POLITECNICO DI MILANO

School of Civil, Environmental and Land Management Engineering

Master of Science in
Civil Engineering for Risk Mitigation

Sensitivity Analysis of Influencing Factors in Probabilistic Runway Risk Assessment

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Abstract

The air transport industry plays a major role in world economic activity for it is less time consuming that other transportation means. This highly growing aviation industry is one of the highly rick probable means of transport. The aim of reducing the Risks of Aircrafts near and on the Runway area, is the main reason behind this study.

Aiming in mitigating the risks near the runway which happen during the begging phases and ending phases of flight, the FAA introduced different standards for Runway Safety Aras depending on the type and size of aircraft using the runway. However, there are also other factors affecting the safe operations which may lead to the different hazards.

In this thesis, the effects of these factors on the normal operation are studied in two parts. In the first part, the data of previously occurred events was collected, filtered and different factors which are behind the event are studied. In the second part, three sample airports are selected, the effects of different factors studied using the risk analysis software called RSARA. Observing the results of the analysis, different comments are given.

Keywords: Airport, Runway, Runway Safety Area, Risk Analysis

Chapter 1

Introduction

1.1. Introduction

From year 2005 to 2014, 48% of fatal accidents occur during final approach and landing phases of the plane. 13% of the fatal accidents occur during the takeoff and climb phases of the plane. Regarding to the onboard fatalities for the same year interval, 38% and 10% during the final approach and landing and takeoff and climb phases respectively (*Boeing 2015, Statistical Summary of Commercial Jet Airplanes accidents, Worldwide Operation 1959-2014*). Accidents and incidents on and near the runways estimated to cost the global industry about $900M every year (*according to the study reports from NLR-ATSI*[1]).

Landing overruns, landing undershoots, takeoff overruns, veer-offs during landing and takeoff are the major types of accidents that occur during these phases of flight. Records show that while most accidents occur within the boundaries of the runway strip, most fatalities occur near but off the airport area.

The risks of an aircraft overrunning during Landing and Takeoff, undershooting during Landing, Veer-offs, depend on a number of factors related to the operation conditions, the weather, the runway surface conditions, the distance required to land or takeoff, the presence of obstacles and the available runway distance, are few of them. The possibility of human errors or aircraft system faults during the landing or takeoff phases of the flight also may contribute to the risks.

[1]*NLR-ATSI- National Aerospace Laboratory of the Netherlands-Air transport Safety Institute*

Recently, Federal Aviation Administration (FAA) standards for Airports require runways to include a runway safety area (RSA). According to FAA definition, RSA is a graded and clean area surrounding the runway that “should be capable, under normal (dry) conditions, of supporting airplanes without causing structural damage to airplanes or injury to their occupants”. Its purpose is to improve the safety of airplanes during landing and takeoff. The size of the RSA depends on the type and size of aircraft using the runway.

The standard dimensions of RSA have changed over time due to the higher safety expectations of aviation users and to accommodate a highly growing aircraft performances. Today, a standard RSA can be as large as 500 feet wide and extend 1,000 feet beyond each runway end. In many instances, meeting the standard RSA dimensions is not possible because of different constraints, mainly such as obstacles or land unavailability because many airports are constructed before the provision of the RSA with standard dimensions which is before 1960s. In such cases, it is essential to look for alternatives that minimizes the risk of possible hazards, to the extent practicable, in relation to site-specific conditions.

For some airports which doesn’t have enough space for the extension of RSA to the standard dimensions, for being landlocked or face insurmountable challenges due to terrain or environmental restrictions such as wetlands, recently, the introduction of Engineered Material Arresting Systems (EMAS)[2] has provided an alternative to achieve safety levels similar to those provided by the standards, but using only 60% of the area. Another alternative that has been used worldwide is the use of declared distances.

2. EMAS is bed of cellular cement blocks placed at the end of a runway to decelerate an overrunning aircraft in an emergency. It is passive system that will reliably & predictably crush under the weight of an aircraft.

1.2. Objective

The Report consists of two parts: in the first one, necessary data of accident and incident occurred in USA between 2000 and 2014 have been collected from NTSB database and an archive has been created filtering in a way needed for this specific study and used for different statistical analysis, while in the second part, sample of three airports were selected for the specific study.
Two of them, **A1** and **A2** have been chosen from Italy and **A3** has been selected and from USA.

Normal Operational data and Weather data of the year 2014 have been collected for the selected airports including the RSA conditions and obstacles. Runway Safety Area Risk Analysis (RSARA) software runs a simulation to assess the risk for each historical operation and outputs the average risk levels and probability distributions for each type of incident and each RSA section challenged by the operations. Finally based on the result from the statistics and simulation the possible recommendations and conclusions are made.

1.3. Document Outline

Chapter 2: Background and Literature
It broadly presents the key concepts regarding this study. The briefed observation of few of the previous studies related to this study are also included.

Chapter 3: Statistical Sensitivity Analysis on U.S. Airports Accident / Incident Database
In this chapter, the data of Accident and incidents occurred between 2000 and 2014 in US are collected and filtered, different sensitivity analysis are done using some of the factors behind the events.

Chapter 4: Development of Risk Models for RSA

This development of risk models are discussed in this chapter. The analysis of RSA risk requires three models that consider probability (frequency), location and consequences. The three of the model approaches are represented in this chapter.

Chapter 5: Risk assessment of runway and RSA

The risk assessment of selected sample airports and doing the sensitivity analysis for the output result of the software with variety of the factors affecting the results are mainly dealt in this chapter.

Chapter 6: Conclusion

This chapter contains the conclusion of the study.

Chapter 2

Background and Literature Review

2.1. Background

The air transport industry plays a major role in world economic activity. One of the key elements to maintaining the vitality of civil aviation is to ensure safe, secure, efficient and environmentally sustainable operations at the global, regional and national levels.

Some 3.2 billion passengers used air transport for their business and tourism needs in 2014, according to preliminary figures on scheduled services. Figure 2. Gibes insight about the traffic volume variation in the world.
The number of annual total passengers carried was up approximately 5% compared to 2013 and is expected to reach over 6.4 billion by 2030, based on current projections.

Aircraft departures reached 33 million globally during 2014, establishing a new record and surpassing the 2013 figure by roughly one million flights. Solid global economic growth and improving world trade helped world scheduled passenger traffic grow at a rate of 5.9% in 2014 (expressed in terms of revenue passenger-kilometers or RPKs), compared to 5.5% in 2013.

The Asia/Pacific region was the world's largest air travel market in 2014, with a 31% share in terms of world RPKs. The second and third largest air travel markets were Europe and North America, representing 27% and 25%, respectively. The Middle East Region, accounting for 9% of world RPKs, recorded the fastest growth rate at 12.8%. The Latin America and Caribbean Region increased by a solid 5.9% while African growth registered in at 1.5%.

This highly growing demand in Aviation industry is threatened bay different hazards which are natural and manmade hazards.
As statistics indicates, most of the events occur during the takeoff and landing phases of flight. From previous studies it is possible to reduce the accidents/incidents occur near and on the runway by taking different measures.
The focus of this study is about the factors that are influencing the risk of overrun, undershoots and veer-offs during the takeoff and landing phase of flight.

- Takeoff is the phase of flight in which an aircraft goes through a transition from moving along the ground (taxiing) to flying in the air, usually starting on a runway. Figure 1. Shows all the phases of a flight from takeoff to landing.
- Landing is the last part of a flight, where the aircraft returns to the ground. Aircraft usually land at an airport on a firm runway, generally constructed of asphalt concrete, concrete, gravel or grass.

What are the effects and the preventive measures that must be taken in order to minimize the fatality rates? This was studied by taking three sample airports and analyzing the probability of occurrence mainly, by using the analysis software called RSARA and giving a comments on the results.

Figure 1. Different Phases of Flight

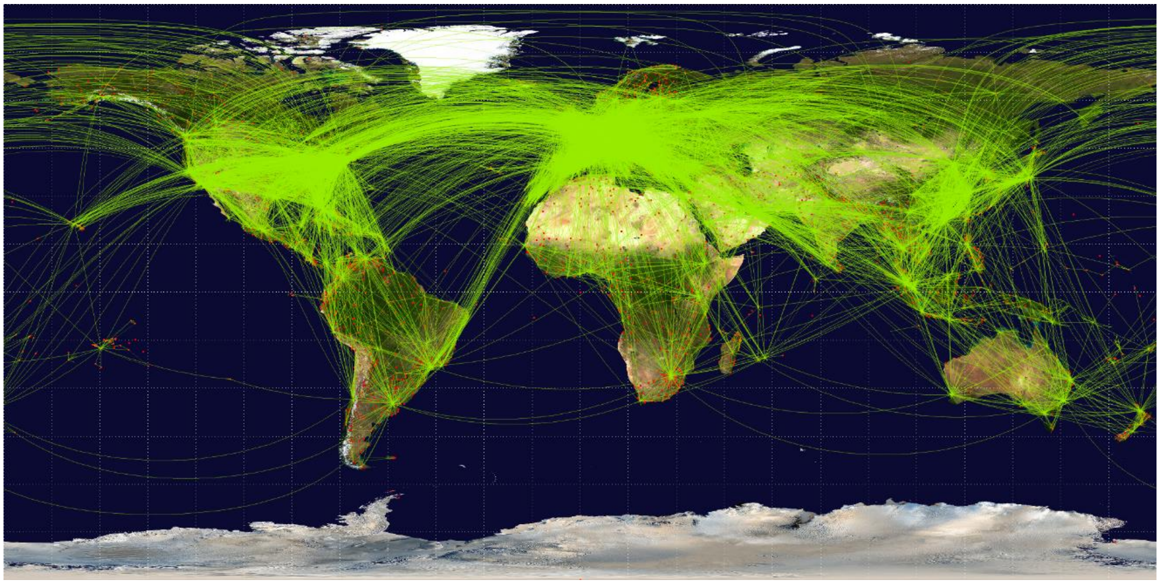

Figure 2. Scheduled Airline Traffic in 2009

2.1.1. Key Concepts

2.1.1.1. Airport

An Airport is an aerodrome with facilities for flights to take off and land. Airports often have facilities to store and maintain aircraft, and a control tower. An airport consists of a landing area, which comprises an aerially accessible open space including at least one operationally active surface such as a runway for a plane to take off or a helipad, and often includes adjacent utility buildings such as control towers, hangars and terminals. Figure 3. Shows what a single registered airport contains most of the time.

Larger airports may have fixed base operator services, airport aprons, air traffic control centers, passenger facilities such as restaurants and lounges, and emergency services.

An airport with a helipad for rotorcraft but no runway is called a heliport. An airport for use by seaplanes and amphibious aircraft is called a seaplane base. Such a base typically includes a stretch of open water for takeoffs and landings, and seaplane docks for tying-up. An international airport has additional facilities for customs and immigration.

The terms aerodrome, airfield, and airstrip may also be used to refer to airports, and the terms heliport[3] and seaplane base [4]refer to airports dedicated exclusively to helicopters, seaplanes, or short take-off and landing aircraft.

[3] *A **heliport** is a small airport suitable only for use by helicopters. Heliports typically contain one or more helipads and may have limited facilities such as fuel, lighting, a windsock, or even hangars.*
[4] *A **seaplane base** is a type of airport that is located in a body of water, usually a river or lake, where seaplanes and aircraft take-off and land*

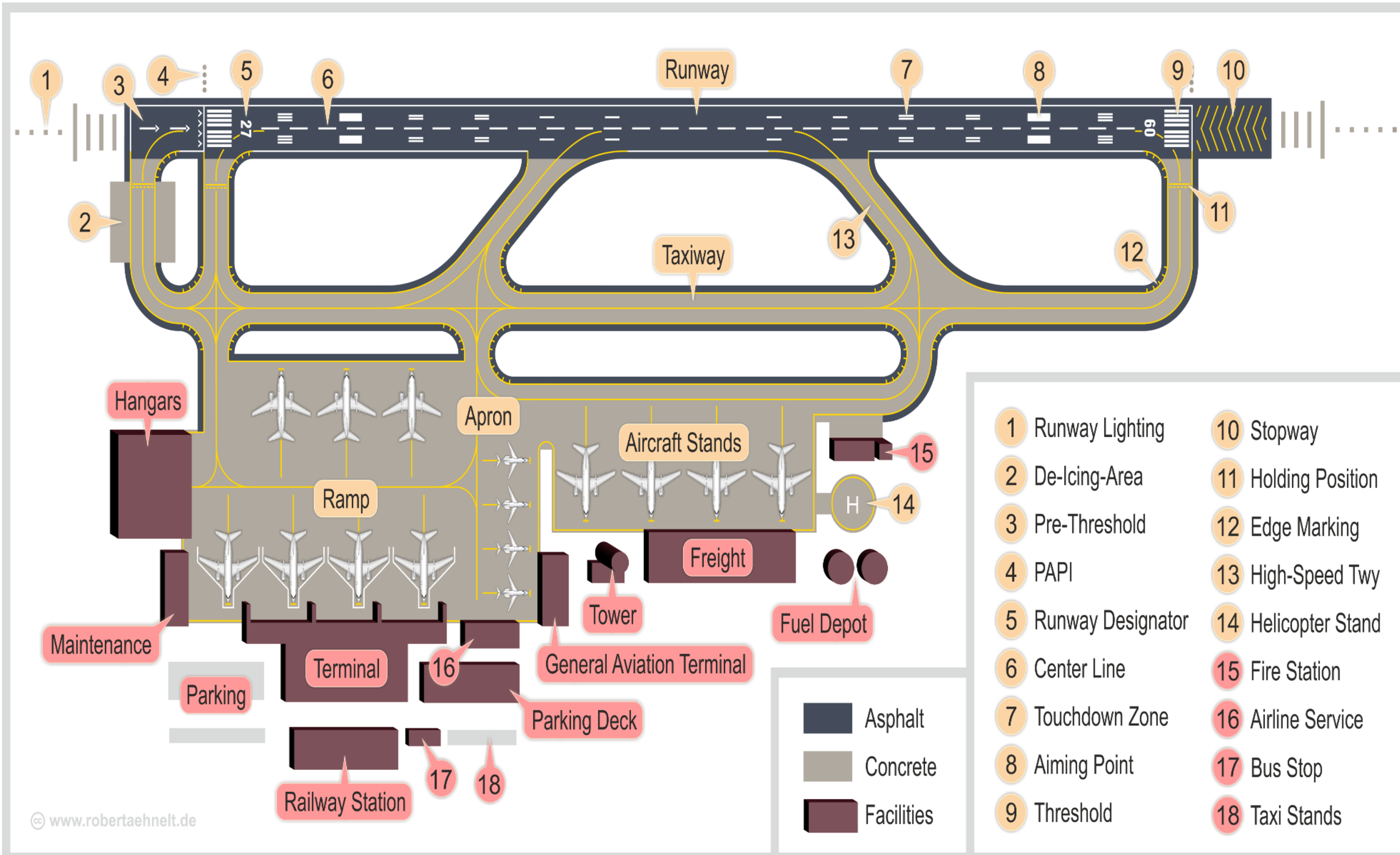

Figure 3. Sample Infrastructure of a Typical Airport

In colloquial use, the terms airport and aerodrome are often interchanged. However, in general, the term airport may imply or confer a certain stature upon the aviation facility that an aerodrome may not have achieved.
In some jurisdictions, airport is a legal term of art reserved exclusively for those aerodromes certified or licensed as airports by the relevant national aviation authority after meeting specified certification criteria or regulatory requirements.

The longest public-use runway in the world is at Qamdo Bangda Airport in China. It has a length of 5,500 m (18,045ft). The world's widest paved runway is at Ulyanovsk Vostochny Airport in Russia and is 105m (344ft) wide.

As of 2009, the CIA stated that there were approximately 44,000 airports or airfields recognizable from the air" around the world, including 15,095 in the US, the US having the most in the world. Figure 4 shows the airport distribution in the world in 2008.

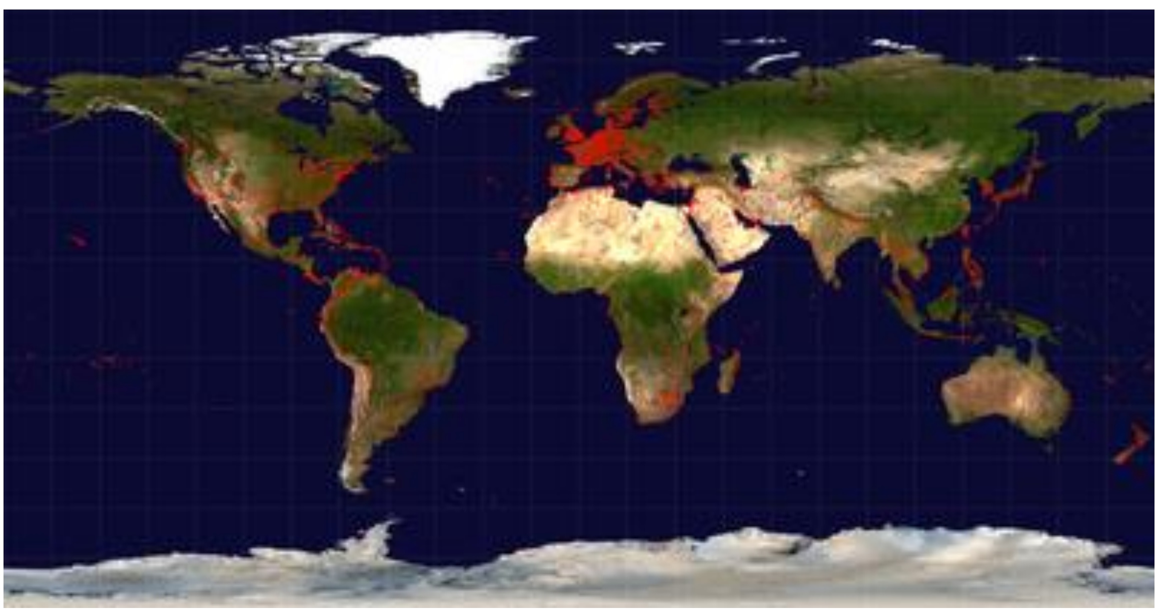

Figure 4. Airport Distribution in 2008

2.1.1.2. Category of Airports

The United States Federal Aviation Administration (FAA) has a system for categorizing public-use airports that is primarily based on the level of commercial passenger traffic through each facility.

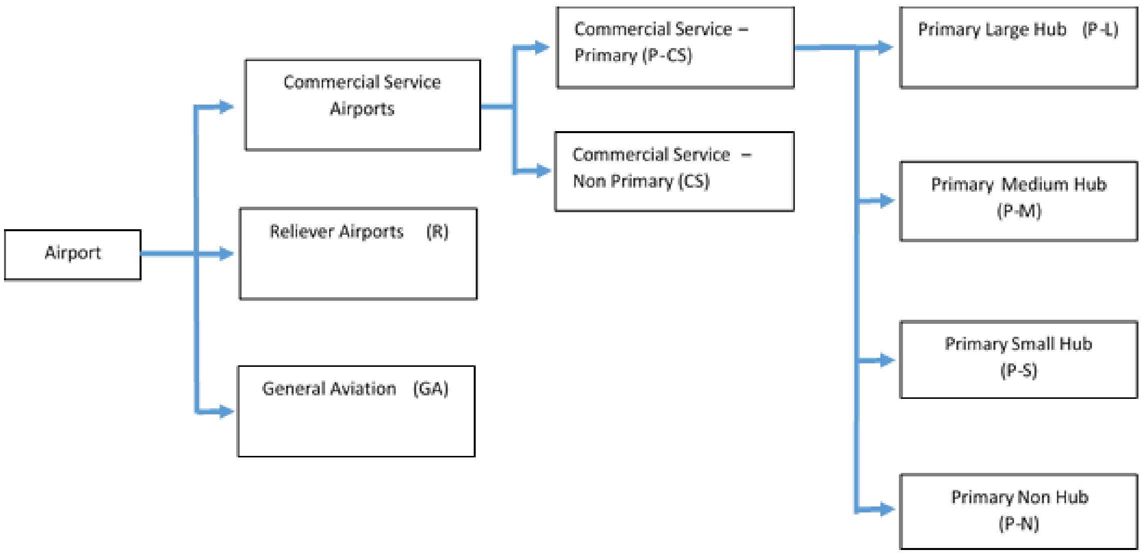

Figure 5. FAA Category of Airports

- ❖ Commercial service – primary (P-CS) are publicly owned airports that receive scheduled passenger service and have more than 10,000 passenger boarding each year. Each primary airport is further classified by the FAA as one of the following four "hub" types (s):
  - P-L: Large hub that accounts for at least 1% of total U.S. passenger enplanements.
  - P-M: Medium hub that accounts for between 0.25% and 1% of total U.S. passenger enplanements.
  - P-S: Small hub that accounts for between 0.05% and 0.25% of total U.S. passenger enplanements.
  - P-N: Non hub that accounts for less than 0.05% of total U.S. passenger enplanements, but more than 10,000 annual enplanements.

- Commercial service – non primary (CS) are publicly owned airports that receive scheduled passenger service and have at least 2,500 passenger boarding each year.
- Reliever airports (R) are designated by the FAA to relieve congestion at a large commercial service airport and to provide more general aviation access to the overall community.
- General aviation airports (GA) are the largest single group of airports in the U.S. airport system.

2.1.1.3. Runway

According to the International Civil Aviation Organization (ICAO), a runway is a "defined rectangular area on a land aerodrome prepared for the landing and takeoff of aircraft". Runways may be a man-made surface (often asphalt, concrete, or a mixture of both) or a natural surface (grass, dirt, gravel, ice, or salt).

Runways are named by a number between 01 and 36, which is generally the magnetic azimuth of the runway's heading in decadegrees: a runway numbered 09 points east (90°), runway 18 is south (180°), runway 27 points west (270°) and runway 36 points to the north (360° rather than 0°). A runway can normally be used in both directions, and is named for each direction separately: e.g., "runway 33" in one direction is "runway 15" when used in the other. The two numbers usually differ by 18 (= 180°). In case of the presence of more than one runways, each runway is identified by appending Left (L), Center (C) and Right (R) to the number. Figure 6 shows a typical runway characteristics with RWY number 27.

Figure 6. Typical Airport Runway

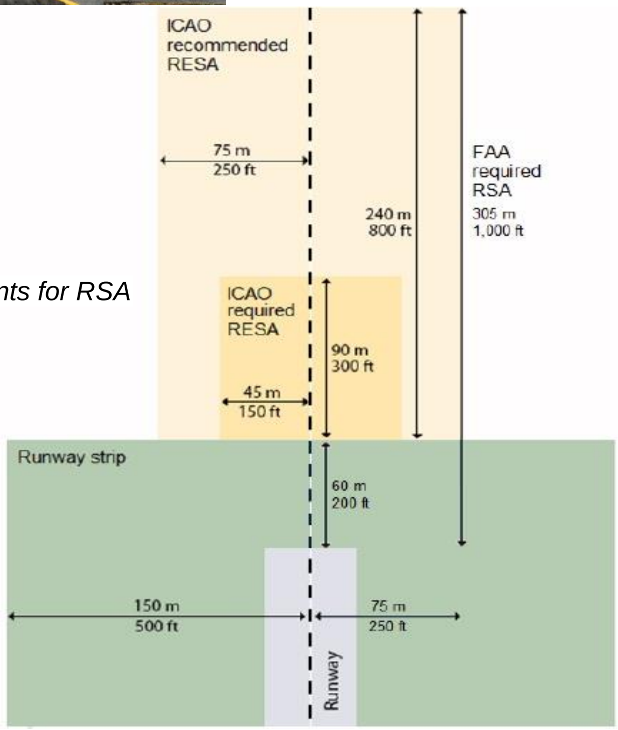

Figure 7. ICAO and FAA Requirements for RSA

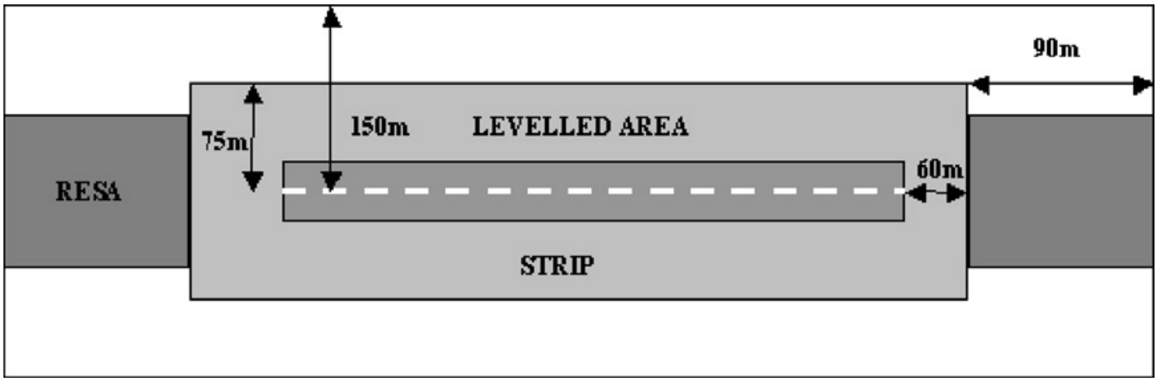

Figure 8. Strip Dimension According to ICAO, Annex 14

2.1.1.4. Runway Safety Area

A runway safety area (RSA) or runway end safety area (RESA) is defined as "the surface surrounding the runway prepared or suitable for reducing the risk of damage to airplanes in the event of undershoot, overshoot, or excursion from the runway.

