The Risk Assessment of Aircraft Runway Overrun Accidents and Incidents

By

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A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of

The Degree of Doctor of Philosophy of Loughborough University

August 2001

Abstract

The UK Civil Aviation Authority has recognised the need for protection against the runway overrun over and above the standard protection recommended by ICAO Normal protection for the aircraft is provided in ICAO's Annex 14 by the strip at the end of a runway, and a recommendation for the installation of a Runway End Safety Area (RESA) In the UK, the CAA has stated that as part of their safety management system the aerodrome licensee should review the RESA distance requirement for their individual circumstances on an annual basis through a risk assessment However, current industry knowledge of circumstantial factors in runway overruns is limited Also, current models that are used to determine likely overrun wreckage locations and RESA dimensions take no account of the operational conditions surrounding the overruns or the aerodrome being assessed This study has attempted to address these needs by highlighting common factors present in overrun occurrences through the compilation and analysis of a database of runway overruns, and through the construction of a model of wreckage location that takes account of the conditions at an individual aerodrome A model of overrun probability has been constructed and the consequences of an overrun have been examined One outcome of the study is an awareness that the industry is in an extremely poor state of knowledge of operational characteristics of non-accident flights, which if not addressed will be a major barrier to future advancement of aviation safety improvement and research

Keywords Risk assessment, Runway overrun, Aircraft, Aviation, Aerodrome design, Accident, Incident, Safety, Statistical analysis

Acknowledgements

I have been assisted in the completion of this study by a great number of different individuals and organisations, some of whom may not even be aware of its existence or of their help Consequently, it will be impossible to list everyone who has contributed, but a big "thank you" to all who have

More specifically, I would like to thank my supervisor Bob Caves Not only did he provide me with the opportunity to do the PhD, but he also thought I was up to the task, and was genuinely selflessly interested in the subject and my advancement

Many thanks also go to my Director of Research, David Gillingwater for his valuable encouragement, David Pitfield for his help with the tricky maths, and Ian Humphreys for his support, and interest in aircraft, real ale, and cockles Likewise, thanks go to all the other members of Transport Studies, who directly or indirectly have contributed to the work or my time at Loughborough

The study would not have been possible without the financial support of the EPSRC which funded the work under grant reference GR/M20983/01 and under the title "Runway overrun risk assessment and consequence analysis". It would also not have been possible without the support and help of Adrian Sayce and Graham Skillen of the CAA, the help of Captain John Savage, or the data that were provided freely by the NTSB, the FAA, the Transportation Safety Board of Canada, the Australian Transport Safety Bureau, and the CAA

I would also like to thank all my friends just for generally being friends and doing things that friends are supposed to do Specifically, thanks go to Matt and Richard for thinking that the idea of me doing a PhD was ridiculous, and for providing some sort of perspective by reminding me that doing a PhD is not the same as "a proper job" Special thanks must also go to Alla for making the last couple of years very exciting, and for giving me an extra impetus to get the work finished

Last but definitely not least, I'd like to thank my family for everything, and I really do mean everything

Dedicated to those awkward people who have to ask why.

Contents

1 Introduction

1 1 Justification for research

A runway overrun occurs when an aircraft departs the end of a runway and can occur on takeoff or on landing It would occur on landing if the aircraft were unable to decelerate and stop before the runway end, and on takeoff if there is a problem that causes the takeoff to be abandoned and the aircraft is again unable to stop before the runway end.

The requirements that must be met by an aerodrome operator in the UK in order to retain an operating license undergo constant gradual change This is illustrated by the regulations that are designed to ensure that the aerodrome environment allows aircraft to leave the end of the runway without disastrous consequences Until recently, the dimensions of the runway end safety area were stipulated in accordance with the length of the associated runway, and if the minimum requirements could not be met, an assessment of the risk had to be carried out Minimum requirements are now mandatory, and it has now been recommended by the Civil Aviation Authority that runway end safety areas are provided in excess of the minimum requirement and that the required dimensions should be determined by an annual risk assessment by the aerodrome licensee

A problem with this approach is that the aviation industry is in a poor state of knowledge of the actual risk factors that determine the probability and consequences of an overrun occurrence Although much anecdotal evidence exists of the nature of likely risk factors, it is not backed up by statistical evidence There is a danger that decisions made to manage overrun risk in the absence of an understanding of the risk will lead to inefficient allocation of resources and mitigation measures which do not alter the risk, in addition to a false sense of safety

This thesis has attempted to rectify this situation by determining the factors that account for the risk of an overrun occurring, as well as the determinants of overrun consequences and the quantification of the risk to the extent possible It was also felt that the illumination of these factors would naturally indicate mitigation measures, and therefore, that any effort in this area would assist the decision making task of aerodrome managers, regulators, and airlines

1 2 Summary of thesis

Chapters 2 and 3 of the thesis provide a background to the study Firstly it is put in the context of the theory and application of risk assessment, and secondly existing overrun management and mitigation measures are discussed

Chapter 4 describes current risk assessment methodologies in detail and then explains the advances in overrun risk assessment methodology that have been developed in this present work, including a technique of wreckage location normalisation that takes account of local aerodrome and meteorological conditions

Chapter 5 describes the choices made in data selection and the process of its collection Prior to this study, the data that had been collected on overruns was extremely limited, and was not in a form that would allow meaningful analysis The first necessary step was to collect the data, the collection of which occupied the majority of the study period In order to determine risk factors, this data had to be compared with data from non-overrun flights, which is difficult to obtain This was achieved for a small proportion of the factors that were examined, although it is likely that these may be amongst some of the most important

Chapter 6 contains the bulk of the data analysis and although the comparison with non-overrun flights is limited, other useful information is presented, particularly concerning causes determined by the investigation authorities, and the differences between the nature of the operations that have resulted in a landing overrun after a precision approach compared to those that overran after flying an approach that was not a precision approach

Chapter 7 presents overrun probability models for takeoff and landing These are compared with existing methods of overrun risk determination, and found to be more effective

Chapter 8 presents new wreckage location models that take account of the operational characteristics of the overrunning aircraft, and also the effect of the runway end

Chapter 9 highlights two major factors in the outcome of a runway overrun and these are presented as a model of consequences, although it is acknowledged that the value of the model would be increased by the addition of expert judgement

Chapter 10 discusses the application of the developed risk assessment methodology, and includes an example of a risk assessment at a hypothetical aerodrome

Chapter 11 re-evaluates the risk assessment methodology in the light of the proposed advances, and compares the results of the research with the aims Further research needs are highlighted

1 3 Proposed risk assessment process

Figure 1 1 shows the application of the proposed risk assessment process The risk factors present at the study aerodrome are fed in to the overrun risk model, along with the aerodrome physical characteristics and information on the fleet mix at the aerodrome The resultant overrun probabilities are then combined with the aerodrome characteristics, fleet characteristics, and overrun location models to give probabilities per movement or per year of overruns of certain distances This information is input to the overrun consequence model again with aerodrome characteristics and fleet mix to result in figures of aircraft damage caused or injuries incurred per movement or per year

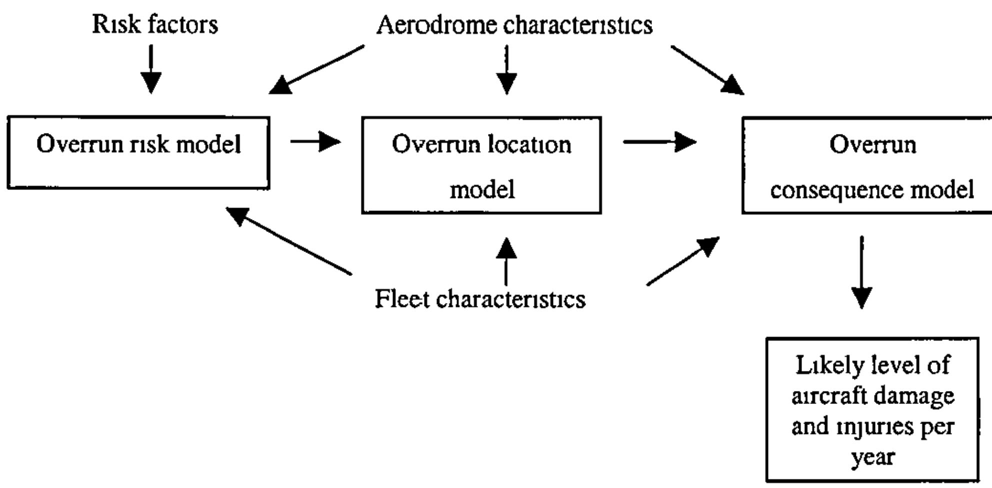


Figure 1. 1

Where this process has been undertaken to date, it has generally been qualitative in nature Little statistical evidence exists on the risk factors involved in overruns, and any quantitative models have been rather crude risk models based upon aircraft type Overrun location models have been used, however, these have been based upon small datasets and the locations have been measured relative to the runway end Models of this type do not seem to be intuitively realistic, as much of the surrounding circumstances of the overrun are ignored Overrun consequence models have in general been qualitative in nature, although a NATS study (2000) has developed an overrun accident consequence model, which inherently does not model overrun consequences adequately as it excludes all situations where the result was less than $1 million worth of damage to the aircraft or 10 percent of the aircraft value, the majority of overruns

This study has been focused on three main areas of the risk assessment process. Firstly, providing a statistical basis for the construction of a quantitative overrun probability model Secondly, the construction of an overrun location model which takes account of the individual circumstances of the overrun aerodrome, in addition to the circumstances at the aerodrome at which a risk assessment is to be carried out Thirdly, the construction of a quantitative overrun consequence model that will enable consequences to be easily assessed All three of these areas are reliant upon the large database of overrun occurrences that has been constructed in order to conduct this study

2 The theory of risk assessment and its application in aviation

2 1 The nature of risk

The first thing that is immediately apparent when looking at the subject of risk assessment is that there are a number of terms that are discussed that are defined differently by different practitioners

Risk

The first opportunity for confusion occurs with the definition of the word risk Kinchin (1982) states that the word risk can refer to either a hazard or to the chance of loss Smith (1992) also notes that risk is sometimes taken as being synonymous with hazard, but that risk has the additional implication of the chance of a particular hazard occurring Covello and Merkhofer (1993) define risk as "a characterisation of a situation or action wherein two or more outcomes are possible, the particular outcome that will occur is unknown, and at least one of the possibilities is undesired"

The confusion is not surprising when the Oxford English dictionary is consulted Its definitions are as follows

> *Hazard* – The risk of loss or harm
> *Risk* – the chance or hazard of commercial loss

According to these definitions the words are interchangeable Like Smith (1992), however, the UK Health and Safety Executive (1998) also make a similar distinction between the meanings of the two words In their report hazard is defined as anything that can cause harm, and risk is defined as the chance that somebody will be harmed by the hazard These last definitions seem to be the most useful and will be used in this report, with slight changes as follows

> *Hazard* – an undesirable circumstance
> *Risk* – the chance that somebody or something will be harmed by the hazard

2 2 Risk management / risk assessment

2 2 1 Risk management

Smith (1992) defines risk management as "reducing the threats to life, property and the environment whilst simultaneously maximising any benefits" He states that a necessary first step is to obtain some assessment of the actual risks involved

According to Cox and Tait (1998) risk management involves the identification, evaluation and control of risks, and a number of different techniques may be used in each stage They state that the first step is risk identification, with the measurement and assessment of risk at the second stage of evaluation

2 2 2 *Risk assessment*

Covello and Merkhofer (1993) define risk assessment as "a systematic process for describing and quantifying the risks associated with hazardous substances, processes, action, or events"

Kates and Kasperson (1983) state that risk assessment comprises three distinct steps

1 An identification of hazards likely to result in disasters
2 An estimation of the risks of such events
3. An evaluation of the social costs of the derived risks

A similar definition of risk assessment is given by White (1982) who has described a risk assessment methodology to determine the risks of radioactive release from a nuclear power plant This process also consists of three steps

1. includes the identification of potential accidents and the quantification of both the frequency and magnitude of the associated radioactive releases to the environment
2. uses the radioactive source term defined in 1 and calculates how the radioactivity is distributed in the environment and what effects it has on public health and property
3 combines the consequences calculated in 2, weighted by their respective frequencies to produce the overall risk from potential nuclear accidents Such results can then be compared to a variety of non-nuclear risks

While these definitions appear to be very similar to the definitions of risk management, in that they include the identification and evaluation of risks, they do not include the control of risk, which appears to be the defining feature of risk management.

A report by the National Academy of Sciences (1983) has recognised the confusion between risk assessment and risk management and offers two definitions to try to separate the two processes The report was primarily concerned with risks to human health The report recommended

Risk assessment to mean the characterisation of the potential adverse health effects of human exposures to environmental hazards Risk assessments include several elements description of the potential adverse health effects based on an evaluation of results of epidemiological, clinical, toxicological, and environmental research, extrapolation from those results to predict the type and estimate the extent of health effects in humans under given conditions of exposure, judgements as to the number and characteristics of persons exposed at various intensities and durations; and summary judgements on the existence and overall magnitude of the public health problem Risk assessment also includes characterisation of the uncertainties inherent in the process of inferring risk

A definition was also given for *risk management* that describes

the process of evaluating alternative regulatory actions and selecting among them. Risk management, which is carried out by regulatory agencies under various legislative mandates, is an agency decision-making process that entails consideration of political, social, economic, and engineering information with risk related information to develop, analyse, and compare regulatory options and to select the appropriate regulatory response to a potential chronic health hazard. The selection process necessarily requires the use of value judgements on such issues as the acceptability of risk and the reasonableness of the costs of control

While the definitions are geared towards risk management by the US Federal Government it is clear that the underlying concepts are that risk assessment should be a scientific technique which objectively determines the magnitude and consequences of risk, and that risk management is a process that should determine the most desirable way to control risks, involving risk assessment as a supporting tool.

The actual risk assessment model proposed in the report has been widely used by several US government agencies for assessing the risks of cancer and other health risks that result from exposure to chemicals The methodology is as follows

1. *Hazard identification* · The determination of whether a particular chemical is or is not causally linked to particular health effects
2. *Dose-response assessment* The determination of the relation between the magnitude of exposure and the probability of occurrence of the health effects in question
3. *Exposure assessment* The determination of the extent of human exposure before or after application of regulatory controls
4. *Risk characterisation* The description of the nature and often the magnitude of human risk, including attendant uncertainty

This model has four steps, the additional step not included in the previous models being exposure assessment This step is aimed at determining and using models of hazard exposure that will result from different scenarios, an example could be the number of people affected by a release of chemicals resulting from a particular type of fire in a plant The activities of this step do occur in the previous models but in the consequence assessment process, rather than being named as a separate step

A further model that treats exposure assessment as a separate step is that of Covello and Merkhofer (1993) as follows

1 *Release assessment*. Quantifying the potential of a risk source to introduce risk agents into the environment
2 *Exposure assessment* Quantifying the exposures to risk agents resulting under specified conditions
3 *Consequence assessment*. Quantifying the relationship between exposures to risk agents and health and environmental consequences
4 *Risk estimation* Estimating the likelihood, timing, nature, and magnitude of adverse consequences

This model treats hazard identification as a separate process that is necessarily conducted prior to risk assessment The proponents of this model argue that treating hazard identification as a component of risk assessment underplays its importance, and that hazard identification provides the essential foundation for and must precede risk assessment

Another outline of methodology is given by Andrews and Moss (1993), who state that risk assessment involves four basic stages

1 the identification of the potential safety hazards
2 the estimation of the probability of occurrence of each hazard
3 the estimation of the consequences of each hazard
4 a comparison of the results of the analysis against the acceptability criteria

This is an example of a model that includes (in addition to hazard identification) a comparison of the results with acceptability criteria While the comparison has to occur at some stage of the risk management process, the proponents of the first four models would argue that the comparison should not comprise part of the risk assessment

2 2 3 Quantitative risk assessment

Quantitative risk assessment (QRA) simply means a risk assessment method that expresses the risk in terms of quantity, or in other words determines the size of the risk and consequences of the realisation of the risk in number terms, as opposed to qualitative risk assessment which expresses the quality of the risk, most often in terms of an increase or decrease

Most of the proposed risk assessment methodologies have in common three basic steps

1 hazard identification (with *hazard* defined as an undesired circumstance)
2 assessment of the risk of the hazard being realised (quantified if performing a quantified risk assessment)
3 assessment of the consequences of the hazard being realised (again quantified if performing a quantified risk assessment), and the combination with the risk of the hazard being realised

2 3 Risk assessment methodology

2 3 1 Hazard identification

A number of different hazard identification techniques are available and are described by Crossland et al (1992) These include safety audits, hazard surveys, hazard indices, and hazard and operability studies Most of these hazard identification techniques have been developed within, and for the use within industries that involve large industrial plants or very complex technological systems for which the consequences of failure would be severely detrimental, for example the chemical industry, the nuclear industry, and within the aircraft manufacturing industry In all of these cases the equipment is so complex that there are many opportunities for it not to operate as designed, and the complex interactions cause the result that there could be many different unwanted outcomes

In many instances of risk assessment the hazard identification is very simple and has already been conducted, for example when assessing the risk of an undesirable environmental occurrence such as a hurricane or earthquake This is also the case with runway overruns The main hazard, that of an aircraft overrunning the runway, has already been identified Where the identification process may have to be applied in detail, may be in determining the factors which can contribute to the risk of overrun occurrence, and the factors that can contribute to the seriousness of the overrun, i e obstacles beyond the runway end

2 3 2 Estimation of the probability of occurrence

There are a number of approaches available for the determination of the probability of occurrence of a hazard, the choice of which is very much determined by the nature of the hazard (Covello and Merkhofer, 1993)

2 3 2 1 Historical inference (sometimes referred to as historical risk analysis or actuarial risk analysis)

One approach (Smith, 1992) is to utilise a historical database of occurrences to determine the average likelihood of occurrence per period of time, for example if there had been 10 earthquakes in the last 100 years the average likelihood of an earthquake occurring per year is 0 1

This method has traditionally been used where the historical database is available so that there can be some reasonable level of confidence that the figures are representative of a wider reality, or in other words that they represent the actual probability rather than a short term anomaly in the data This approach is also most often used where the causal method by which the event occurs is not well understood This approach is typically used for assessing risk of occurrence of environmental hazards such as floods, storms, earthquakes etc There are a number of weaknesses with this approach, and also a number of techniques used to eliminate the weaknesses

Firstly, there is an assumption that events in the future can be extrapolated from past events, and this implies that there will be no change in the underlying causal factors, which in most cases have that possibility For example, many people have associated the increase in incidence of storms and floods with global warming, which if true, would mean that the underlying cause is changing over time A way of combating this weakness is by better understanding of the causal processes A model is built up of the way that causal factors affect the risk of hazard realisation, and the causal factors are monitored Any changes in these factors then alter the risk of hazard realisation and future risk can be assessed by modelling the causal factor changes in the future

Secondly, most statistical techniques attempt to model the realisation of hazards as being random over time, when a lot of processes may not be An earthquake follows a build up of pressure in the earth's crust, and having occurred, may not occur again until the pressure has built up again. Again, an understanding of causal factors can enable a more accurate risk assessment

A third weakness is the requirement for data on past events Some hazards may only occur extremely infrequently, and data therefore may be in very short supply When assessing some risks, for example that of an asteroid hitting the earth or the risk of a very large magnitude of earthquake occurring, the event may happen so infrequently that one has not happened in living memory, or maybe even since records began One method used in this case is that of extrapolating frequencies and consequences of extreme events from those events for which the data is available This is acceptable, but only where the same causal and consequence mechanisms govern both types of event In the case of hazards resulting from a new type of technology the data is obviously not available, so other methods need to be explored The problem of lack of data also makes the modelling of causal factors difficult If there is a lack of data on hazard realisation there is likely to be even less data on the mechanisms of occurrence and causal factors

2 3 2 2 Event tree and fault tree techniques

Event tree and fault tree techniques have been used where direct data on past occurrences does not exist and extrapolation techniques are judged not to be applicable because different mechanisms are believed to influence extreme events to those that influence lesser events. Also, because the failure modes and events are identified, a change in risk can be determined prior to hazard realisation, and for this reason, can be a more powerful tool than historical extrapolation alone. According to Vesely (1984) the event tree technique is an inductive logic technique that can be applied where a chain of events must occur in order for an accident to result An accident will occur if an initial failure is followed by a sequence of further failures For example, an accident chain may occur as follows A chemical plant may involve a process of heating a chemical An initial event could be that the chemical is heated greater than a specified amount For this to cause an accident a temperature sensor in a warning or cut off system may also have to fail, and the vessel carrying the chemical may also have to fail This can be charted as follows

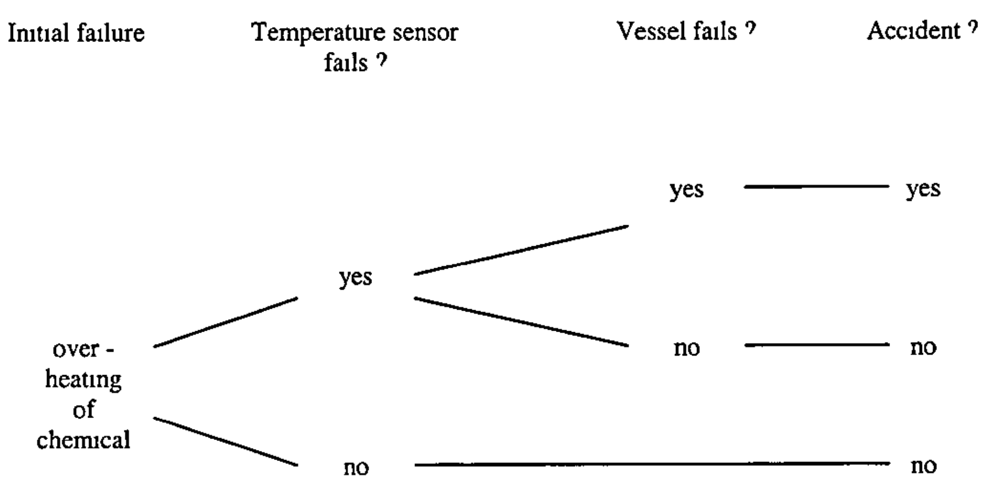


Figure 2.1

In this case the probability of an accident occurring is the product of the probability of the chemical becoming overheated, the probability of the temperature sensor failing, and the probability of the failure of the vessel A complete risk assessment would take account of all accident sequences, and with many industrial applications where many systems can be called upon in an accident situation, the event tree may become very large

Of course, in order to make an assessment of risk an assessment of the probabilities of the failure of each of the components must be made While this may be reasonable in many engineering applications where component failure statistics are readily available, it becomes extremely difficult where humans are part of the system as human failure is more complex and less understood

Another inductive logic technique is the fault tree Whereas the event tree is often used to determine accident probabilities or probability of plant failure, fault trees are frequently used to define system failure The event tree technique is often called a "bottom up" procedure because it is initiated with the fault at the bottom, and worked up to the top event, which is the accident A fault tree technique is often called a "top down" procedure because the start is the top event i e system failure, and the procedure determines which failures would be needed to cause system failure, eventually working back to the identification of the root causes, and the assignment of probabilities to failures

More detailed descriptions of individual modelling methods are contained within Covello and Merkhofer (1993)

2 3 3 Estimation of likely consequences

The next step in the risk assessment process is concerned with determining the likely consequences of hazard realisation The consequence calculation is essentially accomplished by determining the physical processes and phenomena that are associated with each accident sequence These physical processes and phenomena then determine, via appropriate accident models, the consequences that are generated by the accident sequence

Models for determining likely consequences vary in complexity with that of the processes at work If the consequences are identical every time the hazard is realised they will be simple to predict The process of exposure to risk, and consequences of exposure to risk in many situations is very complex This can be illustrated by looking at the consequences of an accident at a nuclear facility that releases radioactive material into the atmosphere

If the interest was in the consequences to the population residing around the plant the first step would be to determine the number of people who would be exposed to the radioactive agent. This would involve determining how many people live in which areas, and also modelling how much of the agent comes into contact with the population in a certain time This will involve modelling the weather conditions and how they affect dispersal After determining the population affected, a second step would be to model the effects on that population This may be a function of the age, prior state of health, and other factors The provision of an accurate risk assessment, therefore, may involve modelling very complex processes, the historical data for which may not be available, especially for new technologies

2 4 *Risk assessment in aviation*

Risk assessment in aviation, as with other risk assessment applications, has been dependant upon the nature of the process and the data available. Risk assessment has been carried out by a number of different bodies within the aviation industry, and a selection of different types of risk assessment in aviation is described in the following section

2 4 1 *Insurance purposes*

Firstly, risk has been assessed for insurance purposes Obviously, these risk assessments are commercially sensitive and therefore not widely published or readily available However, it was stated by Paul Hayes (Director of Air Safety for Airclaims Ltd) that the risk assessments that are carried out are usually relatively simplistic qualitative assessments (personal conversation, 2001) This is because it is very often the case that the market decides the level of premium rather than the risk So for example, although an airline may be perceived as having a relatively high risk of an accident the premium offered may have to be lower than justified because competitors are prepared to offer a lower premium Where insurance is required for an unusual risk, or a one off activity, for example a round-the-world balloon attempt, the risk assessment will be of a more quantitative type and will be more likely to take account of the actual risks involved rather than an average Quantitative risk assessments for insurance purposes are carried out for the quoting of insurance against the loss of a satellite These are based on historical data of booster failure rates

2 4 2 *Comparative risk per airline*

A second category of risk assessment in aviation includes that carried out for purposes of determining comparative risks of flying on different airlines Obviously, air passengers are concerned with the relative risks of flying on different carriers, and businesses would like to know to what risks they are exposing their staff when they are flown on different airlines

Typically, these comparisons are based on historical data of fatal accidents (Airsafe com, 2001, and Air Travelers Association, 1998) Discussion of the various methods of comparison has mainly concerned whether the methods used to determine the relative risk of fatality or crash accurately assesses the "safety" of an airline Barnett and Wang (2000) discuss the different methodologies in use in more detail

A number of major problems exist with this type of airline comparison

Firstly, the risk is determined solely on historical data Whilst this is a valid approach where the underlying causes of risk remain constant, this may not be a valid method in the aviation context Within the aviation system there exist accident investigation authorities. These are charged with investigating the causes of accidents and incidents and making recommendations that ensure that an accident cannot be repeated So, if the system worked as it was intended, the historical data would provide no indication whatsoever of future risk The reduction of the overall accident rate over time provides some evidence of this It is also plausible that an airline that suffers an accident may be less likely to suffer a further accident than an accident-free airline because of the lessons learned and the reduction of complacency.

Secondly, the comparison of risk per airline implicitly assumes that the difference in risk is due to the differences in airline operation, particularly between so-called "developing-world" and "advanced-world" carriers Oster, Strong, and Zorn (1992) conclude that there are significant differences between the accident rates of carriers of different regions, but also between carriers within regions However, they were unable to construct safety rates by carriers by regional market, which would be required to determine whether the airline or the region is the principal source of risk A similar analysis was presented in a Flight Safety Foundation report that compared approach and landing accident rates of operators of different regions but did not control for different route networks (FSF 1998) This was achieved by Barnett and Wang (2000) who claim that when mortality risk per airline is compared on routes that are flown by airlines from advanced and developing world carriers the risk is comparable

An airline comparison methodology that attempts to take account of some of the other contributors to risk is that proposed by Flightsafe Consultants Limited (2001) This methodology also includes fleet average age, fleet composition, air traffic control environment, airfield environment, airline operations, system of regulation, type of airline ownership, type of airline management, and the degree of airline involvement in technical or commercial alliances While it is accepted that these attributes may influence crash risk, in many cases the mechanisms are not proven and the weightings therefore arbitrary The result of the risk assessment therefore depends greatly upon the judgement of the researcher

2 4 3 Ground operations

As the air transport system becomes more congested there is an increased interest by airline management in risk assessment and management to control the risks posed by operations at airports One methodology for assessing and managing ground operations risk has been developed and described by Ashford, Ndoh, and Brooke (1996) The risk analysis model employed is that of

Covello and Merkhofer (1993), but has been extended to include a risk diagnostics component that attempts to provide answers as to why a particular accident or incident occurred, and therefore tries to integrate the risk assessment and management tasks The methodology also attempts to provide answers as to the most cost effective areas of accident reduction, and optimal levels of self-insurance

2 4 4 *Airworthiness certification*

Aircraft airworthiness certification involves large numbers of risk assessments at a number of different levels They are incorporated in the drafting of the aircraft design and operations regulations by the certification authorities, in showing compliance with the regulations by the manufacturers of the aircraft, and in determining maintenance schedules Risk assessments have been conducted at various levels of formality for quite some time, probably for as long as the rules have existed Pugsley (1939) wrote that "data on gust loads and landing accelerations is reaching statistical dimensions, and from such statistics it becomes clear that it is unreasonable to design for strength adequate for all possible gusts or all possible adverse landing conditions". Obviously, if a judgement were made as to the design level of strength, some sort of risk assessment would need to be carried out as to the risk of exposure to certain gust strengths, or landing conditions This may have been a statistical analysis, or could have been a more qualitative assessment

In general as statistical data on failure rates became more readily available, a more probabilistic approach to designing for a certain failure rate was adopted This is described more fully in Tait (1994)

An early example of modern risk assessment techniques being used in aircraft certification is given in the airworthiness objectives for Concorde and which were designed with the intention of achieving on the aircraft at least the same safety levels as those likely for subsonic aeroplanes introduced into service at the same time (TSS, 1969) The standard sets down maximum rates of occurrences for events of different consequences and states that a safety assessment of each system should be carried out in order to ensure that failures were within the tolerable criteria The standard also states that the assessments for rates of failures should be quantitative where that was possible, and assessments for errors due to flight crew or to maintenance action could be qualitative and should indicate how human error was to be minimised by attention to crew load, accessibility, and ergonomics

Lloyd and Tye (1982) describe the methods and techniques of safety assessment of aircraft systems The techniques broadly correspond to the stages or risk assessment described above, but it is acknowledged that the exact form will depend on the system being assessed The general structure is as follows

1. *System definition*
2. *Preliminary hazard analysis*
   Including definition of failure of the system, consequences of failure to the aircraft and occupants, consequences of other malfunctions of the system, and identification of possible sources of flight crew and maintenance error
3. *Formulation of safety objectives for the system*
4. *More extensive failure analysis*
   Perhaps involving fault tree analysis or dependence diagrams (similar to a fault tree) combined with quantitative failure rates
5. *Comparison of calculated probabilities of hazard realisation with safety objectives for system*

2 4 5 Third party risk assessments

There have been conducted a variety of third party risk studies both in the UK and abroad, and which have been reviewed by Piers (1996), Ale and Piers (2000), and Caves (1996) They have been undertaken mainly as evidence for various public enquiries into proposed airport developments, and attempt to determine the risk to the population residing around the airport of death due to being hit by an aircraft

The various methods that have been used to calculate third party risk around airports all contain three main elements

1. The probability of an accident per movement
2. A model of the likely distribution of accidents around the airport under study
3. A model of the likely consequences of an accident

2 4 5 1 Probability of an accident per movement

In all cases the accident rate is determined from historical data on numbers of relevant movements performed, and the number of accidents that occurred during these movements The accident rate thus calculated is multiplied by the number of movements forecast in the design year for the particular airport development under consideration Many of these assessments assume that the underlying accident rate will remain constant over time, and that all efforts to reduce that rate will not be successful The following diagram shows the global accident rate over time

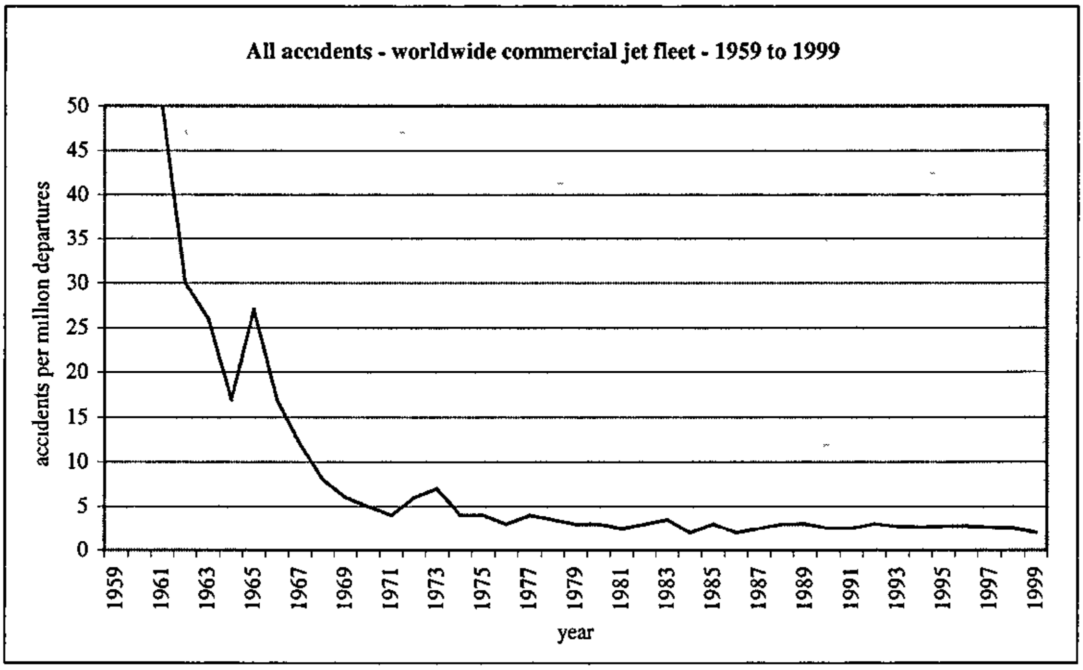


Figure 2.2 (Redrawn from Boeing, 2000)

It can be seen that until the early seventies the accident rate did indeed change greatly with time, although the rate of change has certainly decreased Since the late seventies the rate has not changed at a rate comparable to those in the previous twenty years although the rate has not been stagnant, and therefore the assumption that the rate will not change over time does not appear to be valid, and instead invites a periodical review

An alternative method of determining the probability of an accident, which has been used widely in other technological risk assessments, is event tree analysis However, it is not ideally suited for use in determining aviation accident probability Firstly, it relies on knowledge of the sequence of events that could lead to an accident. Aviation is an extremely complex system involving many different organisations and many of the different actions involve humans The outcomes of human conducted processes can depend on a huge number of factors, many of which are yet to be determined Consider an example of a pilot reading the instruments The probability of the instruments being misread may depend on the design of the instruments, the time of day, the light in the cockpit, the background level of activity in the cockpit, the fatigue of the pilot, whether there is an air traffic control instruction issued at the same time, and possibly many other factors The processes are not known in many cases, and if known the ability to forecast the incidence of many of these factors, is currently extremely limited Also, this is just one example of an opportunity for error For an accident to occur many of these errors may have to occur together A second reason why event tree analysis is not a suitable technique is that knowledge of how the system works and which factors can lead to an accident is extremely poorly understood In many cases, the findings of an accident report come as a surprise to most people outside those actually involved in the accident If people had been asked to assess the likelihood of the occurrence of the factors present in an accident before the accident had occurred, in many cases they would be unsuccessful This is illustrated by the fact that a large number of people in the industry are charged with the problem of doing just that, in order to reduce the accident rate, and still accidents occur

Having decided to use historical data to determine the probability of accident occurrence, the next step is to decide which historical data to use, and this involves a certain amount of subjectivity

Obviously the most relevant accidents are going to be those that have occurred at the airport under study However, just using these accidents will result in a database that is very small The other end of the scale would be to use all the accidents that have occurred around the world, but this would result in a database containing accidents that were irrelevant for a number of reasons For example, the time frame may be different, the type of traffic may not be representative, or the operating conditions may be different

Various studies have used different criteria for their selection of relevant accidents This has resulted in different accident rates and a huge range in the size of the databases

Slater (1993) uses airport related civil aviation accidents that occurred in the UK between 1981and 1992 For aircraft with a maximum take off weight of over 5700 kg the rate is 0 33 accidents per million airport movements This is based on 5 accidents in 15,049,000 movements Obviously this is a relatively simple method but is easily understood The major problem is the reliance upon such small numbers. One more or less accident has large affects on the accident rate, it will increase or decrease it by 20 %

Hillestad (1993) uses a far more complex method for assessing accident risk at Schiphol International Airport in Amsterdam Firstly, global accident rates for various types of aircraft are taken from Flight Safety Digest (1993) for large, medium, and small aircraft, and for general aviation An accident rate for East European aircraft is taken to be twice that of West European aircraft but this factor is not justified in any way Secondly, a set of 114 global accidents occurring between 1987-1991 is examined and it is determined that 14 percent of these could not have happened at Schiphol and therefore all the above accident rates should be scaled down by 14 percent Finally, a forecast of the fleet mix at Schiphol is combined with movements to give likely numbers of accidents occurring at Schiphol in a number of various design years

A danger with complicating the accident rate methodology is that a huge number of assumptions can be introduced, as described above Firstly, the assumption is that aircraft size plays a part in accident risk, for which there exists little evidence Secondly, the assumption is that East European aircraft are inherently less safe than West European aircraft There exists anecdotal evidence that this may be the case, but there also exists evidence that other factors such as geographical area, or type of airline operation play a larger role in determining risk. Thirdly, to state that the accident rates should be scaled down by fourteen percent presumes that the set of 114 accidents is totally representative of the accidents that were used to determine the accident rates Finally, these accidents were chosen on the basis that they occurred to aircraft types that were expected to use Schiphol in the future, the assumption being that each accident occurred because of some inherent quality of that aircraft type

The danger of incorporating large numbers of assumptions is that the outcome of the risk model is heavily dependant on their choice, and a large amount of uncertainty will surround the result

In the calculation of an accident rate, DNV Technica (1994) use a database of crashes that occurred during takeoff/initial climb or landing/final approach at airports in Western Europe and North America during 1980-1992 Certain crashes were then removed from the data

- Crashes where mountainous terrain was a factor
- Crashes associated with a minor airport
- Non-jet crashes
- Non-scheduled crashes
- Crashes occurring to aircraft under 5700 kg
- Test, training flights
- Business, private flights
- Ambulance, medical flights
- Pest control flights
- Landing overshoots
- Approach crashes within 200 metres of the runway apron
- Aborted takeoffs unless more than 200 metres off the runway strip
- Crashes on or to the side of the runway strip

Some of these were excluded because they do not fall within the remit of the study, but most were removed because it was assumed that an accident to these types of aircraft was not relevant This decision incorporates some invalid assumptions Firstly, in excluding accidents that have occurred at minor airports it is assumed that none of these accidents would have occurred had the aircraft been flying to or from a large airport, and therefore that the accident risk is dependant upon airport size Secondly, the exclusion of non-jet and non-scheduled accidents involves the assumption that the likelihood of an accident varies with the type of power plant fitted or with the type of flight Thirdly, the exclusion of accidents where mountainous terrain was a factor involves the assumption that the mountain is always the sole cause of the accident, and that the aircraft would not have crashed had the mountain not been there

Many different ways of determining an accident rate are used yet in most studies there seems to be little justification for the use of one methodology over another These examples serve to highlight an area in which there exists a large amount of anecdotal evidence but very little evidence from scientifically rigorous studies, namely the determinants of the probability of an accident, or rather, the areas of aviation in which the determinants of the probability of an accident are more prevalent

2 4 5 2 The accident distribution model

Many of these risk studies have used an accident distribution model to determine the location of likely accidents These models can be split roughly into three categories.

The models of Solomon (1974), and Aho (1995) divide the area around a runway into segments and then map the historical accident locations onto this area The number of accidents in each cell is then counted This is a rather crude method that will result in large areas with the same impact probability This method also assumes that future accidents will occur with the same location distribution patterns as in the past These models do not differentiate between take off and landing accidents which might be expected to have different distributions. Therefore, unless the datasets contain exactly the same number of each type of accident, the distribution they describe will be skewed to a certain extent

The models of Roberts (1987) and Phillips (1987), Jowett & Cowell (1981), and Slater (1993), all describe the accident location probability for a particular location as a function of the cartesian co-ordinates of that location relative to the runway These models are based on a reasonably large dataset, however, the data contains a considerable number of military accidents (including fighters) and light aircraft accidents, which may not be representative of large civil aerodrome traffic.

The models that have been developed by Smith (1991), Hillestad (1993), Couwenberg (1994), and Gouweleeuw (1995) all try to model the accident location relative to the intended route of the aircraft Unfortunately, many accident reports do not contain accurate location descriptions, and even less describe the intended route of the aircraft, also it is a dubious assumption that an aircraft in severe difficulties will be trying to follow the route used in normal operations

The model developed by Smith (1991) is derived from very small sets of data The longitudinal distribution of probability along the flight path is calculated from just 8 takeoff accidents and 12 landing accidents The lateral distribution of probability is based on expert judgement as to the likelihood of the aircraft diving in a shallow or a steep dive with normal distributions given for any heading change. A model for pilot avoidance of populated areas is also incorporated, however, this is formed entirely from expert judgement

The Hillestad model is also based on a relatively small dataset of 53 accidents, 41 of which occurred on landing, 12 on takeoff There are several problems with this data Firstly, the model uses locations relative to the SID or STAR, but the data points were measured relative to the extended runway centreline Secondly, the dataset is made up from a selection of Boeing data but the criteria for the selection of the data is not given so it may not be representative of world-wide experience Finally, as the data is mainly from landing accidents the distribution is skewed towards the landing condition

NLR (Couwenberg, 1994, and Gouweleeuw, 1995) has developed eight separate route-relative accident location models, based on varying numbers of data points

	Data points
• Heavy traffic (>5700 kg) takeoff accidents beyond the runway end	55
• Heavy traffic landing accidents before the runway threshold	84
• Heavy traffic landing accidents beyond the runway end	39
• Heavy traffic takeoff accidents adjacent to the runway	29
• Heavy traffic landing accidents adjacent to the runway	95
• Light traffic (<5700 kg) takeoff accidents	142
• Light traffic landing accidents before the runway threshold	227
• Light traffic landing accidents beyond the runway threshold	138

The locations of these data points have been translated into individual probability models and have been used in risk analyses for Amsterdam Schiphol, Groningen Eelde, London Heathrow, and Helsinki Vantaa Although these models contain relatively large numbers of data points, being route relative they suffer the uncertainties outlined above concerned with the fact that most accident reports do not describe the intended route, and that a stricken aircraft may deviate from the intended route in a very complex way

The one assumption common to all these models is that the location distribution will be identical at all airports All the models ignore the actual determinants of aircraft location, which is likely to be dependant upon factors peculiar to an airport such as the characteristics of the ground beyond the end of the runway

2 4 5 3 The consequence model

Due to a lack of data, many models of air accident consequences incorporate a high degree of expert judgement and many assumptions, for example the AIRCRASH model (DNV Technica, 1994) used to determine third party risks associated with the second runway at Manchester Airport, and the RAND (1993) model used for assessing the third party risks at Schiphol Both of these models make assumptions for the determinants of consequences and the probabilities of the relevant variables

Other models have incorporated data from accidents in order to reduce uncertainty, this category includes the NLR (Piers, et al 1993) model, a model developed by Eddowes (1994), and a model developed by NATS (Evans, et al 1997) These models, however, are relatively simplistic and the NLR and NATS models have associated with them high degrees of uncertainty. The NLR model uses average area affected, and the NATS model uses aircraft weight to predict debris area and area destroyed, however with R squared values of 0 29 and 0 08, the NATS model does not predict consequences very well at all

2 4 6 Overrun risk assessments

The most recent overrun risk assessment conducted in the UK was conducted in order to assess the risks associated with overrun accidents at Southampton International Airport (Eddowes, 1999), and was qualitative rather than quantitative The structure for the risk assessment conformed to the classic risk assessment model as follows

1 *Hazard Identification*
   Comprised a group review process and was supported by a review of historic overrun accidents
2. *Consequence analysis*
   Comprised a review of historic data on the distance travelled by aircraft that have overrun
3 *Estimation of occurrence likelihood*
   Comprised a qualitative assessment of the significance of present factors using expert judgement
4. *Risk evaluation*
   The identified risk was evaluated against the risk tolerability criteria.

The study referenced an outline risk assessment methodology suggested by the U K Civil Aviation Authority (CAA, 1998) This methodology also conformed to the classic model of hazard identification, consequence evaluation, occurrence likelihood estimation, tolerability evaluation, and risk management Although the authors of the CAA document stress that the methodology is suggested rather than prescribed, the actual hazard identification and mitigation is pre-empted by suggested causal factors and remedies, in a way which suggests that they are proven, when this is not the case This suggestion of unproven factors to look for also has the possibility of improperly leading a hazard identification, when this exercise should be carried out objectively by persons possessing knowledge of the actual aerodrome Although a qualitative risk assessment, in order to cover all the possible hazards may well require the management of processes identified by expert judgement rather than scientific evidence

The above examples of risk assessment in aviation are not the only ones, as it is carried out for a vast number of different bodies in different circumstances, but form an attempt to provide a description of a range of the more relevant and common employments of the technique Obviously, as the nature of the risk and the understanding of the risk vary, so does the application of the risk assessment technique

3 Overrun risk management and mitigation

3 1 Introduction

The measures that are employed within the aviation industry to protect against the aircraft from overrunning the runway end, and mitigation of the consequences of overrunning fall into two categories Firstly there are those measures that try to reduce the occurrence and mitigate the consequences of all types of accident or incident, and secondly there are those measures that are specifically targeted at the overrun occurrence. However, this may not be the most useful division as many measures contain elements that attempt to control many types of risks as well as ones that control overrun risk specifically

3 2 The design of the system

The title for this section may not be quite right because the global aviation system has not been designed as a whole but has evolved over a period of time into the system that exists today In general the system has been reactive, operations have been performed until a problem has arisen, and regulations or a change in operating technique has been introduced to reduce or eliminate the problem This is true in almost every area of the system from airworthiness certification (Tait, 1994), to aerodrome design (ICAO, 1984) to aircraft operations (FSF, 1998) The system as it operates today is comprised of two main elements, design and operation of the aircraft, and the design and operation of the infrastructure Both of these elements and the regulations that surround these elements are products of all of the preceding years experience

3 2 1 Design and operation of the aircraft

3 2 1 1 General airworthiness

Suitability of the aircraft for flight is ensured through the application of two sets of regulations One set governing the performance that is to be expected from the aircraft, and a second set governing how that aircraft should be flown The International Civil Aviation Organisation sets down minimum requirements for airworthiness and continued airworthiness of aircraft, and also the operating regulations, and individual states devise codes that govern aircraft operated by airlines based within that state Not all states devise codes to the same level of detail, and some just require that operations in that state should be governed by the detailed codes of another state. The ICAO publication that contains the minimum standards and recommended practices for the airworthiness of aircraft is Annex 8 to the Chicago Convention on International Civil Aviation (ICAO, 1988), and the standards and recommended practices concerning the operation of the aircraft is contained in Annex 6 (ICAO, 1998) Individual states are not required to rigidly conform to the standards of ICAO but if differences exist the state is required to inform ICAO of the difference In practice most countries conform, some go beyond the minimum requirements, but there are slight differences because ultimately it is for individual states to determine how they will achieve the minimum standards and recommended practices The civil aviation authority in a particular state will be the body responsible for ensuring that operations within the state conform to the standards and recommended practices, and usually will issue documents which are its own interpretation of them It will then be charged with ensuring compliance with its own regulations

The foundation of the performance requirements in the UK is a scale of target probabilities that was developed in relation to statistics of past aircraft accidents and incidents, with the basic aim of ensuring that the most undesirable events are the least likely to occur This is illustrated in table 3 1

In the U K all public transport passenger-carrying aeroplanes are split into four main classes (Swatton, 2000) These are as follows

1. *Class A Aeroplanes*
   Used for all multi-engined turbo-propeller aeroplanes having ten or more passenger seats or a maximum take-off mass exceeding 5700 kg and all multi-engined turbo-jet aeroplanes
2. *Class B Aeroplanes*
   Includes all propeller driven aeroplanes having nine or less passenger seats and a maximum takeoff weight of 5700 kgs or less
3. *Class C Aeroplanes*
   Includes all piston engined with ten or more passenger seats or greater than 5700 kg maximum takeoff weight
4. *Unclassified*
   Includes aircraft that have specialised design features that make them unable to comply fully with the requirements of the appropriate class

In order for a certificate of Airworthiness to be issued by the appropriate regulatory body (in this case the U K Civil Aviation Authority) the aircraft must meet the performance requirements of the class as above but must also comply with certain operating regulations which vary between the classes The basic philosophy behind this approach is to ensure the highest standards of performance are attained by the largest aircraft carrying the largest numbers of fee paying passengers, but that the safety levels achieved across classes are harmonised by applying the most stringent operating regulations to the aircraft with the lowest performance capabilities

In practice the operating regulations will specify a maximum weight that an aircraft is allowed to operate in certain environmental conditions such as temperature, pressure, wind speed etc and under certain physical constraints such as takeoff and landing runway length These restrictions will be contained within a flight manual, which will present this information to the pilot and comprise part of the certificate of airworthiness The construction of the performance limitations contained within the flight manual will involve the demonstration of the aircraft's performance under certain conditions, and a factor added to the demonstrated capability to allow for variations from the demonstrated performance (usually assumed to be near the highest performance capable in those conditions) in everyday service throughout the life of the aircraft

3 2 1.2 Prevention of overruns

An overrun occurs when an aircraft attempts to land or to takeoff, abort, and stop on the runway, and is unable to do so and therefore travels past the runway end Aspects of the operating regulations are directly concerned with preventing this from happening

3 2 1 2 1 Landing

As mentioned above, part of the certification process requires that the distance that the aircraft needs to land and come to a stop (from a specified height above the runway surface[1]) under different meteorological conditions be demonstrated For Class A aircraft the demonstrated distance then has a safety factor added to it, and the landing distance declared by the airport as being available for landing must always exceed the required landing distance plus safety factor, this is enforceable in law Joint Aviation Authorities requirements (to whose regulations UK certificated aircraft have to conform) are that Class A jet aircraft have to include a factor of 1 67 to the demonstrated distance, and Class A turboprop aircraft must include a factor of 1 43 This is intended to always ensure that the aircraft has enough runway to allow for occasions where it is necessary to use more runway than demonstrated and still not depart the end of the runway. It also implicitly indicates that the risk of departing the runway end is reduced by having more distance between the demonstrated distance and the runway end, and therefore conversely that the risk would be increased in cases where the excess distance is reduced

To take account of reduced braking effectiveness on a wet runway for Class A aircraft a further factor of 1 15 has to be added to the calculated dry required landing distance and is contained within JAR – OPS 1 This brings the regulations for certification of UK aircraft into line with those of the US

3 2 1 2 2 Takeoff

The regulations that are concerned with protecting against an overrun after a rejected takeoff are contained within the same JAA publication as those for landing The operating regulations regarding

[1] 50 ft for a normal landing under JAR-25

takeoff performance are governed by the requirement to ensure adequate performance should an engine failure occur These regulations assume an engine failure at the most critical point, which would be decision speed on a balanced field A balanced field is a runway on which if an engine failed at decision speed the aircraft would require the same distance to continue the takeoff and reach a height of 35 ft as it would to decelerate and come to a stop The decision speed is the speed below which if an engine failed the aircraft would not be able to reach a height of 35 ft at the end of the runway, and above which if an engine failed the pilot would not be able to slow and stop on the runway This is illustrated in figure 3 1

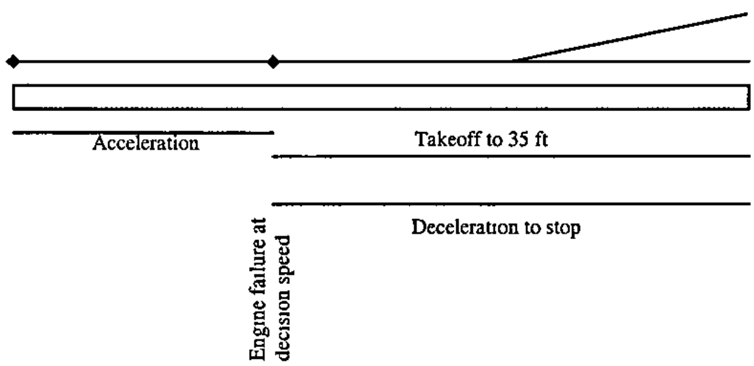


Figure 3.1 Balanced field

The regulations for the operation of Class A aircraft in the UK require that the accelerate stop distance required is greater than the accelerate stop distance available at the aerodrome (in order for the takeoff to be legal other runway distance requirements have also to be met) The accelerate stop distance required is the greater of the following four distances

1 *Accelerate stop distance required – all engines operating (dry hard surface)*
The distance required for the aircraft to accelerate to decision speed plus two seconds, and then to decelerate from this point to a full stop on a dry hard surface

2 *Accelerate stop distance required – all engines operating (wet hard surface)*
The aircraft is required to accelerate to the highest speed from which the aircraft can stop within the accelerate stop distance available plus two seconds, and to decelerate from this point to a full stop on a reference wet hard surface

3 *Accelerate stop distance required – one engine inoperative (dry hard surface)*
This is the distance taken on a dry hard surface to accelerate from a standing start to engine failure speed with all engines operating, then to continue the acceleration

for two seconds past decision speed with one engine inoperative, then to decelerate to a full stop with one engine inoperative

4 *Accelerate stop distance required – one engine inoperative (wet hard surface)*
The distance taken on a reference wet hard surface to accelerate from a standing start to engine failure speed with all engines operating, then to continue the acceleration for two seconds past the highest speed from which the aircraft can stop within the accelerate stop distance available, then to decelerate to a full stop with one engine inoperative

No safety factors are provided on top of these distances so if the accelerate stop distance required equals the accelerate stop distance available at an aerodrome, and an engine fails at decision speed, as long as the pilot reacts as supposed to, and the runway surface is as expected, the aircraft will come to rest exactly at the end of the runway. If the conditions on the day are worse than those demonstrated in certification, the aircraft would depart the end of the runway. However, this should only occur if the engine failure occurs at the most critical point, decision speed The certification authorities have presumably made the assumption that the likelihood of an engine failure at decision speed is sufficiently remote to make the risk posed by sub-standard operation on the day of an engine failure acceptable

In both the takeoff and landing case the actual meteorological conditions and the aircraft weight on the day will alter the distance that the aircraft will need to stop after a landing or a rejected takeoff The available landing distance and the available accelerate stop distance will always need to be in excess of the required distance regardless of the conditions The conditions that the flight manuals take into account are generally aircraft weight, runway slope, wind, air pressure, temperature, and give some guidance for very wet and contaminated runways

3 2 2 Design and operation of the airport

3 2 2 1 Aerodrome design dimensions

The design of the aerodrome has to relate to the characteristics of the aircraft that will use that aerodrome, and the standards and recommended practices that govern aerodrome design also originate from ICAO and are contained within Annex 14 to the Chicago Convention on International Civil Aviation (ICAO, 1999) The authority responsible for civil aviation in a particular country will then usually try to comply with the recommendations and if it is unable will inform ICAO of any differences As with the regulations for the design and operation of the aircraft in the UK this body is the Civil Aviation Authority The version of ICAO's standards and recommended practices that is enforced in the UK by the Civil Aviation Authority is contained in CAP 168 (CAA, 2001) In order for an aerodrome to be used for public transport in the UK it must be licensed by the CAA, and to become licensed must comply with the requirements of CAP 168. A number of the regulations contained within this document are directly related to the minimisation of the overrun risk and the mitigation of the consequences of an overrun

Chapter three of CAP 168 contains the requirements for the physical characteristics of the aerodrome The physical characteristics vary with the aerodrome reference code, which in turn depends upon the characteristics of the aircraft that intend to use the aerodrome The aerodrome reference code is as shown in 3 2 below. The code is made up of two parts, one of which depends upon the length of runway that is provided at the aerodrome, which in turn has usually been determined by the runway requirements of the type of aircraft that the aerodrome has been designed to accommodate The second element of the code depends upon the physical dimensions of the largest aircraft that is likely to operate at the aerodrome

3 2 2 1 1 *The runway*

The maximum longitudinal slope of the runway is dependent upon the aerodrome code number in that the slope should not be greater than one percent for aerodromes of code number 3 or 4, or more than two percent for aerodromes of code numbers 1 or 2 This therefore provides maximum limits of runway slope, and the actual effect of the slope on the landing distance and accelerate stop distance will be accommodated by the change in required distance as indicated by the flight manual and described in *3 2 1* above

The runway is surrounded by an area of ground which one of its purposes is to reduce the risk of damage to an aeroplane running off the runway It is designed to achieve this by meeting longitudinal and transverse slope requirements, by having bearing strength adequate to support aircraft that stray on to it and emergency services vehicles, and by being clear of obstacles or ditches which may damage an aircraft It should be cleared and graded and be able to bear the weight of an aircraft and emergency vehicles regardless of the aerodrome reference number

The runway strip should extend beyond the runway end and stopway for 30 m where the code number is 1 and the runway is a visual runway If a runway where the code number is 1 is an instrument runway or the code number is 2, 3, or 4 the runway strip should extend for 60 m beyond the runway end and stopway Various widths are specified for visual runways, for an instrument runway the strip should extend each side of the centreline and extended centreline of the runway from 60 m before the threshold to 60 m beyond the end of the declared landing distance for a distance of at least 150 m where the code number is 3 or 4 and 75m where the code number is 1 or 2 This provides an area into which the aircraft is able to run without suffering major damage

In addition to the runway strip are provided runway end safety areas These are areas at the ends of a runway designed to minimise damage to aircraft that run off the end of a runway or land short of a runway They should be provided at each end of the runway strip enclosing all runways where the code number is 3 or 4 and where the code number is 1 or 2 if the runway is an instrument runway It is stated that a runway end safety area should have a minimum length of 90 m where the code number is 3 or 4 and 30 m where the code number is 1 or 2 and the runway is an instrument runway It is also stated that runway end safety areas extend to at least 240 metres where the code is 3 or 4 and up to at least 120 metres where the code number is 1 or 2 and the runway is an instrument runway The minimum width should normally be twice that of the associated runway, symmetrically disposed about the extended centreline of the runway The surface of the strip need not be prepared to the same standard as the runway strip but should not hinder the movement of rescue and fire fighting vehicles, or endanger aircraft Figure 3 2 pictures the strip and runway end safety area of a typical runway (not to scale)

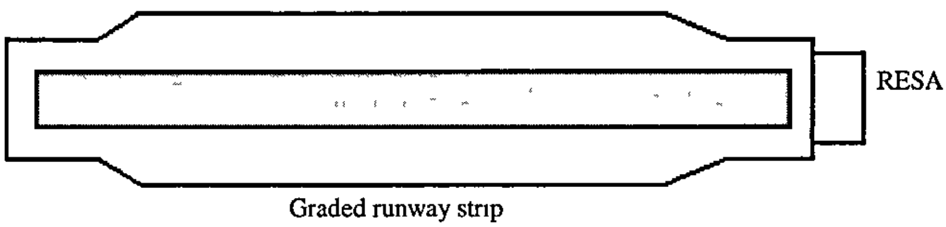


Figure 3.2

Until recently the criteria for provision of safety areas was solely dependent upon the code number of the aerodrome, which in turn is dependent upon the reference field length of the design aircraft However it may not be the case that overrun risk is totally dependent upon reference field length, and therefore mitigation measures may not be tailored to the actual risk of overrun occurrence An attempt at reducing this mismatch has been made by adding that as part of the aerodrome's safety management system that the aerodrome licensee should determine on an annual basis the runway end safety area requirement through the use of a risk assessment. The CAA guidance document for the assessment of overrun risks in relation to runway end safety areas was described in 2 4 6

If the aerodrome code number approach to overrun consequence mitigation (still the primary determinate of runway end safety area provision) is compared to overrun avoidance and consequence mitigation provided by regulations governing the operation of aircraft described above, it can be seen that the two methods do not naturally relate The factors applied to landing distances ımply that the rısk of an overrun ıs reduced by provıdıng runway greater than that demonstrated to be necessary, and there ıs no reason why thıs should not also be the case for the rejected takeoff occurrence Operatıons at aerodromes vary greatly ın the mıx of aırcraft runway requırement, on take off or landıng, and avaılable runway length If ıt ıs ındeed the case, as ımplıed by aırcraft operatıng regulatıons, that the rısk of an overrun varıes wıth the excess amount of runway remaınıng, the provısıon of runway end safety areas by aerodrome reference code would result ın a mısmatch and result ın the actual rısk of occurrence and extent of consequences varyıng greatly between dıfferent aerodromes

3 2 2 1 2Rescue and fire fightıng provısıon

The mınımum scale of rescue and fire fightıng servıces to be provıded at an aerodrome depends upon a reference code, whıch ın turn ıs based on the sıze of the largest aırcraft that ıs expected to use the aerodrome durıng a twelve-month perıod The codes for the categorıes that correspond to the largest aırcraft are contaıned wıthın table 3 3 The codes take account of the fuselage length and wıdth, and whıle not matchıng rescue and fire fightıng provısıon to the rısk do ensure that adequate provısıon ıs made for the most extreme case that ıs lıkely to occur at the aerodrome

3 2 2 1 3Safety management phılosophy of the CAA

The approach to safety management at an aerodrome ın the past has been that as outlıned above, ı e to set and enforce rıgıd regulatıons However, there appears to be an ıncreasıng change ın thınkıng A number of documents have been publıshed by the CAA whıch have suggested that the evolvıng methodology to be requıred ıs one whıch bears more of a resemblance to the recognısed prıncıples of rısk assessment and management that have been descrıbed ın chapter 2 (see "Guıdance on aerodrome development procedures" (CAA, 2000), "Guıdance for developıng and audıtıng a formal safety management system" (CAA, 2000), and "The management of safety" (CAA, 2000)) These documents descrıbe a process where the lıcensee shows to the CAA that rısks have been ıdentıfied, assessed and mıtıgated where necessary, the CAA provıdıng an audıt of the process as carrıed out by the lıcensee

In 1998 a document was publıshed by the UK Cıvıl Avıatıon Authorıty entıtled *"Rısks from aeroplanes overrunnıng aerodrome runways"* Thıs was brıefly mentıoned towards the end of the prevıous chapter and ın 3 2 2 1 1 Thıs document states that the runway end safety area provısıon stıpulated ın CAP 168 ıs a mınımum requırement and ıs desıgned to accommodate the statıstıcal majorıty of overruns and to mınımıse theır consequences The document agaın emphasıses that the regulated should demonstrate that rısk has been managed systematıcally and guıdance ıs provıded ın that document specıfically to assıst the assessment of consequentıal rısks arısıng from overruns at a particular aerodrome The guidance suggests the adoption of tolerability criteria as contained in the regulations concerning the certification of large aircraft JAR 25 (JAA, 1994), and contained in table 3 1 This would ensure a step towards the harmonisation of the overrun risk management philosophy between the licensing of aerodromes and the certification and operation of aircraft

As stated in the previous chapter the document outlines a risk assessment and management methodology that conforms with the methodology used in other industries. The document outlines the steps in the risk assessment process, and perhaps because of the acknowledged industry wide lack of understanding of the overrun occurrence, advocates a qualitative risk assessment Again as stated in the previous chapter, the worrying aspect of this document is the suggestion of overrun risk factors where the causal links have not been proven The authors of the report have compiled a list of factors involved in overrun accidents as follows

- Runway contamination and / or runway friction characteristics
- Obstructions beyond the runway end safety area
- The lack of approach aids, particularly precision instrument systems
- The non-use of public transport performance safety factors by flights when the runway length is critical and adverse weather prevails
- Problems encountered close to decision speed on take off
- A malfunction of an aeroplane system
- The type and / or operating characteristics of aeroplanes using the runway
- Failure to adhere to approved operating techniques, and other inappropriate action by flight crew

It is stated that, "prior to any attempt to reduce accidents, causal or contributory factors must be known and understood In the case of overrun accidents the causes have usually been the result of one, or a combination of, the [above factors]" It is debateable whether the inclusion of such a list is entirely useful to the overall risk assessment process

Firstly, the document states that overrun accidents have <u>usually</u> had the above as causal or contributory factors Why has only a sample of the total been given? Surely it would be more useful to give a complete list and leave the decision as to the relevance of the factor to a particular aerodrome to the risk assessment practitioner Also, the list appears to be very subjective in its choice of factors, particularly concerning the lack of approach aids One recent overrun in the UK (Fokker-70, East midlands Airport, (AAIB, 1996)) occurred after the aircraft had flown a fully coupled automatic approach and landing with the pilots simply providing braking during rollout This plus the fact that a precision approach is not intended to alter the overrun risk at all, rather to deliver the aircraft in worse weather to the same touchdown position as a non-precision approach, suggests that a properly scientific study of overrun risk may not come to the same conclusions Also, Savage (1999) stated that in British Airways operations an increasing number of poorly executed visual approaches were due to lack of practice by the pilots, rather than any intrinsic characteristic of the approach

Secondly, three of these factors maybe unconnected to any possible actions of an aerodrome licensee, which could lead the licensee to believe the aerodrome can do nothing to affect a substantial proportion of prevailing overrun risk factors, although it was highlighted later that characteristics of the aerodrome may influence the actions of the pilots This leads on to the third point, which is that in order for a risk assessment practitioner to assess the applicability of a risk factor, more needs to be known about each case It is not sufficient to know the factors present in overrun accidents in isolation, an understanding needs to be achieved of how these factors combined with other factors, aerodrome or otherwise, to result in an overrun in those particular circumstances, whether it is unusual for those factors to occur in normal operations, and also whether the operations which suffered these overruns are similar to the operations conducted at the aerodrome under study

The arguments for including such a list are that where the practitioner has no knowledge of overrun risk at all, it is useful to provide a starting point, and a good starting point would be past experience However, it is questionable whether a risk assessment by a person not possessing any understanding of the risk represents best practice, and it may not result in the risk being managed in the most effective and efficient way.

3 3 Evolution of the system

The methods of controlling risk through aircraft and aerodrome licensing described above constantly evolve through experience and feedback from the operators themselves An example of this is the move towards a safety auditing approach adopted by the UK Civil Aviation Authority (see CAA guidance documents above), and the updates and amendments to aircraft certification and operating regulations This kind of feedback tends to prevent serious mismatches between the application of the regulations and the actual operation of the system However, often this is only effective where the possible outcomes are relatively self-evident On occasion flaws exist within the system, which are hidden from the operators of the system and only manifest themselves when a particular combination of circumstances arise If enough of these circumstances manifest at the same time and place, an accident can arise Obviously, the fact that the system has broken down to the extent that an accident has occurred, is cause for some alarm and in order to determine whether it is cost effective to prevent similar accidents in the future, the causes of the accident must be determined

3 2 1 Accident and incident investigation

Annex 13 of the Chicago Convention on International Aviation published by the International Civil Aviation Organisation (ICAO, 2000) contains the international standards and recommended practices for signatory states for aircraft accident and incident investigation An interpretation of these practices is then incorporated into the laws of the individual countries In the UK these regulations take the form of the Civil Aviation Regulations 1996 (The secretary of state for transport, 1996), which charge the secretary of state with appointing inspectors of air accidents, and who form a body known as the Air Accidents Investigation Branch of the Department of Transport, Local Government, and the Regions The objective of the investigation of an accident or incident under these regulations is the prevention of accidents and incidents, which is accomplished by issuing recommendations to bodies involved in the accident, which may or may not decide to alter their method of operation accordingly

A major problem with this approach, however, is that by definition the Air Accidents Investigation Branch only become involved after an accident or incident has occurred, and therefore only after the system has broken down to a great extent A number of participants within the industry have formed the opinion that in order to better prevent accidents in the future initiatives have to be taken before an accident has happened (see Savage, (1999) and Rebender, (2001)) These initiatives have come from various sources and attempt to identify risk factors and potential sources of problems before an accident occurs

3 2 2 Incident reporting schemes

One hypothesis is that a better understanding of the system as a whole, in addition to its failings will enable pilots and other participants to better manage the operation of the system However, in many cases safety issues do not come to light because of fear of punishment Rather than address the root cause of this situation, which is the lack of understanding in the population as a whole of how best to manage safety and a general unwillingness to accept collective responsibility for an undesired circumstance, attempts have been made to overcome the result by setting up confidential reporting schemes These attempt to provide a way of disseminating safety information to those who may be most in need of it, without fear of punishment for those reporting the problem

3 2 2 1 The Chirp Charitable Trust

CHIRP is an acronym that stands for the UK Confidential Human Factors Reporting Scheme Although existing since 1982, it was established in its present form in 1996, and is funded by the UK Civil Aviation Authority The corporate structure of the organisation is selected in order to be an independent body that is able to attract and disseminate information on air safety issues Information that is received by the scheme is validated and then made available as widely as possible whilst maintaining the confidentiality of the source When it is appropriate to do so, report information is discussed with relevant agencies with the aim of finding a solution, and whilst still maintaining confidentiality A newsletter containing disidentified information is sent four times a year to all commercially licensed pilots, air traffic controllers and engineering personnel, and a database is maintained with the objective of identifying and analysing trends

The following excerpt is taken from the April 2001 Chirp newsletter (CHIRP, 2001)

In my Company it is increasingly expected that we use contingency fuel to cover many foreseeable and, indeed, planned variations These include

- *Operation at greater than, or less than, planned Mach Nos to satisfy ever greater demand for on time arrival due to overstretched terminal handling facilities "It is not policy to load extra fuel for this purpose "*
- *Published statistical variations in route fuel "When statistics show a recommendation to carry extra fuel only sufficient extra should be uplifted for the predicted additional fuel burn over and above the planned contingency fuel, not in addition "*
- *Inability to get planned flight levels - (much) lower levels accepted before engine start*
- *Regular periods of cruise at uneconomical speeds due to slower traffic ahead or faster traffic behind*
- *Frequent en-route time restrictions on airways with 15-minute separation*
- *Fuel used during Push and Hold and Remote hold operations*
- *En route track lengthening due avoidance of forecast weather - and much more*

There is no doubt that the Company has cleared its policy on contingency and extra fuel with the CAA. The question is whether the CAA has cleared all this with the "man on the Clapham omnibus" sitting on the jury by whom the Captain, accused of endangering the lives of his passengers by carrying too little fuel, will be judged

It will be no consolation to me to find the CAA and my Flight Operations Director in the same cell!

