copy 2

REVIEW OF AIRCRAFT CRASH DATABASES

and

EVALUATION OF THE PROBABILITY OF AIRCRAFT CRASHES ON TO A MAGLEV GUIDE-WAY

TECHNICAL REPORT

Submitted to

Safety & Security Division
Volpe National Transportation Systems Center
Kendall Square
Cambridge, MA 02142

Under

Contract # DTRS-57-91-C-00062/TTD 3

by

Technology & Management Systems, Inc
99 South Bedford Street, Suite 211
Burlington, MA 01803

Project # 65_03

9 December, 1991

REVIEW OF AIRCRAFT CRASH DATABASES

and

EVALUATION OF THE PROBABILITY OF AIRCRAFT CRASHES ON TO A MAGLEV GUIDE-WAY

TECHNICAL REPORT

Submitted to

Safety & Security Division
Volpe National Transportation Systems Center
Kendall Square
Cambridge, MA 02142

Under

Contract # DTRS-57-91-C-00062/TTD 3

by

Technology & Management Systems, Inc
99 South Bedford Street, Suite 211
Burlington, MA 01803

Project # 65_03

9 December, 1991

ACKNOWLEDGMENT

This report was prepared by Technology & Management Systems, Inc. (TMS) for the Volpe National Transportation System Center (VNTSC) of the U.S. Department of Transportation, Cambridge, MA 02142. The project was performed under contract # DTRS 57-91-00062/TTD 3. Dr. Phani K. Raj as the Project Manager at TMS. Technical contributions to the project and the preparation of the report were made by Mr. Sandeep Grover and Dr. Phani Raj.

Mr. Robert Rudich of VNTSC was the Project Technical Liaison at VNTSC. We acknowledge with thanks the support of Mr. Robert Rudich and Mr. William Hathaway of the Safety & Security Division at VNTSC.

Throughout the course of this study, we received information and reports from aircraft companies such as Boeing, McDonnell Douglas and from agencies such as the NTSB, FAA, ICAO and others without whose input this report would not have been possible. We acknowledge with gratitude the sharing of information and knowledge by many individuals in each of the above organizations.

We acknowledge with special thanks the assistance and cooperation provided by Mr. John Mogul of the FAA Office of Flight Standards, Eastern Region. He spent considerable time educating us on the intricacies of the ICAO's Collision Risk Model and its use.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The System Safety & Security Division at The Volpe National Transportation System Center (VNTSC), Cambridge, MA is participating in an overall risk assessment study on the safety of High Speed Magnetic Levitation Transportation Systems ("MagLev"). Transrapid Maglev technology is currently under consideration for application in several different corridors in the U.S. as well as in Germany. One of the projects being considered in the U.S. is the Florida Magnetic Levitation Demonstration Project which proposes to link Orlando International Airport to a point southwest of the airport on International Drive (near the Disney World). The proposed Maglev guideway will be approximately 13.5 miles in length and will be elevated for majority of the route. The vehicle planned for revenue service, the TR-07 Maglev system, is currently undergoing the final stages of certification testing at the Transrapid Test Facility in Emsland, Germany.

One of the important issues involved in the consideration of the MagLev system is safety. Many different aspects of the safety in transporting people at high speeds are being studied. In general, risk analysis methodology is being utilized to determine the acceptability of the system as a passenger carrier from the perspective of people safety. In these studies, a number of potential accident scenarios are postulated, their occurrence probabilities and consequences (if the scenario occurs) are calculated. One such accident scenario is the impact of an aircraft crashing on to the MagLev guideway in the vicinity of Orlando International Airport. Such a crash resulting in serious damage to the guideway, if it occurs at a time the MagLev vehicle is about to pass over the affected section of the guideway, can result in serious injury and casualties among the travelling public.

It is with a view to determining the potential for occurrence of such an aircraft accident scenario that the work reported in this report was undertaken.

1.2 OBJECTIVES

The were principally two objectives of the study. These were to,

a) Evaluate the probability of aircraft crashes occurring in the vicinity of Orlando International Airport that would have detrimental consequences on a MagLev guideway in that region.

b) Obtain the aviation industry experience quantitative information on human factor errors (i.e., maintenance shop and ground crew errors) and their contributory effect on aircraft accidents.

It was anticipated that a review of historical data on near airport aircraft accidents and crashes would provide information to achieve the first objective. The second objective would provide reasonable information on the potential for MagLev system accidents caused by human errors (maintenance and operation) because of the several similarities between aircraft operations and MagLev operations. These similarities include (i) the high speed, (ii) complex technology, (ii) approximately the same number of passengers per trip, (iv) no provision for "halting" between the origin and destination, etc.

1.3 APPROACH

In order to achieve the above objectives we conducted a study in two phases.

The first phase consisted of,

- o identifying and contacting potential sources of aircraft accident data through library research, personal contacts, telephone interviews, etc.
- o obtaining hard copy data on air accidents from a number of organizations. These included the Federal Aviation Administration (FAA), the National Transportation Safety Board (NTSB), the International Civil Aviation Organization (ICAO), aircraft companies Boeing and McDonnell Douglas, and a numerous other sources.
- o discussing with a number of individuals in each of these organizations the various aspects of their respective databases, model details, etc.

The second phase of the study involved,

- o the analysis of the data gathered. The analysis involved, first, the determination of (from these data) the US national average aircraft crash rate value. This rate was separately calculated for both commercial air carriers and general aviation operations. Also the data on the geographic distribution of air accidents in airports were gathered and evaluated.
- o the application of the calculated results to the case of air operations at the Orlando International Airport to determine the statistical expected value for annual aircraft crashes.

These results obtained from the extrapolation of the national statistics were compared with the actual experience at this airport and certain conclusions were drawn.

- development of a stochastic risk model to determine not only the number of expected aircraft crashes at Orlando airport but also the spatial distribution probabilities of these accidents. Using this model a generalized model was developed to determine the annual probability of aircraft impact on a MagLev guideway whose spatial extent and location are specified. Two example calculations were also developed.

The details of the work performed in this project are provided in the subsequent chapters.

1.4 ORGANIZATION OF THE REPORT

This report consists two major parts. The first part deals with the type of data that were collected during the investigation period. The second part presents the analysis that was conducted using the pertinent data.

Chapter 2 describes the details of our efforts in gathering aircraft accident data. The chapter provides details on sources that were contacted and the types of data collected. Both accident data per se and information on evaluative models, if any, were collected. Specifically, the details of the ICAO's Collision Risk Model (currently used by the FAA in assessing the risk of aircraft collision with obstacles in airports) are presented in this chapter. Finally, discussions are provided on the data including their limitations.

The application of the data collected to determining the probability of aircraft impact on a proposed MagLev guideway at Orlando airport is described in Chapter 3. A mathematical model is presented and its application to two specific examples is illustrated. Several conclusions are drawn from the results.

Chapter 4 presents the conclusions and recommendations from this study.

CHAPTER 2

AIRCRAFT ACCIDENT DATA

2.0 DATA RELATING TO AIRCRAFT ACCIDENTS

The aircraft accident data that have been obtained and used in this study were obtained from a number of different agencies. We have managed to obtain pertinent data for the estimation of the probability of an aircraft deviating from its flight path. These data are presented in the following sections. However, data on maintenance errors have been difficult to obtain. For the lack of information only the findings on maintenance errors are presented.

In order to assess the type of data that exist with the various agencies the following sources were contacted.

2.1 DATA SOURCES

1) National Transportation Safety Board (NTSB)
2) International Civil Aviation Organization (ICAO)
3) Federal Aviation Administration (FAA)
4) Airline Pilots Association (ALPA)
5) BOEING
6) MCDONNELL DOUGLAS
7) National Aeronautics & Space Agency (NASA)
8) Crew System Ergonomics Information Analysis Center (CSERIAC)
9) Air Owners & Pilots Association (AOPA)

2.2 DATA COLLECTED

The data that have been collected are as follows:

1) FAA's study on the location of Commercial Aircraft Accidents/ Incidents relative to the runways.

2) Air Line Pilots Association's (ALPA) compilation of accidents /incidents involving runway overruns, undershoots, veeroffs.

3) CSERIAC preliminary bibliographic search on maintenance errors.

4) BOEING's statistical summary of Commercial Jet Aircraft Accidents.

5) McDonnell Douglas Commercial Jet Transport Safety Statistics.

6) FAA's Selected Statistics concerning pilot-reported pilot deviations (1986-1988).

7) NTSB's Annual Review of Aircraft Accident Data 1985-1987.

8) International Civil Aviation Organization's (ICAO) Collision Risk Model.

9) National Aeronautics & Space Agency (NASA) Aviation Safety Reporting System (ASRS).

10) FAA's Accident Incident Data System (AIDS)

Of these reports and summaries that have been collected the most pertinent data in the estimation of the probability of an aircraft deviating from its flight path are the FAA study on impact locations, ALPA's compilation of accidents/incidents involving runway overruns, undershoots, veeroffs, and the accident data published by the NTSB.

The BOEING and McDonnell Douglas reports provide numbers for accidents that are attributed to maintenance/ground crew. These statistical data are for the period 1959-1990. A brief description of all the above mentioned reports is provided in Appendix B.

2.3 DESCRIPTION OF PERTINENT DATA USED IN THE ANALYSIS

2.3.1 NTSB accident Data

The National Transportation Safety Board reports the total number of aircraft accidents under two major categories: a) U.S. Carrier operations and b) U.S. General Aviation.

These reports present a statistical compilation and review of air carrier accidents that occurred during the period 1985-1987. Accident data upon which these reports are based on are obtained from the Safety Board's automated Aviation Accident System. The accidents reported are all those involving U.S. registered aircraft conducting operations under Title 14 of the Code of Federal Regulations (CFR) Parts 121, 125, 127 and 135.

Part 121 applies to large commercial air carriers such as major airlines and cargo haulers. Part 125 covers the operation of large, privately owned aircraft not held for hire. Part 127 regulates the operations of helicopters used as scheduled air carriers and Part 135 applies to commercial air carriers commonly referred to as commuter airlines and air taxis.

The reports are divided into three sections: 14 CFR 121, 125, 127 Operations; Scheduled 14 CFR 135 Operations; and Nonscheduled 14 CFR 135 Operations. Each section gives an overview of accidents and their consequences for the corresponding year and for the 4 preceding years. Tables summarizing accidents, fatal accidents,

Table 2-1
NTSB Accident Rates

Table 2 - ACCIDENT RATES
14 CFR 121, 125, 127 OPERATIONS

	1983	1984	1985	1986	1987
Aircraft Miles Flown (Thousands)	3,069,318	3,428,063	3,631,017	4,053,726	4,334,532
Aircraft Hours Flown	7,298,799	8,165,124	8,709,894	9,918,189	10,534,200
Departures Flown	5,444,374	5,898,852	6,306,759	7,247,400	7,503,968
Accident Rates *					
Per Million Miles Flown	0.0078	0.0050	0.0061	0.0057	0.0081
Per Hundred Thousand Hours Flown	0.329	0.208	0.253	0.232	0.332
Per Hundred Thousand Departures Flown	0.441	0.288	0.349	0.317	0.466
Fatal Accident Rates *					
Per Million Miles Flown	0.0013	0.0003	0.0019	0.0005	0.0009
Per Hundred Thousand Hours Flown	0.055	0.012	0.080	0.020	0.038
Per Hundred Thousand Departures Flown	0.073	0.017	0.111	0.028	0.053

* The 12/7/87 suicide/sabotage involving a PSA BAe-146 and the 4/2/86 sabotage of a TWA B727-200 are excluded from accident rate computations.

Table 21 - ACCIDENT RATES
SCHEDULED 14 CFR 135 OPERATIONS

	1983	1984	1985	1986	1987
Aircraft Miles Flown (Thousands)	253,572	291,460	300,817	308,147	388,350
Aircraft Hours Flown	1,510,908	1,745,762	1,737,106	1,723,034	2,159,199
Departures Flown	2,328,430	2,676,590	2,561,463	2,707,593	3,149,778
Accident Rates					
Per Million Miles Flown	0.0670	0.0755	0.0698	0.0487	0.0824
Per Hundred Thousand Hours Flown	1.125	1.260	1.209	0.871	1.482
Per Hundred Thousand Departures Flown	0.730	0.822	0.820	0.554	1.016
Fatal Accident Rates					
Per Million Miles Flown	0.0079	0.0240	0.0232	0.0062	0.0257
Per Hundred Thousand Hours Flown	0.132	0.401	0.403	0.116	0.463
Per Hundred Thousand Departures Flown	0.086	0.262	0.273	0.074	0.317

Table 40 - ACCIDENT RATES
NONSCHEDULED 14 CFR 135 OPERATIONS

	1983	1984	1985	1986	1987
Aircraft Hours Flown	2,574,883	3,079,007	2,782,696	2,913,358	2,877,002
Accident Rates *					
All Accidents	5.48	4.74	5.46	3.98	3.41
Fatal Accidents	1.05	0.75	1.26	1.06	1.04

*Per Hundred Thousand Hours Flown

Source: NTSB (1987)

fatalities and rates have been provided. Table 2-1 shows the accident rates as broken down by the various CFR's.

Similarly, the reports on General Aviation deal with U.S registered general aviation aircraft not conducting operations under 14 CFR 121, 125, 127 or 14 CFR 135. These reports are divided into five sections. The first section presents a wide range of information on all general aviation accidents, including historical comparison data for similar types of aircraft, and aircraft being operated for particular purposes. The four remaining sections contain information on fatal accidents, serious injury accidents, property damage accidents and mid-air collisions.

2.3.2 Description of the FAA study on undershoot/overruns/veeroffs

The FAA study on undershoot/overruns/veeroffs (Ref: David, Robert) conducted by the FAA's Office of Safety Oversight provides information on the location of aircraft accidents/incidents in the airport vicinity relative to runways. It is based on a review of 500 individual NTSB accident dockets. This study defines accident/incidents as follows:

a) Undershoot: During landing the aircraft touches down prior to the runway, usually due to the loss, lack, or misinterpretation of visual cues. For the purposes of the study, an undershoot is a touchdown in the approach area within 2000 ft of the runway threshold.

b) Landing off: During landing, any part of the aircraft's landing gear touches down off the runway after the aircraft has passed the runway threshold.

c) Veeroff: During landing rollout or takeoff roll, the aircraft runs off the runway.

d) Overrun: During landing rollout or takeoff roll, the aircraft runs off the end of the runway. Aircraft that runs off the side of the runway but comes to rest beyond the departure end of the runway have also been included in this category.

e) Other: During landing, the aircraft impacts the ground more than 2000 ft from the runway threshold. During takeoff, the aircraft becomes airborne, but then impacts the ground prior to making the first airborne power or reaching Visual Flight Rules (VFR) pattern altitude.

The Air line Pilots Association has done a similar study based on world-wide accidents and incidents wherein the X & Y coordinates of the location of the aircraft are pinpointed with reference to the threshold/departure end and the runway centerline respectively.

However, for some of the occurrences the impact location data reported are incomplete.

The FAA study on impact locations can be utilized in defining the probability distribution curve that will be govern the probability of an aircraft crashing within the vicinity of an airport relative to the runway.

2.3.3 Boeing & McDonnell Douglas reports

The reports obtained from Boeing and McDonnell Douglas provide accident data for all accidents that have occured between 1958-1959. These reports provide the percentage of time that an aircraft spends during the different phases of operation such as taxing, intial climb, cruising and landing and the percentage of accidents that have occured during these phases.

Figure 2-1 (Boeing report) & Figure 2-2 (McDonnell Douglas report) show that for an average flight time of 1.6 hours, the percentage of aircraft accidents that occur during the taxing, take-off, final approach and landing phases is more than 65%. The percentage of accidents occurring in the final approach and landing phases amounts to nearly half of the total accidents.

Clearly, the critical stages of operation are the landing and takeoff phases since an aircraft spends very little time in the these phases but the number of accidents that occur in these phases is quite large.