Past standards called for the RSA to extend only 60m (200 feet) from the ends of the runway. Currently the international standard ICAO requires a 90m (300 feet) RESA starting from the end of the runway strip (which itself is 60m from the end of the runway), and recommends but not requires a 240m RESA beyond that. In the U.S., the recommended RSA may extend to 500 feet in width, and 1,000 feet beyond each runway end according to US as shown in figure 7 in the previous page. The standard dimensions have increased over time to accommodate larger and faster aircraft, and to improve safety.

The implementation of standards and recommended practices prescribed by ICAO are sometimes faced with difficulties. The application of RESA at some airports is not possible due to physical or other conditions of specific location. These conditions occur in the form of unfavorable terrain, water surfaces (sea, rivers, lakes), roads, parking lots, railroads, buildings, populated areas, fences, etc. which are located behind the end of runway strip. These barriers are located in an area that should be flat and without obstacles.

Analysis shows that in some cases restrictions and physical barriers are only some dozens of meters beyond the end of runway. In those cases, which are relatively rare, it is not possible to use either standard or recommended RESA dimension.

2.1.1.5. Runway strip

The runway strip is defined as the ground area surrounding the runway and stop areas in order to reduce the damage associated with potential (longitudinal and lateral) overrunning. It does so by providing an area levelled according to certain surface slope and strength requirements. As the strip is clear of obstacles, it also protects aircraft overflying it during failed takeoff and landing operations.

2.1.1.6. Risk assessment

Risk assessment is the process which associates “hazards” with “risks”. When we know the various impacts a hazard may have on our mission and an estimate of how likely it is to occur we can now call the hazard a risk.

Risk is defined as a measure of the threat to safety posed by the accident scenarios and their consequences.

The modeling approach adopted for the quantitative assessment of the risks associated with runway operations involves several methodological steps which are defined as:

- Identification of hazardous conditions and accident scenarios,
- Determination of probabilities of the accident identified; and
- Definition of consequences of such an accident (fatalities and aircraft damages).

From above three steps for quantitative assessment of the risk, the identification of the hazards phase given emphasis for in the second part of this study, the software results of the probability of occurrence are calculated in terms of the hazards types that are specifically addressed by the software.

2.1.1.7. Identification of Hazardous Conditions

A hazard is any condition, object, activity or event with the potential of causing injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function.

In order to identify the hazards inside airport, the scenarios were defined in terms of consequences, not the causes of loss of control.

Looking at absolute values by phase of flights, aerodrome can be seen as the critical location where efforts have to be constantly performed to maintain a uniform high level of safety with the involvement of different types of actors on aerodrome platform.

The outcome of the hazards identification process has the form of a list of hazards; this hazards logging is useful for subsequent analysis. The following are the hazards that possibly occur near and on the runway of the airports.

- Landing overrun;
- Take-off overrun;
- Landing undershoot;
- Landing veer-off;
- Take-off veer-off;

Overruns:

The overrun accident is an accident during a landing or an aborted take-off, when the pilot is unable to prevent the aircraft from leaving the paved surface of the runway from its ends. It is a “longitudinal deviation”, that is the longitudinal distance traveled beyond the accelerate/stop distance available (for takeoff events), and beyond the landing distance available (for landing events).

Undershoot:

The under shoot accident is a “longitudinal deviation”, that is the longitudinal distance the aircraft undershoots the intended runway threshold. Figure 10 if a typical example of undershooting.

Veer-Offs:

The veer-off accident, both take-off and landing, is an overruns in which the aircraft leaves the side (as opposed to the end) of the runway.

It is a “lateral deviation” that is the lateral distance to the extended runway centerline. Figure 11 and figure 12 are examples of veer-offd during landing and takeoff.

Figure 9. . An ANA ALL Nippon Airways plane, Overrun the Runway during Landing at Shonai Airport Japan, December 08, 2012

Figure 11. Boeing 777-200 operated by British Airways Landed before the Threshold, at London Heathrow Airport due to Engine failure,
17 January, 2008

Figure 10. An Asiana Airlines plane veered off the Runway during Landing at Hiroshima airport in Japan, April 15, 2015

Figure 12. An Airplane operated by Longanair veered of the Run-way during Takeoff at Stornoway Airport in UK, December 2, 2015

2.1.1.8. Factors Influencing the Hazard Scenarios

In order to develop risk mitigation strategies and tools, it is important to identify hazards associated with runway overruns, undershoots and veer-offs.

A wide variety of factors that may influence overrun, undershoot and veer-off risk, were identified from the literature review. These are of differing significance, and it would be impractical to take detailed account of all of them in this specific study.

A number of categories of factors that may be relevant to overrun, undershoot and veer-off risk can be identified, as follows:

- ❖ Aircraft characteristics
- ❖ Airfield characteristics
- ❖ Weather characteristics
- ❖ Airfield system faults
- ❖ Aircraft system faults

- Pilot related issues

Within each of these different categories, a number of different factors can be identified. These are discussed further below.

Aircraft_characteristics:

- The basic performance characteristics (e.g., Accelerate-Stop Distance Required vs. Accelerate-Stop Distance Available), taking account of operating conditions (atmospheric conditions and aircraft weight)
- Use of reduced thrust on takeoff – reduced safety margin for overrun
- Safety margins applied, e.g. public service performance safety factors
- Takeoff speed
- Approach speed
- Stall speed
- Weight
- Reverse thrust availability
- Aircraft age/condition
- Operation with malfunction for which account is taken in performance calculation

Aircraft system faults:

- Primary flight instruments
- Engine failure – single and multiple
- Brake system
- Landing gear
- Control surfaces
- Electrical system
- Hydraulic system
- Operation with unknown damage

Airfield characteristics:

- Runway length, relative to operational requirements (ASDA vs. ASDR etc.)
- Runway surface condition – friction characteristics
- Runway surface condition – drainage characteristics
- Runway profile – hump near touchdown zone increasing landing overrun risk
- Runway dimensions – non-standard
- Altitude

Airfield system faults:

- Lighting
- Instrument approach aids
- Glide slope indicator
- External agents – Bird strike, foreign object damage (FOD)

Weather characteristics:

- Visibility – e.g., affecting aircraft positioning
- Precipitation (rain, hail, snow) – affecting runway surface condition or visibility
- Wind direction and strength (e.g., tailwind/crosswind)
- Variability/consistency of wind speed and direction –airport specific conditions
- Wind shear – airport specific conditions
- Bright sun light – causing pilot distraction or illusion
- Ceiling
- Temperature

Pilot-related issues:

- Training/competence
- Availability and adherence to defined procedures
- Experience of airport
- Fatigue
- Communications error or misinterpretation of reported conditions
- Use of wrong runway/intersection
- Visual illusion
- “Over-consideration” for comfort (i.e., the pilot’s attempt to land as smooth as possible, leading to a long flare and touchdown, thus reducing the runway length available for landing roll. Flare is the landing phase when the rate of descent will be reduced by transitioning to a stall attitude.)

2.1.1.9. Navigational aids

For aircraft to be able to follow their scheduled route without deviations and incidents such as loss of separation, or in a worst case scenario, collisions, there are numerous systems permitting the positioning of aircraft.

The main ones are:

1. Distance Measuring Equipment (DME): normally used alongside VOR, this system uses basic radio telemetry to provide information on the diagonal distance between the aircraft and the ground station receiving the impulses sent by the on-board interrogator.
   The simultaneous tuning of two or more ground stations, together with a navigation calculator, enables the positioning in two dimensions, latitude and longitude, of any aircraft.

2. Global Navigation Satellite System (GNSS) at present, this system consists of GPS (Global Positioning System) and Glonass (Global Orbitary Navigation Satellite System).

3. VHF Omnidirectional Radio Range (VOR): a directional transmission system. The information can be interpreted by an on-board VOR receiver and be used for positioning in space or to guide the aircraft, keeping it within the selected radial. If using the Doppler VOR this is called DVOR.

4. Tactical Navigation equipment (TACAN): operationally analogous to the VOR and DME combination, and mainly used for military aviation.

5. Non Directional Beacon (NDB): non-directional radio transmitter. This gives vertical plane surface situations referring to reference axes fixed on the aircraft.

6. Instrument Landing System (ILS): system formed by two directional transmission components: the localizer (LOC) and the glide path (GP or GS). These components are used to define the heading and descent surfaces, the intersection of which defines the descent flight path.

   The last component of the ILS are the radio beacons, which activate the corresponding aircraft receiver when it is over its vertical. Its purpose is to provide the crew with information on their distance from the runway threshold. There are usually 3 radio beacons.

7. Visual Aids: to complement the ILS there are visual approach slope indicator systems, including T-VASIS[5], AT-VASIS[6], PAPI[7] and APAPI[8].

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[5] ***T-VASIS****- "T"-Visual Approach Slope Indicator System. It is system provides approach slope guidance by symbolic means as distinct from color differentiations, color being used only to provide a conspicuous warning signal when an approach is made which grossly undershoots the correct approach slope*.

[6] ***AT-VASIS:*** *abbreviated T visual approach slope indicator system*

2.1.1.10. Instrument Landing System

Instrumental landing system is further classified in to three categories.

- ILS Category I
- ILS Category II
- ILS Category III

2.1.1.10.1. **ILS Category I**

An ILS which provides a specified quality of guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the ILS glide path at a height of 200ft or less above the threshold. Using this category of equipment and provided that appropriate supplementary ground and airborne equipment is installed and operating, operations can be permitted down to a decision height of 200ft and with a runway visual range (RVR) of the order of 800 meters.

2.1.1.10.2. ILS Category II

An ILS which provides a specified quality of guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the ILS glide path at a height of 50ft or less above the threshold. Using this category of equipment and provided that appropriate supplementary ground and airborne equipment is installed and rating, operations can be permitted down to a decision height of 100ft and with a RVR of the order of 400 meters.

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[7] ***PAPI:*** *precision approach path indicator*

[8] ***APAPI:*** *abbreviated precision approach path indicator*

2.1.1.10.3. ILS Category III

An ILS which, with the aid of ancillary equipment where necessary, provides the specified quality of guidance information from the coverage limit of the facility to and along the surface of the runway. Using this category of equipment and provided that appropriate supplementary ground and airborne equipment is installed and operating, operations can be permitted with no decision height limitation and without reliance on external visual reference.

2.1.1.11. Standard Instrument Departure (SID)

A SID is an air traffic control coded departure procedure that has been established at certain airports to simplify clearance delivery procedures. SIDs are supposed to be easy to understand and, if possible, limited to one page.

Although a SID will keep aircraft away from terrain, it is optimized for air traffic control route of flight and will not always provide the lowest climb gradient. It strikes a balance between terrain and obstacle avoidance, noise abatement (if necessary), and airspace management considerations.

In order to legally fly a SID, a pilot must possess at least the current version of the SID's textual description. SIDs in the United States are created by either the military (the USAF or USN) or the FAA (which includes US Army fields). The main difference between US military and civilian SIDs is that military SIDs depict obstacles, ATC climb gradients, and obstacle climb gradients, while civilian SIDs depict only minimum obstacle climb gradients.

There are three main types of SIDs: pilot-nav SIDs, radar vector SIDs, and hybrid SIDs.

- A pilot-nav SID is a SID where the pilot is primarily responsible for navigation along the SID route. It allows for the aircraft to get from the runway to its assigned route with no vectoring required from air traffic control. They are established for airports where terrain and related safety factors dictate a specific ground track be flown.

- A radar vector SID is used where air traffic control provides radar navigational guidance to a filed or assigned route or to a fix depicted on a SID. Flying a vector SID may require first flying an obstacle departure procedure (ODP). This is usually annotated in the ODP section stating, "Fly runway heading to xxx prior to making any turns." Vector SIDs give air traffic control more control over air traffic routing than do pilot-nav SIDs.

- A hybrid SID is a departure that combines elements of both the pilot-nav and radar vector departures. A hybrid SID usually requires the pilot to fly a set of instructions, then be vectored to a defined route to a transition to leave the terminal area.

2.2. Literature Review

One could try to reduce risks in an activity by totally avoiding specific hazards, but doing this may result in missing out the greater benefits.
Like all other travelling means, flying is hazardous, but by identifying the inherent hazards and assessing the associated risks, we can put mitigating features in place so that the benefits can be achieved reducing the possible risks.
A risk is “the combination of probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequence of the occurrence” (United Kingdom’s Regulator of Air Traffic Service).

A risk assessment is a process to identify potential hazards and analyze what could happen if a hazard occurs and its objective to obtain an understanding of how to access the various levels of hazards and to gain an insight on logical approaches to deal with those hazards.

Risk assessments are utilized in many areas of aviation, from designing aircraft systems to establishing operational standards and air traffic control rules. However, there is no satisfactory information available for assessing the risk of accidents occurring near and at airports.

In recent years due to the advancement of the aviation industry and its exposure to hazards there are a high needs for researches and possible risk assessments which provides sufficient assurance for general public to use the service without worry. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry.

To assess risk from an airport design standpoint, the U.K. Civil Aviation Authority (CAA) Safety Regulation Group conducted a study on aircraft overrun risk, which guides airports on overrun risk assessment and provides advice on how to reduce it (CAA 1998).This paper addresses some of the hazards arising from an airport runways and its associated operations. It describes an approach to risk assessment.

In the United States, studies also have been carried out to set criteria for the design of airport safety areas, particularly in California. Garbell (1988) pioneered the accident-potential concept that led to the adoption of safety areas at a number of airports. A 1990 FAA study (David, 1990) compiled data regarding the location of commercial aircraft accidents relative to the runway involved. The database was used to validate the Runway safety area (RSA) dimensions adopted by the FAA, and it is still effective today.

Most of all, Recently The Airport Cooperative Research Program (ACRP) undertaking research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration which are sponsored by the Federal Aviation Administration (FAA).From the released research reports Report 3, Report 50, and Report 107, are more specifically related to work

ACRP Report 3: Analysis of Aircraft Overruns and Undershoots for Runway Safety Areas

This report provides a risk-based assessment that is rational and accounts for the variability of several risk factors associated with aircraft overruns and undershoots.is report uses a probabilistic approach—a quantitative assessment—to analyze the RSA and begins a discussion on how alternatives to a standard 1,000-foot RSA may adequately mitigate risk. The report also assesses the factors that increase the risk of such accidents occurring, helps with understanding how these incidents may happen, and suggests that aircraft overrun and undershoot risks are related to specific operational factors and develops assessment approaches for those risks.

ACRP Report 50 Improved Models for Risk Assessment of Runway Safety Areas

It expands on the research presented in *ACRP Report 3* to include the analysis of aircraft veer-offs, both landing and takeoff veer-offs.

The probability of occurrence, location and consequences are considered for the risk analysis. It also developed a user-friendly software analysis tool, Runway Safety

Area Risk Analysis (RSARA) that can be used by airport and industry stakeholders to quantify risk and support planning and engineering decisions. The use of declared distances, the implementation of the Engineered Material Arresting System (EMAS) and the incorporation of a risk approach for consideration of obstacles in or in the vicinity of the RSA.

ACRP Report 107: Development of a Runway Veer-Off Location Distribution Risk Assessment Model and Reporting Template

It provides airports and their stakeholders with a method to assess the risk of lateral runway excursions, also known as veer-offs, and suggests ways to improve veer-off incident/accident reporting. Similar to previous ACRP studies specially with *ACRP Report 50*, the basis of this risk-based methodology is a three-part model: probability of veer-off, location of veer-off, and consequences of the veer-off. The

The culmination of this research is the development of the Lateral Runway Safety Area Risk Analysis (LRSARA) tool that practitioners can use to determine the probability of runway veer-offs in specific areas at their particular airport.

A Study of Runway Excursions from a European perspective

In this report causal and contributory factors that may lead to a runway excursion are identified by analyzing data of runway excursions that occurred during the period 1980-2008. The scope of this report includes runway excursions that have taken place globally with a focus on the European context.

The Development of Probabilistic Models to Estimate Accident Risk (due to Runway Overrun and Landing Undershoot) Applicable to the Design and Construction of Runway Safety Areas

In this paper they proposed the risk models for runway overrun and landing undershoot, using a probabilistic Approach. Furthermore, these models permit comparison of the results of different risk mitigation actions in terms of operational risk and safety.

Modelling the location and consequences of aircraft accidents

This paper aims to summarize the work on the location and consequence models. The projects overall focused on the development of an improved airport risk assessment methodology aimed at assessing risks related to aircraft accidents at and in the vicinity of airports and managing Runway Safety Areas (RSAs) as a risk mitigation measure. Mostly similar to the ACRP Reports regarding the content.

Chapter 3

Statistical Sensitivity Analysis on U.S. Airports Accident / Incident Database

3.1. Introduction

Two databases that contains a significant number of relevant accidents and incidents on and near airports during Landing and Takeoff phases of flight were created for this study. Two Other databases comprising Historical operations data (HOD) and the Historical Weather data (HWD) of the three selected Airports, were also developed for the second part of the study especially for the input for RSARA software.

Accident/Incident data were collected from reliable data sources and filtered in a way that it is required for this specific study and statistical sensitivity analysis is done for different factors.

The Initial focus of study was to collect the data of Accidents and Incidents that occurred in Airports in Europe and in USA from 2000 through 2014. Data unavailability, Inaccessibility because of security reasons or confidentiality of the data, Inaccessibility because of languages, Inaccessibility because of codes and presence of the event details in report form (one event one report) are some of the main reasons that forced the focus of study to be on Accidents and Incidents occurred in only in USA.

3.2. Filtration of the Data

Total of 28486 accident/incident data were collected. And later different filtration criteria applied on the data so that the relevant events could be screened and make them comparable. The first attempt of the study focus was United States of

America and Europe. But, due to some limitations mentioned above, the accident and incidents happened in USA only were given all the focus for this specific study.

The filtering Criteria were:

Table 1.The Filtration Criteria used for the Database development and Sensitivity Analysis

1	Event date	01/01/2000 - 31/12/2014
2	Investigation type	Accidents and Incidents
3	Country	United States
4	Aircraft Category	Airplane
5	Number of Engines	Two and above
6	Phases of Flight	Landing and Takeoff

3.3. Source of the data

NTSB accident/incident database is the main source of the data. In addition, part of the data was complemented from other sources of information, particularly for Category of Airports, Runway information, and Instrumental Landing System (ILS) availability in the airports. Based on the filtering criteria chosen, the information were gathered from the data sources listed below:
The sources of data for the development of the database of accidents and incidents during landing and takeoff phases of flight are:

- National Transportation Safety Board Accident Database and Synopses, USA (NTSB).
- World Aero Data Database used for data about airport details
- AirNave.com, Airport Details and the presence of Navigational Aids.

- WIKIPEDIA, List of Airports in the United States, For FAA Category of Airports.
- Sky Vector Aeronautical Charts

3.4. Accident/Incident Database Organization

The accident and incident database was organized in Microsoft Excel. The system provides some software tools that facilitate the use of the database in a flexible manner. The database includes, for each individual event or operation,

- Event Date
- Investigation Type
- Accident Number
- Country, Location
- Airport Code
- FAA Category
- Number of Runways
- Names of RNW
- Kind of NAVAID
- Airport Code
- Aircraft Category
- Model of the Aircraft
- Number of Engines
- Weather Condition
- Latitude and Longitude.

A unique identifier was assigned to each event, and the descriptions of each field and the database rules are available in Appendix.

3.5. Data Sample Description

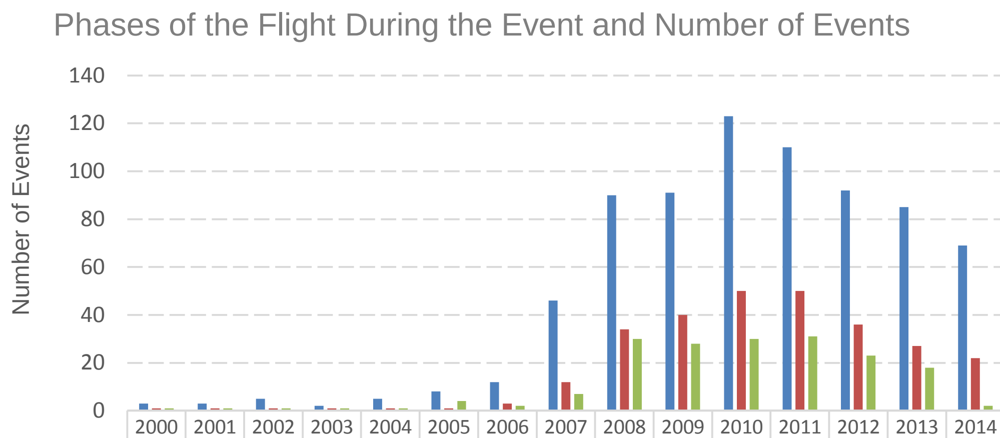
The only and found to be the best source of accidents and incidents data was the National Transportation Safety Board Accident Database and Synopses, USA (NTSB).

Limiting the date between 2000 and 2014, the total number of accidents and incidents data collected from the specified source was 28486, before all the filtration was done. Only 2754 (9.67%) of the events were registered from the remaining part of the world. This is one more reason that the study is mainly focused on the events occurred in USA.

The Filtrations were done step by step according to the criteria listed above.

1. The first filtration was by location, in this case, the events which occurred in USA only in specified period of time are 25732.
2. The second filtration criteria was by aircraft category, only Airplanes are filtered from the available aircraft types few of them are Helicopter, Balloons and Glyrocrafts. After the second filtration 8938 events remained.
3. The third filtration criteria was number of engines, Airplanes with two and more than two engines were considered and the resulting events were 1204.
4. The fourth criteria and the main focus of the study was the phases of the flight and he landing and takeoff phases were chosen. The resulting filtered events were 460 of which 280 occurred during landing phase and 180 occurred during takeoff phase.

Note: Some events registered do not contain full and necessary information and some are registered repeatedly. In this case they are deleted. F



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Other Phases	3	3	5	2	5	8	12	46	90	91	123	110	92	85	69
Landnding	1	1	1	1	1	1	3	12	34	40	50	50	36	27	22
Takeoff	1	1	1	1	1	4	2	7	30	28	30	31	23	18	2

Figure 13. Comparison between Number of Events of Landing, Takeoff and Number of Events in all other phases of Flight

Observation:

- For the years from 2000 to 2006 the number of events registered are very low compared to the following years. Underreporting and Lower volume of traffic are the main reasons for this variation.
- A rapid increase in events observed from 2007 to 2010 because of the increase in demand of aviation.
- The decrease in number of events from 2010 to 2014 because of two main reasons. The advancement in technology aiding the flight, is the first one. The second one is the time taken for investigation, i.e. investigation of a certain event may take months even years sometime till preparing the final report for the concerned body.

3.6. Statistical sensitivity analysis

One important part of this study is to determine how some of the parameters, which are collected and stored in the database are related to the event type and how these parameters are related to each other. The observed relation of these parameters with the events and with each other are:

i. Event type and Phases of the flight
ii. Meteorological conditions and Event type
iii. FAA Airport Category and the Events
iv. Category of Airports with the event and presence of NAVAIDS
v. Presence of Radio Navigational Aids (NAVAIDS) and the Events
vi. Presence of ILS

3.6.1. Event type and Phases of the flight

Table 2.The Number of Accidents and Incidents

Phases of the Flight	Incidents	Accidents
All Phases	242	962
Landing	42	238
Takeoff	47	133

Observations:

79.9% of the events from the all phases of flight category, 85% from Landing and 73.9% from the Takeoff phase are Accidents as shown in table 2. This statistics indicates only the accidents and incidents reported and stored in the database. As a matter of fact, incidents occur more frequently than the accidents.

The main reason behind the observation of the maximum percentage for accidents is because most of the incidents are not registered, for they are not events causing property damage and loss of live. And the Airport managing body usually doesn't make public this kinds of information for not having a bad image.

Figure 14 show the accidents and Incidents number in phases other than landing and takeoff. As it is explained above, the number of accident reported are greater than the incidents.

In number wise, more number of accidents occur in landing phase are higher than the number of incidents in takeoff phase. Figure 15 and 16 shows the accidents and incidents in landing and takeoff phases respectively.