It can be seen that in this report the pilot is not only able to criticise the policies of his own company, but also those of the Civil Aviation Authority Also, the submission of the report to the CHIRP scheme provides an indication that the pilot hopes that by doing so, something may be done about it This report also highlights a further argument about whether the public should be privy to more information on the workings of the aviation system Many within the industry feel that safety should not be talked about at all because the public are not fit to come to a proper decision and will decide unreasonably that it is not safe The writer of the above report certainly feels that if the public knew more about some of the workings of the system there may be calls for change, which could ultimately be the most morally acceptable solution. Arguments certainly exist for a wider dissemination of aviation safety information, one of which is that secrecy breeds mistrust, however, a fuller discussion of these arguments is better placed outside of this thesis If the public knew more and considered the system less safe than in the current situation they could demand increased safety, therefore improving things for those in the industry concerned that the public wouldn't understand

3 2 2 2 ASRS

ASRS stands for the Aviation Safety Reporting Scheme, which is a scheme similar to CHIRP and run by NASA Its purpose is to identify deficiencies and discrepancies in the American National Aviation system Like CHIRP it is a voluntary reporting system that aims to be confidential and non-punitive Also like CHIRP it disseminates information through a newsletter and bulletin, and provides a database for analysis However, the database of ASRS is available to anyone who would like information from it unlike the UK system, which is a secure system only open on request to other safety systems and professional bodies

3 2 2 3 Other confidential reporting systems

Other systems exist which are based on the ASRS / CHIRPS model and these include

• Confidential Aviation Safety Reporting System	Canada
• SECURITAS	Canada
• Confidential Aviation Incident Reporting System	Australia
• Voluntary Aviation Reporting System	Russia
• Taiwan Aviation Confidential Aviation Reporting Enterprise	Taiwan
• Korean Confidential Aviation Incident Reporting System	Korea

3 2 3 Individual airline efforts

Obviously an individual airline may be best placed to recognise problems with the system as a whole and many airlines are becoming more proactive in their approach to safety The realisation is occurring that an accident can be disastrous for the long-term profits of an airline and it may no longer be acceptable to simply assert that the airline was fully compliant with the relevant regulations There may also be an underlying feeling that the system of regulation functions too slowly to adequately protect against all types of safety deficiency, and therefore in order to avoid accidents it is the airline that needs to take the lead This is generally being accomplished in one of two ways

3 2 3 1 Reporting schemes

Many of the world's airlines have tried to embrace the principles of the confidential reporting schemes described above by setting up internal schemes, however, these operate according to many different philosophies due to the vagaries of the political systems and cultural climate prevalent in different countries Because of these differences, some of the schemes will receive many reports and will attempt to operate with minimum blame in order to obtain the maximum safety benefit, while others, due to fear of punishment for those submitting the report, will be much less effective

3 2 3 2 Flight monitoring schemes

Flight monitoring schemes were first introduced into airline operations in order to reduce maintenance costs The system consisted of a quick access recorder being installed in an aircraft, which could record specified characteristics that could then be easily analysed The system enabled maintenance costs to be reduced by enabling the maintenance to be better coordinated with the actual operational stresses of the aircraft rather than generic measures such as hours flown This system developed as it was realised that it could become a powerful safety analysis tool as it enabled the operation of the aircraft to be monitored Trends could be investigated, the impact of different types of training and equipment could be evaluated, and areas of concern, be they geographic or systemic, could be highlighted Again the take up of these systems has depended upon many factors and therefore their extent varies throughout the world. Many European airlines have made significant use of these systems (Savage, 1999), however, US airlines have made slower progress due to issues concerning disclosure of the data (FSF, 1998)

3 2 3 3 BASIS

BASIS is an acronym that stands for British Airways Safety Information System This is a computerised system, which aims to bring together the different elements of various reporting systems and flight monitoring schemes and which is available to any airline If an airline bought all of the various modules they would have a system that would be comprised of monitoring schemes for flight crew, cabin crew, maintenance, and ground handling, together with auditing tools and a facility for exchanging disidentified incident data with other airlines. In addition would be the facility to monitor flight operations and perform incident analyses through the use of simulation (BA, 2001)

Obviously, due to the airline specific nature, information from systems such as these is highly confidential The danger would be that if it were made public, an airline that was very proactive regarding safety, and encouraged safety reporting may appear less safe than one which punished those that spoke out and therefore received fewer reports

4 Advances in methodology

Three main advances in methodology are proposed to aid the risk assessment of overruns The first of these is a normalisation method, which will normalise the overrun wreckage locations beyond the runway end for the effects of meteorological and terrain conditions The second is a method for determining the likely normalised wreckage location, which takes in to account the length of runway and its relationship to the required distance The third is the proposed use of an overrun risk model which will determine overrun risk given certain operational characteristics

4 1 Current methodology and justification for change

4 1 1 Normalisation of wreckage location

4 1 1 1 Current methodology

Current methods of assessing the adequacy of runway end safety areas, public safety zones, and third party risk assessments all make use of wreckage location models, which model wreckage location relative to the runway end Many of these use wreckage location models, which are based on the wreckage locations of past accidents Examples of these models that include overrun locations are the NLR model (Piers, 1993), and the NATS model (Cowell, 1997), which has recently been adopted for the determination of Public Safety Zone dimensions in the UK The philosophy behind the use of these models is that the locations of past overruns can be used to predict locations in the future and also at aerodromes which have not suffered overruns This assertion may be flawed however because a study of these accidents reveals that there is evidence that wreckage location may be determined by local conditions If so, the assumption that the distributions would remain the same regardless of local conditions would result in calculations of risk that would not resemble the true levels of risk In the UK where Public Safety Zones are based on the generated risk contours of such a model, the result may be that some locations may suffer stricter planning controls than that warranted by the risk, and other locations less strict

4 1 1 2 Terrain characteristics

The influence of local terrain characteristics on overrun wreckage location is illustrated by the following examples The first of which was an aircraft that overran the runway after a landing in the United States on the 30th of December 1989 The deceleration characteristics are taken from the flight data recorder and are depicted in figure 4 1

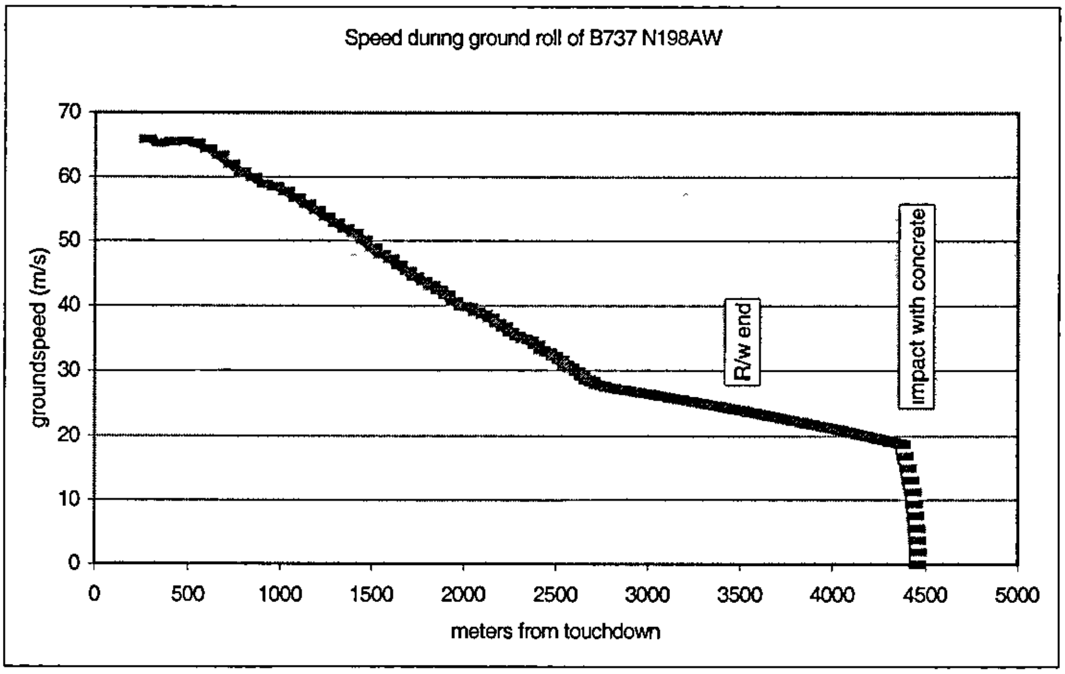


Figure 4.1

The aircraft's brakes failed whilst decelerating on the runway, which accounts for the decrease in the rate of deceleration The area beyond the runway end was also paved and the deceleration of the aircraft did not change with the transition The aircraft was on fire at this point and the pilot tried to slow the aircraft by aiming for what he thought was a ditch and which turned out to be the remnants of a concrete arresting gear structure After crashing into the concrete the aircraft came to an abrupt halt It is plausible that at a different aerodrome with different terrain characteristics, the aircraft could have come to rest in a very different location The aerodrome was the intended destination aerodrome, so the pilot did not therefore choose it for any particular characteristics

Figure 4 2 shows the deceleration characteristics of a DC-10, which overran the runway after a landing at John F Kennedy Airport in New York It can be seen that the rate of deceleration of the aircraft after the runway end decreased, the opposite to that which occurred in the previous example. This is also likely to be due to the conditions of the terrain because after the runway end was 150 m of paved area, which sloped down towards a tidal waterway

Figure 4 3 is an example of an overrun for which the rate of deceleration remained largely unchanged after leaving the end of the runway This was a BAe 146, which overran after a landing at Rifle / Garfield County Airport, Colorado, on the 20th of February 1996 These are just three examples from aircraft that overran and for which deceleration information was available from the flight recorder or report Many more examples exist for which deceleration information is not available but it is likely that the local conditions may have severely affected the wreckage position A Learjet collided with the ILS antenna, which the report stated as bringing the aircraft to a halt

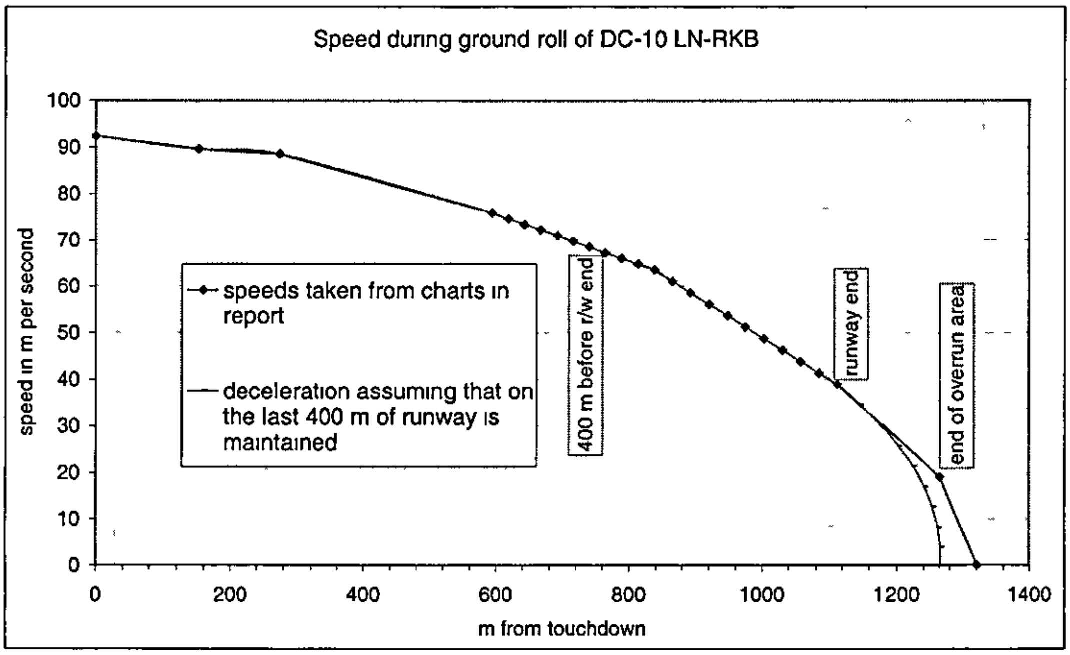


Figure 4.2

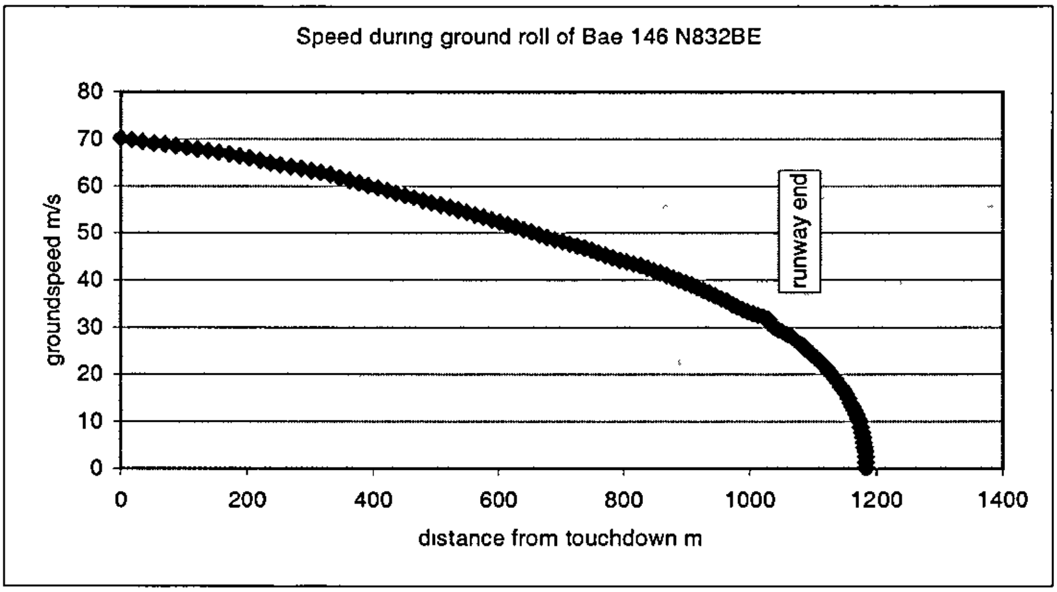


Figure 4.3

A Cessna Citation travelled off the end of the runway, became airborne again off an embankment, crashed into the ILS localiser and came to rest in a trailer park Other aircraft have encountered terrain as varied as downslopes, embankments, snowbanks, lakes, ditches, fences, railway lines, construction sites, and vehicles on roads, and in parking lots. To assume that these aircraft would come to rest in the same places at other aerodromes with very different terrain characteristics would not seem to be justified

4 1.1 3 Characteristics accommodated by the flight manual

The performance of an aircraft, both in terms of landing distance and accelerate stop distance, can be greatly affected by local conditions at an aerodrome This is reflected in the flight manuals, which govern the amount of runway needed for an operation under certain conditions The major factors which affect the distances and which are included in the flight manual calculations are runway slope, altitude, and air temperature

If a runway slopes downhill, the distance taken to come to a stop will be greater In the accelerate stop case the aircraft will accelerate quicker, but will decelerate at a lesser rate, consequently the affect on overall distance will not be as great as in the landing case The affects will be reversed on a runway that slopes uphill

The altitude and air temperature affect the landing and accelerate stop distances in the same way At high altitudes and temperatures the air is less dense than at lower altitudes and temperatures In the landing case in less dense air the aircraft experiences less drag, consequently it flies faster through the air and any aerodynamic braking devices such as reverse thrust or spoilers will not be as effective as in denser air, and the landing distance will be greater In the takeoff case in less dense air the engines will be less effective and the distance taken to reach flying speed will be greater As the wings will also generate less lift at a given speed, flying speed will be greater Also, in the case of a rejected takeoff, any aerodynamic braking devices will be less effective, all of which combines to produce a greater accelerate stop distance requirement in less dense air

As the distances are affected by these conditions, which can vary greatly between aerodromes and would affect distance requirements greatly, it seems as though any attempt to model wreckage position should take these into account in some sort of normalisation The normalisation methodology proposed is described later in this chapter

4 1 2 Methodology for determining likely normalised wreckage location

As stated above, current wreckage location models do not take into account the local terrain or meteorological conditions Neither do they make any attempt to make reference to the differing operational characteristics of the aircraft involved in runway overruns, or relate this to the length of runway they overran For example, a current model may include an overrun as depicted in figure 4 4

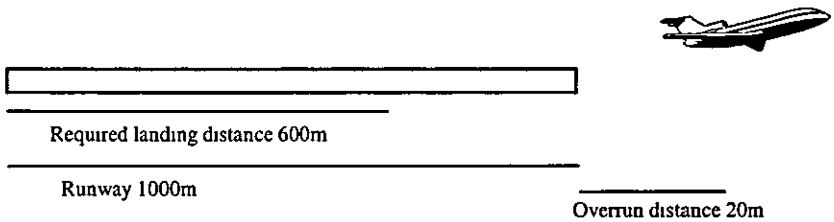


Figure 4.4

A small business jet has a required landing distance of 600 metres on a 1000 metre runway The aircraft has overrun the runway by 20 metres Current model methodology would include this overrun as an overrun of 20 metres, but the distance of 20 metres would be the only characteristic of the overrun that would be referenced in the model

The reasons for the aircraft coming to a stop twenty metres past the end of the runway are likely to be a complex combination of the circumstances of the overrun Likely factors could be the actual landing distance requirement and how that relates to the runway length, the runway surface condition and slope, and the characteristics of terrain beyond the runway end, amongst others The terrain beyond the runway end may be particularly important, as if it was the case that the aircraft left the runway at a high speed and stopped suddenly on collision with an object, this needs to be known in order to assess the outcome at an aerodrome with different terrain characteristics In fact, current wreckage location models ignore every characteristic of the overrun that may lead to a different outcome at other aerodromes, and average characteristics are assumed at every aerodrome that is assessed For the reasons outlined above every aerodrome is not likely to be the same and therefore a methodology is proposed which accommodates some of the most influential of these factors, in order to more properly match the location model to the individual circumstances of the assessed aerodrome The construction of a model is described later in this chapter

4 1 3 Overrun probability model

The most recent overrun risk assessments in the UK have been qualitative in nature (see Eddowes, 1999) These have involved assessments by a combination of outside consultants and people who have been more closely involved with operations at a particular aerodrome However, since a large amount of data on the nature of past overrun accidents and incidents has never been collected, the conclusions drawn may not be born out by past experience While experts may be very well placed to assess the consequences of an overrun at a particular aerodrome, assessing the factors which could cause an overrun with no or limited knowledge of the characteristics of actual past overruns may well result in a risk assessment which is not very accurate The argument that a pilot is the only person qualified to assess the risk may also not be one hundred percent correct While it is certainly true that a pilot who has extensive flight experience knows what happens in normal flights, to say that they can therefore determine all the circumstances in all types of operation that may result in an overrun may be spurious However, in the absence of data on past events a risk assessment must make use of available resources, and obviously expert judgement is one of these resources, but if the subject can be illuminated by the collection and analysis of freely available data, it is felt that an attempt must be made to do so

The collection and analysis of past overrun data and the construction of risk models is described in the following chapters

4 2 The proposed normalisation of wreckage location

4 2 1 Procedure

The procedure for normalisation that has been adopted is as follows

1. Normalisation for terrain conditions after the runway end

If deceleration information is available from the flight data recorder, normalisation can be carried out by the determination of the distance that the aircraft would have travelled had there been an infinite length of runway, and by assuming that the deceleration that was achieved on the runway was continued To avoid the introduction of subjectivity as to the period of runway deceleration (in a typical landing rollout an aircraft will experience a number of different rates of deceleration) it is assumed that the deceleration would have continued at the same rate as the average rate achieved on the final 400m of the runway

Where deceleration information is not available, but aircraft mass, runway exit speed, overrun distance, and off runway ground conditions are known, normalisation is conducted according to the method described in 4 2 2 This involves a model which determines the deceleration achieved after the runway end by type of terrain, and was constructed through the use of deceleration information from those overrun aircraft for which the information was known

2 *Normalisation of the resultant distance and the required distance*

The required distance and the actual distance the aircraft took to land (from 50 ft) or to accelerate and stop can then be normalised for temperature, slope, and altitude, utilising ICAO general correction factors taken from ICAO's aerodrome design manual (ICAO, 1984) The result is a normalised distance that the aircraft took to come to rest in relation to the normalised distance that the regulations state that the aircraft should take The justification for the use of ICAO general correction factors is given in Appendix A

Required distance, in this case, is defined as the factored accelerate / stop distance or landing distance quoted by the manufacturer of the aircraft for the incident conditions. In almost all cases these will be the certificated distances in the flight manual However, in some cases, performance information may be quoted in the aircraft operating manual which is not a legal requirement, but which the pilot would be expected to take into account when deciding whether or not to take off or land under those conditions

The ICAO correction factors are

For runway slope

10 per cent for each one per cent of the runway slope, as defined as the runway length divided by the difference in elevation between the two thresholds

The aerodrome design manual states that the runway length determined by takeoff requirements should be increased by this amount It also states that the landing distance requirements may also be affected by runway slope, but does not state the extent

There will be no correction for the effects of runway slope in the accelerate / stop case on dry or wet runways as the effects of slope will tend to cancel out over the acceleration and deceleration However, where the runway is contaminated, the distance will be corrected for slope using the above factor This is because the effects of runway slope will be greatly magnified on a contaminated runway due to the depleted friction characteristics In the landing case this factor will be used as the distance is affected, this is illustrated in the study of flight manual factors Where there are changes in slope along the runway, and overrun area, the average slope over the ground run (touchdown to stop) has been used, in order to simplify the calculations.

For temperature and elevation

The distance is increased at the rate of 7 per cent per 300m of elevation

The runway length should be increased at the rate of 1 per cent for every 1 deg C by which the temperature exceeds the temperature in the standard atmosphere for the elevation

The design manual implies that if the total correction for elevation and temperature exceeds 35 % these factor increases may not be accurate, for it suggests that a specific study be carried out instead

4 2 2 Terrain condition deceleration model

4 2 2 1 Model development

This deceleration model, which describes the deceleration of an aircraft after the runway end, has utilised data taken from aircraft accident and incident reports. In the majority of cases a complete speed / time history of the deceleration period is not available, therefore average acceleration has been measured after the runway end using the following equation

$$V^2 = u^2 + 2as$$

and therefore

$$a = \frac{V^2 - u^2}{2s}$$

where

V	=	final velocity ms^{-1}
u	=	initial velocity ms^{-1}
a	=	acceleration ms^{-2}
s	=	displacement m

There are a number of factors that will affect the deceleration of the aircraft These are the type of ground that the aircraft is travelling over, the aerodynamics of the aircraft, the braking and reverse thrust, and also the initial speed of the aircraft For this analysis it has been assumed that the aerodynamic braking effects are negligible, as the aircraft are generally at the low end of the speed curve when they have left the runway surface The flight recorder information in most cases is not detailed enough to determine the level of braking or reverse thrust, although it is known that in some cases the brakes were not operating at all The type of ground that the aircraft has travelled over is known in most cases, although the description given is usually a very general description such as "unpaved"

A multiple regression was first used in order to determine whether the differences in deceleration could be explained by the condition of the brakes (i e operating or not operating), initial speed of the aircraft, and by differences in the runway surface condition This regression was conducted on the data shown in table 4 1.

The process of regression using dummy variables is as follows The three types of ground condition have been assigned values as in table 4 2 Dry pavement has been chosen as the base case and therefore has been assigned the values 0 0, and for which no ground type coefficient will be calculated The coefficient that will be calculated for an increase of the value of Z1 by one applies when the ground is icy pavement, and the coefficient that will be calculated for an increase of the value of Z2 by one applies when the ground is wet pavement In the final formula the calculated coefficients will be added or subtracted from the dry pavement values depending upon the actual ground types

The results of this first regression are contained in tables 4 3, 4 4, and, 4 5

The t statistics for these coefficients indicate that for this small sample, there is a statistically significant correlation between a and the initial speed of the aircraft, but that the values for a on icy or wet pavements are not statistically different from a on dry pavements Also, an unexpected result is that higher values of a have been achieved on wet runway surfaces than on dry runway surfaces in this sample, and would suggest that the major determinant of deceleration of the aircraft on the runway surface is not the condition of the surface The report descriptions suggest that a likely factor could be the actions of the pilot This regression has an R squared value of 0 662, which implies that 66 percent of the variation of a is explained by the changes of the independent variables

A second regression was performed on data for decelerations that have occurred after the runway end. This data is contained in table 4 6, and the results shown in tables 4 7, 4 8 and 4 9 As mentioned above, in many cases the description given in accident / incident reports of the ground condition off the end of the runway is somewhat vague, and in these circumstances some amount of subjectivity is involved in the classification of the ground The definitions of the classifications used in this regression are as follows, and dummy values were assigned as in table 4 6.

Dry pavement

Wet pavement

Icy pavement

Dry grass – Dirt or grass which is dry

Wet grass – Grass which is wet, but the aircraft rolls or skids across the surface rather than digs in

Mud – Wet dirt or grass into which the aircraft sinks or creates gouge marks

Gravel – Arrester bed gravel as described in RAE technical report 68032

Water – A lake, river, or sea

Obstacles – Large obstacles such as buildings, concrete walls, vehicles.

The classification of the ground was that which made up the majority of the ground over which the aircraft has overrun

In the second regression icy pavement has been assigned values of zero and therefore provides the reference value

The t statistics for the results in tables 4.7, 4 8 and 4 9 suggest that there is still a significant correlation between initial speed and *a* and also that *a* calculated for brakes working are not statistically significantly different from those calculated where the brakes are not working The only ground types on which the values of *a* are statistically significantly different from those values given on icy pavement are obstacles, water, and gravel This model also suggests that the values given for deceleration on dry pavement will be less than those on an icy pavement, which is not an expected result

The next regression was performed on the same dataset but the ground classification categories were combined into the following new categories with pavement / wet grass / dry grass providing the reference The groupings of ground types are based on the similarities of the coefficients and their t statistics in the previous regression The results are shown in tables 4.10, 4 11 and 4 12

Pavement / wet grass / dry grass

Mud / gravel

Obstacles / water

This regression gives results for the three categories of ground condition, which are statistically significantly different from each other, although R squared is relatively low at 0 558. This indicates that approximately half the variation in *a* is due to factors other than these classifications of ground, and initial speed, but the slightly higher value of R squared in the previous regression suggests that some of the variation is due to different types of ground condition within these broad descriptions, however the numbers of observations are too few for the values to be statistically significant

This last regression gives three equations as follows

For wet grass / dry grass / pavement

$a =$ -0 0185 - 0 06749initial velocity m/s

For mud / gravel

$a =$ -2 8065 -0 06749initial speed m/s

For obstacles / water

$a =$ -8 5365 -0 06749initial speed m/s

4 2 2 2 *Model application*

Where overrun distance, and off runway ground conditions are known, normalisation can now be conducted This would utilise the above three equations, and the original equation, which has been repeated below

$$a = \frac{V^2 - u^2}{2s}$$

To normalise to conditions of pavement / wet grass / dry grass

-0 0185 - 0 06749initial velocity m/s

should be substituted for a, and the equation resolved to obtain a distance

The normalisation is also to be carried out on those occurrences that have occurred on pavement or grass, so that effectively all are normalised to average conditions of deceleration for the particular ground type Where runway exit speed is known, this can be used to generate distance travelled on standard ground using the above formula Where it is not known, the runway-overrun distance can be used to calculate an initial speed The formula used will depend upon actual ground type as above The calculated initial speed can then be used to calculate distance travelled on standard ground as in the cases for which the initial speed is known

5 Database development

5 1 *Available data*

Once the need for a study of overrun accidents was established (see chapter 4), a review of all available sources of data was conducted These are discussed below

5 1 1 *World Aircraft Accident Summary*

This is a publication by the UK Civil Aviation Authority that is continually updated The publication contains summaries of aircraft accidents that have occurred worldwide The information that is contained is usually the date of accident, aircraft type and registration, the year the aircraft was built, aircraft operator, accident location, flight type, phase of flight in which the accident occurred, numbers of occupants, extent of damage to the aircraft, and a brief accident description The following is an example of an entry, the extent of details given is typical.

1/1/1998 Boeing 757 G-WJAN Built 97 Airtours Int.
Puerto Plata Airp., Puerto Plata, Dominican Republic. Landing Crew 8 Pax 211
Loss 8 %
The 757 was over rotated on touchdown at Puerto Plata and its tail struck the runway The pilot elected to abort the landing and divert to Santo Domingo, where a safe landing was later made The accident happened in daylight (1530L) and in VMC The aircraft was operating a charter flight from the UK via Bangor, Maine

Very rarely is there a fuller description of the accident, so while this is a useful accident search tool, its use for accident analysis is somewhat limited

5 1 2 *Flight International Annual Review of accident statistics*

The magazine *Flight International* publishes an annual review of accident statistics (Flight International, 1998) This contains similar data as the World Aircraft Accident Summary, but usually contains a less detailed description, and in general more of the entries are unknown Again, this could be used as a search tool but not for any detailed analysis

5 1 3 *SRG Fatal Accident Database*

The SRG Fatal Accident Database is a database kept by the Safety Regulation Group of the UK CAA, which contains details of global fatal accidents It contains roughly the same types of entries as the World Aircraft Accident Summary, with usually a slightly more detailed description However, as it only contains details of fatal accidents, its usefulness in a study of overruns, or any other study in to the causes of accidents, is limited

5 1 4 A review of aircraft accidents between 1984 and 1988 relating to Public Safety Zones (CAA, 1989)

This report is one of a series of periodical reports, which explore the relationship between aircraft accident locations relative to runways and Public Safety Zones in the UK The reports contain a list of accidents relating to runway ends, but the information for each accident is less than that contained in the World Aircraft Accident Summary, and the distance relative to the runway not given in many cases Also, the overruns that are included are definitely not an exhaustive list

5 1 5 Location of Aircraft Accidents / Incidents Relative to Runways (David, 1990)

This document contains brief information on commercial aircraft overruns and veeroffs that occurred in the US between 1978 and 1987 The document contains data on date, aircraft type, runway identification, length and condition, operator, and location relative to the runway Again, this is not sufficient for a detailed analysis The difficulty with the use of the above data sources is that they have all been compiled with the use of restrictive selection criteria, the most restrictive being the inclusion of aircraft accidents only. It was felt that any proper study of overruns should include all instances where the aircraft travelled off the end of the runway, whatever the outcome because it was likely that this was determined by local conditions Most of the above sources did not include occasions where an incident occurred (individual definitions of an accident and incident may vary) and none included occasions that were classified as being less severe than an incident (usually no damage or injuries) The inclusion of all instances where an aircraft travelled off the end of the runway required that the individual investigating authorities and regulators be contacted for the data, which still did not guarantee that all overruns had been included because in some circumstances the overrun need not be reported (usually where there is no damage or injuries)

It was also felt that where possible data should be taken from the original accident reports, this was because no existing databases contained data on all overruns, and that the data contained within these databases contained insufficient data to conduct a multidimensional analysis Also, it was clear after a comparison of these publications, that many of them arbitrarily omitted quite a number of accidents However, they were useful in providing a starting point for the search

5 1 6 *Overruns occurring in Canada*

The Transportation Safety Board of Canada was contacted and asked to provide details of all overrun occurrences to jet and turboprop powered aircraft between 1980 and 1998, and reports were duly sent It was not possible to determine whether other overruns occurred that were not reported to or investigated by the Canadian TSB

5 1 7 *Overruns occurring in Australia*

The Australian Bureau of Air Safety Investigation was also contacted and asked to provide details of all overrun occurrences to jet and turboprop powered aircraft between 1980 and 1998, and reports were duly sent Again it was not possible to determine whether other overruns occurred that were not reported to or investigated by the Australian BASI

5 1 8 *Overruns occurring in the UK*

The UK Air Accident Investigation Branch was contacted for information on overrun occurrences to jet and turboprop powered aircraft between 1980 and 1998, and this information was furnished in the form of accident reports and bulletins However, an unpublished document by the UK CAA (Runway end safety area provision), mentioned overrun occurrences that had not been investigated by the AAIB An effort was then made to find information on these occurrences, for some of which were found brief descriptions from the CAA SRG Safety Analysis and Data department

5 1.9 *Overruns occurring in the USA*

Overrun accidents and incidents to jet and turboprop powered aircraft occurring between 1980 and 1998 were identified through the use of the above data sources, the National Transportation Safety Board online accident and incident database (NTSB, 2001), and the FAA online incident datasystem (FAA, 2001) The combination of these three sources provides a list that contains the majority of the relevant overrun occurrences It is not possible to determine how many are excluded as some may not be reported or investigated The possibility of this is illustrated by an overrun that occurred at Washington National Airport on the 24th September 1985 This was investigated by the NTSB and the details for it are contained in David (1990) but it does not appear in the NTSB online database as an accident or incident, and when contacted, The NTSB stated that they had no information about the occurrence

The NTSB and the FAA were contacted for investigation reports for the identified overruns which were duly sent

5 2 *Quality of data*

The quality and detail of data that was obtained from the investigating authorities varied greatly. The most detail was obtained when a published report was issued which was usually when the overrun was deemed to be most serious, i e. major damage or injuries, on commercially operated aircraft. This pattern was constant for all four countries, and broadly speaking meant that the detail of the investigation became less with diminishing seriousness of the overrun Reports of overruns which resulted in little or no damage or injuries may contain little more than identification data, and a couple of sentences of description

The majority of overruns investigated by the US NTSB did not result in a published report However, these did result in a "factual report" which is a file containing all information collected as part of the investigation This was useful as in many cases it would contain information that is of use to the researcher but would not be contained in a published report, for example, the raw data from the flight data recorder of the accident aircraft The disadvantage of the "factual report" data is that conflicts often exist between statements of different parties that were involved in the overrun, for example, a difference between the statements of the pilot and the airport manager as to the runway condition, without any guidance for the reader as to the investigating authority's views on the most likely circumstances In these cases, where one circumstance seems much more likely than another it has been entered into the database, where not, neither have been entered

For a reason that is unclear to this researcher, the information which is collected for an incident investigation by the FAA is discarded after two years, so much of this information has been taken from the online datasystem which provides identification data and a short description of the events

Some of the reports contain obvious mistakes or inconsistencies For example, a Canadian report into an overrun to a Convair 580 on the 21st July 1993 (Transportation Safety Board of Canada, Report no A93P0131), states the runway limit weight for a landing at an alternate airport when the airport of landing was the destination airport Another example is the clear inconsistency contained in the report into an overrun of an Avro 146 contained within the NTSB database (NTSB, 2001). This report states that on a 7000 ft runway where the aircraft came to a halt 300 ft past the runway end (a total of 7300 ft past the landing threshold) "the airplane touched down 4600 ft beyond the runway threshold and travelled 3400 ft before coming to a halt" (a total of 8000 ft) In cases such as these, as in the case above, where one circumstance is far more likely it has been entered, where not, neither are entered

5 3 Database fields

5 3 1 Definition inconsistency

The reading of the relevant reports needed a considerable amount of time relative to that spent actually entering data Also, the actual data fields that were relevant to the study of overruns were not known For these reasons an effort was made to enter all the data from the report, which would save time going back at a later date to find relevant, and also the data would be available for future research One drawback with this method is that a large number of different terms may be used which are not all defined by the investigation bodies, and which can lead to inconsistencies in the data However, the overall affect of the definition inaccuracies in relation to the amount of data is considered to be relatively small One example of this is in runway length It was clear that different reports were quoting different characteristics as "runway length", especially in the NTSB "factual reports" Some quoted the length of paved surface, and some quoted length of declared distance while often no definition was given If there appeared to be an inconsistency an attempt to check the information with another source was made A further example was in the location of the aircraft relative to the runway In only a small proportion of reports was it stated from which point on the aircraft the measurement was taken For a large aircraft, taking the measurement from the nose or the tail could make a large difference to the proportional overrun difference

5 3 2 Size of database

The database contains 180 overruns, 137 of which have occurred after a landing, 43 after a rejected takeoff There are 185 fields in the database, of which each entry has on average half of the fields filled

5 3 3 Field definitions

The definitions of the fields within the database are presented in appendix C

6 Database analysis

6 1 Introduction

Chapter 6 contains the description and analysis of the contents of the overrun database, the compilation of which is described in Chapter 5 As stated above, the reason for the compilation of the database is to enable the determination of the major factors that affect the risk of the occurrence of an overrun, and to support the construction of models The database consists of all occasions where a jet or turboprop powered aircraft has exited the end of the runway (including where this has been onto a paved overrun), in the U S , Canada, the United Kingdom, and Australia, between 1st January 1980 and 31st December 1998, both after a landing and after a rejected takeoff The decision was made to include occasions where no injuries occurred, and the aircraft was not damaged because, in many of these cases, had they occurred at a different airport, the consequences would have been more serious

Due to there being a large amount of data in the overrun database, this chapter, which contains the analysis of the data, is also rather large In order for the reader to digest more easily the contents, all of the statistically significant and most interesting results have been presented again in summary form at the end of the chapter

Section 6 2 is an overview of the contents of the database This contains a description of the types of overrun in terms of phase, country of origin, flight type, etc Where possible, this information has been combined with information on movements in order to provide overrun rates that can be compared

Section 6 3 is concerned with aircraft weight Information on the weights of non-overrun flights was available and comparisons are made between the weights of aircraft that have suffered overruns compared to those that have not

6 4 examines the amount of distance available between the end of the required landing or accelerate stop distance and the runway end Similar data were available for non-overrun landings and this is compared with the situation during overruns Unfortunately no non-overrun data were available for the rejected takeoff case so this comparison is not made

Section 6 5 explores aircraft damage incurred in overrun occurrences A study is conducted into the correlation of damage with other characteristics such as phase, flight type, aircraft weight, runway exit speed, and numbers of obstacles encountered by the aircraft beyond the runway end The analysis of damage was necessary in order to facilitate the construction of a consequence model that is described in Chapter 8 Also in section 6 5 is an analysis of characteristics that are associated with the aircraft catching fire after an overrun, and the severity of a fire with flight phase. The reason for this analysis was mainly to test the validity in overruns of the assumption of other third party risk models (e g DNV Technica, 1994) that takeoff accidents are more serious, due to the higher risk of fire from the greater amounts of fuel on board the aircraft

Section 6 6 describes the meteorological conditions in which the overruns have occurred. Unfortunately, information on the conditions in which non-overrun flights have occurred has not been available, and therefore much of the analysis is limited to the comparison between the conditions experienced by aircraft that overran after a landing or a takeoff This comparison is still interesting as if there is a clear difference between conditions experienced by the two types of overrun, either the different operations generally take place in different conditions, or the conditions are affecting the risk of an overrun after a takeoff or a landing in a different way This information can indicate areas that may merit future research

Section 6 7 specifically examines landing overruns Firstly, touchdown point and landing speed and whether there is a difference in these characteristics across flight types The analysis then moves on to the characteristics of landing overruns that have occurred after a precision approach has been flown, compared to where an approach has been flown that was not a precision approach The main reason for this comparison was to determine the characteristics that were correlated with overruns that flew the two types of approach It was felt that this study had to be carried out, as one dimensional studies of relative risk of the two types of approach have been conducted that have totally ignored the possibility that the type of approach may not be the risk factor, but merely an indicator of other more important characteristics (i e FSF, 1998) A second related reason for this exploration was the CAA guidance document entitled "Risks from aeroplanes overrunning aerodrome runways" (1998) which suggested that the implementation of a precision approach system would universally reduce overrun risk, despite the fact that many overruns in the UK and worldwide have occurred after the aircraft has flown a precision approach

Section 6 8 describes the rejected takeoff overruns that are contained within the database Unfortunately, comparison data for non-overrun takeoffs was not available and therefore this section is really only simple description that may serve to indicate possible areas for further research

Section 6 9 shows the wreckage distributions split by flight phase It can be seen that the distributions of the two phases are very different The locations are measured relative to the runway ends as in existing models, which are then compared to distributions of the same overruns measured to the required distances, normalised, and measured as percentages to take account of the different runway requirements

As mentioned above, section 6 10 summarises the more interesting and statistically significant results of this chapter

6 2 Overview

6 2 1 Phase of flight

The database contains 180 overrun occurrences 137 (76 1 %) of which occurred after a landing, 43 (23 9 %) after a rejected takeoff

6 2 2 Country

5 (2 8 %) of the overruns occurred in Australia (100 % landing), 16 (8 9 %) occurred in Canada (81 % landing, 19 % takeoff), 26 (14 4 %) in the U K (81 % landing, 19 % takeoff), and 133 (73 9 %) in the USA (73 7 % landing, 26 3 % takeoff)

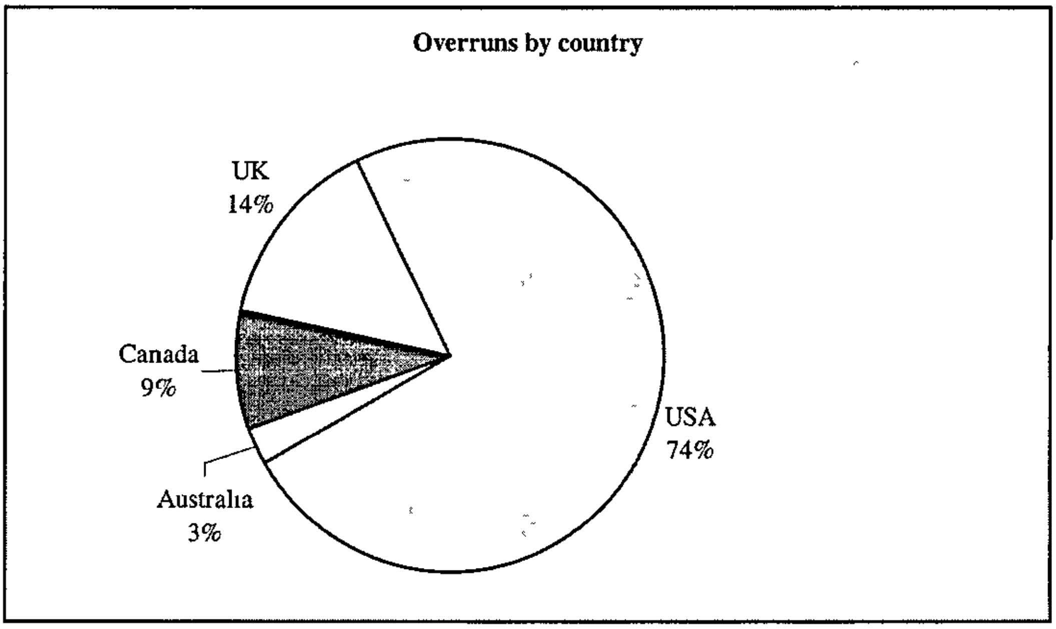


Figure 6. 1

6 2 3 Aircraft type

The database contains only fixed wing jet or turboprop powered aircraft 20 of the 137 aircraft that overran after landing and 2 of the 43 aircraft that overran after takeoff had a maximum takeoff weight of below 12500 lbs The maximum gross weight was unknown in 10 cases (9 landing and 1 takeoff) 144 of the aircraft were powered by turbofan engines, 35 were powered by turboprop engines, and one case was of an unknown engine type The maximum takeoff weights of the aircraft in the database have been split by takeoffs and landings and are shown in figures 6 2 and 6 3

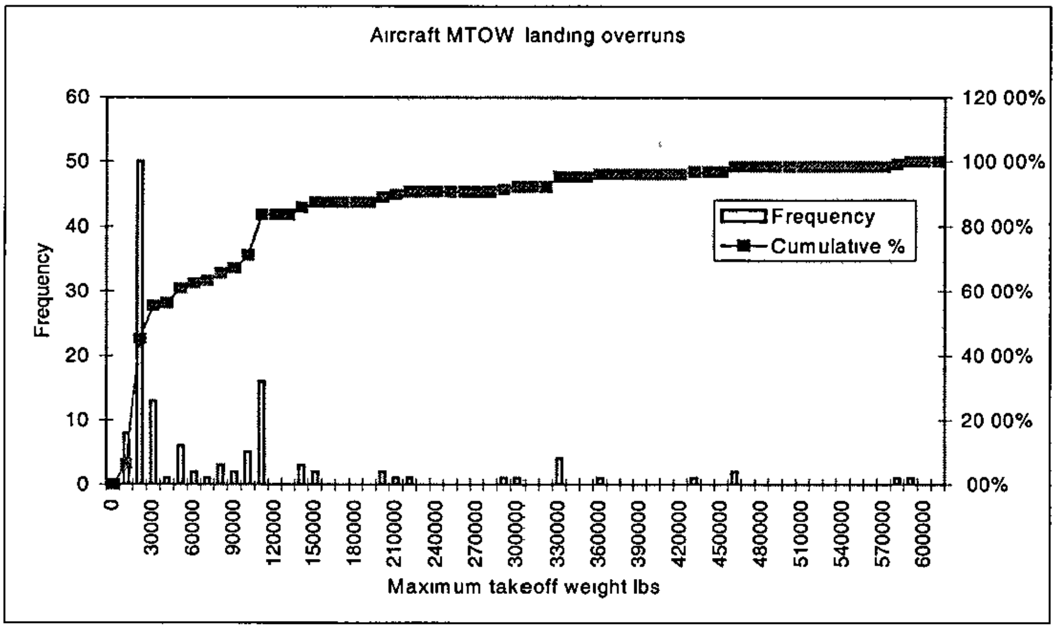


Figure 6. 2

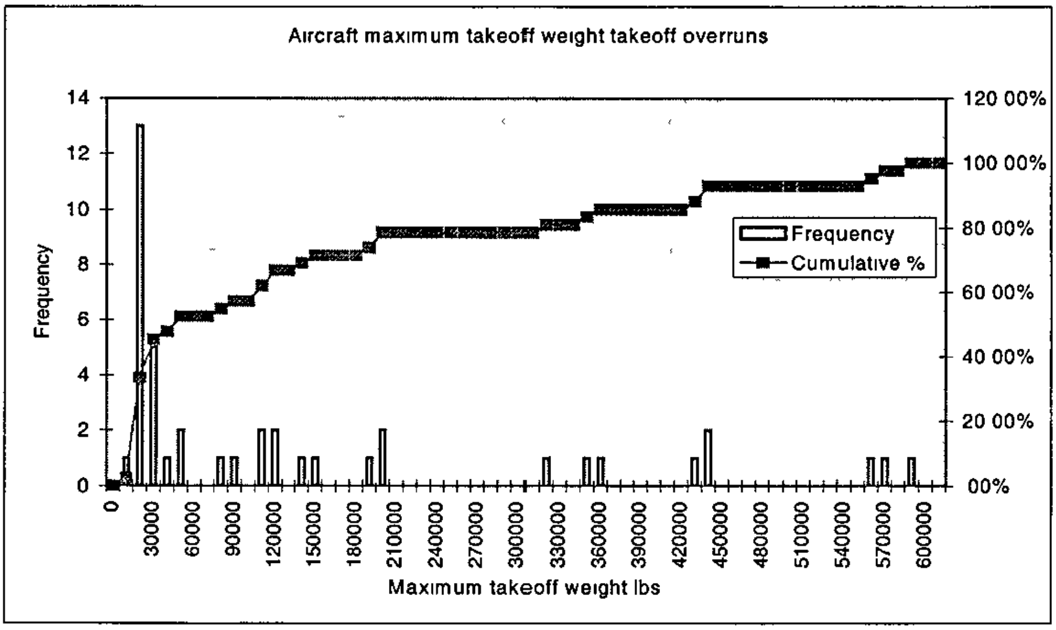


Figure 6. 3

6 2 4 Flight type

2 (1 1 %) of the overruns were of an unknown flight type, 61 (33 9 %) occurred to general aviation flights (82 % landing, 18 % takeoff), 26 (14 4 %) occurred to freight flights (76 9 % landing, 23 1 % takeoff), and 91 (50 6 %) occurred to passenger flights (71 4 % landing, 28 6 % takeoff) Flight types of all overruns are shown in figure 6 4.

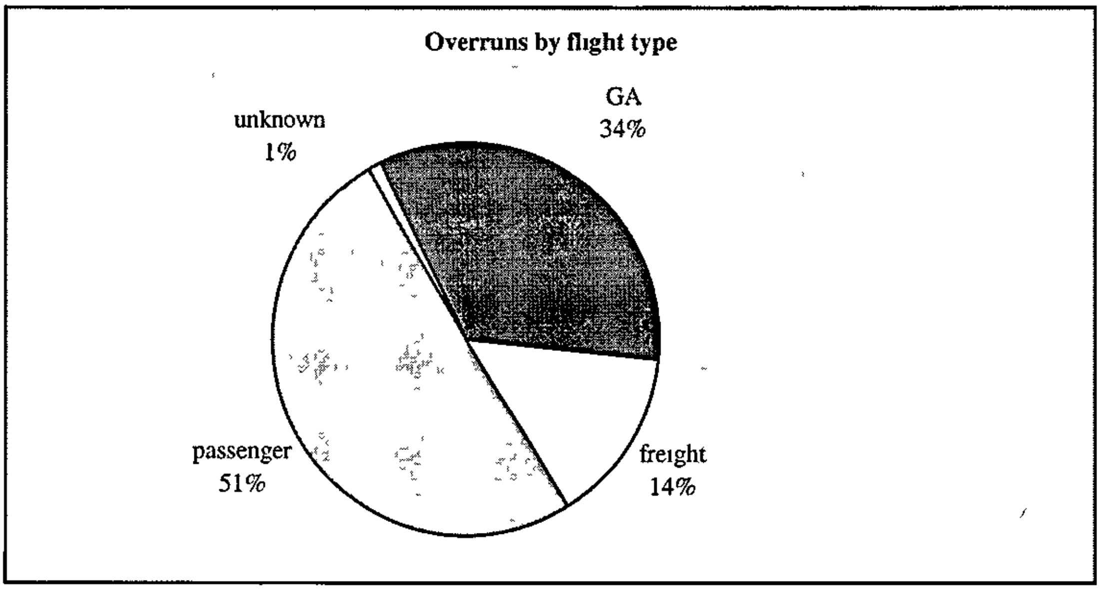


Figure 6. 4

In the U K during this period were 26 overruns, 9 of which were general aviation operations (26 9 %), 2 were freight operations (7 7 %), and 15 were passenger operations (50 %)

6 2 5 Overruns per year

Figures 6 5, 6 6, and 6 7 show overruns per year. Figure 6 7 shows that while the percentage split changes from year to year, over the study period it seems as though there has been no significant change in split per phase of flight

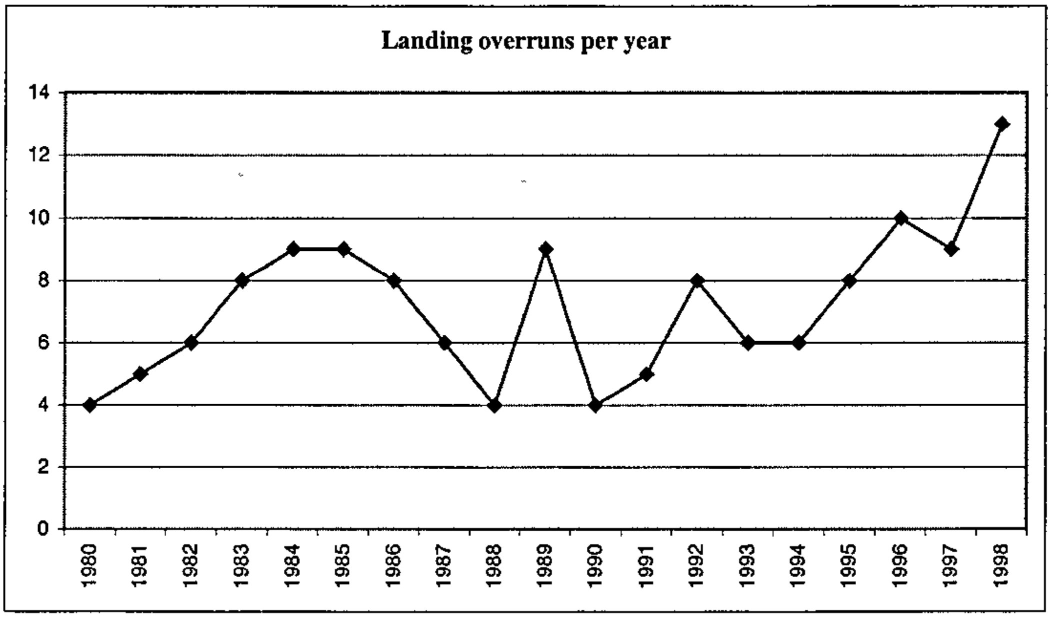


Figure 6. 5

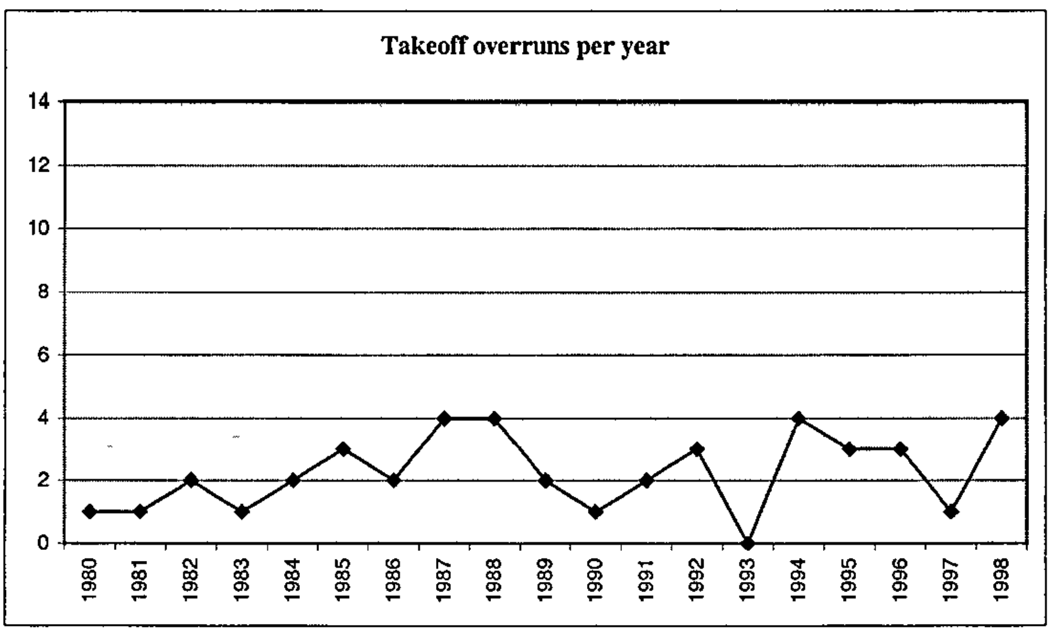


Figure 6. 6

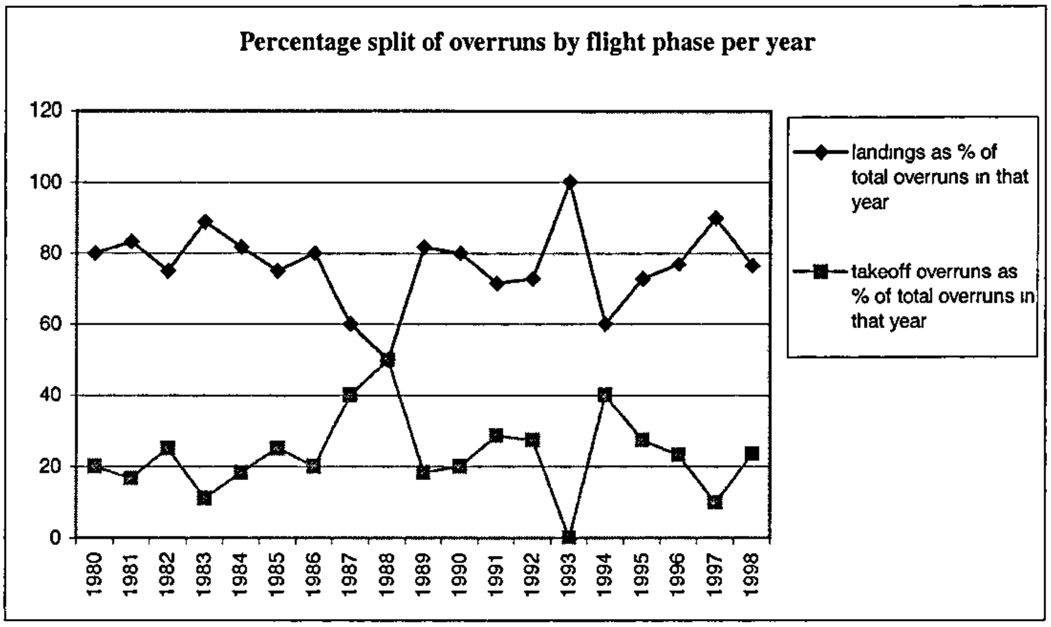


Figure 6. 7

6 2 6 Overruns per month

Figures 6 8, 6 9 and 6 10 show overruns per month It can be seen that the landing and takeoff split varies greatly from month to month During the months of May, June, July and August the ratios have been approximately 60 % landing overruns to 40 % takeoff overruns, however, during November, December, January, and February the split has been more like 85 % landing overruns to 15 % takeoff overruns Fisher's exact test indicates that the difference in proportions of each flight type in the months of January and August significant at the 0 05 level, i e unlikely to have occurred by chance As the proportions of takeoff and landing overruns seem to follow the season, it may indicate that a risk factor for landing overruns also follows a seasonal basis (given also that the absolute number of landing overruns is increased during winter months)

As Chapter 6 contains a large number of statistics that have been tested for significance, only the result of the test in terms of the significance will appear in the text from this point forwards Appendix B contains information on the tests that were employed

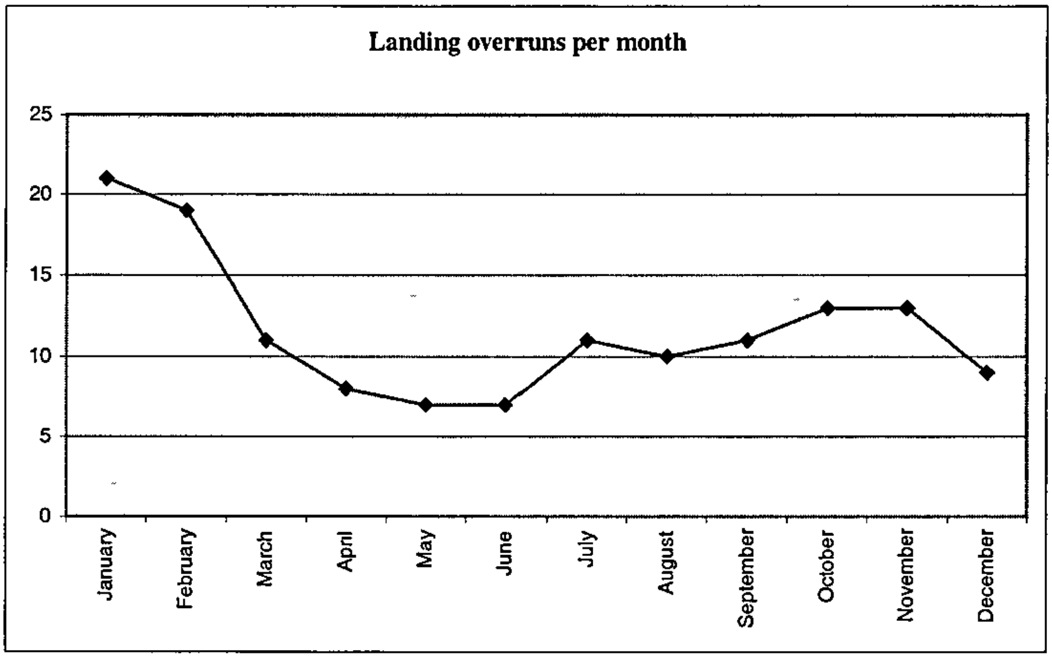


Figure 6. 8

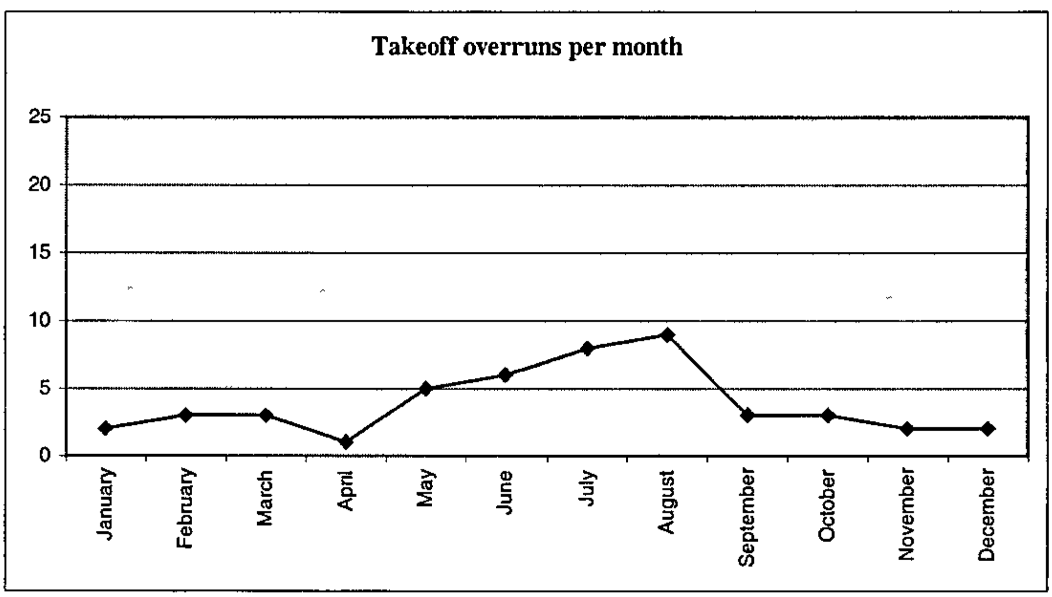


Figure 6. 9

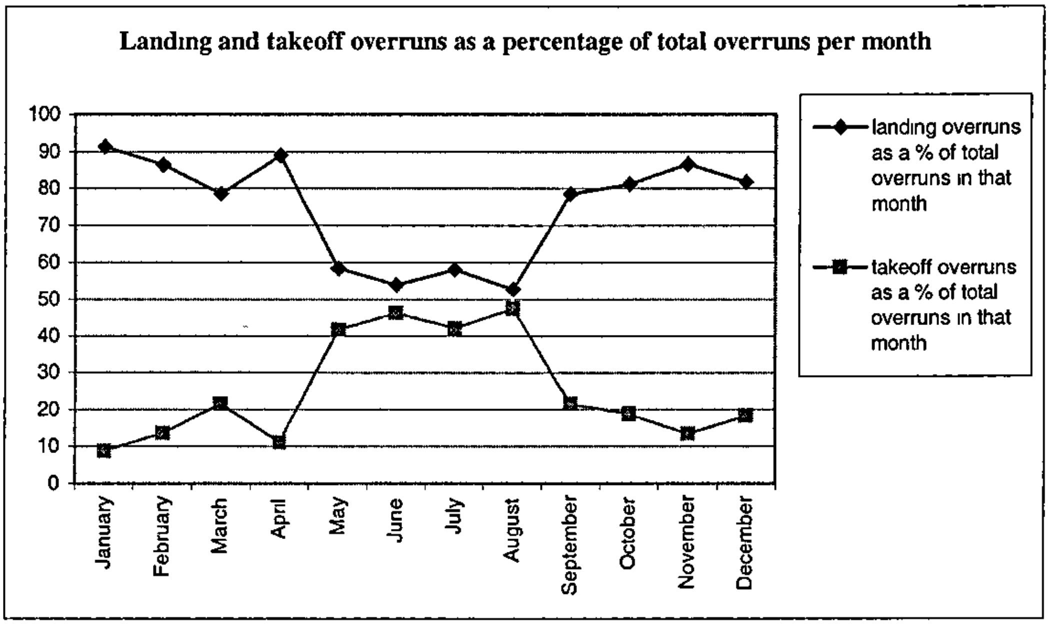


Figure 6. 10

6 2 7 US overrun rates

Relevant US operatıons data ıs avaılable for commercıal operatıons durıng the study perıod ın the FAA Termınal Area Forecast (FAA, 2000), and dısplayed ın table 6 1, whıch refers to aırcraft operatıons, eıther a takeoff or a landıng One aır carrıer operatıon represents eıther a takeoff or a landıng of a commercıal aırcraft wıth seatıng capacıty of more than 60 seats Commuter operatıons ınclude takeoffs and landıngs by aırcraft wıth 60 or fewer seats conductıng scheduled commercıal flıghts Aır taxı operatıons ınclude takeoffs and landıngs by aırcraft wıth 60 or fewer seats conducted on non-scheduled or for hıre flıghts

The aır taxı operatıons may contaın pıston engıne powered and rotary wıng aırcraft therefore these had to be removed Aır taxı total numbers of landıngs by aırcraft type are gıven for 1996, 1997, and 1998, ın the General Avıatıon and Aır Taxı actıvıty survey (FAA, 2000) The splıt by aırcraft type ıs reproduced ın table 6 2 Unfortunately the totals must be used rather than the percentage splıt because the termınal area forecast data ıs not splıt between aır taxı and commuter Thıs may ıntroduce ınaccuracıes because the general avıatıon survey data ıs based on a sample, whereas the termınal area forecast data ıs based on a full count

If it is assumed that the terminal area forecast data does not include "other aircraft", being gliders and lighter-than-air craft, and "experimental", being amateur built and exhibition craft, only the piston and rotorcraft landings must be removed The average numbers of piston and rotorcraft in air taxi and general aviation operation can be calculated for 1996, 1997, and 1998 and the same ratios applied to the data for the whole study period

As the number of landings split by aircraft type includes both air taxi and general aviation operations the proportions to be taken from each group must be determined The survey also contains data on aircraft use by hours flown by aircraft type. For the two aircraft types, piston engine and rotorcraft, an estimate is given as to the number of hours flown in air taxi operation against general aviation operation for the three years, this is shown in table 6 3

Assuming that the ratio remains the same for landings as for hours flown the average splits between general aviation and air taxi for these three years can be estimated If it is then assumed that the proportions of rotorcraft and piston engine aircraft in air taxi and general aviation operations was the same for the remaining years of the study period and the ratios remain the same for takeoffs as landings, the figures in table 6 4 are obtained The result of the calculations being that in any one year 35 % of the air taxi and commuter flights are conducted by piston engined aircraft or rotorcraft

Figure 6 11 compares US commercial operation landing and takeoff overrun rates per year of the study period, assuming that in each year there are an equal number of landings and takeoffs

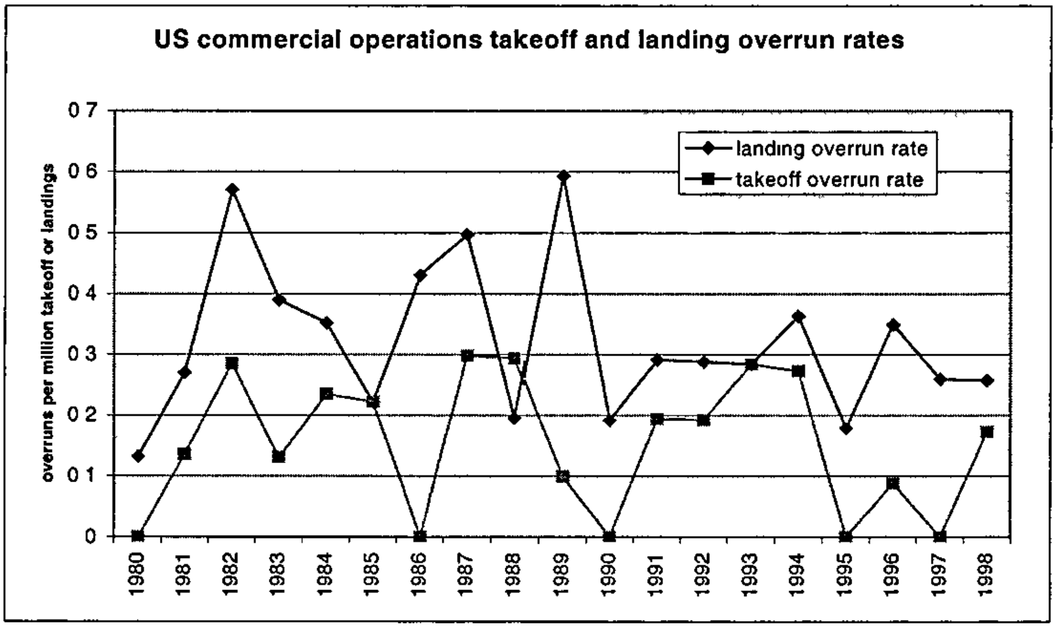


Figure 6. 11

This chart is interesting for two reasons Firstly, there is a large variability of the overrun rates between years Secondly, there appears to have been no improvement of the takeoff or landing overrun rates throughout the study period

The aggregated rates for the whole study period are shown in table 6 5

6 2 8   UK overrun rates

6 2 8 1 UK Monthly rates

Table 6 6 contains numbers of UK overruns and movements occurring per month during 1980-98 inclusive Overruns are included if they occurred to jet or turboprop aircraft on takeoff or landing All aircraft movements from reporting airports are included and are taken from Civil Aviation Authority Monthly Statistics (CAA, 1980-98) The aircraft movements include military movements that typically account for 3 percent of the total monthly movements and remain constant month to month (based on CAA monthly movements 1998)

The overrun rates are presented graphically in figure 6 12

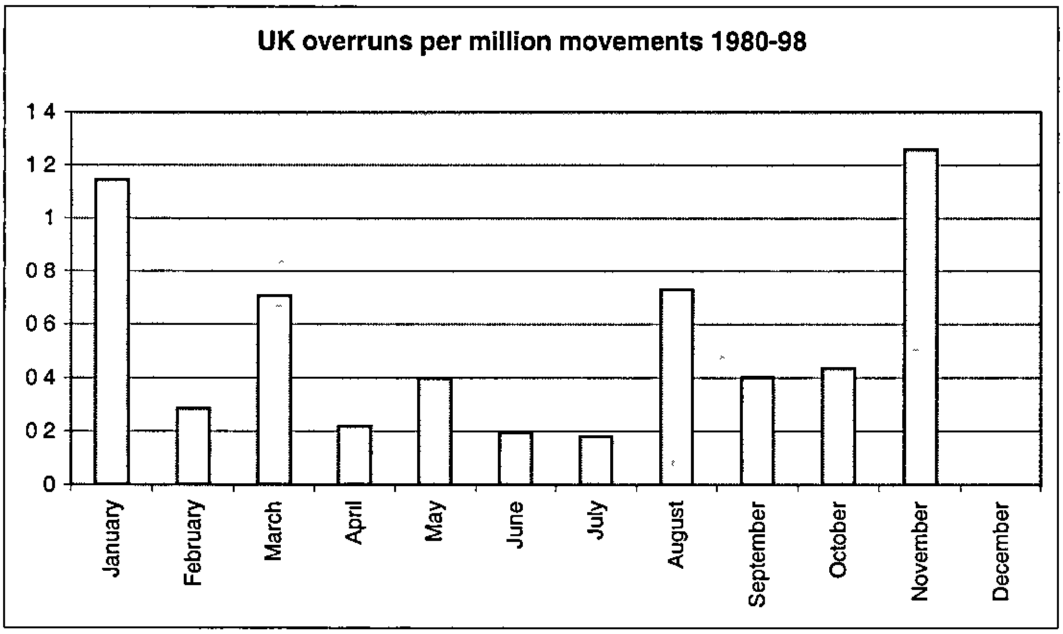


Figure 6. 12

It appears that there are large differences in overrun rates between months However, the differences are not significant

Figures 6 13 and 6 14 depict separate UK landing and takeoff-overrun rates In the landing case, the difference in rates of November and December is again not significant, as is the difference in rates of August and September in the takeoff case

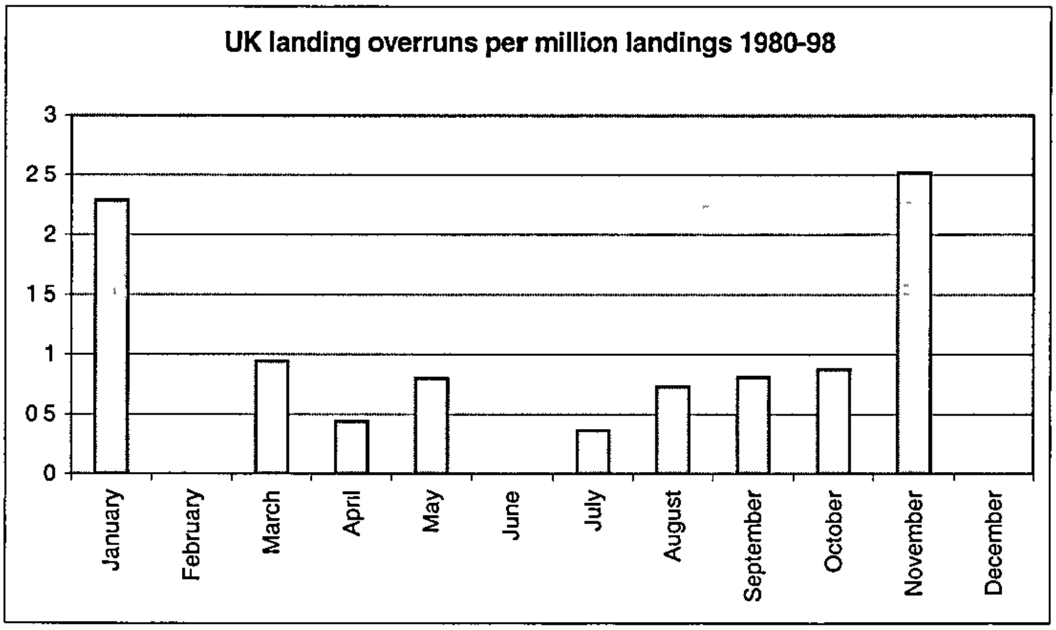


Figure 6. 13

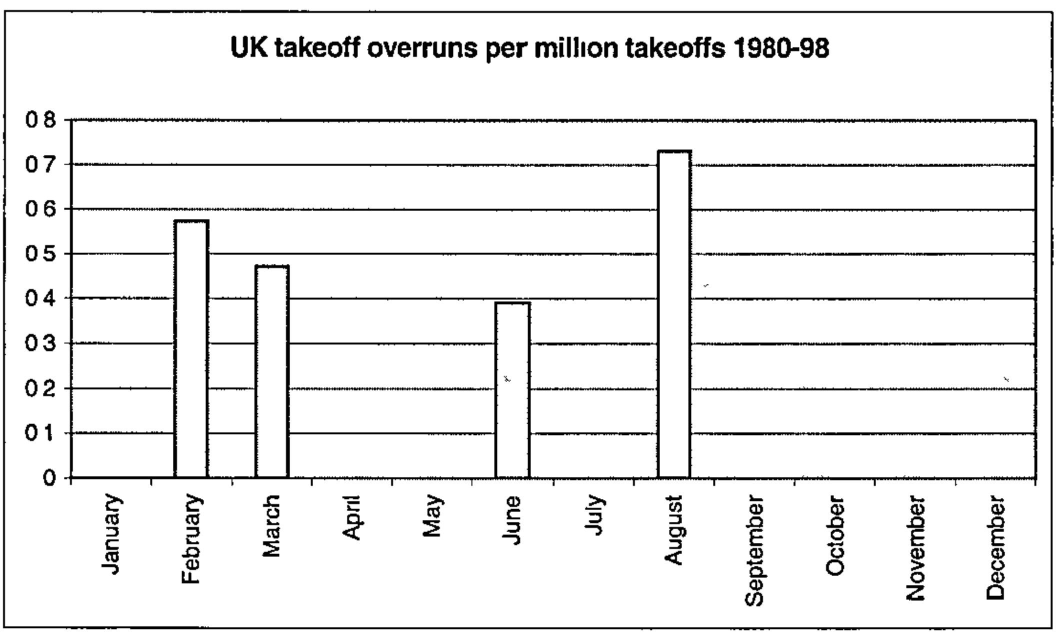


Figure 6. 14

6 2 8 2 UK air transport / non-air transport overrun rates

Table 6 7 contains figures for UK air transport and non-air transport movement rates (excluding military, for all reporting UK and Channel Islands airports) for 1980-98 inclusive (CAA, 1980-98).