Based on the data the shape of the bell curve during the take-off phase will be flatter than that for the landing phase. This evidence is used in defining the bimodal shape of the probability distribution that is utilized in the mathematical analysis presented in Chapter 3.

2.4 DATA ANALYSIS

In order to establish the aircraft accident rate we have looked at the data collected from NTSB and the FAA. The NTSB provides the total number of accidents for two categories a) Commercial Air Carriers (Title 14 CFR 121, 125 & 127) and b) General Aviation.

The total number of aircraft accidents utilized for the accident rates for Commercial Air Carriers have been taken from the data provided for the period 1984-1988 (Ref: NTSB 1987). Similarly, the total number of accidents in the General Aviation category are for the period 1986-1988 (Ref: NTSB 1988).

Although, the aircraft accident rates for Commercial Air Carriers have been provided in terms of total number of departures flown,

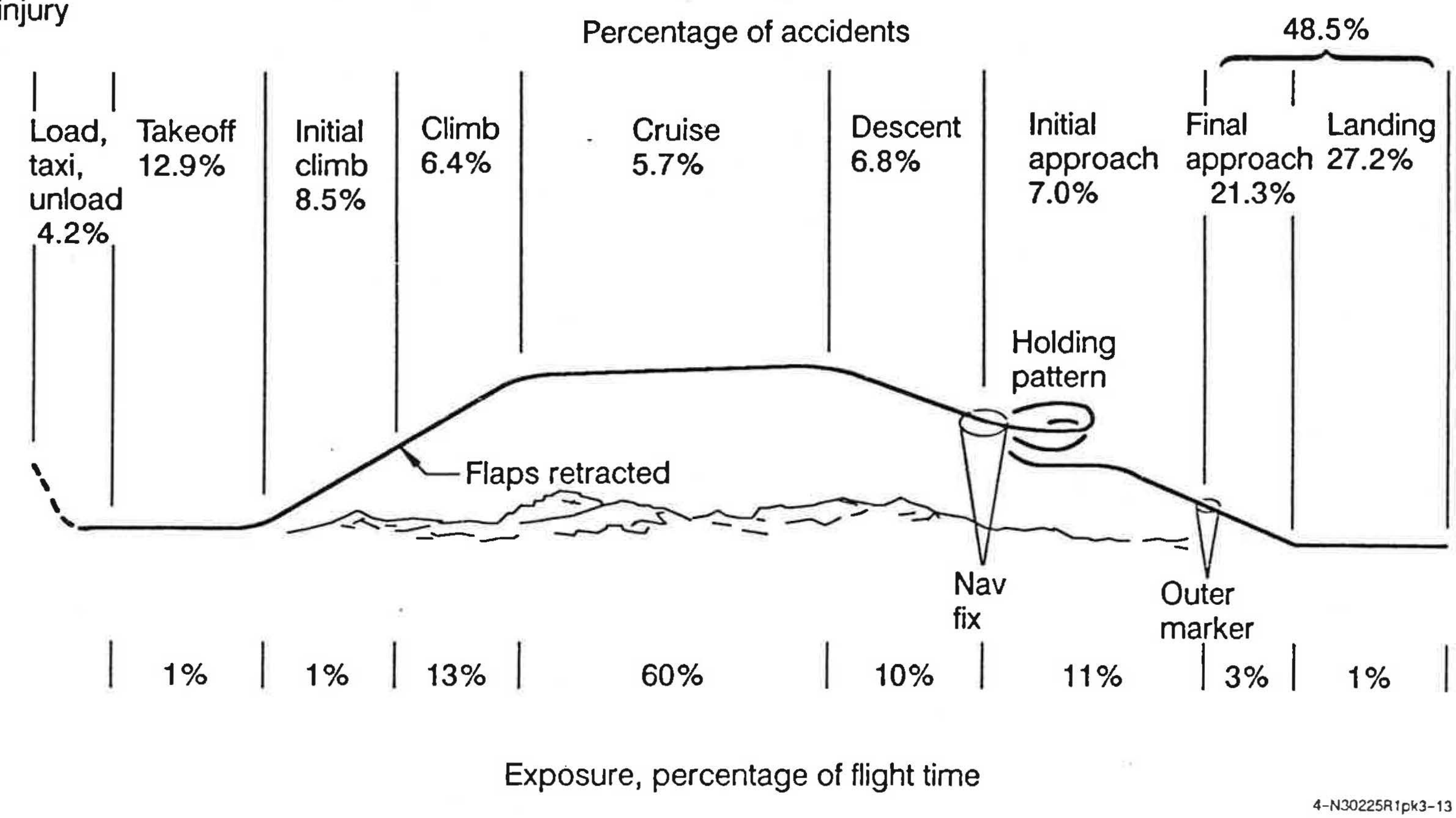
Figure 2-1
Boeing's report on exposure of an aircraft
as a percentage of flight time

All Accidents*

Worldwide Commercial Jet Fleet – 1959-1990

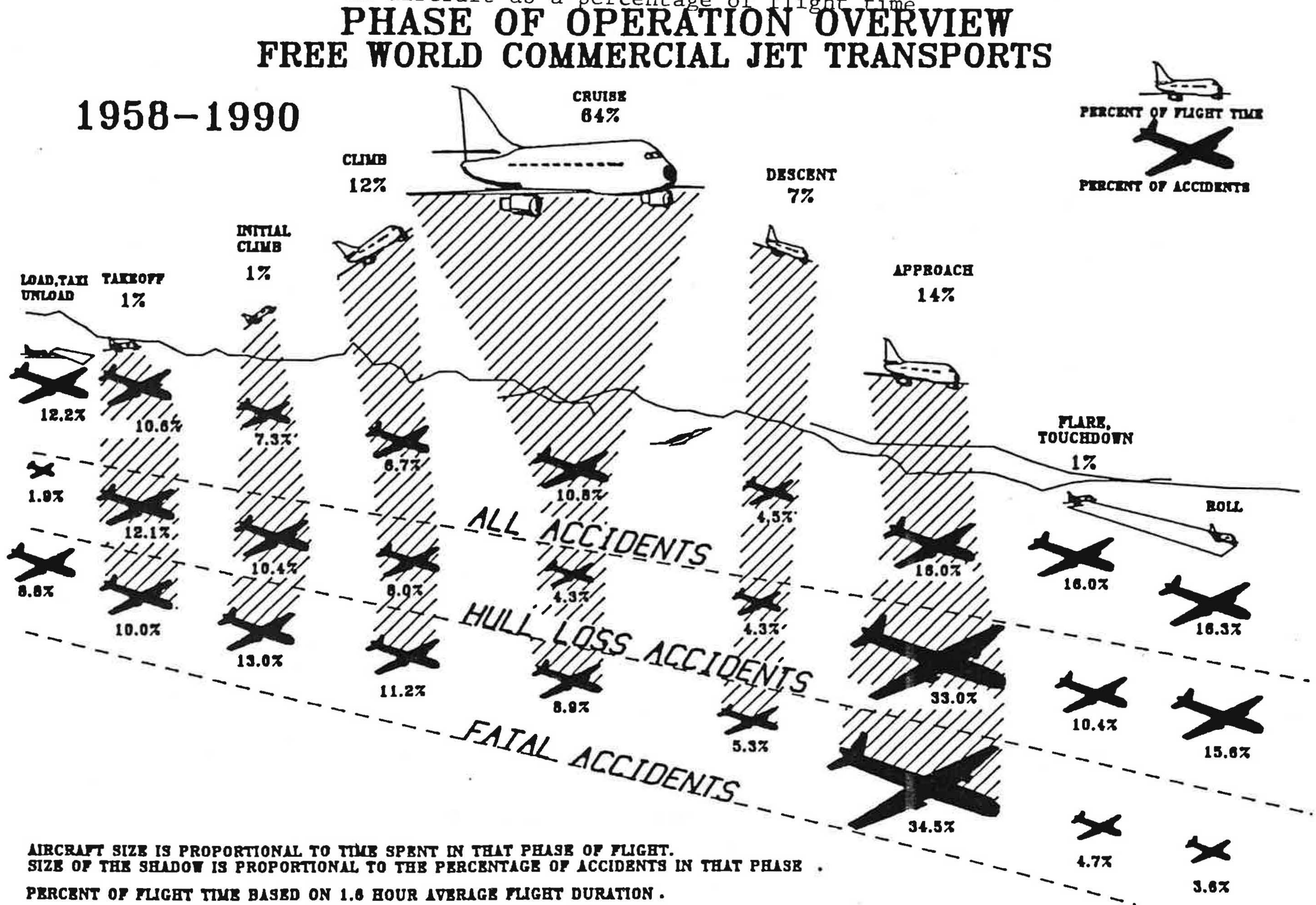
Exposure percentage based on an average flight duration of 1.6 hours

*Excludes
- Sabotage
- Military action
- Turbulence injury
- Evacuation injury



Source: Boeing Product Safety OF
Group (B-210B)

Figure 2-2
McDonnell Douglas's report on exposure of an aircraft as a percentage of flight time



Source: Douglas Aircraft

the aircraft accident rates for the General Aviation category are in terms of total number of hours flown.

In order to calculate the weighted average accident rate between the rates for Commercial Air Carriers and General Aviation we need to compute General Aviation accident rates in terms of total number of departures.

The total number of departures for General Aviation are published by the FAA's Office of Management Systems, Standards & Statistics in the FAA Air Traffic Activity FY 1990 (Ref: Trembley, Nancy) as shown in Table 2-2.

Note that in calculating the General Aviation aircraft accident rate, the total number of aircraft accidents have been taken from the numbers provided by NTSB. However, the total number of departures that have taken place for General Aviation are based on Air Traffic Activity at FAA airport traffic control towers.

The accident rates for Commercial Air Carriers and General Aviation are indicated in Tables 2-3a & 2-3b. It is seen that the average crash rate for Air Carriers is 3.55 per million departures and that for General Aviation is 65.7 per million departures. These rates are national averages. However, we assume that the same rates hold good for Orlando International Airport also. Based on this assumption we calculate the overall accident rate for this airport which includes the air carrier and general aviation operations.

The FAA Air Traffic Activity for the FY 1990 also provides the number of operations both for General Aviation and Air Carrier categories that have taken place at the Orlando International Airport as follows:

1) # of operations for Commercial Air Carriers = 190,996/year (Ref: Trembley, Nancy FAA 1990)

2) # of operations for General Aviation = 245,348/year (Ref: Trembley, Nancy FAA 1990)

3) Expected value for crashes - Commercial Air carriers = 0.68 crashes/yr

4) Expected value for crashes - General Aviation = 16.12 crashes/yr

5) Weighted average accident rate = 38.5 accidents per million departures

The average accident rate that has been used in the final analysis is 38.5 per million departures. This is the weighted average of the accident rates for U.S. carriers and those calculated for

Table 2-2
Air Traffic Activity at FAA control towers

TABLE IB--AIR TRAFFIC ACTIVITY AT FAA AIRPORT TRAFFIC CONTROL TOWERS, BY AVIATION CATEGORY--FISCAL YEARS 1986-1990

Year	Total		Air Carrier		Air Taxi		General Aviation		Military	
	Total	Annual Change	Total	Annual Change	Total	Annual Change	Total	Annual Change	Total	Annual Change
Total Airport Operations										
1990	63,668,880	+4	12,858,718	+3	8,837,671	+7	39,169,795	+4	2,802,696	+1
1989	61,345,173	+*	12,519,891	-2	8,296,725	+1	37,753,005	+1	2,775,552	-*
1988	61,299,017	+1	12,752,997	-2	8,255,279	+12	37,503,249	-1	2,787,492	+2
1987	60,976,559	+3	13,062,061	+6	7,347,057	+6	37,830,524	+2	2,736,917	+4
1986	58,956,464	+2	12,300,371	+9	6,915,478	-*	37,100,657	-*	2,639,958	+4
Itinerant Operations										
1990	45,609,732	+3	12,858,718	+3	8,837,671	+7	22,479,781	+2	1,433,562	+1
1989	44,307,914	-*	12,519,891	-2	8,296,725	+1	22,078,592	-*	1,412,706	-*
1988	44,521,425	+1	12,752,997	-2	8,255,279	+12	22,096,026	+*	1,417,123	+3
1987	43,869,898	+3	13,062,061	+6	7,347,057	+6	22,078,782	+1	1,381,998	+2
1986	42,515,777	+2	12,300,371	+9	6,915,478	-*	21,942,188	-2	1,357,740	+5
Local Operations										
1990	18,059,148	+6	0	0	0	0	16,690,014	+6	1,369,134	-*
1989	17,037,259	+2	0	0	0	0	15,674,413	+2	1,362,846	+*
1988	16,777,592	-2	0	0	0	0	15,407,223	-2	1,370,369	+1
1987	17,106,661	+4	0	0	0	0	15,751,742	+4	1,354,919	+6
1986	16,440,687	+2	0	0	0	0	15,158,469	+2	1,282,218	+2

* Less than 0.5 percent.

Table 2-3 a

Summary of Aircraft Accident Data - General Aviation

Year	Type of Operation	Number of Operations	Number of Accidents	Accident Rate per million departures
1986	General Aviation	37,100,657	2578	69.4
1987	General Aviation	37,830,524	2459	65.0
1988	General Aviation	37,503,249	2354	62.7

AVERAGE = 65.7

Table 2-3 b

Summary of Aircraft Accident Data - Air Carrier operations

Year	Type of operation	Number of operations	Number of Accidents	Accident Rate per million departures
1984	14 CFR 121, 125, 127	5,898,852	17	2.80
1985	14 CFR 121, 125, 127	6,306,759	22	3.49
1986	14 CFR 121, 125, 127	7,226,306	24	3.18
1987	14 CFR 121, 125, 127	7,558,235	36	4.63
1988	14 CFR 121, 125, 127	7,622,365	29	3.67

AVERAGE = 3.55

Sources of Data: NTSB (1988) & Trembley, Nancy (1990)

General Aviation. Note that the expected value for crashes (Air Carrier Operations) at the Orlando International airport is 0.68 crashes per year. This is in line with the evidence that during the period 1986-1988, two crashes took place at the Orlando international Airport under Commercial Air Carrier operations.

Using national statistics for General Aviation and extrapolating to Orlando international airport, we predict that the expected value of crashes at Orlando is 16.12 crashes per year. However, for the lack of details we have not been able to verify this number for General Aviation.

For the purposes of this study it is sufficient to note that the average accident rate for Commercial Air Carriers during the period 1984-1988 is approximately three accidents per million departures. Note this number is in the same regime as the statistic (3 to 5 accidents per million departures) provided by Boeing's statistical summary for Commercial Jet Aircraft for the period 1959-1990 as shown in Figure 2-3. This is the approximate probability of an accident taking place at any time.

The FAA study provides scatter diagrams which show the locations of impact relative to the runway. Based on these scatter diagrams we define an "impact location domain" as the area near the runway where at least 90% of crashes occur.