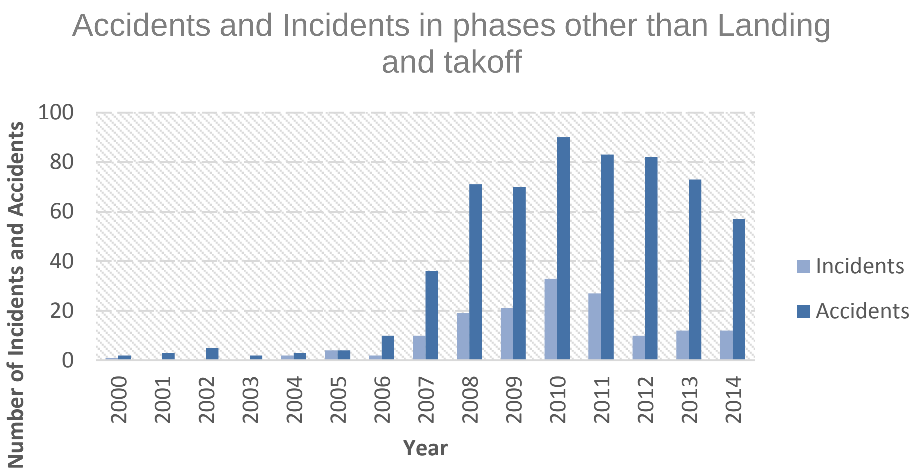


Figure 14. The relation between the types of Events (Accidents/Incidents) and Number of Events in all Phases of the Flight other than landing and takeoff

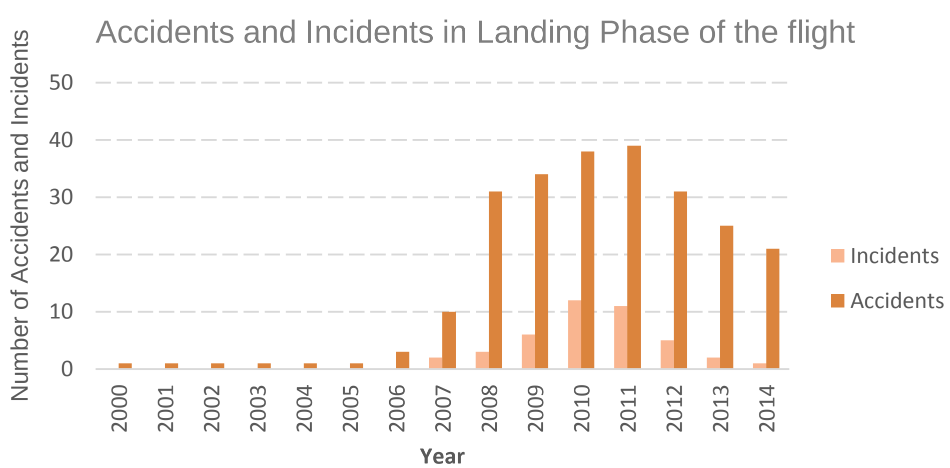


Figure 15. The relation between the types of Events (Accidents/Incidents) and Number of Events in Landing Phase of the Flight

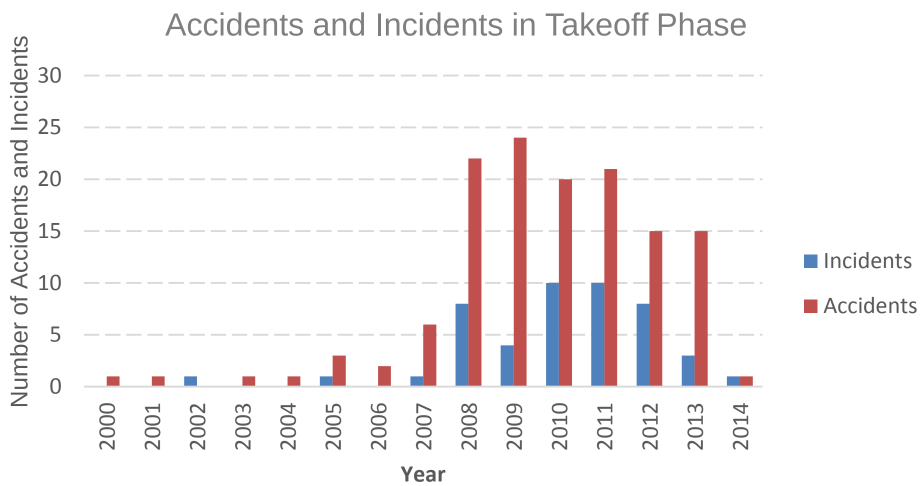


Figure 16. The relation between the types of Events (Accidents/Incidents) and Number of Events in Takeoff Phase of the Flights

3.6.2. Meteorological conditions and Event type

The two types of Aviation Meteorological Condition are Visual Meteorological Condition (VMC) and Instrumental Meteorological Condition (IMC).
Visual Meteorological Conditions (or VMC) is an aviation flight category in which visual flight rules (VFR) flight is permitted—that is, conditions in which pilots have sufficient visibility to fly the aircraft maintaining visual separation from terrain and other aircraft.
Instrument meteorological conditions (IMC) is an aviation flight category that describes weather conditions that require pilots to fly primarily by reference to instruments, and therefore under instrument flight rules (IFR), rather than by outside visual references under visual flight rules (VFR).

Observations:
From total of 280 Events occurred between 2000 and 2014 during landing, 87% or 244 of them occurred in VMC and 13% or 36 of them occurred in IMC. For

Takeoff phase total events 180, 90% or 162 of the occurred in VMC and 10% or 18 of them occurred in IMC. This indicates that in VMC the major role is played by the pilot, in fact, if there are no other factors leading the specific flight to accident or incident.

This indicates that the weather condition is not main cause of the accident or incident. Especially for the events occurred in landing and takeoff phases, the factors are mostly are: the runway condition, the aircraft condition and human errors.

The number of events during IMC are low, this indicates that the instruments used for the navigation helped reduce the events, or their severity.

The landing phase of the flight uses more navigational aiding instruments than the takeoff phase. Nevertheless, more number of events occur in landing than takeoff phase even in VMC, fig 17and 18.This is due to the nature of the phase, landing phase of flight is more risk prone than the takeoff phase of flight.

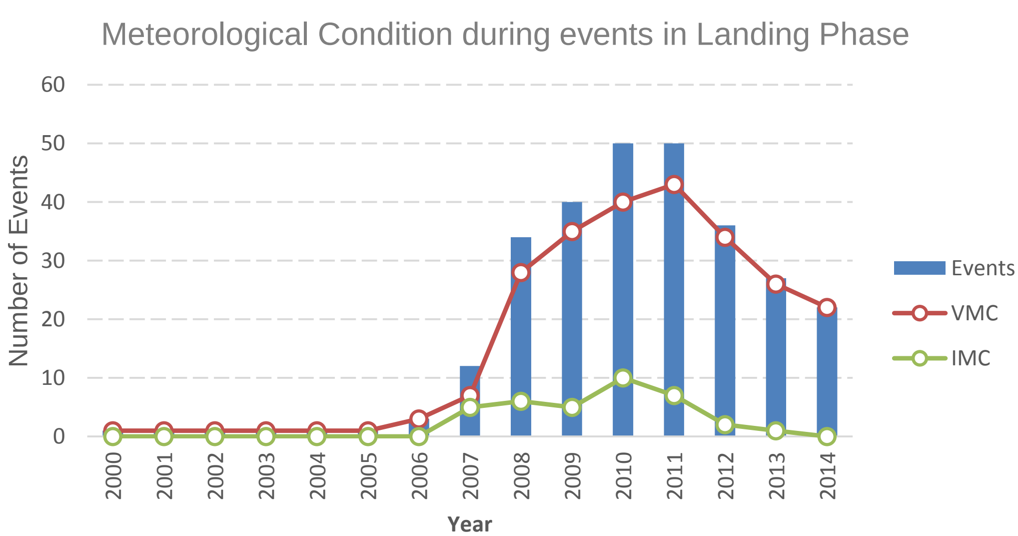


Figure 17. The Relation between the Meteorological Conditions during Events and the Number of Events which Occurred during Landing Phase of Flight

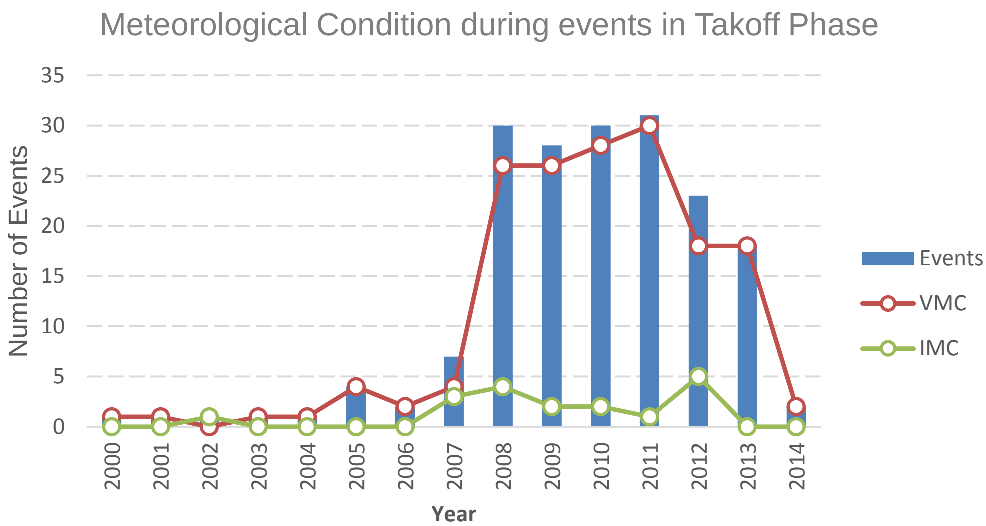


Figure 18. The Relation between the Meteorological Conditions during Events and the Number of Events which Occurred during Takeoff Phase of Flight

3.6.3. FAA Airport Category and the Events

- P-L Primary Large Hub
- P-M Primary Medium Hub
- P-S Primary Small Hub
- P-N Primary Non Hub
- CS Non-Primary Commercial Service
- R Reliever Airports
- GA General Aviation Airports

Observations:

Table 3 contains the number of events occurred in the main four FAA categories of airports. The P-CS and the GA have approximately equal number of events in landing phase. The P-CS has greater event number than the GA in takeoff phase as shown in table 5.

The primary reason for the large number of events occurrence in P-CS is the high traffic, the condition of airports and the aircraft conditions.

For the GA, for most of them are not equipped with navigational aids and other facilities in the airports like the primary airports, this is one reason for large number of event occurrence in relatively less traffic.2

CS has the list number of events in both cases, this is mainly the small traffic.

From the sub divisions of P-CS, shown in tables 4 and 6, the P-L have the higher number of events for obvious reason, which is the high traffic volume. And relatively the P-N also has high number of event, this is because P-N has less facility for it has less traffic than all other P-CS sub divisions.

Figures 19 and 20, the pie charts show the percentage of the events in the main FAA categories and the P-CS category in further detail.

The P-M has lesser events from the sub categories of P-CS, this is because most of them are equipped with the instrument and the traffic volume is also medium.

Landing Phase of Flight

Table 3.FAA Main Category of Airports and the Number of Events in Landing Phase of Flight

Landing Phase	
Category	Events in number
P-CS	110
CS	13
R	39
GA	118

Table 4. FAA Sub Categories of P-CS

Category	Evens in Number
P-L	30
P-M	17
P-S	22
P-N	41

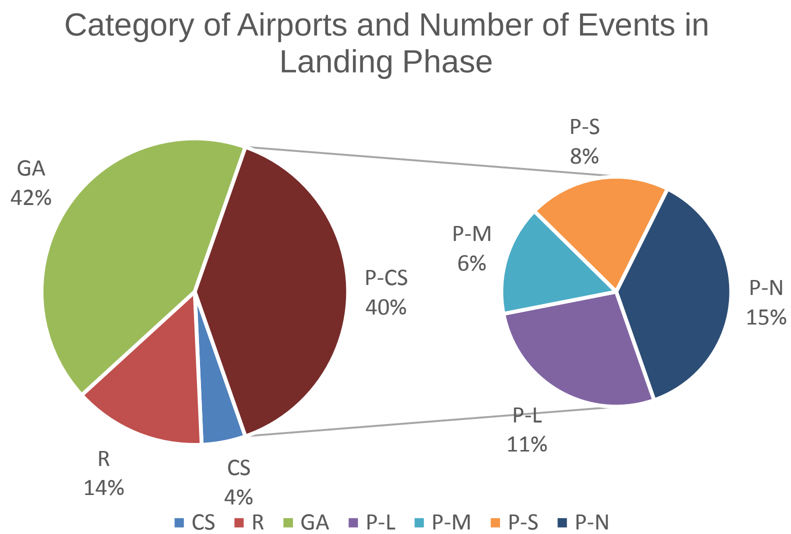


Figure 19. The Relation between FAA Category of Airports on which the Events Occurred and the Percentage of Events in Landing Phases of Flight

Takeoff Phase of Flight

Table 5.FAA Main Category of Airports and the Number of Events in Takeoff Phase of Flight

Takeoff Phase	
Category	Events in number
P-CS	76
CS	8
R	40
GA	56

Table 6.FAA Sub Categories of PC-S

Category	Evens in Number
P-L	25
P-M	7
P-S	12
P-N	32

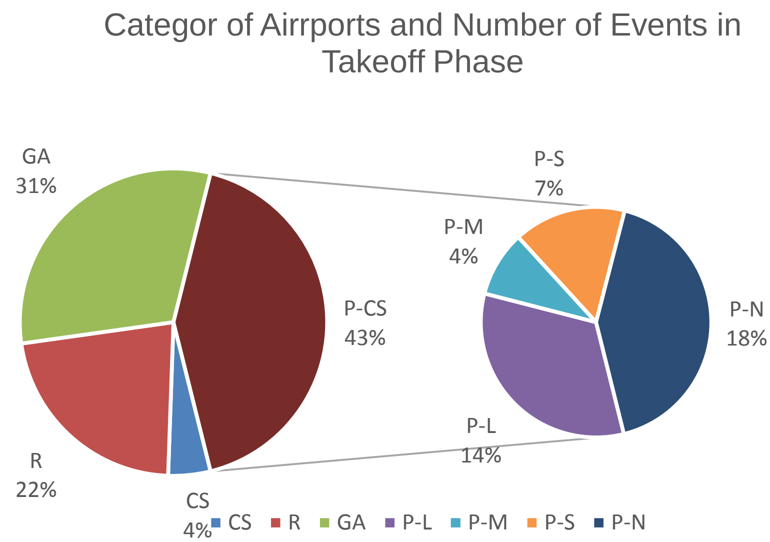


Figure 20. The Relation between FAA Category of Airports on which the Events Occurred and the Percentage of Events in Takeoff Phases of Flight

3.6.4. Category of Airports with the event and presence of NAVAIDS

Landing phase of flight

Observations:

Airports in primary category group are mostly equipped with NAVAIDS, and the cause of the event is not related to the nave aids. But, when smaller the Airport is the lesser the traffic and the more is the events.
This is because of the unavailability of the NAVAIDS mostly, in addition to human errors, runway conditions and the aircraft conditions.

General aviation airports are airport with most of the evens categorized in an airport without NAVAIDS.

From this the presence of NAVAIDS reduces the incidents and accidents occurs in an airport.

Table 7.The number of Events in different FAA Categories of Airports with/without NAVAIDS

Category of Airports	Number of Events	In the airports with NAVAIDS	In the airports without NAVAIDS
P-L	30	30	0
P-M	17	17	0
P-S	22	20	2
P-N	41	41	0
CS	6	6	0
R	39	26	13
GA	118	38	80

3.6.5. Presence of Radio Navigational Aids (NAVAIDS) and the Events

Observations:

180 of the events occurred during landing are happened in the Airports having the Radio Navigational Aids. Here, two assumptions are made. From all the Airports in which the events occurred in landing phase of the flight, approximately 84% of the events occurred in Airports categorized under GA, R, CS, P-N and P-S. The airports in this category are mostly with two runways (One runway with both ends service).

In this study it is generalized that all these airport have two runways. The other one is, from observation on the airports with two run ways is in terms of the presence of any kinds of Radio Navigation Aids that helps either for landing or takeoff of the planes.

Usually, most of the landings on that airport happened on the runway end equipped with the NAVAIDS that helps for safe landing of the plane. So, for this study it is generalized that all the landings of the planes occurs on the runway end with NAVAIDS that helps for the proper landing of the planes. From all the

280 events occurred during landing 180 or 64% of the events occurred on or near the runway which is equipped with NAVAIDS.

Figure 22 the number of events occurred in airports with NAVAIDS are studied to see the relation with the meteorological condition. 155 of 180 occurred in VMC, from this it can be concluded that the cause of most of the events is not weather condition related. Figure 23, shows the year wise distribution of events in airports with and without NAVAIDS in relation to the meteorological condition during the event.

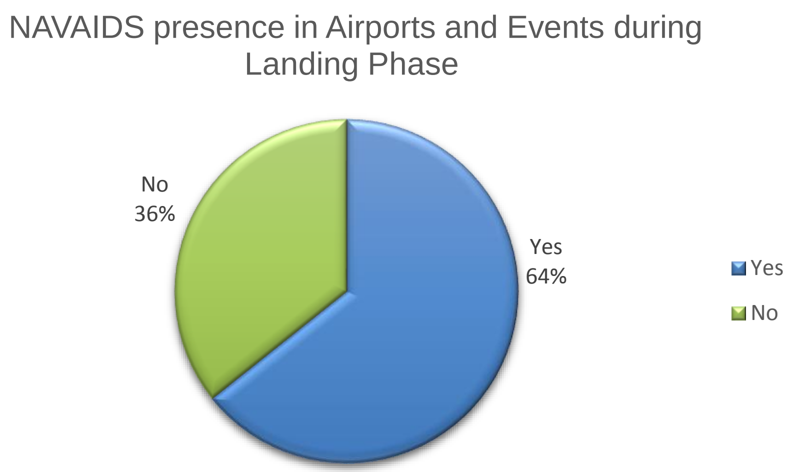


Figure 21. The Percentage of Airports with/ without NAVAIDS during an Events in Landing Phase

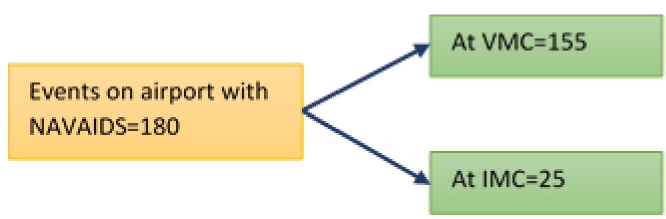


Figure 22. The Relation between the Number of Events in an Airports with NAVAIDS and the Weather Condition during an Event in Landing

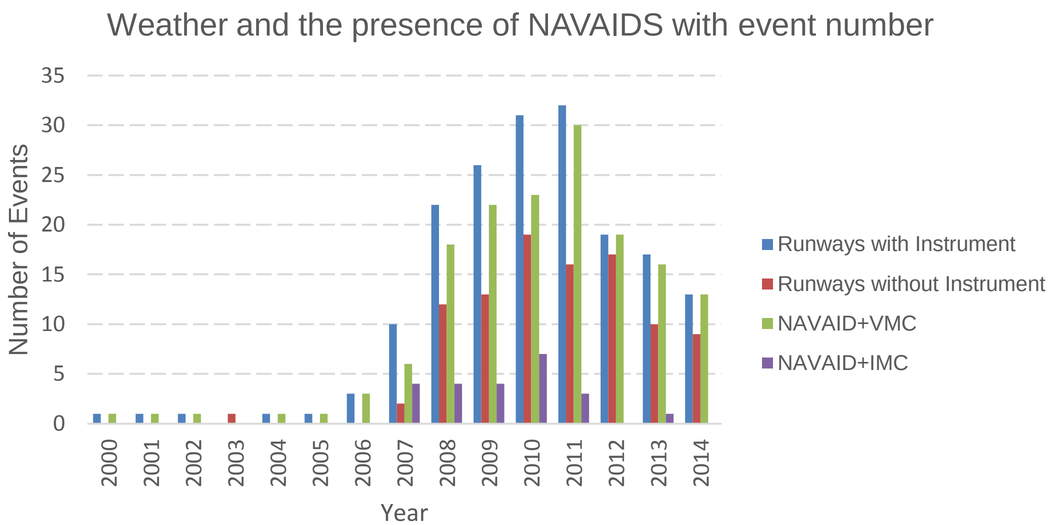


Figure 23. The Relation between the Number of Events in an Airport with/without NAVAIDS and the Respective Weather Condition

3.6.6. Presence of ILS

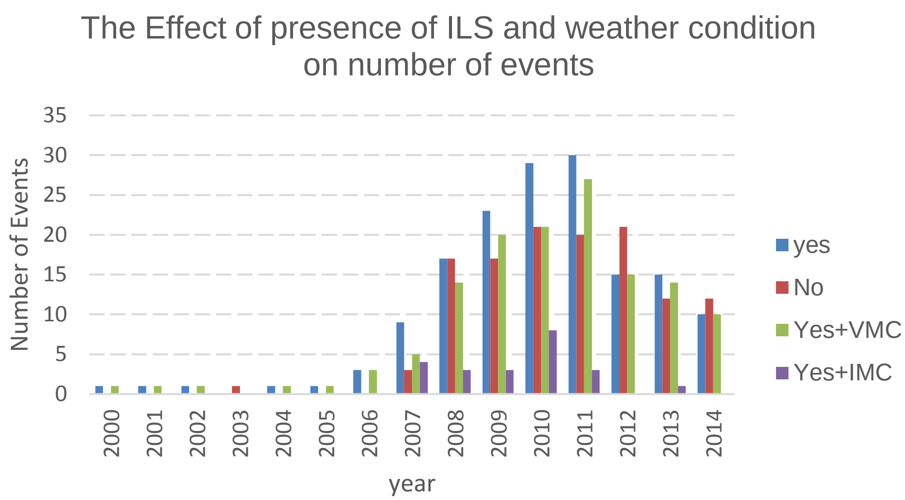


Figure 24. The Number of Events in Airports with/without ILS with Respective Weather Condition

When the number of in the airports with ILS are only counted, they are about two third of the total events. This is unrealistic and there must be other factors that Couse the events. To observe this the weather condition is included in addition to the presence of the ILS.

It is seen that most of the events occurred in Visual Meteorological Conditions. From this we can reach at concluding that the cause of the events are mostly likely related to the Human errors, Aircraft condition and Airport conditions.

CHAPTER 4

Development of Risk Models for RSA

The analysis of RSA risk requires three models that consider probability (frequency), location and consequences. The outcome of the analysis is the risk of accident during runway excursions and undershoots. The three model approach is represented in figure 25.

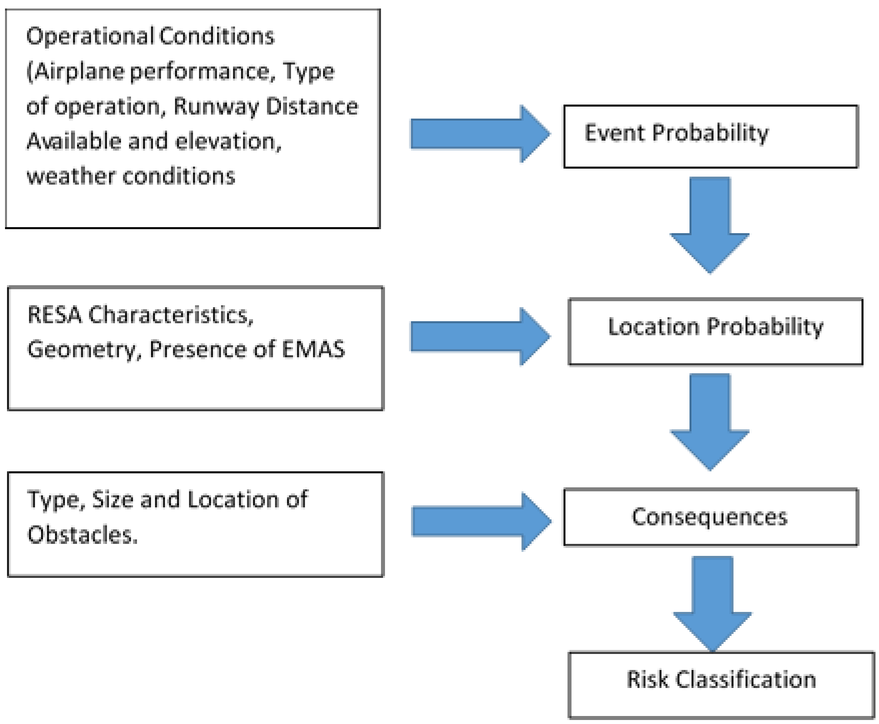


Figure 25. Risk Modelling Approach for RSA

4.1. Event Probability Model

The first model is used to estimate the probability that an event will occur given certain operational conditions. This probability does not address the likelihood that the aircraft may strike an obstacle or will stop beyond a certain distance.

The model uses independent variables associated with causal and contributing factors for the incident. For example, under tailwind conditions it is more likely that an overrun will occur, and this is one of the factors used in the models for overruns. Although human and organizational factors are among the most important causes of aircraft accidents, it was not possible to directly incorporate these factors into the risk models. Since this model is specific for the event type, five different models are required, e.g., one for landing overruns and another one for takeoff overruns.

Backward stepwise logistic regression was used to calibrate five frequency models, one for each type of incident: LDOR, LDUS, LDVO, TOVO, and TOOR. Various numerical techniques were evaluated to conduct the multivariate analysis, and logistic regression was the preferred statistical procedure for a number of reasons.

The goal was to develop risk models based on actual accidents/ incidents and normal operation conditions so that the probability of occurrence for certain conditions may be estimated. The use of such models will help evaluate the likelihood of incident occurrence for a runway that is subject to certain environmental and traffic conditions over the year.
The frequency model is in the following form:

$$P\{Accident\_Occurence\} = \frac{1}{1+e^{-(b_0+b_1X_1+b_2X_2+b_3X_3+...)}}$$

Where

P {Accident_Occurrence} = the probability (0–100%) of an accident type occurring given certain operational conditions;

X_i = independent variables (e.g., ceiling, visibility, crosswind, precipitation, aircraft type, criticality factor); and

b_i = regression coefficients.

The technique used to develop the models is able to identify relationships missed by forward stepwise logistic regression. The predictor variables were entered by blocks, each consisting of related factors, such that the change in the model's substantive significance could be observed as the variables were included. Table 8 summarizes the model coefficients obtained for each model.