An estimate of the composition of the 2000 UK general aviation fleet is given by GAMTA, and is shown in table 6 8

No information is available on general aviation movement rates per aircraft type, nor movements per UK registered and foreign registered general aviation aircraft, nor flight durations per aircraft type therefore estimates have been made as to utilisation rates of the different categories of UK general aviation aircraft types These estimates have been made by Dr R E Caves, course director of the Airport Planning and Management MSc course at Loughborough University Turboprop and jet powered general aviation aircraft are assumed to fly for on average 500 hours per year with average flight durations of one hour per flight Piston engined aircraft are assumed to fly on average 50 hours per year and are assumed to all be involved in training flights, therefore an average of 4 flights per hour is assumed (majority being touch and go operations) Turbine engined helicopters are assumed to have the same average flight characteristics as turboprop and jet powered general aviation aircraft i e 500 hours per year and 1 hour per flight Piston engined helicopters are assumed to have the same flight characteristics as piston engined aircraft (50 hours per year, 4 flights per hour), as these are also assumed to be predominantly involved in training operations At the 2000 UK fleet sizes, these assumptions result in 4,088,800 movements compared with 1,328,695 non-air transport (excluding military) movements at all UK and Channel Islands reporting aerodromes A ratio of approximately 3 to 1 non-reported to reported movements

According to these assumptions, piston engined aircraft and helicopters accounted for 93 percent of the non-air transport movements by non-air transport operators in the UK in the year 2000 The air transport movements also contain helicopter movements, which are assumed to be negligible at reporting aerodromes

Assuming that this split was constant throughout the study period, the resulting movement figures after the non-air transport piston engined aircraft and helicopters have been removed are contained in table 7 9 The totals for the study period are 27,144,479 air transport movements, and 1,904,884 non-air transport movements (excluding military movements) at UK reporting aerodromes If the same ratio of 3 to 1 is assumed for non-reported to reported movements this would result in 5,714,652 non-air transport (excluding military movements) at UK aerodromes

During 1980-98 inclusive there were 17 overruns (14 landing, 3 takeoff) that occurred to flights that would have been classed as "air transport" and 9 overruns (7 landing, 2 takeoff) that occurred to flights that would have been classed as "non-air transport" These give overrun rates of 0 63 per million movements for air transport, and 1 57 per million movements for non-air transport aircraft, which is a significant difference

The air transport landing overrun rate is therefore 1 03 landing overruns per million landings, and the air transport takeoff overrun rate is 0 22 takeoff overruns per million takeoffs The non-air transport jet and turboprop landing overrun rate is 2 45 landing overruns per million landings, and the non-air transport jet and turboprop takeoff overrun rate is 0 70 takeoff overruns per million takeoffs

6 2 8 3 UK passenger / cargo overrun rates

CAP 701 (CAA, 2000) contains figures for UK registered or operated aeroplanes above 5700 kg maximum takeoff weight, engaged in public transport flights excluding positioning flights and air taxi flights, split by passenger and cargo services These are contained in table 6 10

In the same period there were 9 passenger aircraft overruns and 2 freight aircraft overruns with the same inclusion criteria, which give overrun rates of 0 69 per million passenger aircraft movements, and 3 54 per million freight aircraft movements This is not a significant difference

A study on the safety performance of cargo operators in terms of the fatal accident rate was conducted by Roelen, Pikaar, and Ovaa (2000), and which calculated accident rates of 1 14 accidents per million passenger flights, and 3 50 accidents per million cargo flights This was based on global western-built jet and turboprop operations between 1970 and 1999 of aircraft above 5700 kgs maximum takeoff weight, and hull losses and fatal accidents The rates are comparable to the UK overrun rates above, however, these differences are significant

6 2 8 4 UK operators / foreign operators

CAP 701 (CAA, 2000) contains figures for air transport movements by foreign public transport operators at UK airports during the years 1990-98 inclusive These can be compared with figures for total air transport movements at UK airports for the same years from CAP 552 in order to calculate the numbers of movements by UK public transport operators These figures are shown in table 6 11

During this period 11 overruns occurred on air transport flights, 3 of which occurred to foreign operators and 8 to UK operators. These give overrun rates of 0 82 per million air transport movements for the foreign operators, and 0 70 per million air transport movements for the UK operators, not a significant difference

6 2 9 Australian overrun rates

A request was made to the Australian Department of Transport and Regional Services for movement statistics During the years 1990 to 1998 inclusive in Australia there were 11564013 international and domestic scheduled movements of jet and turboprop powered aircraft In this period no overruns occurred to aircraft falling within this category In the same period there occurred 3749988 general aviation and charter movements (Australian statistics amalgamate the two categories) of jet and turboprop aircraft, and 5 overruns to aircraft falling within this category, which were all landing overruns This gives a rate of 1 33 overruns per million movements, a significantly different rate from that of scheduled operations

6 2 10 Canadian overrun rates

A request was made to Transport Canada for movement statistics During the years 1985 to 1998 inclusive in Canada there were 31372707 aircraft movements by jet or turboprop powered aircraft During this period 10 overruns occurred to aircraft in this category This gives an overrun rate of 0 32 overruns per million movements

The takeoff-overrun rate during this period was 0 19 takeoff-overruns per million takeoffs. The landing overrun rate during this period was 0 45 landing overruns per million landings

A direct comparison can be carried out between the Canadian and Australian overrun rates over the period 1990 to 1998 inclusive In this period there occurred in Canada 21947049 movements to jet and turboprop powered aircraft, and 8 overruns to aircraft within this category This gives an overrun rate of 0 36 overruns per million movements In the same period there occurred in Australia 15314001 movements to jet and turboprop powered aircraft and 5 overruns to aircraft within this category This gives an overrun rate of 0 33 overruns per million movements The differences in the rates of the two countries are not significant

6 3 Aircraft weight

6 3 1 Maximum takeoff weight comparison with non-overrun flights

Figures 6 15 and figure 6 16 compare the aircraft weight as a percentage of maximum takeoff weight in overruns, with that in non-overrun flights The non-overrun flight data is taken from 73000 takeoffs conducted over the period of a year by a major European scheduled airline Approximately 30000 of which were B-747s, 30000 were B-767s, and 13000 were A320s These flights therefore cover a range of aircraft sizes, airports, runway lengths, and operating conditions

The main reason that data from this particular airline has been used is that it was available Data of this type is difficult to obtain for two reasons Firstly, the data is only available where the airline has in place a system of operational flight monitoring This is a system, usually involving quick access flight recorders, that records parameters of the flight to be analysed at a later date as part of the airlines maintenance and risk management program. This type of system is certainly not universal Secondly, the airline has to have an agreement with its pilots which would allow independent analysis of the data, the majority of airlines that were approached who had a system such as this were not able to release any data to an outside body

The aircraft chosen from the fleet of the major European airline were chosen because between them they would encompass a large variety of types of operation, types of airport, weather and geographical area It includes high intensive short haul operations throughout Europe, in addition to medium and long haul destinations In addition the flights are taken from the period of a year, which has ensured no seasonal bias

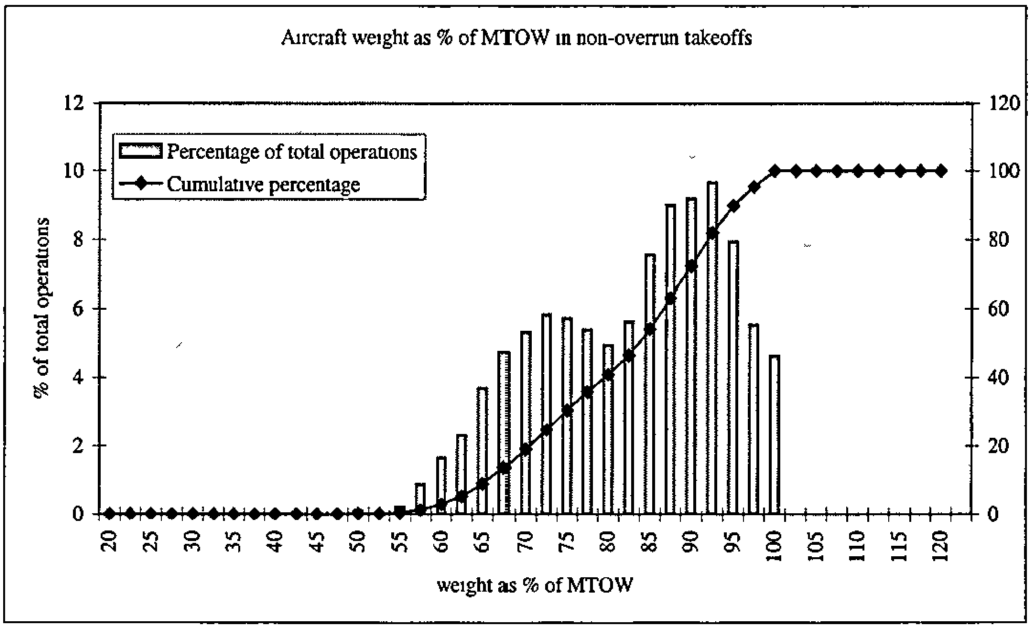


Figure 6. 15

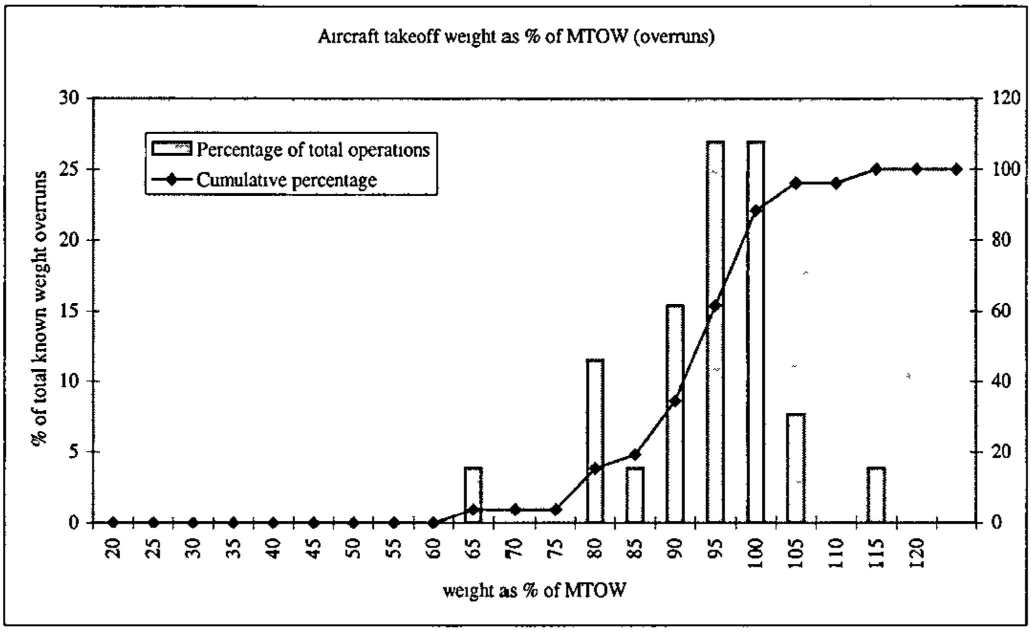


Figure 6. 16

It can be seen that approximately 85 percent of the takeoffs that resulted in a takeoff overrun had takeoff weights of more than 80 percent of the maximum takeoff weight This compares to approximately 60 percent of the non-overrun takeoffs Approximately 65 percent of the takeoffs that resulted in a takeoff overrun had weights more than 90 percent of their maximum takeoff weight, compared to 30 percent of the non-accident takeoffs Approximately 11 percent of the takeoffs that resulted in an overrun had weights more than 100 percent of their maximum takeoff weight, compared to 0 06 percent of the non-accident takeoffs

The mean of the takeoff weight as a percentage of the maximum takeoff weight for non-overrun flights is 80 92 percent. The mean of the takeoff weight as a percentage of the maximum takeoff weight for overrun flights is 91 98 percent This difference is significant The standard deviation of the takeoff weight as a percentage of the maximum takeoff weight for non-overrun flights is 11 78 The standard deviation of the takeoff weight as a percentage of the maximum takeoff weight for overrun flights is 9 74 This is also a significant difference The difference in means and variance may indicate one of two situations Either the non-overrun flight data are not representative of the wider population of non-overrun flights from which the overrun data were taken and that there is no underlying difference between the means or variance of the takeoff weight as a percentage of maximum takeoff weight for overrun and non-overrun flights Alternatively, the non-overrun data is representative and the differences reflect differences in the means of wider populations of overrun and non-overrun takeoffs

The 95 percent confidence intervals for the difference in means are 7 1 and 15 0, which indicates that there is a 95 percent chance that in the wider populations, the mean of takeoff weight as a percentage of maximum takeoff weight is between 7 1 and 15 percent of MTOW greater for aircraft involved in takeoff overruns than in those that do not suffer takeoff overruns This does not imply a causal link, but given that aircraft with higher takeoff weights need a greater amount of runway to accelerate and stop, it seems likely that a higher takeoff weight may lead to a greater risk of overrunning As stated above, the results also depend upon the non-overrun takeoff data being representative of the wider population of non-overrun takeoffs The data is made up of a wide mix of operations at different airports around the world, but one criticism could be that the data is only from one airline, and therefore the operational policy of this airline may bias the data in some way However, until data from alternative airlines is available, this cannot be tested

6 3 2 Maximum landing weight comparison with non-overrun flights

Figures 6 17 and 6 18 compare landing weight as a percentage of maximum landing weight for overruns and non-overrun flights

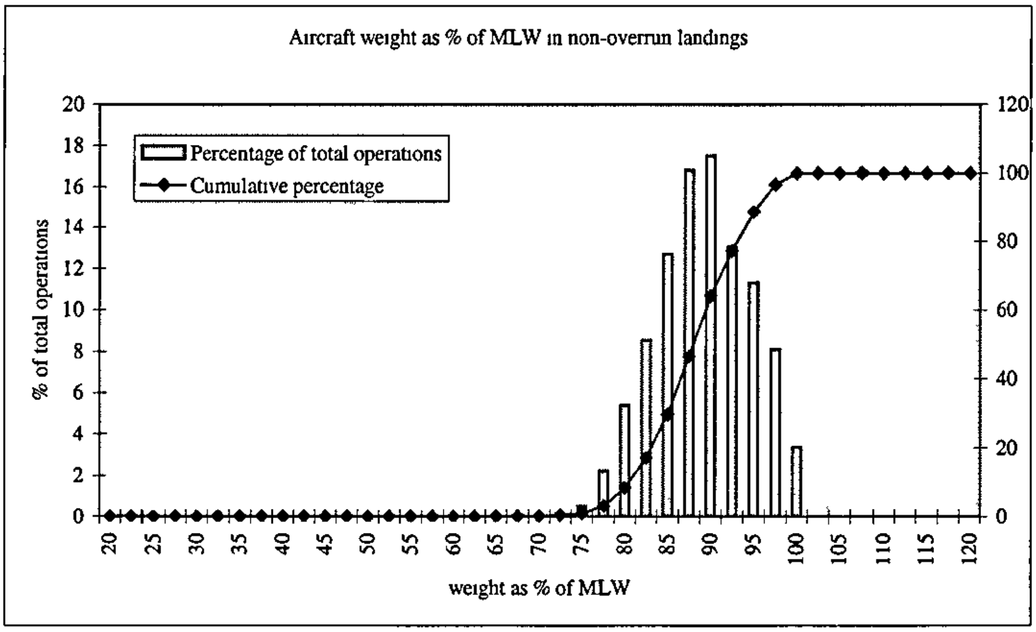


Figure 6. 17

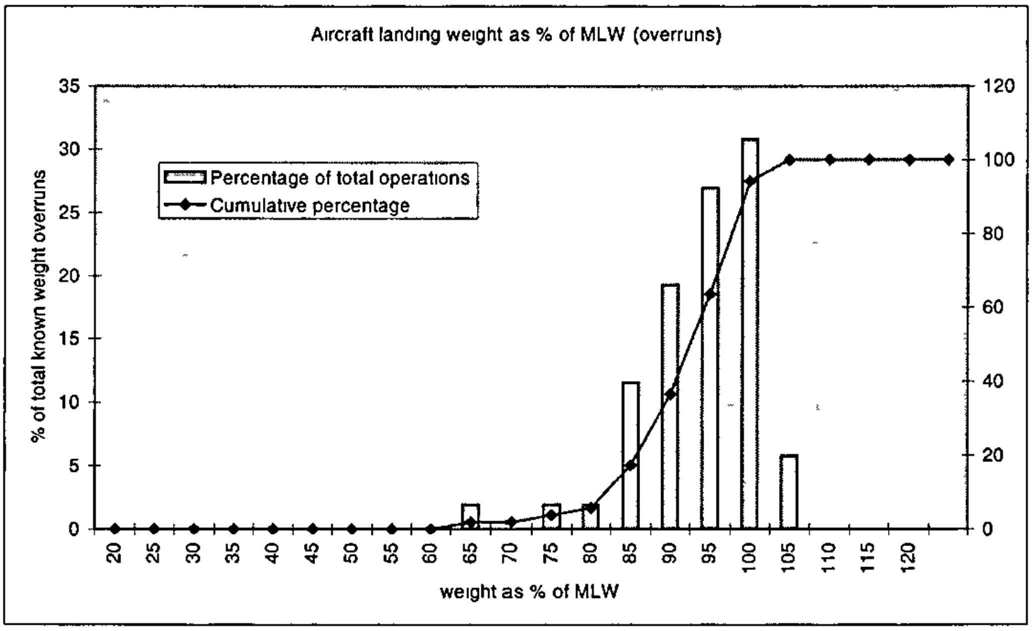


Figure 6. 18

It can be seen that approximately 95 percent of the landings that resulted in an overrun had weights more than 80 percent of their maximum landing weight, which is roughly the same proportion as in non-overrun landings Approximately 65 percent of the landings that resulted in an overrun had weights more than 90 percent of their maximum landing weight, compared to 35 percent of the non-overrun landings Approximately 6 percent of the landings that resulted in an overrun had weights more than 100 percent of their maximum landing weight, compared to 0 0015 percent of the non-accident landings

The mean of actual landing weight as a percentage of maximum landing weight in aircraft that have overrun after a landing is 91 4 percent The mean of actual landing weight as a percentage of maximum landing weight in aircraft that did not overrun after a landing is 87 5 percent, not as great a difference as for takeoffs, but still significant The standard deviation of the percentages for overrun landings is 7 8, and the standard deviation for non-overrun landings is 5 5, also a significant difference As with the takeoff data this may reflect the overrun data being representative of a wider variation in operating conditions

The 95 percent confidence intervals for the difference in means are 1 7 and 6 0 which indicates that it is likely that the difference in the wider population means is between these figures, and it is therefore likely that the mean of landing weights as a percentage of maximum landing weights is greater in overrun landings than non-overrun landings Again the same caveats should be applied to these results as for takeoff weights above

6 3 3 *Maximum legal weight for particular operational conditions*

Figures 6 19 and 6 20 compare the aircraft weight as a percentage of the maximum legal weight for the particular conditions in which the operation was being conducted Unfortunately this information is only available for overruns It can be seen, in both the landing and takeoff case, that the weights are closer to the maximum authorised for the particular conditions, than to the maximum takeoff or landing weights This indicates that in many cases conditions, usually weather conditions or runway lengths, are restricting the operational aircraft weights in flights that resulted in overruns

In some cases this information was given in the accident report This was usually given less frequently than the weight relative to the maximum takeoff or landing weight In cases where this information was not reported, it was calculated using a flight manual for the particular aircraft type In some cases the flight manual for the specific certification authority was not available but the UK manual for that aircraft type was available In those cases the UK weights were used Of the 43 cases for which the weight relative to the maximum allowable weight in the particular operational conditions was known, 24 were given in the report, a further 19 were calculated from manuals and 6 were taken from the UK chart where the aircraft was certificated according to US certification rules It was the opinion of Graham Skillen, Head of Flight Test at the UK CAA, that the weights calculated by the UK flight manuals would not be appreciably different from those of the applicable manual

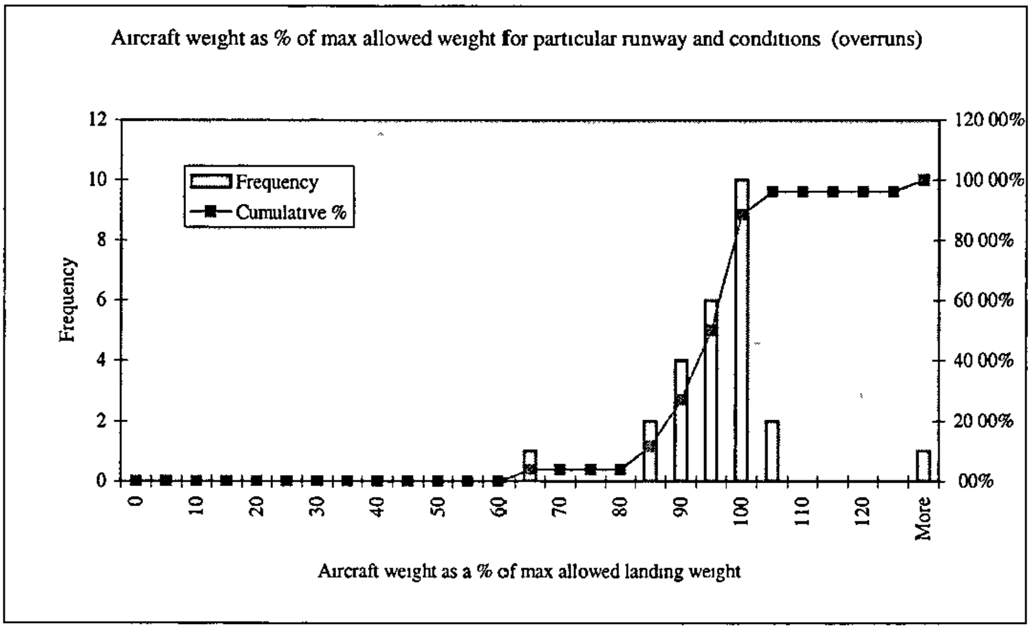


Figure 6. 19

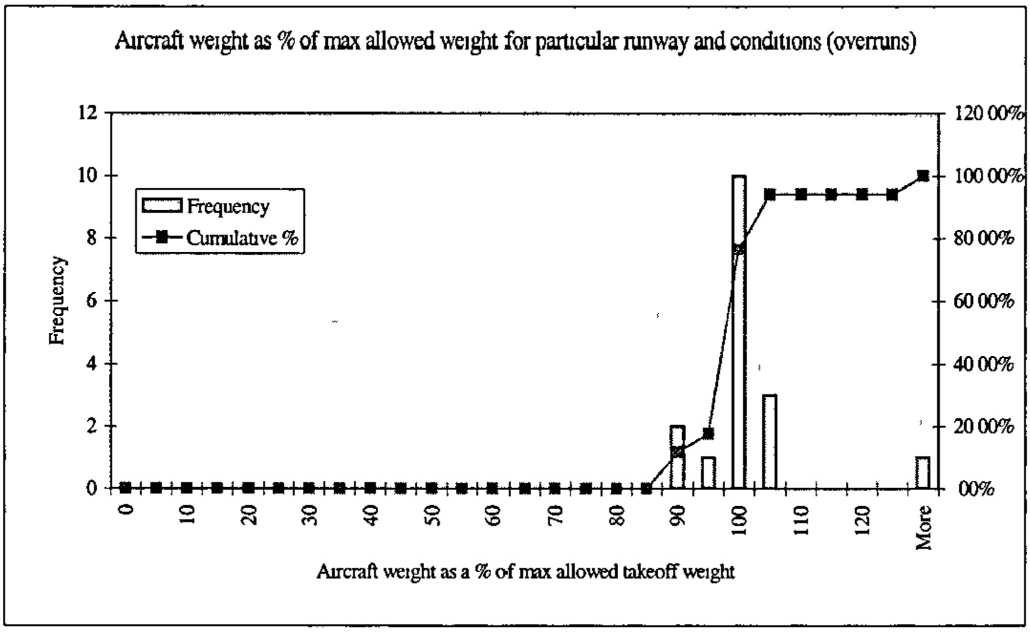


Figure 6. 20

6 4 Excess distance

6 4 1 Situation during overruns

A measure of the excess distance remaining between the end of the required distance for a particular operation and the runway end (the start of the required distance being at the approach end of the runway) shows how much excess runway is available, and can therefore be utilised by the aircraft for deceleration, before the aircraft overruns the runway end Figure 6 21 shows a histogram of excess distances available for takeoff overrun cases.

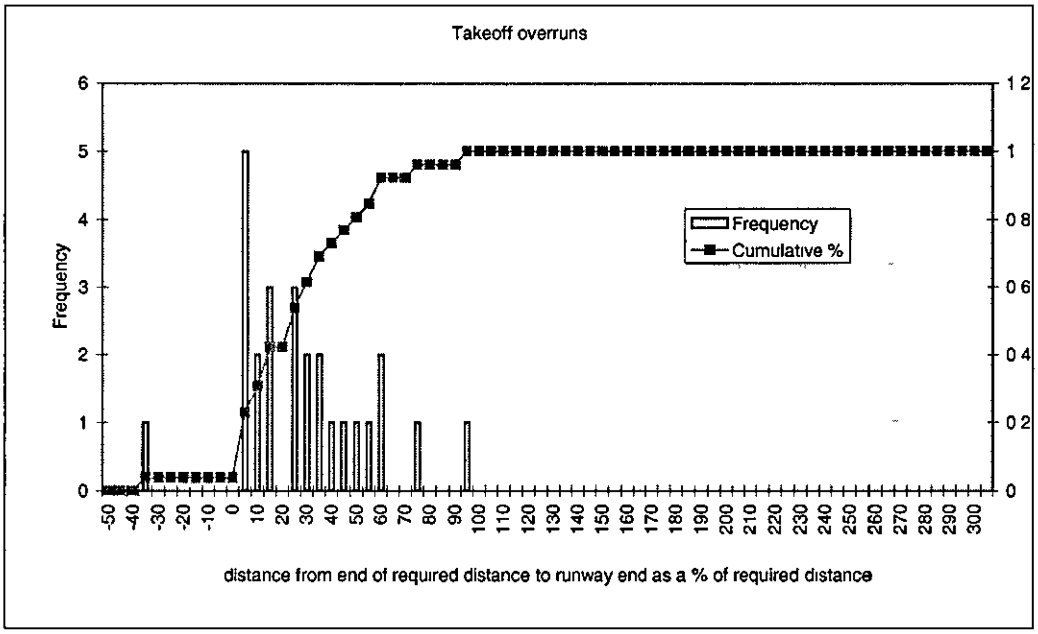


Figure 6. 21

There were 26 takeoff cases in total where it was possible to calculate the required accelerate stop distance One further case was an unauthorised takeoff, unauthorised because the aircraft was exceeding the maximum weight limits (the required distance was not given in the report and could not be calculated because the chart was not available, so is not included in figure 6 21), and in a further sixteen cases it was not possible to calculate the distance, because either the aircraft weight was not given in the report or that a flight manual for the particular aircraft was not available The distances have been shown as a percentage of the required accelerate stop distance in order to take account of the differences in aircraft sizes and operational conditions

It can be seen that in one case the required accelerate stop distance exceeded the available runway by approximately thirty five percent of the required landing distance The average excess distance available was twenty six percent of the accelerate stop distance, and the peak band was between zero and five percent available as excess distance

Figure 6 22 shows a histogram of excess distances available for landing overrun cases

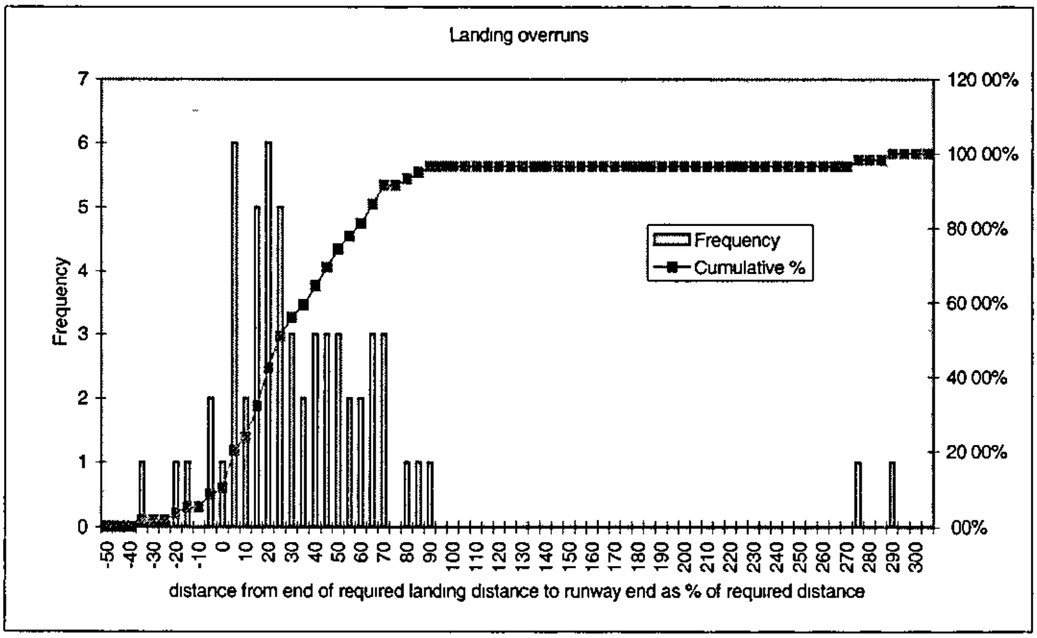


Figure 6. 22

In fifty-nine cases the excess distance could be calculated In addition were seventy-three cases in which the distance could not be calculated (again because either the weight was not given in the report or that the flight manual was not available), and a further five cases where the landing was unauthorised, the distance was not given and could not be calculated (one was unauthorised because the landing distance required exceeded that available but the distance itself was not quoted in the report and therefore does not appear in figure 6 22, three were due to weather being below minimums, and a fifth for unspecified reasons)

In the landing case it can be seen that the peak value band is also between zero and five percent of the landing distance However, a greater proportion of the landings were conducted with insufficient runway available than takeoffs (10 percent compared to 4 percent) This is perhaps not surprising when it is considered that the planning for a takeoff takes place on the ground, whereas the planning for a landing takes place in a moving aircraft in a more time-constrained atmosphere What is also interesting about the above two charts ıs that the dıstrıbutıon of excess dıstance ın the takeoff case appears to peak and cut off at zero excess dıstance avaılable However, ın the landıng case, the cases for whıch the landıng dıstance requıred exceed the landıng dıstance avaılable appear to form part of a close to normal dıstrıbutıon Thıs could also be due to the dıfferent sıtuatıons ın whıch the plannıng for the two phases of the operatıon ıs carrıed out

The calculatıon methodology for the requıred dıstances ıs sımılar to that of the maxımum legal weıght ın 6 3 3. In 58 cases the ınformatıon was gıven ın the accıdent report In 13 cases where the requıred dıstance was not reported, ıt was calculated usıng a flıght manual for the partıcular aırcraft type In 10 cases the flıght manual for the specıfic certıficatıon authorıty was not avaılable but the UK manual for that aırcraft type was avaılable In those cases the UK calculated dıstances were used Agaın, ıt was the opınıon of Graham Skıllen, Head of Flıght Test at the UK CAA, that the dıstances calculated by the UK flıght manuals would not be apprecıably dıfferent from those of the applıcable manual

6 4 2 Comparıson wıth non-overrun operatıons

Data were obtaıned for landıngs that dıd not result ın an overrun, from a major European aırlıne The data comprısed 29684 B-747 landıngs, 13797 A320 landıngs, and 27391 B-767 landıngs In the B-747 case unfortunately only the aırport of landıng ıs known, not the runway used, and ıt has therefore been assumed that the runway used was the longest avaılable at the aırport Also, the landıng dıstance that has been calculated ıs an approxımate figure based on the landıng elevatıon and the mode landıng weıght of the total landıngs of the fleet The three aırcraft types wıll be consıdered separately, ın order to reveal any dıfferences

Fıgure 6 23 shows the excess dıstance for landıng overrun cases mınus the general avıatıon aırcraft overruns These have been removed ın order to provıde a dataset wıth characterıstıcs closer to those of the non-overrun flıghts The resultant dıstrıbutıon appears to be closer to a normal dıstrıbutıon than that ıncludıng general avıatıon overrun landıngs

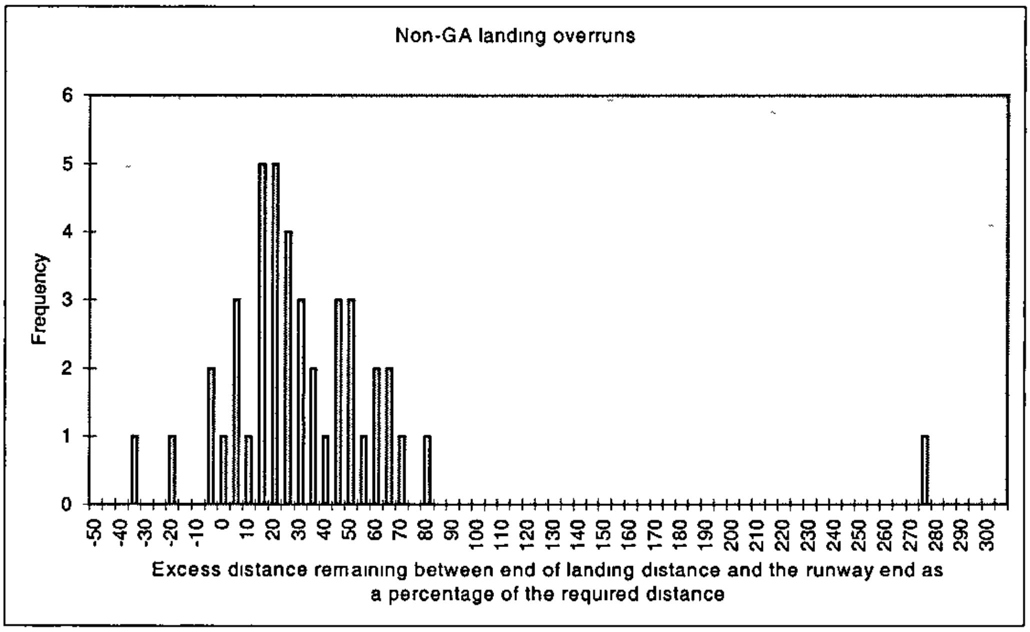


Figure 6. 23

Figures 6 24, 6 25 and 6 26 show the excess distances for the non-overrun landings

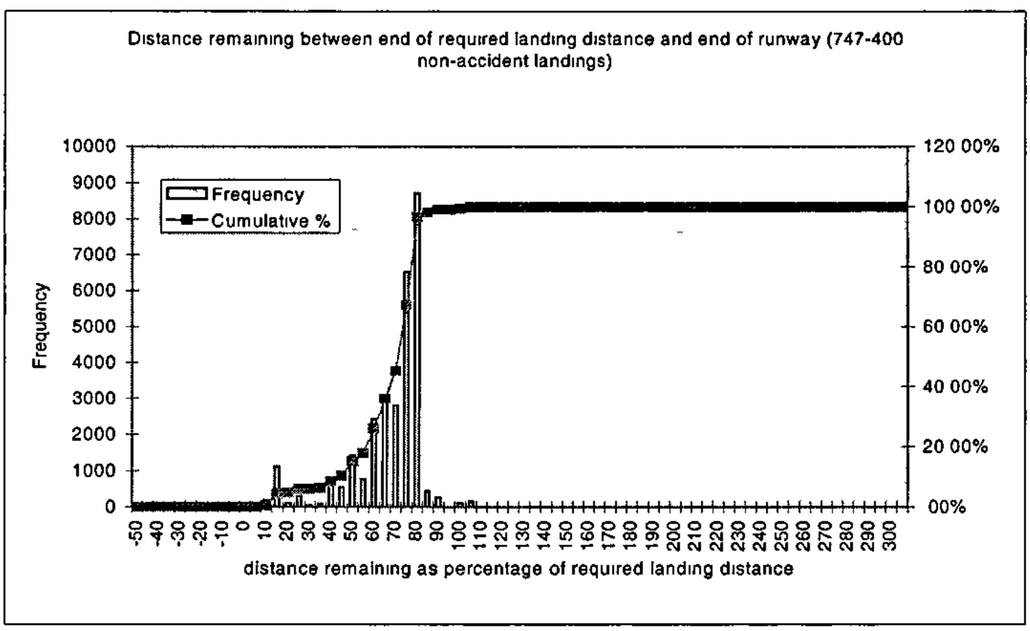


Figure 6. 24

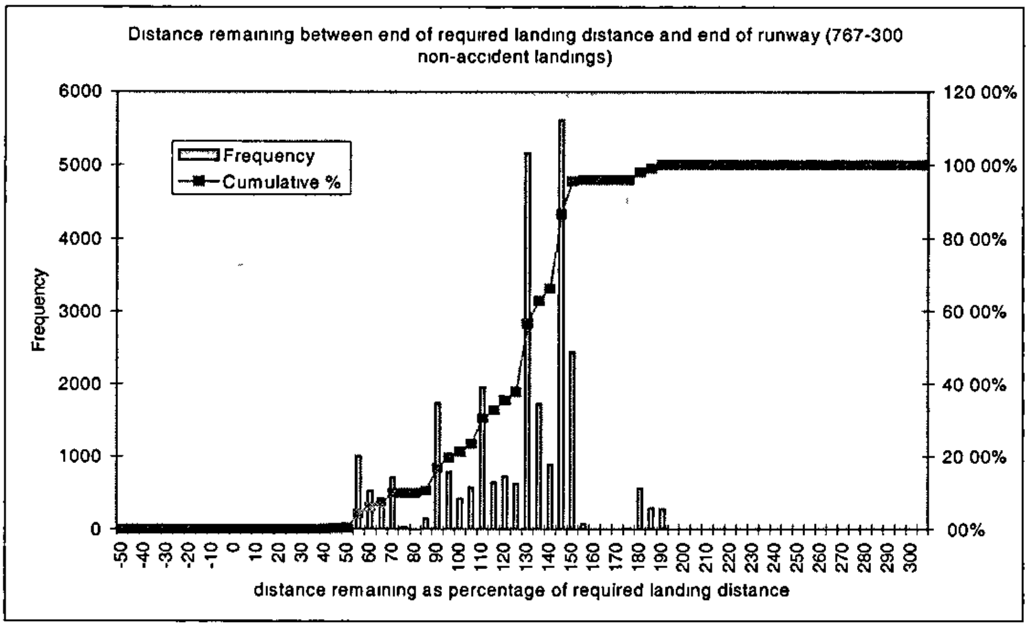


Figure 6. 25

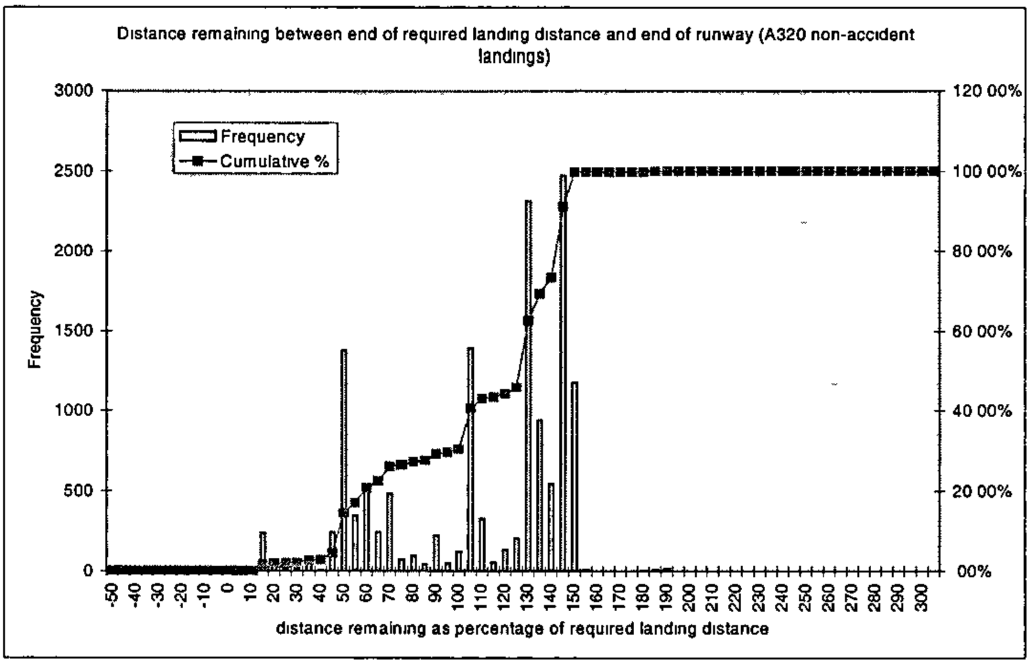


Figure 6. 26

The shapes of the distributions are similar in all three cases, and all have a greater average amount of excess runway available than the distribution of remaining distances of those aircraft that suffered an overrun This is not surprising as the greater the amount of runway available, the more runway the aircraft can utilise to decelerate before it overruns The major problem with this approach, however, is that the required landing distances for the non-overrun flights are calculated in average conditions, not the actual conditions on the day

The factor likely to have the largest influence on the majority of the calculated landing distances is the aircraft weight, the landing distances for the non-overrun flights being calculated using the mode fleet weight Figures 6 27, 6 28 and 6 29 show the actual weights for the three fleets The maximum landing weight of the B-747 was 285760 kgs, that of the B-767 was 136000 kgs, and that of the A320 was 64500 kgs

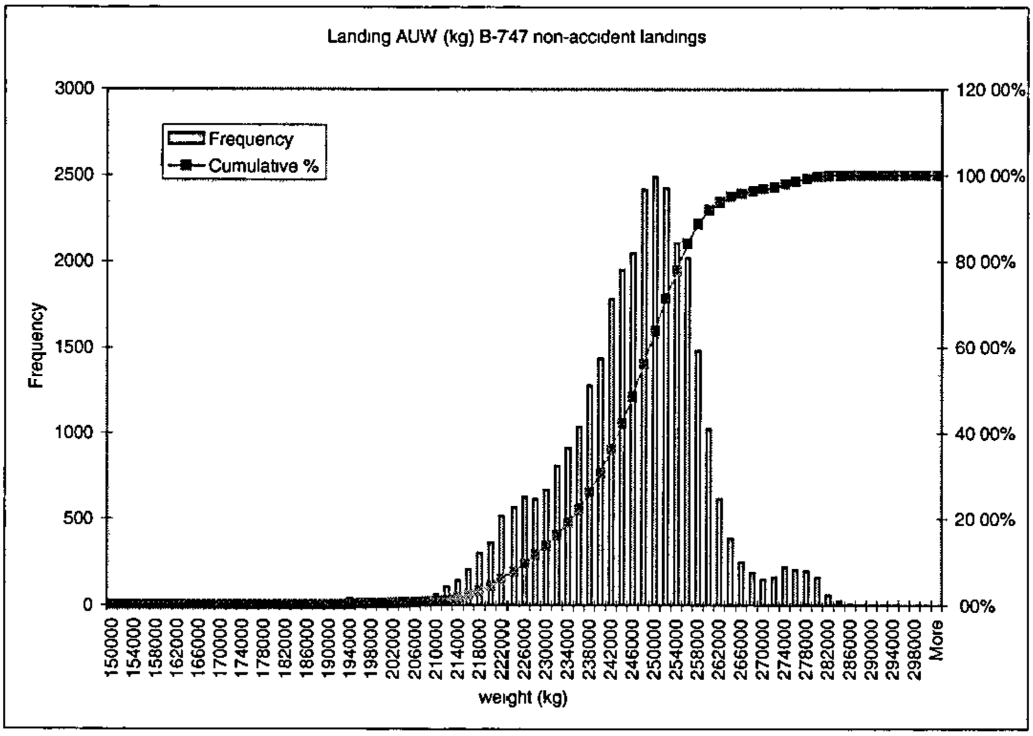


Figure 6. 27

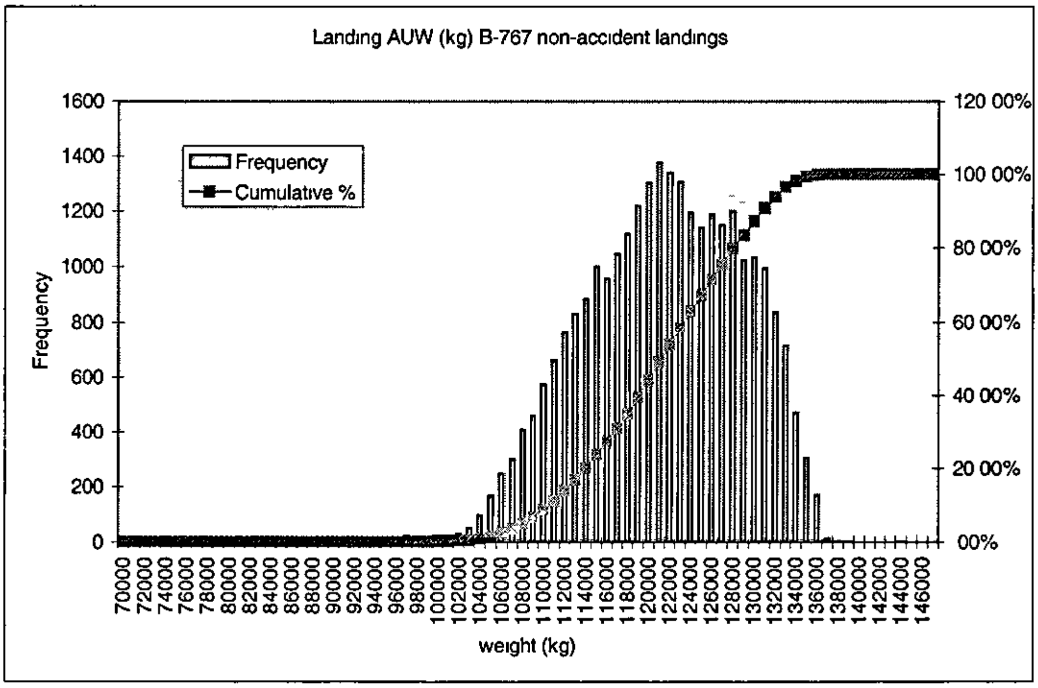


Figure 6. 28

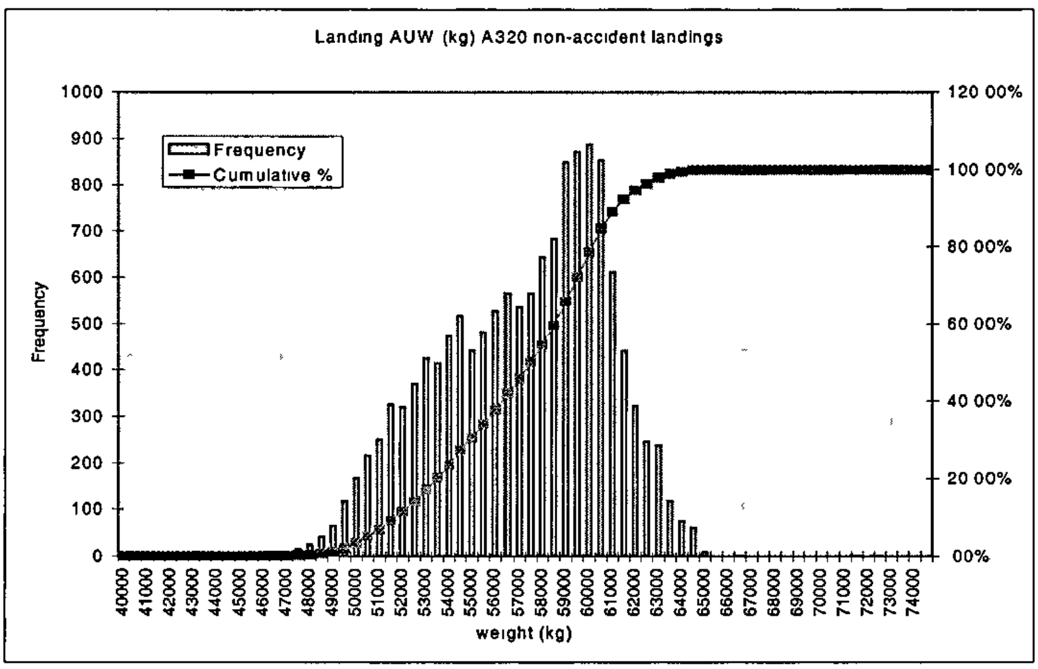


Figure 6. 29

In the cases of the B-747 and the A320 more than 50 percent of the cases are below the mode weight, which means that the majority of landings will be at a weight below the landing weight used to calculate the distance, and therefore that the majority of non-overrun landings will have a greater amount of excess distance available than shown in figures 6 24, 6 25 and 6 26 Slightly less than 50 percent of the B-767 cases are below the mode weight An estimate of how much the remaining distance would change by using the actual weight can be made by referring to the study of aircraft flight manual required distances in Appendix A Table 6 12 contains flight manual distances taken from this study for the B-737 and B-747, and the factor increases in landing distance with weight increase These factor increases apply under dry conditions of sea level pressure altitude, no wind, and no runway slope

If the figure for percentage increase in distance per one percent increase in weight is applied to the B-747 landing distances, assuming that all of the weights are increased by 14 4 percent (from the mode value of 250000 kg to the maximum value of 286000 kg), the distances will be increased by 23 2 percent (and the distance remaining therefore reduced by 23 2 percent, i e 50 percent excess distance will be reduced to 26 8 percent excess distance) This will still only place a small fraction of the excess distances close to zero, and it will not change the shape of the distribution Also, there will still remain a large difference between the excess distances available of the non-overrun landings and the overrun landings

If the largest factor increase of the two aircraft, that of the B-747, is applied to the B-767 values for landing distance using the same methodology as above, the landing distance increases by 22 5 percent (from the mode value of 121000 kg to the maximum value of 138000 kg) This will not result in any of the B-767 non-overrun landings having a landing distance remaining of less than 15 percent of the landing distance required, also the distribution will still not resemble that of the excess distances of the overrun landings

If the same methodology is also applied to the A320 non-overrun landings the distances are increased by 11 4 percent, the result is that a minority of A320 non-overrun landings will have an excess distance of 5 percent, while the majority will have excess distance of greater than 40 percent of the required landing distance

The above increases represent a worst-case scenario, that all of the non-overrun landings were conducted at maximum landing weights rather than at the fleet mode weight, therefore it is likely that the actual non-overrun distributions will not differ as greatly from the distributions based on the mode weight Also, the differences due to the actual conditions in which the landings were conducted are not likely to alter the distributions of remaining distance to the extent that there is not a significant difference between those distances remaining of the non-overrun landings, and those of the overrun landings

6 5 Aircraft damage

The aim of section 6 5 is to determine the causal and circumstantial factors of various degrees of aircraft damage due to the overrunning of the runway The results of this section are used in the construction of an overrun consequence model described in Chapter 8

6 5 1 Damage by flight phase

Figures 6 30 and 6 31 show aircraft damage incurred in landing and takeoff overruns.

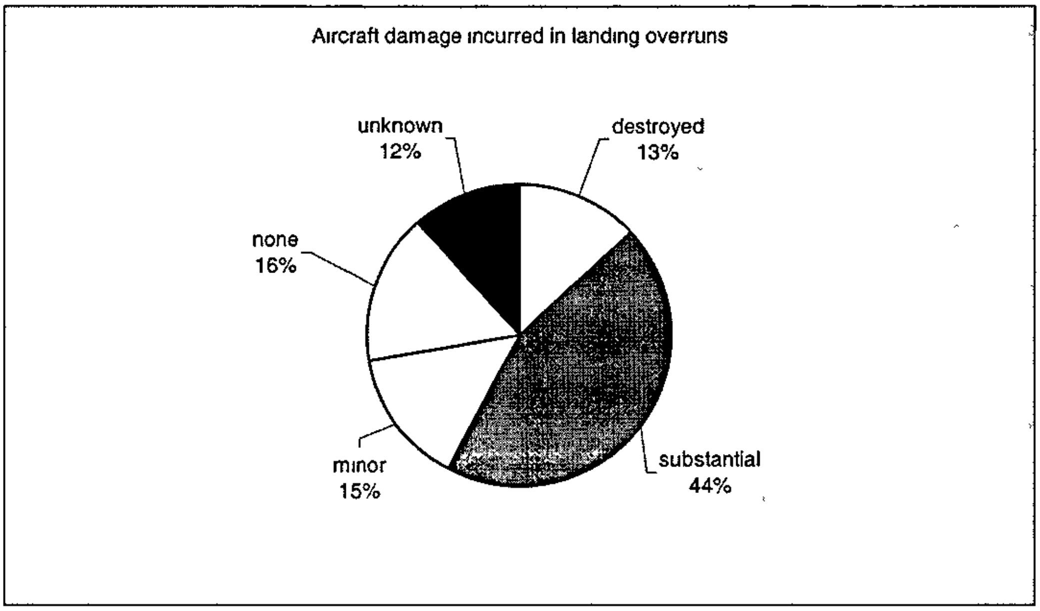


Figure 6. 30

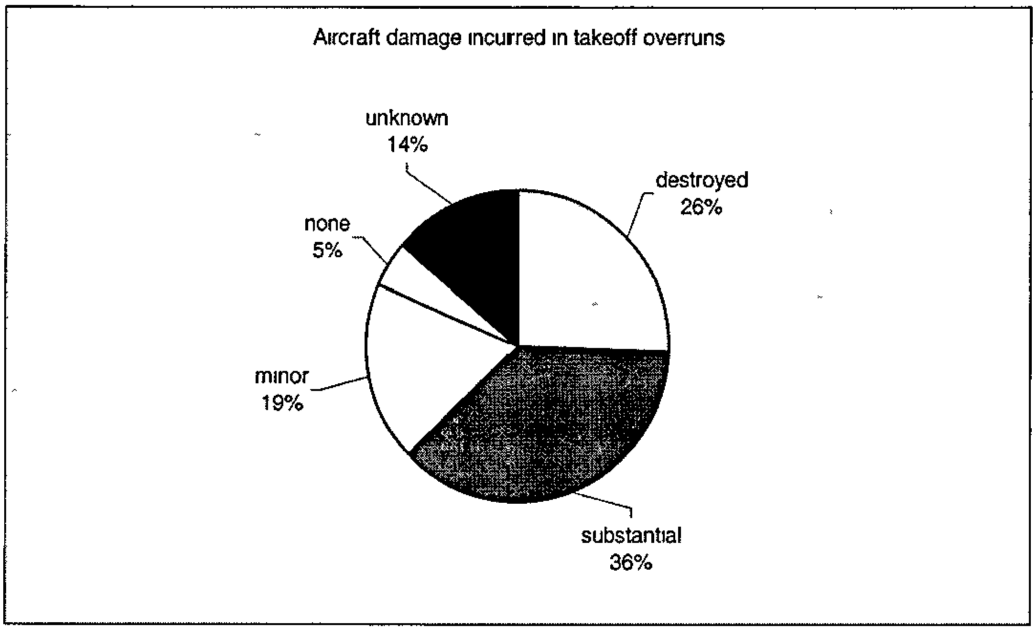


Figure 6. 31

It can be seen that 16 % of the aircraft involved in landing overruns did not incur any damage, whereas only 5% of the aircraft involved in takeoff overruns incurred no damage 13 % of the aircraft involved in landing overruns were destroyed, compared to 26 % of those involved in takeoff overruns, and in general the aircraft that overran after a takeoff were more badly damaged than those that overran after a landing, however, these differences are not significant

Intuitively it seems more likely that the aircraft would suffer more damage after a takeoff overrun than a landing overrun because the aircraft is usually heavier on takeoff and therefore would contain more energy than on landing, and secondly a rejected takeoff is usually due to a problem with the aircraft therefore it may be more likely to be uncontrollable

6 5 2 Damage by flight type

Figures 6 32, 6 33 and 6 34 show damage incurred by aircraft involved in freight, passenger and general aviation operations

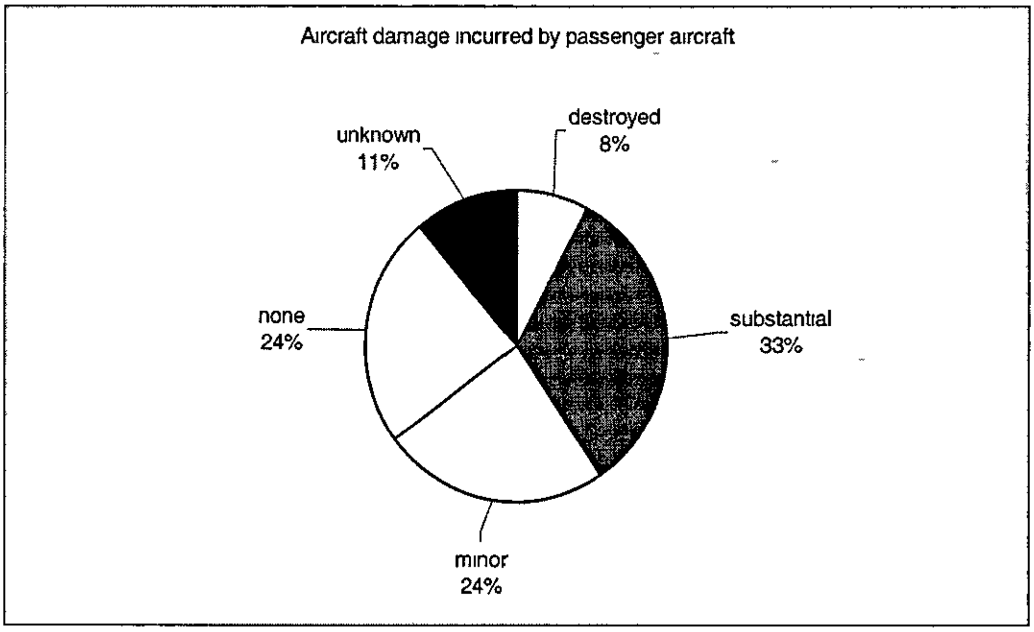


Figure 6. 32

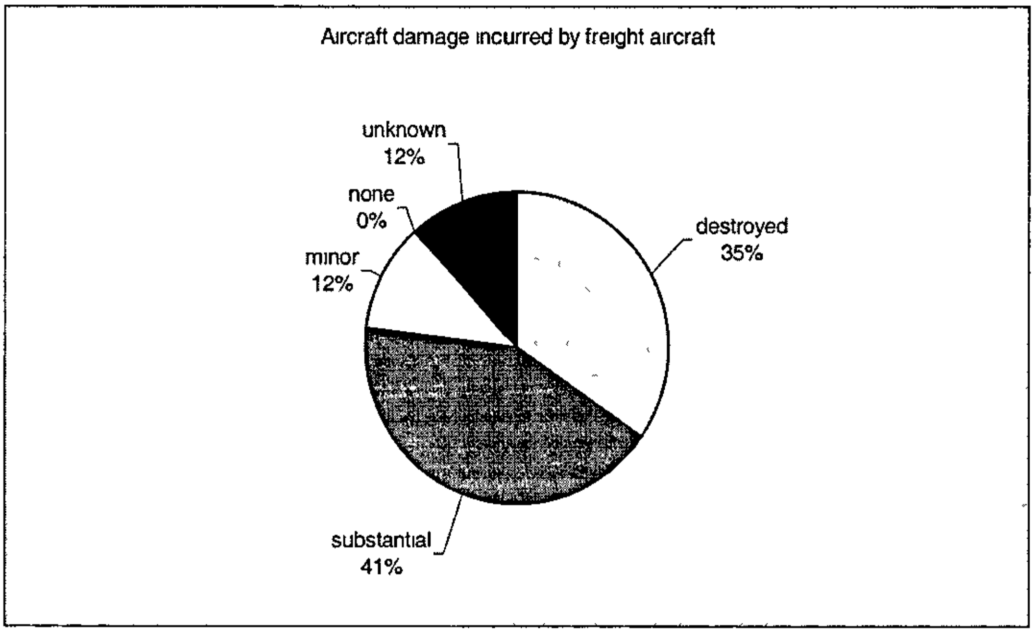


Figure 6. 33

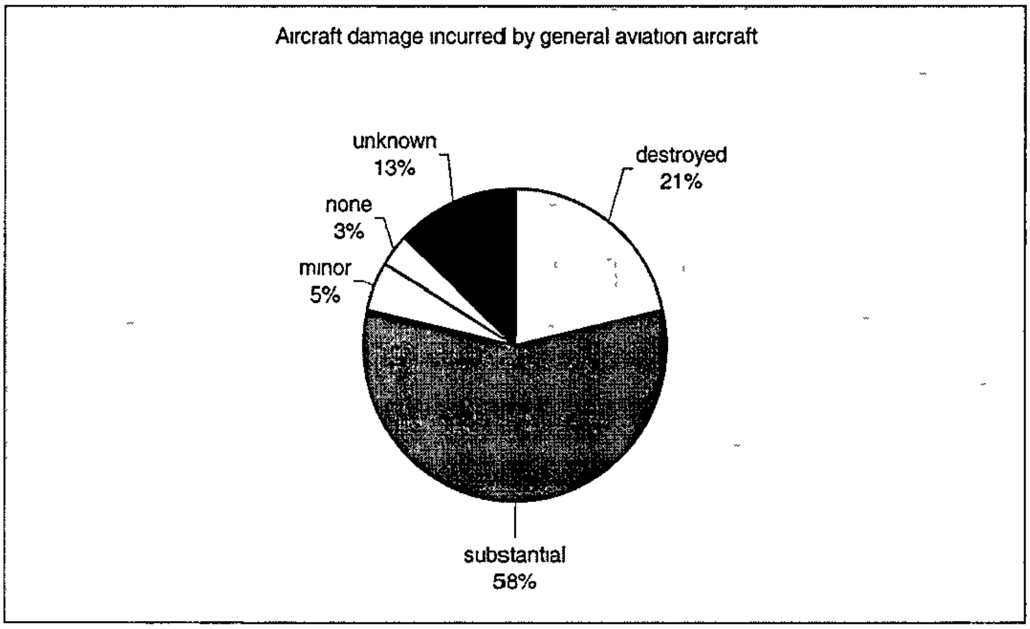


Figure 6. 34

It can be seen that 24 % of passenger aircraft that have had an overrun have incurred no damage This can be contrasted with only 3 % of general aviation aircraft, and none involved in freight operations, however, some of the difference may be due to reporting bias The proportion of aircraft that have been substantially damaged or destroyed has also varied between flight types, being 41 % of passenger aircraft overruns, 76 % of freight aircraft overruns, and 79 % of general aviation aircraft overruns. A Kruskal Wallis test gives mean ranks of 59 73 for passenger aircraft, 97 49 for general aviation aircraft and 104 26 for freight aircraft indicating that on average passenger aircraft have suffered less damage in an overrun than general aviation aircraft, which have also suffered less on average than freight aircraft These differences are significant

6 5 3 Aircraft weight versus flight type

One hypothesis could be that the reason for the differences is the varying sizes of the aircraft involved in each type of operation, with larger aircraft being less likely to be damaged Indeed, figures 6 35, 6 36 and 6 37 do seem to suggest that freight and general aviation aircraft are of similar maximum gross weights, and passenger aircraft tend to be heavier The mean maximum gross weight of passenger aircraft that have overrun and the maximum gross weight is known is 133190 lbs, that of freight aircraft is 81767 lbs, and that of general aviation aircraft is 40008 lbs However, as freight aircraft have a higher mean weight than general aviation aircraft, this does not explain why freight aircraft have been damaged more severely than general aviation aircraft

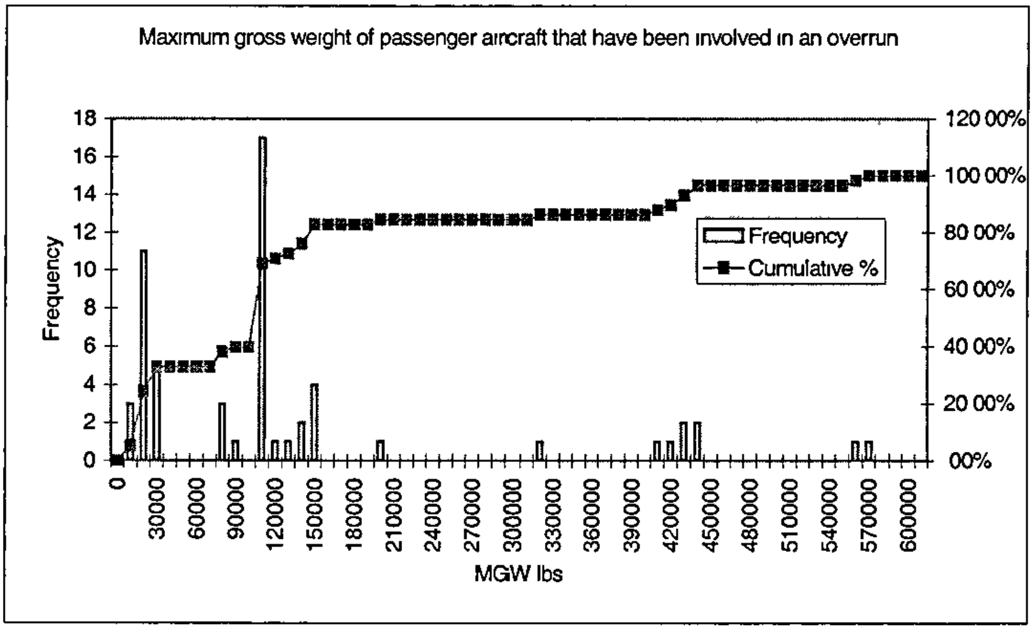


Figure 6. 35

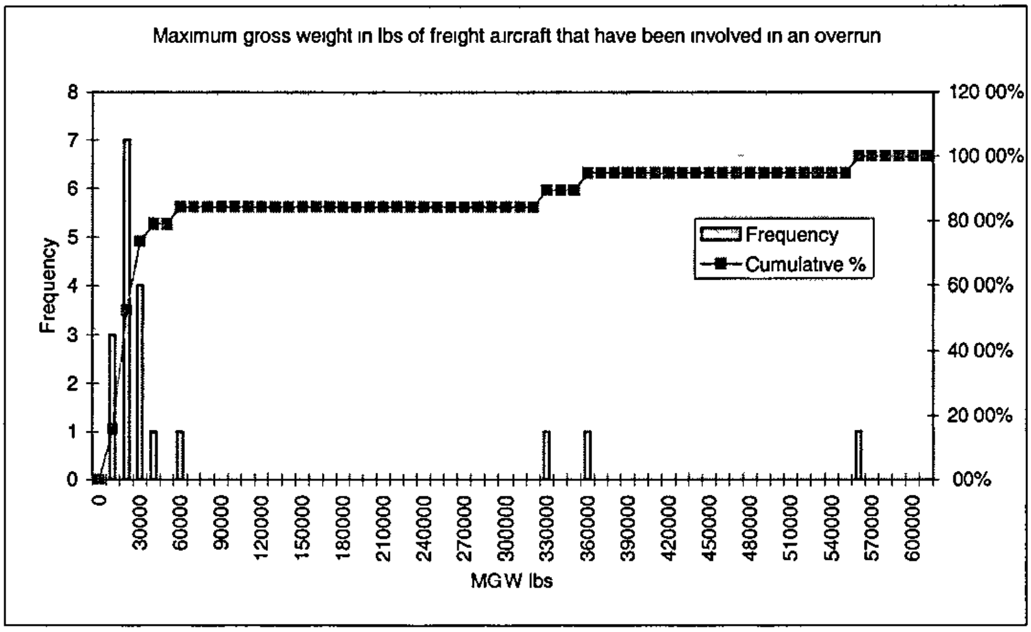


Figure 6. 36

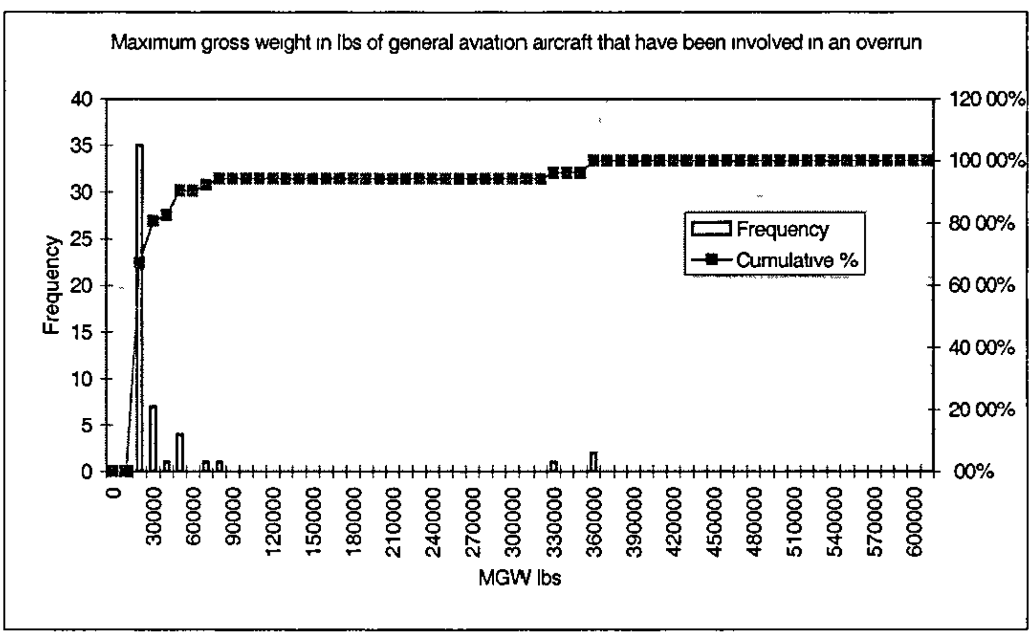


Figure 6. 37

6 5 4 Damage versus aircraft weight

The mean maximum gross weight where the weight was known in aircraft that sustained no damage was 144290 lbs, that of aircraft that sustained minor damage was 129428 lbs, that of aircraft that sustained substantial damage was 59455 lbs and that of those that were destroyed was 104626 lbs As damage sustained goes from none to substantial damage the aircraft have been lighter, however this trend does not continue with aircraft that have been destroyed, and therefore it does not seem as though aircraft damage is directly correlated with aircraft weight

6 5 5 Damage versus runway exit speed

A factor that would be expected to influence damage incurred by the aircraft is the runway exit speed, and this is depicted in figures 6 38, 6 39, 6 40 and 6 41.