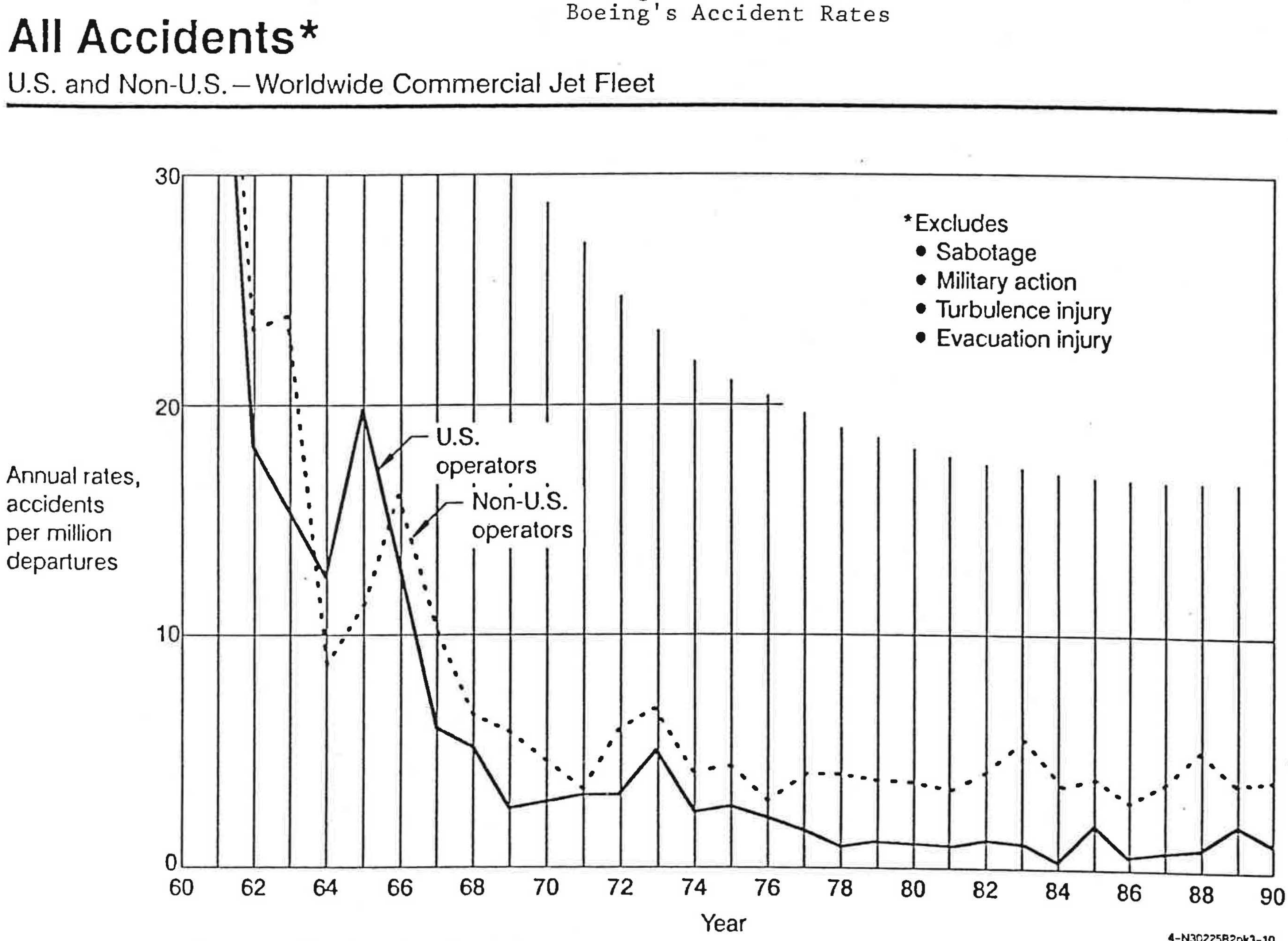
In the FAA study there were a total of 18 undershoot, 11 landing offs, 97 veeroffs, 33 overruns, and 87 other accident /incidents during the period 1978-1987. Figure 2-4a is a scatter diagram which shows overrun locations with respect to the departure end and the extended centerline of the runway. Similarly, a scatter diagram for undershoots relative to the threshold of the runway has been provided (Figure 2-4b). As seen from the scatter diagram Figure 2-4a, the impact location domain for overruns is 1800 ft by 700 ft.

Out of a total number of 33 overruns that have taken place within the period 1978-1987, all the aircraft involved came to a rest within 1600 ft of the runway end, with 93% of them stopping within 1000 ft. Similarly, using the distribution of the Y distance it is noted that 95% of the aircraft involved in these overruns came to a stop within 250 feet of the extended centerline. Similar information are provided for veeroffs, landing offs and other accidents/incidents.

Based on this evidence the probability of an accident taking place beyond a rectangular impact location area [(1500 ft + runway length + 1500 ft) * 700 ft)] can be expected to be very low.

The application of the results developed in this chapter to evaluating the annual probability of impact on a Maglev Guideway

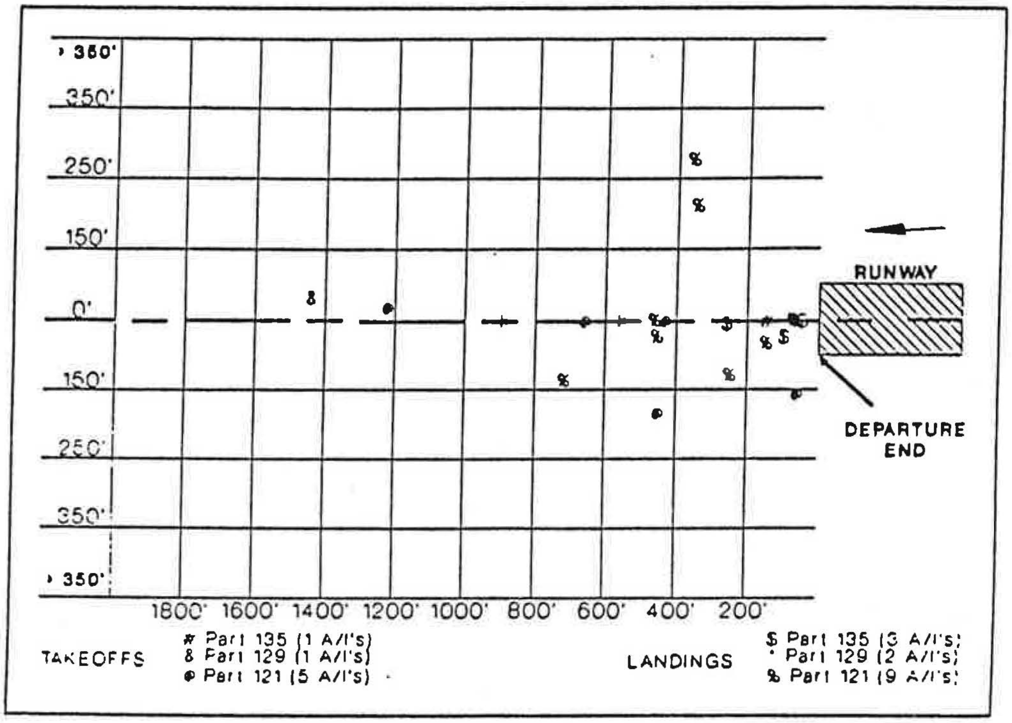
Figure 2-3
Boeing's Accident Rates



Source: Boeing Product Safety Organization

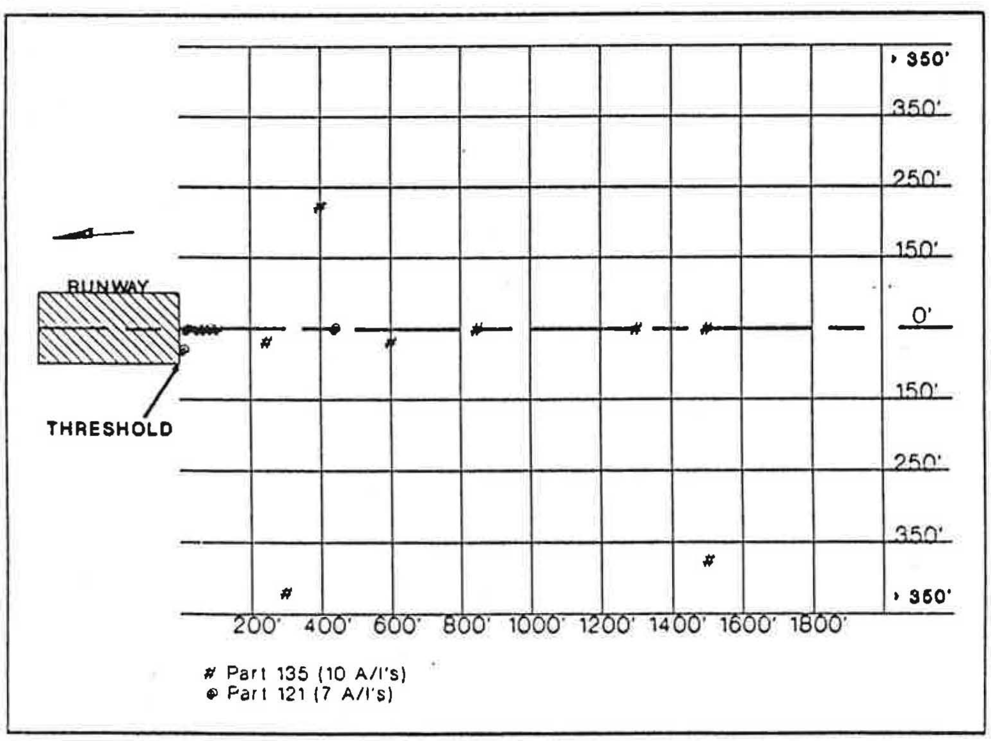
BOEING's accident rates

Figure 2-4a
Scatter diagram for Overruns



Overrun Locations

Figure 2-4b
Scatter digram for Undershoots



Undershoot Locations

Source: David, Robert

system located in the vicinity of an airport is discussed in detail in Chapter 3.

2.5 FINDINGS

2.5.1 Findings on the probability estimate of an aircraft deviating and crashing into the Maglev guideway.

1) The aircraft average accident rate for 14 CFR 121, 125, 127 for the period 1984-1988 is **3.554** accidents per million departures.

2) The average accident rate for the General Aviation category between the period 1986-1988 is **65.7** accidents per million departures.

3) The weighted average accident rate based on national statistics is **38.5** accidents per million departures.

4) The expected number of crashes at the Orlando International Airport for 14 CFR 121, 125, 127 is **0.68** crashes per year.

5) The expected number of crashes at the Orlando International Airport for the General Aviation category is **16.12** crashes per year.

2.5.2 Findings on Maintenance error levels

Due to the similarities between the Maglev system and aircraft operations, the quantification of human factor error levels occuring due to maintenace/ground crew in aircraft operations can be extrapolated to understand the potential safety impacts that may occur with maintenance personnel servicing the Maglev system.

In order to obtain this data several agencies were contacted as listed in section 2.1. The McDonnell Douglas and Boeing reports provide statistics on accidents attributed to maintenance/ground crew. These data are generally considered as "soft data". Further definition of what types of maintenance/ground crew errors can be considered as relavant to the Maglev system needs to be specified before further investigation can be done.

Additionally, a database search was conducted on NASA's Aviation Safety Reporting System (ASRS) to try to quantify the number of accidents occuring due to errors in maintenance. Again, the difficulty in relying on the figures supplied by NASA is that the database consists of voluntary reports and is restricted only to incidents rather than accidents. Based on these three sources, the findings on human factor errors are as follows:

1) **Based on the McDonnell Douglas report 4.05% accidents were caused by maintenance/ground crew personnel for commercial jet transport.**

   The Accident Source Personnel for free world commercial jet transport (Figure 2-5) shows the breakdown of accidents. A total of 1429 accidents took place between 1958-1990. Of these accidents, 51 are attributed to ground crew whereas 7 accidents occurred due to maintenance crew.

2) **Boeing reports that between 1959-1990, 2.8% of all aircraft accidents were attributed to the primary cause maintenance. In the last ten years 1981-1990 this maintenance figure as a primary cause increased to 3.4%.**

   Figure 2-6 shows the fraction of accidents attributable to maintenance/ground crew personnel for the Worldwide Commercial Jet Fleet.

3) **Based on the search conducted at NASA's ASRS database maintenance related incidents for the period 01/01/86-06/01/91 were in the regime of 0.7% to 1.58%.**

   Table 2-4 shows the fraction of incidents attributable to maintenance/ground crew errors.

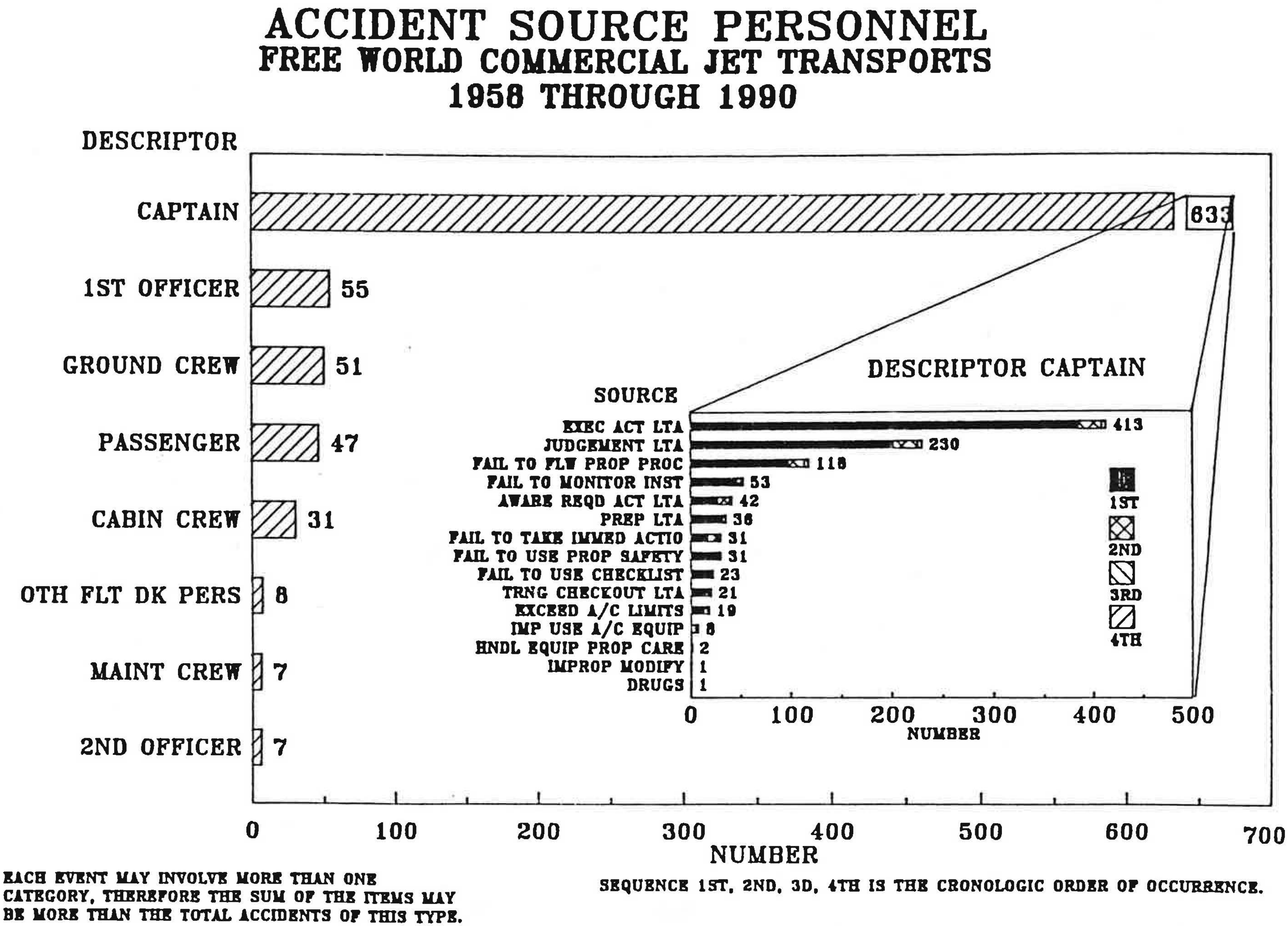
Other sources such as the FAA and the NTSB were contacted for information on maintenance error levels. The NTSB database contains some figures on improper maintenance and these figures would have to be requested. At the time of writing this report information from FAA's AIDS database was still awaited.