Table 8.Independent Variables Used in the Analysis

Variable	LDOR	LDUS	LDVO	TOOR	TOVO
Adjusted Constant	-13.065	-15.378	-13.088	-14.293	-15.612
User Class F		1.693		1.266	
User Class G	1.539	1.288	1.682		2.094
User Class T/C	-0.498	0.017			
Aircraft Class A/B	-1.013	-0.778	-0.770	-1.150	-0.852
Aircraft Class D/E/F	0.935	0.138	-0.252	-2.108	-0.091
Ceiling less than 200 ft	-0.019	0.070		0.792	
Ceiling 200 to 1000 ft	-0.772	-1.144		-0.114	
Ceiling 1000 to 2500 ft	-0.345	-0.721			
Visibility less than 2 SM	2.881	3.096	2.143	1.364	2.042
Visibility from 2 to 4 SM	1.532	1.824		-0.334	0.808
Visibility from 4 to 8 SM	0.200	0.416		0.652	-1.500
Xwind from 5 to 12 kt	-0.913	-0.295	0.653	-0.695	0.102
Xwind from 2 to 5 kt	-1.342	-0.698	-0.091	-1.045	
Xwind more than 12 kt	-0.921	-1.166	2.192	0.219	0.706
Tailwind from 5 to 12 kt			0.066		
Tailwind more than 12 kt	0.786		0.98		
Temp less than 5 C	0.043	0.197	0.558	0.269	0.988
Temp from 5 to 15 C	-0.019	-0.71	-0.453	-0.544	-0.42
Temp more than 25 C	-1.067	-0.463	0.291	0.315	-0.921
Icing Conditions	2.007	2.703	2.67	3.324	
Rain		0.991	-0.126	0.355	-1.541
Snow	0.449	-0.25	0.548	0.721	0.963
Frozen Precipitation			-0.103		
Gusts		0.041	-0.036	0.006	
Fog			1.74		
Thunderstorm	-1.344				
Turboprop			-2.517	0.56	1.522
Foreign OD	0.929	1.354	-0.334		-0.236
Hub/Non-Hub Airport	1.334				-0.692
Log Criticality Factor	9.237	1.629	4.318		1.707
Night Conditions			-1.36		

4.2. Event Location Model

The second component is the location model. The analyst usually is interested in evaluating the likelihood that an aircraft will depart the runway and stop beyond the RSA or strike an obstacle.

The location model is used to estimate the probability that the aircraft stops beyond a certain distance from the runway. The probability of an accident is not equal for all locations around the airport. The probability of an accident in the proximity of the runways is higher than at larger distances from the runway. Since this model is specific for the event type, five different models are required, e.g., one for landing overruns and another one for takeoff overruns.

The accident location models are based on historical accident data for aircraft overruns, veer-offs, and undershoots. The accident location for overruns depends on the type of terrain (paved or unpaved) and if EMAS is installed in the RSA. When EMAS is available, during landing and takeoff overruns, the aircraft will stop at shorter distances, and typical deceleration for the type of aircraft is used to assess the location probability.

Figures 17 to 19 show the axis locations used to represent each type of incident. The reference location of the aircraft is its nose wheel. For overruns and undershoots, the x-y origin is the centerline at the runway end. For veer-offs, the y-axis origin is the edge of the runway, not necessarily the edge of the paved area when the runway has shoulders.

4.2.1. Longitudinal Distribution

For the longitudinal distribution, the basic model is:

$$P\left\{Location > x\right\} = e^{-ax^n}$$

Where

P {Location > x} = the probability the overrun/undershoot distance along the runway centerline beyond the runway end is greater than x;

x = a given location or distance beyond the runway end; and

a, n = regression coefficients.

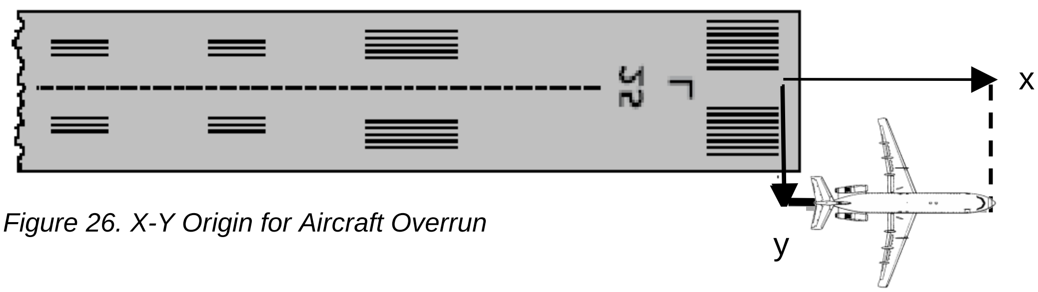


Figure 26. X-Y Origin for Aircraft Overrun

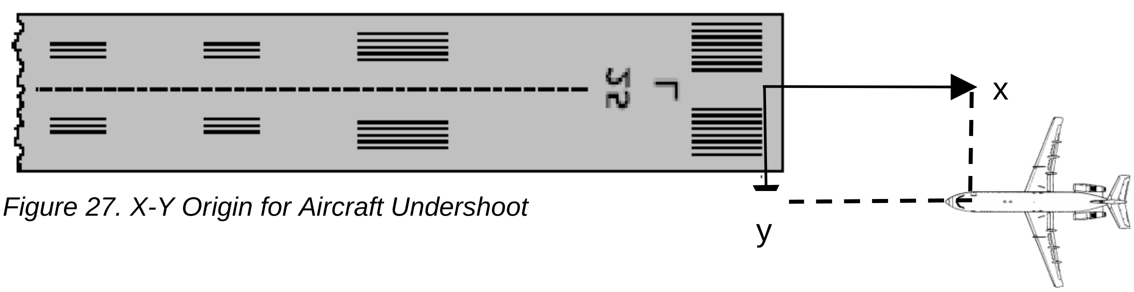


Figure 27. X-Y Origin for Aircraft Undershoot

4.2.2. Transvers Distribution

For the transverse distribution, the same model structure was selected. However, given the accident's transverse location for aircraft overruns and undershoots, in general, is not reported if the wreckage location is within the extended runway lateral limits, it was necessary to use weight factors to reduce model bias, particularly for modeling the tail of the probability distribution.

The model can be represented by the following equation:

$$P\{Location > y\} = e^{-by^{m}}$$

Where

P {Location>y} = the probability the overrun/undershoot distance from the runway border (veer offs) or centerline (overruns and undershoots) is greater than y;

y = a given location or distance from the extended runway centerline or runway border; and

b, m = regression coefficients.

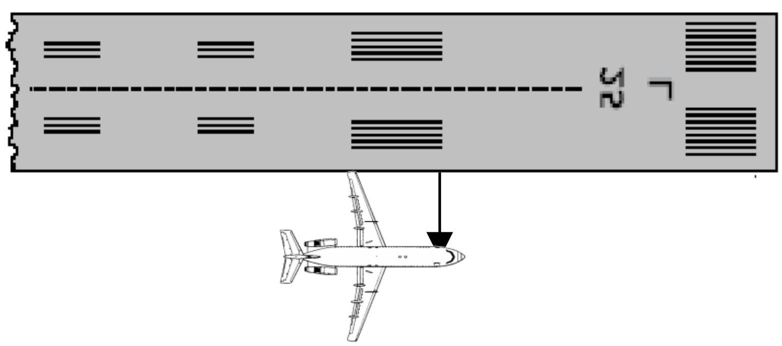


Figure 28. Y Origin for Aircraft Veer-Off

4.3. Consequence

Risk is the likelihood of the worst credible consequence for a hazard. Many overruns, veer-offs and undershoots have resulted in aircraft hull loss and multiple fatalities, and therefore, the worst credible level of consequences may be assumed to be catastrophic, according to the severity classification defined by the FAA.
In some situations, a pilot may lose control of the aircraft, resulting in the destruction of the equipment with possible fatalities, even when the aircraft accident takes place inside the RSA or the runway; however, in the majority of accidents, the RSA will offer some protection to mitigate consequences.

Consequences will depend on the type of structures and the level of energy during the aircraft collision. Possible obstacles may include buildings, ditches, highways, fences, pronounced drops in terrain, unprepared rough terrain, trees, and even NAVAID structures, like approach lighting system (ALS) towers and Localizer antennas, particularly if mounted on sturdy structures.

The energy of the aircraft during the collision is related to its speed when it strikes the obstacle, i.e. the greater speeds are expected to result in more severe consequences. Also, the consequences will depend on the type of obstacle.
The variables assumed to have an impact on consequences resulting from overruns, veer-offs, and undershoots are:
_ Obstacle type, size and location.
_ Aircraft Size (wingspan) and speed.

The basic approach is that presented in ACRP Report 03, as summarized in the ensuing sections. The approach described in ACRP Report 03 was intended to model accident and incident consequences so that they could be combined with the probability of aircraft overruns and undershoots for an assessment of risk. The approach is rational because it is based on physical and mathematical principles.
The basic idea was to assess the effect of different obstacles at various locations in the vicinity or inside the RSA. The approach integrates the probability distribu-

tions defined by the location models with the location, size, and characteristics of existing obstacles in the runway RSA and its vicinity.

The main purpose of modelling consequences of aircraft accidents is to obtain an assessment of risk based on the likelihood for the worst credible consequence. It was not deemed necessary to develop a consequence model for each type of accident, as was done to model frequency and location. The approach used can be used to address any of the five types of incidents included in the analysis.

CHAPTER 5

Risk assessment of runway and RSA

One of the main part of this study was to do the risk assessment of selected sample airports and do the sensitivity analysis for the output result of the software with variety of the factors affecting the results. The estimated risk is associated with the likelihood of an accident, rather than an incident. According to NTSB, accident is defined as an occurrence associated with the operation of an aircraft where as a result of the operation, any person receives fatal or serious injury or any aircraft receives substantial damage.

The software is called Runway Safety Area Risk Analysis (RSARA). It is developed by Airport Cooperative Research Program (ACRP), project ACRP 4-08 – Improved models for Risk Assessment of Runway Safety Area (RSA) and it is intended to serve as a tool to help airport operators evaluate the risks associated with their RSA conditions.

The followings are the types of aircraft accidents to which the associated risks are to be evaluated.

- Landing Overrun (LDOR)
- Takeoff Overrun (TOOR)
- Landing Undershoot (LDUS)
- Landing Veer-offs (LDVO)
- Takeoff Veer-offs (TOVO)

The analysis types are

1. The probability that the aircraft will exit the runway and stop beyond the limits of the RSA or, in case of undershooting, that the aircraft will touch down prior to the RSA.
2. Considering the obstacles inside or in the vicinity of the RSA to evaluate the risk of an accident with catastrophic consequences

5.1. Input Data

Input data required to run the analysis include the following information:

- Sample of historical operations data (date and time, aircraft model, runway used, type of operation, etc.).
- Sample of historical weather data for the airport covering the period of sample of historical operations (wind, temperature, precipitation, visibility, etc.).
- Characteristics of runways (elevation, direction, declared distances).
- Characteristics of RSAs (geometry, type of surface, presence of EMAS, location, size and category of obstacles).
- General information (airport annual traffic volume, annual growth rate).

Historical operation data and weather data of 2014 were collected and organized in a format which is proper for the software. These two data were in an excel format.

5.1.1. Sources of the input data

Different data bases are used for the collection of the input data of each airports.

For HOD:

- Airport database over world airports(www.flightradar24.com/data/airports/)
- Aircraft Type Identification Data(www.csgnetwork.com/aviationtypeid.html)
- Aviation System Performance Metrics (ASPM)

For WD:

- Weather Underground (www.wunderground.com)

Characteristics of runways:

- (www.enav.it/portal/page/portal/PortaleENAV/Home/AIP)
- Wikipedia

Characteristics of RSAs:

- Google Earth and google map
- Wikipedia

General information:

- Wikipedia

5.1.2. Problems during the collection of the data:

- The size of the data
- The units of the measurements
- Unavailability of full data of one parameter in one source
- Available but not for free
- Inaccessibility of the Data (Confidentiality and Language)

5.2. Selection of the Airports

In this part of the study three airports randomly selected from Italy and United States, based on the location because it determines the weather condition on the airport, the volume of traffic, the characteristics of the runway, the characteristics of the runway safety area, availability of necessary data.

Two of the airports were selected from Italy, on this study we name them as A1 and A2. A1 is located to the north of Italy. A2 is located to the south of Italy. A3 is the name given to the remaining Airport from US.

5.2.1. Airport A1

The airport served 8,696,085 passengers in 2014 and is one of the busiest airports in Italy.

It is popular with low-cost airlines.

Airfield Information

Table 9.Airfield Information of Airport A1

Location	Italy
Coordinates	45°40′08″ N 009°42′01″ E
Airport type	Public
Elevation AMSL	782ft
Accelerate-Stop distance available for takeoff (ASDA)	9550ft for RWY 10 and 9525ft for RWY 28
Landing Distance available(LDA)	8640ft for RWY 10 and 8930ft for RWY28
surface type of RWY 10/28	Asphalt surface
Annual Traffic Growth (%)	2.5
Category of ILS	CAT III on RWY 28

Figure 30. Runway Detail of Airport A1

5.2.2. Airport A2

It is the busiest airport in south of Italy and the 6th busiest in Italy with 7.304.012 passengers in 2014.

Major airlines such as Alitalia, Lufthansa and Air Berlin offer services here and connect numerous European destinations such as Rome, Munich and Berlin, while low cost airlines such as EasyJet and Ryanair offer extensive flights to many leisure destinations.

Airfield Information

Table 10.Airfield Information of Airport A2

Location	Italy
Coordinates	37°28′00″N 15°03′50″E
Airport type	Public
Elevation AMSL	39ft
Accelerate-Stop distance available for takeoff (ASDA)	7992ft for RWY 08 and 7992ft for RWY 26
Landing Distance available(LDA)	7677ft for RWY 08 and 7710ft for RWY26
surface type of RWY 08/26	Asphalt surface
Annual Traffic Growth (%)	10.2
Category of ILS	CAT I on RWY 08

Figure 31. Runway Detail of Airport A2

5.2.3. Airport A3

The National Plan of Integrated Airport Systems for 2011–2015 categorized it as a primary commercial service airport since it has over 10,000 passengers boarding per year.

The main runway, at 5,701 feet (1,738 m), is one of the shortest of any major airport in the United States, and passenger airliners at the airport have never been larger than the Boeing 757.

Airfield Information

Table 11.Airfield Information of Airport A3

Location	USA
Coordinates	33°40′32″N 117°52′06″W
Airport type	Public
Elevation AMSL	56ft
Accelerate-Stop distance available for takeoff (ASDA)	5701ft for RWY 08 and 5701ft for RWY 26
Landing Distance available(LDA)	5701ft for RWY 08 and 5701ft for RWY26
surface type of RWY 08/26	Asphalt surface
Annual Traffic Growth (%)	2
Category of ILS	CAT I on RWY 20R

Figure 32. Runway Detail of Airport A3

5.3. RSARA simulation

The result of the simulation done by the software usually help the airport stakeholders to evaluate Runway Safety Area alternatives. The following are some of the capabilities of the software:

- Performs full risk assessment for multiple runways.
- Enters multiple obstacles to each RSA scenario.
- Characterizes different categories for obstacles.
- Automatically corrects for required distances (landing and takeoff) based on elevation, temperature, wind, and runway surface condition.
- Generates analysis reports from software with summaries of following parameters:
- Average risk for each type of incident by runway, by RSA section, and total for the airport.
- The expected number of years to occur an accident for a user-defined annual traffic volume and growth rate.
- Percentage of operations subject to a probability higher than a user-defined target level of safety (TLS).
- Graphical outputs with the distribution of risk for each RSA and each type of event.

The target level of safety selected for this specific study in 1.0E-6 (one event in one million movements).
The HOD and WD are entered using Microsoft Excel templates with automatic checks for value ranges and data format. Figures 35 and 36 shows the software screen for the input of HOD and WD with the excel template used.

The template for drawing the RSA for the overrun and undershoot was created by using Microsoft Excel (figure 34). It consists of an area formed by matrix of cells. Each cell corresponds to a coordinate that is referenced to the center of the runway. The default coordinate grid is set at 10x10ft.
For defining the type of the surface or category of obstacles in RSA, different letters are assigned according to the provision. These codes are provided on the software manual. For example ‘n’ for part of RSA with grass, soil, unpaved area,

‘p’ for part of RSA with asphalt, paved, concrete, ‘e’ for EMAS,’1’ for concrete buildings, large holes, water body and so on.
The figure below shows the program screen and the input Airport characteristics, HOD and WD templates used for the input.

Output
After the completing the analyses, two types of results seen on the Output option of the main menu. These are the results for individual runways and the consolidated results for the whole airport. The results of individual runways for the normal operation of 2014 for the three selected airports, A1, A2 and A3 are shown in the figures 37 to 42 for individual runways.

The results are presented both in tabular and graphical format. Each folder contains the risk estimate for each types of events and individual operations and the total risk during landing and takeoff and the total risk during veer-offs.

In results in the table format the first table contains the information about the airport annual volume, expected traffic growth rate and target level of safety which are the inputs we used for the software analysis.

The second table that titled Risk for Movements challenging RSA, contains results for the RSA adjacent to the arrival end of the runway selected per type of events.
-The first column shows the incident types.
-The second column shows the average probability of incident outside the RSA.
-The third column shows the average number of years expected between events.
-The fourth column shows the percentage of movements with a risk higher than the TLS.
-The last column shows the average number of years expected between critical incidents for TLS.

The third table titled veer-off Risk for movements on RWYs, contains the results for the veer-offs only. It comprises the lateral safety areas of the runway. The configuration of the table are similar with the risk table for overrun and under-shoot.

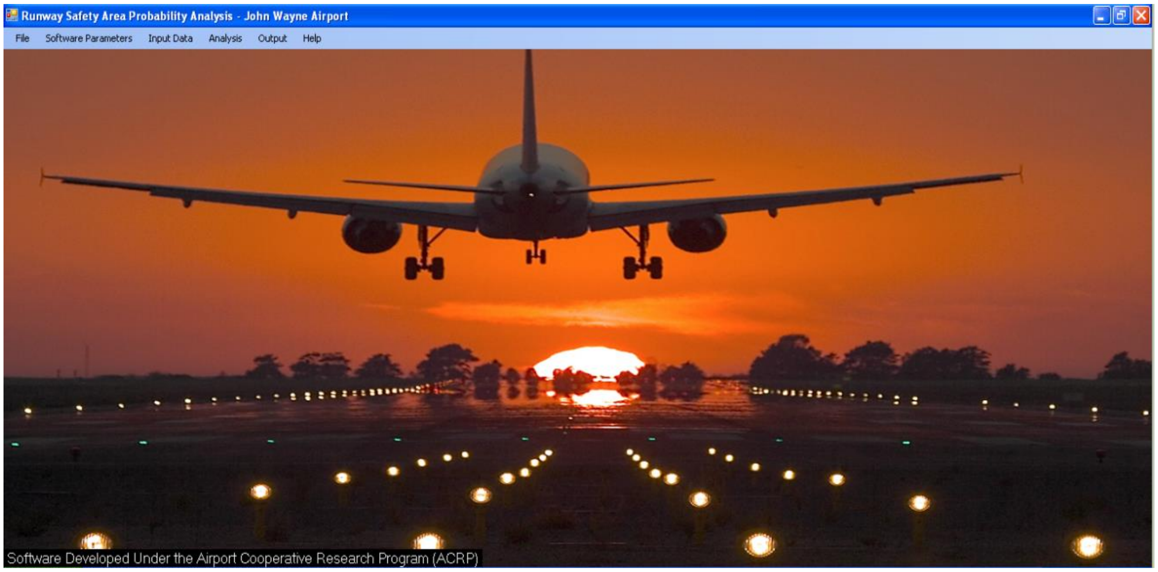


Figure 33. RSARA Main Program Screen

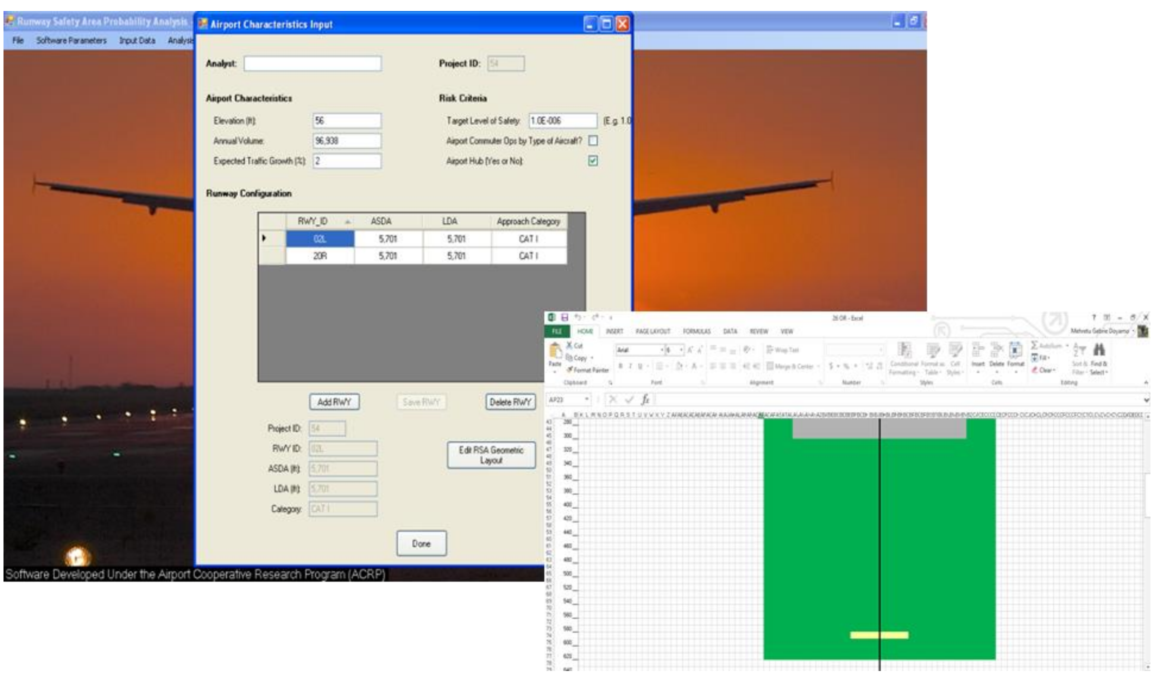


Figure 34. Example of Airport Characteristics Input Screen and the RESA Geometry Template

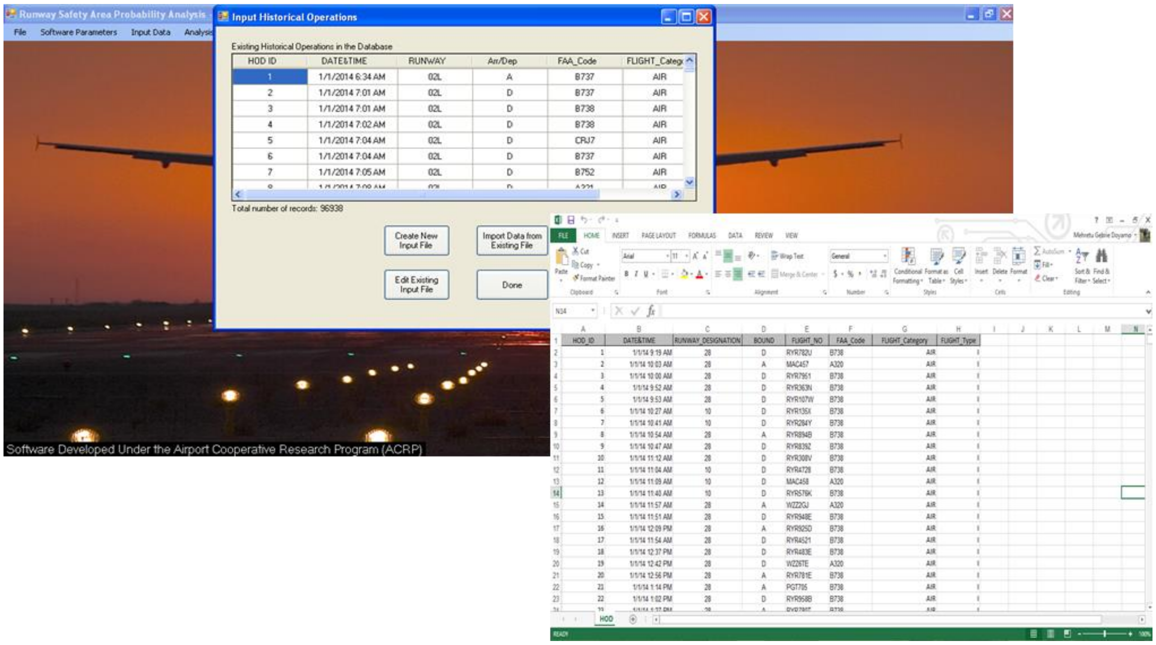


Figure 35. Example of HOD Input Screen and the HOD Excel Template

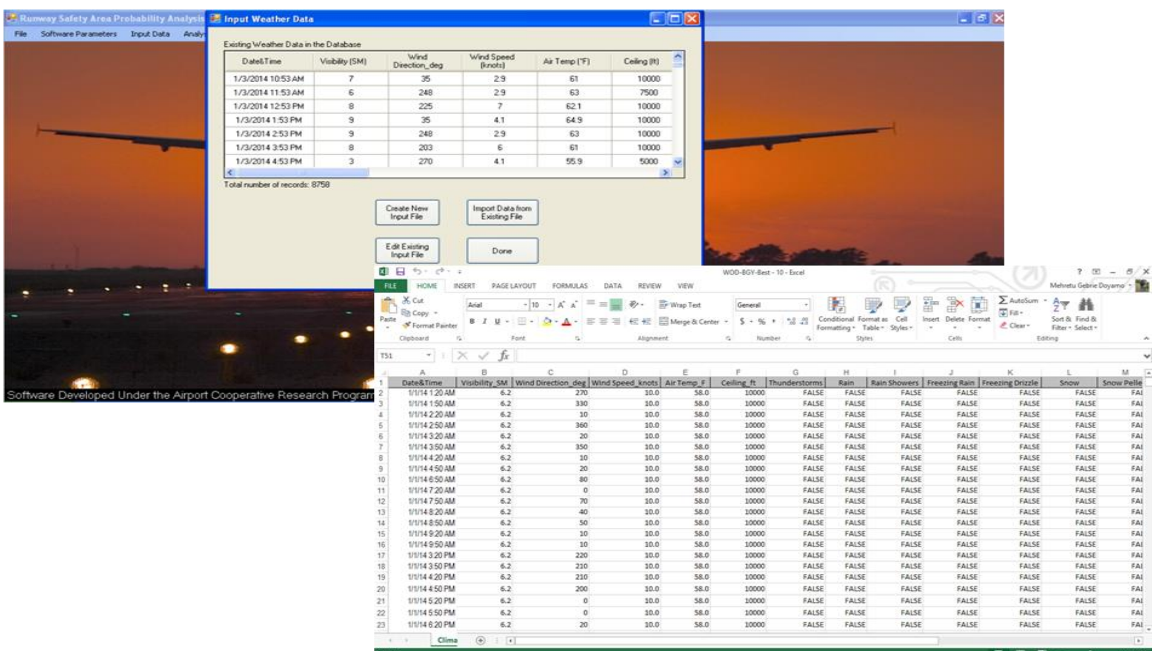


Figure 36. Example of WD Input Screen and the WD Excel Template

Summary of Results

RSA Risk Analysis

Normal Analysis

Airport Annual Volume:	72,318
Expected Traffic growth rate:	2.50%
Target Level of Safety (TLS):	1.0E-06