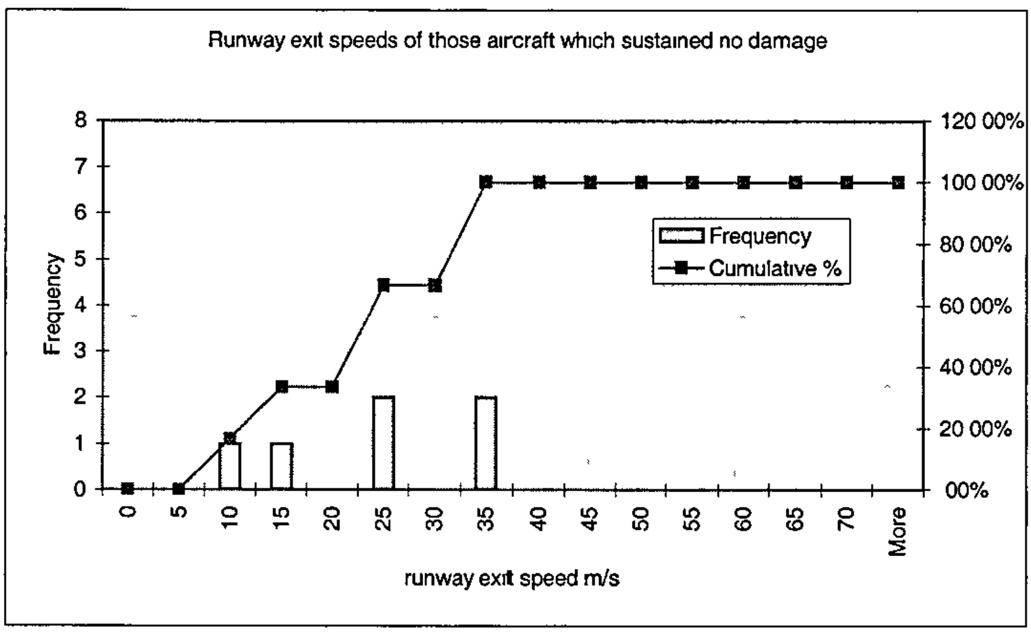


Figure 6. 38

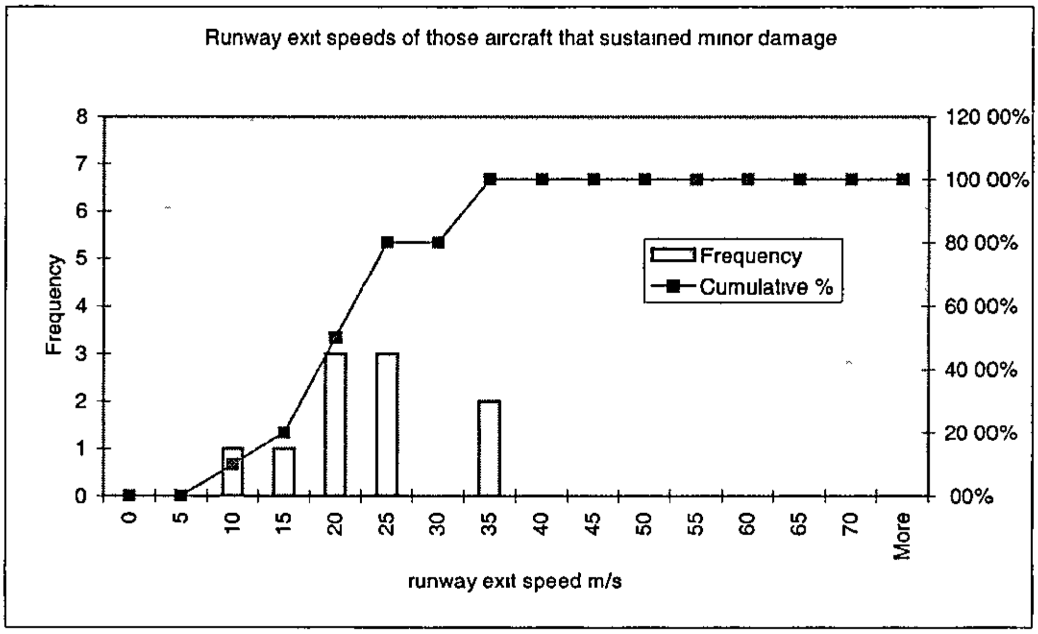


Figure 6. 39

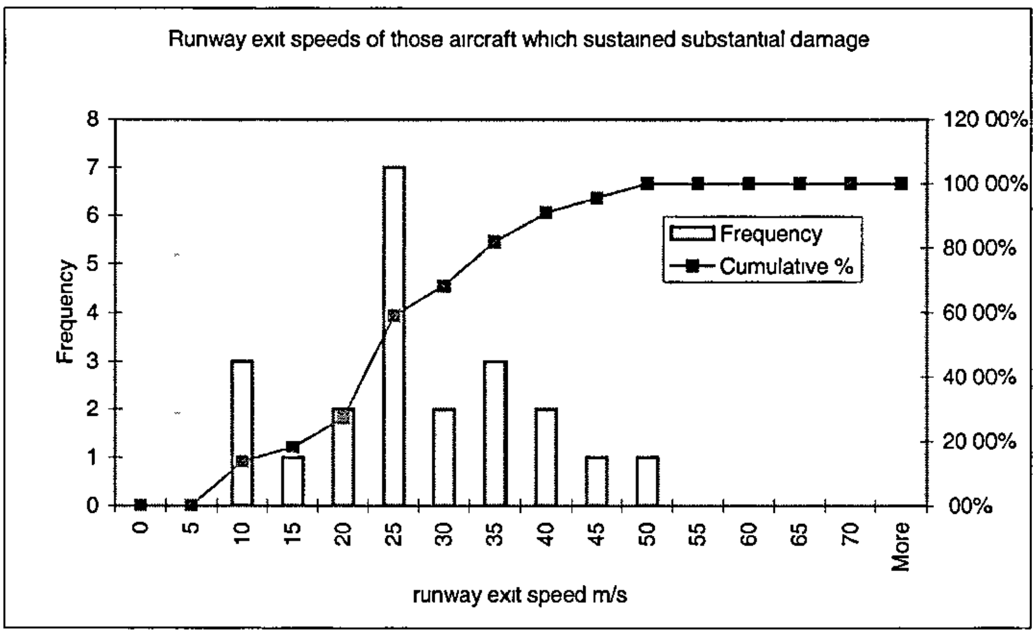


Figure 6. 40

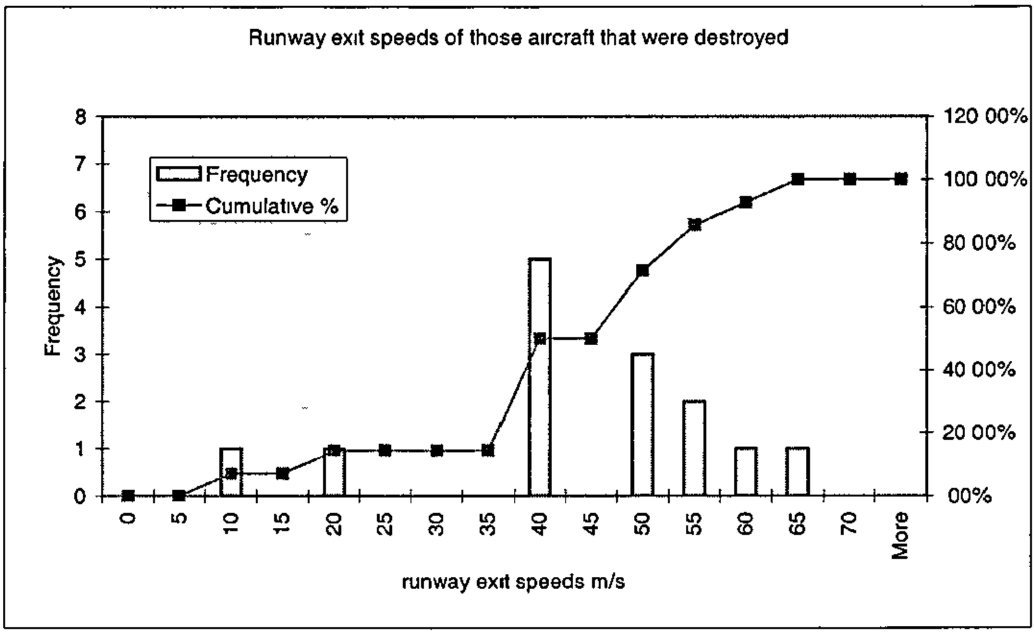


Figure 6. 41

The mean runway exit speed of those aircraft where the exit speed is known and that have incurred no damage is 21 3 metres / second, that of aircraft that sustained minor damage is 20 5 m/s, that of aircraft that sustained substantial damage is 25 1 m/s, and that of those that were destroyed was 41 7 m/s these results suggest that there may be some sort of correlation between runway exit speed and damage, however the non-linear characteristic of the correlation suggests that other factors may also contribute to the level of damage incurred

The difference between the runway exit speeds of those aircraft that sustained no damage or minor damage is not significant The difference between the runway exit speeds of those aircraft that sustained no damage or substantial damage is also not significant However, the difference between the runway exit speeds of those aircraft that sustained substantial damage or were destroyed is significant, as is the difference between the exit speeds of those that sustained no damage or were destroyed It therefore seems that runway exit speed is one determinant of aircraft damage, however, this may not be a simple relationship

6 5 6 Damage versus number of obstacles encountered after the runway end

A factor that would be expected to influence damage incurred is whether an aircraft encounters an obstacle after leaving the runway Figures 6 42, 6 43, 6 44 and 6 45 show the number of obstacles encountered by aircraft after leaving the runway end compared with damage incurred to the aircraft

An obstacle is defined as something in the overrun area that it would be reasonable to assume would damage the aircraft if encountered This obviously involves some subjectivity, which is inevitable when trying to classify objects with limited descriptions Objects classified as an obstacle would include ditches, fences, trees, rocks, cables, vehicles, rivers, lakes, ILS antennas etc

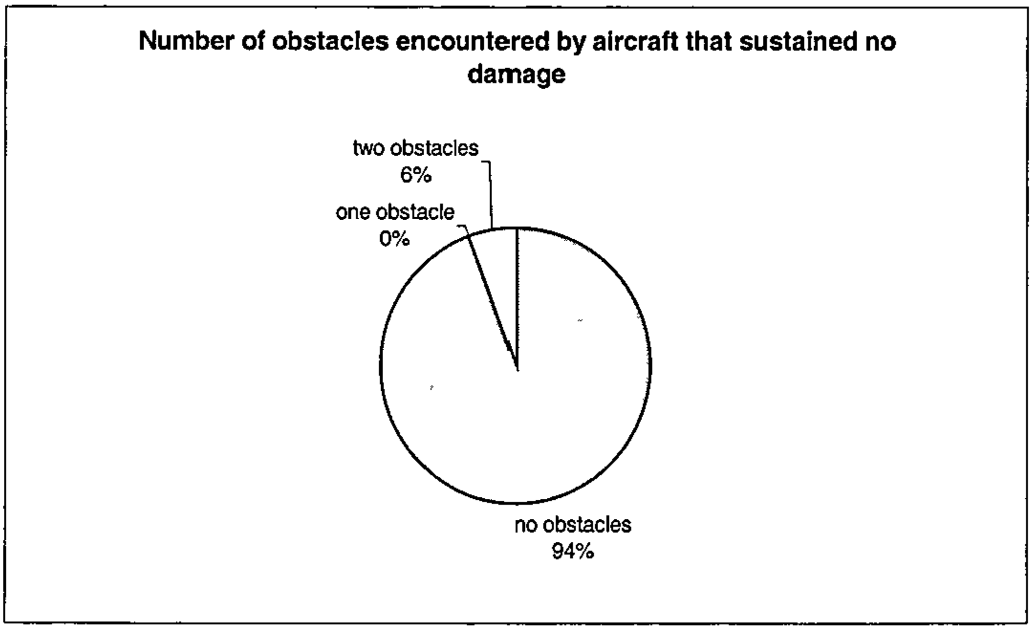


Figure 6. 42

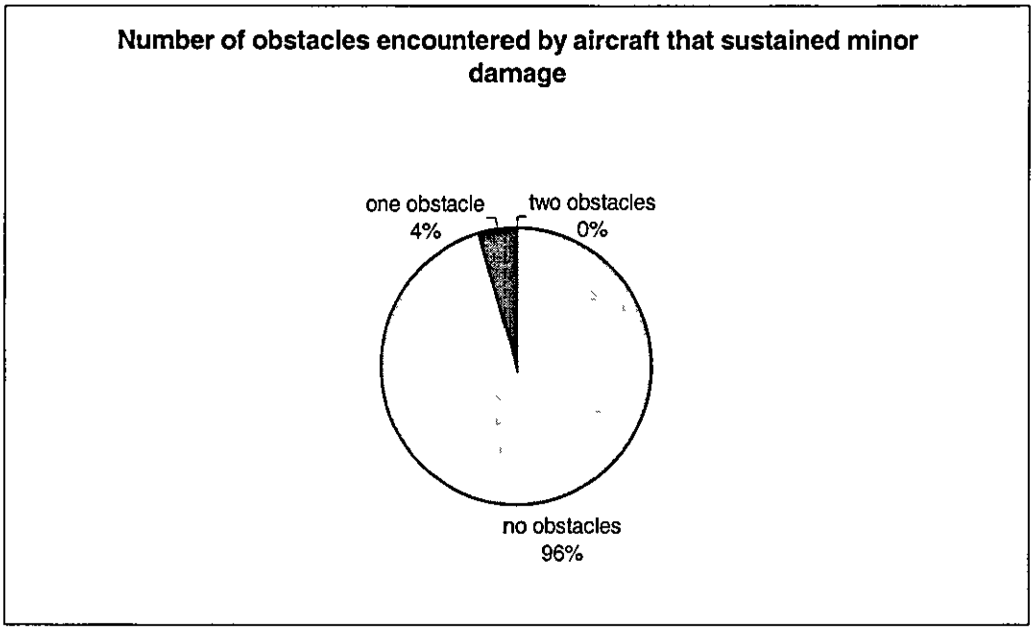


Figure 6. 43

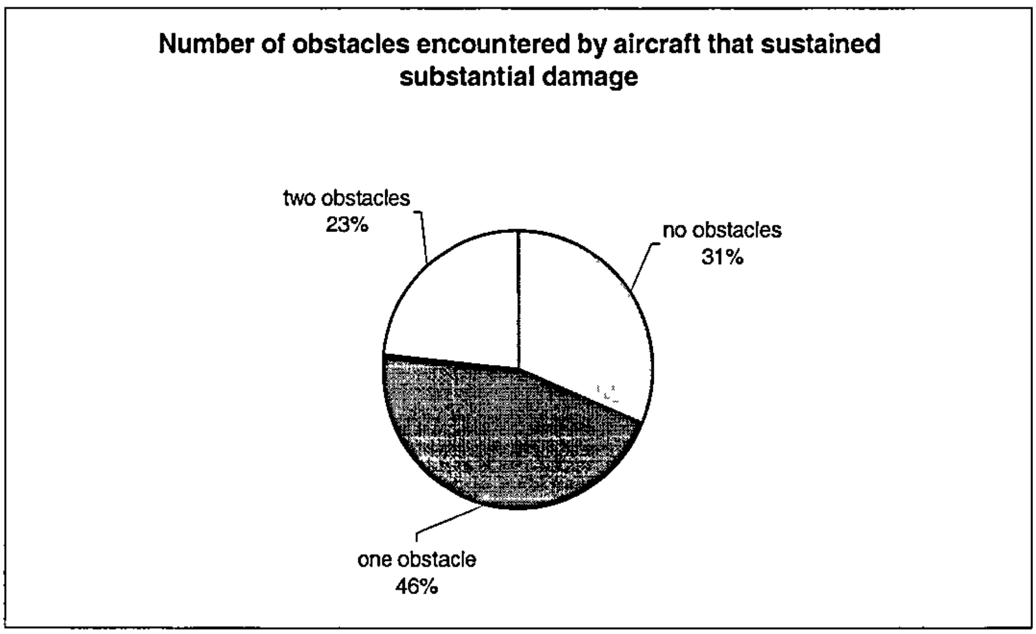


Figure 6. 44

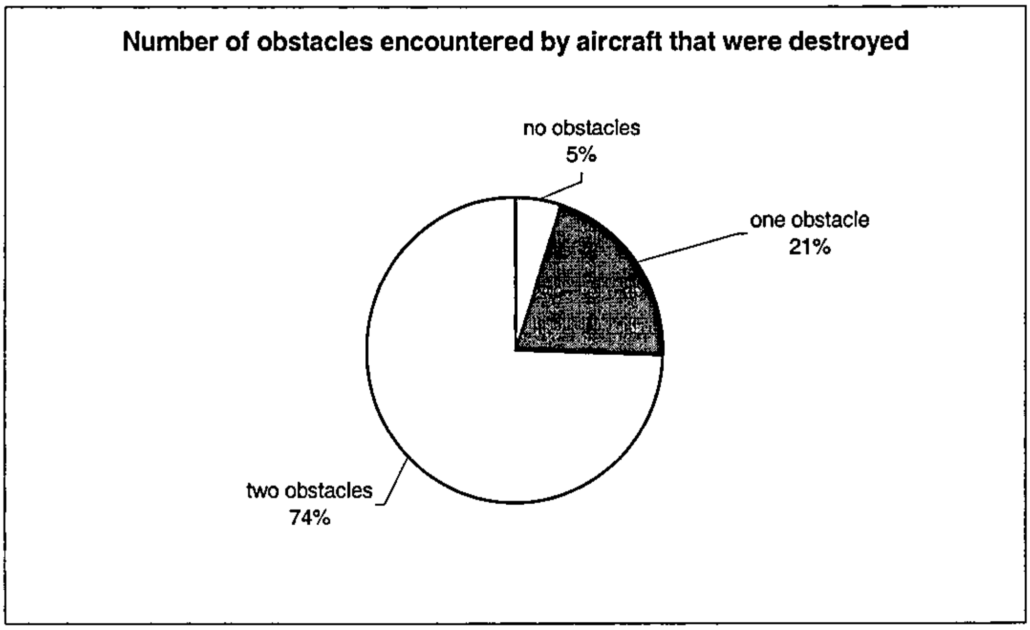


Figure 6. 45

On average aircraft that suffered no damage and minor damage encountered the fewest obstacles, more obstacles were encountered by those aircraft that suffered substantial damage, obstacles were encountered most frequently by those aircraft that were destroyed, and the differences were significant

Figures 6 46 and 6 47 show damage sustained where the aircraft has encountered no obstacles after the runway end, and where it has encountered at least one obstacle after the runway end for the cases where the damage and the number of obstacles were known It can be seen that aircraft that struck an obstacle suffered much more damage on average than those that did not The differences again are significant

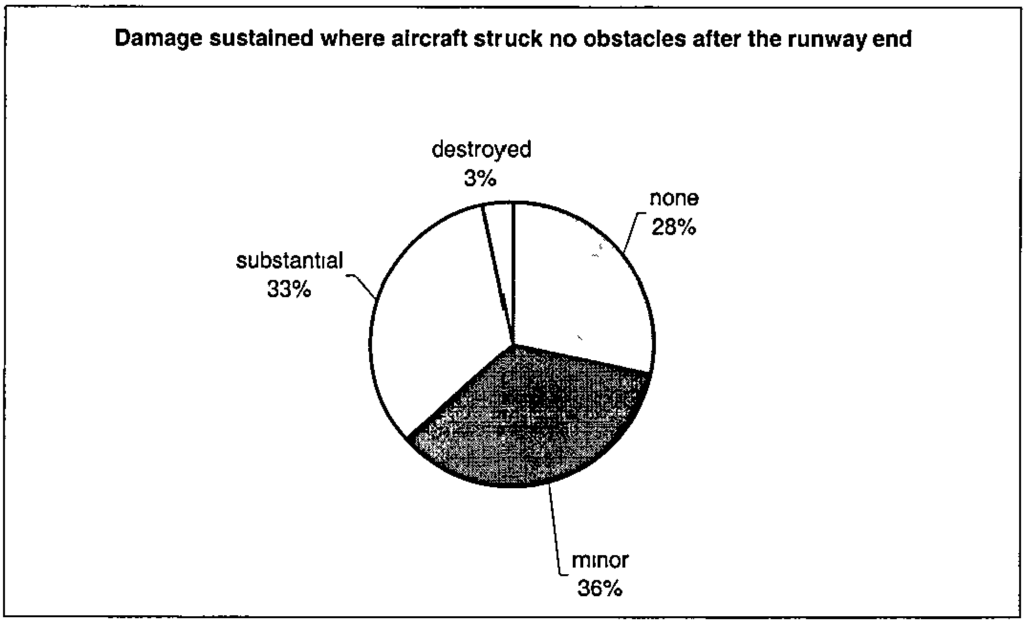


Figure 6. 46

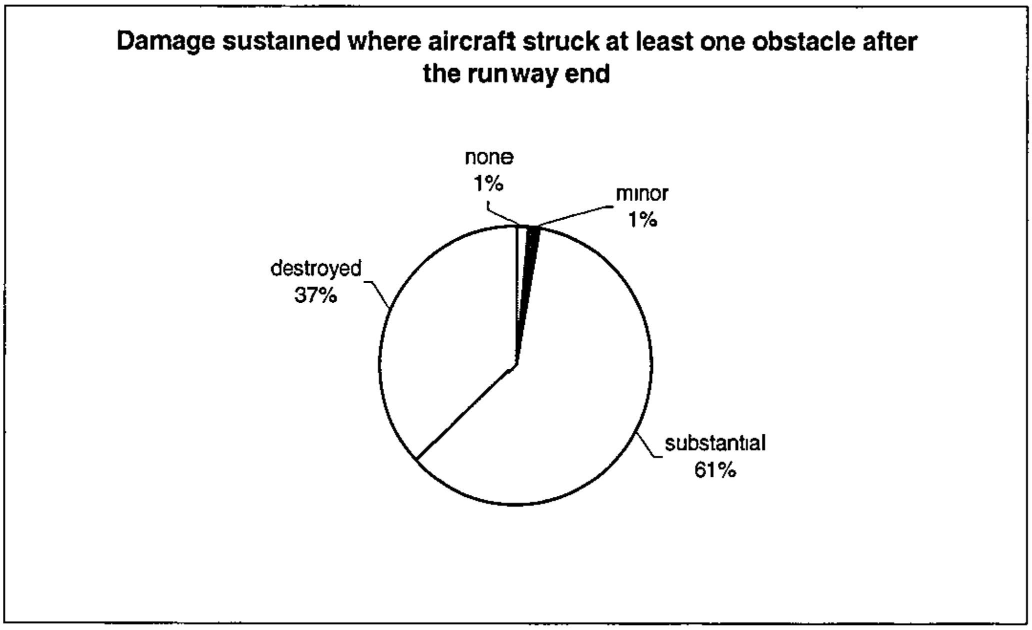


Figure 6. 47

6 5 7 Aircraft weight versus number of obstacles encountered beyond the runway end

The strong correlation between damage caused, and the number of obstacles encountered by the aircraft after leaving the runway end, may indicate that the reason that there seemed to be a correlation between aircraft maximum gross weight and damage incurred, is due to the use of airfields which are more likely to possess obstacles beyond the runway end by smaller aircraft

The mean maximum gross weight of aircraft that did not encounter any obstacles and where the weight was known was 117302 lbs. That of aircraft that encountered one obstacle was 82378 lbs, and that of aircraft that encountered two obstacles was 46669 lbs These differences are significant, so this does therefore seem possible

6 5 8 Aircraft fire

The aim of section 6 5 8 is to determine the causal and circumstantial factors of aircraft fires after an aircraft has overrun the runway end

6 5 8 1 Aircraft fire versus flight phase

It has been assumed that a fire is more likely to break out after a rejected takeoff, than after a landing, largely because an aircraft will have more fuel on board on takeoff than landing (see DNV Technica, 1994) Figures 6 30 and 6 31 in 6 5 1 show damage incurred by flight phase It was also noted in 6 5 1 that on average those aircraft that overran after a takeoff overrun suffered more damage than those that overran after a landing but there was not a significant difference

Fire was experienced after a takeoff overrun in 9 out of 39 cases where this was known (23 %) and after a landing overrun in 8 of 121 cases (7 %), a significant difference

Other contributory factors that would be expected to affect the probability of fire occurrence are aircraft size, runway exit speed, and whether any obstacles have been struck

6 5 8 2 Maximum gross weight by flight phase

The mean maximum gross weight of those aircraft that have overrun after a landing and where the weight was known is 69934 lbs That of those that have overrun after a rejected takeoff is 144005 lbs, which is a significant difference

6 5 8 3 Runway exit speed versus flight phase

Figures 6 48 and 6 49 show runway exit speed versus phase

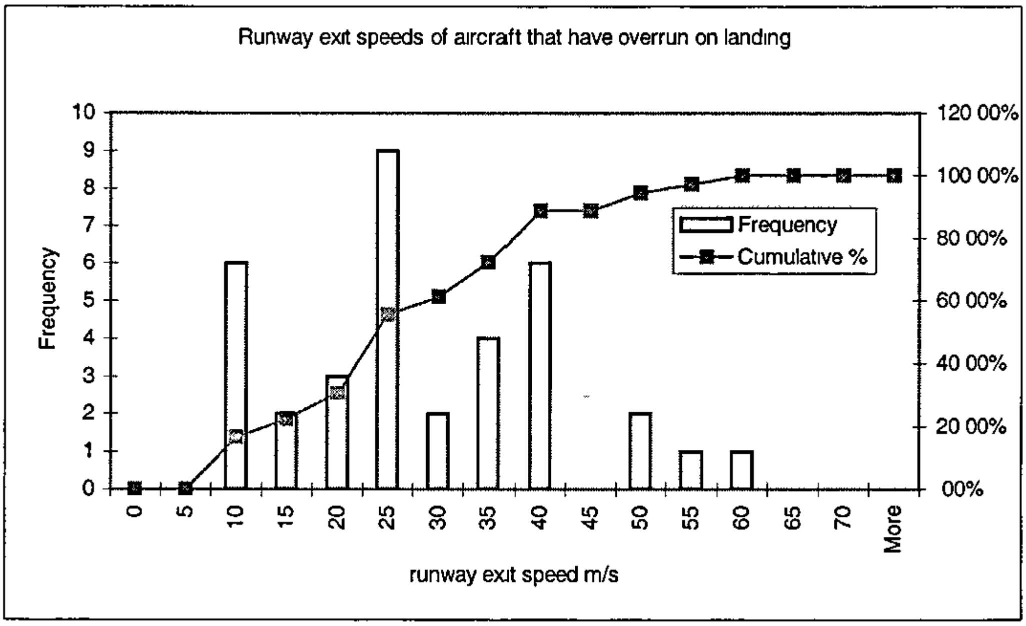


Figure 6. 48

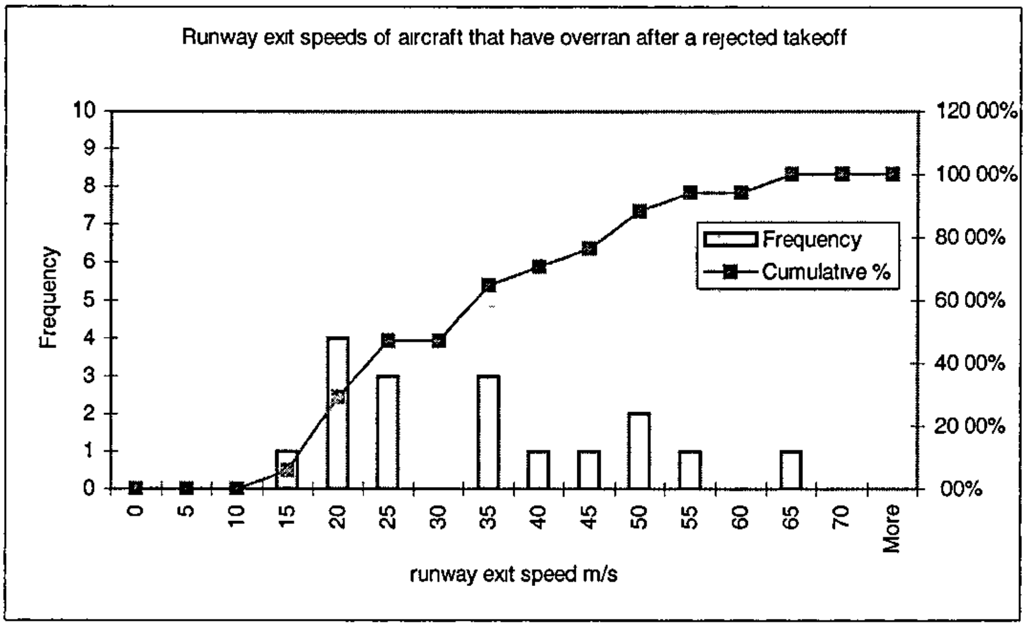


Figure 6. 49

Mean runway exit speed for those cases where the exit speed is known and the aircraft has overrun after a landing is 26 1 metres per second That for those that have overrun after a rejected takeoff is 32 0 m/s, however, the difference is not significant

6 5 8 4 Runway exit speed versus incidence of fire

It is possible that fires are caused by higher runway exit speeds

The mean runway exit speed of those aircraft that caught fire and the exit speed were known was 41 4 m/s That of the aircraft that did not catch fire was 26 0 m/s The difference is significant, and therefore provides supporting evidence for this hypothesis

6 5 8 5 Number of obstacles struck beyond the runway end versus phase

In order to determine whether the higher incidence of fires during takeoff overruns has been due simply to the operation being a takeoff and therefore more fuel on board, or that perhaps the aircraft that have overrun after a takeoff have encountered more obstacles beyond the runway end Figures 6 50 and 6 51 compare the numbers of obstacles struck beyond the end of the runway for each of the two phases

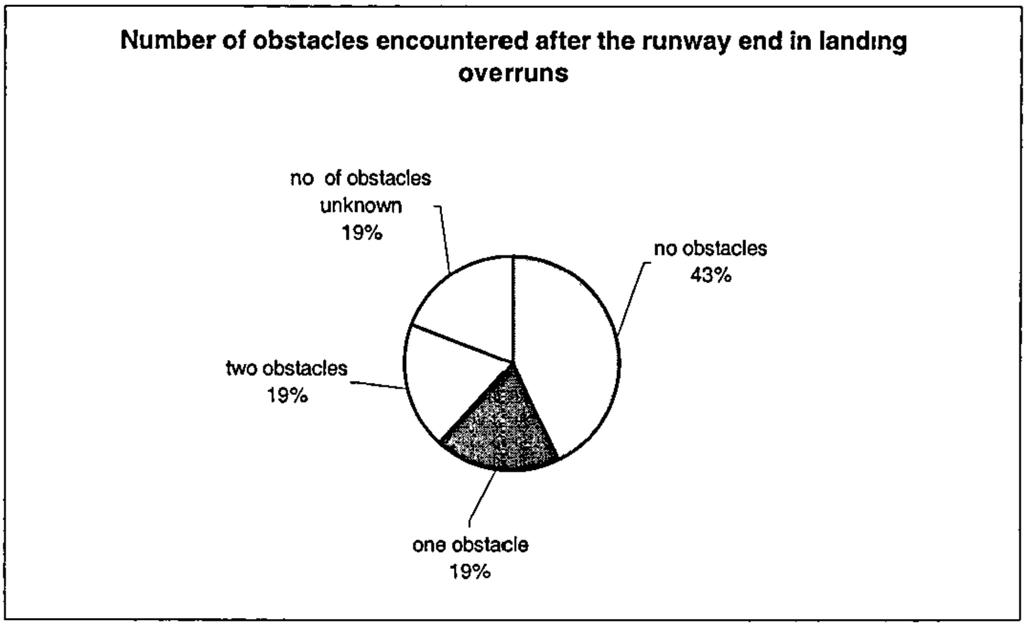


Figure 6. 50

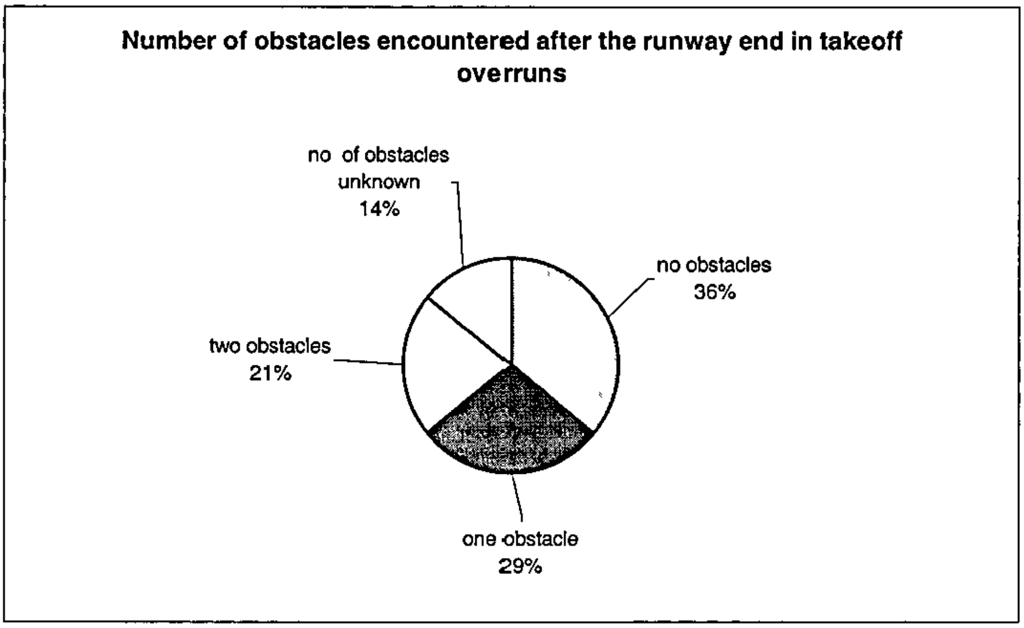


Figure 6. 51

There is a slight increase in the number of obstacles struck after the runway end in takeoff overruns compared to the number struck in landing overruns However, the difference is not significant, and therefore the increase in incidence of fire may not be due to increased numbers of obstacles

6 5 8 6 Numbers of obstacles struck versus incidence of fire

The relationship between fire and obstacles struck is further explored in figures 6 52 and 6 53 On average, those that caught fire have struck more obstacles at an incidence that is statistically significant

It is plausible therefore that although aircraft have caught fire more frequently after a rejected takeoff than after a landing, the difference may be caused by the particular circumstances surrounding the individual takeoff overruns rather than the overruns occurring after a takeoff This may seem contrary to the non-significant difference between incidence of encounters with obstacles by phase in 6 5 8 5, however, there was a difference, just not large enough to be significant

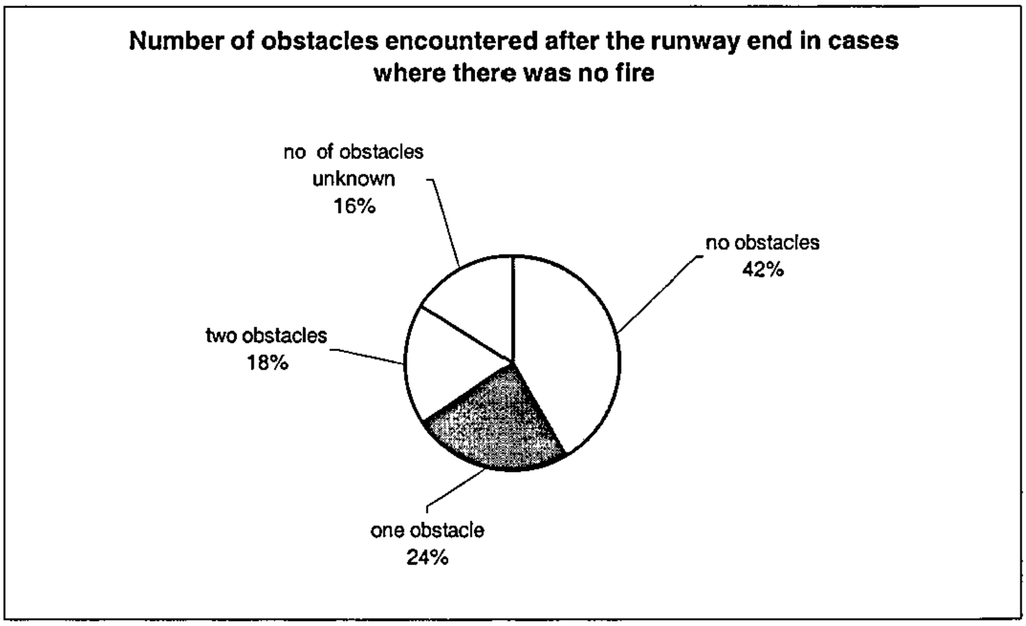


Figure 6. 52

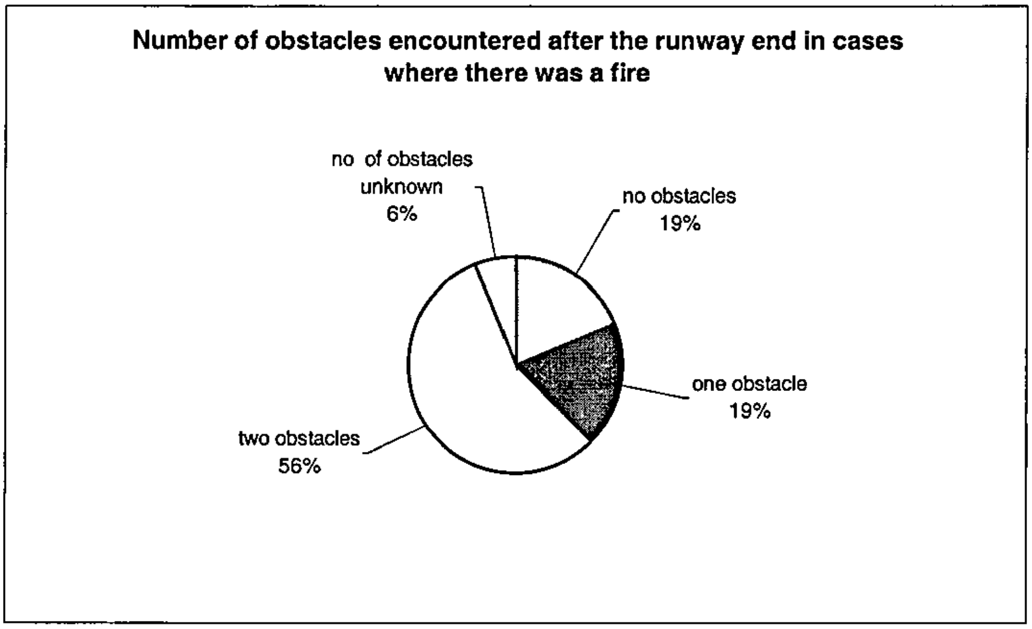


Figure 6. 53

6 5 8 7 Numbers of obstacles struck by phase, and incidence of fire

In order to further separate the contributions to incidence of fire between the numbers of obstacles that were struck, and the differences in the operation due to phase, the incidence of fire has been calculated whilst holding the numbers of obstacles that were stuck constant

After suffering a landing overrun the aircraft struck no obstacles and did not catch fire in 48 cases, and caught fire in 1 case This is compared with 11 cases of not catching fire and 2 cases of catching fire after a takeoff overrun Of the aircraft that struck no obstacles, therefore, the ones that overran after a rejected takeoff caught fire more often, furthermore, the difference was significant

After suffering a landing overrun the aircraft struck one obstacle and did not catch fire in 24 cases, and caught fire in 1 case This is compared with 10 cases of not catching fire and 2 cases of catching fire after a takeoff overrun Again, those that overran after a rejected takeoff caught fire more often than after a landing overrun, however, the difference was not significant

After suffering a landing overrun the aircraft struck two obstacles and did not catch fire in 20 cases, and caught fire in 6 cases This is compared with 6 cases of not catching fire and 3 cases of catching fire after a takeoff overrun This result is similar to the cases where one obstacle was struck in that those that overran after a rejected takeoff caught fire more often than after a landing overrun, but the difference was not significant

These results seem to indicate that given similar terrain fire occurs more often after a rejected takeoff than a landing

6 5 8 8 Damage incurred in fires by phase

If the hypothesis that a fire after a takeoff overrun is more serious than a fire after a landing overrun were true it would be expected to be reflected in the damage incurred in fires due to overruns Table 6 13 shows the damage incurred by aircraft that suffered fires after overrunning on takeoff and landing, and suggests that whether a fire occurs after a takeoff or landing, the aircraft is almost equally likely to be substantially damaged or destroyed These broad definitions of aircraft damage may not, however, be the best way of determining the severity of a fire

6 5 8 9 Injuries incurred in fires by phase

Table 6 14 explores the number of injuries incurred when a fire has broken out The small number of cases involved enables them to be looked at on a case-by-case basis

The aircraft that have suffered a fire after overrunning the runway have been of two broad sizes, those over one hundred passengers, and those of less than ten passengers Of those of over one hundred occupants no injuries have been incurred during the overrun (the figures do not include injuries that have resulted from an emergency evacuation), this is true of both landing and takeoff overruns Table 6 15 enables an easier comparison of takeoff and landing injuries for aircraft with less than 10 occupants It shows total numbers of injuries to occupants of aircraft of less than ten seats that caught fire

On average the occupants of those aircraft that overran after a takeoff overrun and caught fire received more serious injuries than the occupants of aircraft that suffered landing overruns However, this result is not significant

6 5 8 10 All injuries by phase

Table 6 18 contains aggregated injury data by flight phase for all overruns

On average more serious injuries have been sustained in landing overruns than in takeoff overruns, however the difference is not significant.

6 6 *Meteorological conditions*

Prevailing meteorological conditions obviously have the potential to affect the risk of the occurrence of an overrun In order to properly assess risk, the occurrence rate of a risk factor in operations that result in an overrun needs to be compared with the occurrence rate of the risk factor in operations that do not result in an overrun Unfortunately, statistics are not available for the occurrence of many risk factors in successful flights, however, collecting and investigating the occurrence rate of these factors in unsuccessful flights is an important step towards a greater understanding of the contributors to risk

6 6 1 *Wind*

It is possible that wind is a contributory factor to overrun risk, especially on landing (see CAA, 1998) Figures 6 54 and 6 55 compare the headwind component of wind speed between landing and takeoff overruns In these figures tailwind is positive and headwind is negative.

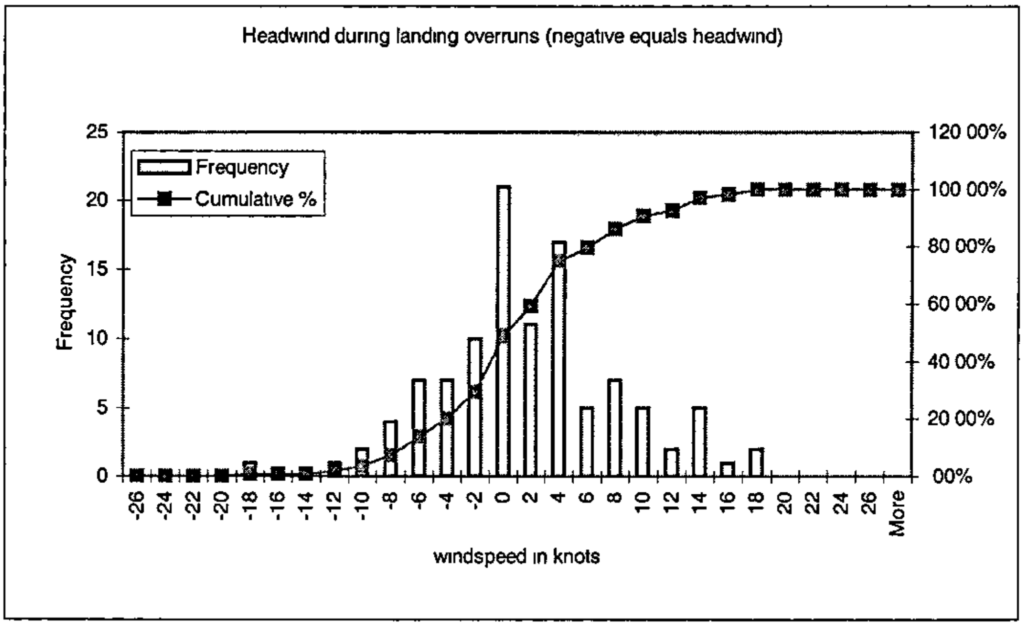


Figure 6. 54

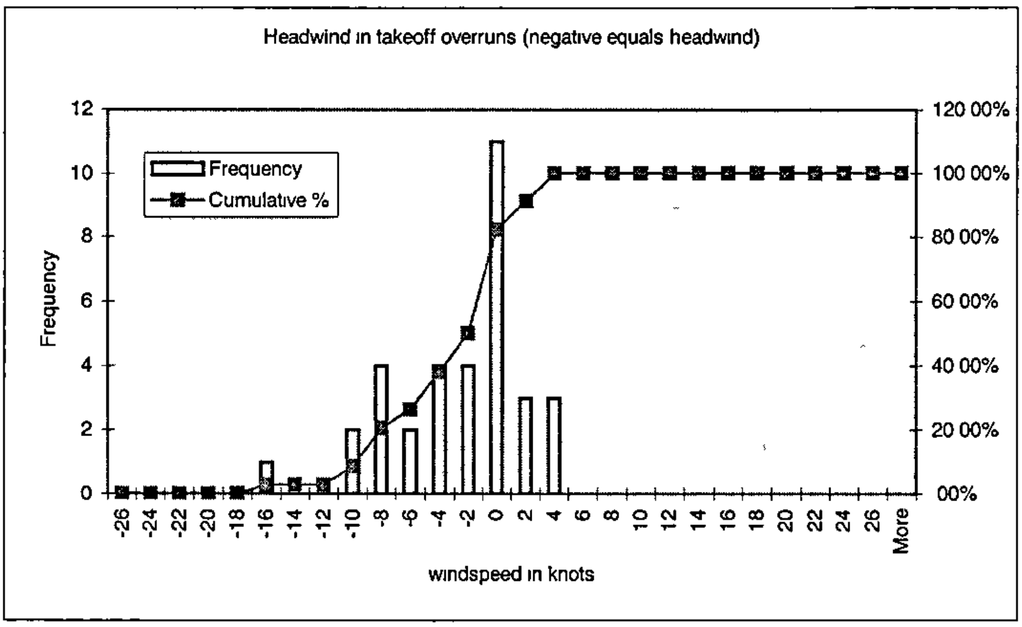


Figure 6. 55

On average the landing overruns have occurred in tailwinds more often than takeoffs The difference is also significant

Table 7 19 contains the proportion of landings and takeoffs conducted in differing wind conditions.

The estimate of one airline of the number of landings that occurred with a tailwind was approximately 5 percent, and the number of takeoffs with a tailwind was approximately 2 percent (Savage, 2001) If these are accurate figures the rate at which landing overruns occur with a tailwind may be ten times higher than the rate at which landings occur with a tailwind

6 6 2 *Light conditions*

Of the landing overruns where the light condition was known 88 (66 percent) occurred during the day, and 45 (34 percent) occurred during the night Of the rejected takeoff overruns where the light condition was known 31 (77 5 percent) occurred during the day and 9 (22 5 percent) occurred during the night Day is defined as after sunrise and before sunset, and night is defined as after sunset and before sunrise It can be seen that a greater proportion of landing overruns have occurred at night than takeoff overruns However, the difference is not significant

Khatwa and Helmreich (1998) state that, from discussions with airlines and airport operators, approximately 20 to 25 percent of landings occur at night If this figure is correct the rate at which landing overruns occur at night is approximately one and a half times the rate at which landings occur at night, and the rate at which landing overruns occur during the day is approximately 0 8 times the rate at which landings occur during the day

Khatwa and Helmreich (1999) also give rates of worldwide fatal approach and landing accidents between 1980-1996 to jet and turboprop aircraft above 5700 kgs The figures are shown in table 6 20 This study of exclusively fatal approach and landing accidents gives a higher percentage of these types of accidents occurring at night, when compared with overruns

6 6 3 *Conditions of visibility*

There were 116 landing overruns, and 36 takeoff overruns where the visibility was known The average visibility experienced during a landing overrun was 13651 metres, and during a rejected takeoff overrun was 17433 metres Also, 30 percent of the landing overruns took place in visibility of less than two miles, and 55 percent of the landing overruns took place in visibility of less than four miles This is contrasted with 14 percent of the takeoff overruns taking place in visibility of less than two miles, and 19 percent of the takeoff overruns taking place in visibility of less than four miles These differences are significant, however, until the data can be compared with that for non-overrun operations, the influence of visibility on overrun rate cannot be quantified

6.6.4 *Type of prevailing weather*

Figures 6.56 and 6.57 show weather conditions at the time of the occurrence

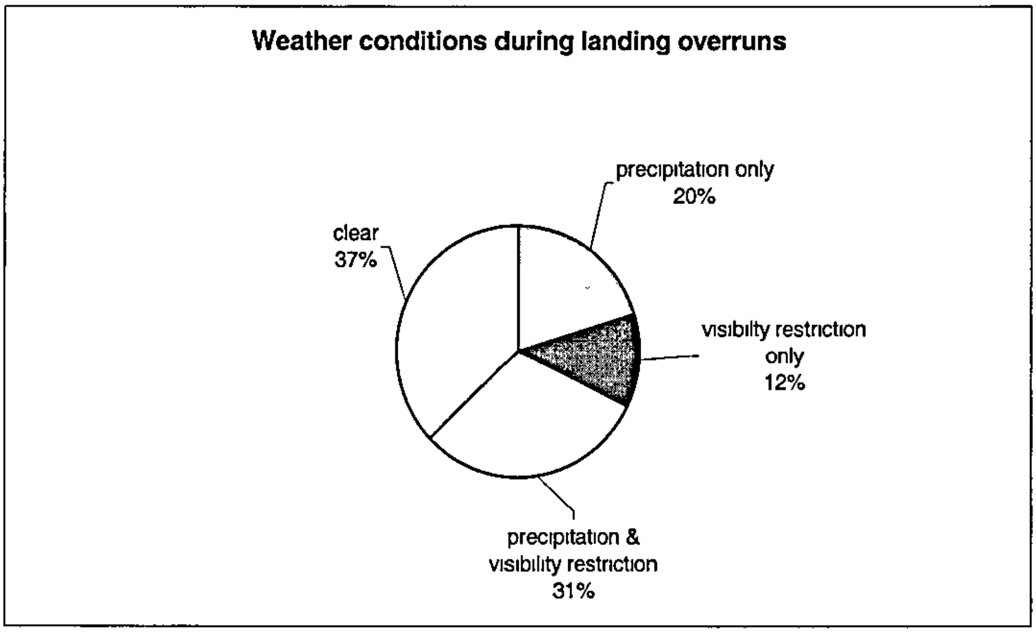


Figure 6. 56

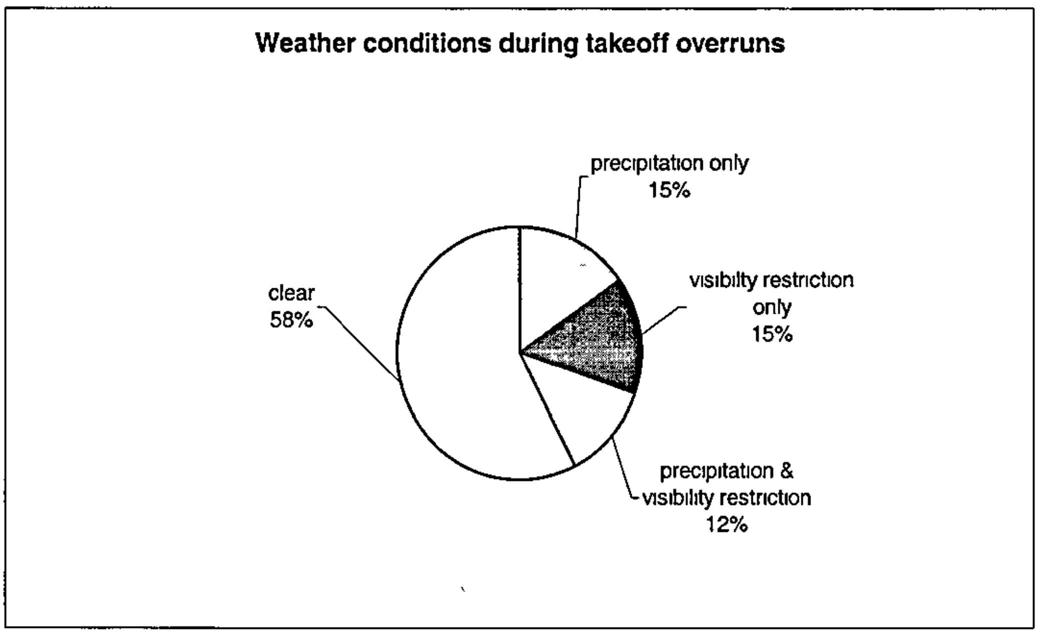


Figure 6. 57

There were 118 landing overruns and 33 takeoff overruns where the weather conditions were known *Precipitation* is defined as rain, snow, sleet, or hail *Visibility restriction* is defined as fog, smoke, haze, or mist In general the landing overruns occurred in poorer weather conditions than the takeoff overruns, however, the difference was not significant although the landing overruns seem to have occurred in poor weather at a greater rate than non-overrun landings

6 6 5 Runway condition

Figures 6 58 and 6 59 show runway condition during overruns The descriptions of runway condition in accident reports are often fairly vague and in many cases it has been necessary to make a judgement as to the actual condition Where the report has stated a combination of states, for example "snow and ice", if neither state appears to be predominant the more severe state has been assumed, otherwise a judgement has been taken as to the state that describes the majority of the runway

The runway condition was known in 114 landing overruns and 35 takeoff overruns

It can be seen that landing overruns have taken place in a variety of runway conditions, with only 30 percent of landing overruns taking place on a dry runway compared to 66 percent of takeoff overruns In the landing case 29 percent occurred on very wet, flooded, snow, ice or slush covered runways, whereas only 14 percent of the takeoff overruns occurred in these conditions These are also significant differences

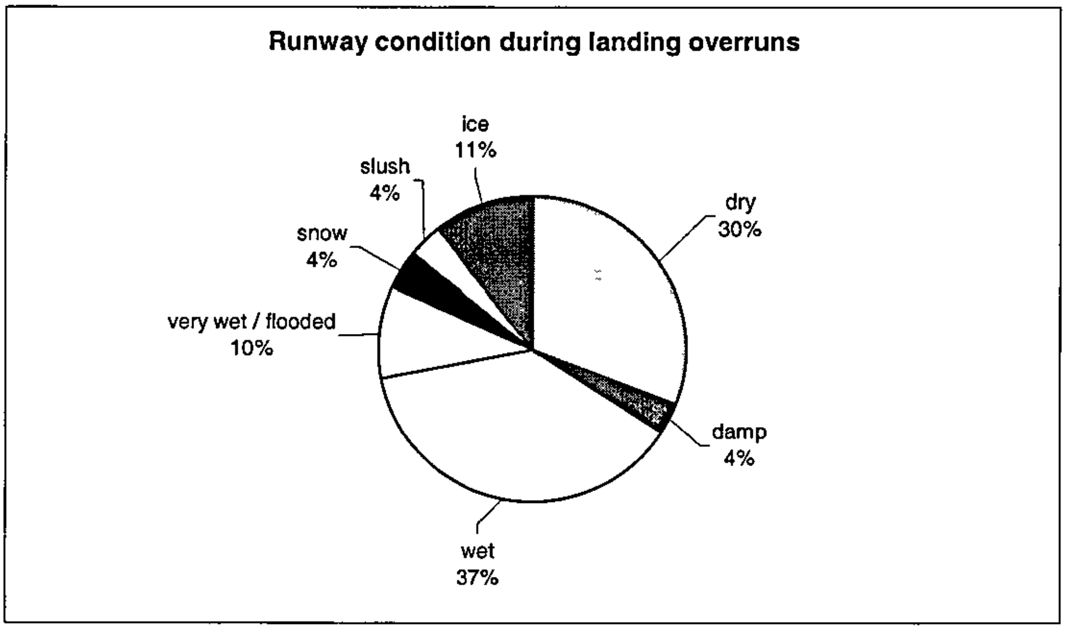


Figure 6. 58

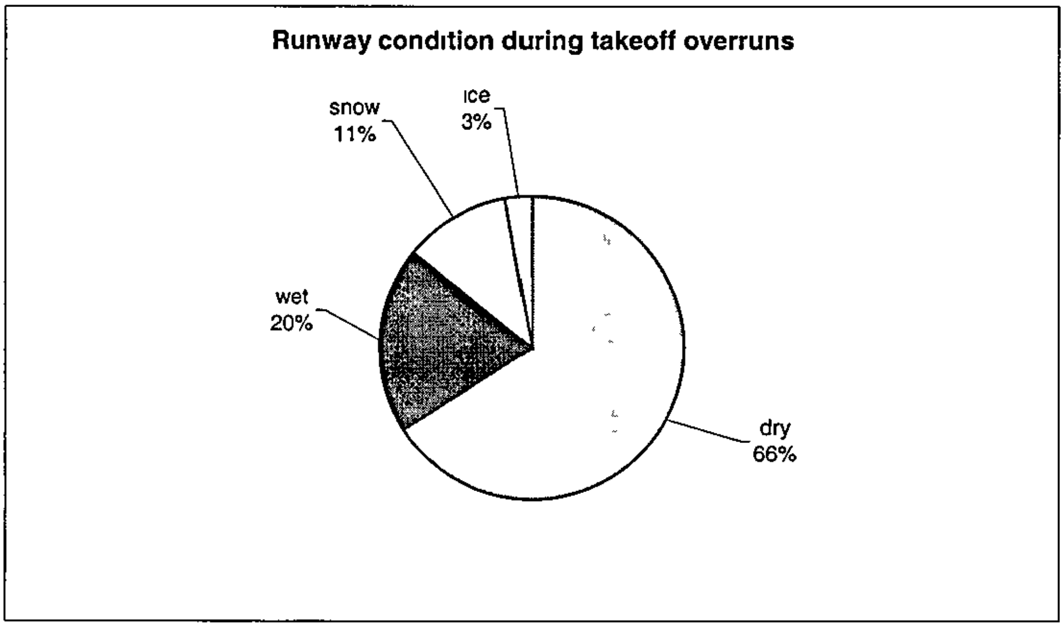


Figure 6. 59

6 7 *Landıng*

Sectıon 6 7 concentrates on aspects of landıng overruns, ın partıcular the dıfferences between those occasıons where the aırcraft overran after flyıng a precısıon approach and those occasıons where the aırcraft overran after flyıng an approach whıch was not a precısıon approach

6 7 1 *Landıng speed*

Of a total of 137 landıngs that resulted ın an overrun, 30 (22%) are known to have been conducted wıth excessıve speed, and 6 (4 %) are known to have been conducted wıth no excessıve speed In 101 cases (74 %), whether the landıng speed was excessıve was not known However, ıt ıs lıkely that the speed was not excessıve ın the majorıty of these unknown cases Thıs ıs because accıdent reports focus on the parts of the operatıon that dıd not work as desıgned and usually ıgnore the aspects that dıd Of the 101 cases where the speed ıs not known, 69 (51% of total landıng overruns) gıve findıngs that do not mentıon speed In 32 cases (23 % of total) the speed was unknown and no findıngs were gıven These figures are shown ın Fıgure 6 60

The same problems are encountered wıth other attrıbutes taken from accıdent reports The maın problems are due to accıdent reports not beıng wrıtten wıth a standard lexıcology, and also from them tendıng to be vague A typıcal sentence ın the findıngs sectıon of the NTSB database may state "aırspeed – excessıve – pılot ın command" Thıs does not state where ın the approach the speed was excessıve or by how much, but ıt was excessıve somewhere durıng the approach and landıng The crıterıa for ınclusıon ın the category "speed known to be excessıve" ıs that an excessıve speed was mentıoned ın the findıngs of the report To be ıncluded ın the category "speed known to not be excessıve" the speed of the aırcraft had to be wıthın normal operatıonal parameters durıng the approach and landıng

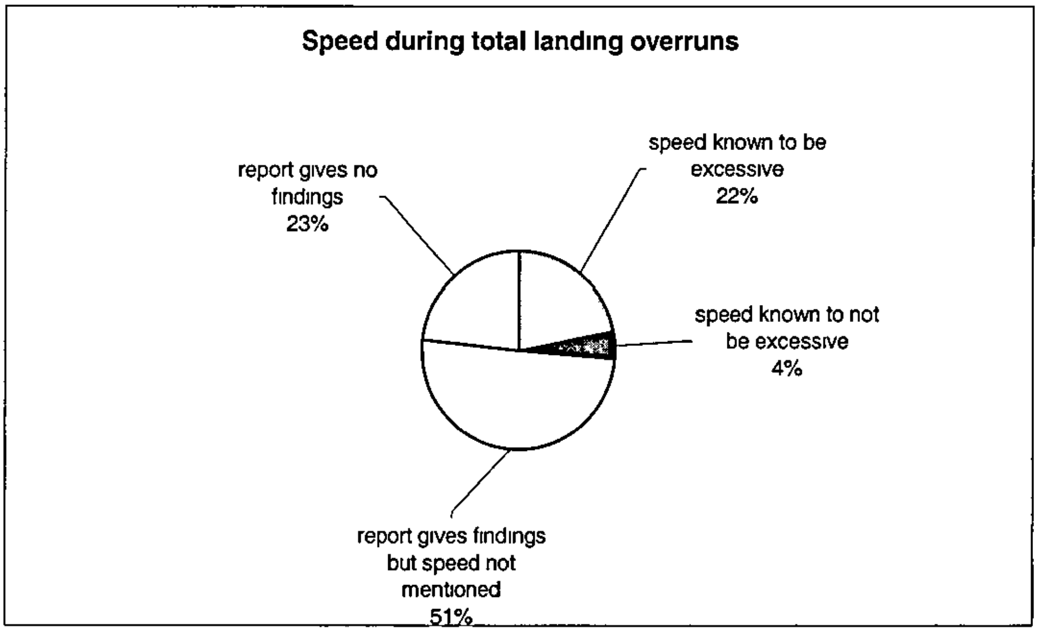


Figure 6. 60

6 7 2 Landing speed versus flight type

Figures 6 61, 6 62 and 6 63 show landing speed versus flight type In total there were 64 passenger landing overruns, 22 freight landing overruns, and 50 general aviation landing overruns

The proportion of landing overruns for which the speed was known to be excessive is highest in passenger overruns, then in freight overruns, and lowest in general aviation overruns Also, the proportion of landing overruns that fell into the category "report gives findings but speed not mentioned", which might be expected to form some indication of cases for which the speed was not excessive increases from passenger to freight to general aviation operations This indicates that different categories of flight may in general have different overrun causal factors A further factor that may affect the results is that in general, general aviation aircraft do not carry flight data recorders although some of the general aviation flights were passenger aircraft flying under general aviation flight rules, for example an empty positioning flight This leaves open the possibility that general aviation aircraft were flown at an excessive speed but this is unknown because of the absence of a data recorder.