2.6 LIMITATIONS OF THE DATA

The total number of operations used in the above analysis is restricted to U.S. Carriers. Although the FAA Office of Management Systems, Management Standards & Statistics provides counts of air carrier Part 121, 135, towered general aviation and military operations, data on number of operations involving single engine small aircraft at small airports are not recorded. According to the census carried out by the Civil Aviation Patrol it is generally assumed that non-towered operations are in the same proportion as towered operations. However, this does not conclusively include small aircraft operations that are not documented.

A major limitation is the lack of information collected on exact impact locations of aircraft crashes on a world-wide basis. Although, the ALPA report provides a comprehensive listing of

Maintenance error levels provided by McDonnell Douglas



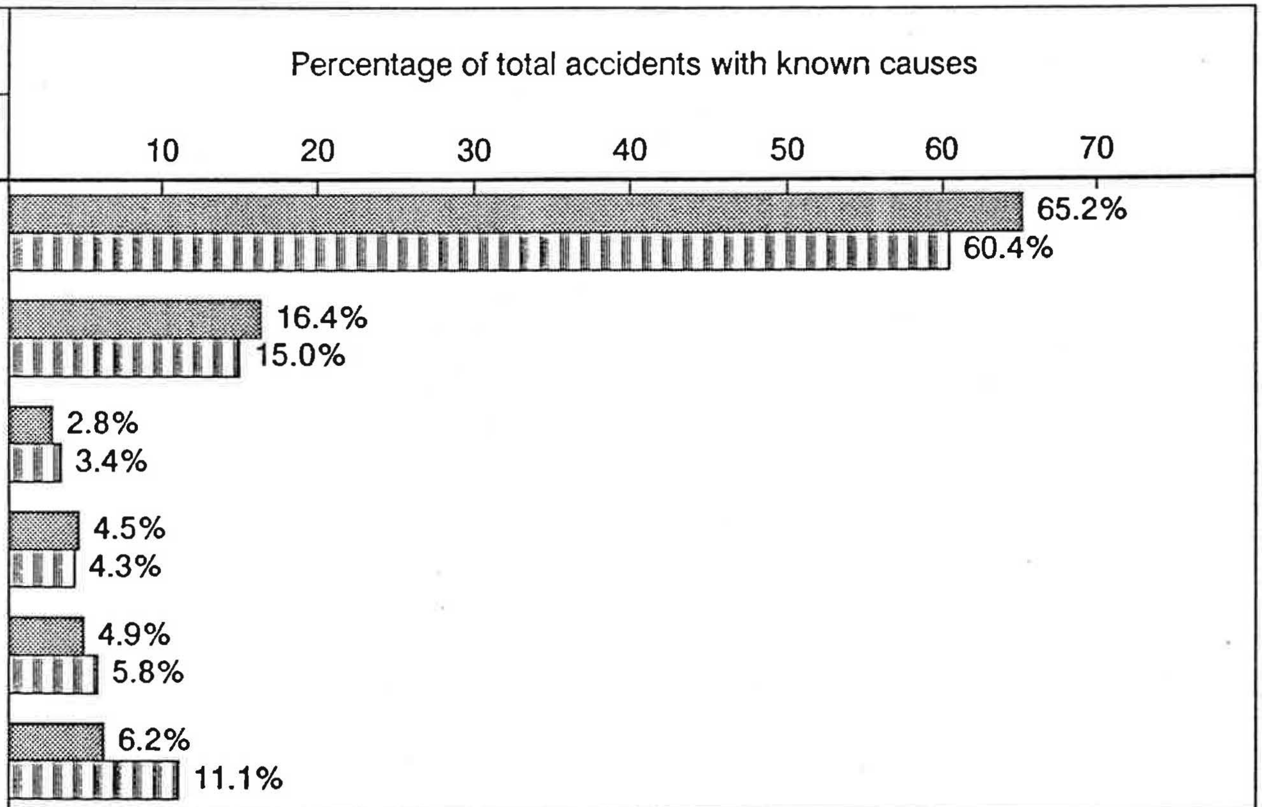
Source: Douglas Aircraft

Figure 2-6
Maintenance error levels as provided by Boeing

Primary Cause Factors – All Accidents*

Worldwide Commercial Jet Fleet

Primary factor	Number of accidents	
	Total	Last 10 years
Flightcrew	493	125
Airplane**	124	31
Maintenance	21	7
Weather	34	9
Airport/ATC	37	12
Miscellaneous (other)	47	23
Total with known causes	756	207
Unknown or awaiting reports	117	70
Total	873	277



* Excludes
- Sabotage
- Military action
- Turbulence injury
- Evacuation injury

** Includes
- Airframe
- Aircraft systems
- Powerplant

Legend:

- 1959-1990
- Last 10 years (1981-1990)

4-N30225R2pk3-14

Source: Boeing Product Safety Group

Table 2-4

Number of incidents involving maintenance/ground crew as extracted from NASA's ASRS database

Incident	1986	1987	1988	1989	1990	1991*
Loss of Aircraft Control in Air Traffic Area or Control Zone	3	10	22	26	29	7
Controlled Flight Toward Terrain in Air Traffic Area or Control Zone	7	14	18	38	31	16
Critical Aircraft Equipment Problems involving Ground Maintenance Personnel	35	78	90	159	225	111
Less Severe Aircraft Equipment Problems involving Ground Maintenance Personnel	18	110	108	100	153	62
Total Number of Database Incidents	8990	13610	16371	24939	27718	13226

Source.: NASA's ASRS database

accidents, most accidents occurring in other countries do not report distances from a given reference point.

The Boeing and McDonnell reports are restricted to commercial jet and turboprop aircraft over a critical weight of 66,000 pounds.

The analysis does not take into account specific parameters such as different airport configurations, flight patters, approach patterns, diverse departures routes, climb gradients, etc,.

Data on maintenance error levels are not specifically maintained by most of the sources that were contacted. It may be possible that the operations and maintenance divisions of major commercial air carriers maintain some records. In any case these records are considered sensitive and inaccessible at this point.

2.7 ICAO's COLLISION RISK MODEL (CRM)

The ICAO has developed a Collision Risk Model for Instrument Landing System (ILS) approaches and missed approaches. This model measures in simple terms the effect of obstacles in the approach, missed approach, and the transitional areas of ILS procedures. The data used in this model are based on over 2000 Instrument Flight Rules (IFR) approaches made by aircraft under Instrument Meteorological Conditions (IMC) recorded in the U.S., U.K., Germany and the Netherlands.

The Collision Risk Model calculates a numerical risk for the precision segment of an ILS approach. The risk is calculated for that portion of the approach after the aircraft is established on the final approach course from the precision final approach fix (PFAF) until the aircraft reaches the decision height (DH), and for the straight portion of the missed approach. Figure 2-7 shows the segments of an ILS approach procedure. The Initial Approach Fix (IAF) is usually in excess of 5 nautical miles from the PFAF.

In making an ILS approach to a runway, an aeroplane descends on a glide path towards the runway threshold. If the aeroplane is not correctly aligned or if visual reference is not available at a prespecified point then the pilot has to initiate a missed approach. Figure 2-8 shows the side view of an ILS approach and a missed approach.

The necessary airspace for an approach/landing by a correctly aligned aeroplane is normally free of obstacles. Usually the obstacles under consideration are either laterally off the path or vertically beneath the path or both. These obstacles present a risk to aeroplane that deviate substantially from the intended path. The risk presented by an obstacle depends on two factors, the location of the obstacle relative to the nominal path of the

]Figure 2.7: Segments of an approach procedure

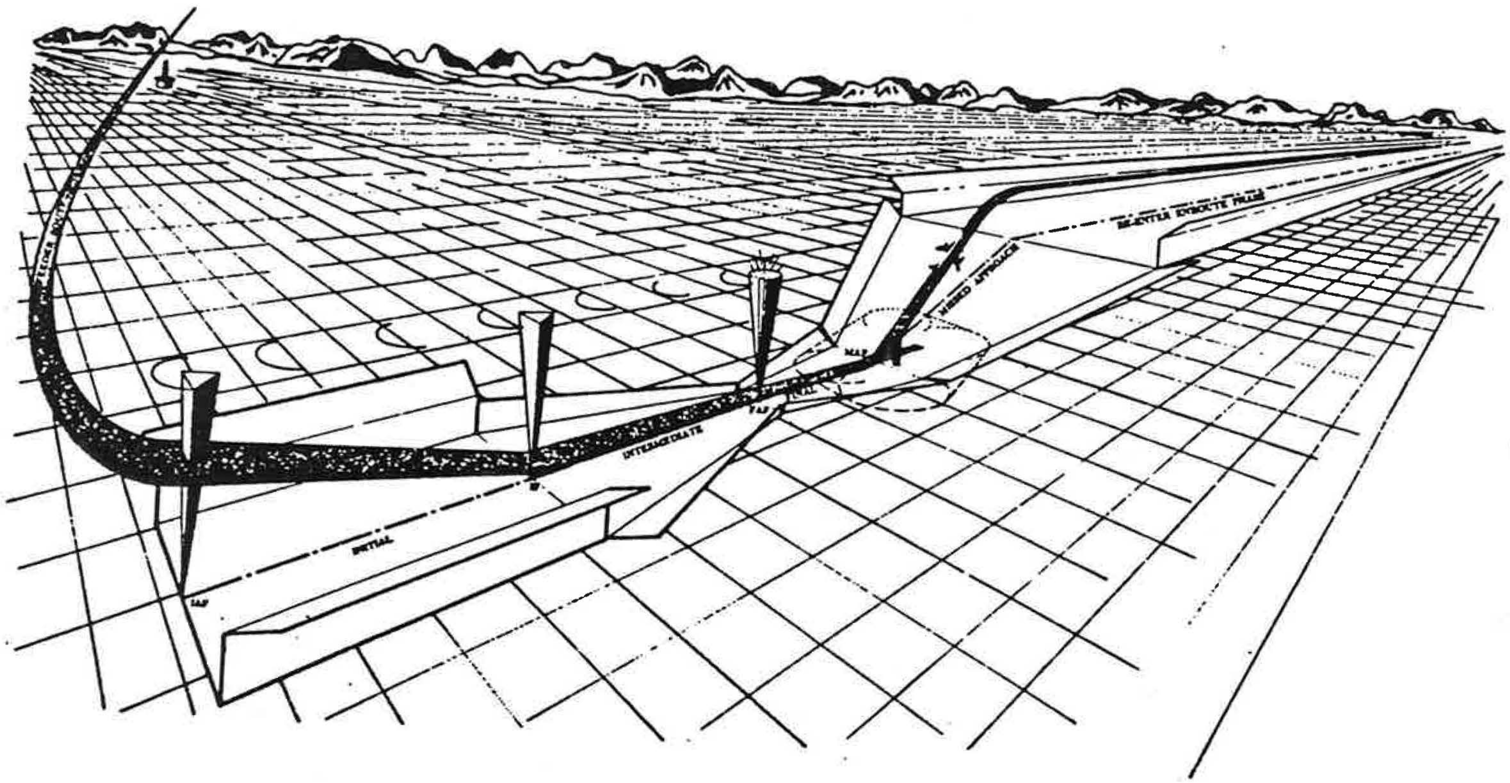


Fig 2-7 SEGMENTS OF AN APPROACH PROCEDURE. Par 214.

Source: ICAO

Figure 2-8
Sideview of an ILS & missed approach

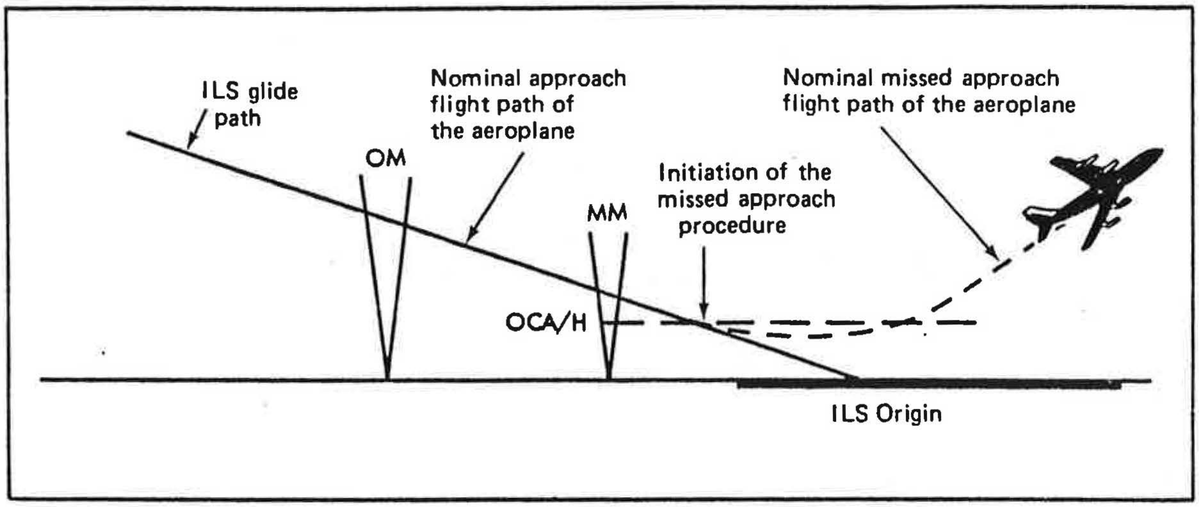
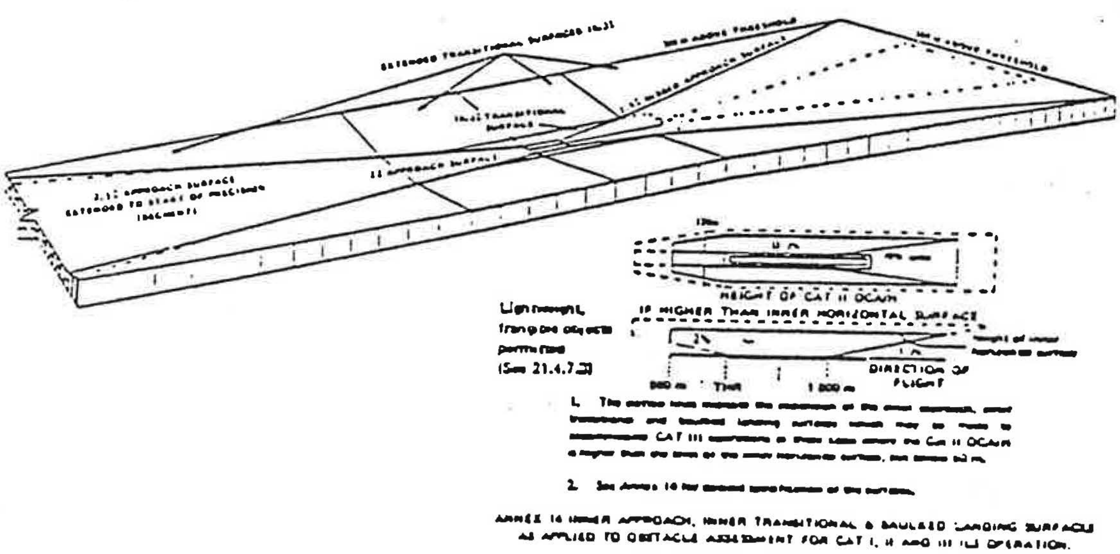


Figure 2-9
ILS imaginary surfaces



Source: ICAO

aeroplane and the extent to which aeroplane are likely to spread about the nominal path.

The CRM is a computer program that contains information describing the spread of aeroplane about the nominal path when it is in the glide slope or when it executes a missed approach. The program uses this information to evaluate a risk or collision probability for individual obstacles of known location and size. These individual risks are then accumulated to produce a total risk associated with the complete set of obstacles considered. The final value, representing a risk or probability of collision per approach, can then be compared with a target level of safety to determine whether the degree of risk associated with the particular operation is acceptable.