Risk for Movements Challenging RSA 10

Incident	Average Probability	Avrg # of Years to Incident/ Accident	% Movements Above TLS	Avrg # of Years to Critical Incident for TLS
LDOR	3.1E-07	48	6.1	21
TOOR	3.4E-07	47	1.8	23
LDUS	3.1E-07	>100	8.5	>100
Total	**3.3E-07**	**30**	**4.0**	**12**

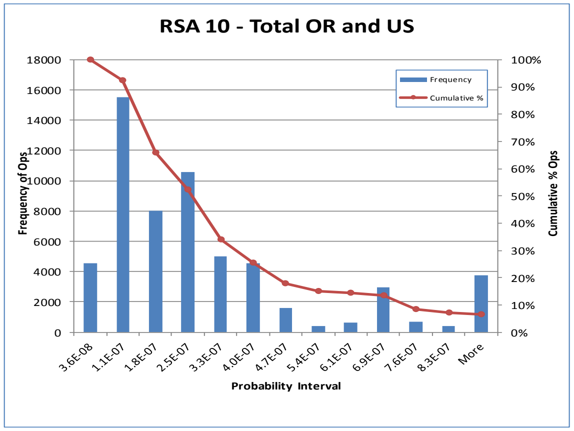
Veer-Off Risk for Movements on RWY 10

LDVO	8.7E-08	>100	1.7	>100
TOVO	8.9E-09	>100	0.0	90
Total	**1.1E-08**	**>100**	**0.0**	**89**

Notes

1 - Fields in orange may be directly changed in spreadsheet by user
2 - Results for overrun and undershoot consider all movements challenging the RSA
3 - Results for veer-off consider the movements operating on the specific runway
4 - Histogram only contains data for overruns and undershoots on the specific RSA; histogram for veer-offs are available in folder "Plots"

Histogram of Risk



Histogram of Risk

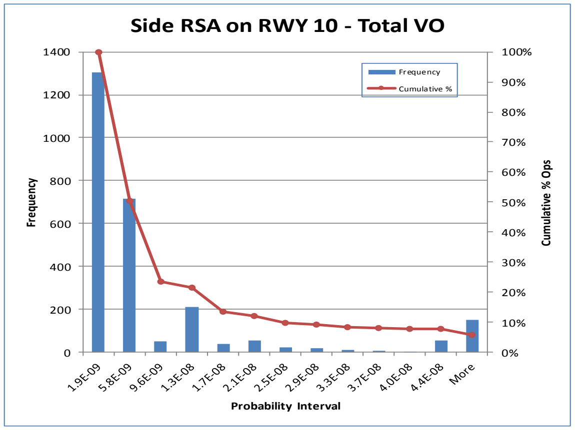


Figure 37. RSARA Individual Runway Result for RWY 10 of Airport A1

RSA Risk Analysis

Normal Analysis

Airport Annual Volume:	72,318
Expected Traffic growth rate:	2.50%
Target Level of Safety (TLS):	1.0E-06

Risk for Movements Challenging RSA 28

Incident	Average Probability	Avrg # of Years to Incident/ Accident	% Movements Above TLS	Avrg # of Years to Critical Incident for TLS
LDOR	2.7E-07	>100	8.5	>100
TOOR	3.1E-07	>100	2.8	90
LDUS	4.9E-07	36	9.6	21
Total	**4.7E-07**	**35**	**9.0**	**20**

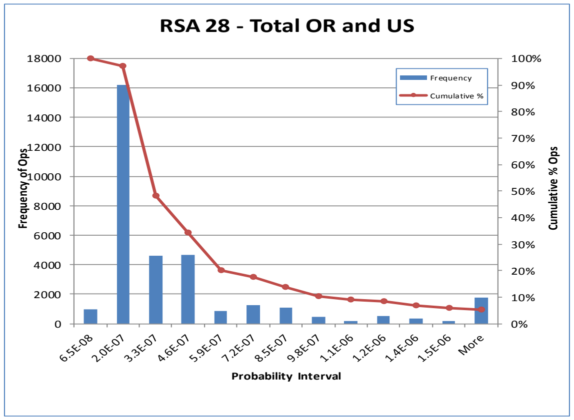
Veer-Off Risk for Movements on RWY 28

LDVO	8.1E-08	92	1.3	21
TOVO	8.6E-09	>100	0.0	23
Total	**4.6E-08**	**88**	**0.7**	**12**

Notes

1 - Fields in orange may be directly changed in spreadsheet by user
2 - Results for overrun and undershoot consider all movements challenging the RSA
3 - Results for veer-off consider the movements operating on the specific runway
4 - Histogram only contains data for overruns and undershoots on the specific RSA; histogram for veer-offs are available in folder "Plots"

Histogram of Risk



Histogram of Risk

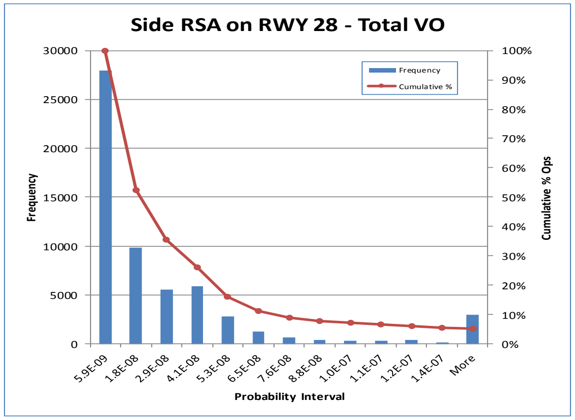


Figure 38. RSARA Individual Runway Result for RWY 28 of Airport A1

Summary of Results

RSA Risk Analysis

Normal Analysis

Airport Annual Volume:	45,955
Expected Traffic growth rate:	10.20%
Target Level of Safety (TLS):	1.0E-06

Risk for Movements Challenging RSA 8

Incident	Average Probability	Avrg # of Years to Incident/ Accident	% Movements Above TLS	Avrg # of Years to Critical Incident for TLS
LDOR	2.9E-07	39	3.1	27
TOOR	4.2E-07	29	0.4	21
LDUS	2.5E-07	34	1.9	21
Total	**3.2E-07**	**23**	**1.6**	**13**

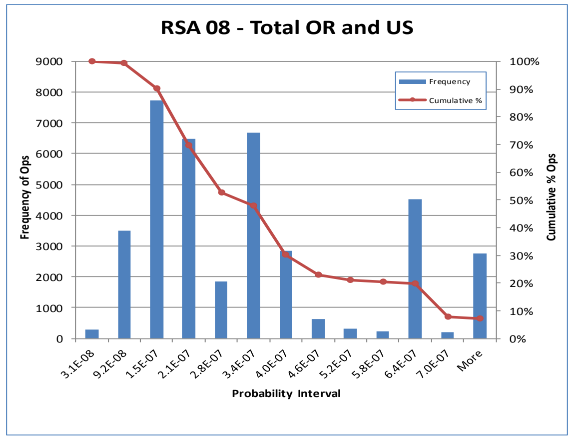
Veer-Off Risk for Movements on RWY 8

LDVO	7.9E-08	46	0.2	21
TOVO	4.8E-09	81	0.0	27
Total	**5.4E-08**	**46**	**0.1**	**17**

Notes

1 - Fields in orange may be directly changed in spreadsheet by user
2 - Results for overrun and undershoot consider all movements challenging the RSA
3 - Results for veer-off consider the movements operating on the specific runway
4 - Histogram only contains data for overruns and undershoots on the specific RSA; histogram for veer-offs are available in folder "Plots"

Histogram of Risk



Histogram of Risk

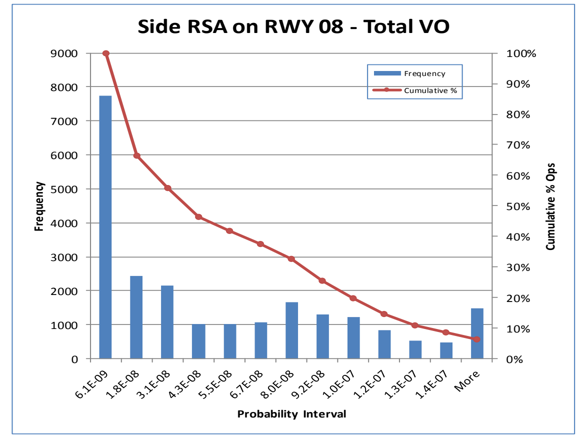


Figure 39.RSARA Individual Runway Result for RWY 08 of Airport A2

Summary of Results

RSA Risk Analysis

Normal Analysis

Airport Annual Volume:	45,955
Expected Traffic growth rate:	10.20%
Target Level of Safety (TLS):	1.0E-06

Risk for Movements Challenging RSA 26

Incident	Average Probability	Avrg # of Years to Incident/ Accident	% Movements Above TLS	Avrg # of Years to Critical Incident for TLS
LDOR	2.4E-07	35	2.0	21
TOOR	4.2E-07	36	0.3	27
LDUS	2.6E-07	40	2.3	27
Total	**2.9E-07**	**26**	**1.6**	**15**

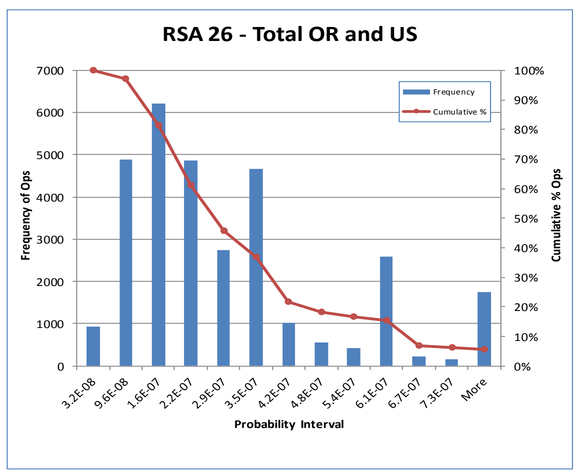
Veer-Off Risk for Movements on RWY 26

LDVO	8.7E-08	51	0.3	27
TOVO	5.2E-09	74	0.0	21
Total	**3.4E-08**	**50**	**0.1**	**17**

Notes

1 - Fields in orange may be directly changed in spreadsheet by user
2 - Results for overrun and undershoot consider all movements challenging the RSA
3 - Results for veer-off consider the movements operating on the specific runway
4 - Histogram only contains data for overruns and undershoots on the specific RSA; histogram for veer-offs are available in folder "Plots"

Histogram of Risk



Histogram of Risk

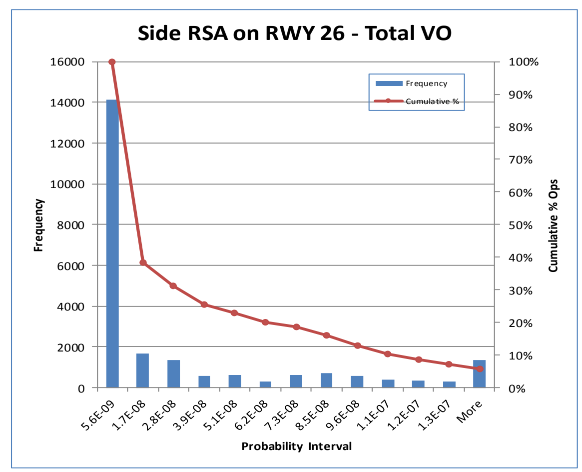


Figure 40. RSARA Individual Runway Result for RWY 26 of Airport A2

Summary of Results

RSA Risk Analysis

Normal Analysis

Airport Annual Volume:	96,938
Expected Traffic growth rate:	2.00%
Target Level of Safety (TLS):	1.0E-06

Risk for Movements Challenging RSA 02L

Incident	Average Probability	Avrg # of Years to Incident/ Accident	% Movements Above TLS	Avrg # of Years to Critical Incident for TLS
LDOR	1.9E-07	87	1.5	32
TOOR	1.3E-07	95	0.0	27
LDUS	1.9E-07	91	1.7	34
Total	**1.7E-07**	**50**	**1.0**	**12**

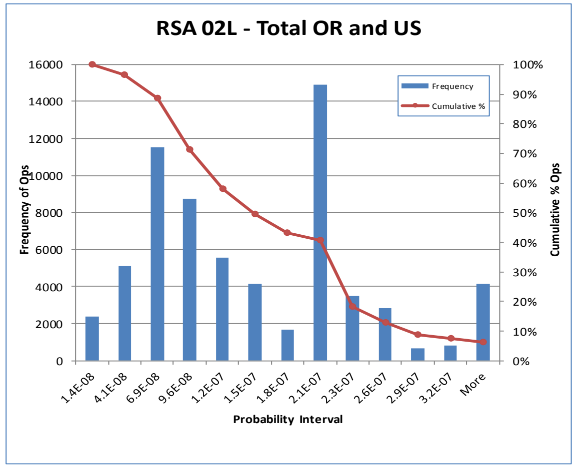
Veer-Off Risk for Movements on RWY 02L

LDVO	2.1E-07	86	1.0	34
TOVO	2.3E-08	>100	0.0	29
Total	**1.1E-07**	**81**	**0.5**	**18**

Notes

1 - Fields in orange may be directly changed in spreadsheet by user
2 - Results for overrun and undershoot consider all movements challenging the RSA
3 - Results for veer-off consider the movements operating on the specific runway
4 - Histogram only contains data for overruns and undershoots on the specific RSA; histogram for veer-offs are available in folder "Plots"

Histogram of Risk



Histogram of Risk

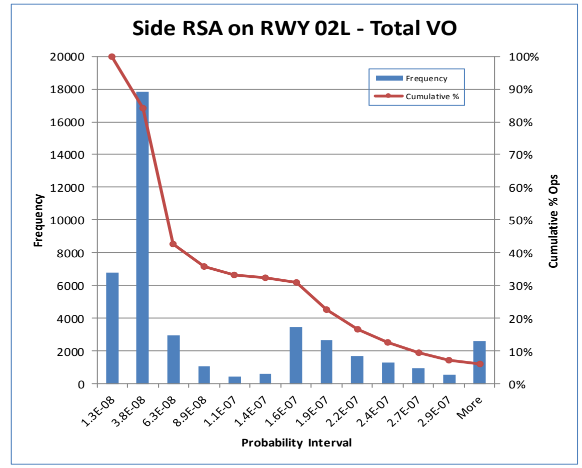


Figure 41.RSARA Individual Runway Result for RWY 02L of Airport A3

Summary of Results

RSA Risk Analysis

Normal Analysis

Airport Annual Volume:	96,938
Expected Traffic growth rate:	2.00%
Target Level of Safety (TLS):	1.0E-06

Risk for Movements Challenging RSA 20R

Incident	Average Probability	Avrg # of Years to Incident/ Accident	% Movements Above TLS	Avrg # of Years to Critical Incident for TLS
LDOR	2.7E-07	77	2.7	34
TOOR	1.4E-07	96	0.0	29
LDUS	1.6E-07	95	1.2	32
Total	**1.8E-07**	**48**	**1.2**	**13**

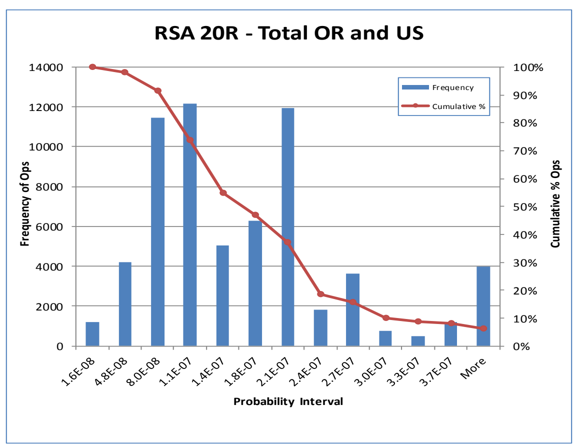
Veer-Off Risk for Movements on RWY 20R

LDVO	1.7E-07	91	1.0	32
TOVO	2.2E-08	>100	0.0	27
Total	**9.1E-08**	**85**	**0.5**	**17**

Notes

1 - Fields in orange may be directly changed in spreadsheet by user
2 - Results for overrun and undershoot consider all movements challenging the RSA
3 - Results for veer-off consider the movements operating on the specific runway
4 - Histogram only contains data for overruns and undershoots on the specific RSA; histogram for veer-offs are available in folder "Plots"

Histogram of Risk



Histogram of Risk

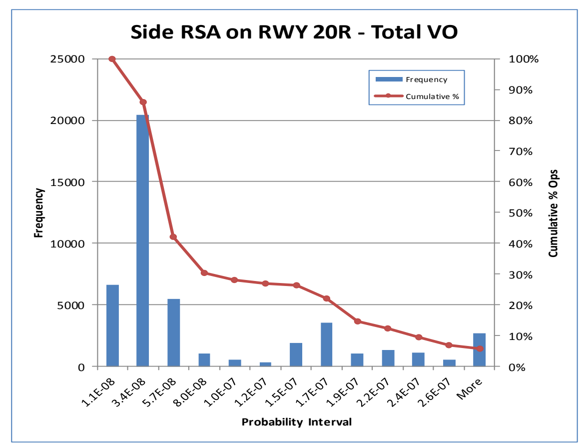


Figure 42.RSARA Individual Runway Result for RWY 20R of Airport A3

5.4. Sensitivity Analysis

Sensitivity analysis are done for observing how different input parameters affects the output result specially the average probability of incident outside the RSA and the average number of years between events. Generally, different parameters were considered for all three airports except weather input. The sensitivity for weather change is done for all three airports.

5.4.1. Airport A1

For Airport A1, three kinds of Sensitivity Analysis are done.
These are:

- **The effect of change in weather input parameter on the average probability of incident outside the RSA.**

In this part of the study, only the change in WD input the center of the focus keeping all the other input parameters the same. Three weather conditions are considered. The first one is Normal Weather, which is the exact one year WD of the Airport. The second is the Best Weather, which is developed by considering the best weather condition scenario Regression Coefficients which are seen on table 6. From the Available Variables, the Ceiling, Visibility, Temperature and Wind Speed are the once given emphasis in addition to making FALSE all the variables which are expressed as TRUE/FALSE, some of them are Rain, Snow, and Ice. The third is the Bad Weather, for which the same procedure is followed like the second one. Choosing the Coefficients of bad weather scenario and making TRUE all the variables which are expressed in the form of TRUE or FALSE.

- **The effect of change in the RESA Geometric layout on the average probability of incident outside the RSA.**

In this part of study, the change in types of the areas of the RESA is considered. Four types of area are chosen. Each type of area is assumed to cover all the available RESA. These areas are: the Normal, which is the exact RESA geometry of the Runway, the area which is assumed to be fully paved, the area which is assumed to be fully covered by grass, and the area which is fully covered by EMAS. This is done by using the available codes provided for the development of RESA surface. ‘p’ for paved area, ‘n’ for area covered by grass and ‘e’ for area covered by EMAS.

- **The Effect of the change in approach categories on the average probability of incident outside the RSA.**

There are three approach categories, CAT I. CAT II and CAT III. The originally present category of approach, the condition of the runway without the approach system, the runway with CAT I approach category, the runway with CAT II approach category and the runway with approach category CAT III are the divisions of which the analysis result of the average probability is incident occurring outside the RSA is observed.

5.4.2. Airport A2

- **The effect of change in weather input parameter on the average probability of incident outside the RSA.**

In this study exactly the same procedure which is followed for the Airport A1 is followed.

- **The effect of change in the expected annual traffic growth rate on the average number of years between an events.**

During the gathering of input data for the RSARA software, the expected annual traffic growth rate for a year 2014 was found to be 10.2% which is high related to the normal expected annual traffic growth rate which is seen in most of the Airports in year 2014. So, it is found to be interesting to observe the effect of the change in annual traffic growth rate on the number of years between an events. 10.2% is the exact expected annual traffic growth rate and 8%, 6%,4% and 2.5% are the annul traffic growth rates whose changes in the number of years are studied in this part.

5.4.3. Airport A3

- **The effect of change in weather input parameter on the average probability of incident outside the RSA.**

The same procedures are followed

- **The effect of the change in runway length on the average probability of incident outside the RSA.**

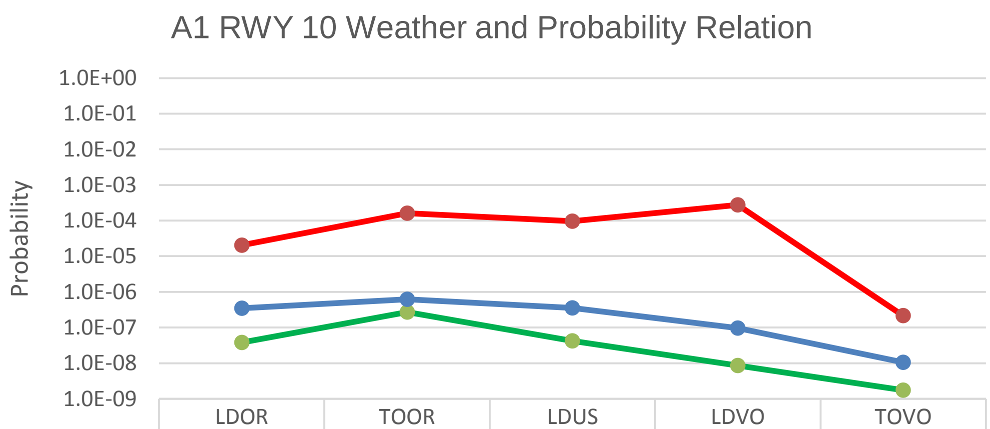
The unique characteristics of the third airport chosen for this study, A3 is, it is one of the airports In US with the shortest runway length. Taking this as a base for this study, the changed in runway lengths and their effects on the output average probability of incidents outside the RSA is observed.

The runway length for airport A3 it 5701ft, and the four cases are considered. The first and the second cases are reducing the runway length by 1000ft and 2000ft, the third and the fourth are adding 1000ft and 2000ft on the normal runway length and these variations in runway length and their respective result in the average probability are studied.

5.5. Analysis Results and Discussions

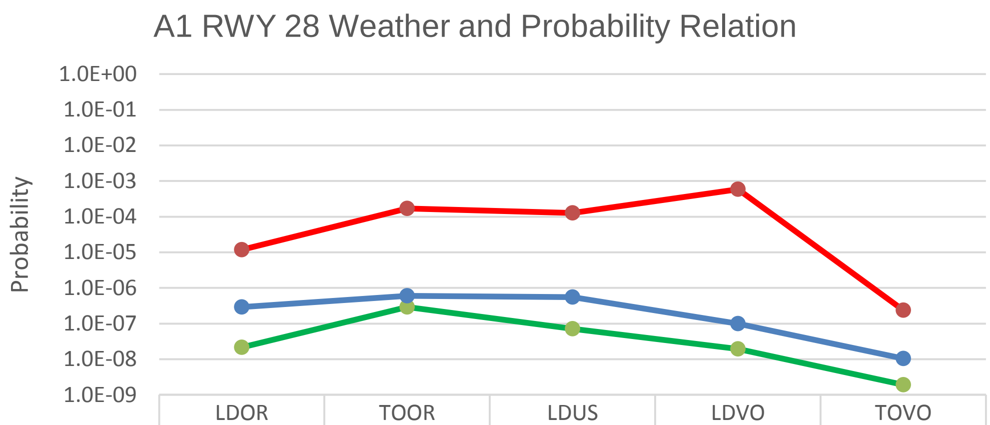
5.5.1. RSARA results and discussions for Airport A1

5.5.1.1. Change in weather condition and their effects on the probability of Incidents outside the RSA



	LDOR	TOOR	LDUS	LDVO	TOVO
Worst	2.0E-05	1.6E-04	9.6E-05	2.8E-04	2.0E-07
Normal	3.1E-07	3.4E-07	3.1E-07	8.7E-08	8.9E-09
Best	3.8E-08	2.7E-07	4.2E-08	8.6E-09	1.7E-09

Figure 43.The Relationship between the change in WD and the Analysis result of Average Probability of Incident outside the RSA on RWY 10



	LDOR	TOOR	LDUS	LDVO	TOVO
Worst	1.1E-05	1.7E-04	1.3E-04	5.9E-04	2.3E-07
Normal	2.7E-07	3.1E-07	4.9E-07	8.1E-08	8.6E-09
Best	2.2E-08	2.9E-07	7.2E-08	2.0E-08	1.9E-09

Figure 44.The Relationship between the change in WD and the Analysis result of Average Probability of Incident outside the RSA on RWY 28

As it is seen in figure 42 for RWY 10 and figure 43 for RWY 28, the worst weather scenario has highest probability of occurrence beyond the RSA fir all the types of events, LDOR, TOOR, LDUS, LDVO and TOVO.