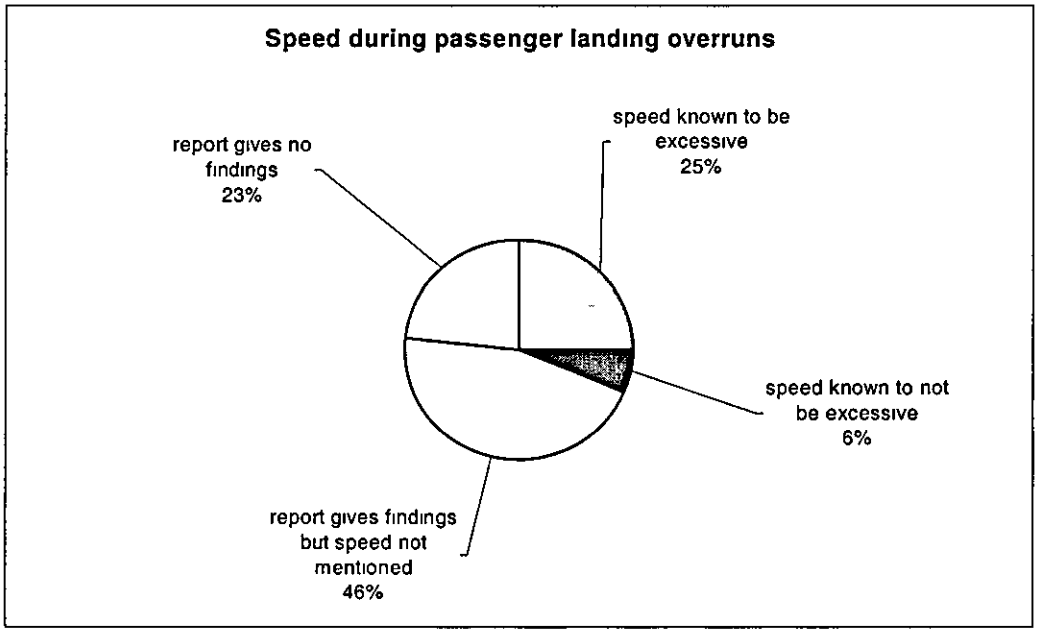


Figure 6. 61

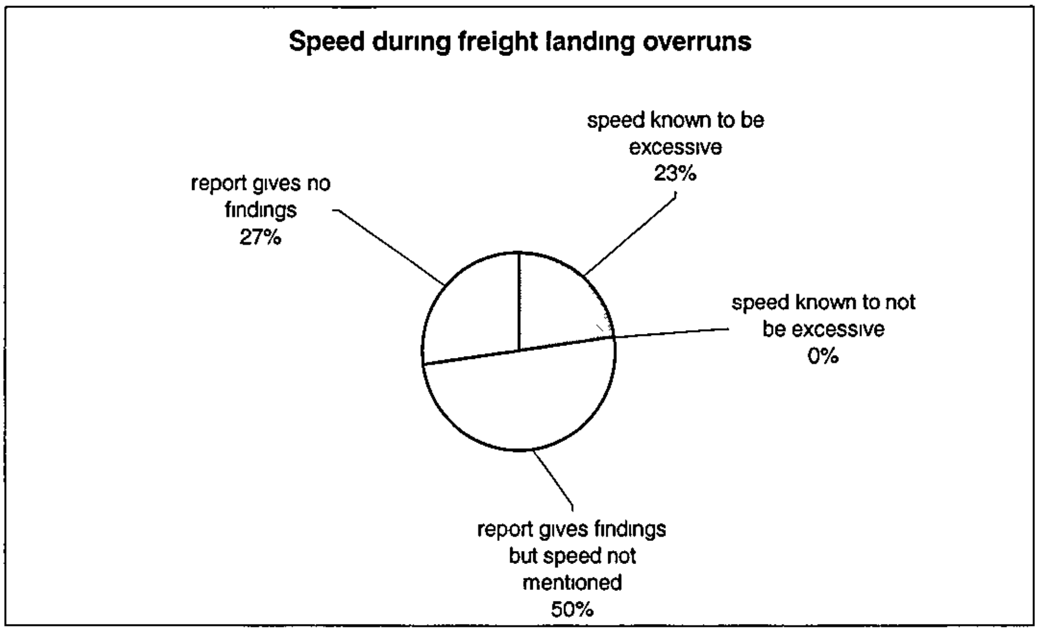


Figure 6. 62

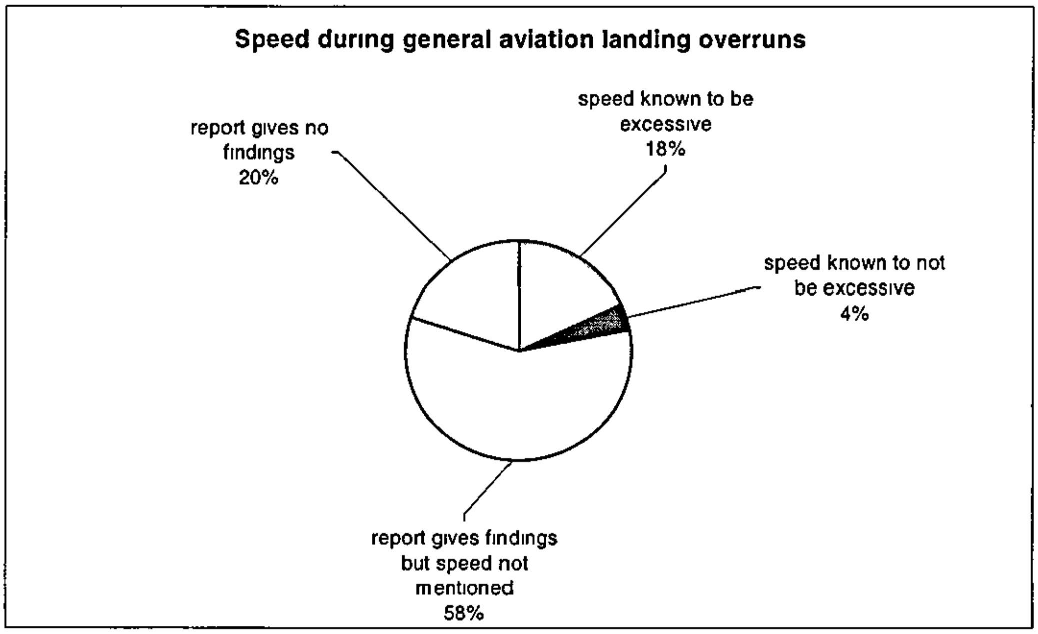


Figure 6. 63

In order to determine the effects on overrun risk of landing at an excessive speed, it is desirable to compare the landing speeds of those landings that have resulted in an overrun with the landing speeds of operations that have not resulted in an overrun Unfortunately data is not available that is comparable to that collected from the accident reports The main reason being that the definition used for "excessive speed" in accident reports is unknown, and is likely to be a function of the circumstances surrounding the landing rather than an absolute figure It would therefore be extremely difficult to correlate speed with that of non-overrun landings without also examining the circumstances of every normal landing

6 7 3 Touchdown point

Figure 6 64 shows touchdown point relative to the landing threshold (usually the start of the runway) in landing overruns where the touchdown point was known This was known in 92 cases and unknown in 45 cases It can be seen that there is a relatively large peak at 300 – 350 metres from the threshold This is due to a number of reports simply stating that the landing was on target, which on many runways will correspond to 305 metres from the threshold The aircraft have not landed on exactly the same spot but will have landed in the general area There is also a rather long tail to the distribution with the furthest landing point being 2066 metres from the landing threshold

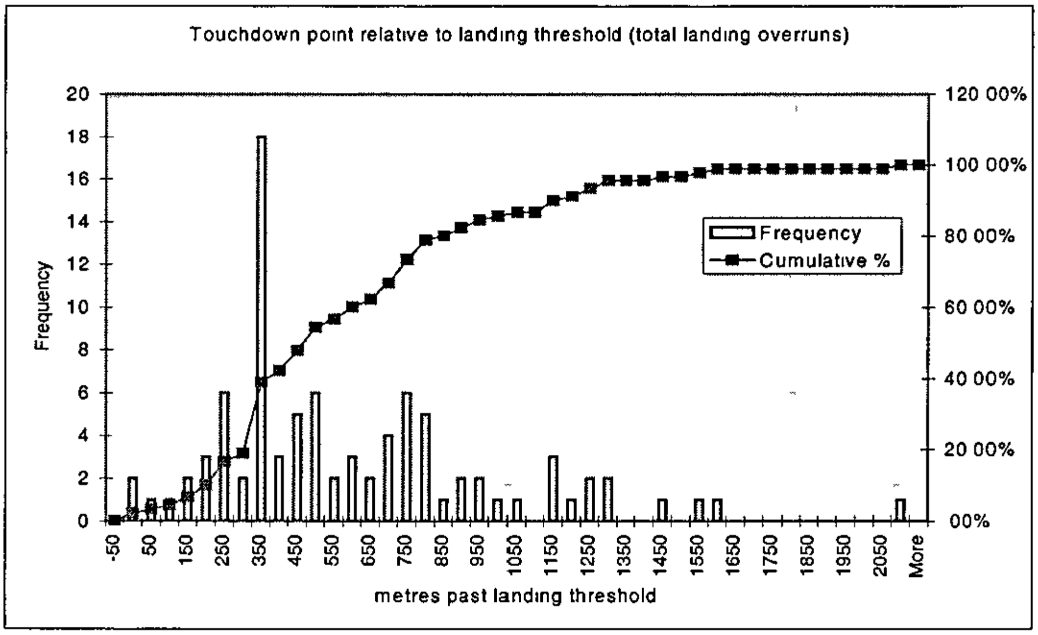


Figure 6. 64

6 7 4 Touchdown point by flight type

Figures 6 65, 6 66, 6 67 and 6 68 have split the touchdown point distribution by flight type, into freight (15 known, 5 unknown), general aviation (32 known, 18 unknown), and passenger aircraft (42 known, 23 unknown)

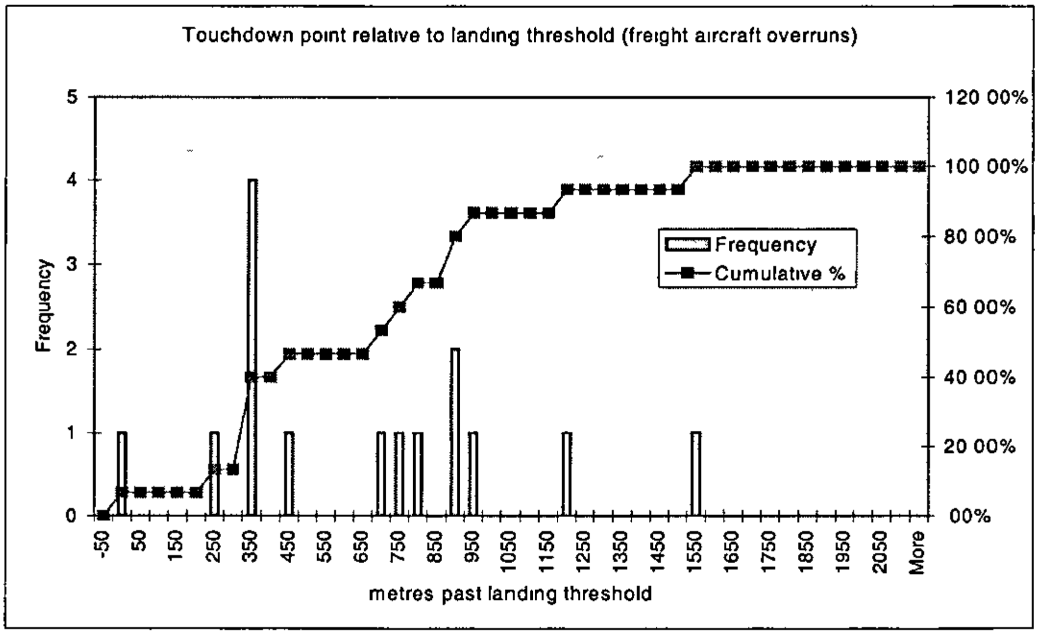
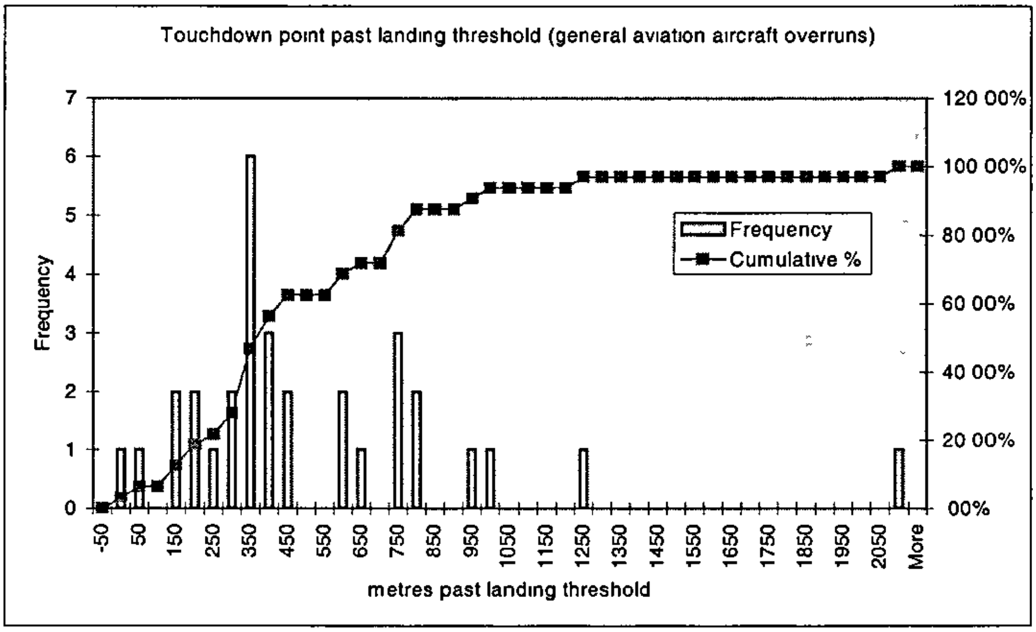


Figure 6. 65



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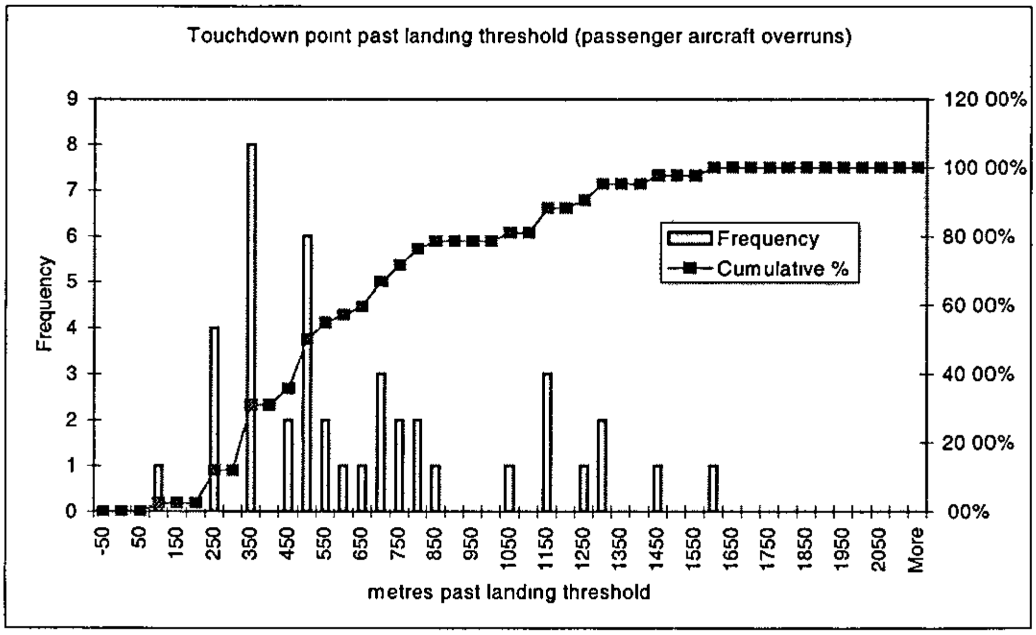


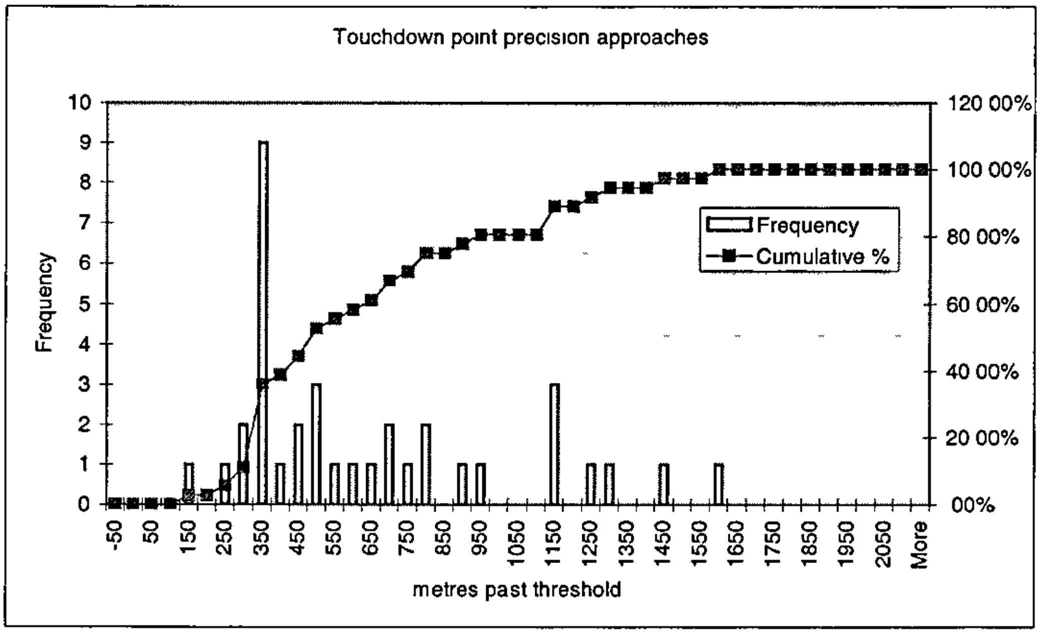
Figure 6. 67

The distributions look similar. Eighty percent of the general aviation aircraft have touched down within 750 metres from the threshold, eighty percent of the freight aircraft have touched down within 900 metres of the threshold, and eighty percent of the passenger aircraft have touched down within 1100 m of the threshold Any differences, however, are not significant

6 7 5 Type of approach

6 7 5 1 Touchdown point versus type of approach

Figures 6 68, and 6 69 show touchdown point where a precision approach was flown, and where an approach was flown that was not a precision approach A precision approach is defined as airport and aircraft equipment that gives the pilot vertical and horizontal guidance to the threshold



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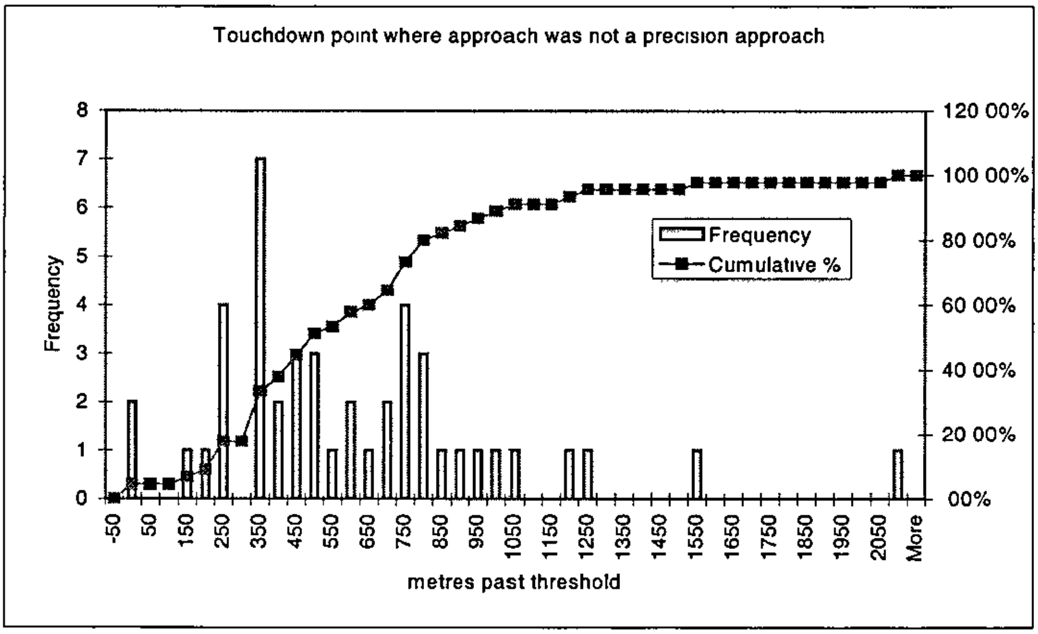

Figure 6. 69

The diagrams above show that for landings that have resulted in an overrun there has been little difference in touchdown position between those landings that have flown a precision approach and those that have not The only apparent differences are that the precision approaches have resulted in fewer aircraft touching down before the intended touchdown zone, and that there is less variation in touchdown point with the precision approach

The differences in the two means and variances are not significant

6 7 5 2 Previous work

A study was conducted under the auspices of the Flight Safety Foundation (FSF) for the Netherlands Directorate-General of Civil Aviation, to explore the influence of fully functioning precision terminal approach and guidance equipment on risk (Enders et al, 1998). The study looked at total hull loss accidents to aircraft operated by commercial operators, during initial and final approach, landing, flare, rollout after touchdown, and go-around at a principal airport The proportion of different approach aid types used by these accident operations was compared with the approach aids used in non-accident flights The study concluded that globally there was evidence for a five-fold increase in risk from flying a non-precision approach rather than a precision approach

This study appears to be confused as to whether an increased accident rate while flying a non-precision approach over a precision approach proves a causal link between risk and approach type The first page of the report states that "the study's conclusions do not imply that a positive association between a risk factor and approach accidents represents causation, but do show that a demonstrated association exists" However, the next sentence states that "airport authorities can significantly minimize risk for approach-and-landing safety with precision approach-and-landing guidance facilities", which implies that the causal link is proven This inconsistency occurs throughout the report

While the study was concerned with accident rates while flying different approaches, it failed to explore the mechanism by which a non-precision approach would lead to an increased accident rate or control for variables with which the different approaches may be associated, such as runway length, type of operator, level of fire and rescue cover etc This last factor may be important because as the study only included total hull loss accidents the level of fire and rescue cover may determine the inclusion of an accident It could be the case, for example, that more non-precision approach accidents occur not because the approach is dangerous but because a non-precision approach is more often associated with a lower standard of fire and rescue cover

A comparison of some of the results of the FSF study can be made with the results of this overrun study Table 6 21 contains results from the FSF study, which are for the period of 1984-93 in North America (this included Canada's principal international airports as defined by ICAO, and the USA's 120 busiest airports)

The FSF study shows an accident rate 8 7 times higher with non-precision approaches than precision approaches Although the study concludes a rate 5 times higher, their calculations actually show a rate 8 7 times greater The reason for the discrepancy was that the FSF study compared the accident rate of the non-precision approaches with the average rate, rather than with the accident rate of the precision approaches

Table 6 22 contains overruns from the current study with the same inclusion criteria A further 2 overruns occurred where the approach type was unknown

These figures show an overrun rate 3 23 times higher when non-precision approaches are flown than when precision approaches are flown However, the difference in rates is not significant

6 7 5 3 Other than precision approach correlations

Given that non-precision approaches may be correlated with more than just the accident or overrun rate, with what are they associated in the overrun database? Ideally, the correlations should be made for all flights rather than just overruns, however, that information is not available As the argument is usually between a precision approach and any other types of approach, this is the distinction that is used for the following comparisons

6 7 5 3 1 Type of approach and runway length

The lengths of runways that have been associated with other than precision approaches in overruns have a mean of 1639 metres The mean of the lengths of runways that have been associated with precision approaches in overruns is 1950 metres The difference is significant and therefore on average where overruns have occurred with an other than precision approach, the runway has been shorter than that when a precision approach was flown

6 7 5 3 2 Type of approach and required landing distance

The distance remaining between the end of the required landing distance and the end of the runway is shown in Figures 6 70 and 6 71

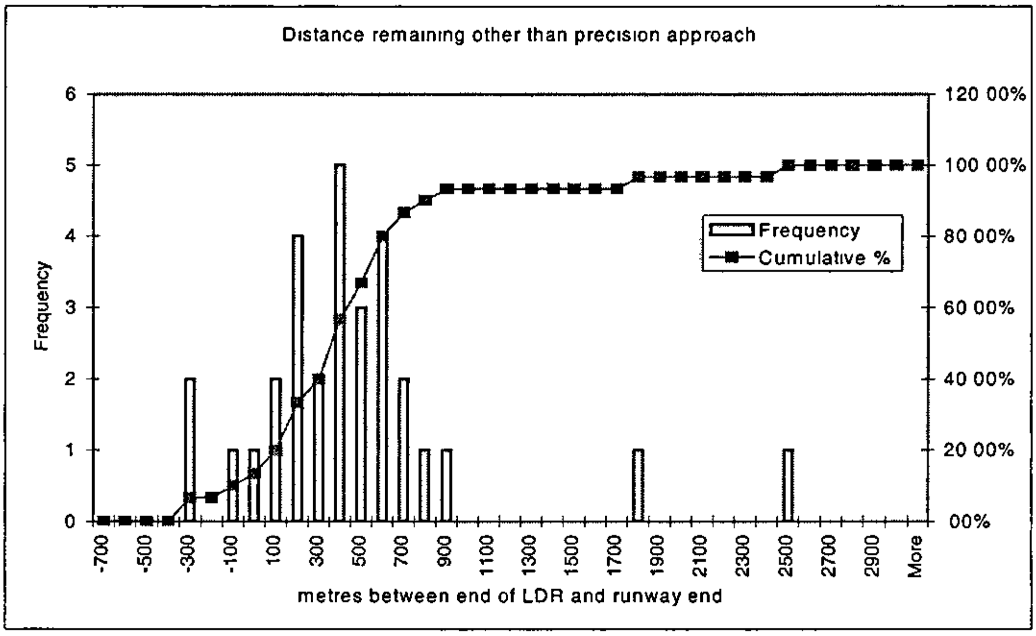

Figure 6. 70

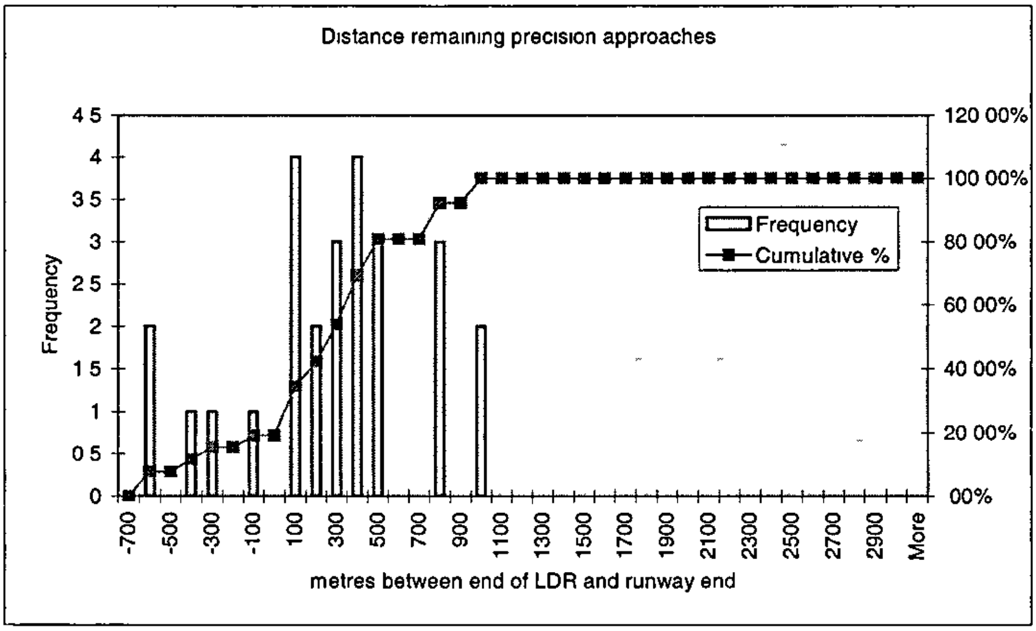

Figure 6. 71

It appears as though the aircraft that have overrun after a precision approach have had less runway remaining between their required landing distance and the runway end than those that have overrun after an approach that was not a precision approach The average distance remaining for other than precision approaches was 553 metres, and that for precision approaches was 439 metres, however, the difference is not significant

In order for the differences in required landing distance to be taken into account, the remaining distance between the required landing distance and the runway end has been calculated as a percentage of the required landing distance This is shown in figures 6 72 and 6 73

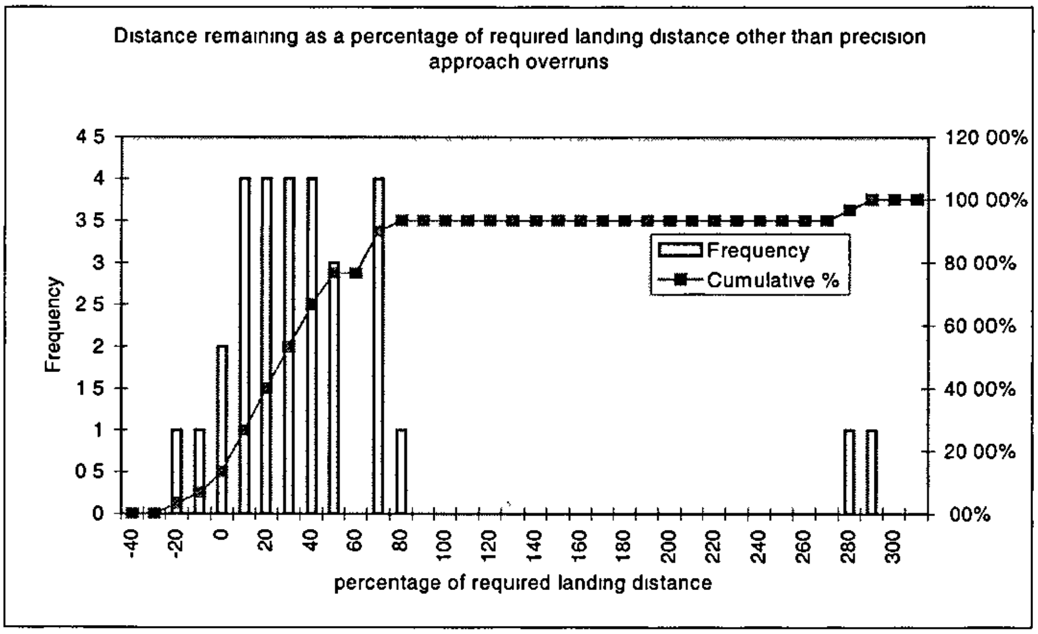

Figure 6. 72

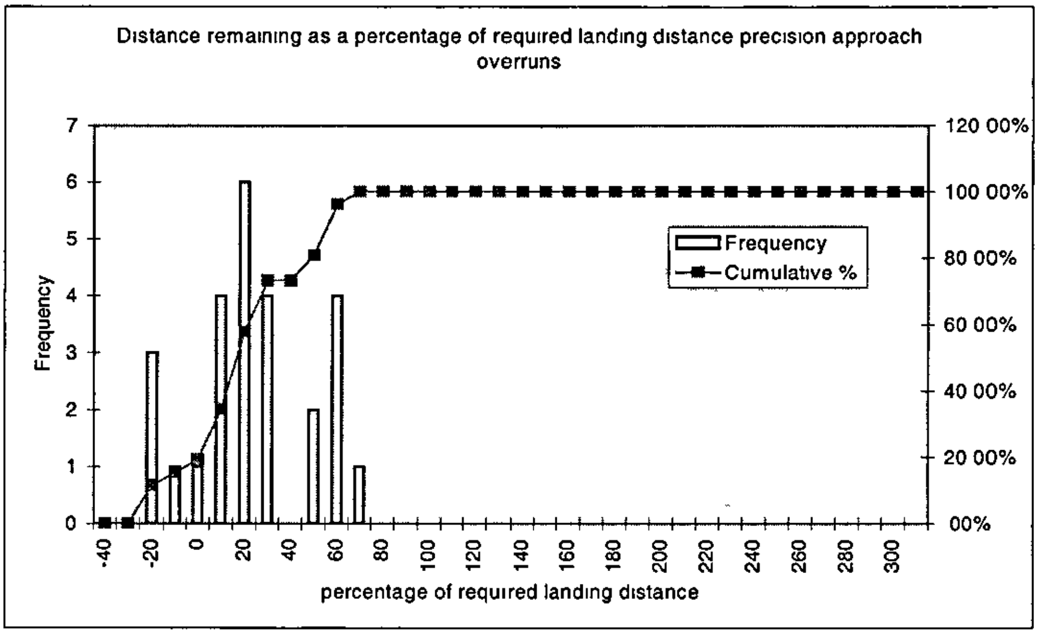

Figure 6. 73

There does not appear to be much of a visible difference between the two distributions The other than precision approach overruns have had on average 43 percent of the required landing distance, as extra runway remaining The precision approach overruns have had on average 18 percent of the required landing distance available as extra runway remaining Therefore, on average the aircraft that have overrun after flying a precision approach have had less runway remaining relative to their operation although the difference is not significant

6 7 5 3 3 Type of approach and flight type

Figures 6 74 and 6 75 show the type of flight that has overrun after flying the two different types of approach It can be seen that more freight and general aviation aircraft have overrun after flying an other than precision approach than a precision approach, and more passenger aircraft have overrun after flying a precision approach, furthermore the differences are significant The difference could occur for one of two reasons Either passenger aircraft are more likely to overrun flying a precision approach than an other than precision approach, and freight and general aviation aircraft are more likely to overrun flying an other than precision approach, or general aviation and freight aircraft more often fly other than precision approaches, and passenger aircraft more often fly precision approaches If the latter is the case, any differences in accident rates of the types of operations would show up as a difference in accident rates for the two approaches even if the two approach types were equally risky This seems to be overlooked by most recent studies of approach risk (e g Enders, et al, 1998)

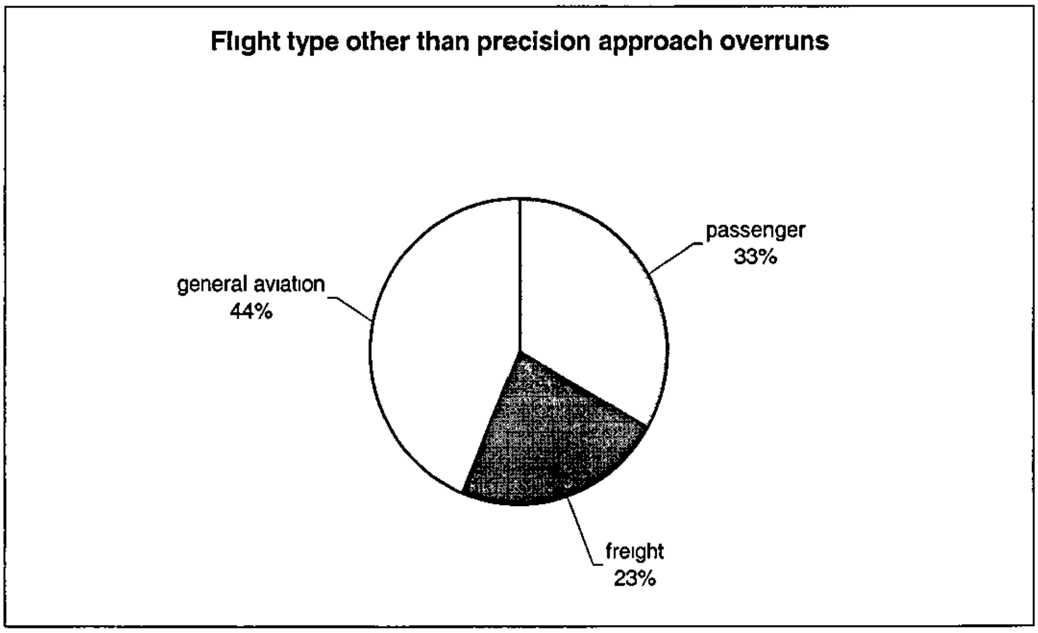

Figure 6. 74

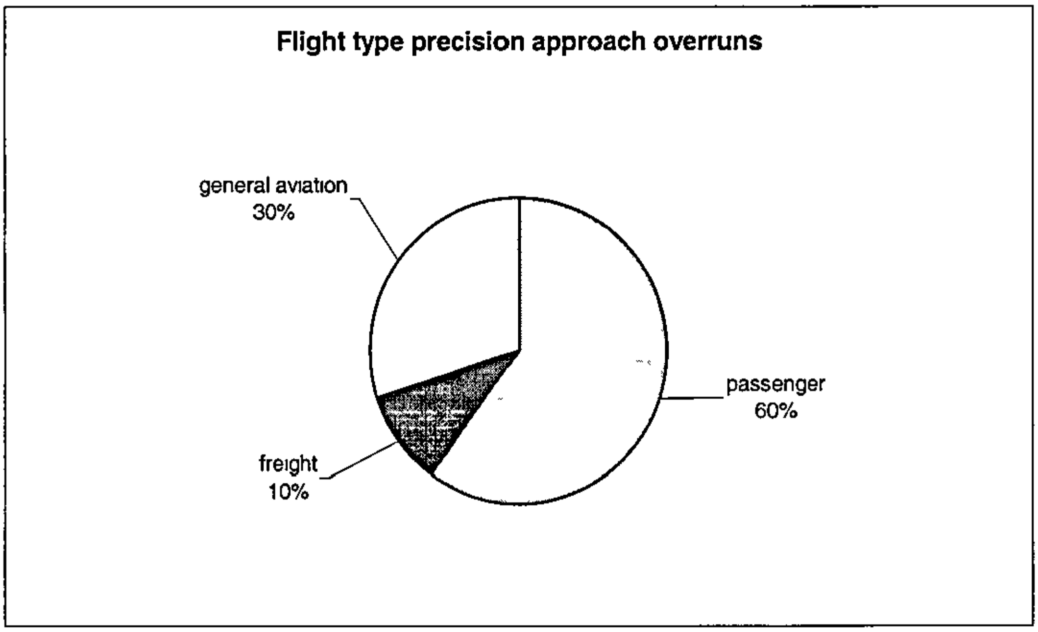

Figure 6. 75

6 7 5 3 4 Type of approach and Captains experience

Captains of those aircraft that overran after flying a precision approach had on average 6681 total hours flying experience, those that overran after flying an approach that was not a precision approach had on average 5720 hours, however, this is not a significant difference

Captains of those aircraft that overran after flying a precision approach had on average 1741 hours on type, compared to 2622 for precision approaches, but again this is not a significant difference

6 7 5 3 5 Type of approach and problems before landing

The aircraft that flew a precision approach and suffered a landing overrun had a problem with the aircraft before the landing in 2 of 49 cases (4 %), those that overran after flying an other than precision approach had a problem in 10 of 54 cases (19 %), a significant difference A problem was defined as a failure before landing that made flight difficult for the pilot i e. power failure, in flight fire, electrical failure, no landing gear, uncommanded engine surges etc

Five of the fifty-four overruns that occurred after other than precision approaches were actually emergency landings, against none of the forty-nine overruns that occurred after precision approaches, also a significant difference If it is actually the case that aircraft that need to make an emergency landing are more likely to find an airport with an other than precision approach, the apparent link between approach type and accident risk may be even less likely to be causal If aircraft that have to make an emergency landing are more at risk of having an accident than those that do not, and these aircraft are more likely to fly an other than precision approach, the accident risk may have little causal connection with approach type.

6 7 5 3 6 Type of approach and weather

The proportions of overruns that have occurred during the day and night are virtually exactly the same for each approach type (other than precision 64 9 % day, 35 1 % night, precision 65 3 % day, 34 7 % night)

Figures 6.76 and 6 77 show the wind experienced by the aircraft on landing for the two approach types Both have means of a tailwind (0 68 kts tailwind for other than precision approaches, and 2 15 kts tailwind for precision approaches) and on average the precision approach overruns have landed with higher tailwinds, although the difference is not significant

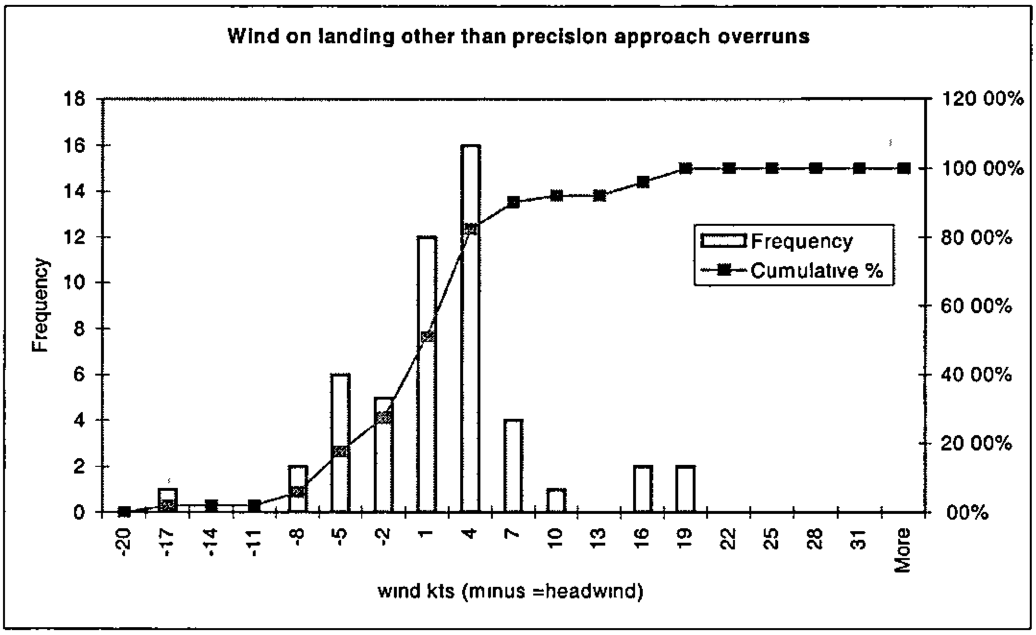

Figure 6. 76

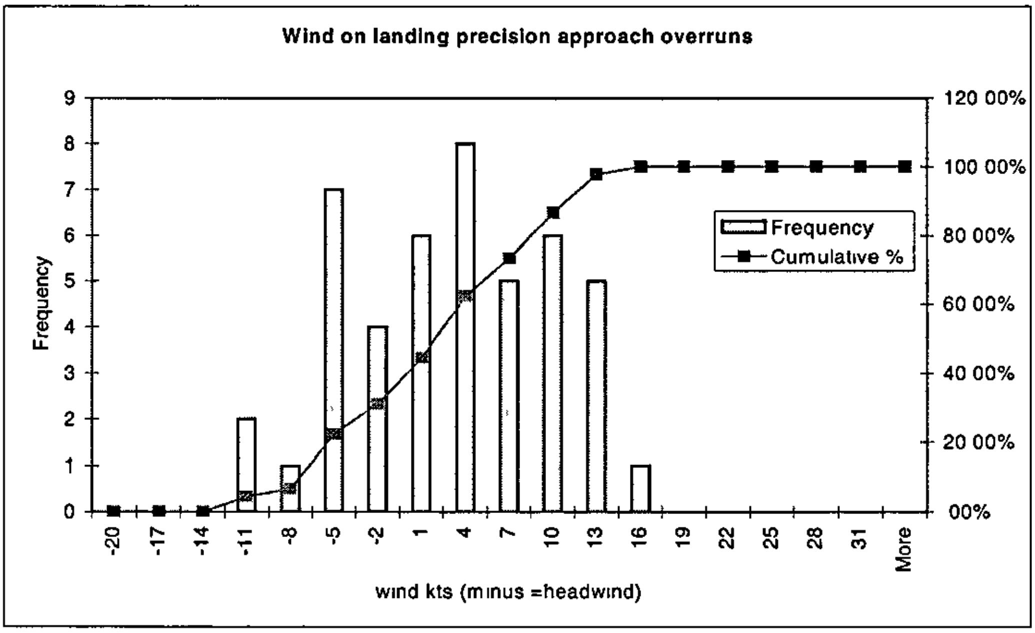

Figure 6. 77

Figures 6 78 and 6 79 show the weather conditions at the time of landing for the overruns that have occurred after the two types of approach The weather conditions present are significantly different In 29 percent of the other than precision approach overruns, some sort of precipitation was present at the time of the landing, however, in the case of the precision approach overruns precipitation was present in 77 percent of the occurrences

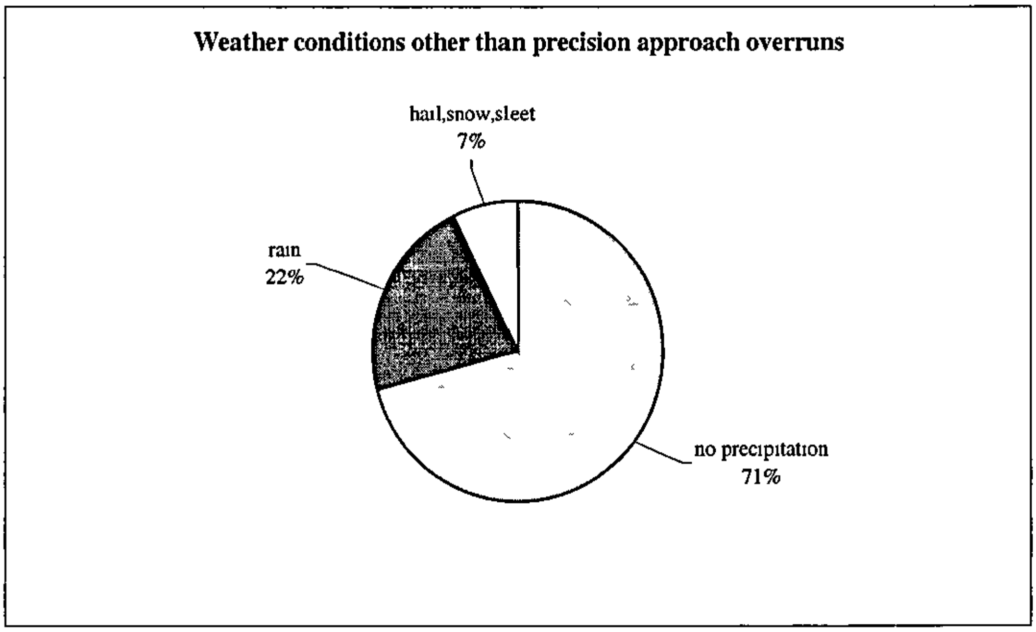

Figure 6. 78

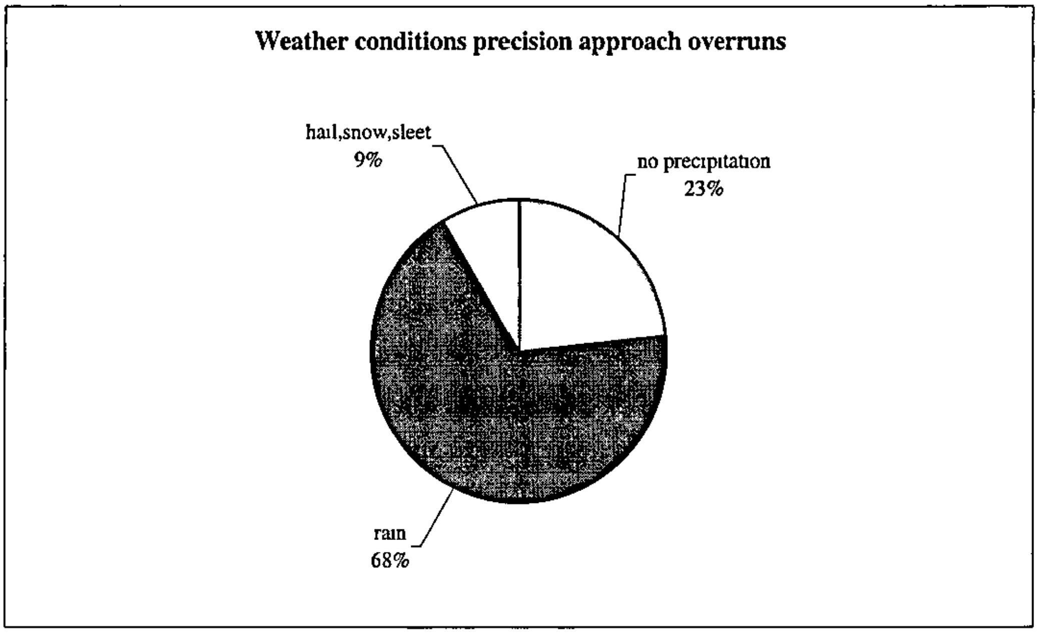

Figure 6. 79

This split is also very apparent when looking at the condition of the runway for the overruns that have occurred after each type of approach, shown in figures 6 80 and 6 81 It can be seen that the runway was dry in 48 percent of the other than precision approach overruns, compared to only 11 percent of the precision approach overruns, which again is a significant difference

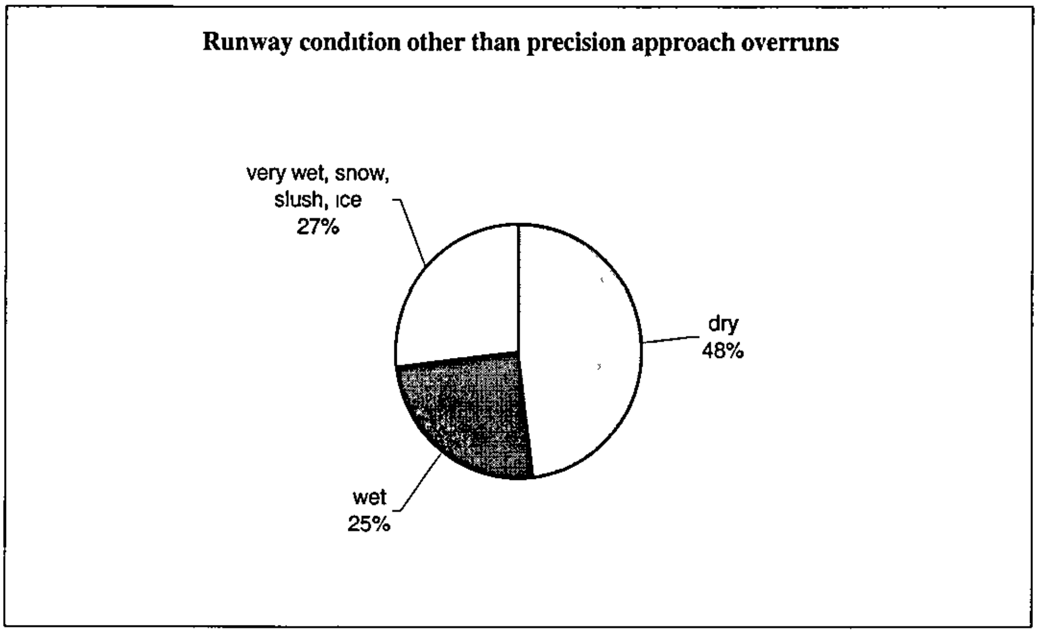

Figure 6. 80

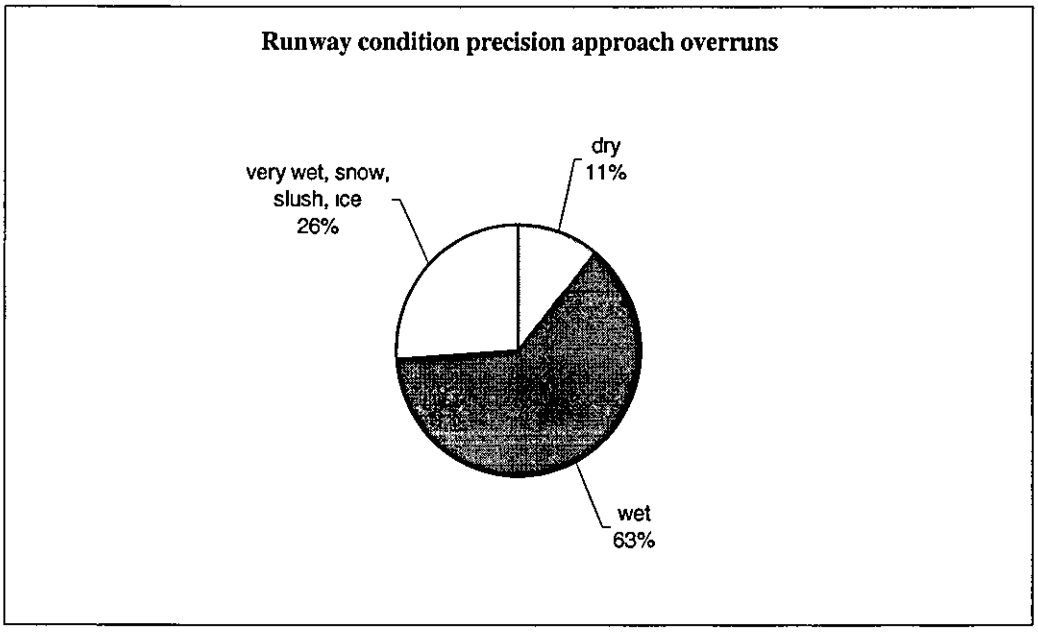

Figure 6. 81

Unfortunately, runway slope information was only available for a small number of cases (20 other than precision approach overruns, and 32 precision approach overruns) 60 percent of the other than precision approach overruns where the slope was known occurred on runways with a downslope, compared to 56 percent of the precision approach overruns where the slope was known However, the difference is not significant The average runway slope for other than precision approach overruns was 0 29 percent downslope, the average runway slope for precision approach overruns was a downslope of 0 08 percent, again not significant

The average visibility during overruns that flew an other than precision approach was 19035 metres The average visibility during overruns that flew a precision approach was 6679 metres, a significant difference Due to these being skewed distributions, in both cases, the majority of overruns actually landed in visibility poorer than the average This difference is not surprising, because the express purpose of a precision approach is to enable the aircraft to land in poorer visibility than would be possible when flying an other than precision approach As weather conditions such as rain and snow are very often associated with poor visibility it is perhaps also not surprising that precision approach overruns have occurred in these conditions and on runways that have a degraded surface condition

The height at which the runway became visual when the approach flown was a precision approach was above minimums in 40 of 43 cases (93 percent), and in 50 of 54 cases (also 93 percent) where the approach was not a precision approach Minimums are taken to be the height below which the pilot was not allowed to descend without having visual contact with the runway In both cases, where the report stated that the weather was visual meteorological conditions, it is assumed that the runway was acquired visually above any minimum descent restrictions

6 7 5 3 7 Type of approach and quality of approach flown

An approach was considered stable if by 1000 ft above touchdown in instrument meteorological conditions, and by 500 ft above touchdown in visual meteorological conditions the following conditions were met

1 The aircraft was on the correct flight path
2 Only small changes in heading and pitch were required to maintain that path
3 The aircraft speed was not more than Vref +20 kts indicated airspeed and not less than Vref
4 The aircraft was in the proper landing configuration
5 Sink rate is less than 1000 ft per minute
6 The power setting is appropriate for the configuration
7 All briefings and checklists have been performed

Of the 30 occasions where aircraft suffered an overrun after flying a precision approach and the quality of approach was known 14 flew an unstable approach (53 percent). Of the 41 occasions where aircraft suffered an overrun after flying an other than precision approach and the quality of approach was known 25 (61 percent) flew an unstable approach, however, the difference is not significant

6 7 5 3 8 Type of approach and causes

A study was conducted as to the characteristics of the overrun accidents and incidents that were mentioned in the causes section of the reports The causes section of the reports varied greatly with report type These ranged from large sections of descriptive narrative in the formal published reports, to descriptive codes for the NTSB investigated overruns for which a formal report was not published, and to no causes being mentioned for some of the more minor incidents i e where the aircraft was not damaged and there were no injuries

This was not an exhaustive study of everything that was mentioned, because the data soon becomes unwieldy, rather an investigation of the frequency of occurrence of a few key factors

One problem with studying the causes section of reports is that whether a factor is considered a cause can depend upon the subjective reasoning of the investigator. For example, for one particular accident, one investigator may argue that bad weather was a cause of the accident, whereas another investigator may reason that it was not the bad weather that caused the accident but the way that the pilot reacted to the bad weather Another example may be a situation in which the pilot should have flown a go-around but didn't One investigator may say the accident is the pilot's fault for not flying a go-around, another investigator may consider that it is the fault of the airline for not giving the pilot enough training in handling those sorts of situations

The factors that were studied for inclusion in the causes section as primary causes or contributory factors are as follows

1 Poor visibility
2 Downhill runway
3 Tailwind
4 Wet weather
5 Snow, slush, or ice covered runway
6 Minimum descent altitude exceeded without visual contact with the runway
7 Excessive airspeed on approach or at touchdown
8 Long touchdown
9 Aircraft equipment or function problem before landing

10 Aircraft equipment or function problem during rollout

11 Poor choice of runway

12 Poor approach planning

13 Procedures not followed

14 Failure to perform go-around

15 Improper operation of aircraft equipment

Fifty other than precision approach overruns and forty precision approach overruns had a causes section to the report The causes information is contained in table 6 23 and the more interesting results commented on below

Poor visibility

Eight percent (4) of the other than precision approach overruns and 20 percent (8) of the precision approach overruns had poor visibility mentioned as a cause or contributory factor to the overrun, which is a significant difference Of the 4 other than precision approach overruns where poor visibility was mentioned, only one descended below minimum descent altitude without visual reference, and in none of the eight precision approach overruns where poor visibility was mentioned did the pilot descend below minimum descent altitude without visual reference, however, in one of the eight the weather was below the minimum required for the approach

This is interesting because while it might be expected that precision approaches be conducted into poorer visibility than other than precision approaches it is not expected that the poorer visibility will affect the accident rate However, these figures show that a statistically significantly higher proportion of precision approach overruns have poor visibility stated as a cause or contributory factor to the overrun than other than precision approach overruns This is even though in all but one of the precision approach cases the visibility was within the required parameters

It is the opinion of this researcher that stating that poor visibility was a cause or contributed to the accident is of little use, as it provides no opportunity to improve the system The visibility at airports cannot be altered What can be altered are the aircraft operating regulations that determine the visibility in which they are operated Therefore it was not the poor visibility that contributed to the accident but the regulations that allowed aircraft to operate in that level of visibility A judgement then has to be made as to whether the loss sustained in the accidents due to poor visibility is worth restricting the operations in this visibility, or providing further training for pilots in assessing and operating in low visibility.

Wet weather

The precision approach is designed to allow operations into lower visibility than the other than precision approach so it might be expected that more precision approaches be operated into wet weather than other than precision approaches as wet weather often accompanies poor visibility However, operating regulations are designed to allow operations into wet weather without increased risk so it is surprising that more precision approach overrun reports than other than precision overrun reports describe the weather as contributing to the accident

Long touchdown

Thirty four percent (17) of the other than precision approach overruns and forty five percent (18) of the precision approach overruns have a long touchdown mentioned as a cause or contributory factor This is not a significant difference and is surprising as a precision approach is often mentioned as a tool that can reduce the overrun rate, presumably by altering the touchdown point, and yet a greater proportion of precision approach overruns have long touchdown mentioned as a cause or contributory factor than have other than precision approach overruns

The statistically significant findings of the causes study in summary are contained in table 6 24

If these results are combined with the correlations with approach type an impression begins to form that in general the landing overruns that have occurred after a precision approach was flown are of a different nature than those which have occurred after an other than precision approach has been flown

If only the statistically significant differences are examined it is found that the precision approach overruns are associated with longer runways, passenger aircraft, normally operating aircraft, predominantly wet weather and runways, and poor visibility

Conversely, overruns that have occurred after an approach has been flown which was not a precision approach have been associated with shorter runways, freight and general aviation aircraft, aircraft that have suffered a problem in flight, a poor choice of runway by the crew, improper use of aircraft equipment by the crew, predominantly dry weather and runways, and good visibility

In the light of this evidence that in general precision approach overruns appear to be due to poor weather, and other than precision approach overruns appear to be characterised by mechanical problems, and poor operation of the aircraft by the crew, it seems as though the difference in overrun rates of the two approach types is more likely to be influenced by the type of traffic utilising the two approaches rather than the actual approach Therefore the universal installation of precision approaches is individually unlikely to prevent the overruns that have occurred after flying an approach that was not a precision approach

6 7 5 4 *Precision approach overrun touchdown points compared with precision approach non-overrun flights touchdown points*

Figures 6 82 and 6 83 compare the touchdown points of aircraft that have flown a precision approach and overran the runway, with those of aircraft that have flown a precision approach and not overrun the runway

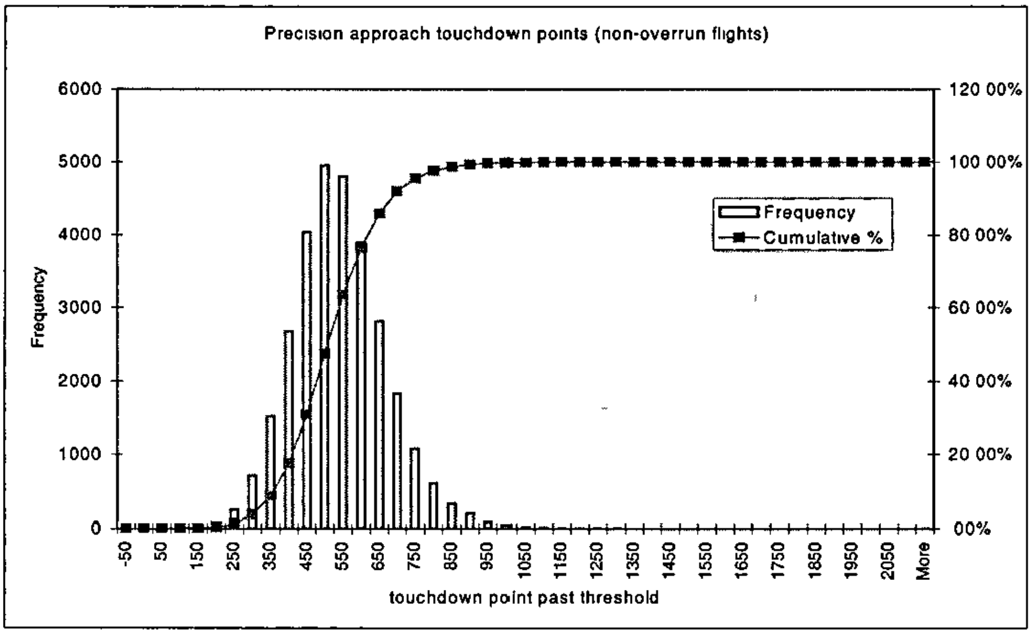

Figure 6. 82

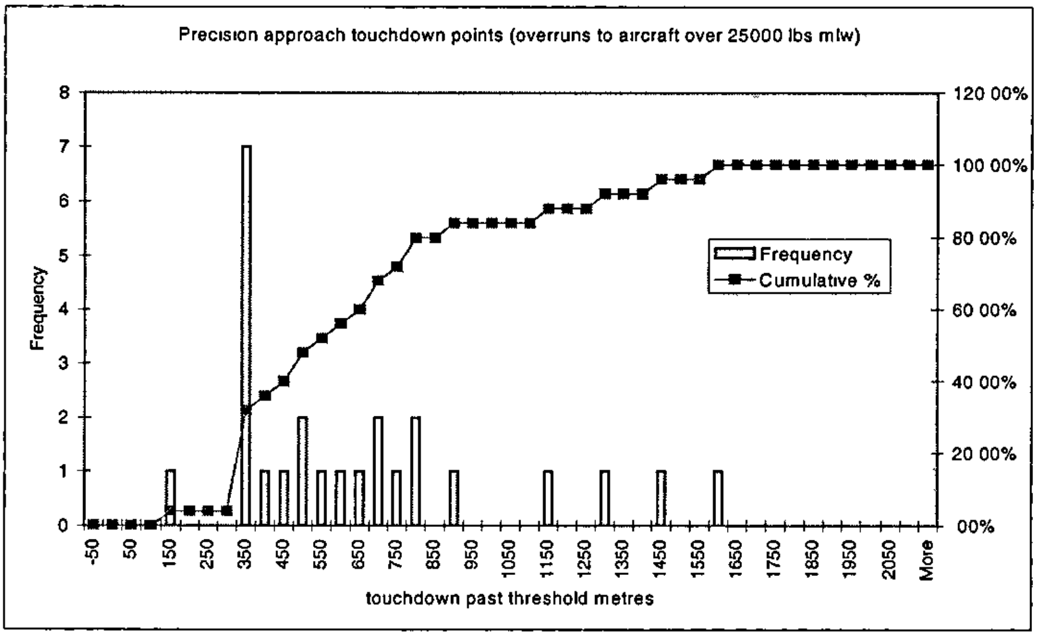

Figure 6. 83

The landings that have comprised those which did not overrun are made up of 10253 B-747 landings, 9397 B-767 landings, and 10363 A320 landings There is a visible difference to the two distributions in that the touchdown points of those aircraft that overran the runway have a rather long tail to the right of the distribution

The mean touchdown distance beyond the threshold for non-overrun precision approaches was 526 metres The mean touchdown distance beyond the threshold for precision approach overruns to aircraft over 25000 lbs maximum landing weight was 631 metres However, even though the mean overrun touchdown point was further down the runway there was not a statistically significant difference between the mean of the normal touchdown points and the mean of the overrun touchdown points Also, there is not a statistically significant difference between the variances of the two distributions

Some of the overrun touchdown points were simply described as being "on target" These were given a touchdown point of 305 metres beyond the threshold, the most common glide slope origin point However, even if these cases are assigned touchdown points of 526 metres, which is the mean normal landing touchdown point, there is no statistically significant difference between the means or variances of the two distributions

6 8 Takeoff

In Australia, the U K , Canada, and the United States between 1st January 1980 and 1st January 1999 there were 43 jet or turboprop takeoff overruns

6 8 1 Flight type

The 43 takeoff overruns were comprised of six freight aircraft overruns (14 percent), eleven general aviation overruns (26 percent), and twenty-six passenger aircraft overruns (61 percent) This compares to twenty freight landing overruns (15 percent), fifty general aviation landing overruns (36 percent), sixty five passenger landing overruns (48 percent), and two landing overruns where the flight type was unknown The differences in flight types between the two types of overrun is significant and provides evidence that the ratio of takeoff-overrun rate to landing overrun rate is not constant across all types of flight The ratios are shown in table 6 23

6 8 2 Aircraft performance characteristics

In general a takeoff overrun occurs when a problem occurs during the takeoff run, the pilot makes a judgement that it is safer to try to stop the aircraft on the runway rather than take it into the air, and the aircraft is unable to stop on the runway

V1 is a predetermined speed that the aircraft reaches during the takeoff run On a balanced takeoff on a critical length runway, if an engine fails before V1 the aircraft will not be able to reach a safe flying speed by the end of the runway, if an engine fails after V1 the aircraft will be travelling too fast to be able to stop on the remaining runway So, if engine failure is recognised before V1 the pilot should stop, if after V1 the takeoff should be continued Figure 6 84 shows the speeds at which the takeoff overruns were aborted relative to V1 for the 32 cases where this information was known

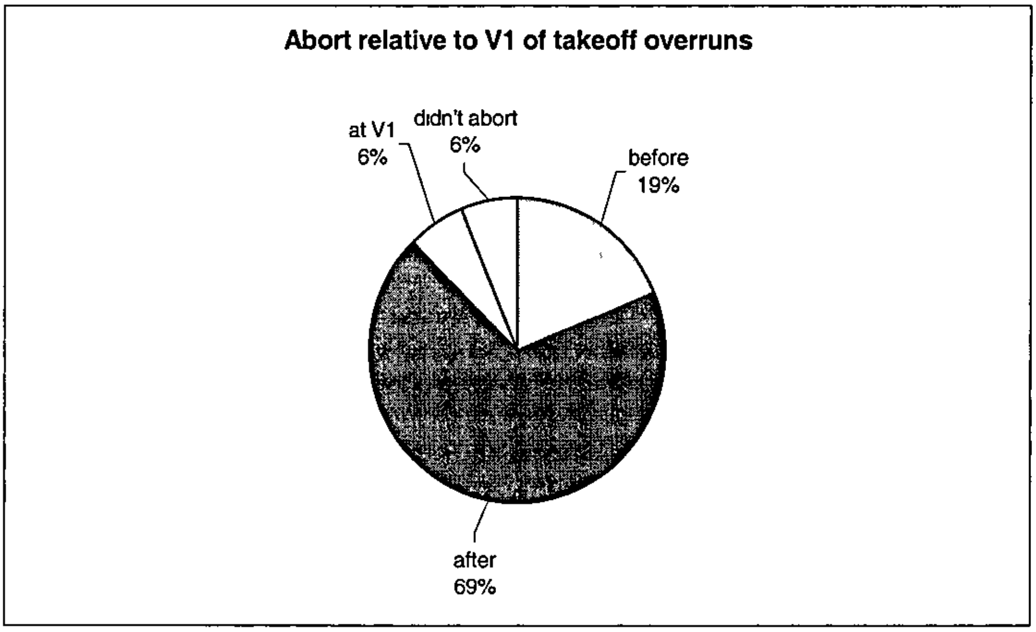

Figure 6. 84

V1 only tells the pilot about the performance capability of the aircraft relative to engine failure However, the types of problems that lead to takeoff overruns are varied This is illustrated in figure 6 85.