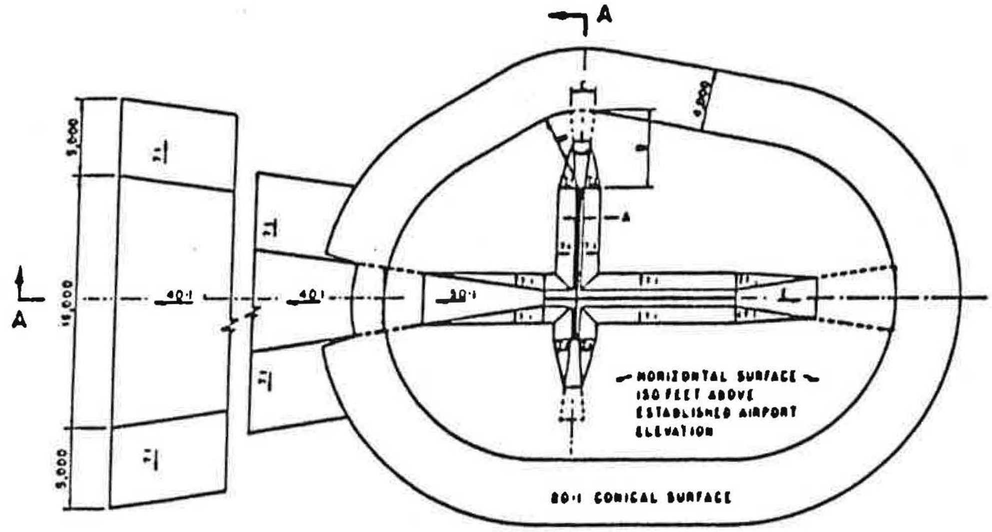
The model uses Obstruction data sheets as specified by the Federal Aviation Regulations (FAR-77), "Objects Affecting Navigable Airspace" and FAA "Specifications Obstruction Chart and related Products" developed by the photogrammatic branch of the National Ocean Service. Figure 2-9 shows the ILS imaginary surfaces and Figure 2-10 shows Civil Airport imaginary surfaces which when penetrated call for the collision risk model to be run so as to assess a numerical risk for the obstacles individually, as well as cumulatively.

The process of running the Collision Risk Model (CRM) involves filling out the appropriate Obstruction Data Sheets. The Obstruction Data Sheets (ODS) and the map of the Orlando International Airport have been obtained. The CRM requires position and dimension data for all relevant obstacles. The data can be entered in the coordinate system (x_k, y_k, z_k) as shown in Figure 2-11. Obstacles must be in a specific form; namely they are either "spike" obstacles defined by the coordinates (x_k, y_k, z_k) or "wall" obstacles defined by the coordinates (x_k, y_{k1}, y_{k2}, z_k) as shown in Figure 2-12. Each of these obstacles is defined by its range from the runway threshold (x value), the lateral distances from its sides to the extended runway center line (one or two y values), and its height above the runway threshold elevation (z value).

Figure 2-13 shows how a railroad would be modelled so as to feed the input values into the CRM. The standard height for a train is assumed to be 17 ft on a 5 ft bed. Table 2-5 shows a sample printout of the result of the CRM model. The last column in the table are the values for the obstacle probabilities.

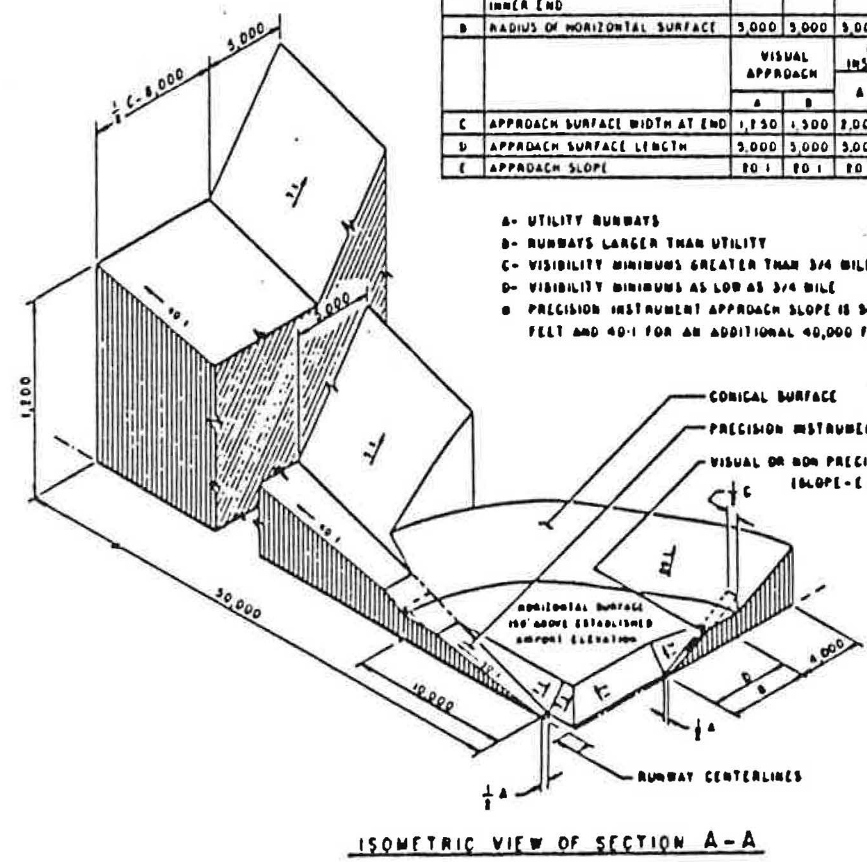
Given that all the obstacles at the Orlando International are determined it would approximately a week to prepare the data sheets per routing of the Maglev system. This is also dependant on the number of approach procedures that may be affected by the routing of the Maglev guideway. It is estimated that at least 30 data points would have to be input into the model. A request would have

Figure 2-10
Civil Airport imaginary surfaces



DIM	ITEM	DIMENSIONAL STANDARDS (FEET)					
		VISUAL RUNWAY		NON-PRECISION INSTRUMENT RUNWAY			PRECISION INSTRUMENT RUNWAY
		A	B	A	B		
					C	D	
A	WIDTH OF PRIMARY SURFACE AND APPROACH SURFACE WIDTH AT INNER END	250	500	500	500	1,000	1,000
B	RADIUS OF HORIZONTAL SURFACE	5,000	5,000	5,000	10,000	10,000	10,000
		VISUAL APPROACH		NON-PRECISION INSTRUMENT APPROACH			PRECISION INSTRUMENT APPROACH
		A	B	A	B		
					C	D	
C	APPROACH SURFACE WIDTH AT END	1,250	1,500	2,000	3,500	4,000	16,000
D	APPROACH SURFACE LENGTH	5,000	5,000	5,000	10,000	10,000	*
E	APPROACH SLOPE	20:1	20:1	20:1	34:1	34:1	*

A- UTILITY RUNWAYS
B- RUNWAYS LARGER THAN UTILITY
C- VISIBILITY MINIMUMS GREATER THAN 3/4 MILE
D- VISIBILITY MINIMUMS AS LOW AS 3/4 MILE
* PRECISION INSTRUMENT APPROACH SLOPE IS 50:1 FOR INNER 10,000 FEET AND 40:1 FOR AN ADDITIONAL 40,000 FEET



ISOMETRIC VIEW OF SECTION A-A

FAR-77 CIVIL AIRPORT IMAGINARY SURFACES

Source: ICAO

Figure 2-11
Co-ordinate system for the Collision Risk Model

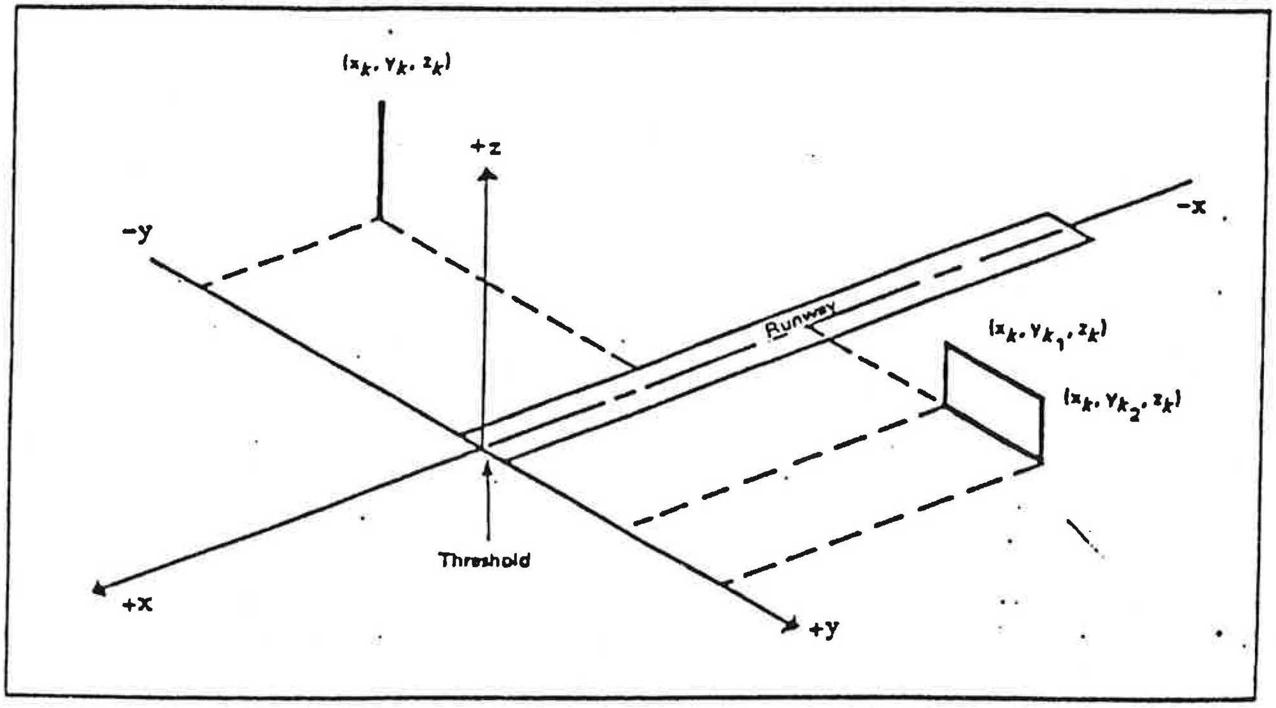
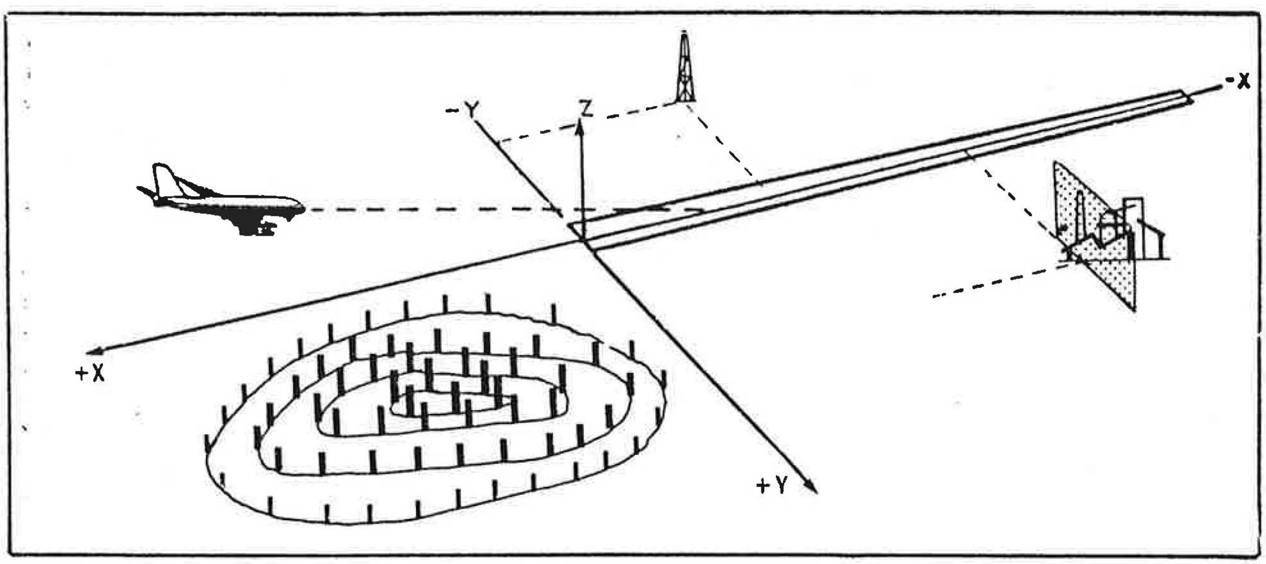


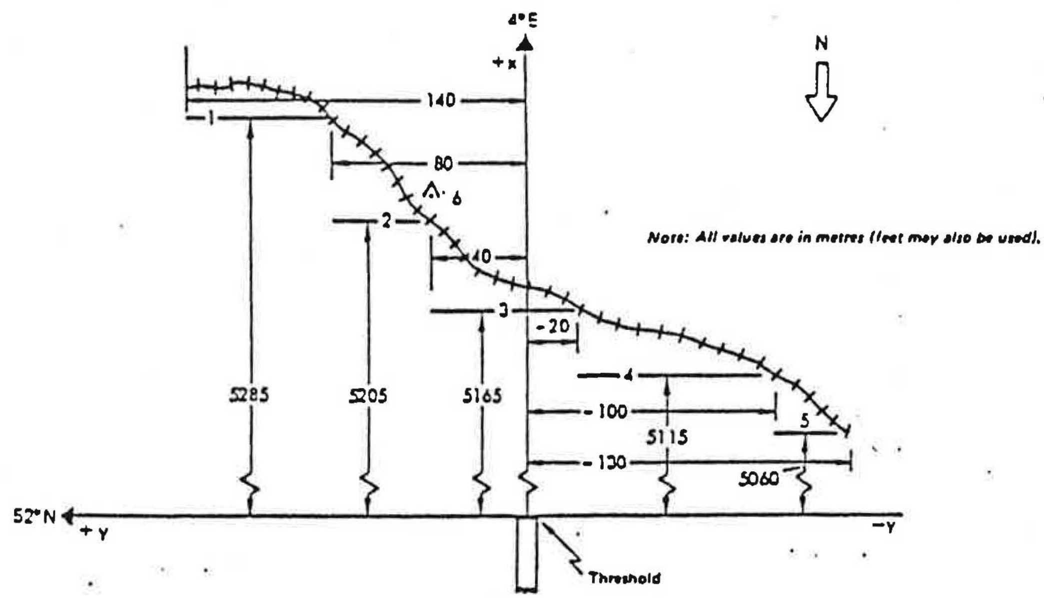
Figure 2-12
Spike" and "Wall" obstacles as required by the Collision Risk Model



Source ICAO

Figure 2-13

Obstacle modelling of a railroad



Obs. No.	Obstacle Name	Obstacle Height* (m)	Runway Co-ordinate System			Geographical Co-ordinate System											
						x				y1				y2			
			x (m)	y1 (m)	y2 (m)	N/S	degrees	minutes	seconds	E/W	degrees	minutes	seconds	E/W	degrees	minutes	seconds
1	Railroad	127	5285	80	140	N	51	57	08.78	E	4	00	04.21	E	4	00	07.37
2	Railroad	125	5205	40	80	N	51	57	11.37	E	4	00	02.10	E	4	00	04.21
3	Railroad	121	5165	−20	40	N	51	57	12.67	E	3	59	58.95	E	4	00	02.10
4	Railroad	125	5115	−20	−100	N	51	57	14.29	E	3	59	58.95	E	3	59	54.74
5	Railroad	120	5060	−100	−130	N	51	57	16.07	E	3	59	54.74	E	3	59	53.16
6	Tower	158	5215	40	40	N	51	57	11.05	E	4	00	02.10	E	4	00	04.10

* Altitude may also be used. If the obstacle is a road or railroad interval, use the maximum height (or altitude) in the interval with an allowance for traffic on the road or railroad.

