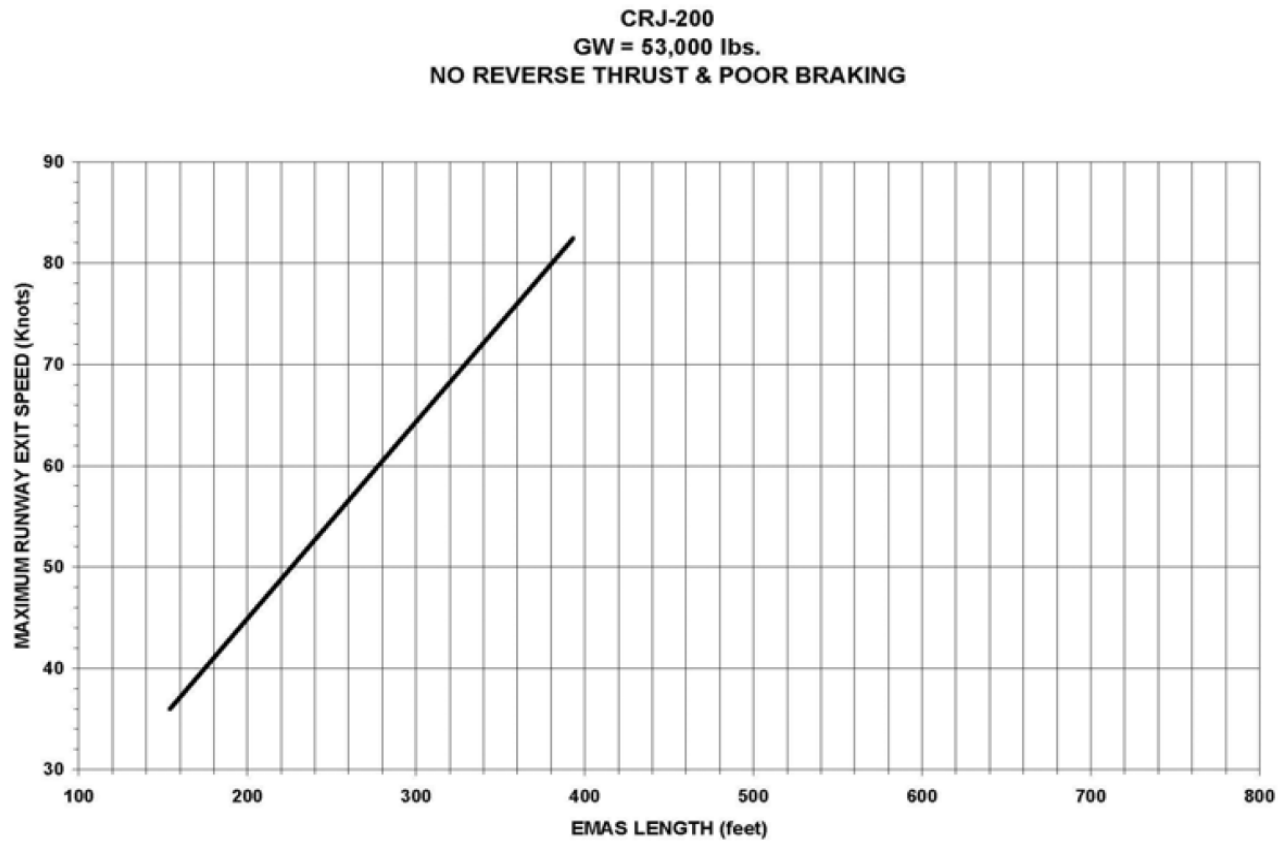


Source: FAA, 2005

⁵⁹ Figure notes:

1. EMAS includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas.
2. Poor braking simulated using a braking friction coefficient ($\mu = 0.25$).

Figure F.5: Estimated EMAS stopping capability for a Bombardier CRJ-200 aircraft (narrowbody)⁶⁰



Source: FAA, 2005

⁶⁰ Figure notes:

1. EMAS includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas.
2. Poor braking simulated using a braking friction coefficient ($\mu = 0.25$).

Runway excursions
Part 2: Minimising the likelihood and consequences of runway excursions
An Australian perspective