In worst weather scenario the maximum probability of is on events during landing due to veer off. This is due to the bad weather scenario considered.

The best weather scenario has the lowest probability of the three considered scenarios.
Both runways has same shape of variation. This is due to weather affects the runways in the one airport equally.

5.5.1.2. Change in the runway RESA geometry and the resulting probability

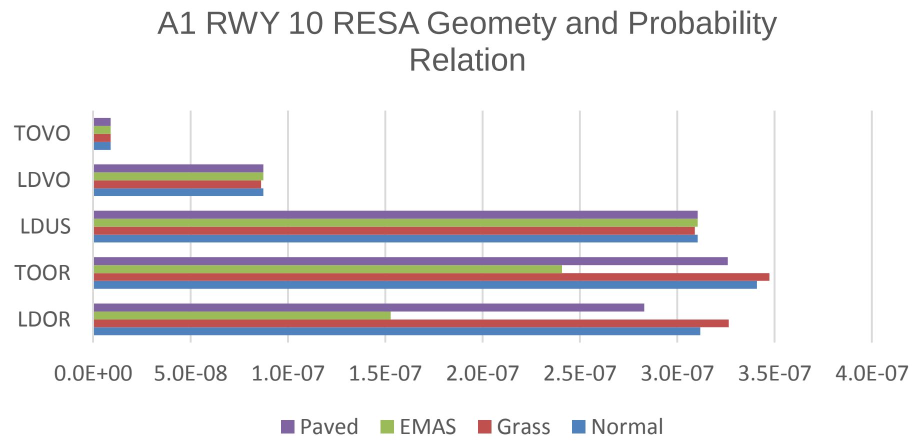


Figure 45.The Relationship between the Change in RESA Geometry and the Output Average Probability of Incident outside the RSA on RWY 10.

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The probability of event occurrence beyond the RSA is low and the same for the TOVO and LDVO as shown in Figures 44 and 45. This is because the area type changed are both ends of the runway not the sides of the runway.

Generally observed that the EMAS coverage of the area results in lower probability of occurrence. And grass covered area generally has the higher probability.

LDUS has the maximum value for RWY 28 (figure 45), this is because the majority of the landings are on runway 28 for it has ILS CAT III.

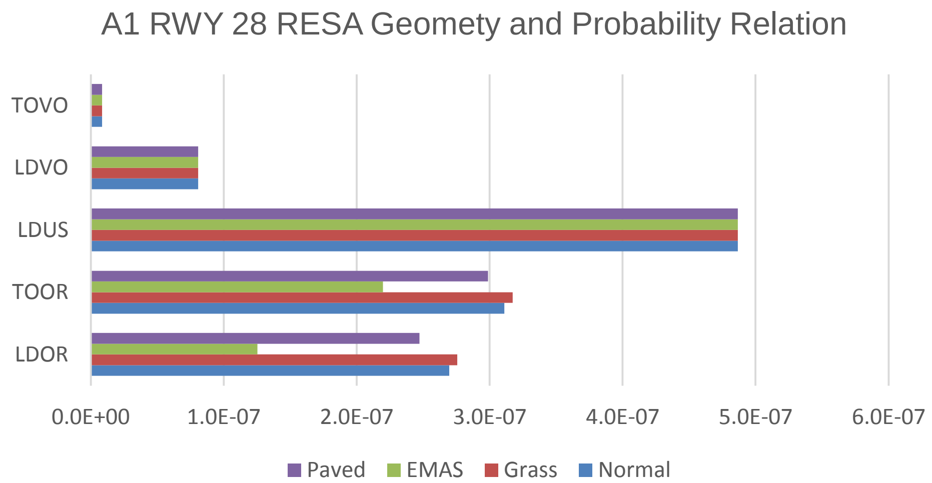


Figure 46.The Relationship between the Change in RESA Geometry and the Output Average Probability of Incident outside the RSA on RWY 28.

5.5.1.3. Change in approach category and their effect of the resulting probability

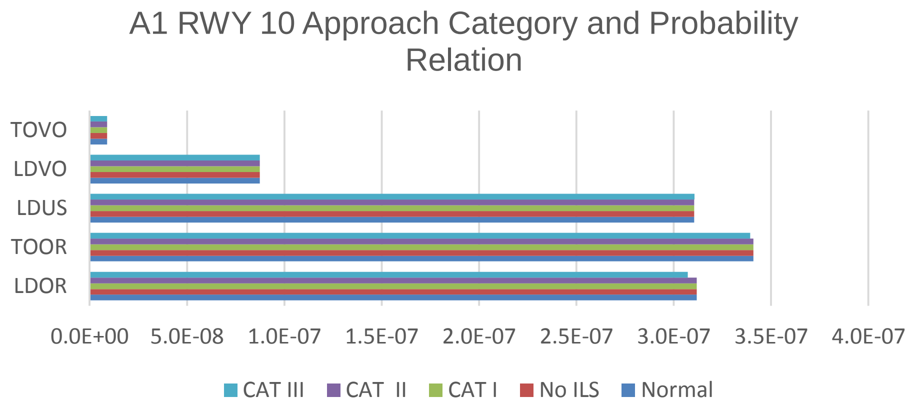


Figure 47.The Relationship between the Approach Category and the Output Average Probability of Incident outside the RSA on RWY 10.

The probability results are the same for each event types. This is because in the method, ACRP Originally had attempted to include the type of approach in the models however the available data would limit consideration of other factors and significantly reduce the sample size. The field available in the software is only for recording information about the airport. Therefore different type of ILS do not make any changes in amount of probability.

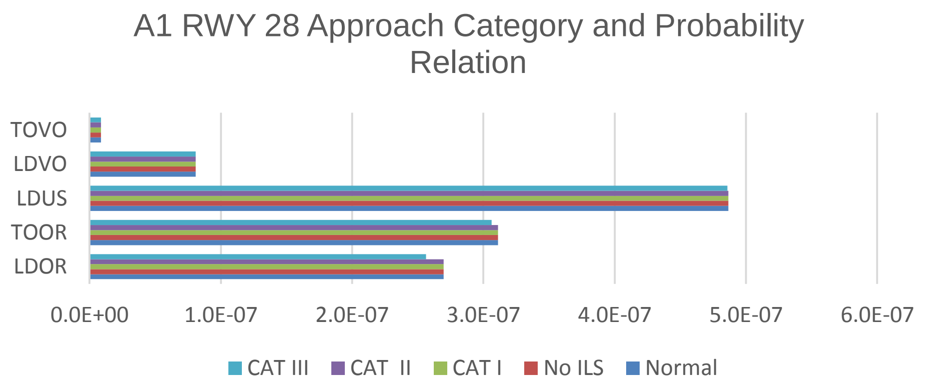
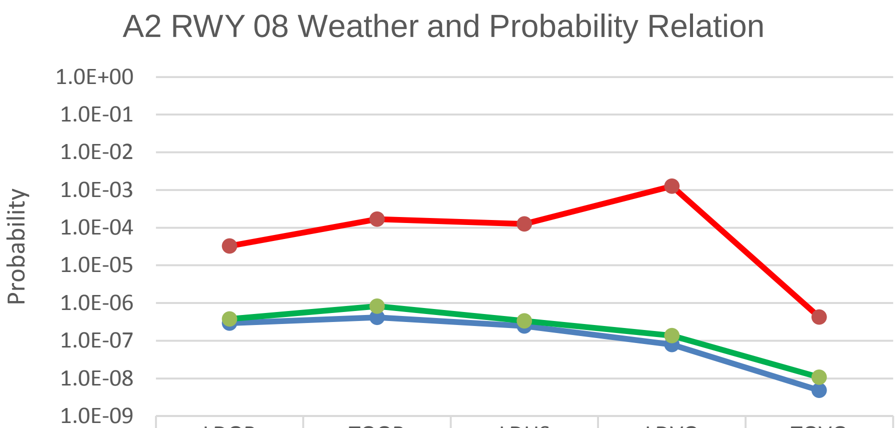


Figure 48.The Relationship between the Approach Category and the Output Average Probability of Incident outside the RSA on RWY 28.

5.5.2. RSARA results and discussions for Airport A2

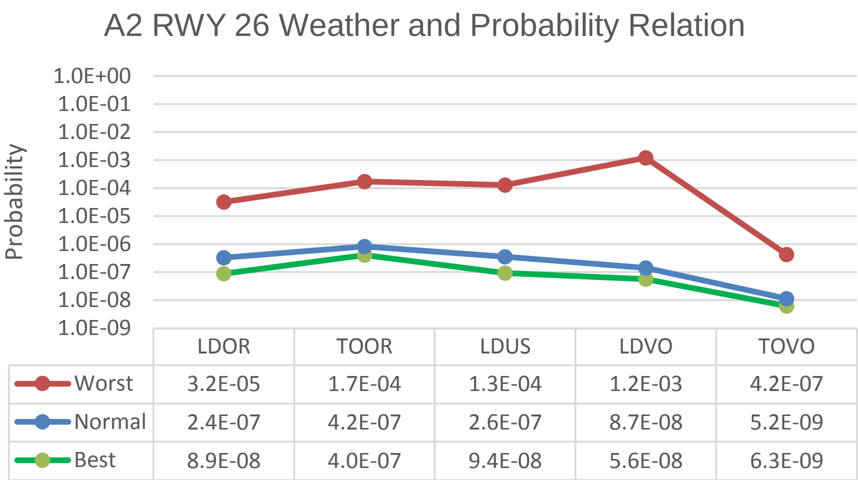
5.5.2.1. Change in weather condition and their effects on the probability of Incidents outside the RSA



	LDOR	TOOR	LDUS	LDVO	TOVO
Worst	3.2E-05	1.7E-04	1.3E-04	1.3E-03	4.2E-07
Best	8.9E-08	4.0E-07	9.1E-08	5.6E-08	6.0E-09
Normal	2.9E-07	4.2E-07	2.5E-07	7.9E-08	4.8E-09

Figure 49.The Relationship between the change in WD and the Analysis result of Average Probability of Incident outside the RSA on RWY 08.

For the weather case on the second Airport, the reasoning behind the shape are almost the same with the reasoning used for the first airports. The RWY 08 (figure 48) the probability of the best weather scenario has the maximum probability than the normal weather, this is because, Airports A2 is located to the south of Italy and A1 is relatively to the north and the annual weather condition to the south of Italy is better than to the north with respect to negatively affecting the flight process.



	LDOR	TOOR	LDUS	LDVO	TOVO
Worst	3.2E-05	1.7E-04	1.3E-04	1.2E-03	4.2E-07
Normal	2.4E-07	4.2E-07	2.6E-07	8.7E-08	5.2E-09
Best	8.9E-08	4.0E-07	9.4E-08	5.6E-08	6.3E-09

Figure 50.The Relationship between the change in WD and the Analysis result of Average Probability of Incident outside the RSA on RWY 26

5.5.2.2. The change in expected annual traffic growth rate and their result in number of years between an events.

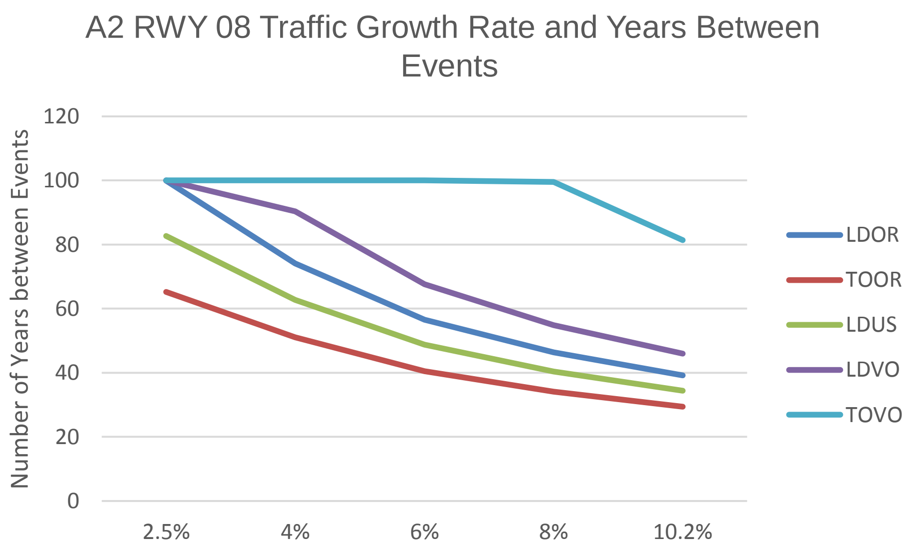


Figure 51.The Relation between the Expected Annual Traffic Growth Rates with the Number of Years between Events on RWY 08.

Figure 50 and 51 show the variation in annual traffic growth rate and respective change in number of years between events.

On both runways the increase in annual traffic results in reduction of the number of years between the events.
Generally the number of years between events due to overruns both in landing and takeoff phases of flight are lesser. This is due to the high traffic congestion on the runway during this phases of the flight.

The lines are not extended beyond the number of years greater than 100, it is limited at 100 because the software output result expresses the number of years greater than 100 as '>100'. So, the horizontal line at 100 indicates the number is greater than 100.

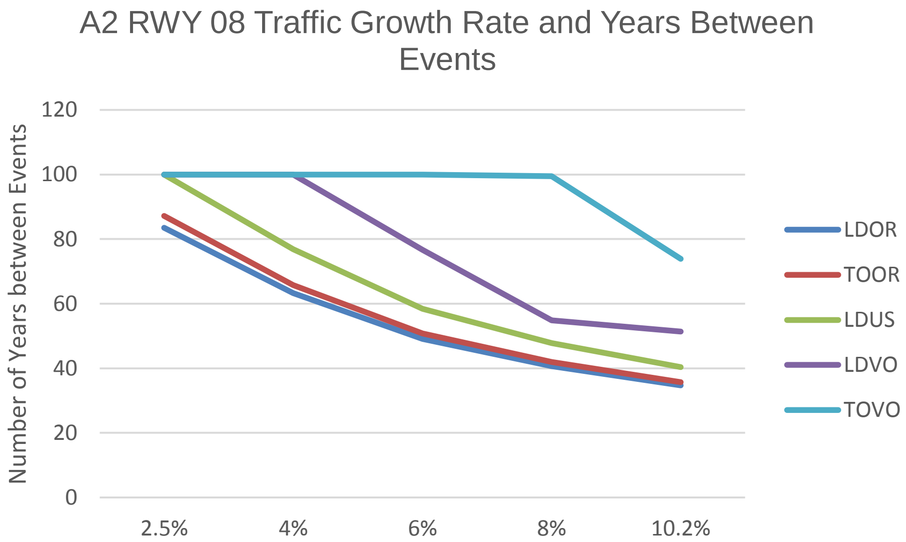
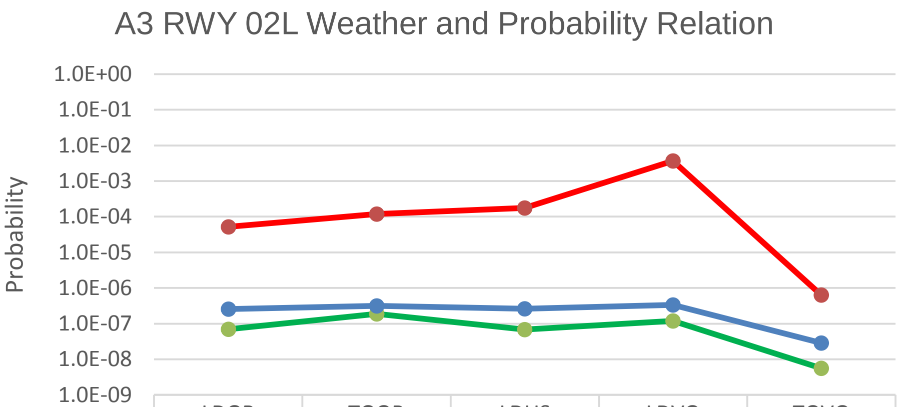


Figure 52.The Relation between the Expected Annual Traffic Growth Rates with the Number of Years between Events on RWY 26.

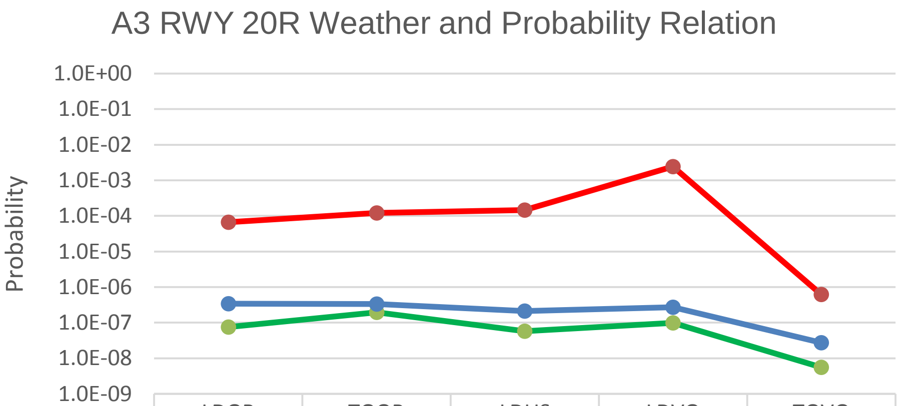
5.5.3. RSARA results and discussions for Airport A3

5.5.3.1. Change in weather condition and their effects on the probability of Incidents outside the RSA



	LDOR	TOOR	LDUS	LDVO	TOVO
Worst	5.2E-05	1.2E-04	1.8E-04	3.7E-03	6.1E-07
Normal	1.9E-07	1.3E-07	1.9E-07	2.1E-07	2.3E-08
Best	6.9E-08	1.9E-07	6.8E-08	1.2E-07	5.6E-09

Figure 53.The Relationship between the change in WD and the Analysis result of Average Probability of Incident outside the RSA on RWY 02L.



	LDOR	TOOR	LDUS	LDVO	TOVO
Worst	6.7E-05	1.2E-04	1.5E-04	2.4E-03	5.9E-07
Normal	2.7E-07	1.4E-07	1.6E-07	1.7E-07	2.2E-08
Best	7.6E-08	2.0E-07	5.7E-08	9.9E-08	5.5E-09

Figure 54.The Relationship between the change in WD and the Analysis result of Average Probability of Incident outside the RSA on RWY 20R.

For normal, best and worst scenarios of weather for the third airport the reasoning behind the shape are the same with the reasoning for the previous airports A1 and A2.

5.5.3.2. The change in runway length and their effect on the probability

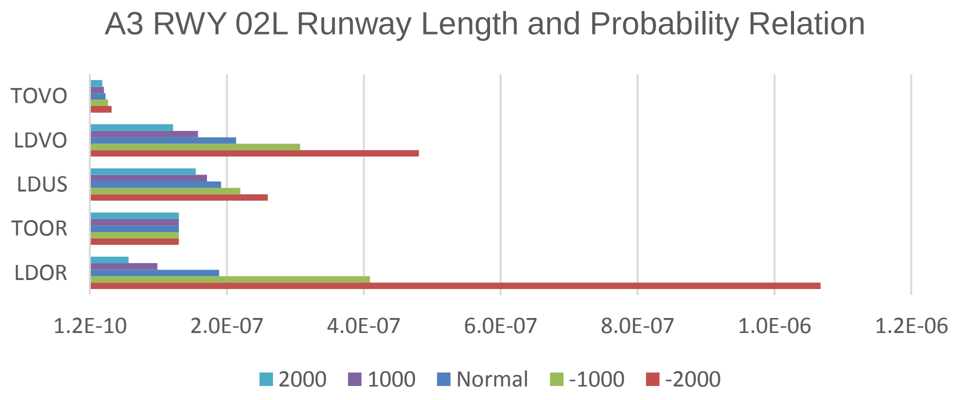


Figure 55.The Relation between the Change in Runway Length and the Resulting Average Probability of Incident outside the RSA on RWY 02L.

Figure 54 and 55 shows how the change in runway length affect the probability of event occurrence beyond the RSA.
Generally the shorter the runway length is the higher the probability would be. Mostly the events related to landing LDOR, LDUS and LDVO have higher probability of occurrence the shorter the runway gets.

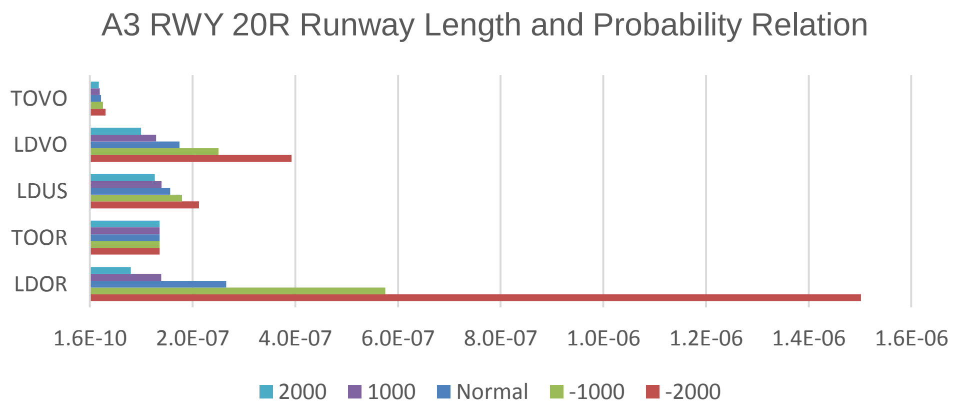


Figure 56.The Relation between the Change in Runway Length and the Resulting Average Probability of Incident outside the RSA on RWY 20R.

CHAPTER 6

Conclusion

From the results of sensitivity analysis in both cases, the sensitivity analysis by using the accident and incident data and the sensitivity analysis base on the variation of the input factors for the risk analysis by RSARA:

Statistical sensitivity analysis:

- The number of accidents are greater in every conditions considered, this is because of the reporting of the incidents.
- The usage of technology aided navigation reduces the occurrence probability of incidents and accidents.
- The smaller the airport is the lesser it has full facility. This leads to the higher rate of events compared to the big airports.
- The traffic volume played a vital role for the events occurred in the airports categorized in large categories in addition to the aircraft condition and human errors.

RSA Risk Assessment:

- The change in weather condition affects the probability of the events to occur beyond the RSA. The worse the weather is, the higher the probability gets.
- The type of the RESA, affects the probability. The presence of the EMAS is the best of all types of the RESA.
- The annual traffic growth rate is one also one if the main reasons for the high frequency of the events. The higher is the percentage the more frequent will be the event.
- The length of the runway affects the probability positively. The longer the runway length the lesser probable will be the events.

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Appendix A

The following table presents a summary of Accidents and Incidents in landing phase of flight, identified in the databases screened.