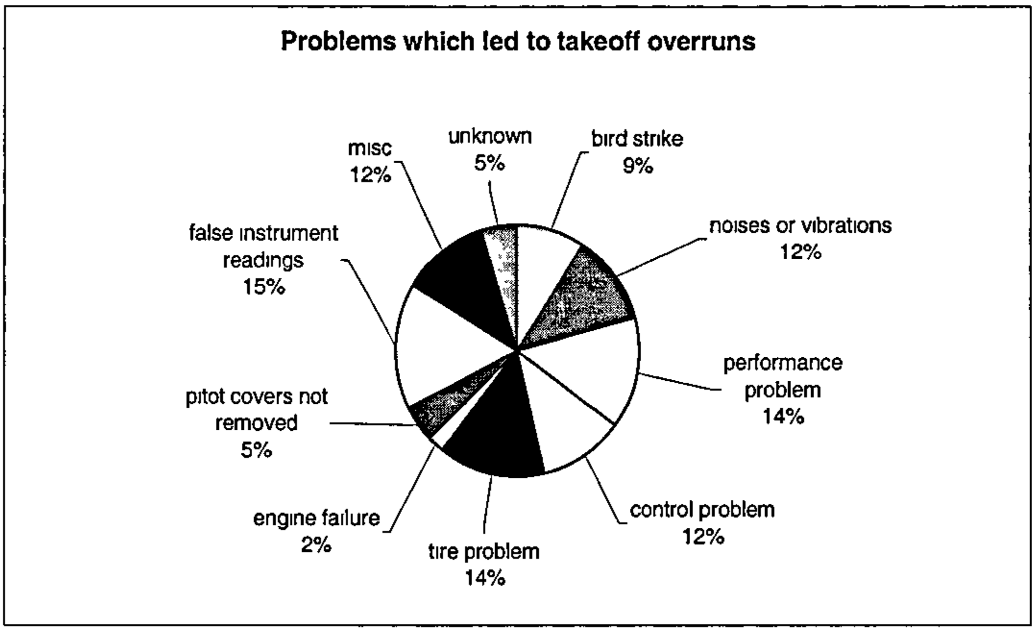

Figure 6. 85

The aircraft that have overrun after a rejected takeoff have aborted for many different reasons, the majority of which are not engine failures Even within the categories are variations of problems, for example, the category "performance problem" includes lack of acceleration due to the parking brake being set, and fuel flow problems to the engine The category "miscellaneous" includes the cabin door not being secured, the wrong runway being selected, and a helicopter being flown over the aircraft as it was about to rotate The one factor that ties the vast majority of the circumstances together is that they were not engine failures

6 8 3 Excess distance remaining between required accelerate stop distance and available accelerate stop distance

Figure 6 86 shows the distance remaining between the accelerate stop distance required by the operation and that available for the operation In most cases the available accelerate stop distance was not known, in which case the runway length was used. The accelerate stop distances were taken from the report if they were mentioned If not, they were calculated from flight manuals using the parameters of the operation given in the report Where the takeoff speeds were mentioned they were used, where not, a balanced runway was assumed Of the 43 takeoff overruns the information was given or it was possible to calculate this distance in 26 cases

It is apparent that while some of the operations only had a small amount of excess distance available, this was certainly not the rule

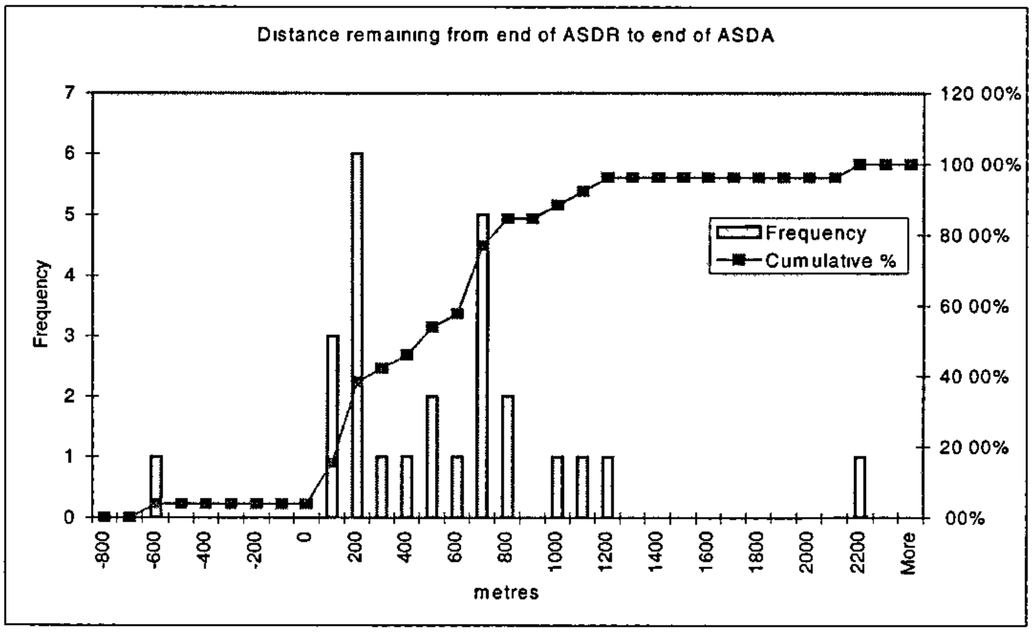

Figure 6. 86

Figure 6 87 represents the excess distance as a percentage of the required accelerate stop distance Unfortunately, this information is not available for non-overrun rejected or successful takeoffs so no comparisons could be made

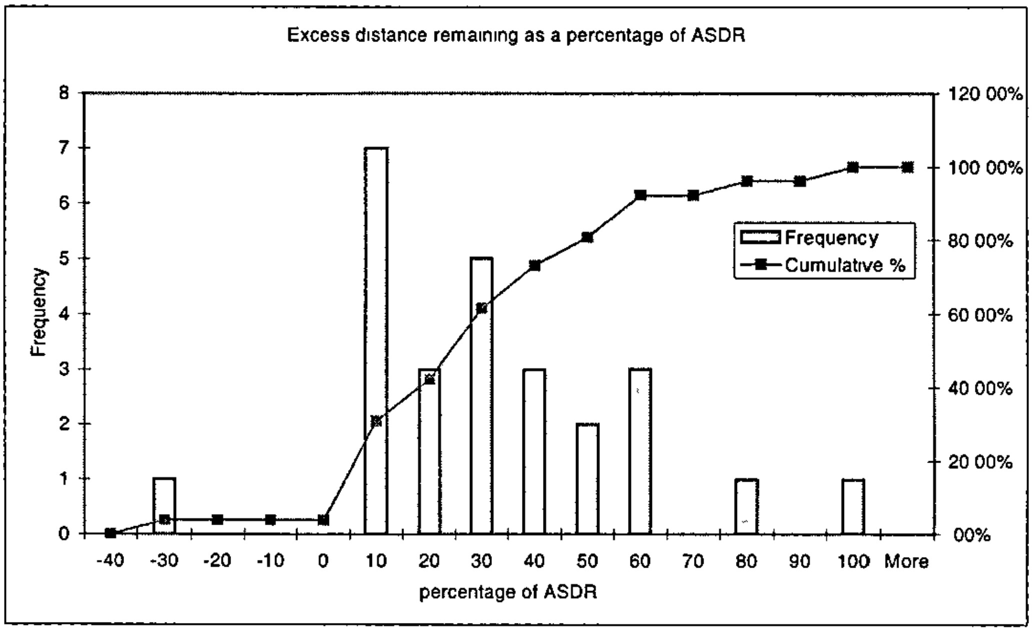

Figure 6. 87

6 8 4 Runway slope

Of the twenty-two takeoff overruns where the runway slope was known, eight occurred on runways with a downhill slope, five occurred on level runways and nine occurred on runways with an uphill slope

6 8 5 Runway condition

Of the thirty-five takeoff overruns where the runway condition was known twenty-three occurred on dry runways, seven on wet runways and five on snow covered runways This is shown in figure 6 88

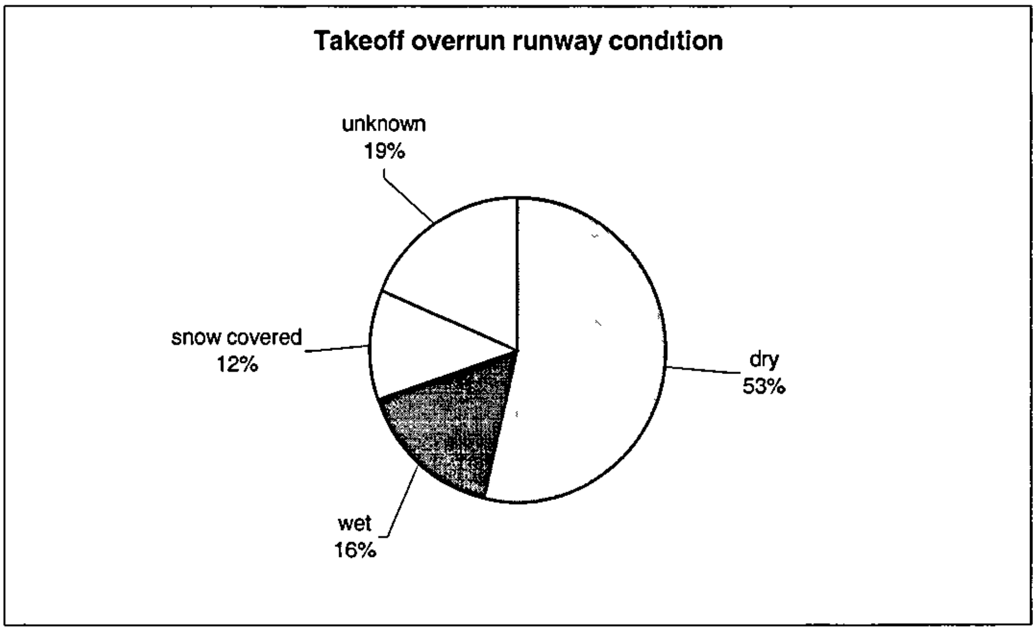

Figure 6. 88

6 8 6 Light condition

Of the forty overruns where the time of occurrence was known thirty-one (78 percent) occurred in the daytime and nine (22 percent) occurred at night

6 8 7 Weather conditions

Figure 6 90 shows weather conditions during takeoff overruns Of the thirty three where the conditions were known, nineteen experienced no precipitation or restrictions to visibility, three experienced rain, three experienced rain and fog, two experienced snow, one experienced snow and fog, and five experienced haze or fog with no precipitation

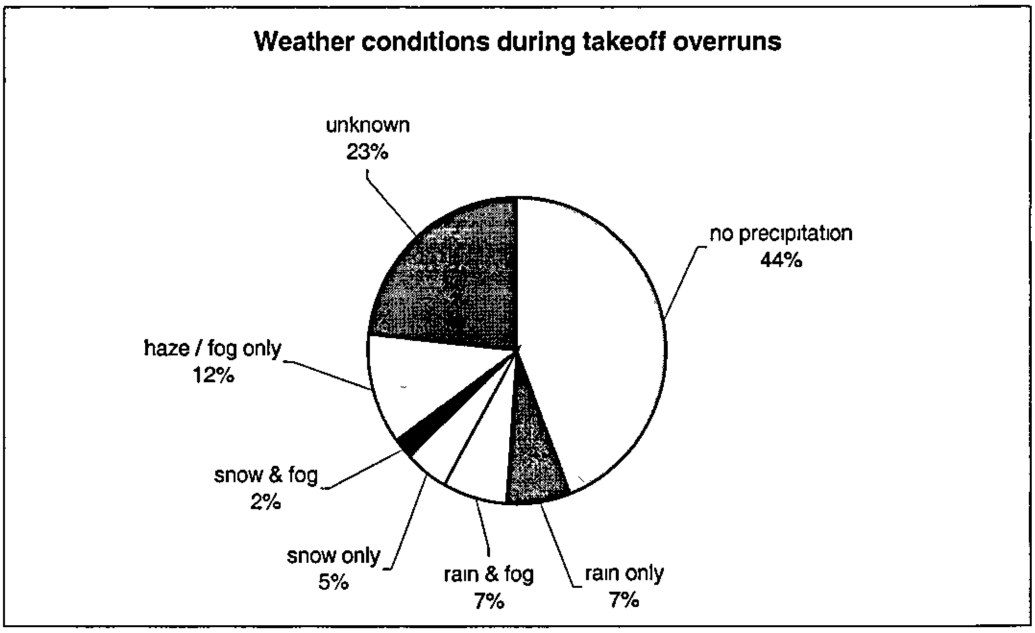

Figure 6. 89

6 8 8 Visibility

Average visibility experienced during takeoff overruns was 17333 metres Visibility experienced during takeoff overruns was in general far greater than visibility experienced during landing overruns where the average experienced was 13352 metres The difference is significant

6 8 9 Wind

Figure 6 90 shows wind experienced during takeoff overruns for the thirty-four cases where wind was known Headwinds are minus figures In twenty-eight of these cases there was a headwind or calm conditions, in six cases the takeoff was with a tailwind but the strongest tailwind was only four kts

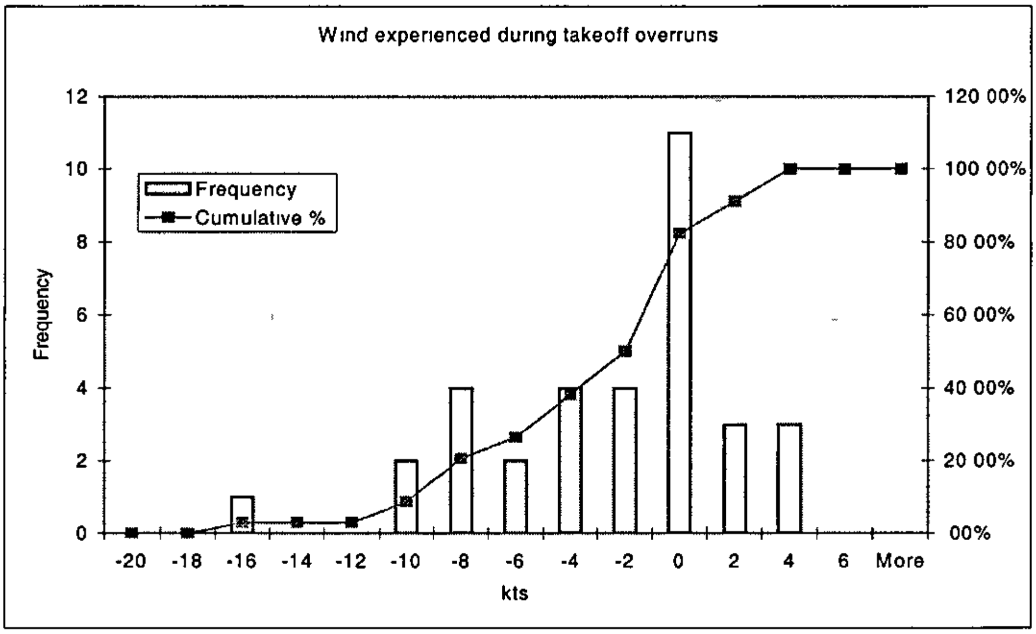

Figure 6. 90

6 8 10 Captain's flight experience

On average captains who had a takeoff overrun had 10652 hours flight experience at the time of the overrun Captains who have had a landing overrun had on average 10131 flying hours, which is not a significant difference

On average the captains who had a takeoff overrun had 2295 hours experience on the aircraft type at the time of the overrun, although approximately half of them had a thousand hours or less Captains involved in a landing overrun had on average 2101 hours on type, which is again not a significant difference

6 8 11 Causes

A study was conducted into the characteristics mentioned in the causes section of the accident / incident reports for the takeoff overruns These are presented in table 6 26, which is not an exhaustive list but contains the characteristics that occurred most often Causes and contributory factors were available for thirty-three of the forty-three takeoff overruns The most frequently cited cause or contributory factor was the reason for the abort (30 of 33 cases) i e if the abort was due to a bird strike, the causes section mentions the bird strike as a cause or contributory factor. The second most frequently cited factor was the takeoff being aborted from a position from which it was impossible to stop the aircraft on the runway (12 of 33 cases)

6 9 *Summary*

Overruns occurred at an approximate rate of three to one landing overruns to takeoff overruns This ratio was constant across flight types

The takeoff and landing overrun rates of US commercial operations have not improved over the period 1980-1998

The US commercial jet and turboprop takeoff overrun rate over the period 1980 to 1998 was 0 135 overruns per million takeoffs

The US commercial jet and turboprop landing overrun rate over the period 1980 to 1998 was 0 323 overruns per million landings

The UK air transport takeoff overrun rate over the period 1980 to 1998 was 0 22 takeoff overruns per million takeoffs

The UK air transport landing overrun rate over the period 1980 to 1998 was 1 03 landing overruns per million landings

The UK non-air transport jet and turboprop takeoff overrun rate over the period 1980 to 1998 was 0 70 takeoff overruns per million takeoffs

The UK non-air transport jet and turboprop landing overrun rate over the period 1980 to 1998 was 2 45 landing overruns per million landings

During the years 1990 to 1998 Australia experienced no scheduled operation overruns

During the years 1990 to 1998 Australia experienced no takeoff overruns to general aviation or charter jet and turboprop operations

During the years 1990 to 1998 Australia experienced a general aviation / charter operation jet and turboprop landing overrun rate of 2 67 landing overruns per million landings

During the years 1985 to 1998 Canada experienced a jet and turboprop takeoff-overrun rate of 0 19 takeoff-overruns per million takeoffs

During the years 1985 to 1998 Canada experienced a jet and turboprop landing overrun rate of 0 45 landing overruns per million landings

The mean of takeoff weight as a percentage of the maximum takeoff weight in takeoff overruns could be between 1 071 and 1 15 times that in non-overrun takeoffs

The mean of landing weight as a percentage of maximum landing weight in landing overruns could be between 1 017 and 1 06 times that in non-overrun landings

17 percent of the landing overruns where the required landing distance could be calculated landed with less runway length available than required

6 percent of the takeoff overruns where the required accelerate stop distance could be calculated took off with less accelerate stop distance available than required

It is likely that landings that have resulted in an overrun have landed on average with less excess distance remaining between the end of the required landing distance and the runway end, than non-overrun landings

There is no statistically significant difference between the average levels of damage incurred in takeoff and landing overruns, when comparing all aircraft

Passenger aircraft as a group on average suffered the least damage in overruns, general aviation aircraft suffered more damage, and freight aircraft suffered the most damage

There is no statistically significant difference in runway exit speeds of those aircraft that suffered no damage, minor damage, or substantial damage Those that were destroyed had on average higher runway exit speeds than those that suffered less extensive damage

There was no statistically significant difference between the numbers of obstacles encountered beyond the runway end by those aircraft that suffered no damage or minor damage

Those aircraft that suffered substantial damage encountered obstacles beyond the runway end more frequently than those that suffered less extensive damage

A greater percentage of those aircraft that were destroyed encountered obstacles beyond the runway end than those that suffered less extensive damage

Aircraft that encountered one obstacle had on average lighter maximum gross weights than those that did not encounter any obstacles

Aircraft that encountered two obstacles had on average lighter maximum gross weights than those that did not encounter any obstacles or encountered one obstacle

A greater percentage of aircraft experienced fire after a takeoff overrun than after a landing overrun

Aircraft that overran after a rejected takeoff had on average higher maximum gross weights than those that overran after a landing

Those aircraft that caught fire had on average higher runway exit speeds than those that did not

Those aircraft that caught fire had struck more obstacles after the runway end than those that did not

A greater percentage of aircraft that struck no obstacles caught fire after a takeoff overrun than after a landing overrun

Where the aircraft struck one obstacle after the runway end, there was no statistically significant difference between the incidence of fire for the two types of overrun

Where the aircraft struck two obstacles after the runway end, there was no statistically significant difference between the incidence of fire for the two types of overrun

Where a fire occurred, there was no statistically significant difference in damage to the aircraft for the two types of overrun

Where a fire occurred, no injuries were incurred to the occupants of aircraft where total numbers of persons on board were greater than one hundred

Where a fire occurred, there was no statistically significant difference in injuries to the occupants of the aircraft for the two types of overrun

Where no fire occurred, the occupants of aircraft that overran after a rejected takeoff received on average more serious injuries than the occupants of aircraft that overran after a landing

Landing overruns occurred more when there was a tailwind than did takeoff overruns

Landing overruns occurred in poorer visibility than takeoff overruns

A greater percentage of landing overruns occurred on runways that were wet, very wet, snow, slush, or ice covered than during takeoff overruns

There is no statistically significant difference between the touchdown points of passenger aircraft, freight aircraft, or general aviation aircraft that experienced landing overruns

There is no statistically significant difference between the mean touchdown points or the variance of touchdown point for those aircraft that suffered a landing overrun after flying a precision approach compared to those that flew an approach that was not a precision approach

During the years 1984 to 1993 at Canada's principal international airports and the USA's 120 busiest airports there was no statistically significant difference between the overrun rates of those aircraft that flew a precision approach compared to those which did not

Aircraft that overran after flying a precision approach did so on longer runways than those that overran after flying an alternative type of approach

More of the aircraft that overran after flying an approach that was not a precision approach were freight or general aviation aircraft than were passenger aircraft

A greater percentage of aircraft that overran after flying a precision approach experienced problems before landing than those aircraft that overran after flying a precision approach

Precipitation was present in a greater percentage of landing overruns that occurred after the aircraft flew a precision approach than during landing overruns that occurred after the aircraft flew an alternative approach

The runway was wet during a greater percentage of landing overruns that occurred after the aircraft flew a precision approach than during landing overruns that occurred after the aircraft flew an alternative approach

The visibility was poorer on average during landing overruns that occurred after the aircraft flew a precision approach than during overruns that occurred after the aircraft flew an alternative approach

Poor visibility was cited as a primary cause or causal factor in a greater percentage of landing overruns that occurred after the aircraft flew a precision approach than in landing overruns that occurred after the aircraft flew an alternative approach

Twenty percent of the landing overruns where causes were mentioned had a tailwind cited as a primary cause or contributory factor

Wet weather was cited as a primary cause or causal factor more frequently during landing overruns that occurred after the aircraft flew a precision approach (38 percent of those where causes mentioned) than during overruns that occurred after the aircraft flew an alternative approach (20 percent of those where causes were mentioned

16 percent of the landing overruns where causes were mentioned cited snow, slush or ice-covered runway as a primary cause or contributory factor.

26 percent of the landing overruns where causes were mentioned cited excess airspeed on approach or touchdown as a primary cause or contributory factor

39 percent of the landing overruns where causes were mentioned cited long touchdown as a primary cause or contributory factor

None of the aircraft that overran after flying a precision approach and where causes were mentioned had aircraft equipment or function problem before touchdown mentioned as a cause or contributory factor 16 percent of the aircraft that overran after flying an alternative approach and where causes were mentioned had aircraft equipment or function problem before touchdown mentioned as a cause or contributory factor

18 percent of the landing overruns where causes were mentioned had poor approach planning mentioned as a cause or contributory factor

21 percent of the landing overruns where causes were mentioned had procedures not followed mentioned as a cause or contributory factor

20 percent of the landing overruns where causes were mentioned had failure to perform go-around mentioned as a cause or contributory factor

Improper use of aircraft equipment was cited as a primary cause or causal factor less frequently during landing overruns that occurred after the aircraft flew a precision approach (20 percent of those where causes mentioned) than during overruns that occurred after the aircraft flew an alternative approach (32 percent of those where causes were mentioned

There is no statistically significant difference between the touchdown points of aircraft that overran after flying a precision approach and a sample of touchdown points from aircraft that flew a precision approach and did not overrun

The proportions of flight types of aircraft that overran after a rejected takeoff is different to the proportions of flight types of aircraft that overran after a landing

69 percent of takeoff overruns were aborted at a speed higher than V1, 20 percent were aborted at a speed lower than V1.

Of the 41 takeoff overrun cases where the reason for the abort was known, only one was due to engine failure

The majority of rejected takeoff overruns occurred on dry runways

The majority of rejected takeoff overruns occurred when there was no precipitation

91 percent of the takeoff overruns where causes were mentioned cited the reason for the abort as a cause or contributory factor

36 percent of the takeoff overruns where causes were mentioned cited the takeoff being aborted at a position from which it was impossible to stop the aircraft on the runway as a cause or contributory factor

7 Risk models

The first step of an overrun risk assessment is the calculation of the probability of overrun occurrence The method of calculation depends largely on the understanding of the causes of overrun accidents

7 1 Aerodrome historical overrun rate

In order to calculate the probability of an overrun occurring at an aerodrome the most obvious starting point is the historical overrun rate at that aerodrome However, at most aerodromes overruns have not occurred although a risk may exist, and therefore revealed overrun rates at individual airports may not be good indicators of the risk

7 2 Regional overrun rate

In order to obtain an accident rate that is less affected by statistical anomalies attempts have been made by other authors to widen the study area This may involve obtaining an accident rate for a whole country or a larger region such as Europe or North America, and is the approach taken by Slater (1993) and DNV Technica (1994) A problem with this approach that has been acknowledged by these studies is that this approach implicitly assumes that all aerodromes in the study area have equal risk To more accurately calculate the risk, studies have attempted to calculate an accident rate based on movements and accidents that are relevant to the study aerodrome However, decisions on the relevance of accidents and movements are varied and subjective and consequently different assumptions can result in very different accident rates Most studies tend to limit the geographical area to one that is reasonably operationally similar For example, if studying an airport in Western Europe, the sample data area is usually also limited to Western Europe, perhaps also including North America (e g Cowell et al, 1997) Other restrictions are often introduced to exclude some accidents that it has been decided could not occur at the aerodrome under study, for example Hillestad et al (1993) in a study of third party risks at Schiphol Airport exclude many accidents that were due to aircraft flying into high terrain because there is no high terrain around Schiphol Airport However, there are two problems with this approach Firstly, it is only correct to remove the accident from the analysis if the absence of the risk factor, high terrain in this case, would definitely have resulted in the accident not occurring If the high terrain was not the initiating factor, and the aircraft would have crashed even if it were not there, the accident should not be removed Secondly, this approach only serves to reduce the accident rate Some risk factors may be present at the study aerodrome that had they been present at other aerodromes, would have caused an accident, however, this effect is much harder to assess and this researcher is not aware of any studies that have attempted to determine these effects on the overrun rate

7 3 Accident rates split by operation

The determination of rates solely by geographic area will again result in an average rate for that area Usually, therefore, the data is further split in order to obtain rates for individual types of operation, which involves a judgement as to the causes and risk factors of the accidents Many studies have determined rates based on the type of aircraft being operated (e g Hillestad et al and Cowell et al), citing differing accident rates of aircraft types as justification However, two problems are associated with this decision Firstly, these studies may not have tested statistically the differences between the rates, and if not, it is not known if these differences have occurred by chance Secondly, the link between accident rates and aircraft type may not be a causal link but an association, more important factors could be the way the aircraft is flown or the operational environment in which it is flown

Many studies calculate separate accident rates for general aviation aircraft, which may be sensible, as these do not have to conform to operating regulations that are as strict as those for commercial operations, and therefore may be expected to have higher accident rates However, most studies do not apply statistical tests to determine whether the assumed differences in rates are likely to have occurred by chance

7 4 Accident rates by risk factor

A more realistic approach to the calculation of an accident rate would be to determine risk given the risk factors present at the study aerodrome This seems a logical approach, as a study of causes of overrun accidents indicates that aerodrome characteristics are mentioned relatively frequently Also, it would seem likely that this approach would result in the most realistic calculation, as it takes into account actual rather than average risk However, a perfect application of this approach involves the collection of factors present during overrun accidents and their comparison with the incidence of these factors in non-accident flights At present the ability to achieve this is limited due to the general non-availability of information on non-overrun flights This is due to the industry not collecting relevant multi-dimensional information

A small amount of limited information was made available to this study by a major European airline, which has enabled the construction of two risk models, one that models takeoff risk and the other the landing risk The landing risk model predicts the probability of a landing overrun given the distance remaining between the end of the required landing distance and the runway end The takeoff overrun risk model predicts the probability of a takeoff overrun given the aircraft weight expressed as a percentage of the maximum takeoff weight

In the US during 1980-98 there were 446,612,105 air carrier (commercial aircraft with 60 or more seats), air taxi (aircraft with 60 or fewer seats conducted on non-scheduled or for-hire flights) and commuter movements (aircraft with 60 or fewer seats conducting scheduled commercial flights) (FAA, 2000). In the UK during this time there were 27,144,479 air transport movements (CAA, 1980-98). In Canada during this time there were 103,500,000 aircraft movements at towered airports (Transport Canada, 2000). In Australia during 1988 to 1998 there were 12,021,140 scheduled aircraft movements (DOTRS, 2001). This comes to a total of 589,277,724, or 294,638,862 takeoffs and 294,638,862 landings. During this period there occurred 82 landing overruns, with the same inclusion criteria, giving an overall rate of 0.278 landing overruns per million landings.

It was suspected that the probability of an overrun occurring varies with the amount of excess distance available between the end of the required landing distance, and the runway end. Indeed, as discussed in chapter 3, the operating regulations require more runway to be available than that shown to be required in certification implying that an increase in runway available decreases the risk of an overrun. Section 6.4.2 contains information on excess distance for both overrun and non-overrun landings. Assuming the non-overrun landings to be representative of all non-general aviation landings a model of overrun risk given excess distance can be constructed.

The following equations comprise a logistic regression model that determines the probability of an overrun occurring given the excess runway available between the end of the required landing distance and the runway end.

$$P(landingoverrun) = \frac{1}{1 + e^{-(-11.091 - 0.66D)}}$$

and

$$P(nolandingoverrun) = 1 - P(landingoverrun)$$

where

D = excess distance remaining between the end of the required landing distance and the runway end as a percentage of the required landing distance

The first statistic of note is the model chi-square, which being significant, indicates that the ability to predict overrun probability is significantly improved by including excess runway distance available in the model Secondly, a statistically significant exp β value of 0 936 (95% confidence intervals of 0 927 and 0 944) indicates that as the excess distance increases, the probability of an overrun occurring decreases, as expected However, the Hosmer and Lemeshow's measure of 0 11, indicates that roughly 90 percent of the determinants of overrun occurrence are not explained by this model This is not unexpected because it is acknowledged that the probability of any type of aircraft accident is dependent upon a number of different factors, and in fact 11 percent of the determinants of a landing overrun being the amount of excess distance available actually appears to be quite high

The adequacy of this model in predicting landing overrun occurrence can be compared with the adequacy of a model that determines probability based upon flight type as other models have done It was seen in 6 2 8 2 that the UK air transport landing overrun rate 1980-98 was 1 03 overruns per million landings, and the non-air transport rate was 2 45 per million landings. The non-air transport rate was therefore 2 4 times greater These rates could be applied to an aerodrome based upon the traffic mix to derive an overall overrun rate at that aerodrome, however, a model constructed as above, based upon the flight type has a Hosmer and Lemeshow's measure of 0 005 percent This indicates that the flight type only accounts for 0 005 percent of the determinants of overrun probability, approximately 22 times less than a model based upon the excess distance available

Data were also available on aircraft landing weight as a percentage of maximum landing weight for overruns and a sample of non-overrun landings from the same source as the non-overrun excess distances described above The distributions are shown in figures 7 1 and 7 2 The mean of the landing weight as a percentage of maximum landing weight is 87 5 percent for non-overrun landings and 92 3 percent for landing overruns A model constructed as above, predicting overrun probability given landing weight as a percentage of maximum landing weight, has a Hosmer and Lemeshow's measure of 0 024 This indicates that whereas excess distance available accounts for approximately 11 percent of the determinants of landing overrun probability, landing weight relative to maximum landing weight accounts for 2 4 percent, over 4 times less

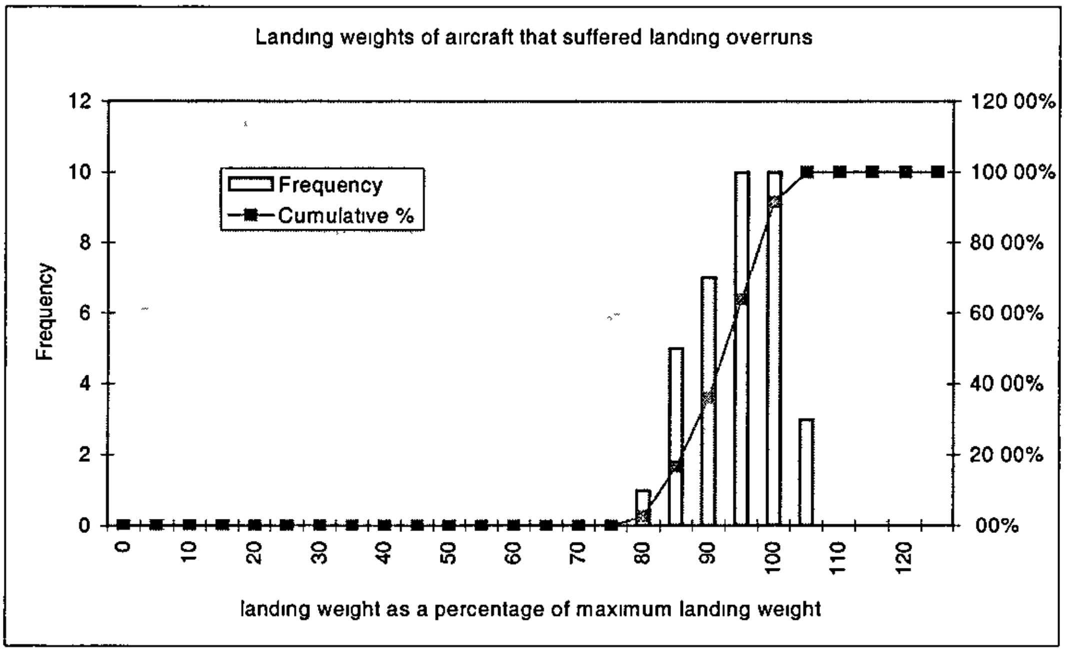

Figure 7. 1

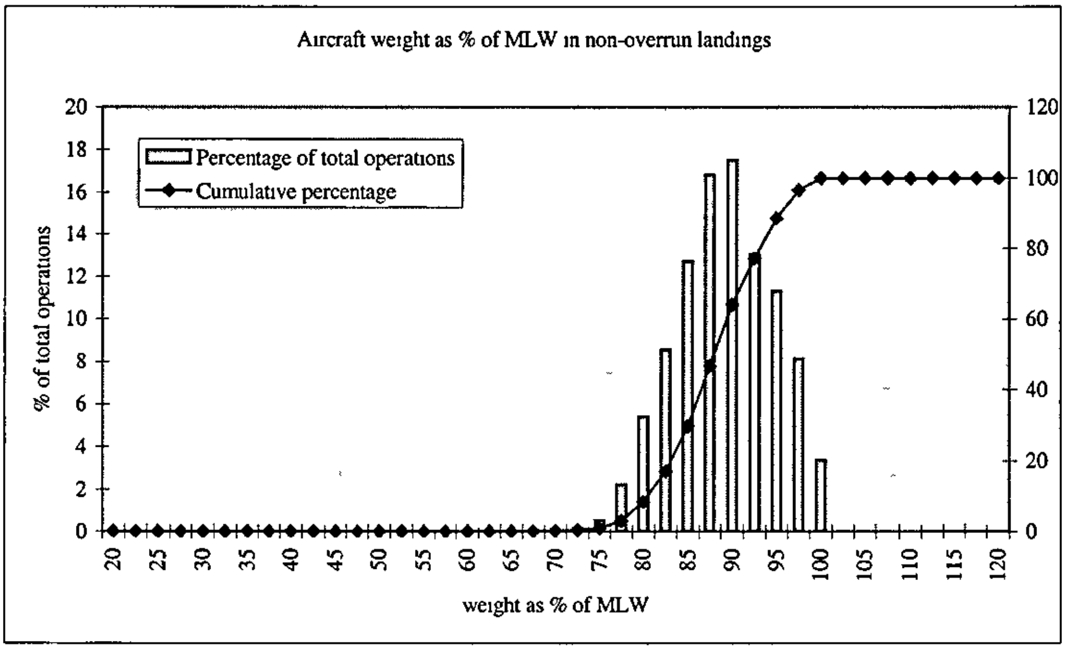

Figure 7. 2

In order to determine whether the two models are both describing the same effect or if they are independent, the landing weight has been plotted against the excess distance available in figures 7 3 and 7 4 Figure 7 3 expresses the amount of excess distance as a percentage of the total required landing distance, whereas figure 7 4 is the actual figure in metres

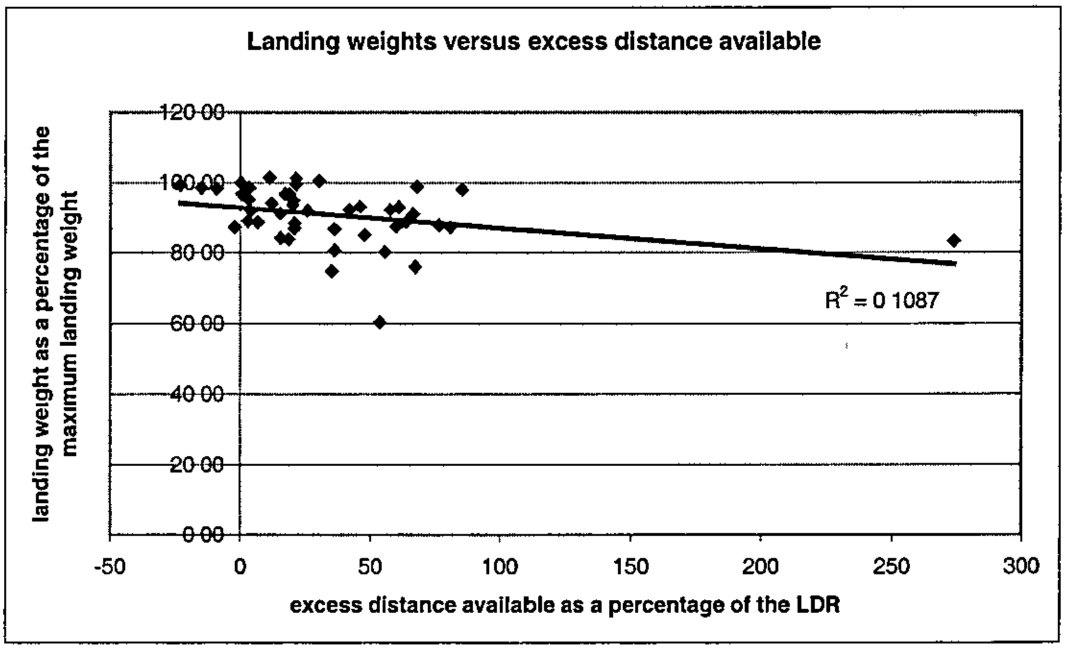

Figure 7. 3

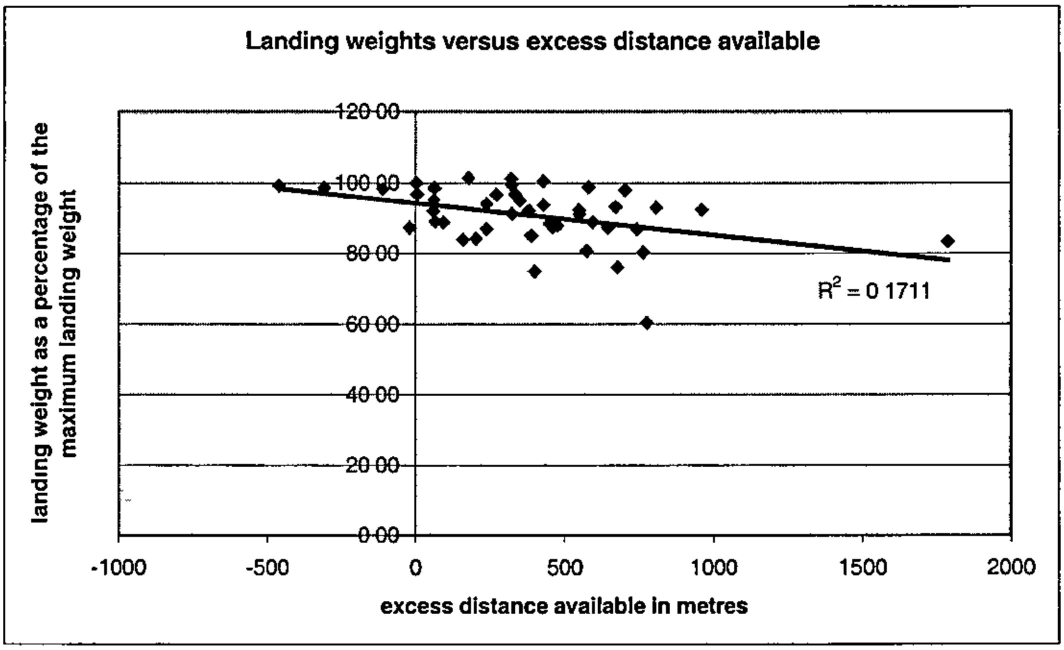

Figure 7. 4

There does appear to be some degree of correlation, however, in the case with the highest correlation R square is still only 0 17 and therefore it appears that the two models may be describing different, but related effects on overrun risk This provides some justification for using both models in the risk calculation

It would have been desırable to also construct a takeoff overrun probabılıty model based upon the amount of excess dıstance avaılable, however accelerate stop dıstance ınformatıon for non-overrun takeoffs was not avaılable, so a model has been constructed whıch ıs based upon takeoff weıght as a percentage of maxımum takeoff weıght

In the study perıod as descrıbed ın 7 5 there were 294,638,862 takeoffs and 32 takeoff overruns meetıng the ınclusıon crıterıa, gıvıng a takeoff-overrun rate of 0 109 per mıllıon takeoffs. The takeoff weıght as a percentage of the maxımum takeoff weıght was known ın 22 cases and ıs shown ın figure 7 5 Fıgure 7 6 shows the same ınformatıon for non-overrun takeoffs.

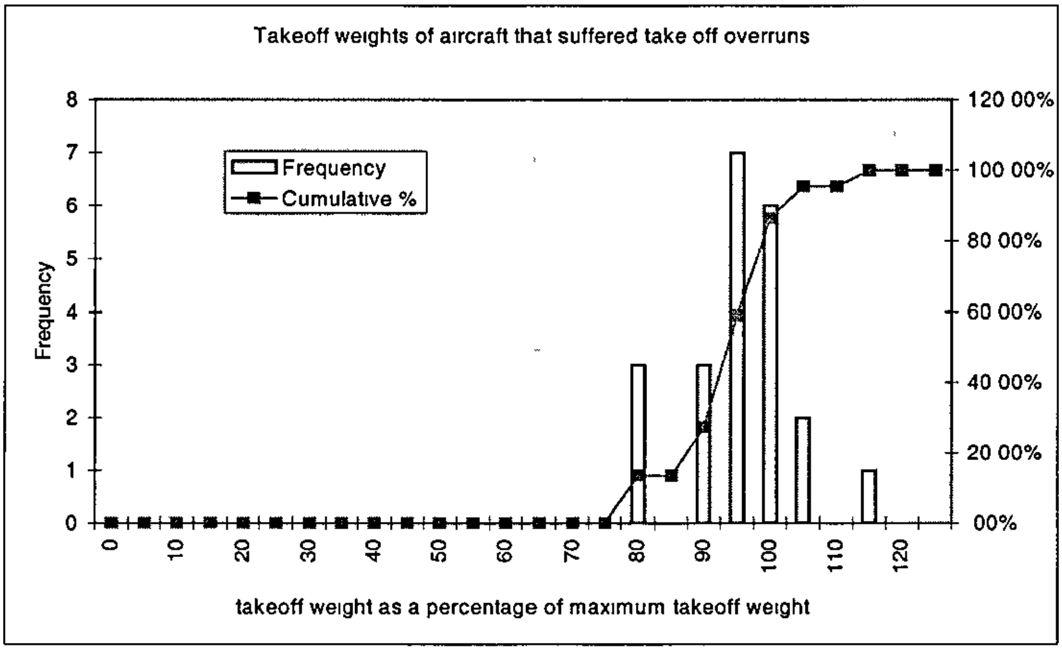

Figure 7. 5

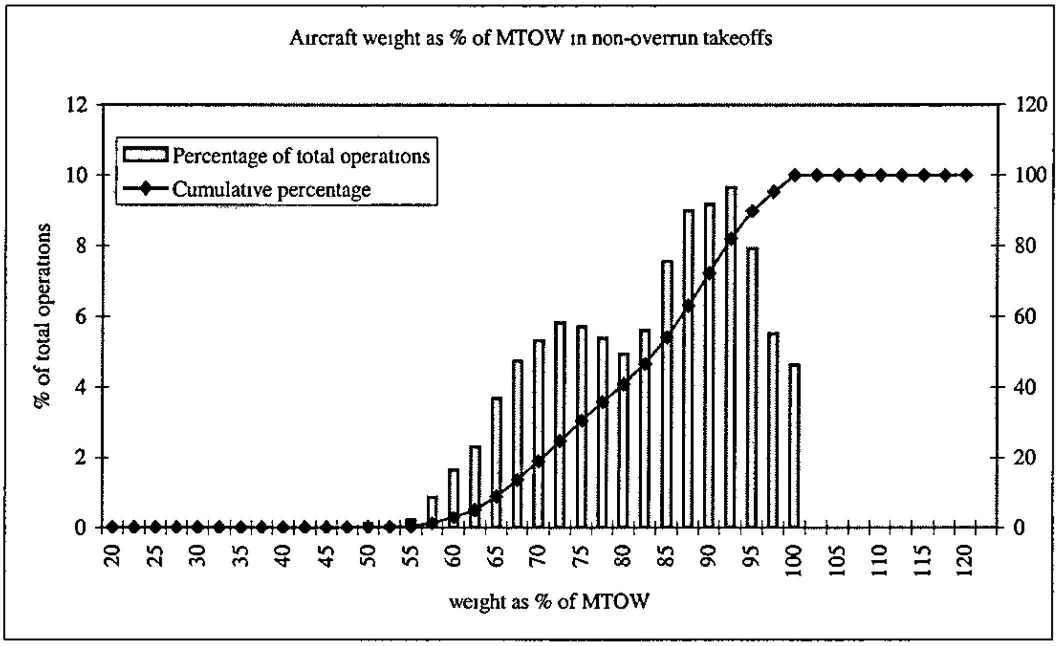

Figure 7. 6

The mean of the takeoff weight as a percentage of maximum takeoff weight is 80 9 percent for non-overrun takeoffs and 93 5 percent for takeoff overruns, a statistically significant difference

The model takes the form shown below

$$P(takeoffoverrun) = \frac{1}{1 + e^{-(-32\ 290 + 0.172W)}}$$

$$P(notakeoffoverrun) = 1 - P(takeoffoverrun)$$

where

P = probability

W = takeoff weight as a percentage of maximum takeoff weight

This model assumes that the takeoff data used is representative of all non-overrun takeoffs as well as rejected takeoffs that stopped on the runway surface The model implies that as takeoff weight as a percentage of maximum takeoff weight increases, probability of an overrun occurring also increases

Hosmer and Lemeshow's measure is 0 048, which indicates that 4 8 percent of the determinants of takeoff overrun occurrence are explained by takeoff weight as a percentage of maximum takeoff weight This is approximately twice the measure given by the landing weight model, indicating that weight as a percentage of maximum weight has more impact on overrun probability in the takeoff case than in the landing case The comparison with excess distance in the landing case indicates that excess distance may be a better indicator, however, until the information is available this is not known

A similar model that predicts takeoff-overrun probability given flight type, and constructed using UK air transport / non-air transport data as in the example above, can be compared with the model based on take off weight The model based on flight type indicates that flight type is not a statistically significant predictor of overrun probability and has a Hosmer and Lemeshow's measure of 0 009 which indicates that only 0 9 percent of the determinants of takeoff overrun probability are explained by flight type, even though non-air transport had a takeoff overrun rate approximately three times higher than air transport Therefore, a model based on takeoff weight explains over 5 times more of the outcome in terms of an overrun than does a model based upon flight type

7 7 *Further models*

Described above are the only overrun probability models that it was possible to construct with the data available The models appear to be a significant improvement on previous models that have simply been based upon flight type It is desirable to construct further models, as the analysis in Chapter six indicates that other areas such as weather and runway surface condition may also be significant in determining overrun probability, although care must be taken during their construction If the models are one dimensional in character as the models described above, further models may be describing effects that are already contained in previous models For example, some of the overrun and non-overrun flights that were used for the construction of the above models will have taken place in poor weather The above models indicate that the overrun was due to the weight or the excess distance available, whereas another model may indicate that it was due to the poor weather If separate models are constructed, there is a danger of duplicating the calculated risk, because of correlated data The remedy for this is to use multidimensional data, i e in this example weather and weight data for the same flights, however, most data collected and used in aviation research is one-dimensional in nature (e g Khatwa and Helmreich, 1999) At present, therefore, the construction of multidimensional models is difficult although the combination of one-dimensional models should be possible if correlations are carefully avoided A major problem with the combination of one-dimensional models, however, is the difficulty of testing for correlations when the data is collected for the models is from different samples

8 Wreckage location models

This chapter contains the wreckage location distributions of the overruns in the database The distance that has been measured is the distance along the runway centreline from a series of defined locations as described below The distance along the centreline of the runway is known in 137 of the 180 overruns in the database (102 landing cases, 35 takeoff cases) The distance from the extended centreline is known in 91 of the 180 cases (58 landing cases, 33 takeoff cases) In the cases where the distance along the centreline is known but not the distance from the centreline, the wreckage is assumed to have come to rest on the extended centreline The distributions are shown with all the locations to the same side of the centreline The locations were actually distributed almost equally to each side of the centreline

8 1 Wreckage location measured relative to the runway end

Figures 8 1 and 8 2 show the wreckage location measured relative to the runway end in the landing and takeoff cases The runway end is defined as the limit of the takeoff run available or the accelerate stop distance available in the takeoff case, or the end of the landing distance available in the landing case The takeoff-overrun distribution contains two occasions where the wreckage location is before the runway end These occurrences have been included because the aircraft travelled past the ends of their respective accelerate stop distances This type of overrun model, but without accounting for the cases that did not reach the end of the runway, has been used in order to validate dimensions of public safety zones (CAA, 1989), in addition to being used for the construction of new public safety zone dimensions (Evans et al 1997) The criticisms of models related to the runway end are discussed in Chapter 4

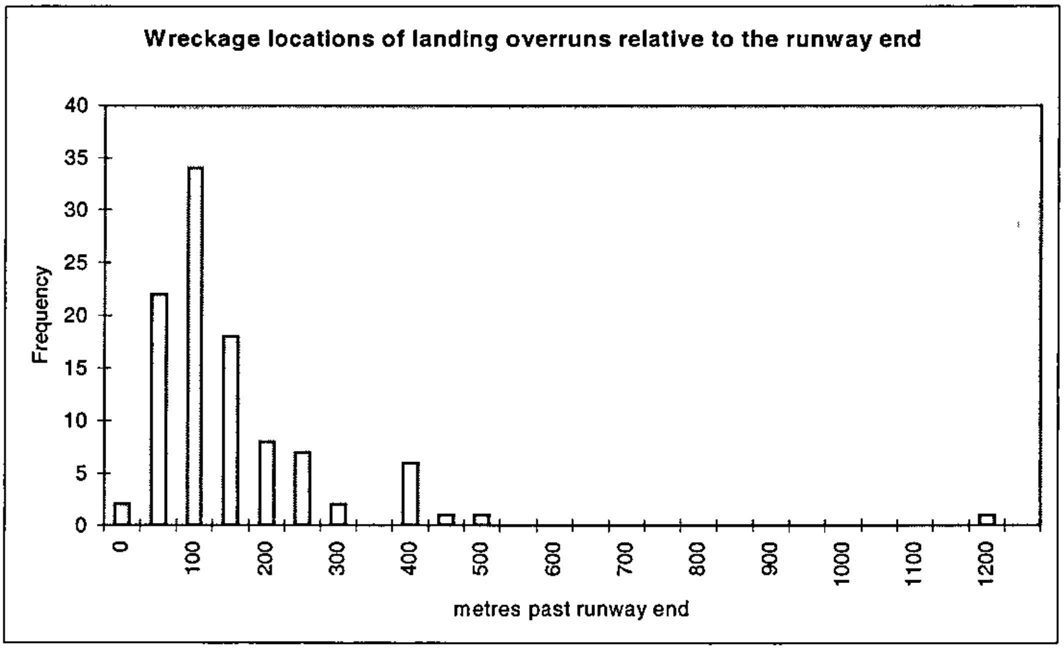

Figure 8. 1

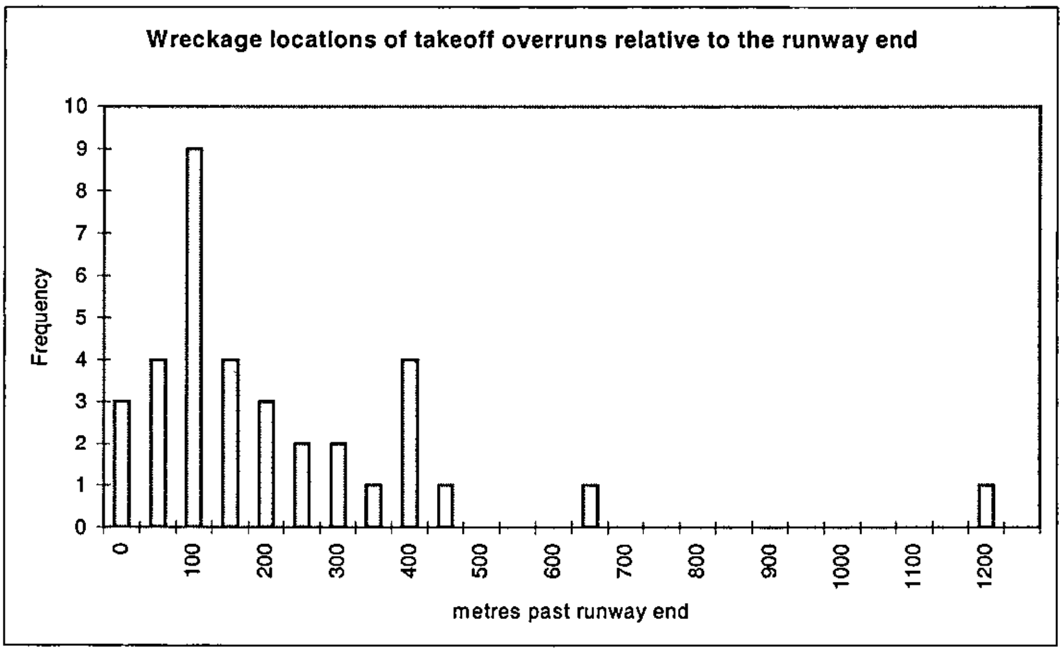

Figure 8. 2

8 2 Wreckage location measured from the end of the required distance

Figures 8 3 and 8 4 show the distributions of wreckage locations measured from the end of the required landing distance in the landing case, and from the end of the required accelerate stop distance (emergency distance) in the takeoff case It can be seen that the distributions are different for the two types of overrun

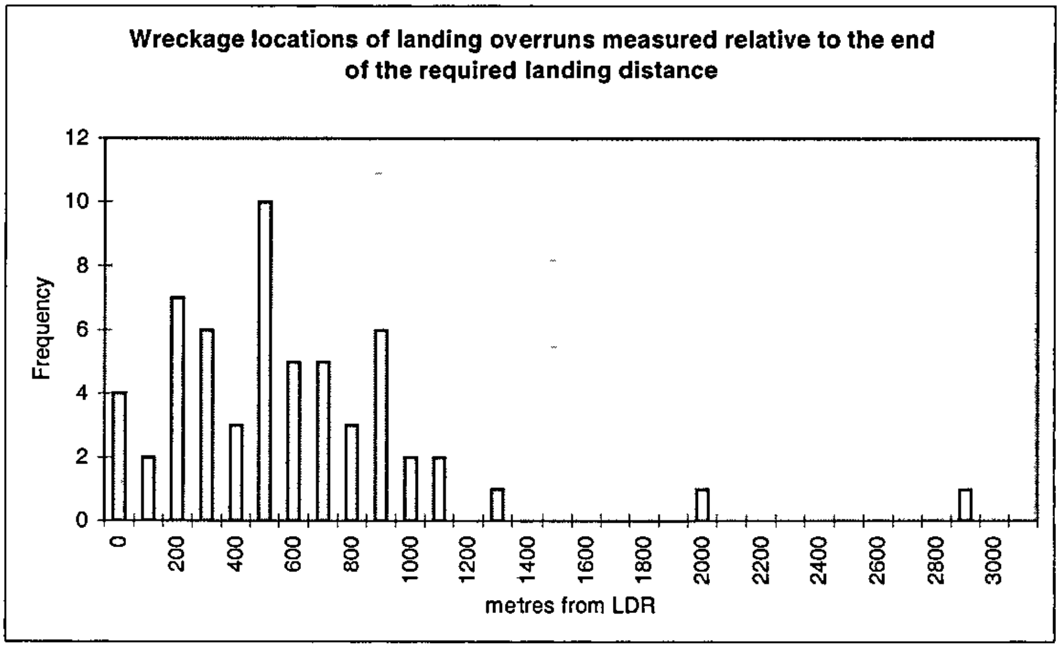

Figure 8. 3

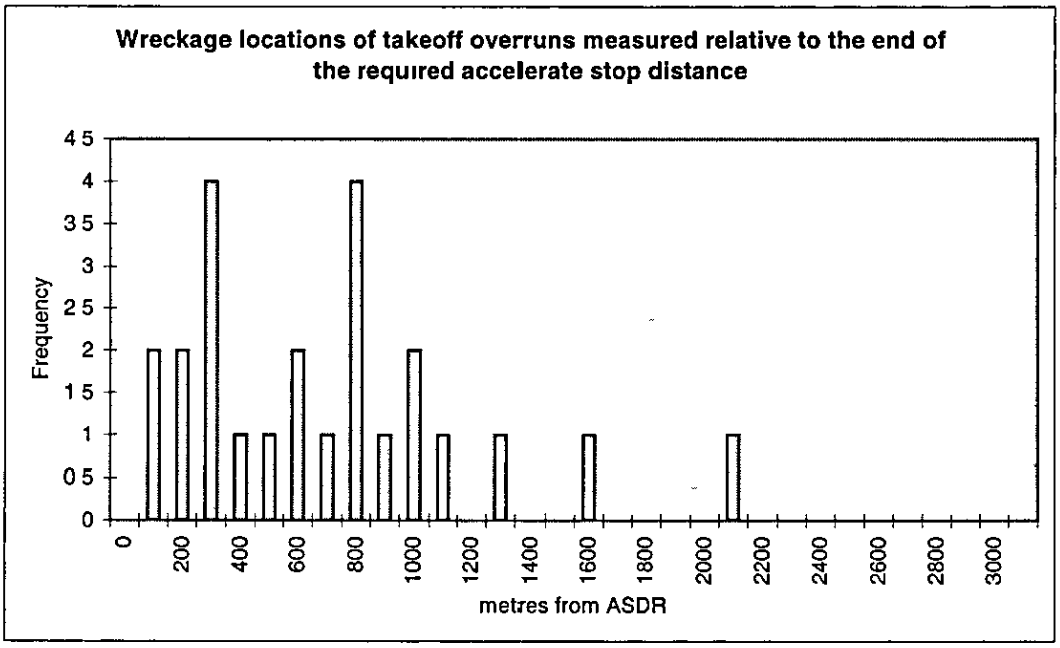

Figure 8. 4

8 3 *Normalised wreckage location*

Figures 8 5 and 8 6 show the wreckage location positions after being normalised for ground conditions, temperature, pressure altitude and runway slope The normalisation process has been described in chapter 4 The normalised positions have been measured from the end of the normalised required distance These distributions are slightly different from the non-normalised distributions, in that in both cases the peaks appear to have been flattened, and the tail to the right of the distribution has been lengthened

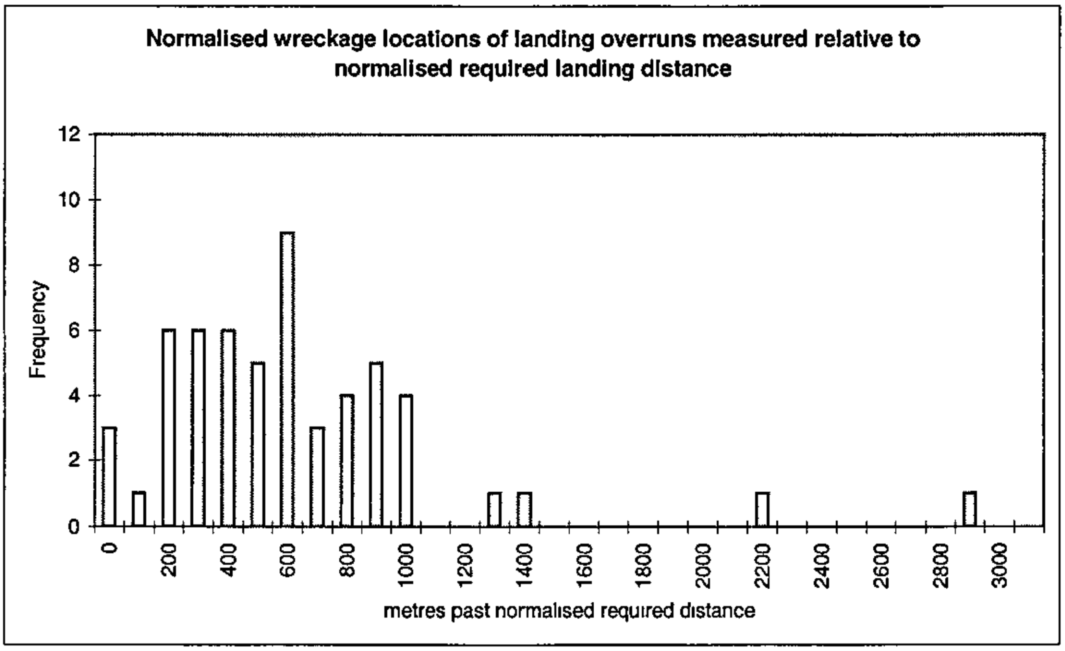

Figure 8. 5

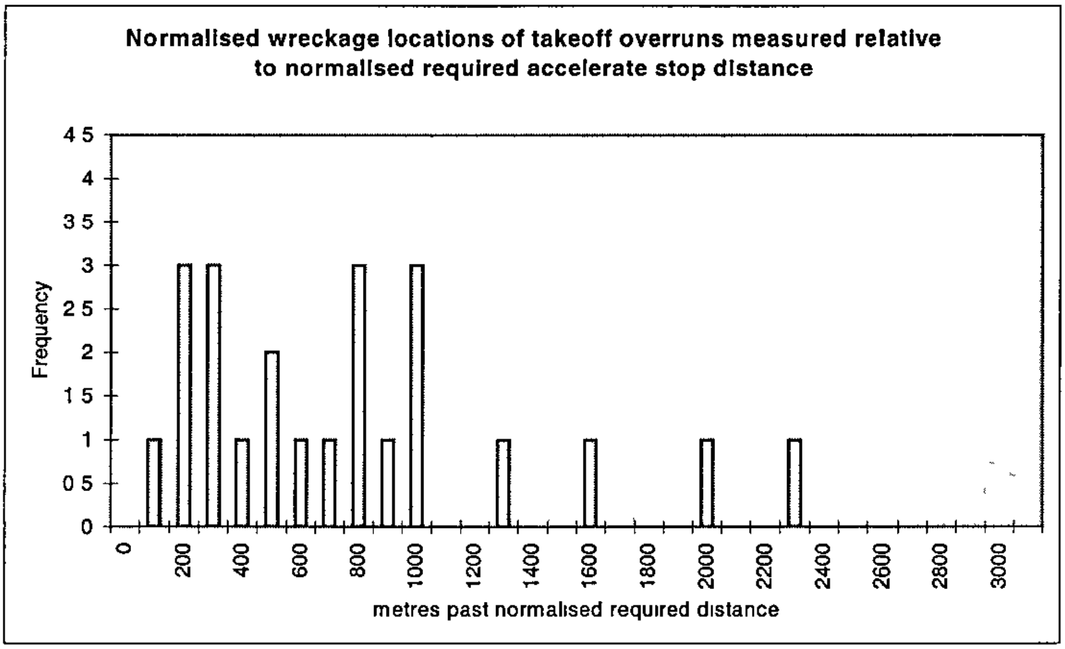

Figure 8. 6

8 4 Normalised wreckage locations relative to the end of the normalised required distance expressed as a percentage of the normalised required distance

Figures 8 7 and 8 8 show the normalised wreckage locations with the distance from the end of the normalised required distance expressed as a percentage of the normalised required distance Therefore, if the normalised required distance was 1000 metres, and the normalised position in which the aircraft came to rest was 2000 metres beyond, the figure in the chart would be 200 percent Expressing the positions in this way takes into account the different runway requirements of different sizes and operating characteristics of the aircraft in the database

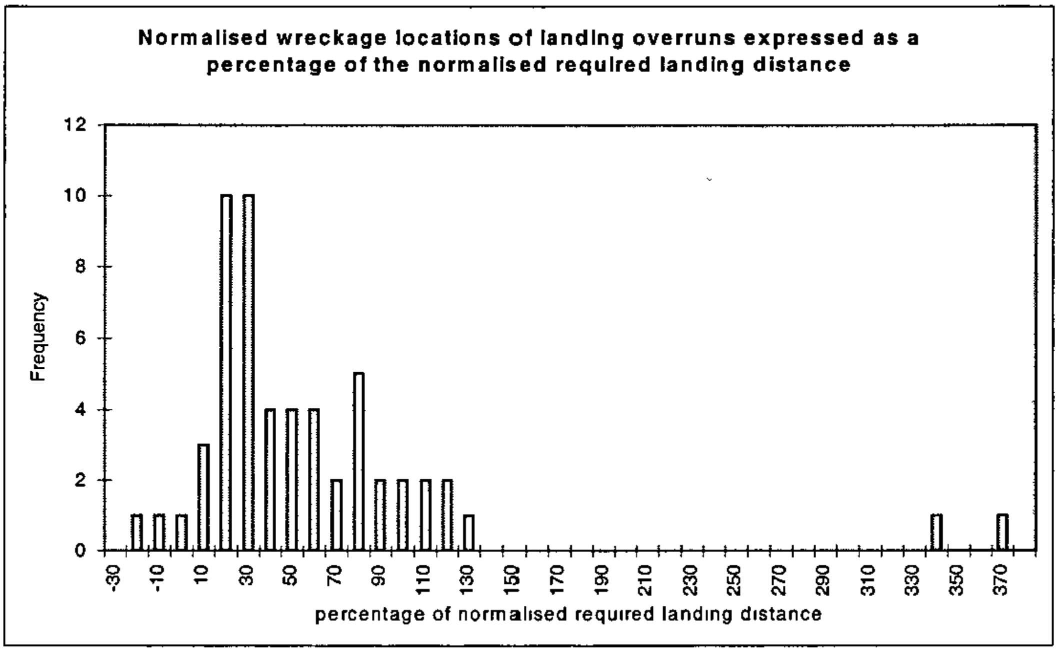

Figure 8. 7

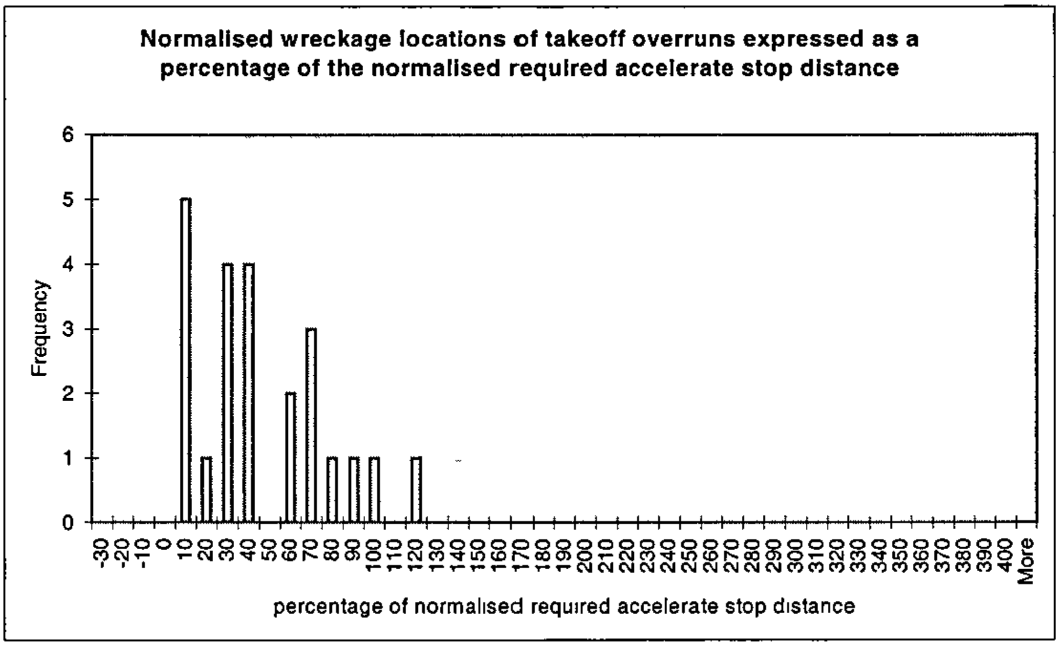

Figure 8. 8

8 5 Application of wreckage location models

Two wreckage location models have been constructed that take account of intended normal operation by expressing distance relative to the required distance, take account of local conditions through normalisation, and take account of differences between operations by expressing location as a percentage of the required distance However, the application of these models in an aerodrome risk assessment needs to be examined.