Figure I-A-5. A Method of Partitioning a Continuous Obstacle (Railroad)

Source: ICAO

Table 2-5
Sample printout of the results of the CRM

ICAO COLLISION RISK MODEL/ RISK REPORTS PAGE 15

ICAO REFERENCE CRM EXAMPLE 4 DATE NOV 01, 1982
USER REFERENCE FANTASY AERODROME TIME 12:41:41

CRM MANUAL DOC 9274-AN904 PART I APP D/E ILS CATEGORY I
EXAMPLE 4

SPEED CATEGORY D MINIMUM ACCEPTABLE OCH ABOVE THRESHOLD 88 METRES

TOTAL RISK FOR THIS APPROACH 9.0E-08

THE RISK OF HITTING THE GROUND PLANE IS LESS THAN 1.0E-15.

IDENT	DESCRIPTION	X METRES	Y1 METRES	Y2 METRES	Z METRES	RISK
OBSTACLE WITH HIGHEST INDIVIDUAL RISK						
A-23	HILL A	1600.00	0.00	0.00	52.00	3.3E-08
ALL OBSTACLES						
A5-01	RAILROAD	5285.00	80.00	140.00	127.00	3.6E-11
A5-06	TOWER	5215.00	40.00	40.00	155.00	1.5E-08
A5-02	RAILROAD	5205.00	40.00	80.00	125.00	9.8E-11
A5-03	RAILROAD	5165.00	-20.00	40.00	121.00	1.2E-10
A5-04	RAILROAD	5115.00	-100.00	-20.00	125.00	2.0E-10
A5-05	RAILROAD	5060.00	-130.00	-100.00	120.00	1.1E-11
A-03	HILL A	2000.00	0.00	0.00	42.00	9.7E-15
A-04	HILL A	2000.00	200.00	200.00	60.00	2.1E-14
A-05	HILL A	2000.00	400.00	400.00	70.00	*
A-06	HILL A	2000.00	600.00	600.00	79.00	*
A-07	HILL A	2000.00	800.00	800.00	86.00	*
A-08	HILL A	2000.00	1000.00	1000.00	88.00	*
A-09	HILL A	2000.00	1200.00	1200.00	89.00	*
A-13	HILL A	1800.00	0.00	0.00	56.00	2.9E-08
A-14	HILL A	1800.00	200.00	200.00	66.00	5.6E-12
A-15	HILL A	1800.00	400.00	400.00	76.00	*
A-16	HILL A	1800.00	600.00	600.00	90.00	*
A-17	HILL A	1800.00	800.00	800.00	104.00	*
A-18	HILL A	1800.00	1000.00	1000.00	112.00	*
A-19	HILL A	1800.00	1200.00	1200.00	110.00	*
A-20	HILL A	1800.00	1400.00	1400.00	100.00	*
A-13A	HILL A	1800.00	100.00	100.00	62.00	7.0E-09
A-23	HILL A	1600.00	0.00	0.00	52.00	3.3E-08
A-24	HILL A	1600.00	200.00	200.00	57.00	1.4E-13
A-25	HILL A	1600.00	400.00	400.00	74.00	*
A-26	HILL A	1600.00	600.00	600.00	100.00	*
A-27	HILL A	1600.00	800.00	800.00	108.00	*
A-28	HILL A	1600.00	1000.00	1000.00	116.00	*
A-29	HILL A	1600.00	1200.00	1200.00	109.00	*
A-30	HILL A	1600.00	1400.00	1400.00	103.00	*

* REPRESENTS A RISK LESS THAN 1.0E-15.

Source: ICAO

to be made to the FAA operational branch in Oklahoma City to the run the CRM model. It is estimated that the turnaround time involved could be 2-3 months as an estimate. This is mainly due to the fact that the CRM model is being run currently on other major tests/projects.

CHAPTER 3

ANALYSIS OF

MAGNETIC LEVITATION VEHICLE GUIDEWAY IMPACT

FROM POTENTIAL AIRCRAFT CRASHES IN AN AIRPORT

3.1 INTRODUCTION

In the previous chapter the historical data on aircraft crashes in airports in the United States were analyzed and discussed. The principal finding from the analysis presented in the previous chapter was that the rate of air crashes is significantly higher in General Aviation operations than in Commercial Air Carrier operations. It was also found that the application of the national air accident statistics to the operations in Orlando International Airport, FL indicated relatively few air carrier accidents per year (0.68/year) where as the General Aviation operations in the same airport could result in as many as 16 accidents per year given the volume of General Aviation operations in that airport.

We discuss in this chapter the potential for impact of aircraft crashes on a Magnetic Levitation Guideway ("guideway") proposed to be built in Orlando airport. Specifically, the probability of aircraft impact anywhere on the guideway, in a given year, is being calculated. It is anticipated that the annual guideway impact probability will be dependent on (i) the number of air operations in the airport, both air carrier and general aviation, (ii) the rate of air crashes in the airport vicinity, (iii) the distribution of the air crashes in the airport vicinity and (iv) the overall dimension and physical location of the guideway with respect to the runway.

The analysis indicated in this chapter is divided into three parts. First the aircraft crash statistics as they apply to a specific airport (in this case Orlando, FL) are discussed. This includes the probability of air crash occurrence and its spatial distribution relative to the runway. Second, we discuss the calculation of the impact probability on a guideway whose location in the airport area is indicated in very generalized way. Third, the results from the analysis are applied to a two example positions of the guideway in the airport and impact probabilities are calculated for these examples.

3.2 ANALYSIS

3.2.1 Aircraft Crash Statistics

It is well known that air crashes occur, predominantly, during landing and (to a lesser degree) during take offs. Air crashes, in general, are rare events. Also, the mean number of crashes per year in a given airport depend on the airport geography, climate and occurrences of bad weather, types of air operations (commercial air carrier, general aviation, etc), availability of instrument landing systems, radar systems, etc. The Crash Rate ("β") is defined as the average number of aircraft crash accidents per air operation. Air operation includes take off, landing and taxiing operations. The details of the historical data and the number of operations in US in general and Orlando in particular were indicated in Chapter 2. The results from Chapter 2 are used here.

The value of this parameter β is, unfortunately, not available for all airports in the U.S. Only aggregate accident statistics for the U.S. as a whole are available. Hence, by virtue of non availability of individual airport data we assume that the crash rate is the same for all airports.

The parameter "Crash Frequency" (λ) is defined as the average number of crashes expected in an airport in a unit time (generally a year). The value for the crash frequency can be calculated using the equation,.

$$\lambda = \beta \times N_o \quad (3.1)$$

where,

β = Crash rate for the given airport (equal to the ratio of total number of crashes of all types of aircraft in a given period to the total number of aircraft operations of all types of aircraft during the same period).

N_o = Average number of air operations in the specified airport in a year.

In general, the value of β is very small; it is of the order of magnitude 10^{-6} for commercial air carriers and order of magnitude 10^{-5} for general aviation. The values obtained from US national air crash statistics indicate the following values for β (in crashes per operation).

β = 3.554×10^{-6} for Commercial Air Carriers

β = 65.700×10^{-6} for general aviation

The value of the crash frequency λ, however, depends on the number of operations in an airport.

Because the accidents are rare and the number of crashes are relatively few, we can represent the crash statistics by a Poisson distribution. This distribution is given by,

$$P(N) = \frac{(\lambda t)^{N} e^{-\lambda t}}{N!} \qquad (3.2)$$

where,

P(N) = The probability of occurrence of exactly N crashes in a period of "t" years at an airport.

The annual probability P(N>=1) that one or more crashes occur can be calculated from equation (3.2) as follows:

$$P(N>=1) = 1 - P(0) = 1 - e^{-\lambda} \qquad (3.3)$$

3.2.2 Geographic Distribution of Aircraft Crashes in Airport Area

It is found that most crashes occur very close to the runway and in most cases at or near the end points on the runway called the "threshold" point for the landing end and the "departure end" for the take off end. A detailed discussion of the results from an FAA study on aircraft undershoots/overruns/veeroffs is provided in Section 2.3.2.

We establish, for the purposes of convenience, an X-Y coordinate system with the origin at the intersection of the runway center line and the landing end of the runway (i.e, the threshold line). The positive X- coordinate is in the direction of landing. Y coordinate is in a direction normal to the runway length.

Longitudinal Crash Probability Density Distribution

The geographic distribution of impact points indicate a bimodal distribution along the runway length. Figure 2-7 showed the locations of aircraft over runs and under shoots. Figure 3.1a and Figure 3.1b show, respectively, the same data as histograms of number of accidents vs distance from runway ends. Unfortunately, no data are available for crashes on the runway.

It can be argued that the histograms in Figure 3.1a and Figure 3.1b indicate a near normal distribution of accidents with respect to the distances from the end points. We extend this argument to the runway side also and hypothesize a bi-modal Gaussian distribution of accidents relative to the center point of the runway. This distribution is schematically illustrated in Figure 3-2. Using this bi-modal distribution of impact locations along the length of the runway we can estimate the probability that any "X" direction point is impacted by an aircraft accident.

Figure 3-2 shows, schematically, the plot of the variation of the crash probability density function [$p_x(X)$] along the runway centerline. This is a conditional probability function in that it specifies the crash occurrence probability between any X and X+dX given that a crash has occurred anywhere in the airport area. That is,

$p_x(X)\ dX$ = The normalized conditional probability that an aircraft crash occurs in the interval X and X+dX given that a crash occurs anywhere in the airport region.

The bimodal probability function can be represented by assuming that the statistic is normally distributed and that the standard deviation of both humps is the same, namely, σ_x. The bi-modal distribution is given by,

$$p_x(X) = \frac{1}{(2(2\pi)^{0.5}\ \sigma_x)} [\exp(- X^2/2\sigma^2_x) + \exp(- (X-L)^2/2\sigma^2_x)] \qquad (3.4)$$

Cross Runway Crash Probability Density Distribution

Figure 3.3a shows the distribution of off runway centerline veeroff type of air crashes. This distribution can be approximated by a normal distribution. Figure 3.3b shows similar off centerline crashes in the region of extended runway. This distribution is very similar to that shown in Figure 3.3a when the "unknown distance"

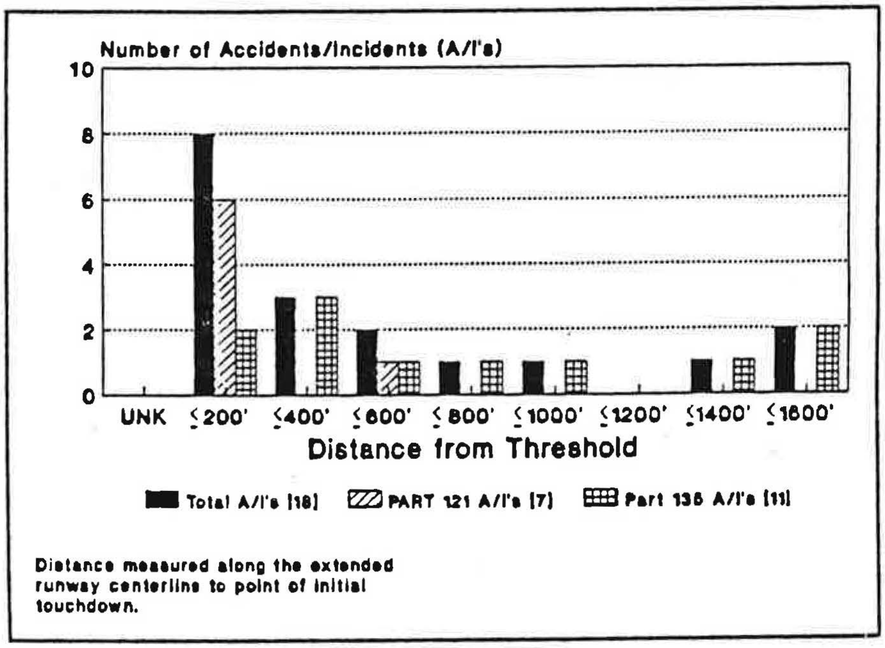


Figure 3.1a: Undershoots: Distribution from the Threshold Point

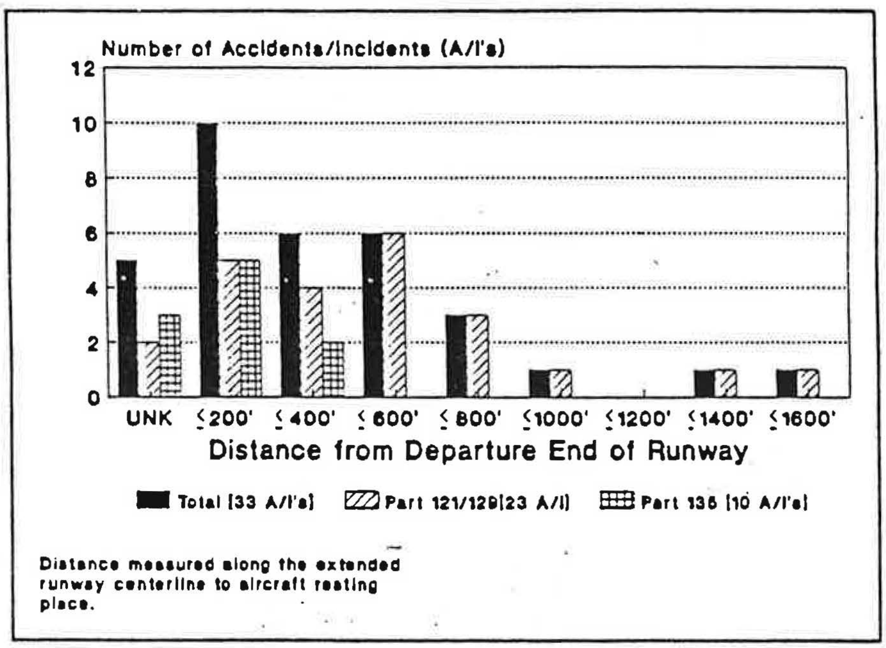


Figure 3.1b: Overruns: Distribution from the Departure End.