Event-	Event type	Country	Location	AirportCode	FAACategory	#ofRWYs	KindofNAVAID	Model	#of Engines	Weather
12/18/2014	Accident	US	San Antonio, TX	SAT	P-M	3	ILS/DME	310J	2	VMC
10/23/2014	Accident	US	Mesa, AZ	IWA	P-N	3	LOC/GS	690B	2	VMC
09/27/2014	Accident	US	Hazleton, PA	HZL	GA	1	LOCALIZER	D55	2	VMC
09/25/2014	Accident	US	Oneida, TN	SCX	GA	1	SDF	C90	2	VMC
09/23/2014	Accident	US	Oakland, CA	SDF	P-S	3	ILS/DME and LOCAL-IZER	PA 31T - II	2	VMC
09/04/2014	Accident	US	Fairbanks, AK	AK22	GA	2	NO	PA 18-135	24	VMC
08/11/2014	Accident	US	Gainesville, FL	GNV	P-N	2	ILS	PA 34-200T	2	VMC
08/06/2014	Accident	US	Gulf Shores, AL	JKA	GA	2	ILS/DME	PA 34-220T	2	VMC
07/29/2014	Accident	US	San Diego, CA	SAN	P-L	1	ILS/DME	757-222	2	VMC
07/02/2014	Accident	US	Willcox, AZ	P33	GA	1	NO	500 S	2	VMC
06/26/2014	Accident	US	Gulf Shores, AL	JKA	GA	2	ILS/DME	95 55	2	VMC
06/25/2014	Accident	US	Houston, MS	M44	GA	1	NO	C90A	2	VMC
06/13/2014	Accident	US	Tupelo, MS	TUP	CS	1	ILS/DME	58	2	VMC
06/02/2014	Accident	US	Dayton, TN	2A0	GA	1	NO	SA 226AT	2	VMC

05/24/2014	Accident	US	Perkasie, PA	CKZ	GA	1	NO	182J	2	VMC
04/29/2014	Accident	US	Fort Pierce, FL	FPR	GA	3	ILS/DME	76	2	VMC
04/22/2014	Accident	US	Horseshoe Bay, TX	KDZB	GA	1	NO	421	2	VMC
03/26/2014	Incident	US	Traverse City, MI	TVC	P-N	2	ILS	560XL	2	VMC
03/16/2014	Accident	US	Zephyrhills, FL	ZPH	GA	2	NO	500	2	VMC
02/16/2014	Accident	US	Allentown, PA	XLL	GA	2	NO	PA-30	2	VMC
01/28/2014	Accident	US	West Palm Beach, FL	PBI	P-M	3	ILS/DME ,LOC/GS	PA-34-200	2	VMC
01/15/2014	Accident	US	Coldwater, MI	KOEB	GA	3	NO	340	2	VMC
12/09/2013	Accident	US	Kalispell, MT	GPI	P-N	2	ILS	58P	2	VMC
10/30/2013	Accident	US	Lubbock, TX	LBB	P-S	3	ILS/DME, ILS	500 - B	2	VMC
10/17/2013	Accident	US	Franklin, NC	1A5	GA	1	NO	PA-31-350	2	VMC
10/15/2013	Accident	US	Wichita, KS	KAAO	R	1	ILS/DME	EMB-500	2	VMC
10/12/2013	Accident	US	Calexico, CA	CXL	GA	1	NO	PA 31P	2	VMC
10/09/2013	Accident	US	Onaway, MI	Y96	GA	1	NO	310R	2	VMC
09/23/2013	Accident	US	Sandpoint, ID	SZT	GA	1	LOC/DME	PA60 602P	2	VMC
09/15/2013	Accident	US	San Luis Obispo, CA	SBP	P-N	2	ILS	T310R	2	VMC
09/08/2013	Accident	US	Doylestown, PA	DYL	R	1	NO	PA-31P	2	VMC
08/13/2013	Accident	US	Peoria, IL	3MY	GA	1	NO	58P	2	VMC
08/04/2013	Accident	US	West Mifflin, PA	AGC	R	2	ILS	PA-34-200T	2	VMC
07/30/2013	Accident	US	Billings, MT	BIL	P-S	3	ILS,ILS/DME	PA-44-180	2	VMC
07/05/2013	Accident	US	Casa Grande, AZ	CGZ	GA	1	ILS	PA-44-180	2	VMC
05/13/2013	Accident	US	McMinnville, OR	MMV	GA	2	ILS	35A	2	VMC

05/08/2013	Accident	US	Bakersfield, CA	L45	GA	1	NO	310R	2	VMC
05/02/2013	Accident	US	Catskill, NY	33GA	GA	1	NO	G-44	2	VMC
04/24/2013	Incident	US	Clearwater, FL	KPIE	P-S	4	ILS,LOC/GS	P180	2	VMC
04/12/2013	Accident	US	Santa Monica, CA	SMO	R	1	NO	95-C55	2	VMC
04/05/2013	Incident	US	Meridian, MS	MEI	CS	2	ILS,ILS/DME	EMB-500	2	VMC
04/05/2013	Accident	US	Hammonton, NJ	N81	GA	1	NO	414	2	VMC
04/01/2013	Accident	US	Fort Lauderdale, FL	FXE	R	2	ILS	402C	2	VMC
03/27/2013	Accident	US	Amarillo, TX	81XA	GA	2	NO	421C	2	VMC
03/07/2013	Accident	US	Atlanta, GA	KATL	P-L	5	ILS,ILS/DME	757-232	2	VMC
02/24/2013	Accident	US	Tunica, MS	UTA	GA	1	ILS/DME	ERJ 190-100 IGW	2	VMC
02/16/2013	Accident	US	Dutch Harbor, AK	PADU	P-N	1	MLS	PA-31-350	2	VMC
02/07/2013	Accident	US	Winston-Salem, NC	INT	GA	2	ILS	58	2	VMC
01/11/2013	Accident	US	Alexandria, MN	AXN	GA	2	ILS	65-B80	2	IMC
12/01/2012	Accident	US	Melbourne, AR	42A	GA	1	NO	8KCAB	2	VMC
11/09/2012	Incident	US	Minneapolis, MN	MSP	P-L	4	ILS,ILS/DME, LOCAL-IZER,LOC/DME	SA227-AC	2	VMC
10/31/2012	Accident	US	Boyne City, MI	N98	GA	1	NO	P180	2	IMC
10/22/2012	Accident	US	Sturtevant, WI	C89	GA	2	NO	B90	2	IMC
10/11/2012	Accident	US	Palm Coast, FL	XFL	GA	3	NO	DA 42 NG	2	VMC
09/18/2012	Accident	US	Macon, GA	MAC	GA	2	LOC/DME	400	2	VMC
09/11/2012	Accident	US	Kenedy, TX	2R9	GA	1	NO	421C	2	VMC
09/03/2012	Accident	US	Spanoway, WA	S44	GA	1	NO	95-55	2	VMC

08/31/2012	Incident	US	Nantucket, MA	ACK	P-N	3	ILS/DME	402C	2	VMC
08/29/2012	Accident	US	Millville, NJ	MIV	GA	2	ILS	95-A55	2	VMC
08/23/2012	Accident	US	Scappoose, OR	SPB	GA	1	LOC/DME	PA-30 B	2	VMC
08/01/2012	Accident	US	Grand Forks, ND	GFK	P-N	4	ILS/DME	PA-44-180	2	VMC
07/20/2012	Accident	US	Medford, OR	MFR	P-N	1	ILS/DME	G58	2	VMC
07/14/2012	Accident	US	Grand Forks, ND	KGFK	P-N	4	ILS/DME	PA-44-180	2	VMC
07/10/2012	Accident	US	Sugar Loaf Mountain, MI	Y04	GA	1	NO	58	2	VMC
06/14/2012	Accident	US	Ozark, MO	KAIZ	GA	1	LOCALIZER	560	2	VMC
05/30/2012	Accident	US	Jerome, ID	KJER	GA	1	NO	P337H	2	VMC
05/24/2012	Accident	US	McGrath, AK	AK40	GA	1	NO	1900C	2	VMC
05/03/2012	Accident	US	Chefornak, AK	PACK	CS	1	NO	SC7 SERIES 3	2	VMC
04/24/2012	Accident	US	Sioux Falls, SD	FSD	P-N	3	ILS	58	2	VMC
04/03/2012	Accident	US	San Marcos, TX	HYI	R	3	ILS	PA-34-200T	2	VMC
04/02/2012	Accident	US	Philadelphia, PA	PHL	P-L	4	ILS/DME	PA-60-602P	2	VMC
03/27/2012	Accident	US	Battle Creek, MI	KBTL	GA	3	ILS	441	2	VMC
03/23/2012	Accident	US	Conrad, MT	S01	GA	2	NO	690C	2	IMC
03/05/2012	Incident	US	Anchorage, AK	PANC	P-M	3	ILS/DME	35A	2	VMC
03/02/2012	Accident	US	Roanoke, TX	52F	GA	1	NO	PA-30	2	VMC
02/16/2012	Incident	US	Fort Lauderdale, FL	FLL	P-L	2	ILS/DME	402B	2	VMC
02/15/2012	Accident	US	South Charles-ton, WV	WV12	GA	1	NO	58	2	VMC
02/14/2012	Accident	US	Hollister, CA	CVH	GA	1	NO	G18	2	VMC
02/11/2012	Accident	US	Wheatland, WY	EAN	GA	1	NO	31A	2	VMC

02/06/2012	Accident	US	Culpeper, VA	CJR	GA	1	LOCALIZER	PA-30	2	VMC
02/01/2012	Accident	US	Anchorage, AK	PAMR	CS	3	NO	99	2	VMC
01/30/2012	Incident	US	Baltimore, MD	BWI	P-L	3	ILS,ILS/DME	G150	2	VMC
01/07/2012	Accident	US	Santa Ana, CA	SNA	P-M	3	ILS/DME	58P	2	VMC
01/05/2012	Accident	US	Las Vegas, NV	VGT	P-N	3	ILS/DME	AEROSTAR 601P	2	VMC
01/02/2012	Accident	US	Shelter Island, NY	NA	GA	1	NO	PA-34-200T	2	VMC
12/28/2011	Accident	US	Picayune, MS	MJD	GA	1	NO	MU-2B-20	2	VMC
12/19/2011	Accident	US	Lawrenceville, GA	LZU	R	1	ILS	PA-44-180	2	VMC
12/09/2011	Accident	US	Pampa, TX	PPA	GA	2	NO	421B	2	IMC
12/08/2011	Accident	US	Kaltag, AK	PAKV	GA	1	NO	PA-31-350	2	IMC
12/02/2011	Accident	US	San Carlos, CA	SQL	R	1	NO	76	2	VMC
11/25/2011	Accident	US	Sedona, AZ	SEZ	GA	1	NO	310I	2	VMC
11/19/2011	Accident	US	Lyman, MS	MS82	GA	1	NO	C-45G	2	VMC
11/16/2011	Accident	US	Flint, MI	FNT	P-S	2	ILS	P180	2	VMC
11/03/2011	Incident	US	Key West, FL	EYW	P-S	1	NO	550	2	VMC
10/31/2011	Accident	US	Key West, FL	EYW	P-S	1	NO	G150	2	VMC
10/23/2011	Incident	US	Atlanta, GA	ATL	P-L	5	ILS,ILS/DME	CL600 2C10	2	VMC
09/28/2011	Accident	US	Atlanta, GA	RYY	R	1	ILS	MU-2B-25	2	VMC
09/26/2011	Incident	US	Denver, CO	DEN	P-L	6	ILS/DME	757-222	2	VMC
09/17/2011	Accident	US	Hillsboro, TX	KINJ	GA	1	NO	B90	2	VMC
09/04/2011	Accident	US	Phoenix, AZ	DVT	R	2	NO	PA-44-180	2	VMC
09/04/2011	Accident	US	Georgetown, DE	GED	GA	2	NO	TB-25N	2	VMC

09/01/2011	Incident	US	Baton Rouge, LA	BTR	P-S	3	ILS/DME	CL-600-2B19	2	VMC
08/21/2011	Accident	US	Dillingham, AK	PADL	P-N	1	MLS,LOC/DME	G-44	2	VMC
07/19/2011	Accident	US	Colville, WA	63S	GA	1	NO	95-B55 (T42A)	2	VMC
07/12/2011	Accident	US	Opa-Locka, FL	OPF	R	3	ILS,ILS/DME	35	2	VMC
06/30/2011	Accident	US	Casper, WY	KCPR	P-N	2	ILS	PA-31-350	2	VMC
06/15/2011	Accident	US	Nashville, TN	JWN	R	1	ILS/DME	525A	2	IMC
06/12/2011	Accident	US	Cold Bay, AK	PACD	CS	2	ILS,MLS	DC-6B	4	VMC
06/03/2011	Incident	US	Chicago, IL	ORD	P-L	8	ILS,ILS/DME, LOCAL-IZER	EMB-145	2	VMC
06/01/2011	Accident	US	Nome, AK	PAOM	P-N	2	MLS,ILS/DME	EA500	2	VMC
05/27/2011	Incident	US	Newburgh, NY	SWF	P-N	2	ILS,ILS/DME	GULFSTREAM 200	2	VMC
05/25/2011	Accident	US	Sedona, AZ	SEZ	GA	1	NO	EMB-500	2	VMC
05/17/2011	Incident	US	Denver, CO	DEN	P-L	6	ILS/DME	1900D	2	VMC
05/11/2011	Accident	US	Clayton, NY	28NK	GA	1	NO	PA-23-250	2	VMC
04/26/2011	Incident	US	Chicago, IL	KMDW	P-L	5	ILS/DME	737-7Q8	2	IMC
04/21/2011	Accident	US	Teterboro, NJ	TEB	R	2	ILS,ILS/DME	BD700 1A10	2	VMC
04/12/2011	Accident	US	Austin, TX	AUS	P-M	2	ILS/DME	PA-30	2	VMC
04/08/2011	Accident	US	Eden Prairie, MN	FCM	R	3	ILS	500-S	2	VMC
04/01/2011	Accident	US	Sanford, FL	SFB	P-S	4	ILS/DME	310F	2	VMC
03/28/2011	Accident	US	Canadian, TX	HHF	GA	2	NO	425	2	IMC
03/23/2011	Accident	US	Sellersburg, IN	KJVY	R	2	ILS	Falcon 10	2	VMC
03/18/2011	Incident	US	Akron, OH	CAK	P-S	2	ILS,ILS/DME	EMB-145XR	2	VMC
03/14/2011	Accident	US	New York, NY	ISP	P-S	4	ILS	414	2	VMC
03/10/2011	Accident	US	Seattle, WA	BFI	P-N	2	ILS/DME	SA227-AC	2	VMC

03/04/2011	Accident	US	Houston, TX	KHOU	P-M	4	ILS/DME	25	2	IMC
02/25/2011	Accident	US	Princeton, NJ	39N	R	1	NO	PA-60-601P	2	IMC
02/24/2011	Accident	US	New York, NY	KLGA	P-L	2	ILS,ILS/DME, LOC/DME	ERJ 190-100 IGW	2	VMC
02/22/2011	Accident	US	North Bend, OR	KOTH	P-N	2	ILS,MLS	PA-31P-350	2	VMC
02/21/2011	Accident	US	Romeoville, IL	LOT	R	2	LOC/DME	310Q	2	VMC
02/21/2011	Accident	US	Prospect Heights, IL	PWK	R	3	ILS	58	2	VMC
02/05/2011	Accident	US	Bogalusa, LA	BXA	GA	1	LOCALIZER	PA-34-220T	2	VMC
02/03/2011	Accident	US	Albuquerque, NM	ABQ	P-M	3	ILS,ILS/DME	402	2	VMC
01/31/2011	Incident	US	Dayton, OH	KDAY	P-S	3	ILS,ILS/DME	EMB-145LR	2	VMC
01/16/2011	Incident	US	Walterboro, SC	RBW	GA	3	ILS/DME	MU-2B-20	2	VMC
01/09/2011	Accident	US	Lancaster, CA	KWJF	GA	1	NO	310C	2	VMC
12/29/2010	Incident	US	Jackson Hole, WY	JAC	P-N	1	ILS/DME	757-223	2	IMC
12/22/2010	Accident	US	Saint Michael, AK	PAMK	GA	1	NO	PA-31-350	2	VMC
12/16/2010	Accident	US	Ozark, AR	7M5	GA	1	NO	95-C55	2	VMC
12/13/2010	Incident	US	Birmingham, AL	BHM	P-S	2	ILS,ILS/DME, LOC/DME	560XL	2	VMC
12/01/2010	Incident	US	Toledo, OH	TOL	P-N	2	ILS	560XL	2	VMC
11/28/2010	Accident	US	Nocagdoches, TX	OCH	GA	1	ILS/DME	PA-34-200T	2	VMC
11/22/2010	Incident	US	Jackson, WY	JAC	P-N	1	ILS/DME	GULFSTREAM 200	2	IMC
11/19/2010	Accident	US	Williston, FL	X60	GA	2	NO	95-C55	2	VMC
11/17/2010	Accident	US	Portland, OR	HIO	R	3	ILS	25B	2	IMC

11/10/2010	Accident	US	Tucson, AZ	TUS	P-S	3	ILS/DME	PA30	2	VMC
10/23/2010	Accident	US	Camp Verde, AZ	19AZ	GA	1	NO	340A	2	VMC
10/18/2010	Incident	US	Fort Lauderdale, FL	FLL	P-L	2	ILS/DME	SHORTS SC7 SKYVAN	2	VMC
10/01/2010	Accident	US	Manteo, NC	MQI	GA	2	NO	550	2	IMC
10/01/2010	Incident	US	Teterboro, NJ	KTEB	R	2	ILS,ILS/DME	G-IV	2	IMC
09/28/2010	Incident	US	Idaho Falls, ID	KIDA	P-N	2	ILS/DME	F90	2	VMC
09/26/2010	Accident	US	Boerne Stage, TX	5C1	GA	1	NO	310K	2	VMC
09/23/2010	Accident	US	Northampton, MA	7B2	GA	1	NO	PA34	2	VMC
09/18/2010	Accident	US	Denton, TX	DTO	R	1	ILS	320	2	VMC
09/15/2010	Accident	US	Inverness, FL	X40	GA	1	NO	PA-34-200T	2	VMC
08/04/2010	Accident	US	Vici, OK	5O1	GA	1	NO	414	2	VMC
07/27/2010	Incident	US	San Juan, PR	SJU	P-M	2	ILS,ILS/DME	402C	2	VMC
07/26/2010	Incident	US	Hyannis, MA	HYA	P-N	2	ILS/DME	402C	2	VMC
07/22/2010	Accident	US	Cleburne, TX	CPT	GA	1	LOC/DME	Aerostar	2	VMC
07/02/2010	Accident	US	Las Vegas, NV	LAS	P-L	4	LOC/DME	E-55	2	VMC
06/21/2010	Accident	US	Storm Lake, IA	SLB	GA	3	NO	525A	2	VMC
06/12/2010	Accident	US	Denver, CO	DEN	P-L	6	ILS/DME	1900D	2	IMC
06/09/2010	Accident	US	Ankeny, IA	IKV	R	2	ILS/DME	PA-34-220T	2	VMC
06/03/2010	Accident	US	Fort Worth, TX	AFW	R	2	ILS/DME	C90	2	VMC
06/01/2010	Accident	US	Okmulgee, OK	OKM	GA	1	ILS	PA-44-180	2	VMC
05/23/2010	Incident	US	Ontario, CA	ONT	P-M	2	ILS,ILS/DME	CL-600-2B19	2	VMC
05/19/2010	Accident	US	West Memphis, AR	KAWM	R	1	ILS/DME	SA-226AT	2	VMC

04/28/2010	Accident	US	Phoenix, AZ	DVT	R	2	NO	Rutan Defiant 40	2	VMC
04/19/2010	Incident	US	Burbank, CA	KBUR	P-M	2	ILS	737-7H4	2	VMC
04/03/2010	Accident	US	Princeton, KY	2M0	GA	1	NO	MU-2B-26A	2	VMC
03/31/2010	Accident	US	Sevierville, TN	GKT	GA	1	NO	95-B55 (T42A)	2	VMC
03/27/2010	Accident	US	Naples, FL	APF	R	2	NO	58	2	VMC
03/26/2010	Accident	US	Sedona, AZ	SEZ	GA	1	NO	PA-34-220T	2	VMC
03/21/2010	Accident	US	Lumberton, NJ	N14	GA	1	NO	B95	2	VMC
03/21/2010	Accident	US	Santa Barbara, CA	SBA	P-N	3	ILS/DME	58	2	VMC
03/15/2010	Accident	US	Shelby, NC	EHO	GA	1	NO	T337G	2	VMC
03/02/2010	Accident	US	DeKalb, IL	DKB	GA	2	ILS/DME	65-A90	2	VMC
03/01/2010	Accident	US	Greensboro, NC	GSO	P-S	3	ILS,ILS/DME, LOC/GS	P180	2	VMC
02/27/2010	Accident	US	Grove City, PA	29D	GA	1	NO	340A	2	VMC
02/04/2010	Accident	US	Columbia, MO	COU	P-N	2	ILS/DME	PA-31T	2	VMC
02/04/2010	Accident	US	Amarillo, TX	KAMA	P-S	2	ILS,LDA/DME	MU-2B-60	2	IMC
01/26/2010	Accident	US	Fallon, NV	FLX	GA	2	NO	8KCAB	2	VMC
01/19/2010	Accident	US	Sioux City, IA	SUX	P-N	2	ILS	B200	2	IMC
01/10/2010	Incident	US	Newark, NJ	KEWR	P-L	3	ILS/DME	A319-131	2	VMC
01/06/2010	Accident	US	Kearney, NE	EAR	P-N	2	ILS/DME	C-99	2	IMC
01/02/2010	Accident	US	Somerset, KY	SME	GA	1	ILS/DME	SA227	2	VMC
12/13/2009	Incident	US	Charlotte, NC	CLT	P-L	4	ILS,ILS/DME	MD	2	IMC
12/10/2009	Accident	US	St. Louis, MO	STL	P-M	4	ILS,ILS/DME	200	2	VMC
10/30/2009	Accident	US	Miami, FL	X44	GA	1	NO	BE-103	2	VMC
10/22/2009	Accident	US	Grand Forks, ND	KGFK	P-N	4	ILS/DME	PA-44-180	2	VMC

10/19/2009	Incident	US	Atlanta Harts-field Intl. Apt.	KATL	P-L	5	ILS/DME	767	2	VMC
10/01/2009	Accident	US	Brooksville, FL	BKV	GA	2	ILS	AEROSTAR	2	VMC
09/27/2009	Accident	US	Vineyard Haven, MA	MVY	P-N	2	ILS/DME	CL-600-2B16	2	IMC
09/26/2009	Accident	US	Skwentna, AK	6AK	GA	1	NO	SC7 SERIES	2	VMC
09/18/2009	Accident	US	Savoonga, AK	SVA	CS	1	NO	212-200	2	VMC
09/17/2009	Accident	US	Anchorage, AK	MRI	CS	3	NO	G-44A	2	VMC
09/08/2009	Incident	US	Los Angeles, CA	KLAX	P-L	4	ILS/DME	737	2	VMC
08/27/2009	Accident	US	Hamilton, MT	6S5	GA	1	NO	AIR CAM	2	VMC
08/25/2009	Accident	US	Savannah, GA	SAV	P-S	2	ILS	PA-34	2	VMC
08/21/2009	Accident	US	Teterboro, NJ	TEB	R	2	ILS,ILS/DME	58	2	VMC
08/02/2009	Accident	US	Lincoln Park, NJ	N07	R	1	NO	PA-34-200T	2	VMC
07/27/2009	Accident	US	Mount Holly, NJ	VAY	R	1	NO	PA-34-200T	2	VMC
07/24/2009	Accident	US	Dayton, OH	MGY	R	1	LOC/DME	H-18	2	VMC
07/22/2009	Accident	US	Walla Walla, WA	ALW	P-N	2	ILS	PA-30	2	VMC
07/13/2009	Accident	US	Yakutat, AK	PAYA	P-N	2	ILS	G18S	2	VMC
06/25/2009	Accident	US	St. Louis, MO	1H0	R	2	NO	PA-31T1	2	VMC
06/16/2009	Accident	US	Arlington, WA	KAWO	GA	2	LOCALIZER	ALPHA-JET	2	VMC
06/11/2009	Incident	US	Atlanta, GA	ATL	P-L	5	ILS,ILS/DME	CL-600-2B1	2	VMC
05/12/2009	Incident	US	Houston, TX	HOU	P-M	4	ILS/DME, LOC/DME	737	2	VMC
05/06/2009	Accident	US	Baltimore, MD	KBWI	P-L	3	ILS,ILS/DME	DC-10	3	VMC
05/04/2009	Accident	US	Denver, CO	KDEN	P-L	6	ILS/DME	A320	2	VMC
04/30/2009	Accident	US	Great Barring-ton, MA	GBR	GA	1	NO	PA-30	2	VMC

04/27/2009	Incident	US	Nantucket, MA	ACK	P-N	3	ILS/DME	402C	2	VMC
04/20/2009	Accident	US	New York, NY	KJFK	P-L	4	ILS,ILS/DME	767	2	VMC
04/08/2009	Accident	US	Roseburg, OR	RBG	GA	1	NO	A36TC	2	VMC
03/29/2009	Accident	US	Salt Lake City, UT	KSLC	P-L	4	ILS/DME	550	2	VMC
03/18/2009	Accident	US	Ocala, FL	OCF	GA	2	ILS	310K	2	VMC
03/14/2009	Accident	US	Buckland, AK	PABL	CS	1	NO	PA-31-350	2	VMC
03/11/2009	Accident	US	Durango, CO	DRO	P-N	1	ILS	58	2	VMC
03/10/2009	Accident	US	Aberdeen, SD	KABR	P-N	2	ILS/DME	402B	2	IMC
03/09/2009	Accident	US	Belmar, NJ	BLM	R	2	LOC/DME	PA-42	2	IMC
03/08/2009	Accident	US	Lumberton, MS	4R1	GA	1	NO	PA-30	2	VMC
02/23/2009	Accident	US	Pueblo, CO	PUB	CS	2	ILS	PA-31T	2	VMC
02/16/2009	Accident	US	Soldotna, AK	PASX	GA	2	NO	65-A90-1	2	VMC
01/03/2009	Accident	US	Brainerd, MN	BRD	P-N	2	ILS,ILS/DME	58	2	VMC
01/03/2009	Accident	US	Telluride, CO	KTEX	CS	1	LDA/DME	45XR	2	IMC
12/24/2008	Accident	US	Batesville, AR	BVX	GA	2	LOC/DME	95-B55	2	VMC
12/23/2008	Accident	US	Lewistown, MO	MO09	GA	1	NO	390	2	VMC
12/21/2008	Accident	US	Jamestown, NY	JHW	CS	2	ILS/DME	FAN JET	2	IMC
12/18/2008	Accident	US	Folkston, GA	3J6	GA	1	NO	PA-34-200	2	VMC
12/14/2008	Accident	US	Gary, IN	GYY	CS	2	ILS/DME	CL-600-2B16	2	VMC
12/11/2008	Incident	US	Fort Lauderdale, FL	FLL	P-L	2	ILS/DME	402C	2	VMC
12/05/2008	Accident	US	Grand Forks, ND	GFK	P-N	4	ILS/DME	500-S	2	IMC
11/23/2008	Accident	US	Kona, HI	HKO	P-S	1	ILS/DME	PA-30	2	VMC
11/21/2008	Accident	US	Middletown, OH	MWO	GA	2	LOCALIZER	AEROSTAR 6	2	VMC