The models could simply be overlaid onto the required distances of the typical operations at the study aerodrome However, this approach would disregard the position of the end of the runway, and its influence on the pilot in determining the final wreckage position

Evidence for the overrun distance correlation with the runway end is provided in figures 8 9 and 8 10 These show the normalised distance past the end of the required distance expressed as a percentage of the normalised required distance, plotted against the distance between the runway end and the end of the required distance as a percentage of the required distance So essentially what is being plotted is the wreckage location relative to the required distance as a function of the excess distance available The relationships indicate that as the excess distance increases, so does the overrun distance beyond the required distance and therefore the runway end has a strong influence on the wreckage location The black lines on the two charts are the regression lines, which can be compared with a line that represents a 1 1 relationship between the excess distance between the required distance and the runway end, and the overrun distance It can be seen that the landing overrun regression line has almost the same slope, indicating that the average relative overrun distance remains virtually constant at approximately 10 percent greater than the excess distance with all values of excess distance In the take off case however, the lines converge, indicating that on average, as the excess distance has increased, the relative overrun distance has decreased

The result in the landing case would be expected if the pilots of the aircraft that have suffered landing overruns have been decelerating less severely on longer runways, i e using up all the distance available The result in the takeoff case would be expected if the pilots are making maximum efforts to stop the aircraft after an abort, regardless of the runway length

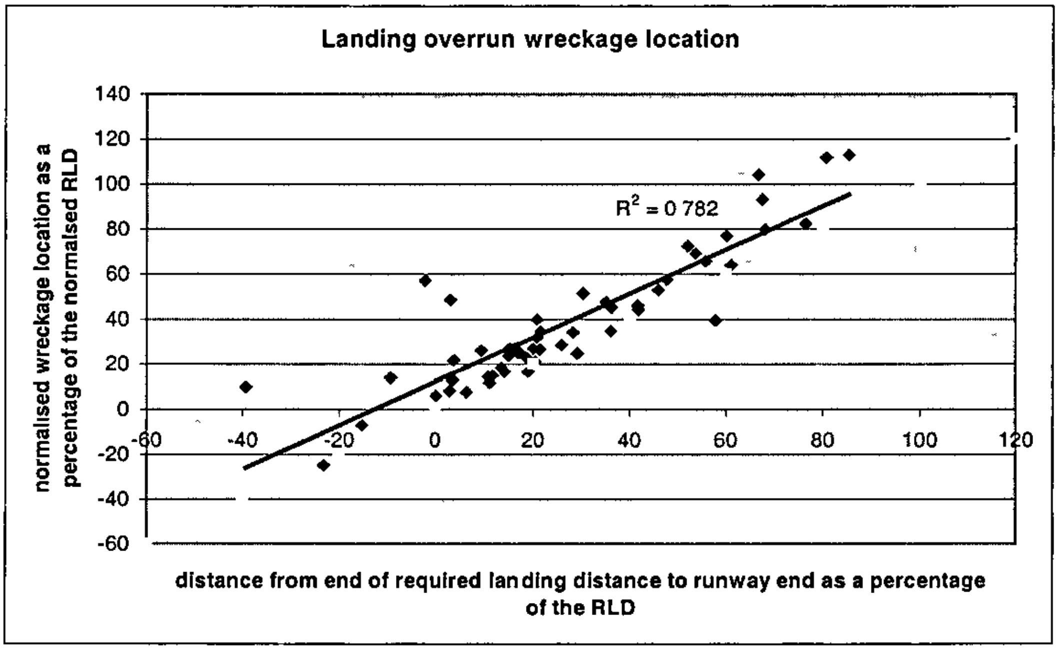

Figure 8. 9

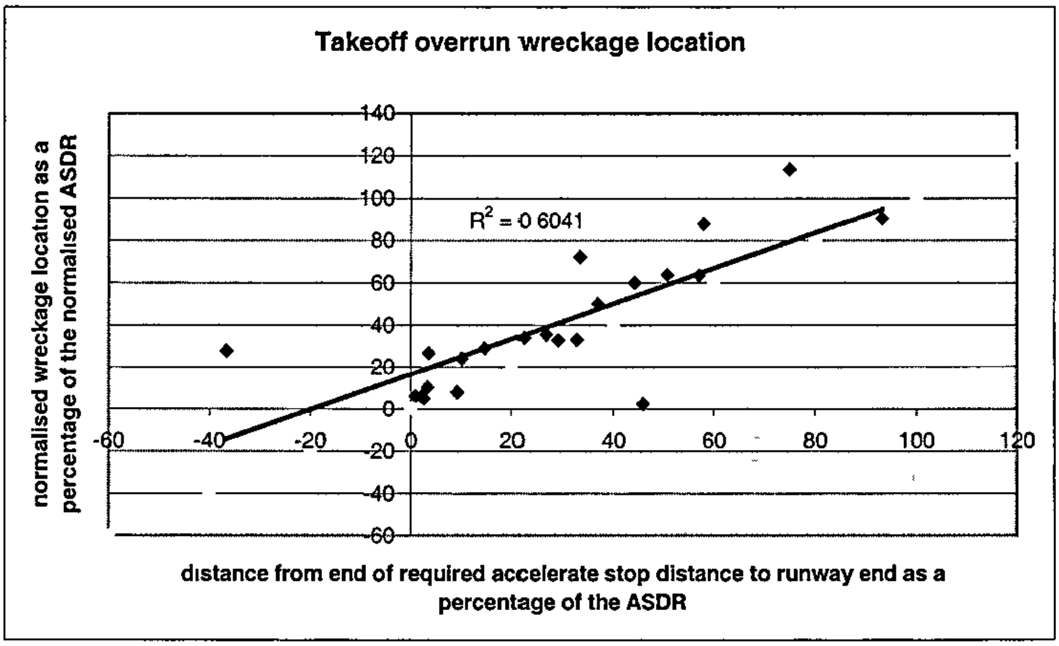

Figure 8. 10

The question that now needs to be answered is how can a model be constructed which will enable the prediction of wreckage location? Figures 8 7 and 8 8 cannot simply be laid on to the ends of the required distances at the study aerodrome, as this would disregard the position of the end of the runway However, existing models measured to the runway end disregard all other aspects of the operation, which would affect the outcome at aerodromes with different operational characteristics

One option may be to construct a linear regression equation that determines likely wreckage location as a function of the excess distance available, for example equations that describe the regression lines in figures 8 9 and 8 10 The distribution that is formed would be comprised of the residuals between the regression line and the actual locations. This would give a model that not only takes account of the position of the runway end, but also the characteristics of the particular operation

The equation that describes the landing overrun regression line in figure 8 9 is as follows

$$L = 11.982 + 1\ 028E$$

where

L = normalised wreckage location relative to the end of the normalised required landing distance expressed as a percentage of the required landing distance

E = excess distance between the end of the required landing distance and the runway end expressed as a percentage of the required landing distance

Figure 8 11 shows residuals between the regression line and the actual locations

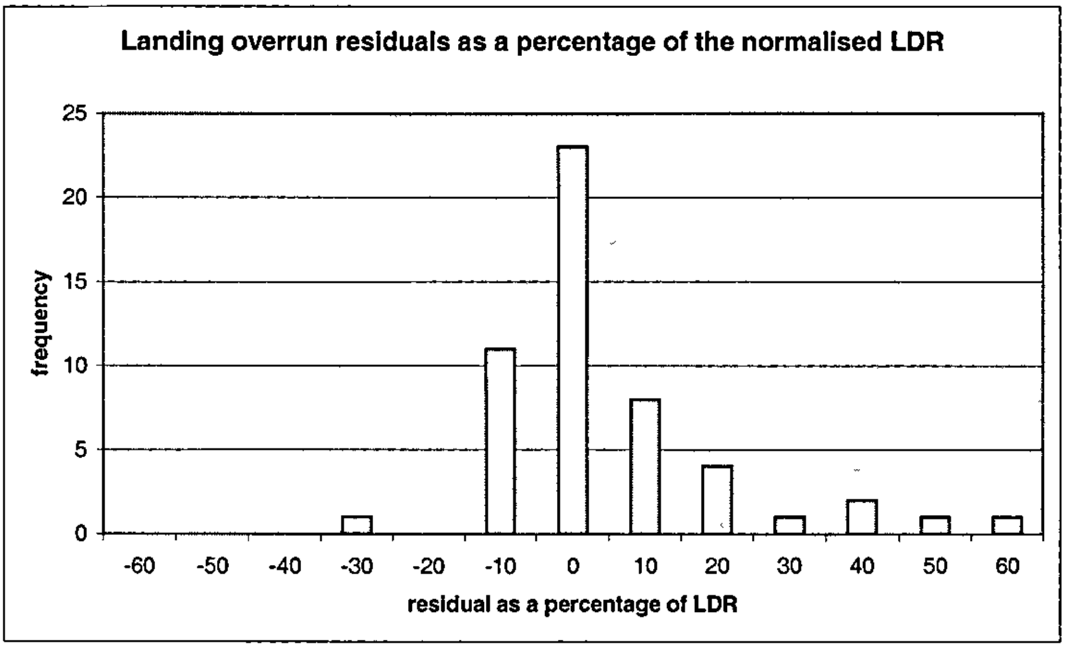

Figure 8. 11

Therefore, on a runway of 2000m where certain operations require 1000 metres of landing distance, the excess distance is 100 percent of the landing distance The above equation predicts a normalised overrun distance of 115 percent of the normalised required distance, or 150 metres past the runway end assuming the aerodrome experiences standard conditions Obviously not every overrun will come to rest exactly 115 metres past the runway end, the distribution of overrun positions is given by the distribution of the differences between the actual locations from the regression line in figure 8 9 Figure 8 12 shows the resultant distribution for this example

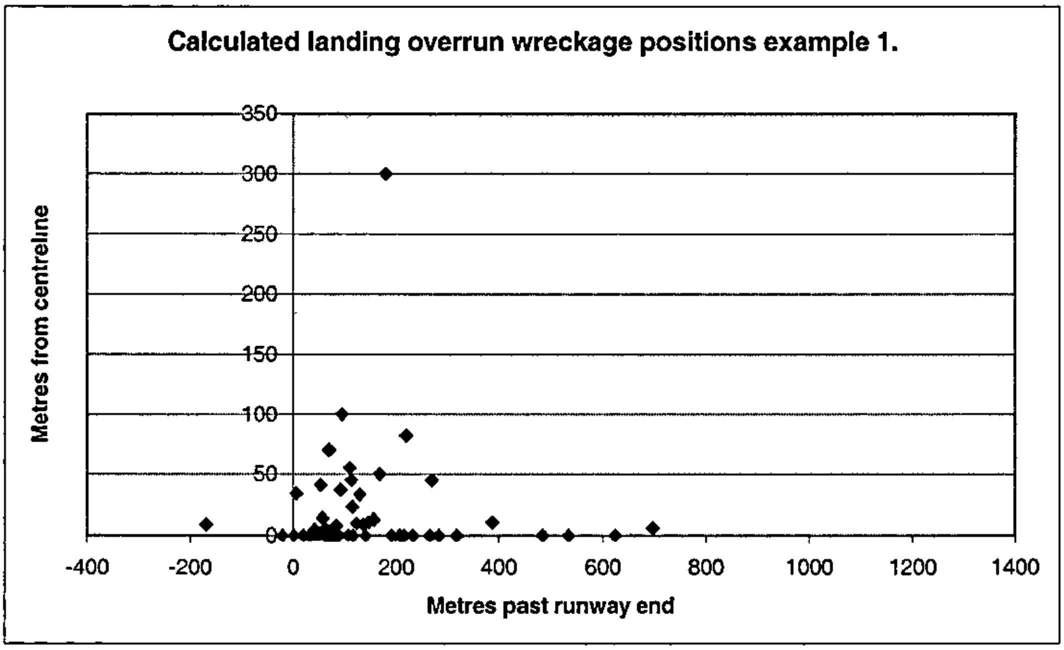

Figure 8. 12

If this technique is applied to a runway of 2000 metres where the typical operation requires 1800 metres of landing distance the excess distance is 11 percent of the required landing distance and therefore the calculated normalised overrun distance would be 23 percent of the required landing distance This gives an overrun distance of 414 metres past the normalised required distance or 214 metres past the runway end if the aerodrome experiences standard conditions Applying the distributions of differences between actual locations and the regression line gives the distribution of figure 8 13

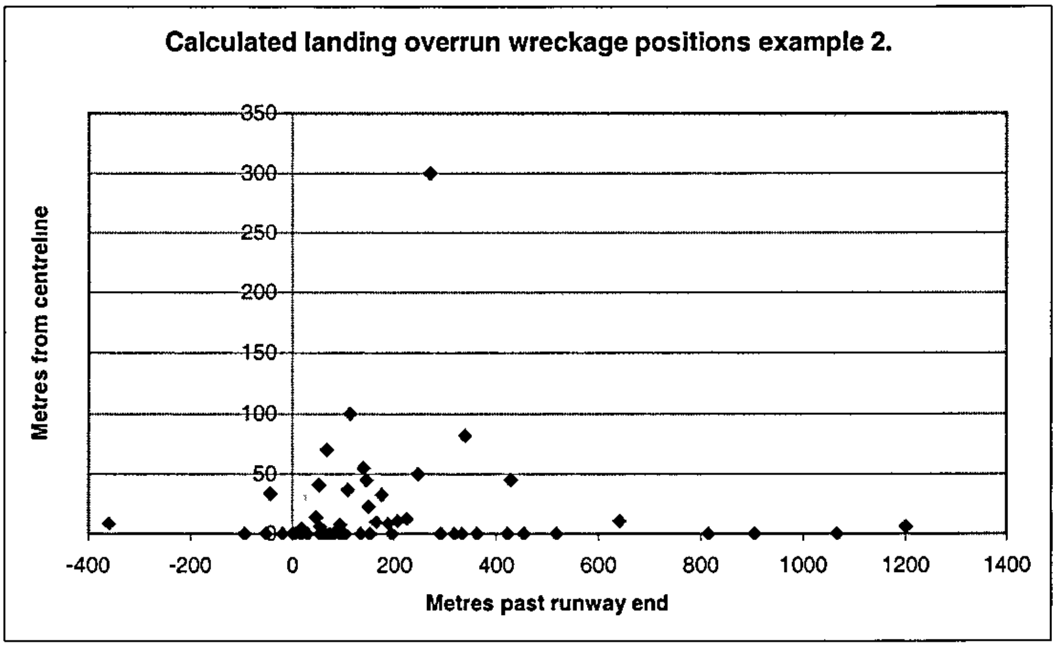

Figure 8. 13

The two distributions are similar, the difference being that in the case of the aerodrome with less excess distance between the end of the required landing distance and the runway end, the overruns come to rest a greater distance beyond the runway end Figures 8 14 and 8 15 show the distributions as frequencies of overruns of certain distances

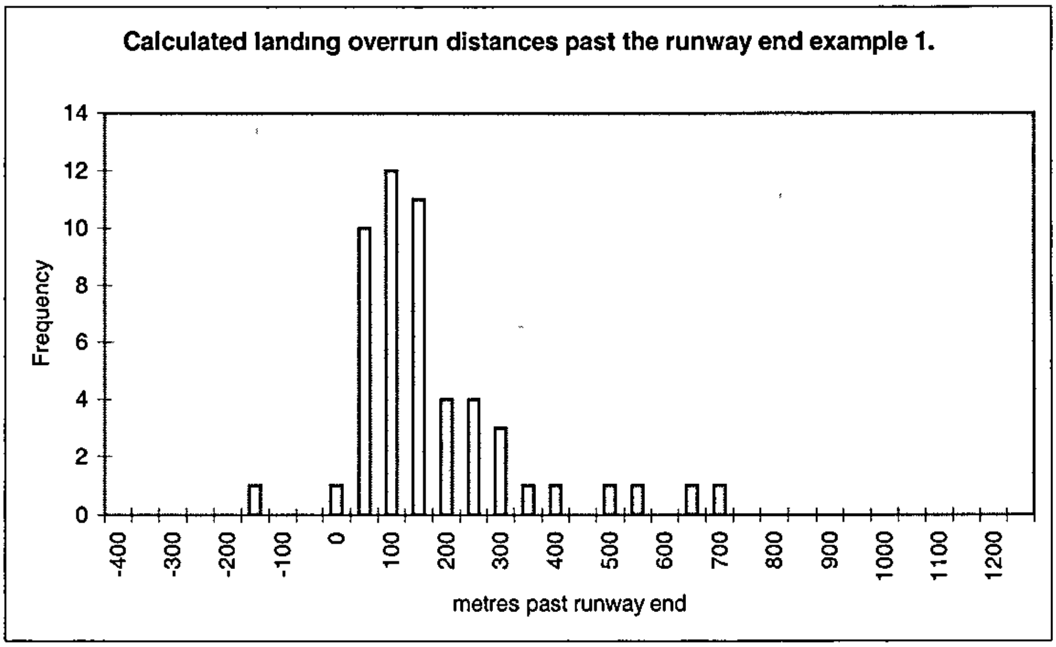

Figure 8. 14

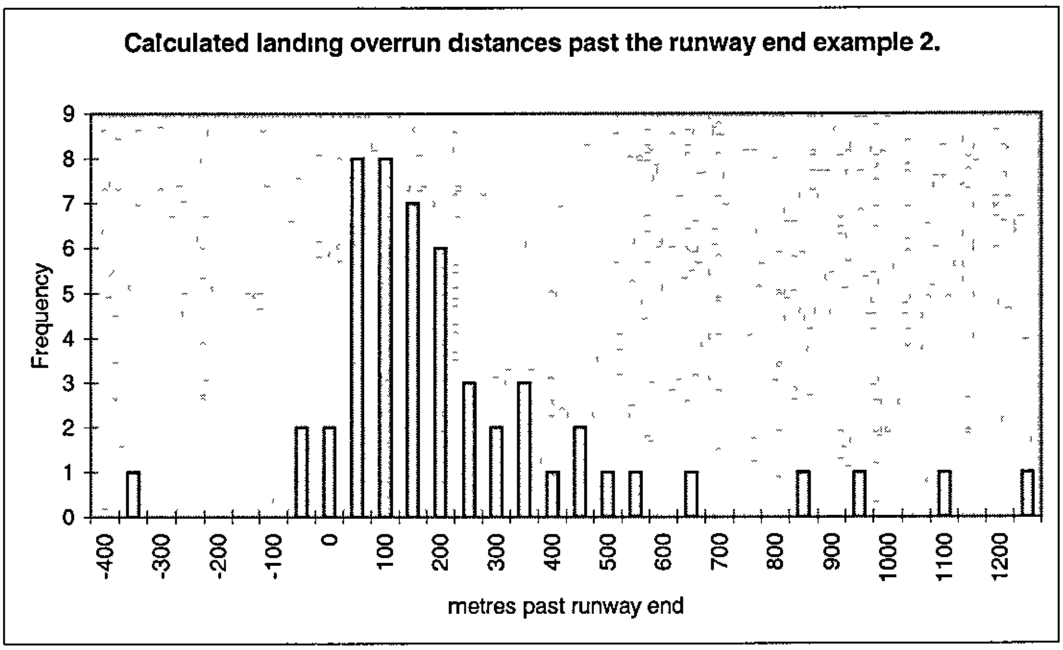

Figure 8. 15

A similar model can be constructed for takeoff overrun wreckage location based on the regression line and variation about the regression line in figure 8 10 The equation that describes the line is as follows

$$T = 16.564 + 0.839D$$

where

T = normalised wreckage location relative to the end of the normalised required accelerate stop distance expressed as a percentage of the required accelerate stop distance

D = excess distance between the end of the required accelerate stop distance and the runway end expressed as a percentage of the required accelerate stop distance

The residuals between the regression line and the actual locations are shown in figure 8 16

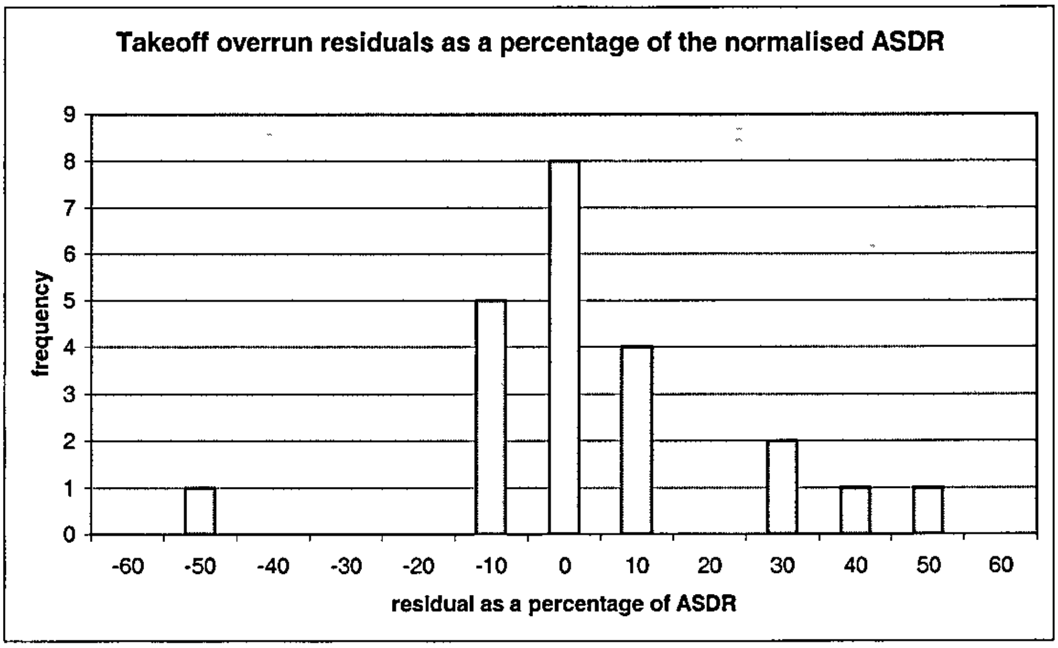

Figure 8. 16

The same examples as for the landing case can be used for the illustration of the takeoff model

On a runway of 2000 metres where certain operations require 1000 metres of runway for takeoff, the excess distance is 100 percent of the required accelerate stop distance The calculated figure for normalised overrun distance beyond the normalised required accelerate stop distance is 100 464 percent of the normalised accelerate stop distance or 5 metres beyond the runway end If the variation about the regression line is added, the wreckage distribution is as in figure 8 17

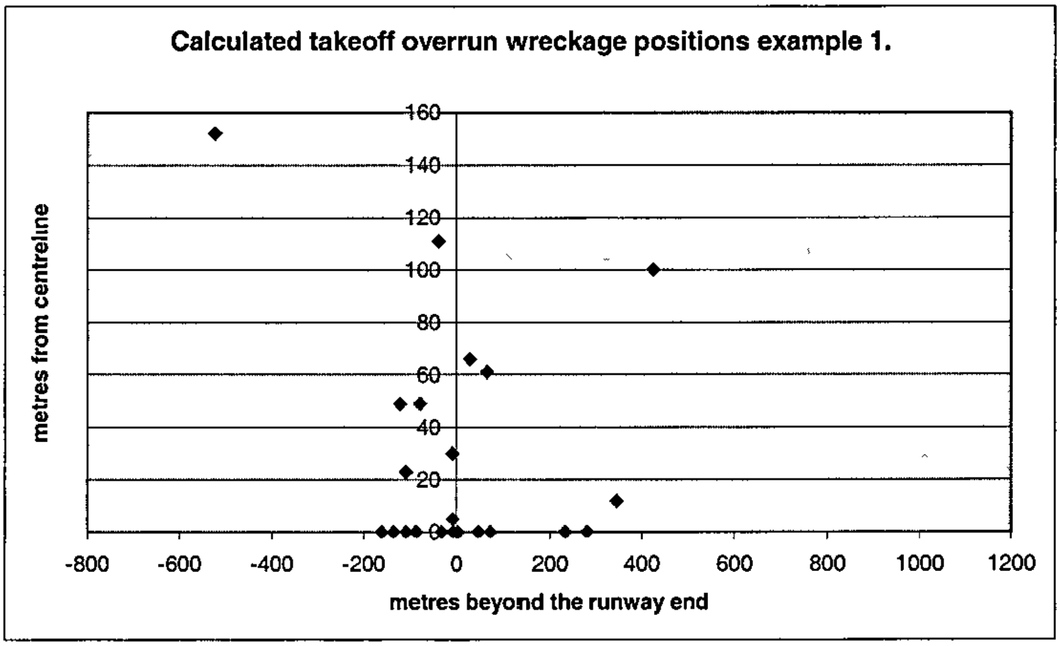

Figure 8. 17

Example 2 is a runway of 2000 metres where typical operations require 1800 metres of accelerate stop distance The calculated distance on this runway for normalised overrun distance beyond normalised accelerate stop distance is 25 793 percent of the accelerate stop distance or 264 metres past the runway end Combining with the variation about the regression line gives the overrun wreckage location distribution in figure 8 18

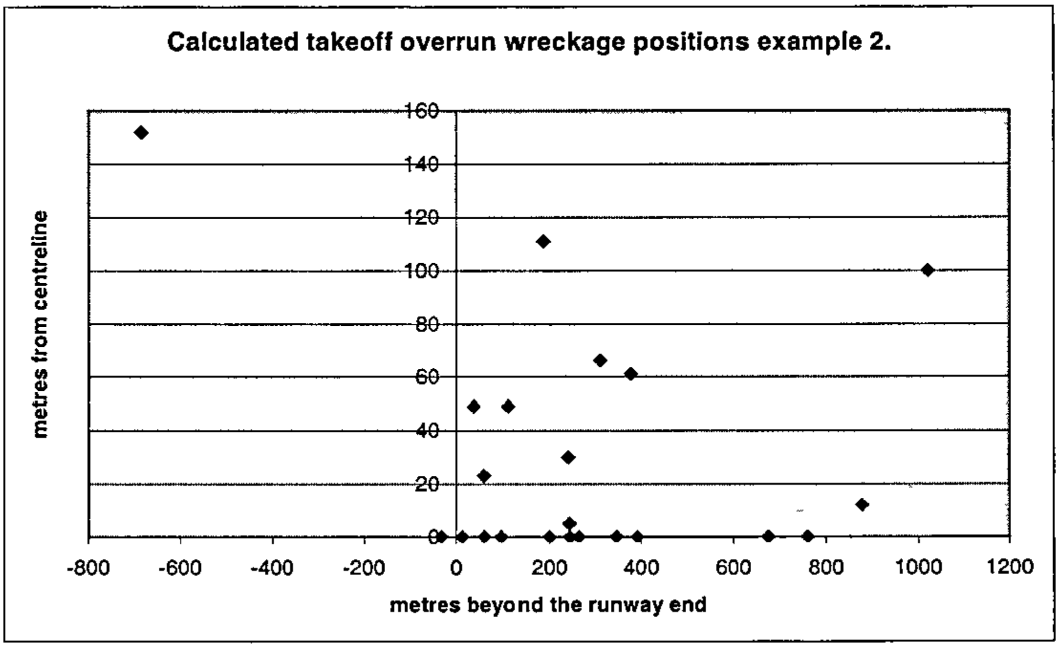

Figure 8. 18

These two example dıstrıbutıons are shown as frequencıes of overruns of varıous dıstances ın figures 8 19 and 8 20

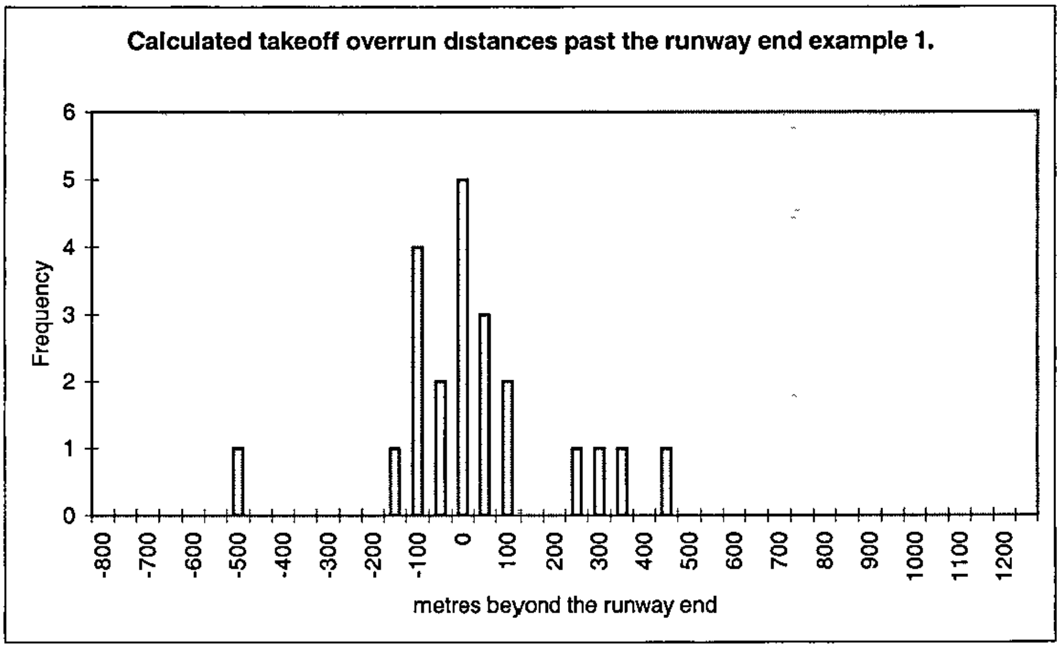

Figure 8. 19

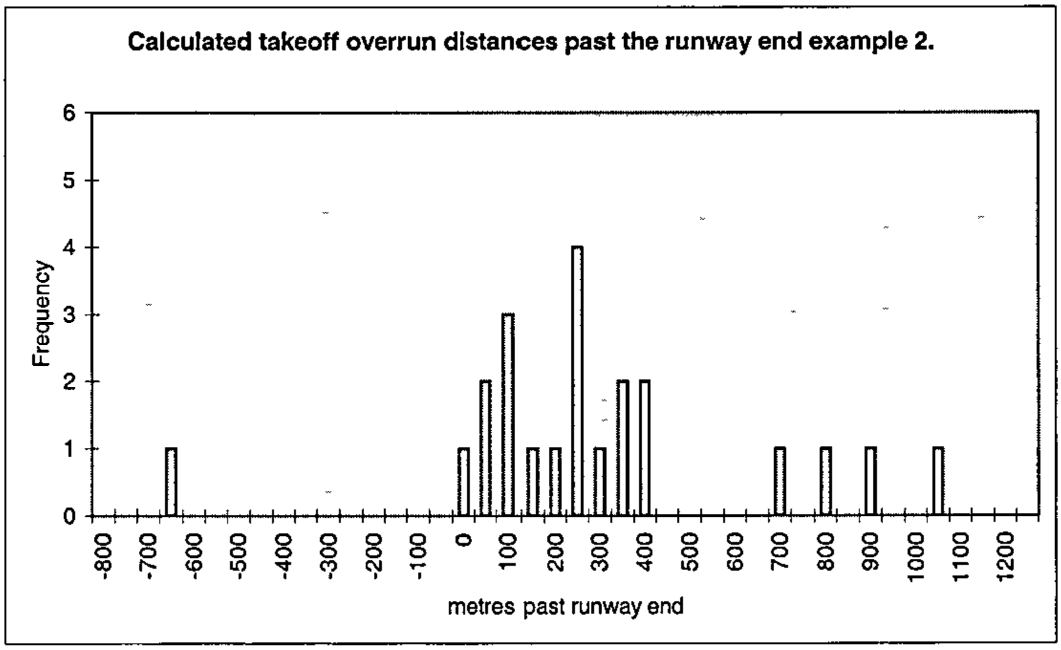

Figure 8. 20

9 Consequence models

9 1 *Introduction*

This section presents two logistic regression models that together predict the consequences in terms of aircraft damage of a runway overrun No distinction is made between whether the overrun has occurred after a takeoff or a landing The first model predicts the probability that the aircraft will either suffer none or minor damage against suffering substantial damage or being destroyed The second model separates probability of substantial damage or aircraft destruction

9 2 *Methodology*

The model methodology is determined by the nature of the available data for predicting damage in aircraft overruns and the nature of the predicted value i e how the damage is described The damage descriptions in accident and incident reports where one has been given can vary widely between a very detailed and full description, to simply the damage descriptions such as is given in the NTSB online database i e none, minor, substantial, and destroyed Employing detailed descriptions would result in no data for a large number of cases, and a large number of categories for the cases where this information was available. The eventual decision was to employ the NTSB categories, assigning damage categories to those overruns where damage information was given and a category had not been assigned The NTSB definitions for these categories are as follows

None No damage

Minor Any damage not severe enough to be classified as substantial

Substantial Damage or structural failure that adversely affects the structural strength, performance, or flight characteristics of the airplane and would normally require major repair or replacement of the affected component Substantial damage is not considered to be

- Engine failure or damage limited to an engine if only one engine fails or is damaged
- Bent aerodynamic fairings
- Dents in the skin
- Damage to landing gear (unless sheared)
- Damage to wheels
- Damage to tires
- Damage to flaps

Destroyed At the inspectors discretion

Obviously, classifying aircraft damage as destroyed involved an amount of subjectivity, as it would have done for the inspector compiling the report. In general, in cases where a damage description was given but not the classification, the aircraft was classified as destroyed when there was strong evidence that the aircraft would have been destroyed i e there was a serious fire, the fuselage was split, or the result was serious structural damage

From analysis of overrun data, some of which is described in Chapter 6, it seemed likely that the data used to predict aircraft damage would be a combination of discrete data i e flight type, whether an obstacle was struck beyond the runway end etc and continuous data i e aircraft weight, runway exit speed etc

According to Tabachnick and Fidell (1996) the most appropriate technique to use where the predictor variables are continuous and discrete and the predicted variable is discrete is polychotomous logistic regression This is because there is a mix of types of predictor variables, and the technique does not require conformity to the assumptions of linear regression

Within polychotomous logistic regression there are a number of approaches to dealing with multiple categories of predicted variable The approach that would appear to be most appropriate in the analysis of this particular data is the nested dichotomies approach, as is suggested by Begg and Gray (1984), Fox (1997), and McCullagh and Nelder (1990) The methodology where four categories are concerned is that the categories are combined into two and a dichotomous logistic regression is used to determine probability of inclusion in each of the two categories, as in figure 9 1. A second dichotomous logistic regression is then used to determine inclusion within each of the two categories that were nested together

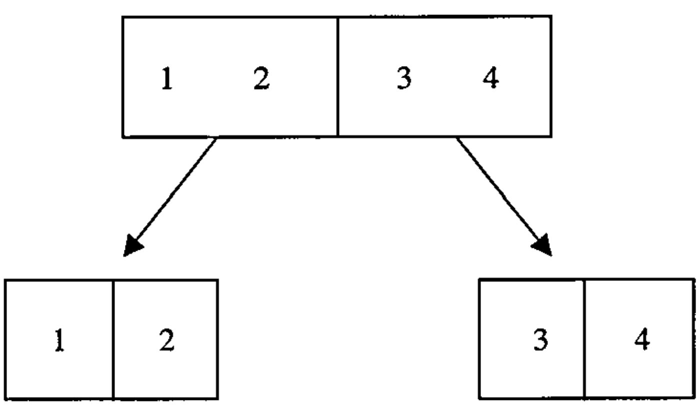

Figure 9.1

This would seem to be sensible in the case of aircraft damage In addition to providing a relatively simple calculation of probabilities, the categories of aircraft damage seem to naturally divide in this way For the aircraft to be included in the group "no damage" it has to have incurred no damage at all, a fairly narrow category For the aircraft to be included in the group "minor damage" it can have incurred any damage up to but no greater than flap, engine, tire damage etc This group is still fairly narrow, encompassing an eventuality that in some cases may only be slightly different from no damage and conceivably could have resulted from very slight differences in aircraft handling, or aerodrome characteristics, than those instances where the aircraft was not damaged Substantial damage, however, is a fairly wide category that would encompass everything from damage to engine cowlings up to the aircraft being almost destroyed. "Destroyed" is also a fairly wide classification and again could encompass a wide variation of actual damage from a fuselage split, to a high-energy collision that resulted in the aircraft being engulfed by fire

9 3 *Probability of aircraft incurring either no damage / minor damage or substantial damage / destroyed*

It was found that, of the data collected in the overrun database, the most reliable predictor of inclusion in the categories no damage / minor damage or substantial damage / destroyed was whether the aircraft struck one obstacle beyond the runway end

An obstacle is defined as in 6 5 6 as something in the overrun area that it would be reasonable to assume would damage the aircraft if encountered. This obviously involves some subjectivity, which is inevitable when trying to classify objects with limited descriptions Objects classified as an obstacle would include ditches, fences, trees, rocks, cables, vehicles, rivers, lakes, ILS antennas etc. The classification of these obstacles has to be conducted very carefully because it is very easy to fall into the trap of classifying something as an obstacle because damage has been caused to the aircraft, if this was the case the model would fit well, but would not be a good model as the independent data would be derived from the dependent data

The first model is as follows

$$P(sd) = \frac{1}{e^{-(-0\ 547+4\ 116B)}}$$

and

$$P(nm) = 1 - P(sd)$$

Where

P(sd) = probabılıty of the aırcraft sufferıng substantıal damage or beıng destroyed

P(nm) = probabılıty of the aırcraft sufferıng no damage or mınor damage

B = dıd the aırcraft strıke an obstacle beyond the runway end (yes = 1, no = 0)

The Wald statıstıc ındıcates that whether the aırcraft strıkes an obstacle beyond the runway end makes a statıstıcally sıgnıficant contrıbutıon to the model at the 0 05 level of sıgnıficance Also, Hosmer and Lemeshow's measure ındıcates that approxımately 40 percent of the varıance between the two groups ıs accounted for by whether the aırcraft has struck an obstacle Though not a hıgh correlatıon, ıt ıs the best predıctor out of the data that has been collected ın the overrun database. The Wald statıstıc and Hosmer and Lemeshow's measure are descrıbed and promoted as valıd statıstıcal tests by Fıeld (2000)

9 4 *A model that determınes whether the aırcraft wıll suffer substantıal damage or be destroyed gıven that the aırcraft has suffered greater damage than mınor damage*

It was found that of the data collected for the overrun database, the most relıable predıctors of whether the aırcraft wıll suffer substantıal damage or be destroyed are whether the aırcraft has struck a second obstacle beyond the runway end, and the runway exıt speed The model ıs as follows

$$P(d) = \frac{1}{e^{-(-5\,599 + 2\,742 B_2 + 0\,118 S)}}$$

and

$$P(s) = 1 - P(d)$$

Where

P(d) = probability of the aircraft being destroyed

P(s) = probability of the aircraft being substantially damaged

B_2 = did the aircraft strike a second obstacle beyond the runway end (yes = 1, no = 0)

S = runway exit speed in metres per second

The Wald statistic again indicates that these two factors make a statistically significant contribution to the model at the 0 05 significance level However, Hosmer and Lemeshow's measure indicates that 42 percent of the variability between the two groups is taken into account by these two factors, again this does not appear to be very high Of course, as this is a two-stage model, application would require that the uncertainty associated with the first model is carried through into the application of the second model, and therefore certainty of the second stage is reduced

It is perhaps not surprising to obtain results such as these Intuitively, the types of factors which would be expected to determine aircraft damage are variables such as runway exit speed, speed at which obstacles are encountered, the physical construction of the obstacles, the dynamics of the contact with the aircraft, the aircraft type, amongst many others Many of these factors are not reported at all, or not reported in detail in many accident reports, and therefore the construction of a statistical model is difficult

As the data collected for this information is from the accident and incident reports of all overruns occurring between 1980 and 1998 in Australia, Canada, the US, and the UK, it is unlikely that the collection of more data would help, and points towards the conclusion that a model based upon expert judgement may be a better proposition However, the above study has led to the identification of two important factors in aircraft damage due to overruns, namely runway exit speed and obstacles in the overrun area

9 5 *Misclassification of aircraft damage category*

The first model correctly classified 82 percent of cases

The first model predicted two cases as suffering substantial damage or being destroyed, where the aircraft actually suffered no damage or minor damage (one percent of total number predicted) In one of these cases the obstacles were a runway end lighting ditch and a 3ft high gravel embankment, however the aircraft was not damaged In the second case the obstacle was a small ridge and a bog In these cases the problem appears to be the classification of an obstacle, as an obstacle can cover anything from a slight drop off of ground to a large building The problem with using any more disaggregated definitions however is the reduction of data in each category

The first model also predicted 22 cases (17 percent of total number predicted) where the aircraft suffered substantial damage or was destroyed, but the model predicted that it would suffer no damage or minor damage In one of these the landing gear collapsed during roll out so it is unlikely that the damage resulted from the overrun at all, but this is not possible to determine from the report Quite a number of others appear to be quite small aircraft which have overrun into soft ground so it is possible that they may be more likely to be damaged by the wheels digging in, however this is hard to determine because these reports for accidents to smaller aircraft are not in general as detailed as those for larger aircraft

The second model correctly classified 89 percent of cases.

The second model predicted in one case that the aircraft would be destroyed when in fact it suffered substantial damage In this case the aircraft left the runway at a high speed, hit two "dirt berms" and came to rest in a water filled ditch The problem here may lie in the description of the dirt berms The accident report description of the aircraft "hitting" the berms makes them sound like substantial obstacles when they may not be, and justifies the case for inspectors avoiding colloquialisms in accident reports as well as for excluding this point from the analysis

The second model in three cases also predicted that the aircraft would be substantially damaged when it was actually destroyed In one of these cases the aircraft left the runway at a slow speed (10 kts) and came to rest only 30 metres from the runway end but in that distance had travelled over two embankments and through a steel wire fence In this case therefore the classification system does not appear to adequately define the severity of the obstacles In a further case the aircraft left the runway at a high speed and became airborne off an embankment Again, this appears to be a problem with the classification of the obstacle In the final case the obstacle was a large wooden approach light gantry that projected out from the end of the paved surface. At the end of the paved surface was also a sharp drop into water The aircraft departed the runway end and fell onto this structure, the misclassification of which again appears to be due to the obstacle classification system not being able to convey the severity of the obstacle

If the outliers that are due to the inadequacies of the classification system, and the occasions where the damage may have occurred before the overrun are removed, Hosmer and Lemeshow's measure increases to 0 58 for the first model and 0 46 for the second model The resultant models are as follows

$$P(sd) = \frac{1}{e^{-(-1\ 126+5\ 443B)}}$$

and

$$P(nm) = 1 - P(sd)$$

and

$$P(d) = \frac{1}{e^{-(-6\ 189+3\ 216B_2+0\ 122S)}}$$

and

$$P(s) = 1 - P(d)$$

Where

P(sd)	=	probability of the aircraft suffering substantial damage or being destroyed
P(nm)	=	probability of the aircraft suffering no damage or minor damage
B	=	did the aircraft strike an obstacle beyond the runway end (yes = 1, no = 0)
P(d)	=	probability of the aircraft being destroyed
P(s)	=	probability of the aircraft being substantially damaged
B_2	=	did the aircraft strike a second obstacle beyond the runway end (yes = 1, no = 0)
S	=	runway exit speed in metres per second

9 5 *Conclusions*

The models described above have highlighted two major factors that can determine the amount of damage suffered by an aircraft that overruns a runway However, there are still problems with this methodology Evidently, inadequacies with the classification of an obstacle and damage sustained decrease the power of the modelling approach, as does the second relatively low Hosmer and Lemeshow's measure Secondly, the second model requires runway exit speed as a predictor, but how is it to be predicted? It was thought that runway exit speed may have a relationship with the distance from the end of the nominally required distance to the runway end, however, figures 8 9 and 8 10 do not provide evidence that supports this theory In practice therefore, it may be prudent to conduct an expert judgement assessment of the consequences of an overrun at a particular aerodrome whilst bearing in mind the importance of the factors highlighted by this study and the need for further research into the predictors of runway exit speed

10 Risk assessment application

10 1 Introduction

This chapter contains a discussion of the application of the risk assessment process, utilising the advances that have been proposed in this thesis The whole process is first described in principle, then a worked example is given

Figure 10 1 shows the proposed risk assessment process that was introduced in chapter 1

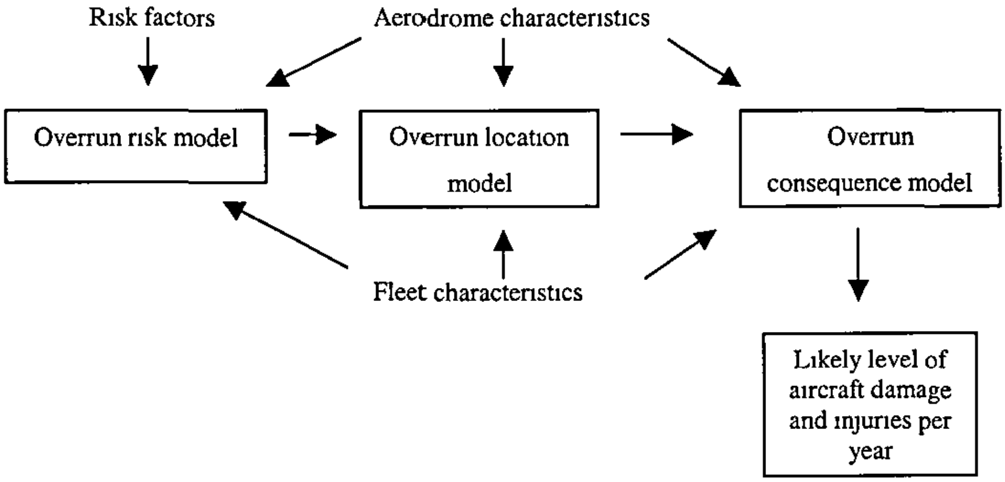

Figure 10. 1

10 2 Overrun probability

The first step in the process is to calculate overrun probability on takeoff and landing at the study aerodrome The risk models described in chapter 7 forms the obvious starting point

One of the landing risk models requires as an input the excess distance available at the aerodrome over that required by landing operations Day to day operations will require varying amounts of landing distance with the varying meteorological conditions, and landing weights of the aircraft, for each aircraft type operating at the aerodrome A perfect study of all operations would therefore be extremely complex, and almost certainly outside the budget and time constraints of a typical risk assessment

For ease of calculation the fleet composition may be broken down into groups of aircraft with similar runway length requirements, by route length i e short haul, medium haul or long haul, or by aircraft type such as wide body, wide body twin, narrow body or maybe a combination of the two methods The optimum methodology for simplifying the traffic mix would have to be determined in discussion with the aerodrome operator, as some aerodromes would have a far less complex traffic mix than others For example, a small regional airport that predominantly serves charter flights to a limited number of destinations is likely to have a fairly homogenous operational mix compared to an airport like Heathrow, which serves many destinations and airlines of different nationalities that may have operational regulations that result in different runway length requirements

The result of the simplification would be broad sections of traffic that require similar lengths of runway to land The effect of the prevailing meteorological conditions on the operational runway length requirements then has to be evaluated It may be that this process is more qualitative in nature and would be achieved through discussions with the aerodrome management and flight departments or chief pilots of the airlines that conduct the majority of the flights that utilise the particular aerodrome Most of the effort could be concentrated on the evaluation of the operations that are critical i e are close to requiring the maximum amount of runway available, as the risk increases exponentially as operations become more critical

The second landing overrun risk model and the takeoff risk model require a figure for actual landing or takeoff weight as a percentage of maximum weight Again this would have to be achieved through discussion with operators at the aerodrome, some of which may be able to supply quite detailed information from flight data monitoring schemes, others may only be able to supply estimates for typical operations If necessary, estimates could be made based on stage length Again efforts could be concentrated on those operations that are near to the maximum weights as the risk also rises exponentially as weights near their maximum limits

The overrun risk models only apply to commercial operations at the aerodrome, as this was the data used to construct the models Further research would have to be conducted to construct similar models for general aviation, but at present the simple GA overrun rates could be used It is likely that most aerodromes that will be conducting detailed overrun risk assessments serve predominantly non-general aviation operations, so the lack of a causal factor model for general aviation is not likely to greatly affect the overall outcome of the majority of the assessments

Further research needs to be conducted in order to quantify the risk due to other likely risk factors such as meteorological conditions, and runway state However, their predominance in overrun occurrences suggests that they should not be ignored In order to account for these factors in the risk assessment discussions with aerodrome management would need to take place in order to evaluate their relevance to the study aerodrome, perhaps in isolation or relative to operations at other aerodromes if a comparative study was being conducted Secondly, short of a full quantification of the risk factors, further discussions would have to take place with aircraft operators to determine the effects of the risk factors present at the aerodrome on the calculated risk from the models of weight and excess distance

Relating this process to figure 10 1 it can be seen that the aerodrome characteristic that is input to the model is the runway length or lengths, The risk factors would most likely be the meteorological conditions at the aerodrome, and the fleet characteristics would be the takeoff and landing weights and the landing distance requirement

10 3 Overrun locations

The two overrun location models require the accelerate stop distance and landing distance requirements of typical operations at the study aerodrome For the reasons outlined in 10 1 it will probably not be practical to obtain the actual requirements of all operations Again, therefore, in conjunction with aircraft operators at the aerodrome, the traffic mix at the aerodrome should be split into a smaller number of groups of aircraft that require similar amounts of available runway This process is likely to be simpler for takeoff than landing as it is likely that many operations will conduct reduced thrust takeoffs that will result in the aircraft using all the available runway length at different weights and in different meteorological conditions

The result of the application of the location models will be a distribution for each of the categories of runway length requirement for takeoff and landing The distributions are normalised distances relative to the normalised required distance. These then need to be de-normalised for the conditions at the study aerodrome As the required distances used for the input to the model are not normalised the normalised distance given by the model can just be related to those required distances This part of the process is not needed as normalising the required distances and then de-normalising them would only result in the same distances In the reverse of the process of normalisation, the factors for altitude, runway slope and temperature difference from the International Standard Atmosphere for the aerodrome altitude would be used to alter the distances given by the location models Typical temperature differences would be taken from aerodrome meteorological records, or the standard temperature given in the airport's entry in the Aeronautical Information Publication (AIP) could be used

The distances would then have to be de-normalised for the conditions of ground off the end of the runway Most aerodromes are likely to have overrun areas that are comprised predominantly of pavement, or grass, which may become mud when wet The deceleration model described in 4 2 2 can then be used to determine likely wreckage locations The deceleration model assumes that the terrain is flat, therefore an allowance must be made for any slopes in the overrun area This will probably be a task that can be easily carried out by a pilot or an aerodrome manager by applying some common sense, and it is envisaged that it would not be too much of a contentious issue i e most people would agree that if the terrain slopes downhill the aircraft is likely to travel further, the issue is by how much

The different categories of aircraft as regards excess distance available, will have different probabilities of overrunning (in the takeoff case if the weights relative to maximum takeoff weight are different for the various groups of excess distance), therefore the distributions will also have different probabilities associated with them This requires therefore that the probabilities of an overrun occurring must be combined with the locations to determine the probabilities of suffering overruns of various distances

Relating this process again to figure 10 1 it can be seen that the aerodrome characteristics that are entered into the overrun location model are the runway length, the runway slope, the altitude of the aerodrome, typical temperatures relative to the ISA, and the terrain characteristics of the overrun area The fleet characteristics are the typical required distances, and these are combined with the outcomes of the overrun risk model to determine likely wreckage locations

10 4 Overrun consequences

The locations determined by the previous stage can now be compared with a map of the areas beyond the runway ends at the study aerodrome This will determine the likelihood of aircraft encountering any obstacles present beyond the runway ends, and also the likelihood of the aircraft travelling beyond the limits of the runway end safety areas

The nature of the overrun consequence models means that although the consequence models have highlighted the most important factors in determining consequences, a more realistic assessment would probably result from an assessment of the consequences with the addition of expert judgement This would allow the assessment to take into account the particular characteristics of obstacles at that aerodrome with their effect on the aircraft types that use the aerodrome. The relationship between the nature of the obstacles and aircraft types was too complex to be modelled from the overrun data, and its assessment lends itself well to expert judgement, as the consequences of each specific aircraft type striking an object are relatively easy to picture Although the construction of statistical consequence models is difficult from a limited dataset due to the requirements of statistical significance, the process of the assessment of consequences would still be greatly aided by the information in the database The specific aircraft types and obstacles present at the study aerodrome can be found in the database, in addition to the outcome in terms of injuries and aircraft damage The circumstances at the study aerodrome can then be compared with those at the aerodrome at which the overrun occurred, to realistically assess the likely outcomes at the study aerodrome in the light of the outcomes of previous overruns In addition, information from the database can be supplemented by information from other studies into crash survivability, for example Horeff (1992), although much of the existing previous research into consequences has focused upon crashes from flight which may have fundamentally different dynamics to overruns

10 5 An example risk assessment of a hypothetical aerodrome

This example aerodrome has a runway of 2000 metres, and a traffic mix as in table 10 1 It has a level runway, is at 300m elevation, and experiences on average standard ISA temperatures Operations are split equally between the two runway ends, and the areas beyond the runway ends are grass

Aircraft type	Movements per year
short haul jet	12000
short haul turboprop	10000
medium haul jet	8000
long haul jet	1000
small cargo aircraft	16000
large cargo aircraft	4000
GA jet	8000
GA non-jet	30000

Table 10. 1

The example will become too complex if carried through for all of the aircraft types, so it will only be done for the medium haul jet aircraft

Hypothetical discussions with airlines at the aerodrome have determined that the typical landing distance for this type of aircraft is 1300 metres, also that approximately 10 landings per year of this type will require 1900 metres of landing distance Utilising the landing overrun probability model based on excess distance available and described in 7 5, overrun probability per landing for the typical medium haul jet landings is 5 6 x 10^{-21} and probability per landing for the critical landings is 4 7 x 10^{-7} Landing overrun probability for the medium haul jet aircraft per year is therefore 4 7 x 10^{-6}

Further hypothetical discussions with airlines operating at the aerodrome has indicated that the typical takeoff weight for this aircraft type is 85 percent of the maximum takeoff weight, also that approximately 3500 of the takeoffs operate at the typical takeoff weight, and approximately 500 of the takeoffs operate at 95 percent of the maximum takeoff weight Utilising the takeoff overrun probability model described in 7 6, probability per takeoff is 2 2 x 10^{-8} for those operating at 85 percent of the maximum takeoff weight, and 1 2 x 10^{-7} for those operating at 95 percent of the maximum takeoff weight The calculated takeoff overrun probability per year for the medium haul jet aircraft is therefore 1 3 x 10^{-4}

Assuming that the operations are spread equally over the two runway directions the probabilities of incurring an overrun at each runway end are half the overall overrun probabilities

The combination of the probabilities of an overrun for each of the four aircraft operational categories, the typical operations and the critical operations for takeoff and landing, with the wreckage location models in chapter 8 gives probabilities of overrunning a certain distance beyond each runway end As the operations are split equally between the two runway ends only the probabilities for one end will be shown As the aerodrome has an elevation of 300 metres the distances calculated by the wreckage location models have to be extended by 7 percent as part of the de-normalisation The aerodrome has a level runway, standard temperatures and a grass overrun area, so de-normalisation only has to be conducted for elevation Figures 10 2, 10 3, 10 4 and 10 5 show calculated probabilities of overruns of certain distances for one runway end

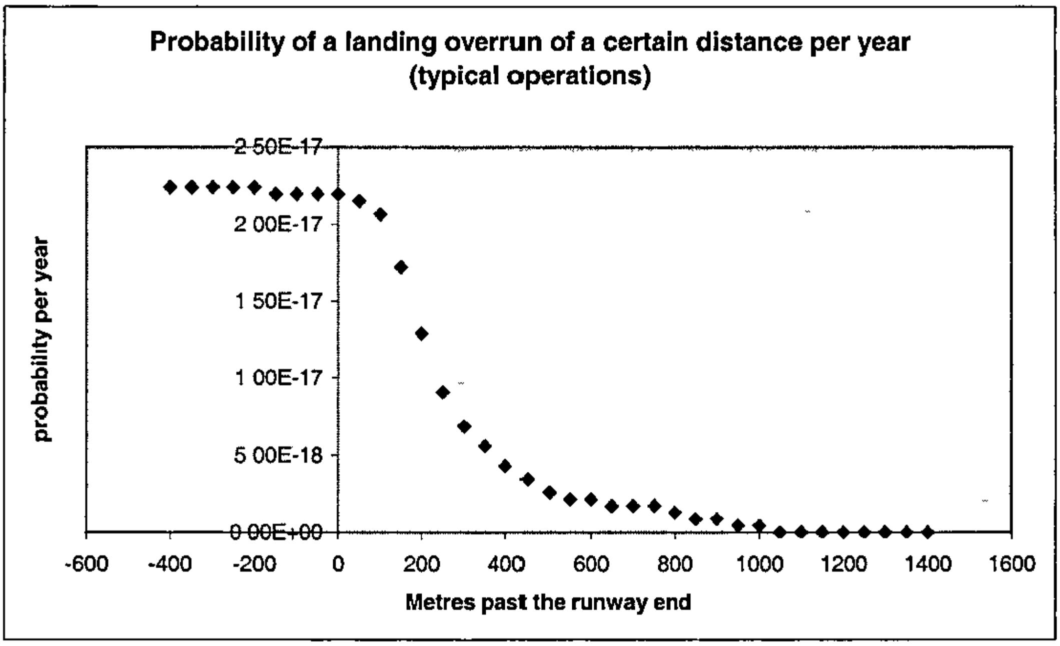

Figure 10. 2

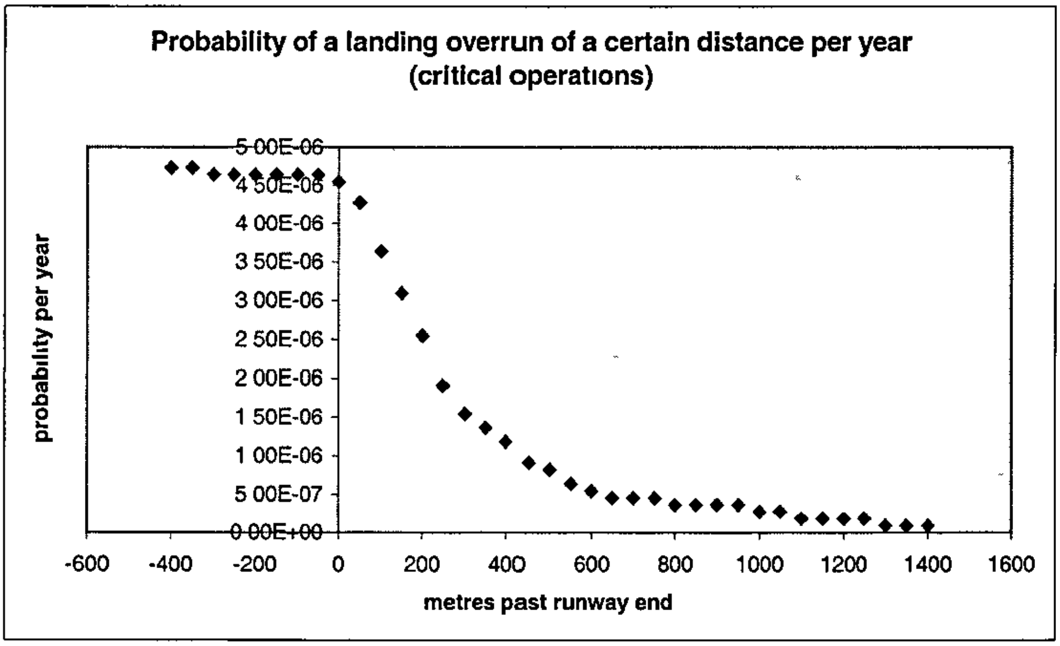

Figure 10. 3

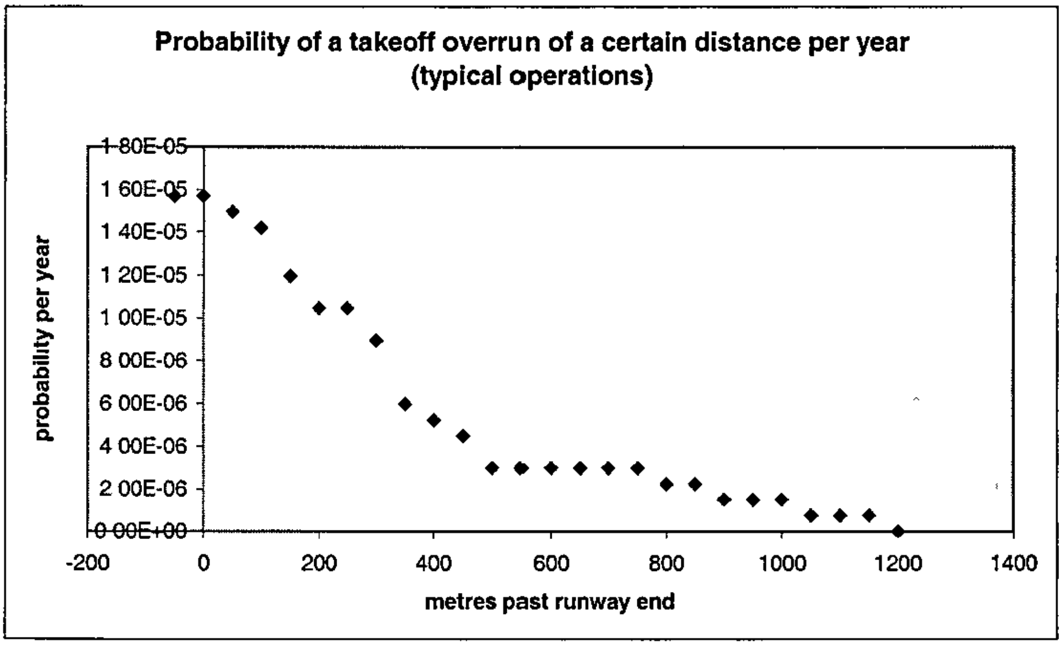

Figure 10. 4

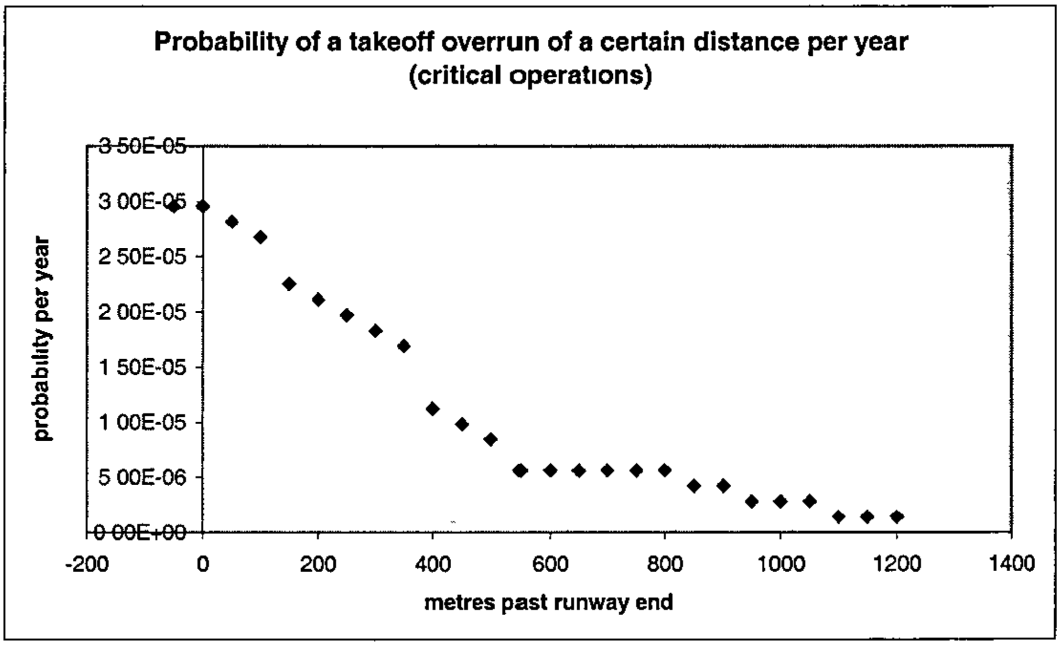

Figure 10. 5

The probabilities from the four different types of operation can then be combined to form a probability distribution for the runway end, shown in figure 10 6

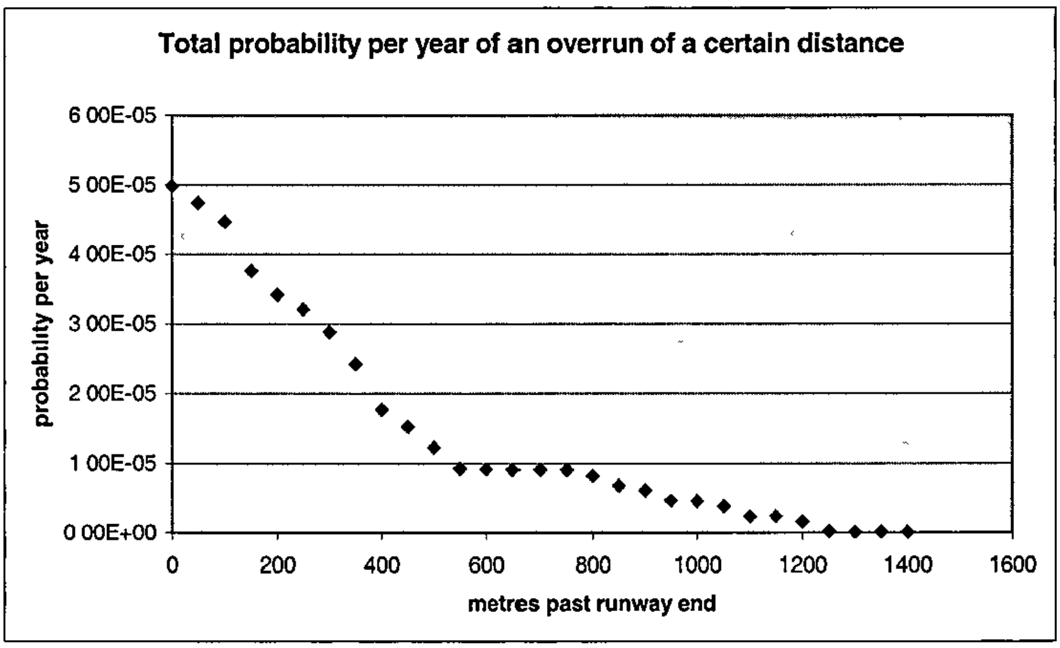

Figure 10. 6

These calculated probabilities per year of suffering an overrun of a particular distance can then be compared with the environment beyond the end of the runway If any obstacles are present, the probability of encountering the obstacle can be calculated through the combination of the distance from the runway end to the obstacle, and the size of the obstacle As stated above, the assessment of the consequences of striking the obstacle can be made by reference to the overrun database If for example there is a shallow ditch and the ILS power supply building in the overrun area, these obstacles can be located in the database It can be seen that those aircraft that did not strike any obstacles had no injuries suffered by their occupants Of those aircraft that only struck a ditch 30 percent of the occupants suffered minor injuries and 1 percent suffered serious injuries There was one aircraft that struck an ILS building at high speed This was a DC-8 freighter that was completely destroyed by fire Although the 5 occupants managed to get out with only minor injuries, had it been a passenger aircraft the consequences would most probably have been much more serious, perhaps as many as 40 percent of the occupants being killed. However, the aircraft left the runway at a higher than average speed, so perhaps the figure should be reduced to allow for overruns of lesser severity, perhaps a figure of 20 percent would be more realistic

Continuing this example with the shallow ditch at 50 metres beyond the end of the runway, and the ILS power supply building at 150 metres beyond the end, assuming that if an aircraft reaches these distances it will strike the ditch but has a one in ten chance of striking the building, and that a 767 has 250 people on board, the probability of a fatality is 1 9 x 10^{-4} per year This is only for the medium haul jet aircraft, the same process would have to be conducted for each aircraft type, for typical and critical operations The process can be put into a spreadsheet format, which would facilitate the exploration of risk mitigation options The inputs could be easily changed and the resultant risk calculation would be instantaneous

11 Conclusions and further work

The broad aims of the thesis were to explore the possibility of constructing quantified models for overrun probability and overrun consequences, and to construct more realistic wreckage location models

11 1 Overrun probability

Prior to this work the only quantified overrun probability models that were used were simple overrun rates given flight type It was shown in Chapter 7 that these models are very poor predictors of overrun rate The original aims of the study in this area were to quantify all of the factors that contributed to overrun risk, however, this was actually only possible for excess distance and aircraft weight in the landing case, and aircraft weight in the takeoff case

Although the development of these models is a significant advance on previous models, it falls short of original expectations The main reason for this is the lack of available information on non-overrun flights At present the only sources for much of the relevant non-overrun flight data are airlines that operate flight data monitoring systems The proportion of airlines that operate these systems is relatively small and generally only includes airlines with fairly large operations There are also problems with obtaining data from airlines that operate these schemes as the airline may not feel comfortable giving outside bodies access to their data for fear of the media or the public getting hold of it The airline may also have an agreement with the pilot's union guaranteeing that the data from the recorder is not given to anyone outside the organisation A further problem is that the system is not a specialised system for accident analysis, but very often is used to reduce maintenance expenditure Therefore it may not be set up to collect data that is relevant to a particular safety study The airline that provided data for this study had a current interest in landing risk, which is why it was possible to extract landing distance data This was not available for the takeoff case because the airlines system was not set up to extract it A further area that it would have been desirable to analyse was that of weather conditions on landing, however, wind and runway conditions were not correlated with the airlines flight information

A further problem is that even with information from an airline, that airlines operations may not be representative of all operations, so ideally information should be collected from many airlines This kind of exercise would seem more suited to being carried out by the Civil Aviation Authority, as it would be better able to convince the airlines that it would be beneficial, and would allay fears that airlines would have about their competitors obtaining their flight data An attempt was made to obtain additional data from other airlines, however, the major UK operator that was contacted did not have an operational flight data-monitoring scheme at the time, and the other major European and global operators that were contacted had agreements with their pilot's unions that meant that no data could be given out

The airline that did supply data was keen to maximise its usefulness, so scope exists with more time to extend the analysis of risk to other aspects of the operation In particular, it is suspected that required accelerate stop distance compared to the available accelerate stop distance, could be important in determining takeoff overrun risk Data already exists on takeoffs on various lengths of runways for non-overrun flights from the sample airline It would be a relatively straightforward task to develop a way to calculate accelerate stop distances for these operations and therefore to develop a model of overrun risk similar to that for landing The task would be slightly more complicated than for the landing case as the issue of reduced thrust takeoffs and their effect upon the accelerate stop distance would have to be addressed The airline may have a uniform policy that may simplify the calculation

Unfortunately no information could be obtained from the sample airline on rejected takeoffs that did not result in the aircraft departing the runway end The airline did collect the data but separated it from the rest of the data in the monitoring scheme The airline was asked if the data could be made available but it could not The reason for this is probably that this type of data is potentially more sensitive than data on non-incident flights If the media obtained the information it could be very damaging for the image of the airline. Unfortunately, the real key to understanding takeoff overrun risk is the comparison with rejected takeoffs that did not leave the runway end, so for this to be accomplished by researchers outside an airline, manufacturer or regulator will be difficult

The analysis of the overrun occurrences has led to the opinion that major factors in landing overrun risk are weather conditions and the runway state It is felt that much of the determination of non-overrun operations in various weather conditions could be achieved without the need for airline data Weather information for many aerodromes can be obtained from the meteorological services in various countries, and information of times of flights could be obtained from the aerodromes themselves, or schedules flight times from the OAG. It is even possible that some aviation enthusiast websites contain details of aircraft operations at some aerodromes A problem with a study of this nature however, would be that in order to properly assess the risk, data from a large number of aerodromes would have to be collected Not only would data from aerodromes that suffer extremes of weather need to be collected but also an assessment of the numbers of flights that fly in relatively benign conditions in order to construct an accurate model. Aspects of the weather that it is felt may be the most appropriate to focus upon would be visibility, runway state, and precipitation Visibility is an interesting area as there appears to be a contradiction involved in an ILS system designed to allow operations in reduced visibility and accident investigation reports stating that the reduced visibility is contributing to the accidents

A related study is comparative risk between day and night operations Estimates of numbers of takeoffs and landings conducted in each condition have been made in Enders et al (1998) however, from conversations with pilots it is clear that this area is one in which it would be difficult to make accurate estimates even at one aerodrome due to the combination between seasonal schedules and day length For a large region incorporating several time zones and latitudes the estimate is likely to be even more inaccurate A possibility for an accurate calculation may be through the combination of OAG data on planned scheduled aircraft departures with local sunrise and sunset time calculators that are available on the web

An area that was missing from the overrun probability models that have been described in this thesis is general aviation Information is harder to obtain for general aviation as it is less regulated than commercial operations and uses airfields that are not required to report traffic figures Also, general aviation operations are much less likely to operate flight data monitoring schemes, and are less likely to carry flight data recorders, therefore the accident reports tend to be less detailed Information is becoming more easily accessible for general aviation operations, probably as interest has increased as the conclusion has been reached that general aviation operations are more dangerous than other types For these reasons a study that is survey based rather than on empirical data may be a more useful approach to the determination of general aviation overrun risk

A valuable study would be the comparison between overrun rates of freight and passenger aircraft for the United States The United States would form the most useful study area as the majority of the overruns occurred in the US so if any differences exist, there is a better chance of them being statistically significant, than in countries with fewer flights over the study period The problems encountered in this study were that movement statistics were not collected uniformly for all flight types All commercial movements are collected as part of the FAA Terminal Area Forecast, but they are not split between freight and passenger movements The OAG contains planned scheduled flights, but this obviously only contains a small sample of all passenger and freight flights, and the Bureau of Transportation Statistics also only collect movement data for scheduled carriers Unless other sources of US data exist that were not found during this study, assumptions may have to be used to calculate non-scheduled passenger and cargo movements, thus reducing the accuracy of any results

Collection of movement rates of Jet and Turboprop powered aircraft would allow the comparison of rates of the two types of operation There were 4 times as many jet powered aircraft in the database than turboprop powered aircraft It is unlikely however that the ratio of jet to turboprop aircraft in non-overrun flights is the same There are reasons why jets may be more susceptible to overruns, i e less effective reverse thrust, faster landing speeds, and greater runway requirements, and this could be tested by the comparison between rates It is likely that movements may be more easily accessible for Canada and Australia as when Transport Canada and the Australian Department of Transport and Regional Services were contacted for Jet and Turboprop movements only, they were sent promptly, with no charge The UK CAA would be able to supply data split by engine type but it would take some time as the system is set up for aircraft type not engine type and it would be a charged for service

The large number of aircraft having problems in the air and then suffering an overrun (approximately 10 percent of the landing overruns) seems to invite research into the best ways of designing the system to allow for these types The rate at which non-overrun flights declare emergencies is far less than 10 percent of all flights, therefore not only is a flight that has declared an emergency more likely to overrun, but also a sizable minority of overruns will be of aircraft that are not operating correctly Unfortunately in general, the investigation report in a situation such as this almost entirely focuses on the circumstances that led to the problem in the air to the exclusion of analysis of the overrun Obviously, in order to cater for these operations an understanding of their characteristics must be reached, which is difficult with the focus of the investigation elsewhere

Although research is being conducted into the assessment of the effects upon the deceleration distance of aircraft on contaminated runways, the contents of the database provide further evidence for its need Of the 26 landing overruns that occurred on contaminated runways the report mentioned whether a braking action advisory was supplied to the pilot by the aerodrome operator in 16 cases Of these 16 occasions a report was not supplied in 7 of them, "good" was issued in one case, "good to fair" in one case, "fair to poor" in 2 cases, and "poor" in 5 cases Any analysis of the implications of these results would have to make the comparison with the incidence of braking action reports in non-overrun operations, and the actions of pilots once a report has been received This information is most probably held in aerodrome tower records

Included in the database is information on whether it was the Captain or the Co-pilot who was at the controls of the aircraft when it overran, and the experience of the pilots in terms of total flying hours and hours flown on the type of aircraft that overran A survey of these characteristics for non-overrun flights would determine whether they affect overrun risk, and could have regulatory or airline policy implications Studies of these characteristics would have to involve airlines as it would only be possible to determine incidence of Captain / Co-pilot involvement with their co-operation An airline would probably also be able to help with a survey of pilot's hours, although this could possibly also be carried out through pilot associations such as BALPA or IFALPA

11 2 Overrun wreckage location model

The wreckage location model is an area that has been significantly advanced by this study Prior to this study there only existed a model that contained information on the position of the aircraft relative to the runway There now exists a model that takes account of the relative operational characteristics of the aircraft as regards the required distance and its relationship to the runway length, the influence of the runway end on the pilot's behaviour, and aerodrome characteristics of elevation, runway slope, temperature, and terrain beyond the runway end Unfortunately, there is no way of testing which model is better at predicting location, other than subjective judgement as to which one should intuitively be the best model

An area for further research would be the determinants of the Y position of the wreckage This is the distance from the runway centreline, at right angles to it The model in its present form only predicts that the spread of locations about the centreline will be the same as the spread in previous overruns, rather like the previous model predicted overall position From a study of accident reports it seems likely that the Y coordinate will be a function of the controllability of the aircraft, which may be difficult to predict, and the position of any obstacles in the overrun area that are visible to the pilot It also seems likely therefore that the Y coordinate is affected by individual aerodrome characteristics, and therefore a risk assessment at an aerodrome should really take this into account

If information on overruns from a wider geographical area is collected there may be the scope for exploring whether there is a difference in location for general aviation versus commercial operations There is likely to be some difference in the distribution, as general aviation operations are not required to apply the same landing distance factors as commercial operations Due to the size of the database it was not possible in this study to determine any differences that were statistically significant A difficulty with this proposed analysis is that general aviation operations will be less extensive in other regions of the world and a problem with all studies of general aviation accidents and incidents is the tendency for the investigation reports to be much less detailed than those for commercial operations

There exists a category of data that is missing from the analysis These are operations that would have been an overrun had the operation been on a shorter runway i e the required distance was exceeded but the aircraft did not leave the runway end This type of data was not included due to the difficulty of obtaining the data As mentioned previously, rejected takeoff data for occasions when the aircraft did not go beyond the runway end was not available but was collected by the airline However, data for the landing case may be more difficult to obtain because it is not collected by the airline This area becomes even more complicated as the pilot may not know when the distance has been exceeded This is for two reasons, firstly no instruments inform the pilot as to the aircraft's position on the runway and human judgement may not be accurate Secondly, The pilot may not know the landing distance requirement The flight department of an airline usually takes the flight manual charts of the aircraft and translates these into weight limits for the runway and meteorological conditions Although the pilot may have a good idea as to the landing distance requirement from the weight limit, the exact distance will not be known A further complication is that the pilot may intentionally extend the distance on the runway because the exit or the terminal building is at the far end of the runway If the runway were shorter the distance would not be extended so occasions such as these would not directly translate into an overrun at another aerodrome

11 3 Consequence model

The original aim of the study was to construct a model of overrun consequences This has been achieved, but the nature of the model means that it needs to be supplemented by a more detailed analysis of the database for characteristics relevant to operations at the study aerodrome A further original aim was to make the risk assessment system useable by aerodrome managers with no expertise in this area Although the application of the probability and location models is a relatively simple procedure that is presentable in a spreadsheet format, the interrogation of the database and application of the findings to the study aerodrome is an area that may need some specialised knowledge.