Source: David (1990)

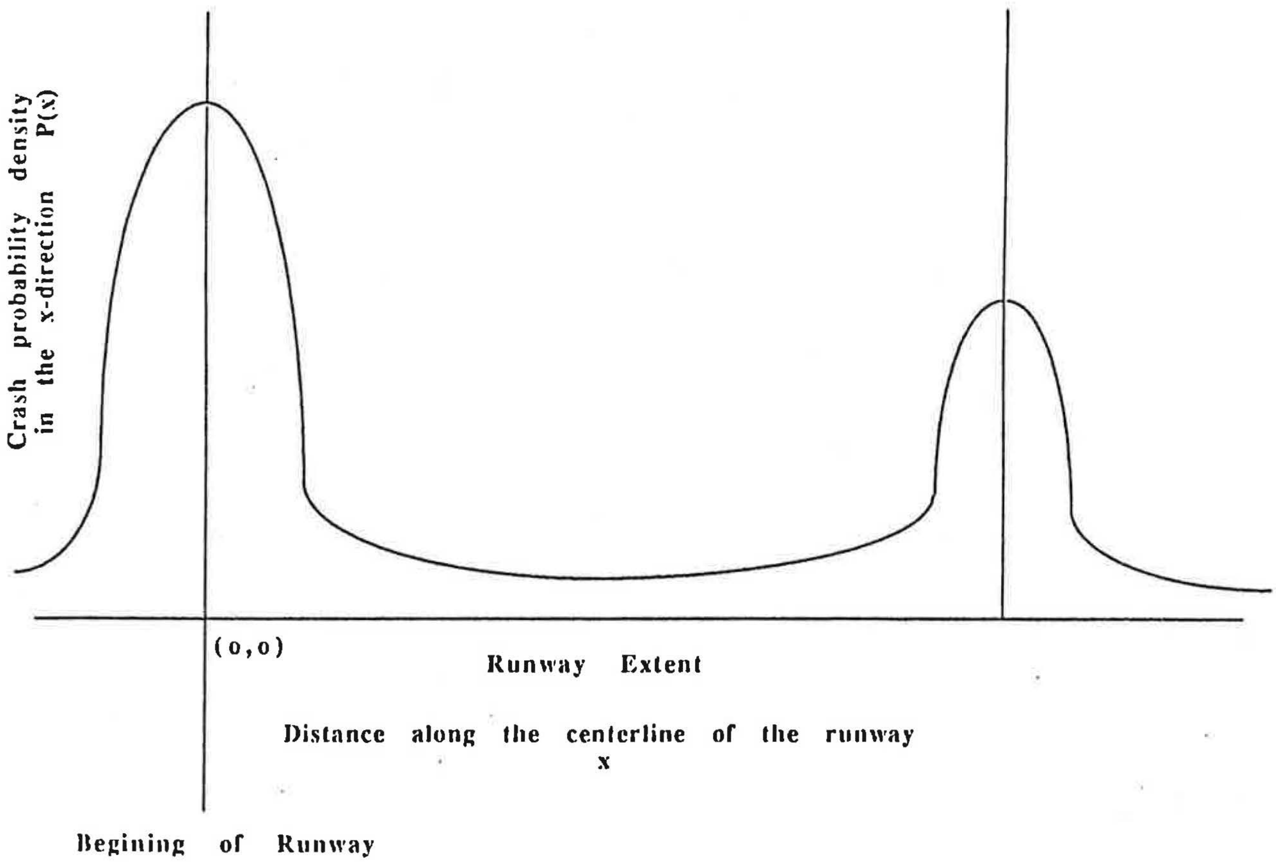


FIGURE 3.2: Schematic Representation of the
Bi-Modal Distribution of the
Axial Probability Density Distribution

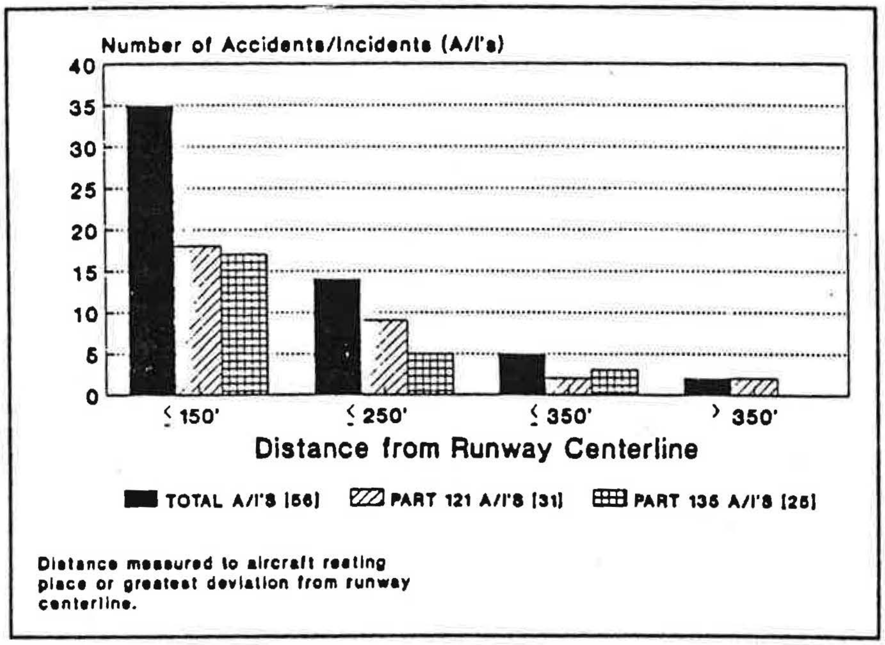


Figure 3.3a: Veeroffs: Distribution of Crashes in a Direction Normal to Runway

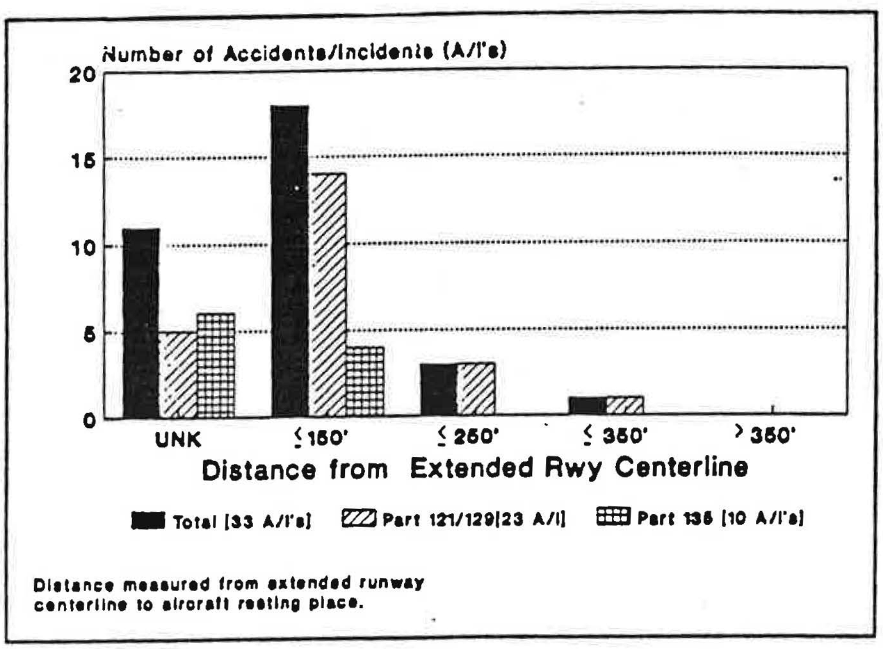


Figure 3.3b: Overruns: Distribution of Crashes from the Extended Runway Centerline

Source: David (1990)

crashes are distributed among other distances in a manner consistent with the number of crashes in each distance interval. Hence, we postulate that the probability density distribution in the cross runway distance is also a Gaussian, irrespective of the X location.

This Y-direction distribution is represented by,

$$p_y(Y) = \frac{1}{(2\pi)^{0.5}\ \sigma_x} \exp(- Y^2/2\sigma^2_y) \qquad (3.5)$$

where σ_y is the Y-direction standard deviation.

It should be noted that both $p_x(X)$ and $p_y(Y)$ are normalized density functions and as such their integration with respect to X or Y (respectively) over $-\infty$ to ∞ results in unity. That is,

$$\int_{-\infty}^{\infty} p_x(X)\ dx = 1 \qquad (3.6a)$$

$$\int_{-\infty}^{\infty} p_y(Y)\ dY = 1 \qquad (3.6b)$$

Hence, the joint normalized joint probability, $p(X,Y)\ dX\ dY$, of a crash occurring within X and X+dX and Y and Y+dY, <u>given</u> that a crash has occurred is given by,

$$p(X,Y)\ dX\ dY = \{\exp(-Y^2/2\sigma^2_y)[\exp(- X^2/2\sigma^2_x)+ \exp(-(X-L)^2/2\sigma^2_x)]\}/(4\pi\ \sigma_x\ \sigma_y) \qquad (3.7)$$

In the above equations σ_x and σ_y are in length units (say, meters) and represent the standard deviations of the crash probability density distributions, respectively, in the X and Y directions.

Values of σ_x and σ_y from National Air Crash Statistics

From the U.S. National air crash statistics (Figures 3.1a & b and Figures 3.3a & b) we obtain the following numerical values for the various statistical parameters.

σ_x = 160 m = 530 ft.

σ_y = 40 m = 130 ft.

3.2.3 IMPACT ON A GUIDEWAY

We assume that the guideway is impacted when ever an aircraft crashes directly on the guideway or within a certain distance from the guideway. This distance is the "effects distance" within which the impact of debris from the crash may adversely effect the guideway structures.

For the purpose of mathematical analysis we show, schematically, in Figure 3-4 a possible location of a Mag-Lev guideway in the vicinity of the airport. This does not mean that the guideway is proposed to be built this way. We also represent the guideway region (including the effects distance on either side of the guideway) by the following analytical expressions.

$$Y_1(X) <= Y(X) <= Y_2(X) \qquad (3.8)$$

where,

$Y(X)$ = is the region within the guideway at any X position

$Y_1(X)$ = equation to the lower bounding line of the guideway region

$Y_2(X)$ = equation to the upper bounding line of the guideway region

We now define a Heviside function H(X,Y) as follows

$$H(X,Y) = \begin{cases} 1 & \text{for all } Y_1(X) <= Y(X) <= Y_2(X) \qquad (3.9a) \\ 0 & \text{for all other Y values at any X} \qquad (3.9b) \end{cases}$$

Hence, the probability of one or more air crashes/year, any where on the guideway region, in an airport area is given by (using equations 3.3, 3.7 and 3.9)

$$P_{Guideway} = (1 - e^{-\lambda}) \int_{X=-\infty}^{X=\infty} \int_{Y=-\infty}^{Y=\infty} H(X,Y)\, p(X,Y)\, dX\, dY \qquad (3.10)$$

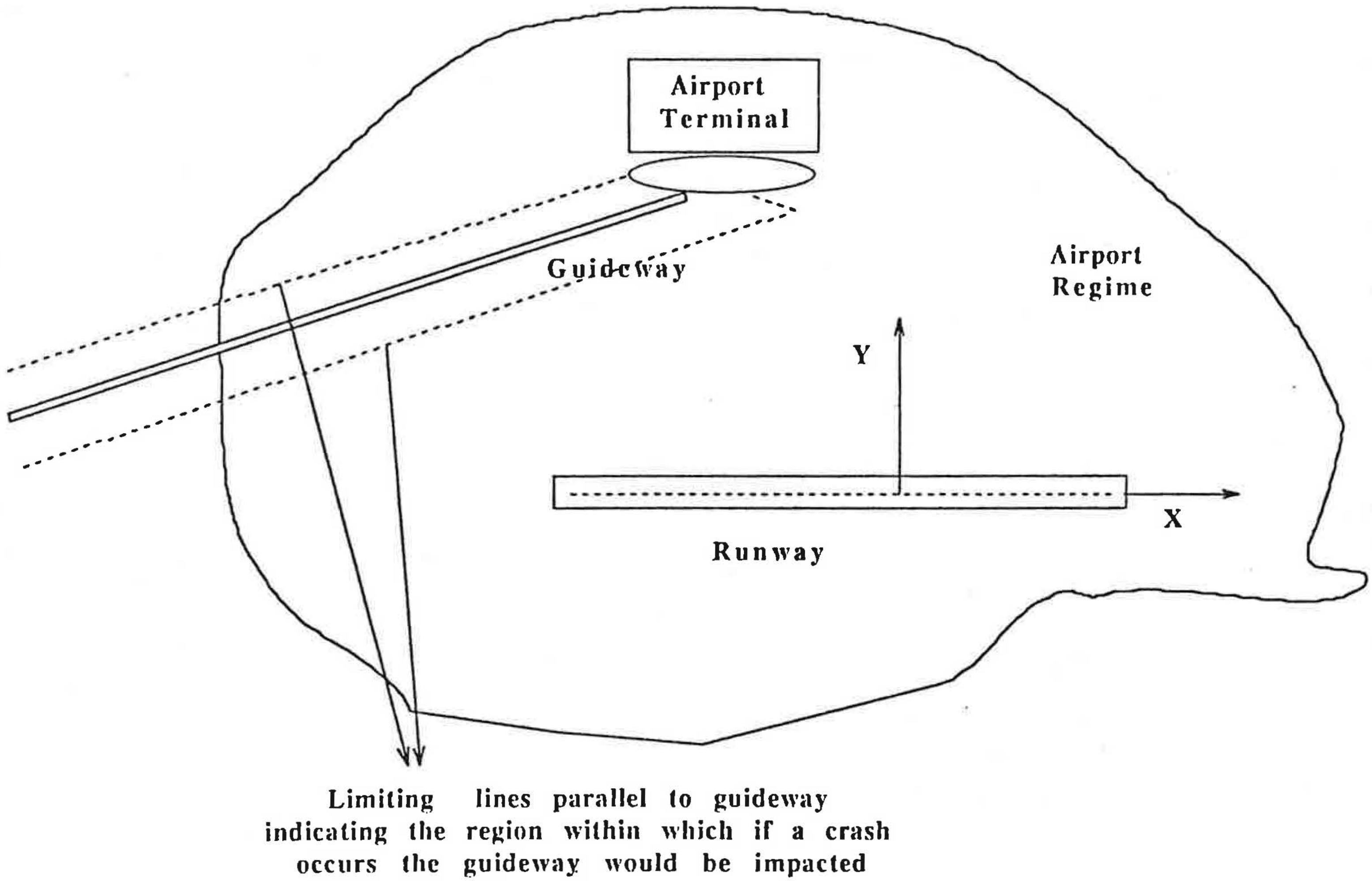


Figure 3.4: Schematic Representation of the Location of the Mag-Lev Guideway relative to the Runway.

where,

$P_{Guideway}$ = Probability of any air crash per year occurring and impacting the guideway region.

For any specified guideway path (which is represented by equation 3.8) it is possible to perform the integration indicated in equation 3.10. That is, the physical location and extent of the guideway has significant effect on it being impacted by air crashes.

To illustrate the application of the above equation to the specific scenario of Orlando airport, we provide the following examples. Again, we wish to stress the fact that the correct calculation will need the exact design of the location and width of the guideway.

3.3 APPLICATIONS EXAMPLES

CASE 1: Guideway Parallel to the Runway

We calculate the probability of impacting a guideway that is parallel to the runway and extends a long distance in either direction from the origin. We represent this guideway region by the equations,

$$Y_1(X) = C_1 \quad \text{and} \quad Y_2(X) = C_2 \qquad (3.11)$$

Hence the width W of the guideway region is

$$W = C_2 - C_1$$

It can be shown by substituting equation 3.11 in 3.9 and the resulting equation in 3.10 and simplifying the integral that we get,

$$P_{Guideway} = (1 - e^{-\lambda}) \left[\mathrm{erf}\left(\frac{C_2}{\sqrt{2}\,\sigma_y}\right) - \mathrm{erf}\left(\frac{C_1}{\sqrt{2}\,\sigma_y}\right) \right] \qquad (3.12)$$

CASE 2: Guideway Normal to the Runway

We describe the equation to the guideway region of interest by the following equations.

$$X_1 <= X <= X_2 \qquad (3.13a)$$

$$-\infty <= Y <= \infty \qquad (3.13b)$$

Again it can be shown that the result of applying the above to equation 3.10 is the following.

$$P_{Guideway} = ((1 - e^{-\lambda})/2) \; \{ [erf(\frac{X_2}{\sqrt{2}\,\sigma_x}) - erf(\frac{X_1}{\sqrt{2}\,\sigma_x})] + [erf(\frac{(X_2-L)}{\sqrt{2}\,\sigma_x}) - erf(\frac{(X_1-L)}{\sqrt{2}\,\sigma_x})] \} \qquad (3.14)$$

3.4 NUMERICAL EXAMPLE

To illustrate the application of the above equations to specific cases we illustrate with two examples for Orlando, FL airport. In the first example, it is assumed that the Mag-Lev guideway is parallel to the main runway and is located at a certain distance from it. In the second case it is assumed that the guideway is normal to the runway and is located a certain distance from one of its ends.

To calculate the probabilities for the above two cases we assume the following values for air operation in Orlando, Fl airport.

N_o = 450,000 (i.e., 200,000 Commercial Air Carrier and 250,000 general aviation operations per year.)

β = 38.5×10^{-6} Average crash rate per operation.

Hence,

λ = 17.32 crashes/ year

From section 3.2.2 we have,

σ_x = 160 m = 530 ft.