11/01/2008	Accident	US	Lawrenceville, GA	KLZU	R	1	ILS	PA-44-180	2	VMC
10/24/2008	Accident	US	Tallahasee, FL	TLH	P-N	2	ILS/DME	PA-34-200T	2	IMC
10/20/2008	Accident	US	Phoenix, AZ	PHX	P-L	3	ILS/DME	320	2	VMC
09/29/2008	Accident	US	Fresno, CA	FAT	P-S	2	ILS/DME,LOC/DME	PA-31-350	2	VMC
09/28/2008	Accident	US	Lancaster, PA	LNS	CS	2	ILS	DA42	2	VMC
09/25/2008	Accident	US	Bridgewater, VA	VBW	GA	1	NO	A200	2	VMC
09/18/2008	Accident	US	Jefferson, GA	19A	GA	1	NO	PA-30	2	VMC
09/09/2008	Accident	US	Lake Placid, NY	LKP	GA	1	NO	310R	2	VMC
08/14/2008	Accident	US	St. Louis, MO	KSTL	P-M	4	ILS,ILS/DME	EMB-145LR	2	VMC
08/13/2008	Accident	US	East Tawas, MI	6D9	GA	1	NO	PA-34-200T	2	VMC
08/03/2008	Accident	US	Reading, PA	RDG	GA	2	ILS,ILS/DME	550	2	VMC
07/30/2008	Accident	US	West Chester, PA	OQN	R	1	NO	EA500	2	VMC
07/16/2008	Accident	US	Sunriver, OR	S21	GA	1	NO	441	2	VMC
06/25/2008	Accident	US	Baker City, OR	BKE	GA	3	NO	690B	2	VMC
06/14/2008	Accident	US	Ocala, FL	KOCF	GA	2	ILS	PA-34	2	VMC
06/06/2008	Accident	US	Pawtucket, RI	SFZ	R	2	LOC/DME	PA-30	2	IMC
05/30/2008	Accident	US	Tacoma, WA	TIW	GA	1	ILS	690A	2	VMC
04/30/2008	Accident	US	Port Heiden, AK	PAPH	GA	1	MLS	560XL	2	VMC
04/19/2008	Accident	US	Carlsbad, CA	CRQ	P-N	1	ILS/DME	510	2	VMC
04/15/2008	Accident	US	White Plains, NY	HPN	P-S	2	ILS/DME	560XL	2	VMC
04/12/2008	Accident	US	Potsdam, NY	PTD	GA	1	NO	EMB-110P1	2	IMC
04/09/2008	Accident	US	Unalaska, AK	PADU	P-N	1	MLS	G-21A	2	VMC
03/27/2008	Incident	US	Houston, TX	KIAH	P-L	5	ILS,ILS/DME,LOC/GS	737-524	2	VMC

02/22/2008	Accident	US	Kayenta, AZ	38AZ	GA	1	NO	1900D	2	IMC
01/29/2008	Accident	US	Marathon, FL	MTH	GA	1	NO	G-21A	2	VMC
12/16/2007	Accident	US	Providence, RI	KPVD	P-M	2	ILS/DME	CL600-2B19	2	IMC
12/02/2007	Accident	US	Coeur d'Alene, ID	COE	GA	2	ILS	551	2	VMC
11/12/2007	Accident	US	Salt Lake City, UT	KSLC	P-L	4	ILS/DME	PA-31-350	2	VMC
11/11/2007	Accident	US	Sugar Land, TX	KSGR	R	1	ILS/DME	G-IV	2	VMC
10/20/2007	Incident	US	Fargo, ND	FAR	P-S	3	ILS	A320-211	2	VMC
10/17/2007	Accident	US	Goodland, KS	GLD	GA	3	ILS/DME	35A	2	IMC
10/09/2007	Incident	US	Chicago, IL	ORD	P-L	8	ILS,ILS/DME, LOCAL-IZER	A320-232	2	VMC
09/14/2007	Accident	US	Atlanta, GA	PDK	R	3	NO	Astra SPX	2	IMC
08/27/2007	Accident	US	Pompano Beach, FL	KPMP	GA	3	LOC/DME	BE-76	2	VMC
08/23/2007	Accident	US	Westhampton, NY	FOK	GA	3	ILS	60	2	IMC
06/30/2007	Accident	US	Conway, AR	KCWS	GA	2	NO	500	2	VMC
04/12/2007	Accident	US	Traverse City, MI	KTVC	P-N	2	ILS	CL-600-2B19	2	IMC
11/01/2006	Accident	US	Fort Lauderdale, FL	KFLL	P-L	2	ILS/DME	HS 125-700A	2	VMC
07/28/2006	Accident	US	Memphis, TN	KMEM	P-M	4	ILS,ILS/DME	MD-10-10F	3	VMC
01/24/2006	Accident	US	Carlsbad, CA	KCRQ	P-N	1	ILS/DME	560	2	VMC
08/19/2005	Accident	US	Agana, GU	GUM	P-S	2	ILS/DME	747-200	4	VMC
05/20/2004	Accident	US	Livermore, CA	LVK	R	2	ILS	PA-34-200T	2	VMC
12/21/2003	Accident	US	Louisville, KY	LOU	R	2	NO	PA-30	2	VMC
06/16/2002	Accident	US	Kansas City, MO	MCI	P-M	3	ILS/DME	DC-9-82	2	VMC

01/14/2001	Accident	US	Troy, AL	TOI	GA	2	ILS/DME	LJ-60	2	VMC
03/05/2000	Accident	US	BURBANK, CA	BUR	P-M	2	ILS	737-300	2	VMC

Appendix B

The following table presents a summary of Accidents and Incidents in takeoff phase of flight, identified in the databases screened.

Event Date	Event type	Country	Location	AirportCode	FAACategory	#ofRWYs	KindofNAVAID	Model	#of En-gines	Weather
09/21/2014	Incident	US	Atlanta, GA	ATL	P-L	5	ILS/DME	747 451	4	VMC
07/02/2014	Accident	US	Harrison, AR	HRO	CS	1	ILS/DME	PA30	2	VMC
12/03/2013	Accident	US	Crescent City, FL	28FL	GA	1	NO	680E	2	VMC
11/25/2013	Accident	US	Nuiqsut, AK	AK15	GA	1	NO	DC-6	4	VMC
10/23/2013	Accident	US	Tucson, AZ	TUS	P-S	3	ILS/DME	PA-23-150	2	VMC
06/24/2013	Accident	US	San Luis Obispo, CA	SBP	P-N	2	ILS	P337H	2	VMC
06/22/2013	Accident	US	Idaho Falls, ID	KIDA	P-N	2	ILS/DME	PA-30	2	VMC
06/20/2013	Accident	US	Dayton, OH	KDAY	P-S	3	ILS,ILS/DME	PA-30	2	VMC
06/18/2013	Accident	US	Cincinnati, OH	KLUK	CS	2	ILS/DME	1124	2	VMC
06/15/2013	Accident	US	Victoria, TX	KVCT	CS	3	ILS/DME	685	2	VMC
06/03/2013	Incident	US	Tallahassee, FL	TLH	P-N	2	ILS/DME	PA-34-200T	2	VMC
06/01/2013	Accident	US	Doylestown, PA	DYL	R	1	NO	CRICKET MC12	2	VMC
05/25/2013	Accident	US	West Palm Beach	F45	R	3	ILS/DME	AIR CAM 912S	2	VMC
05/04/2013	Incident	US	Mena, AR	MEZ	GA	2	ILS/DME	58	2	VMC
03/23/2013	Accident	US	Fullerton, CA	FUL	R	1	LOC/DME	PA-30	2	VMC
03/18/2013	Accident	US	Hillsboro, OR	7S3	GA	1	NO	PA-23-250	2	VMC
03/15/2013	Accident	US	Fort Lauderdale, FL	FXE	R	2	ILS	PA-31T	2	VMC
03/01/2013	Accident	US	Broomfield, CO	KBJC	R	3	ILS	500B	2	VMC

02/17/2013	Accident	US	Casper, WY	CPR	P-N	2	ILS	T310R	2	VMC
02/13/2013	Accident	US	New Smyrna Beach, FL	EVB	R	3	NO	T337C	2	VMC
12/14/2012	Incident	US	Williston, ND	ISN	P-N	2	ILS	SA227-AC	2	IMC
12/08/2012	Accident	US	Lake Worth, FL	LNA	R	3	NO	421C	2	VMC
11/24/2012	Accident	US	Phoenix, AZ	DVT	R	2	NO	PA30	2	VMC
11/21/2012	Accident	US	Mancelona, MI	4Y4	GA	1	NO	310B	2	VMC
11/01/2012	Accident	US	San Marcos, TX	KHYI	R	3	ILS	320E	2	IMC
10/19/2012	Incident	US	Nantucket, MA	ACK	P-N	3	ILS/DME	560XL	2	VMC
09/28/2012	Incident	US	Teterboro, NJ	TEB	R	2	ILS,ILS/DME	60	2	IMC
09/20/2012	Accident	US	New Haven, CT	HVN	P-N	2	ILS/DME	36A	2	VMC
09/09/2012	Accident	US	Washington, PA	AFJ	GA	1	ILS/DME	PA-31-325	2	VMC
09/05/2012	Accident	US	Fort Worth, TX	FWS	R	2	ILS	421B	2	VMC
08/29/2012	Incident	US	Kansas City, MO	MKC	R	2	ILS	BAE JETSTREAM 3101	2	VMC
08/02/2012	Accident	US	Houston, TX	IWS	R	1	NO	E-55	2	VMC
07/28/2012	Accident	US	Henderson, NV	KHND	R	2	NO	P180	2	VMC
07/26/2012	Accident	US	Sedona, AZ	SEZ	GA	1	NO	B60	2	VMC
07/01/2012	Accident	US	Atlanta, GA	KPDK	R	3	ILS	58	2	VMC
06/30/2012	Accident	US	Dalton, GA	DNN	GA	1	ILS	PA-31P	2	VMC
06/17/2012	Incident	US	Las Vegas, NV	LAS	P-L	4	ILS/DME	A320	2	VMC
05/12/2012	Accident	US	Pope Valley, CA	05CL	GA	1	NO	3NM	2	VMC
04/01/2012	Accident	US	Calhoun, KY	96KY	GA	1	NO	58	2	VMC
02/13/2012	Incident	US	Portland, OR	PWM	P-S	2	ILS/DME	MD-10-30F	3	VMC

02/08/2012	Incident	US	Jamaica, NY	JFK	P-L	4	ILS/DME	767	2	IMC
02/02/2012	Accident	US	Pueblo, CO	PUB	CS	3	ILS	35	2	IMC
01/16/2012	Accident	US	Philadelphia, MS	MPE	GA	1	NO	PA-60-601P	2	VMC
12/28/2011	Accident	US	Ft. Lauderdale, FL	FXE	R	2	ILS	650	2	VMC
12/01/2011	Incident	US	Chicago, IL	MDW	P-L	5	ILS/DME	45	2	VMC
11/30/2011	Accident	US	Seattle, WA	BFI	P-N	2	ILS/DME	PA-44-180	2	VMC
11/10/2011	Accident	US	Alamosa, CO	ALS	GA	1	ILS	337G	2	VMC
11/08/2011	Accident	US	Cheyenne, WY	CYS	P-N	2	ILS	PA-31T	2	VMC
10/23/2011	Incident	US	Detroit, MI	DTW	P-L	6	ILS,ILS/DME	747-451	4	VMC
10/10/2011	Incident	US	Atlanta, GA	ATL	P-L	5	ILS,ILS/DME	757-251	2	VMC
09/21/2011	Accident	US	Truckee, CA	TRK	GA	2	NO	PA23	2	VMC
08/26/2011	Accident	US	Saguache, CO	04V	GA	1	NO	PA-30	2	VMC
08/22/2011	Accident	US	Alpine, TX	E38	GA	2	NO	AEROSTAR 601P	2	VMC
08/17/2011	Accident	US	Tupelo, MS	KTUP	CS	1	ILS/DME	310Q	2	VMC
08/08/2011	Incident	US	Chicago, IL	ORD	P-L	8	ILS,ILS/DME, LOCAL-IZER	EMB-145LR	2	VMC
08/03/2011	Accident	US	St. Petersburg, FL	SPG	R	2	NO	PA-30	2	VMC
07/30/2011	Accident	US	Perris, CA	L65	GA	1	NO	76	2	VMC
06/21/2011	Accident	US	Phoenix, AZ	DVT	R	2	NO	320F	2	VMC
06/20/2011	Accident	US	Caldwell, ID	KEUL	R	1	NO	402	2	VMC
06/19/2011	Incident	US	Gulfport, MS	GPT	P-N	2	ILS	EMB-145EP	2	VMC
05/21/2011	Accident	US	Phillipsburg, OH	3I7	GA	1	NO	PA30	2	VMC
05/18/2011	Accident	US	Point Mugu, CA	KNTD	GA	2	ILS/DME	707-321B	4	VMC

05/16/2011	Incident	US	CHICAGO, IL	KORD	P-L	8	ILS,ILS/DME, LOCALI	EMB-145LR	2	VMC
05/02/2011	Accident	US	Miami Gardens, FL	OPF	R	3	ILS,ILS/DME	E18S	2	VMC
04/11/2011	Accident	US	Richmond, VA	RIC	P-S	3	ILS,LOC/GS	PA-31-350	2	VMC
04/03/2011	Accident	US	Ruidoso, NM	SRR	GA	2	ILS/DME	PA-30	2	VMC
04/02/2011	Accident	US	Roswell, NM	ROW	P-N	2	ILS/DME	GVI	2	VMC
03/26/2011	Accident	US	Encinal, TX	XA66	GA	1	NO	B25	2	VMC
03/22/2011	Accident	US	Aberdeen, SD	ABR	P-N	2	ILS/DME	414A	2	IMC
03/16/2011	Accident	US	Long Beach, CA	LGB	P-S	5	ILS	200	2	VMC
03/11/2011	Incident	US	ATLANTA, GA	KATL	P-L	5	ILS,ILS/DME	757-232	2	VMC
01/17/2011	Accident	US	Charlotte Amalie, VI	STT	P-S	1	ILS/DME	340-71	2	VMC
01/03/2011	Accident	US	New Stuyahok, AK	PANW	GA	1	NO	E18S-9700	2	VMC
01/03/2011	Accident	US	Los Angeles, CA	LAX	P-L	4	ILS/DME	737-823	2	VMC
11/11/2010	Accident	US	West Palm Beach	PBI	P-M	3	ILS/DME,LOC/GS	PA-44-180	2	VMC
10/03/2010	Accident	US	Avalon, CA	AVX	GA	1	NO	310	2	IMC
09/12/2010	Accident	US	Clearwater, FL	PIE	P-S	4	ILS, LOC/GS	P-180	2	VMC
08/31/2010	Accident	US	Jacksonville, FL	HEG	R	2	NO	560E	2	VMC
08/23/2010	Accident	US	Douglas, GA	DQH	GA	1	LOC/GS	PA-30	2	VMC
08/19/2010	Accident	US	Bedford, PA	HMZ	GA	1	NO	414	2	IMC
07/27/2010	Accident	US	Oceanside, CA	OKB	GA	1	NO	95 55	2	VMC
07/14/2010	Accident	US	El Monte, CA	EMT	R	1	NO	310K	2	VMC
07/04/2010	Accident	US	Alpine, TX	E38	GA	2	NO	421B	2	VMC
06/24/2010	Accident	US	Ashdown, AR	D05	GA	2	NO	310C	2	VMC
06/07/2010	Accident	US	Edenton, NC	EDE	GA	1	ILS/DME	60	2	VMC

06/05/2010	Accident	US	Custer, SD	KCUT	GA	1	NO	337	2	VMC
06/04/2010	Accident	US	Anderson, IN	KAID	GA	2	ILS	421B	2	VMC
05/21/2010	Incident	US	Anchorage, AK	PANC	P-M	3	ILS/DME	747	4	VMC
04/28/2010	Incident	US	Houston, TX	HOU	P-M	4	ILS/DME	737-7H4	2	VMC
04/20/2010	Accident	US	Tooele, UT	KTVY	GA	1	ILS/DME	PA-44-180	2	VMC
04/07/2010	Accident	US	Ponce, PR	TJPS	P-N	1	NO	404	2	VMC
04/05/2010	Incident	US	Newark, NJ	EWR	P-L	3	ILS/DME	A320	2	VMC
04/01/2010	Accident	US	Eden Prairie, MN	FCM	R	3	ILS	95	2	VMC
03/23/2010	Accident	US	Hollister, CA	CVH	GA	2	NO	PA30	2	VMC
03/18/2010	Accident	US	Lagrange, NY	44N	R	1	NO	95	2	VMC
03/17/2010	Accident	US	Baltimore, MD	MTN	R	1	NO	PA-30	2	VMC
03/15/2010	Accident	US	Kodiak, AK	PADQ	P-N	3	ILS/DME	BN-2A-21	2	VMC
03/04/2010	Accident	US	Louisa, VA	LKU	GA	1	LOCALIZER	T303	2	VMC
02/17/2010	Accident	US	Imperial, CA	IPL	CS	2	NO	CM 170 MAG-ISTER	2	VMC
02/09/2010	Accident	US	Portland, OR	PDX	P-L	3	ILS/DME	58	2	VMC
01/21/2010	Accident	US	Sand Point, AK	SDP	GA	1	NO	1900C	2	VMC
01/19/2010	Incident	US	Charleston, WV	CRW	P-N	1	ILS/DME	CL600	2	VMC
01/11/2010	Incident	US	St. Croix, VI	STX	P-N	1	ILS	ATR72	2	VMC
01/08/2010	Accident	US	Eagle, CO	KEGE	P-N	1	ILS/DME	20C	2	VMC
12/22/2009	Accident	US	Moab, UT	CNY	CS	1	NO	402C	2	IMC
11/17/2009	Accident	US	Saginaw, TX	T67	GA	1	NO	PA-34-200T	2	VMC
11/05/2009	Accident	US	Ft Pierce, FL	FPR	GA	3	ILS/DME	G-111	2	VMC
11/04/2009	Accident	US	Brenham, TX	11R	GA	1	NO	95-B55	2	VMC

10/30/2009	Accident	US	Lawrenceville, GA	LZU	R	1	ILS	310J	2	IMC
10/21/2009	Accident	US	Summerville, SC	DYB	GA	1	NO	PA-23-250	2	VMC
09/24/2009	Accident	US	Nampa, ID	KS67	GA	1	NO	Tangent	2	VMC
09/16/2009	Accident	US	Hayward, CA	HWD	R	2	LOC/DME	B200	2	VMC
07/31/2009	Incident	US	Sugar Land, TX	SGR	R	1	ILS/DME	BE-400A	2	VMC
07/31/2009	Accident	US	Frankfort, MI	FKS	GA	1	NO	337F	2	VMC
07/23/2009	Accident	US	Bismarck, ND	BIS	P-N	2	ILS	C90A	2	VMC
07/11/2009	Accident	US	Angel Fire, NM	KAXX	GA	1	NO	680-F	2	VMC
07/03/2009	Accident	US	Tucson, AZ	TUS	P-S	3	ILS/DME	PA-30	2	VMC
06/26/2009	Incident	US	Cleveland, OH	CLE	P-M	3	ILS/DME	DHC-8-202	2	VMC
06/24/2009	Accident	US	Holbrook, AZ	P14	GA	2	NO	B95	2	VMC
06/05/2009	Accident	US	Sellersburg, IN	JVY	R	2	ILS	550	2	VMC
05/29/2009	Incident	US	Charlotte, NC	CLT	P-L	4	ILS,ILS/DME	CL-600-2B1	2	VMC
05/25/2009	Accident	US	Daytona Beach, FL	DAB	P-N	3	ILS,ILS/DME	500 S	2	VMC
05/08/2009	Accident	US	Alpine, TX	E38	GA	2	NO	421B	2	VMC
04/17/2009	Accident	US	Oakland Park, FL	FXE	R	2	ILS	421B	2	VMC
03/17/2009	Accident	US	Casper, WY	CPR	P-N	2	ILS	Learjet 55	2	VMC
02/14/2009	Accident	US	Rialto, CA	KL67	GA	1	NO	T337	2	VMC
02/12/2009	Accident	US	Porter, TX	9X1	GA	1	NO	95-A55	2	VMC
02/08/2009	Accident	US	Lakeville, NY	NY15	GA	1	NO	PA-30	2	VMC
02/04/2009	Accident	US	Mojave, CA	MHV	GA	3	NO	DC-3/65AR	2	VMC
01/15/2009	Accident	US	Weehawken, NJ	LGA	P-L	2	ILS,ILS/DME	A320	2	VMC
01/12/2009	Accident	US	Corona, CA	AJO	R	1	NO	95-A55	2	VMC

01/02/2009	Incident	US	Atlanta, GA	KATL	P-L	5	ILS,ILS/DME	777	2	VMC
12/27/2008	Accident	US	Fort Myers, FL	RSW	P-M	1	ILS/DME	E18S	2	VMC
12/20/2008	Accident	US	Denver, CO	KDEN	P-L	6	ILS/DME	737-524	2	VMC
10/14/2008	Accident	US	Portland, OR	PDX	P-L	3	ILS/DME,LOC/DME	PA-31-350	2	VMC
09/26/2008	Accident	US	Vineyard Haven	MVY	P-N	2	ILS/DME	402	2	IMC
09/19/2008	Accident	US	Columbia, SC	KCAE	P-S	2	ILS	LR60	2	VMC
09/19/2008	Incident	US	Allentown, PA	ABE	P-N	2	ILS,ILS/DME	CL-600-2C1	2	VMC
09/01/2008	Accident	US	Columbus, OH	LCK	P-N	2	ILS,ILS/DME	CV-580	2	VMC
09/01/2008	Accident	US	Reno, NV	RTS	R	2	ILS/DME	P2V-7	4	VMC
08/22/2008	Accident	US	Moab, UT	CNY	CS	1	NO	A100	2	VMC
08/20/2008	Accident	US	Baltimore, MD	BWI	P-L	3	ILS,ILS/DME	441	2	VMC
08/06/2008	Incident	US	Las Vegas, NV	KLAS	P-L	4	ILS/DME	757	2	VMC
08/04/2008	Accident	US	Aniak, AK	PANI	P-N	2	ILS/DME	PA-31-350	2	VMC
07/29/2008	Incident	US	Anchorage, AK	ANC	P-M	3	ILS/DME	SAAB 340B	2	VMC
07/23/2008	Incident	US	Denver, CO	DEN	P-L	6	ILS/DME	A319-114	2	VMC
07/21/2008	Accident	US	Salt Lake CIty, UT	KSLC	P-L	4	ILS/DME	A200	2	VMC
07/07/2008	Incident	US	St. Louis, MO	KMDW	P-L	5	ILS/DME	MD-81	2	VMC
07/02/2008	Accident	US	Alexandria, MN	AXN	GA	2	ILS	Aerostar 601P	2	VMC
06/29/2008	Accident	US	Jasper, AL	JFX	GA	1	ILS/DME	95-B55	2	IMC
06/18/2008	Accident	US	Hyannis, MA	HYA	P-N	2	ILS/DME	DHC6	2	VMC
06/05/2008	Accident	US	Jackson, MS	HKS	GA	2	ILS	BE-58	2	VMC
06/02/2008	Accident	US	Greenville, NC	PGV	P-N	2	ILS/DME	421C	2	VMC
05/23/2008	Accident	US	Billings, MT	KBIL	P-S	3	ILS	1900C	2	IMC

05/12/2008	Accident	US	Coeur d'Alene, ID	COE	GA	2	NO	E-55	2	VMC
04/19/2008	Incident	US	Newark, NJ	EWR	P-L	3	ILS/DME	747	4	VMC
04/15/2008	Accident	US	San Dimas, CA	POC	R	2	ILS	PA-23-160	2	VMC
03/26/2008	Accident	US	Henderson, NV	HND	R	2	NO	402	2	VMC
03/26/2008	Incident	US	Page, AZ	PGA	P-N	2	NO	1900D	2	VMC
01/16/2008	Accident	US	Cleveland, OH	BKL	R	2	ILS/DME	58	2	VMC
01/16/2008	Accident	US	Tulsa, OK	KTUL	P-S	3	ILS,ILS/DME	500B	2	IMC
01/05/2008	Accident	US	Kodiak, AK	ADQ	P-N	3	ILS/DME	PA-31-350	2	VMC
12/10/2007	Accident	US	Salmon, ID	KSMN	GA	1	NO	200	2	IMC
12/05/2007	Accident	US	Columbus, OH	LCK	P-N	2	ILS,ILS/DME	208B	2	IMC
11/06/2007	Accident	US	Chino, CA	CNO	R	3	ILS	A100	2	IMC
09/21/2007	Accident	US	Ft. Lauderdale, FL	KFXE	R	2	ILS	H-18	2	VMC
07/03/2007	Accident	US	Carlsbad, CA	CRQ	P-N	1	ILS/DME	E90	2	IMC
06/10/2007	Accident	US	Santa Barbara, CA	SBA	P-N	3	ILS/DME	Mystere Fal-con 900	3	VMC
06/04/2007	Incident	US	Bismarck, ND	KBIS	P-N	2	ILS	36	2	VMC
07/29/2006	Accident	US	Sullivan, MO	UUV	GA	1	NO	DHC-6-100	2	VMC
06/25/2006	Accident	US	Fort Pierce, FL	FPR	GA	3	ILS/DME	MU-2B-60	2	VMC
09/21/2005	Incident	US	Los Angeles, CA	KLAX	P-L	4	ILS/DME	A320	2	VMC
03/02/2005	Accident	US	Newark, NJ	EWR	P-L	3	ILS/DME	777-200	2	VMC
02/02/2005	Accident	US	Teterboro, NJ	KTEB	R	2	ILS,ILS/DME	CL-600-1A11	2	VMC
01/14/2005	Accident	US	Patterson, LA	PTN	GA	2	NO	95-B55	2	VMC
06/30/2004	Accident	US	Green Bay, WI	GRB	P-S	2	ILS,ILS/DME	200	2	VMC
03/03/2003	Accident	US	Tracy, CA	KTCY	GA	2	NO	690A	2	VMC

12/13/2002	Incident	US	Manassas, VA	HEF	R	2	LOC/GS	PA-601P	2	IMC
01/24/2001	Accident	US	Nashville, TN	BNA	P-M	4	ILS/DME,LOC/DME,ILS	F90-42	2	VMC
02/16/2000	Accident	US	RANCHO CORDO-VA, CA	MHR	R	2	ILS/DME	DC-8-71F	4	VMC