σ_y = 40 m = 130 ft.

We further assume the following values for the length of runway, and the guideway effects width at Orlando, FL airport.

L = 3500 m = 11,500 ft = Length of runway

W = 100 m = 328 ft = Width of guideway region

<u>Case 1:</u> **<u>Guideway Parallel to the Runway</u>**

Consider a guideway that is parallel to the runway whose center line is at a distance of 800 meters from the center line of the runway. That is,

C_1 = (800-50) m = 2,461 ft

C_2 = (800+50) m = 2,789 ft

The guideway runs parallel and is <u>assumed to extend</u> considerable distance in either direction from the ends of the runway. (Mathematically, the length of the guideway is represented as being infinite relative to the length of the runway). It should also be noted that the crash probability density distribution given in equation 3.4 includes crashes that occur far away from the runway; however, these probabilities are very small because of the Gaussian nature of this density distribution.

We note that the distance chosen (800 m) is 20 (i.e., 800/40) standard deviations away from the centerline of the runway in the Y - direction. Hence, because of the Gaussian nature of the cross runway crash distribution, we can anticipate that the impact probability on the guideway will be very small. This impact probability is calculated using equation 3.12. The result is,

$$P_{Guideway} = (1 - e^{-17.32}) \left[\mathrm{erf}\left(\frac{850}{\sqrt{2}x40}\right) - \mathrm{erf}\left(\frac{750}{\sqrt{2}x40}\right) \right]$$

$$= 2.8 \times 10^{-89} \quad !$$

The reason for this infinitesimally small probability of impact on this (assumed) parallel guideway is because the guideway is in a region where no air crashes have been found in historical data.

If, on the other hand, a guideway were built say 300 m away from the runway and parallel to it then the probability of guideway impact becomes 1.2×10^{-12}. That is, bringing in the guideway a factor of about 3 closer to runway increases the impact probability (all other conditions being the same) by 77 orders of magnitude!

Case 2: Guideway Perpendicular to the Runway

Consider, again for the sake of an illustrative example, a guideway located at about 1000 m before the runway threshold point and lying perpendicular to the runway. That is,

$$X = -1000 \text{ m} = -3028 \text{ ft}$$

$$X_1 = -950 \text{ m}$$

$$X_2 = -1050 \text{ m}$$

This distance is about 6.3 standard deviation in the x direction. Therefore, it can be anticipated that the impact probability will be low.

The annual probability of impact on the above guideway region is calculated using equation 3.14. It can be shown that the value is,

$$P_{\text{Guideway Normal to Runway}} = 2.20 \times 10^{-9} \text{ per year}$$

If the guideway is closer than 1000 m the probability of annual impact increases substantially. For example, if the guideway were only 500 m distance from the threshold point the annual impact probability will be 5×10^{-3} !

3.5 DISCUSSIONS ON RESULTS

In this chapter we have discussed the probability of impact of an aircraft on a Mag-Lev guideway located in the vicinity of the airport. A stochastic model based on historical national air-crash data has been developed to evaluate this impact probability. The model presented is general in that given the air operations in an airport, the impact probability can be determined once the location and width of the are provided. We note that the model developed is general in its applicability and takes into account accidents far from the runway.

Two illustrative examples are presented to indicate the way the model can be used. The air operation statistic pertaining to Orlando, FL airport have been used. It has been assumed that the general aviation accidents also will have effect on the guideway impact probability. It should be noted that the values used for the location of the guideway are fictitious and are not representations of proposed guideway route in and around Orlando, FL airport.

Using these data and assumed locations of guideway it is seen that if the guideway is located several standard deviations (of the crash probability density distribution) then the annual impact probability is extremely small as to be negligible. Given the exact design of the guideway location the probabilities of aircraft impact can be determined using the model indicated in this chapter.

CHAPTER 4

CONCLUSIONS & RECOMMENDATIONS

4.1 CONCLUSIONS

1 Using U.S. National aircraft accident statistics and the air traffic at Orlando International Airport the expected value of the number of air crashes at this airport per year is 16.8 (consisting of 0.68/year from air carrier operations and 16.12 /year from general aviation operations).

Only 2 crashes have been reported over a three year period. These involve only air carrier operations. No data are, however, available for general aviation accidents. It is entirely possible that the general aviation accident data, if accessible, will substantiate the expected number of crashes calculated from the national statistics.

2. Application of the model developed to determine the aircraft impact on MagLev guideway at Orlando airport indicates that the annual probability of impact is extremely low even when air accidents expected from commercial air carrier and general aviation operations are included. These probabilities are less than 10^{-9} per year.

The probability of impact on the guideway was calculated using some assumed guideway location. It is our premise that even when a more realistic guideway location is used the probability of impact will not be substantially different from the ones calculated in the examples.

3. The Collision Risk Model used by the FAA in Regulatory Assessments may be a valuable tool to determine the guideway impact probability and its acceptability to the FAA for locating in the Orlando airport.

4. Very scanty data are available to quantify human factor errors in aircraft maintenance or ground operations and their influence on aircraft accidents. Very limited data obtained from aircraft manufacturer sources indicate that about 3.4 % of all air accidents can be attributed to maintenance errors. NASA analyses indicate this level to be between 0.7 % to 1.58 %.

5. It may be possible to obtain additional data on maintenance errors rates in aircraft maintenance industry. However, this

will involve significant time and expense. Also, it is uncertain whether such an effort will provide any indication of cause (maintenance errors) and effect (aircraft crashes). Not even the thorough investigations of the NTSB seem to provide direct evidence of relationship between maintenance errors and aircraft crashes.

4.2 RECOMMENDATIONS

Based on the study performed and the review of the data we recommend that US DOT,

1. initiate a study to exercise the Collision Risk Model for the Orlando International Airport using two or three alternative routings of the Maglev system.

2. undertake additional research to identify new sources for maintenance error levels in surface transit industry and their impact on accident occurrence.

Appendix A

Names of people contacted at various agencies to obtain data.

1) NTSB:

Mr. Jim Danaher,	(202) 382-6835
Dr. John Lauber,	(202) 382-6600
Mr. Stan Smith,	(202) 382-6672

2) VNTSC:

Ms. Rosemary Booth,	(617) 494-2061
Mr. Stephen Huntley,	(617) 494-2339

3) ALPA:

Mr. Kim Logan,	(703) 689-4190
Mr. Harold F. Marthinsen,	(703) 689-4190

4) FAA:

Mr. Robert Christopher,	(202) 267-7404
Mr. Bob David,	(202) 366-6422
Ms. Anna Johnson,	(202) 366-6170
Mr. Paul Larson,	(202) 267-3296
Mr. John Mogul,	(617) 273-7036
Mr. Jose Ramon,	(202) 267-8724
Mr. Dick Temple,	(202) 267-5824
Ms. Nancy Trembley,	(202) 267-9942

5) BOEING:

Mr. Peter Wheeler,	(206) 237-0241
Ms. Pam Rosnik,	(206) 237-0241

6) McDONNELL DOUGLAS

Mr. Tom Elser,	(213) 496-7436

7) FAA Operational Branch, Oklahoma City

Mr. Al Jones,	(405) 680-5844
Mr. Douglas Burdette	(405) 680-4391

8) CSERIAC

Mr. Michael Gravelle	(513) 255-4881
Other expert sources:	
Mr. John Senders	(207) 483-4646
Mr. Earl Wiener	(305) 284-6595

9) AOPA

Admiral Don Engen	(301) 695-2029

10) NASA Ames Research Center

Mr. Vince Mellone,	(415) 969-3969

11) ICAO

Reinhard Menzel,	(514) 285-6727

Appendix B

Brief description of data collected

1) FAA's study on the location of Commercial Aircraft Accidents/ Incidents relative to the runways.

This document compiles information on the location relative to the runway of accidents/incidents for aircraft involved in commercial air transportation in the U.S. for the period 1978-1987. This study does not include accidents/incidents involving air carriers on non-revenue flights such as a repositioning or ferry flight under FAR Part 91 (General Operating & Flight rules). The number of accidents/incidents have been reported are for FAR Part 121 (Domestic, flag, and supplemental air carriers and commercial operators of large aircraft, Part 129 (Operations of foreign carriers) & Part 135 (Air taxi operators & commercial operators). The main source of information has been obtained from the NTSB accident dockets. Several incidents were also obtained from the FAA's Accident/Incident data System (AIDS).

2) Air Line Pilots Association's compilation of accidents /incidents involving runway overruns, undershoots, veeroffs.

The Accident investigation Department of the Air line Pilots association (ALPA) has used the Overrun/Undershoot/Veeroff database maintained by them to generate a report regarding the location of the aircraft accidents and incidents which have occurred in the vicinity of the airport at which the aircraft was in the process of landing or taking off. This report uses world-wide data collected during the period 1959-1988 from numerous sources such as Civil Aviation Authority (CAA) accident summaries, Aviation Information Services Limited - Major loss Record, NTSB accident reports, FAA Accident Incident Database, Foreign accident reports, ICAO Aircraft Accident digest and the ICAO ADREP database. The information is categorized for both jet aircraft and turboprop aircraft. It is very similar to the FAA report with the exception that it contains data on a world-wide basis.

3) CSERIAC preliminary bibliographic search on maintenance errors.

CSERIAC is a DoD information analysis center hosted by the Armstrong laboratory, Wright Patterson Air Force Base, Ohio, and operated by the University of Dayton Research Institute. The objective of CSERIAC is to support the requirements of government agencies for incorporating crew system ergonomics in the design and operation of human-machine systems.

CSERIAC was contacted for pertinent information on maintenance error levels that exist in the maintenance of aircraft operations. CSERIAC has provided a bibliographic report on Maintenance errors which contains numerous citations that were extracted from NASA-Recon, Transportation Research Information Service (T.R.I.S), Defense Technical Information Center (DTIC) DROLS, PsycINFO, Department of Energy (DOE), Compendex and National Technical Information Service (NTIS) databases.

4) <u>BOEING's statistical summary of Commercial Jet Aircraft Accidents.</u>

This compilation of Commercial Jet Aircraft Accidents covers the period 1959-1990 and is applicable to worldwide commercial jet operators for aircraft heavier than 60,000 pounds maximum gross weight, but do not include turboprop aircraft. Russian manufactured or operated aircraft are also not included because of the inaccurate or incomplete operational data. Similarly, military operators of commercial-type aircraft are also excluded.

The information was compiled using government accident reports along-with information from operators, manufacturers and various private and government information sources. The accident data follow the same definitions of aircraft accident, serious injury and substantial damage as specified by the NTSB. All accidents resulting from sabotage, hijacking, military action or experimental test flying are also excluded.

5) <u>McDonnell Douglas Commercial Jet Transport Safety Statistics.</u>

This publication provides safety related statistics that address "free world" commercial jet aircraft of more than 60,000 pounds maximum gross weight. Aircraft types or models operated by the military or governmental (non-commercial) agencies have been excluded. The statistics were derived from the Douglas Aircraft Safety Information System (SIS) which is a comprehensive database containing more than 134,000 safety related events beginning in 1958. These events have been collected from numerous sources such as the Aviation Information System Limited (AISL), World Airline Accident Summary (WAAS), NTSB, ICAO, and the Civil Aviation Authority (CAA). This report is very similar to the one published by Boeing. One of the differences between the Boeing and the McDonnell Douglas report is that McDonnell Douglas views pilot error as an initiating cause of an aircraft accident versus Boeing's view as an underlying cause.

6) Selected Statistics concerning pilot-reported pilot deviations (1986-1988).

The FAA Office of safety analysis has published a study describing the characteristics and recent trends associated with pilot deviations. A pilot deviation is described as the action of a pilot which results in the violation of a Federal Aviation regulation, or a North American Aerospace Defense Command (NORAD) Air Defense Identification Zone (ADIZ) tolerance. This report covers the period 1986-1988 and the data presented have been taken from the FAA's National Airspace Information Monitoring System (NAIMS) maintained by the Office of Safety Analysis, National Aviation Safety Data Center. The total number of operations used in the study consist of air carrier part 121 and 135 operations, general aviation towered and non-towered operations, and military operations.

7) NTSB's Annual Review of Aircraft Accident Data 1985-1987.

These reports present a statistical compilation and review of air carrier accidents that occurred during the period 1985-1987. The accidents reported are all those involving U.S. registered aircraft conducting operations under Title 14 CFR Parts 121, 125, 127 and 135.

Part 121 applies to large commercial air carriers such as major airlines and cargo haulers. Part 125 covers the operation of large, privately owned aircraft not held for hire. Part 127 regulates the operations of helicopters used as scheduled air carriers and Part 135 applies to commercial air carriers commonly referred to as commuter airlines and air taxis.

The reports are divided into three sections: 14 CFR 121, 125, 127 Operations; Scheduled 14 CFR 135 Operations; and Nonscheduled 14 CFR 135 Operations. Each section gives an overview of accidents and their consequences for the corresponding year and for the 4 preceding years. Tables summarizing accidents, fatal accidents, fatalities and rates have been provided.

A listing of the primary fields of the NTSB database has also been obtained. The purpose is to evaluate the types of data that are collected by the NTSB during their course of an accident investigation.

The NTSB database maintains data on aircraft accident location and direction from the airport. Field 27 of the factual aviation report is accident location which could either be off airport/airstrip, on airport or on airstrip. Field 28 specifies the distance from the airport center. It is known how accurately this figure is maintained in the database.

9) National Aeronautics & Space Agency (NASA) Aviation Safety Reporting System (ASRS).

NASA maintains the ASRS database which contains information regarding field operations. This organization and its database utilize a voluntary reporting system where pilots, controllers and others can submit subjective accounts about safety related aviation incidents. It is important to note that the information stored is not maintained for aviation accidents that have taken place. Since the reporting system is voluntary, the data may contain biases. At the time of writing this report detailed information on maintenance errors had been requested but information on the kinds of primary fields in the database and maintenance error levels had not been received. It is understood that the reports maintained in the ASRS database are mainly narrative. An example would be that a pilot relates the details of an incident, explains what happened, why it happened and suggests improvements.

10) FAA's Accident Incident Data System (AIDS)

Information was still awaited at the time of writing this report.

References

NTSB (1988); "Annual Review of Aircraft Accident Data - U.S. General Aviation Calendar Year 1988". Report # NTSB/ARG-91-01. Office of Research & Engineering, National Transportation Safety Board, Washington, D.C. 20594

NTSB (1987); "Annual Review of Aircraft Accident Data - U.S. Air Carrier Operations Calendar Year 1987". Report # NTSB/ARC-90-01. Office of Research & Engineering, National Transportation Safety Board, Washington, D.C. 20594

Trembley, Nancy; FAA (1990) "FAA Air Activity FY 1990". Federal Aviation Administration, Washington, D.C. 20591

David, Robert E; FAA (1990) "Location of Aircraft Accidents/ Incidents Relative to Runways". Report # DOT/FAA/AOV 90-1. Federal Aviation Administration, Washington, D.C. 20591

BOEING Product Safety Organization (B-210B); "Statistical Summary of Commercial Jet Aircraft Accidents" Worldwide operations 1959-1990. Contact Peter Wheeler. BOEING Commercial Airplane Group, Seattle, Washington 98124

DOUGLAS Aircraft; "Commercial Jet Transport Safety Statistics" 1958-1990. Contact Tom Elser

ALPA (1989) Hagy K.H., Bracken J.M., Marthinsen H.F.,; "Compilation of Accidents/Incidents involving runway overruns/ undershoots/veeroffs". Air Line Pilots Association, Accident Investigation Department, 535 Herndon Parkway, P.O. Box 1169, Herndon, VA 22070.

ICAO; " Manual on the use of the Collision Risk Model (CRM) for ILS operations". ICAO Reference # M380/8. Document # 9274/1. International Civil Aviation Organization, 1000 Sherbrooke St West, Ste 400, Montreal, Canada H3A 2R2