The area of overrun consequences is therefore one in which further research should be carried out The derived consequence model required runway exit speed as an input, however, the determinants of runway exit speed are unknown at present, and investigations suggest that it may be largely random An interesting aside is a graph of runway exit speed shown in figure 11 1 that has been cited in work on overrun arrestor systems (White, et al , 1993) and in overrun risk assessments (Eddowes, 1999) It was reproduced in the accident report of a Learjet at RAF Northolt (AAIB, 1997) and said to provide evidence that no overruns have occurred where the runway exit speed has exceeded 80 knots However, it is unclear as to the source of the information as the chart does not appear in the original report that was cited (David, 1990) Consequently it is unknown whether it is a complete list, or the inclusion criteria that were used

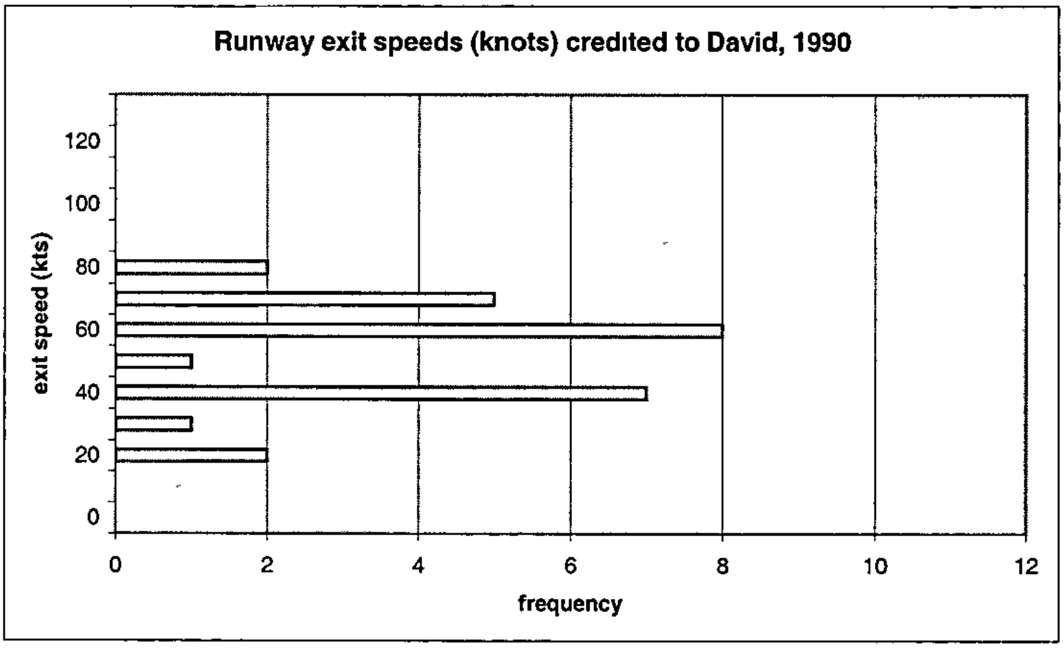

Figure 11. 1

It has been said in White et al (1993), a document that cited David, that this figure contained overruns to aircraft involved in commercial operations between 1975 to 1987 It only contains 26 occurrences If this is compared to Figure 11 2, which contains runway exit speed for all aircraft overruns in the US, Canada, and the UK 1990-98, it can be seen that aircraft have overrun the runway end at considerably higher speeds than suggested by figure 11 1 Figure 11 2 contains speed information for 53 overruns, a further 127 overruns occurred, but the exit speed was not given in the report

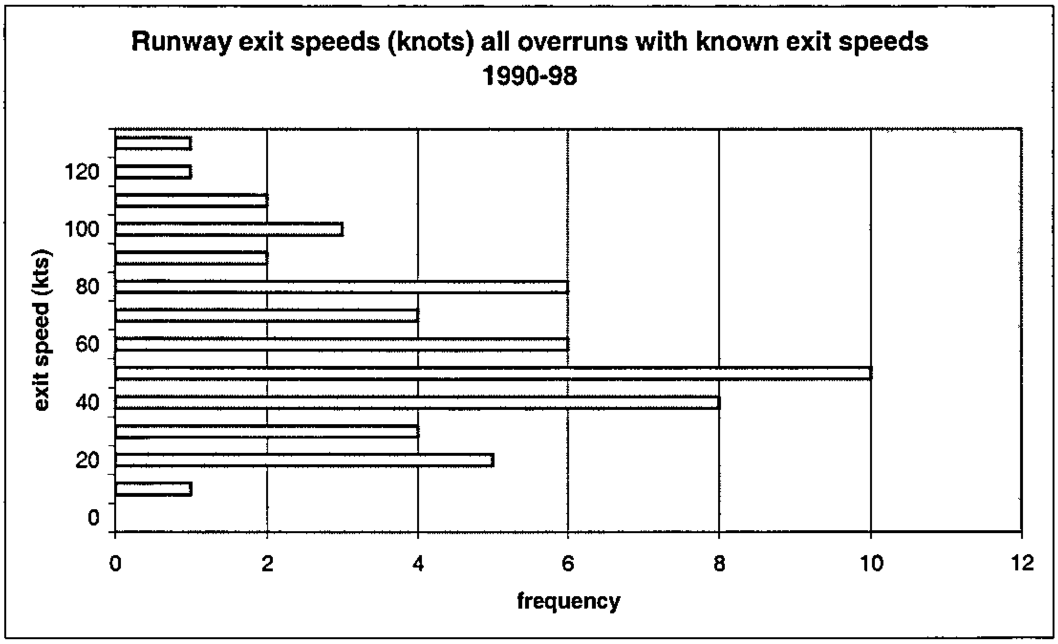

Figure 11. 2

This is obviously worrying as it seems as though work on the requirements of arrester beds and overrun risk assessments have assumed that aircraft have left the runway at speeds slower than is the case, and therefore the potential exists for the risk assessments to be underestimating the risk, and arrester beds to be insufficient

One outcome of the study is a realisation that the areas beyond the ends of runways often contain features that have the potential to damage an aircraft Annex 14 stipulates that where reasonably practicable, any objects that may damage an aircraft should be removed An interesting study of consequences would be an assessment of what would have been the result had the runway end safety areas and runway strips of aerodromes at which aircraft have overrun conformed to the requirements of Annex 14, or conversely, the results of the non-compliance

As the data contained within the database is all the information from overrun accident and incident reports, there does not seem to be much scope for expanding the study One possible avenue may be to compare the dynamics of accidents that have been used to generate other consequence models, with the aircraft dynamics in overruns If there were areas that were similar some of the models may be used to supplement the overrun consequence analysis

11 4 Further findings

One surprising discovery was that there is a wealth of information freely available from the NTSB on US accidents and incidents that has not been requested and is not studied by the UK CAA Contained within the library at Gatwick are US published accident reports, however, the majority of accidents and incidents in the US are not presented in published reports, but as a "factual report" which is comprised of all the information collected as part of the investigation The US air transportation system is similar to that of the UK in many ways, and many UK studies state that conclusions cannot be arrived at from such small datasets as that represented by UK operations, and yet still the US information is ignored

A further discovery that will not come as a surprise to anyone involved in aviation is the number of different descriptions used for the same items Aviation is trying to be as safe as possible and yet there still remain many areas in which confusion seems almost intended For example, when describing which pilot carried out certain actions, reports use the terms first pilot / second pilot, Captain / Co-pilot, First Officer / Second Officer, three different ways of describing the same thing Also, when talking about engines on a two engined aircraft they could be described as left engine / right engine, port engine / starboard engine, or engine number one / engine number two, again three different ways of describing exactly the same thing Similarly, in some overrun reports it is apparent that there is some confusion over the descriptions used for the runway The end of the paved surface, the end of the runway, and the end of the available landing or accelerate stop distance may be at three different points, and some reports have clearly used the wrong description

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Tables

Effect on aircraft and occupants	Normal	Nuisance	Operating limitations; emergency procedures	Significant reduction in safety margins, difficult for crew to cope with adverse conditions, passenger injuries	Large reduction in safety margins, crew extended because of workload or environmental conditions, serious or fatal injury to a small number of occupants	Multiple deaths, usually with loss of aircraft
Probability	Frequent		Reasonably probable	Remote	Extremely remote	Extremely improbable
	1 0 1	0 01	0 001 0 0001	0 00001	0 0000001	0 000000001
Classification of failure conditions	Minor			Major	Hazardous	Catastrophe

Table 3.1 redrawn from JAR-25

Code element one			*Code element two*	
Code number	The greater of TODA or ASDA	Code letter	Wing span	Outer main gear wheel span
1	Less than 800m	A	Up to but not including 15 m	Up to but not including 4 5 m
2	800 m up to but not including 1200 m	B	15 m up to but not including 24 m	4 5 m up to but not including 6 m
3	1200 m up to but not including 1800 m	C	24 m up to but not including 36 m	6 m up to but not including 9 m
4	1800 m and over	D	36 m up to but not including 52 m	9 m up to but not including 14 m
		E	52 m up to but not including 65 m	9 m up to but not including 14 m

Table 3.2 - from CAP 168

Aerodrome rescue and fire fighting category	Aeroplane overall length	Maximum fuselage width
Special	More detailed applicability	
1		
2		
3	12 m up to but not including 18 m	3 m
4	18 m up to but not including 24 m	4 m
5	24 m up to but not including 28 m	4 m

6	28 m up to but not including 39 m	5 m
7	39 m up to but not including 49 m	5 m
8	49 m up to but not including 61 m	7 m
9	61 m up to but not including 76 m	7 m
10	76 m up to but not including 90 m	8 m

Table 3.3 – from CAP 168

Weight kgs	Runway surface	Condition	*a* (m/s/s)	Initial speed (m/s)	Brakes	Classification
139076 0	concrete	dry	-2 53	49 6	1	Dry pavement
36671 00	asphalt	1/4" wet snow	-1 52	46 7	1	Icy pavement
43091 00	asphalt	dry	-0 20	27 9	0	Dry pavement
41730 00	concrete	dry	-1 33	35 7	1	Dry pavement
145694 0	asphalt/concrete	ice covered, compacted snow	-0 99	34 9	1	Icy pavement
43545 00	asphalt/concrete	wet	-1 62	46 7	1	Wet pavement
54885 00	asphalt	dry	-4 33	59 8	1	Dry pavement
155175 0	macadam	dry	-2 97	79 1	1	Dry pavement
42175 00	asphalt	wet	-3 46	53 7	1	Wet pavement
30391 00	asphalt	wet	-2 02	51 2	1	Wet pavement
47174 00	concrete	wet	-3 08	61.3	1	Wet pavement
251744 0	-	wet but no standing water	-4 19	69 7	1	Wet pavement
42638 00	asphalt	wet	-2 82	50 0	1	Wet pavement
253059 0	concrete	dry	-1 69	61 1	1	Dry pavement

Table 4.1

	Z1	Z2
Icy pavement	1	0
Wet pavement	0	1
Dry pavement	0	0

Table 4.2

R	R Square	Adjusted R square	Std Error of the estimate
0 814	0 662	0 512	0 8451

Table 4.3

ANOVA

	Sum of squares	df	Mean square	F	Sig
Regression	12 584	4	3 146	4 405	0 030
Residual	6 428	9	0 714		
Total	19 011	13			

Table 4.4

Coefficients

	Unstandardized coefficients		t
	B	Std Error	
Constant	1 216	1 047	1 161
Initial speed	-0 05058	0 022	-2 284
Brakes	-0 899	1 129	-0 796
Icy pavement	0 492	0 793	0 620
Wet pavement	-0 376	0 513	-0 734

Dependent variable *a*

Table 4.5

weight kgs	surface	*a*	velocity change (m/s)	brakes	classification	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8
139076	122 m overrun, then 5m after overrun	-1 7485	-21 07	1	dry pavement	0	0	0	0	0	0	1	0
36671	snow covered grassy area, chain link fence, came to rest straddling a road (122 m in total)	-3 0411	-27 24	1	mud	0	0	0	1	0	0	0	0
43091	1075 m of pavement	- 0181	-6 24	0	dry pavement	0	0	0	0	0	0	1	0
41730	30 m of mud a foot deep	-3 4512	-14 39	1	mud	0	0	0	1	0	0	0	0
145694	400m ice covered pavement	- 3069	-15 67	1	icy pavement	0	0	0	0	0	0	0	0
43545	138 m of mud / wet sod	-3 3330	-30 33	1	mud	0	0	0	1	0	0	0	0
54885	19 m grass	-1 3756	-7 23	1	dry grass	0	0	0	0	0	1	0	0
155176	197 m mostly pavement then dirt and an ILS building which was destroyed	-9 9556	-62 63	1	obstacles	1	0	0	0	0	0	0	0
30391	91m of unpaved, mud	-5 5913	-31.90	1	mud	0	0	0	1	0	0	0	0
174633	152 m runway overrun area then 49 m sloping to water	-3 7952	-39 06	1	mud	0	0	0	1	0	0	0	0
42638	76 m of mud, (caused ruts)	-2 3800	-19 02	1	mud	0	0	0	1	0	0	0	0
253059	87 8 m asphalt overrun	- 5923	-10 21	1	dry pavement	0	0	0	0	0	0	1	0
43091	84 m of dirt	-2 0815	-18 70	0	dry grass	0	0	0	0	0	1	0	0
253059	251 m wet soil	-3 1270	-39 62	1	mud	0	0	0	1	0	0	0	0
4583	96 m of grass then through a fence and struck a transit van	-7 6600	-38 35	1	obstacles	1	0	0	0	0	0	0	0
108862	40 m of grass / wet mud to a depth of 30-40 cm	-4 4888	-18 95	1	mud	0	0	0	1	0	0	0	0
36394	26 5 m of wet grass	-4 4033	-15 42	1	wet grass	0	0	0	0	1	0	0	0
5683	292 m of wet grass, down an embankment, onto a motorway and	-2 2069	-35 90	1	wet grass	0	0	0	0	1	0	0	0

	collided with cars (although the impact with the road was stated to not have been particularly violent)												
7257	65m through a fence, across a roadway, through a 3 ft high concrete block wall, into a parking lot and struck a pole which severed the wing	-26 397	-58 58	1	obstacles	1	0	0	0	0	0	0	0
37450	146 m of soft grassed peaty soil to a depth of 30 - 45 cm	-3 4784	-31 87	1	mud	0	0	0	1	0	0	0	0
43142	134 m of terrain which included striking an ils antenna, a concrete culvert, a fence and came to rest against a railway embankment	-5 0917	-36 94	1	obstacles	1	0	0	0	0	0	0	0
145694	137 m of snow covered terrain	-1 5428	-20 56	1	mud	0	0	0	1	0	0	0	0
7053	543 m wet sod, drainage ditch	- 8753	-30 84	1	wet grass	0	0	0	0	1	0	0	0
159927	162 m concrete , asphalt , soft ground	-2 7427	-29 81	1	wet pavement	0	0	0	0	0	0	0	1
108409	274 m wet grass	- 7714	-20 56	1	wet grass	0	0	0	0	1	0	0	0
113774	117 m, grass strip, fence, swamp	-2 6517	-24 91	1	wet grass	0	0	0	0	1	0	0	0
3651	76 m, fence , uneven terrain , dirt road , telephone pole , railway tracks	-3 2161	-22 11	1	mud	0	0	0	1	0	0	0	0
14293	~30m , over an embankment, collided with a steel wire fence, came to rest on a second embankment	- 9652	-7 61	1	dry grass	0	0	0	0	0	1	0	0
165561	61 m gravel and mud slope, into water	-4 6040	-23 70	1	mud	0	0	0	1	0	0	0	0
4491	239 m rocky, and mostly wooded downslope	-4 7003	-47 40	1	mud	0	0	0	1	0	0	0	0
268935	44 m paved then 78 m soft ground	-1 8316	-21 14	1	mud	0	0	0	1	0	0	0	0
11900	63 m grass / mud	-1 4615	-13 57	1	wet grass	0	0	0	0	1	0	0	0
48943	87 2 m paved, then wooden approach lighting pier	-1 7520	-17 48	1	wet pavement	0	0	0	0	0	0	0	1
5546	274 m hit a dirt berm, crossed a road, hit another berm, and came to rest nose down in a water filled ditch	-3 6071	-44 46	1	mud	0	0	0	1	0	0	0	0
178489	122 m paved blast pad then 248 m mud	-1 5084	-33 41	1	mud	0	0	0	1	0	0	0	0

66876	128 m soft rain soaked ground	-3 7153	-30 84	1	mud	0	0	0	1	0	0	0	0
6958	91 m Lake Michigan	-12 418	-47 54	1	water	0	1	0	0	0	0	0	0
6260	travelled through three small paddocks and into an open field It went through five fences or hedges and over three ditches	-1 0700	-23 13	1	wet grass	0	0	0	0	1	0	0	0
2948	mud	-6 6459	-46 26	1	mud	0	0	0	1	0	0	0	0
19180	overran a gravel turn round area, then level gravel and clay for 100 ft, then a drop off area containing a number of large rocks	-5 2812	-38 04	1	gravel	0	0	1	0	0	0	0	0
10069	wet grass	-1 4384	-14 39	1	wet grass	0	0	0	0	1	0	0	0
37500	wet grass	- 7992	-5 65	1	wet grass	0	0	0	0	1	0	0	0
26671	mud	-9 1600	-36 57	1	mud	0	0	0	1	0	0	0	0
14381	60 ft of grass then over a sea wall into Lake Pontchartrain (200 ft from shore)	-8 6646	-37 00	1	water	0	1	0	0	0	0	0	0
19787	firm ground, short dry grass, then collided with the ILS power supply building	-1 9022	-30 84	1	dry grass	0	0	0	0	0	1	0	0
62962	sea wall, tidal mud flat	-5 0169	-24 74	1	mud	0	0	0	1	0	0	0	0
11793	12 inch gravel	-3 6312	-13 88	0	gravel	0	0	1	0	0	0	0	0
11793	12 inch gravel	-4 2400-	-15 42	0	gravel	0	0	1	0	0	0	0	0
11793	12 inch gravel	5 7217	-26 21	0	gravel	0	0	1	0	0	0	0	0
11793	12 inch gravel	-4 7421	-20 05	0	gravel	0	0	1	0	0	0	0	0
11793	12 inch gravel	-5 0683	-24 67	0	gravel	0	0	1	0	0	0	0	0
11793	12 inch gravel	-5 1093	-28 78	0	gravel	0	0	1	0	0	0	0	0
11793	12 inch gravel	-5 4249	-33 92	0	gravel	0	0	1	0	0	0	0	0
11793	12 inch gravel	-3 6811	-14 91	1	gravel	0	0	1	0	0	0	0	0

11793	12 inch gravel	-4 2454	-17 48	1	gravel	0	0	1	0	0	0	0	0
11793	12 inch gravel	-4 9241	-26 73	1	gravel	0	0	1	0	0	0	0	0
11793	12 inch gravel	-5 7800	-35 47	1	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-6 2413	-18 50	0	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-6 9480	-23 64	0	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-6 8405	-33 92	0	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-4 3269	-11 82	0	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-6 3323	-36 49	0	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-6 6213	-28 27	0	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-6 4555	-18 50	1	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-6 9908	-25 70	1	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-6 3994	-31 35	1	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-6 3237	-32 38	1	gravel	0	0	1	0	0	0	0	0
11793	18 inch gravel	-7 0789	-39 58	1	gravel	0	0	1	0	0	0	0	0
12428	18 inch gravel	-2 4846	-15 42	0	gravel	0	0	1	0	0	0	0	0
12428	18 inch gravel	-3 9870	-25.19	0	gravel	0	0	1	0	0	0	0	0
17554	18 inch gravel	-3 4607	-23 64	0	gravel	0	0	1	0	0	0	0	0
17554	30 inch gravel	-4 1738	-22 10	0	gravel	0	0	1	0	0	0	0	0
17554	30 inch gravel	-3 9891	-29 30	0	gravel	0	0	1	0	0	0	0	0
17554	30 inch gravel	-3 8526	-34 44	0	gravel	0	0	1	0	0	0	0	0

Table 4.6[1]

[1] The results for gravel are taken from aircraft arrester bed trials using Lightning and Canberra aircraft, and which are described in Bade (1968)

R	R Square	Adjusted R square	Std Error of the estimate
0 783	0 613	0 551	2 367895

Table 4.7

ANOVA

	Sum of squares	df	Mean square	F	Sig
Regression	559 326	10	55 933	9 976	0 00
Residual	353.236	63	5 607		
Total	912 563	73			

Table 4.8

Coefficients

	Unstandardised coefficients		t
	B	Std error	
Constant	3 439	2 714	1 267
Initial speed	-0 09286	0 031	-2 962
Brakes	-0 382	0 846	-0 451
Obstacles	-10 772	2 678	-4 022
Water	-9 673	2 906	-3 328
Gravel	-6 104	2 484	-2.457
Mud	-4 167	2 434	-1 712
Wet grass	-2 906	2 544	-1 142
Dry grass	-3 239	2 724	-1 189
Dry pavement	-1 005	2 750	-0 365
Wet pavement	-3 109	2 927	-1 062

Dependent variable *a*

Table 4.9

R	R Square	Adjusted R square	Std. Error of the estimate
0 747	0 558	0 539	2 400550

Table 4.10

ANOVA

	Sum of squares	df	Mean square	F	Sig

Regression	509 178	3	169 726	29 453	0 00
Residual	403 385	70	5 763		
Total	912 563	73			

Table 4.11

Coefficients

	Unstandardized coefficients		t
	B	Std error	
Constant	-0 0185	0 858	-0 022
Initial speed	-0 06749	0 029	-2 311
Mud / gravel	-2 788	0 665	-4 192
Obstacles / water	-8 518	1 330	-6 407

Dependent variable : *a*

Table 4.12

Year	Air carrier	Air taxi & commuter
1980	10323342	7544615
1981	9698343	7900962
1982	9280794	7326702
1983	9830404	8581209
1984	11030718	9277840
1985	11384390	10297879
1986	12375640	9621333
1987	13137179	10814551
1988	12880128	11680204
1989	12657683	11723650
1990	13027974	12194262
1991	12683466	12257392
1992	12601717	12750270
1993	12751008	12984602
1994	13305172	13454504
1995	13794869	13452351
1996	13994919	13791205
1997	14241504	13732203
1998	14331056	13896065

Table 6. 1

	Total no of landings		
	1996	1997	1998
Fixed wing – Piston	26508734	28912156	27031380
Fixed wing - Turboprop	1804191	1952485	2600054
Fixed wing – Turbojet	1238862	1335881	1894445
Rotorcraft	4560419	5341983	6221975
Other aircraft	329064	288622	642516
Experimental	1541006	1617527	1669119
Total	35982276	39448654	40059488

Table 6. 2

	1996		1997		1998	
	% hours air taxi	% hours GA	% hours air taxi	% hours GA	% hours air taxi	% hours GA
Fixed wing - Piston	4 6	95 4	4 4	95 6	4 9	95 1
Rotorcraft	11 6	88 4	20 5	79 5	30 5	69 5

Table 6. 3

	Air carrier	Air taxi & commuter	landing overruns	landing overruns per million landings	takeoff overruns	takeoff overruns per million takeoffs
1980	10323342	4877628	1	0 131571	0	0
1981	9698343	5108008	2	0 270154	1	0 135077
1982	9280794	4736746	4	0 570714	2	0 285357
1983	9830404	5547790	3	0 390163	1	0 130054
1984	11030718	5998166	3	0 352343	2	0 234895
1985	11384390	6657625	2	0 221705	2	0 221705
1986	12375640	6220235	4	0 430203	0	0
1987	13137179	6991656	5	0 4968	3	0 29808
1988	12880128	7551305	2	0 195777	3	0 293665
1989	12657683	7579393	6	0 592971	1	0 098829

1990	13027974	7883646	2	0 191281	0	0
1991	12683466	7924459	3	0 29115	2	0 1941
1992	12601717	8243107	3	0 287841	2	0 191894
1993	12751008	8394604	3	0 283747	3	0 283747
1994	13305172	8698398	4	0 363577	3	0 272683
1995	13794869	8697006	2	0 177842	0	0
1996	13994919	8916076	4	0 349177	1	0 087294
1997	14241504	8877931	3	0 259522	0	0
1998	14331056	8983869	3	0 257346	2	0 171564

Table 6. 4

	Takeoffs / Landings 1980-98	Overruns 1980-98	Overruns per million takeoffs / landings
US Jet & Turboprop commercial passenger / freight takeoff	185608977	25	0 135
US Jet & Turboprop commercial passenger / freight landing	185608977	60	0 323

Table 6. 5

Month	Overruns	Movements	Overruns per million movements
January	4	3496010	1 144161
February	1	3485595	0 286895
March	3	4241672	0 707268
April	1	4541769	0 220179
May	2	5005250	0 39958
June	1	5117988	0 195389
July	1	5514720	0 181333
August	4	5474154	0 730707
September	2	4958742	0 403328
October	2	4580189	0 436663
November	5	3971277	1 259041
December	0	3421324	0

Table 6. 6

Year	Air transport movements	Non-air transport movements	Total
1980	1050331	1240116	2290447
1981	1020713	1204876	2225589
1982	1063342	1167376	2230718
1983	1113000	1124377	2237377
1984	1177949	1187044	2364993
1985	1201165	1158983	2360148
1986	1231001	1195020	2426021
1987	1311199	1291570	2602769
1988	1393752	1501096	2894848
1989	1478122	1699267	3177389
1990	1535449	1766928	3302377
1991	1460392	1499470	2959862
1992	1546433	1346094	2892527
1993	1584474	1551896	3136370
1994	1649295	1723325	3372620
1995	1715055	1866365	3581420
1996	1783993	1372519	3156512
1997	1861000	1436062	3297062
1998	1967814	1341217	3309031

Total	27144479	26673601	53818080

Table 6. 7

Aircraft Type	Number in U.K. fleet
Piston engined aircraft	7850
Turboprop aircraft	89
Jet aircraft	203
Helicopter piston	302
Helicopter turbine	536

Table 6. 8

Year	Air transport movements	Non-air transport jet and turboprop aircraft movements	Total
1980	1050331	88562	1138893
1981	1020713	86046	1106759
1982	1063342	83368	1146710
1983	1113000	80297	1193297
1984	1177949	84772	1262721
1985	1201165	82768	1283933
1986	1231001	85342	1316343
1987	1311199	92237	1403436
1988	1393752	107200	1500952
1989	1478122	121352	1599474
1990	1535449	126184	1661633
1991	1460392	107084	1567476
1992	1546433	96131	1642564
1993	1584474	110828	1695302
1994	1649295	123071	1772366
1995	1715055	133286	1848341
1996	1783993	98018	1882011
1997	1861000	102556	1963556
1998	1967814	95782	2063596

Total	27144479	1904884	29049363

Table 6. 9

	Passenger movements	Cargo movements	Total
1990	1361400	55800	1417200
1991	1268000	52800	1320800
1992	1352000	53400	1405400
1993	1329800	58200	1388000
1994	1376400	67200	1443600
1995	1474200	67600	1541800
1996	1553600	67200	1620800
1997	1667000	66800	1733800
1998	1754200	75600	1829800
Total	13136600	564600	13701200

Table 6. 10

	Total ATMs at UK airports	Foreign operators air transport movements at UK airports	UK operators ATMs at UK airports
1990	1535449	340000	1195449
1991	1460392	335000	1125392
1992	1546433	362000	1184433
1993	1584474	374000	1210474
1994	1649295	403000	1246295
1995	1715055	418000	1297055
1996	1783993	453000	1330993
1997	1861000	467000	1394000
1998	1870541	506000	1364541
Total	15006632	3658000	11348632

Table 6. 11

Aircraft	Weight	Required landing distance	Percentage increase in weight	Percentage increase in distance	Factor increase in distance per 1 % increase in weight
B-737-200	36000 kg	3625 ft			
	50000 kg	5550 ft	38 89 %	53 10 %	1 011012
B-747-400	330000 kg	8497 ft			
	390000 kg	11056 ft	18 18 %	30.12 %	1 014588

Table 6. 12

Damage	Fire after a takeoff	%	Fire after a landing	%
None	0	0	0	0
Minor	1	11	0	0
Substantial	1	11	2	25
Destroyed	7	78	6	75

Table 6. 13

Phase	People on board	Minor injuries	Serious injuries	Fatalities	% minor injuries	% serious injuries	% fatalities
Landing	5	5	0	0	100	0	0
Landing	2	2	0	0	100	0	0
Landing	8	0	1	7	0	12 5	87 5
Landing	3	0	1	2	0	33	67
Landing	2	0	0	2	0	0	100
Landing	2	0	0	2	0	0	100
Landing	133	0	0	0	0	0	0
Landing	8	0	0	0	0	0	0
Takeoff	unknown	unknown	unknown	unknown	unknown	unknown	unknown
Takeoff	3	3	0	0	100	0	0
Takeoff	3	3	0	0	100	0	0

Takeoff	2	1	1	0	50	50	0
Takeoff	3	0	3	0	0	100	0
Takeoff	5	0	0	4	0	0	80
Takeoff	3	0	0	1	0	0	33
Takeoff	292	0	0	0	0	0	0
Takeoff	127	0	0	0	0	0	0

Table 6. 14

Phase	No injuries	Minor injuries	Serious injuries	Fatalities
Landing	8	13	2	7
Takeoff	3	5	4	7

Table 6. 15

50 or less occupants

Phase	No injuries	Minor injuries	Serious injuries	Fatalities
Landing	521	84	9	0
Takeoff	87	19	10	2

Table 6. 16

51 or more occupants

Phase	No injuries	Minor injuries	Serious injuries	Fatalities
Landing	3981	69	8	4
Takeoff	1983	19	4	2

Table 6. 17

Phase	No injuries	Minor injuries	Serious injuries	Fatalities
Landing	4510	166	19	11
Takeoff	2073	43	18	11

Table 6. 18

	Percentage of total overruns per phase
Landing headwind	34 %
Landing no wind	16 %
Landing tailwind	50 %
Takeoff headwind	62 %
Takeoff no wind	21 %
Takeoff tailwind	18 %

Table 6. 19

Time of day	**Fatal accidents**	**Percent**
Day	143	50
Night	112	39
Twilight	5	2
Unknown	27	9
Total	287	100

Table 6. 20

	Accidents	Movements	Accidents per million movements
Precision approach	10	6249763	1 600
Non-precision approach	6	430321	13 943

Table 6. 21

	Overruns	Movements	Overruns per million movements
Precision approach	9	6249763	1 44
Non-precision approach	2	430321	4 65

Table 6. 22

Characteristic mentioned as cause or contributory factor	*Number of precision approach cases where this characteristic was mentioned (total of 50)*	*Number of other than precision approach cases where this characteristic was mentioned (total of 40)*	*Notes*
Poor visibility	8	4	Higher percentage in precision approaches, significant
Downhill runway	2	2	Non significant difference
Tailwind	8	10	No difference in percentage
Wet weather	15	10	Higher percentage in precision approaches, significant
Snow, slush, or ice covered runway	5	9	No difference in percentage
Minimum descent altitude exceeded without visual contact with the runway	0	3	Non significant difference
Excessive airspeed on approach or touchdown	13	10	Non significant difference
Long touchdown	18	17	Non significant difference
Aircraft equipment or function problem before touchdown	0	8	Higher percentage in other than precision approaches, significant
Aircraft equipment or function problem after touchdown	8	8	Non-significant difference in percentage Typically braking failures, one case landing gear collapse
Poor choice of runway	2	12	Higher percentage in other than precision approaches, significant Poor choices because of runway conditions,

			tailwind, or not enough landing distance
Poor approach planning	7	9	No difference in percentage
Procedures not followed	7	12	Non significant difference
Failure to perform go-around	8	10	Non significant difference
Improper use of aircraft equipment	8	16	Higher percentage in other than precision approaches, significant

Causes of landing overruns

Table 6. 23

Factor mentioned as cause or contributory factor	*Frequency of citation of factor in precision approach overruns relative to not precision approach overruns*
Poor visibility	Higher
Wet weather	Higher
Aircraft equipment or function problem before touchdown	Lower
Poor choice of runway	Lower
Improper use of aircraft equipment	Lower

Table 6. 24

Flight type	**Landing overruns: Takeoff overruns**
Freight	3 33 1
General aviation	4 55 1
Passenger	2 50 1

Table 6. 25

Characteristic mentioned as cause or contributory factor	*Number of cases where this characteristic was*	*Notes*

	mentioned (total of 33)	
The reason for the abort being performed	30	In 3 further cases no abort was performed i e the pilot tried to continue the takeoff and was unsuccessful
Takeoff aborted at a position from which it was impossible to stop the aircraft	12	Includes those cases that mention the abort being performed at a speed above V1
Decision to continue when the aircraft could not takeoff	3	
Lack of performance data	2	
Misidentification of problem	2	
Aircraft not operated correctly	12	
Fatigue	2	
Operating restrictions	1	FAA flight duty time regulations that allowed the crew to be fatigued
Failure of the braking system	2	
Wrong runway selected	3	

Causes of takeoff overruns

Table 6. 26

Appendix A Normalisation factors for the effects of temperature, altitude and runway slope

A 1 Factors accommodated by the flight manual

A 1 1 Introduction

In an effort to determine how landing and takeoff required performance is affected by meteorological conditions, a study of landing and accelerate / stop distances, as quoted in the aircraft flight manuals has been undertaken It was decided to use the distance charts for 6 different aircraft as listed below

DC-8-71

HS 748

DC-9-30

B-737-200

L-1011

B-747-400

The source of the charts was the Flight Department of the Civil Aviation Authority Safety Regulation Group The charts were taken from the certificated flight manuals for the respective aircraft These aircraft were chosen because they represent a broad range of aircraft, in terms of size, number of engines, engine type, and manufacturer, and with the exception of the B-747, overruns have occurred in the study area to all of these aircraft types (the B747 has overrun elsewhere, outside the overrun database geographical area)

In each case, the landing distance at the destination airport and the accelerate / stop distance was determined for two different weights and three different values of the parameter under study, percentage changes could then be evaluated

The weights chosen were different for each aircraft and were chosen because they were the maximum and minimum weights that were represented on the charts (some of the scales on the charts do not cover values outside this weight range, but that does not necessarily mean that these were limit weights for the aircraft)

In calculating the distance, the parameter being investigated is increased and decreased whilst other parameters are kept constant For example, in determining by how much the required distance changes with a change in wind, the distance is calculated for different values of wind, with constant values for other parameters

Parameter	*Value*
Temp relative to ISA	Zero
Outside air temperature	0 degrees C
Airfield elevation	Sea level
Pressure altitude	Sea level
Wind	Zero
Runway slope	Zero
Runway condition	Dry

The distances are calculated for a full flap landing (except for the 737, which have been calculated using flap position 30), and for a typical takeoff flap setting in the takeoff case

In certain cases the value is not given, this is for one of two reasons Not all of the parameters are used for all aircraft in the calculation of required distance, for example the HS 748 2a uses airfield elevation rather than pressure altitude The second reason is that the range shown on the flight manual chart for that particular parameter may not include that value, for example the L-1011 landing field length chart does not include distances for pressure altitudes of below sea level.

Values for V1/Vr have been chosen which ensure that the calculated accelerate stop distance equals the calculated takeoff distance under conditions of dry runway, sea level, 0 deg C, no wind, and zero runway slope, except in the case of the HS 748 where V1 equals Vr Also, the distances are calculated assuming no obstacle clearance issues

For each percentage change in required distance a multiplication factor has been calculated This factor is the multiplication factor per quantity of the parameter under study that will result in the percentage change over the range that was observed For example, the L-1011 landing distance at a weight of 120000 kg is increased by 9 2 % from sea level to an elevation of 5000 ft The multiplication factor per 1000 ft will result in an increase of 9 2% over 5000 ft, and would be used in the following way

$$R \times F^{C}$$

Where·

R	=	Required distance
F	=	Multiplication factor
C	=	Magnitude of the characteristic under study

Continuing with the example of the L-1011, the following figures would be used

$$1620 \text{ m} \times 1\ 017868444^{5} = 1770\text{m}$$

The factor is raised to the power of five because the factor is per thousand feet, and it is the change over five thousand feet that is to be calculated

These multiplication factors are then compared with those calculated for a larger number of aircraft in a study conducted by Biggs et al (1994) in order to investigate takeoff performance and risks of operation on wet and contaminated runways in Canada, and with ICAO airport planning correction factors The conclusion is that the ICAO factors will be used in order to provide a uniform and simple method of normalisation The actual effects of the normalisation factors for runway slope, elevation, and temperature will not affect the majority of the overruns in the database by a large amount Approximately 5 percent of the overruns occurred at aerodromes of over 2000 ft in elevation, and approximately 1 percent of the overruns occurred in temperatures of over 30 degrees Celsius

Pressure altitude							
Aircraft	**Certification rules**	**Phase**	**weight**	**-1000 ft**	**sea level**	**2500 ft**	**5000 ft**
L-1011	BCAR	Landing	120000 kg	-	1620 m	1695 m	1770 m
			215000 kg	-	2335 m	2455 m	2585 m
DC-8-71	FAR 25	Landing	180000 lbs	-	5100 ft	5475 ft	5900 ft
			340000 lbs	-	8800 ft	9425 ft	10250 ft
HS 748 2a	FAR 25	Landing	30000 lbs	-	-	-	-
			43000 lbs	-	-	-	-
DC-9-30	FAR 25	Landing	70000 lbs	-	3500 ft	3750 ft	3950 ft
			110000 lbs	-	5100 ft	5425 ft	5800 ft
B-737-200	BCAR	Landing	36000 kgs	3550 ft	3625 ft	4000 ft	4150 ft
			50000 kgs	5100 ft	5550 ft	6075 ft	6500 ft
B-747-400	FAR 25	Landing	390000 kg	3220 m	3370 m	3550 m	3920 m
			330000 kg	2520 m	2590 m	2770 m	2970 m
L-1011	BCAR	Takeoff	190000 kgs	1940 m	1940 m	2220 m	2620 m
		Flaps 10	240000 kgs	3170 m	3170 m	3730 m	4410 m
				Takeoff field length			
DC-8-71	FAR 25	Takeoff	220000 lbs	4175 ft	4300 ft	4825 ft	5475 ft
		Flaps 15	320000 lbs	8500 ft	8700 ft	8925 ft	11475 ft
HS 748 2a	FAR 25 or JAR 25 (a)	Takeoff	30000 lbs	-	-	-	-
		Flaps 7 5	40000 lbs	-	-	-	-
with water methanol and assuming V1 = VR							
				Takeoff field length			
DC-9-30	FAR 25	Takeoff	75000 lbs	-	3575 ft	3950 ft	4600 ft
		Flaps 5	95000 lbs	-	5375 ft	6075 ft	7250 ft
B-737-200	BCAR	Takeoff	40000 kg	4100 ft	4250 ft	4675 ft	5575 ft
		Flaps 5	50000 kg	6425 ft	6625 ft	7425 ft	9000 ft
B-747-400	FAR 25	Takeoff	390000 kg	3320 m	3480 m	3980 m	4610 m
		Flaps 10	330000 kg	2320 m	2430 m	2770 m	3200 m

Table A.1

Percentage change in required distance due to pressure altitude				
		Perc. change 0>5000 ft	**Factor Per 1000 ft (0>5000 ft)**	**Average factor per 1000 ft**
Aircraft	**Phase**			
L-1011	Landing	9 2	1 017868444	
		10 7	1 020551047	1 0192
DC-8-71	Landing	15 6	1 029571156	
		16 5	1 030975248	1 0303
DC-9-30	Landing	12 9	1 024485486	
		13 7	1 026057179	1 0253
B-737	Landing	14 4	1 027420004	
		17 1	1 032105458	1 0298
B-747	Landing	16 3	1 030697525	
		14 7	1 027759115	1 0292
L-1011	Acc / stop	35 1	1 061939835	
		39 1	1 068257291	1 0651
DC-8-71	Takeoff field length	27 3	1 049501669	
		31 9	1 056931127	1 0532
DC-9-30	Takeoff field length	28 7	1 051710857	
		34 9	1 061675774	1 0567
B-737-200	Acc / stop	31 2	1 055774549	
		35 8	1 063191083	1 0595
B-747-400	Acc / stop	32 5	1 057850599	
		31 7	1 056595462	1 0572

Table A.2

Wind						
Aircraft	**Certification rules**	**Phase**	**weight**	**-10 kts**	**zero**	**+10 kts**
L-1011	BCAR	Landing	120000 kg	1895 m	1625 m	1525 m
			215000 kg	2655 m	2335 m	2235 m
DC-8-71	FAR 25	Landing	180000 lbs	6075 ft	5100 ft	4850 ft
			340000 lbs	10000 ft	8800 ft	8450 ft
HS 748 2a	FAR 25	Landing	30000 lbs	3025 ft	2680 ft	2500 ft
			43000 lbs	4100 ft	3390 ft	3175 ft
DC-9-30	FAR 25	Landing	70000 lbs	4200 ft	3500 ft	3300 ft
			110000 lbs	5900 ft	5100 ft	4860 ft
B-737-200	BCAR	Landing	36000 kgs	4325 ft	3625 ft	3425 ft
			50000 kgs	6750 ft	5550 ft	5200 ft
B-747-400	FAR 25	Landing	390000 kg	3950 m	3370 m	3190 m
			330000 kg	2980 m	2590 m	2460 m
L-1011	BCAR	Takeoff	190000 kg	2500 m	1940 m	1840 m
		Flaps 10	240000 kg	4500 m	3730 m	3530 m
				Takeoff field length		
DC-8-71	FAR 25	Takeoff	220000 lbs	4950 ft	4300 ft	4100 ft
		Flaps 15	320000 lbs	9900 ft	8700 ft	8350 ft
HS 748 2a	FAR 25	Takeoff	30000 lbs	3050 ft	2290 ft	2000 ft
with water methanol and assuming V1 = VR		Flaps 7 5	40000 lbs	5050 ft	3960 ft	3550 ft
				Takeoff field length		
DC-9-30	FAR 25	Takeoff	75000 lbs	4225 ft	3575 ft	3400 ft
		Flaps 5	95000 lbs	6300 ft	5375 ft	5175 ft
B-737-200	BCAR	Takeoff	40000 kg	5350 ft	4250 ft	3950 ft
		Flaps 5	50000 kg	8100 ft	6625 ft	6250 ft
B-747-400	FAR 25	Takeoff	390000 kg	4205 m	3480 m	3360 m
		Flaps 10	330000 kg	2960 m	2430 m	2340 m

Table A.3

The distances calculated based on different wind strength use the factored wind values contained within the charts, i e 50 % of the headwind value and 150% of the tailwind value

Percentage change in required dıstance due to wind					
		Perc. change 0 > -10kts	Average factor change per kt of tailwind	Perc. change 0 > +10 kts	Average factor change per kt of headwınd
Aırcraft	Phase				
L-1011	Landıng	16 6		-6 15	
		13 7	1 0142	-4 28	0 9947
DC-8-71	Landıng	19 1		-4 90	
		13 6	1 0153	-3 98	0 9955
HS 748 2a	Landıng	12 9		-6 72	
		20 9	1 0157	-6 34	0 9933
DC-9-30	Landıng	20 0		-5 71	
		15 7	1 0165	-4 71	0 9947
B-737	Landıng	19 3		-5 52	
		21 6	1 0188	-6 31	0 9939
B-747-400	Landıng	17 2		-5 34	
		15 1	1 0151	-5 02	0 9947
L-1011	Acc / stop	28 9		-5 2	
		20 6	1 0223	-5 4	0 9946
DC-8-71	Takeoff field length	15 1		-4 65	
		13 8	1 0136	-4 02	0 9956
HS 748 2a	Acc / stop	33 2		-12 66	
		27 5	1 0268	-10 35	0 9878
DC-9-30	Takeoff field length	18 2		-4 90	
		17 2	1 0164	-3 72	0 9956
B-737-200	Acc / stop	25 9		-7 06	
		22 3	1 0218	-5 66	0 9934
B-747-400	Acc / stop	20 8		-3 45	
		21 8	1 0195	-3 7	0 9964

Table A.4

Runway slope						
Aircraft	**Certification rules**	**Phase**	**weight**	**-2 %**	**zero**	**+2 %**
L-1011	BCAR	Landing	120000 kg	1685 m	1625 m	1575 m
			215000 kg	2430 m	2335 m	2300 m
DC-8-71	FAR 25	Landing	180000 lbs	-	5100 ft	-
			340000 lbs	-	8800 ft	-
HS 748 2a	FAR 25	Landing	30000 lbs	2790 ft	2675 ft	2575 ft
			43000 lbs	3575 ft	3390 ft	3250 ft
DC-9-30	FAR 25	Landing	70000 lbs	-	3500 ft	-
			110000 lbs	-	5100 ft	-
B-737-200	BCAR	Landing	36000 kgs	3725 ft	3625 ft	3525 ft
			50000 kgs	5700 ft	5550 ft	5350 ft
B-747-400	FAR 25	Landing	390000 kg	-	3370 m	-
			330000 kg	-	2590 m	-
L-1011	BCAR	Takeoff	190000 kg	1940 m	1940 m	1980 m
		Flaps 10	240000 kg	3710 m	3730 m	3930 m
				Takeoff field length		
DC-8-71	FAR 25	Takeoff	220000 lbs	4100 ft	4300 ft	4500 ft
		Flaps 15	320000 lbs	8000 ft	8700 ft	9975 ft
HS 748 2a	FAR 25	Takeoff	30000 lbs	2400 ft	2500 ft	2650 ft
with water methanol and assuming V1 = VR		Flaps 7 5	40000 lbs	4375 ft	4550 ft	4900 ft
				Takeoff field length		
				-2 %	**zero**	**+1.7 %**
DC-9-30	FAR 25	Takeoff	75000 lbs	3425 ft	3600 ft	4650 ft
		Flaps 5	95000 lbs	5100 ft	5425 ft	6650 ft
				-2 %	**zero**	**+2 %**
B-737-200	BCAR	Takeoff	40000 kg	4225 ft	4250 ft	4600 ft
		Flaps 5	50000 kg	6525 ft	6625 ft	6775 ft
B-747-400	FAR 25	Takeoff	390000 kg	3430 m	3480 m	4190 m
		Flaps 10	330000 kg	2400 m	2430 m	2780 m

Table A.5

Percentage change in required distance due to runway slope				
		Perc. change -2% > +2%	Factor change per 1 % of slope	Average factor Change per 1% of slope
Aircraft	Phase			
L-1011	Landing	-6 53	0 983264055	
		-5 35	0 986348505	0 9848
DC-8-71	Landing	-	-	
		-	-	-
HS 748 2a	Landing	-7.71	0 98015161	
		-9 09	0 97645409	0 9783
DC-9-30	Landing	-	-	
		-	-	-
B-737	Landing	-5 37	0 986298133	
		-6 14	0 984282427	0 9853
B-747	Landing	-	-	
		-	-	-
L-1011	Acc / stop	2 06	1 005115256	
		5 93	1 014506094	1 0098
DC-8-71	Takeoff field length	9 76	1 023545526	
		24 69	1 056709786	1 0401
HS 748 2a	Acc / stop	10 42	1 025082119	
		12 00	1 028737345	1 0269
DC-9-30	Takeoff field length	35 77	1 086150063	
		30 39	1 074358059	1 0803
B-737-200	Acc / stop	8 88	1 021486849	
		3 83	1 009443918	1 0155
B-747-400	Acc / stop	22 16	1 051308016	
		15 83	1 037429011	1 0444

Table A.6

Airfield elevation							
Aircraft	**Certification rules**	**Phase**	**weight**	**-1000 ft**	**zero**	**2500 ft**	**5000 ft**
L-1011	BCAR	Landing	120000 kg	-	-	-	-
			215000 kg	-	-	-	-
DC-8-71	FAR 25	Landing	180000 lbs	-	-	-	-
			340000 lbs	-	-	-	-
HS 748	FAR 25	Landing	30000 lbs	-	2680 ft	2890 ft	3020 ft
			43000 lbs	-	3380 ft	3650 ft	3925 ft
DC-9-30	FAR 25	Landing	70000 lbs	-	-	-	-
			110000 lbs	-	-	-	-
B-737-200	BCAR	Landing	36000 kgs	-	-	-	-
			50000 kgs	-	-	-	-
B-747	FAR 25	Landing	390000 kg	-	-	-	-
			330000 kg	-	-	-	-
L-1011	BCAR	Takeoff	190000 kg	-	-	-	-
		Flaps 10	240000 kg	-	-	-	-
				Takeoff field length			
DC-8-71	FAR 25	Takeoff	220000 lbs	-	-	-	-
		Flaps 15	320000 lbs	-	-	-	-
HS 748 2a	FAR 25	Takeoff	30000 lbs	-	2290 ft	2600 ft	2975 ft
with water methanol and assuming V1 = VR		Flaps 7 5	40000 lbs	-	3960 ft	4550 ft	5250 ft
				Takeoff field length			
DC-9-30	FAR 25	Takeoff	75000 lbs	-	-	-	-
		Flaps 5	95000 lbs	-	-	-	-
B-737-200	BCAR	Takeoff	40000 kg	-	-	-	-
		Flaps 5	50000 kg	-	-	-	-
B-747-400	FAR 25	Takeoff	390000 kg	-	-	-	-
		Flaps 10	330000 kg	-	-	-	-

Table A.7

Most of the landing or accelerate / stop distance charts use pressure altitude rather than airfield elevation

Percentage change in required distance due to airfield elevation					
					Average
				Factor	factor
				per 1000 ft	change
Aircraft	**Phase**	**0>2500 ft**	**0>5000 ft**	**(0>5000 ft)**	**per 1000 ft**
L-1011	Landing	-	-	-	
DC-8-71	Landing	-	-	-	
HS 748 2a	Landing	7 84	12 69	1 024175611	
		7 99	16 12	1 030349565	1 0273
DC-9-30	Landing	-	-	-	
B-737	Landing	-	-	-	
B-747	Landing	-	-	-	
L-1011	Acc / stop	-	-	-	
DC-8-71	Takeoff field length	-	-	-	
HS 748 2a	Acc / stop	13 54	29 91	1 053732312	
		14 90	32 58	1 058017433	1 0559
DC-9-30	Takeoff field length	-	-	-	
B-737-200	Acc / stop	-	-	-	
B-747-400	Acc / stop	-	-	-	

Table A.8

Temperature						
				Temp rel to ISA		
Aircraft	**Certification rules**	**Phase**	**weight**	**-20 deg C**	**zero**	**+20 deg C**
L-1011	BCAR	Landing	120000 kg	1560 m	1625 m	1690 m
	RWHS		215000 kg	2225 m	2335 m	2440 m
Temperature effects for this aircraft are advisory only						
DC-8-71	FAR 25	Landing	-	-	-	-
				Temp rel to ISA		
				-20 deg C	**zero**	**+20 deg C**
HS 748 2a	Far 25	Landing	-	-	2680 ft	-
Unfactored landing distance from 50 ft is increased by 0 4% for every deg C by which the temp exceeds I S A						
Regulations do not require difference from I S A to be taken in to account when calculating landing distance						
DC-9-30	FAR 25	Landing	-	-	-	-
				Temp rel to ISA		
				-20 deg C	**zero**	**+20 deg C**
B-737-200	BCAR	Landing	36000 kgs	3371 ft	3625 ft	3879 ft
			50000 kgs	5162 ft	5550 ft	5939 ft
Field length (non standard) = Field length (standard) x (0 0035 x □T+1) □T is deviation from standard day in deg C Temperature effects for this aircraft are advisory only						
B-747-400	FAR 25	Landing	-	-	-	-
				Outside Air Temperature		
				-20 deg C	**zero**	**+20 deg C**
L-1011	BCAR	Takeoff	190000 kg	1810 m	1940 m	2050 m
		Flaps 10	240000 kg	2960 m	3170 m	3380 m
				Outside Air Temperature		
		Takeoff field length		**-20 deg C**	**zero**	**+20 deg C**
DC-8-71	FAR 25	Takeoff	220000 lbs	4075 ft	4300 ft	4575 ft
		Flaps 15	320000 lbs	8075 ft	8700 ft	9350 ft
				Temp rel to ISA		
				-10 deg C	**zero**	**+10 deg C**
HS 748 2a	FAR 25	Takeoff	30000 lbs	2325 ft	2425 ft	2535 ft
with water methanol assuming V1 = VR		Flaps 7 5	40000 lbs	4025 ft	4200 ft	4425 ft

				Outside Air Temperature		
			Takeoff field length	**-20 deg C**	**zero**	**+20 deg C**
DC-9-30	FAR 25	Takeoff	75000 lbs	3375 ft	3575 ft	3825 ft
		Flaps 5	95000 lbs	5050 ft	5375 ft	5800 ft
B-737-200	BCAR	Takeoff	40000 kg	3950 ft	4250 ft	4525 ft
		Flaps 5	50000 kg	6150 ft	6625 ft	7075 ft
B-747-400	FAR 25	Takeoff	390000 kg	3210 m	3480 m	3700 m
		Flaps 10	330000 kg	2280 m	2430 m	2580 m

Table A.9

Percentage change in required distance due to temperature			
		Outside air temperature	
		Perc. change	
		- 20 deg C >	**Average factor**
Aircraft	**Phase**	**+ 20 deg C**	**change per**
L-1011	Landing	8 33	**degree C**
Advisory only for the L-1011		9 66	1 0022
		Temperature relative to ISA	
DC-8-71	Landing	-	
HS 748 2a	Landing	-	
		-	1 004
DC-9-30	Landing	-	
B-737	Landing	-	
Advisory only for the B-737-200		-	1 0035
B-747	Landing	-	
		Outside air temperature	
L-1011	Acc / stop	13 26	
		14 19	1 0032
DC-8-71	Takeoff field length	12 27	
		15 79	1 0033
		Temperature relative to ISA	
		- 10 deg C >	
		+ 10 deg C	
HS 748 2a	Acc / stop	9 03	
		9 94	1 0045
		Outside air temperature	
		- 20 deg C >	
		+ 20 deg C	
DC-9-30	Takeoff field length	13 33	
		14 85	1 0033
B-737-200	Acc / stop	14 56	
		15 04	1 0035
B-747-400	Acc / stop	15 26	
		13 16	1 0033

Table A.10

Runway surface condition							
Aircraft	**Certification rules**	**Phase**	**Weight**	**Dry**	**Wet**	**Very wet/ icy (0.05 coef)**	
L-1011	BCAR	Landing	120000 kg	1625 m	1625m	2420m	
			215000 kg	2335 m	2335m	3920m	
DC-8-71	FAR 25	Landing	180000 lbs	5100 ft	5865 ft	-	
			340000 lbs	8800 ft	10120 ft	-	
						Flooded (2mm over sig prop)	**Icy**
HS 748 2a	FAR 25	Landing	30000 lbs	2680 ft	2680 ft	3284 ft (add 30%)	4556 ft (add 70%)
			43000 lbs	3380 ft	3380 ft	4394 ft (add 30%)	5746 ft (add 70%)
Surface condition effects are advisory only							
DC-9-30	FAR 25	Landing	70000 lbs	3500 ft	4025 ft	-	
			130000 lbs	5100 ft	5865 ft	-	
						Icy	
B-737-200	BCAR	Landing	36000 kgs	3625 ft	3625 ft	5050 ft	
			50000 kgs	5550 ft	5550 ft	7050 ft	
B-747-400	FAR 25	Landing	390000 kgs	3370 m	3876 m	-	
			330000 kgs	2590 m	2979 m	-	

Table A.11

Runway surface condition						
Aircraft	**Certification rules**	**Phase**	**Weight**	**Dry**	**Wet**	**Very wet/ icy (0.05 coef)**
L-1011	BCAR	Takeoff flaps 15	190000 kg	1940 m	1940 m	2840 m
				3170	3170	4200 m
				Takeoff field length		
DC-8-71	FAR 25	Takeoff flaps 15	220000 lbs	4300 ft	4300 ft	-
			320000 lbs	8700 ft	8700 ft	-
HS 748 2a	FAR 25	Takeoff flaps 7 5	30000 lbs	2290 ft	2290 ft	-
With water methanol & assuming V1=Vr			40000 lbs	3960 ft	3960 ft	-
				Takeoff field length		
DC-9-30	FAR 25	Takeoff flaps 5	75000 lbs	3575 ft	3575 ft	-
			95000 lbs	5375 ft	5375 ft	-
						Low braking coefficient conditions
B-737-200	BCAR	Takeoff flaps 5	40000 kg	4250 ft	4250 ft	6150 ft
			50000 kg	6625 ft	6625 ft	8800 ft

Table A.12

The required accelerate stop distances of the L-1011 and the B-737 do not increase on a wet runway Instead, V1 is reduced so that the speed at which an abort is undertaken is slower An extra risk is excepted under these conditions because, if there is an engine failure after wet V1 and before dry V1 the aircraft will not be able to stop on the runway, or be able to fly without compromising the obstacle clearance requirements

The increase in required landing distance for the B-737 seems quite low This is most probably because the demonstrated landing distance does not include the use of the thrust reversers, whereas the determination of landing distance in icy conditions does include their use

The charts containing the effects of very wet / icy conditions for the takeoff of the DC-8-71, the HS 748 2a, and the DC-9-30 are not available to this study at this time, and the operations manual used for the B-747 does not contain information for takeoffs on non-dry runways It is not a requirement for flight manuals to give certified distances for contaminated runways, however some give guidance information, which is often of a different format in the manuals of different aircraft This is the reason for the non-inclusion of the effects of snow or slush in table A 12

Percentage change ın required distance due to surface condıtions									
		Perc. change Dry to Wet		**Perc. change Dry to Very wet / icy**		**Perc. change Dry to Flooded**		**Perc. change Dry to Icy**	
Aırcraft	**Phase**								
			Ave. factor		**Ave. factor**		**Ave. factor**		**Ave. factor**
L-1011	Landıng	0		46 39					
		0	0	32 49	1 3944				
DC-8-71	Landıng	15 00							
		15 00	1 15						
HS 748 2a	Landıng	0		-		30		70	
		0	0	-	-	30	1 3	70	1 7
DC-9-30	Landıng	15							
		15	1 15						
B-737	Landıng	0		-		-		39 31	
		0	0	-	-	-	-	27 03	1 3317
L-1011	Acc / stop	0		45 45					
		0	0	31 63	1 3854				
DC-8-71	Takeoff field length	0							
		0	0						
HS 748 2a	Acc / stop	0							
		0	0						
DC-9-30	Takeoff field length	0							
		0	0						
				Low braking coefficient conditions					
B-737-200	Acc / stop	0		44 71					
		0	0	32 83	1 3877				

Table A.13

A.1 3 Inaccuracies

The percentages shown for the change that occurs in required landing or accelerate / stop distance for a set change in input parameter, will not be constant for all values of weight and input parameter In most cases the relationship will not be linear The relationship becomes complicated as the parameter effect can vary with aircraft weight The percentage change is therefore an estimation of the effect of the parameter on the required distance Also, it is assumed that the parameter effects are independent

A 2 Aircraft Takeoff Performance and Risks for Wet and Contaminated Runways in Canada

Aircraft Takeoff Performance and Risks for Wet and Contaminated Runways in Canada is a report on a study conducted by Sypher Mueller International Incorporated (Biggs et al , 1994) The purpose of the study was to develop recommendations to improve operational safety for Canadian aircraft taking off from wet runways, or runways contaminated with snow, slush, or ice Part of the study involved developing a computer model for calculating the required accelerate / stop distance and takeoff distance under various conditions for a given aircraft type and airport

The development of the model utilises an analysis of various flight manuals, which is similar to the flight manual analysis described above Values for various parameters have been chosen which vary the required distance from a value under a set of standard conditions The various parameters are assumed to act independently, and each parameter value is an average as in the flight manual analysis above

Some of the factors used in this study have not been taken from flight manuals but estimated from other aircraft values For the purposes of this comparison these cases have been omitted Some of the values in the Sypher study may have been taken from a simulator, however it is not clear from the report which methods were used for each aircraft

A 3 Factor comparisons

Three different sources of the effects of various factors on the required distances are now available These are the flight manual charts utilised above, factors suggested by ICAO (ICAO, 1994), and those contained within the Sypher Mueller report These are compared in the following tables

Elevation factor per thousand feet			
Aircraft	Sypher	ICAO	Flight Manuals
Accelerate / stop			
A320	1 044	1 07	-
DC-10-3	1 064	1 07	-
DC-8-61	1 404	1 07	-
DC-9-32	1 0105	1 07	1 0567[a]
F-28-1000	1 019	1 07	-
BA-146-200	-	1 07	-
B747-400	1 050	1 07	1 0572
B747-100	1 069	1 07	-
B767-200	1 051	1 07	-
B757-200	1 051	1 07	-
B737-200 adv	1 018	1 07	-
B727-100	1 0235	1 07	-
L-1011	-	1 07	1 0651
DC-8-71	-	1 07	1 0532[a]
HS 748	-	1 07	1 0559
B737-200	-	1 07	1 0595
Landing			
A320	-	1 07	-
DC-10-3	-	1 07	-
DC-8-61	-	1 07	-
DC-9-32	-	1 07	1 0253
F-28-1000	-	1 07	-
BA-146-200	-	1 07	-
B747-400	-	1 07	1 0292
B747-100	-	1 07	-
B767-200	-	1 07	-
B757-200	-	1 07	-
B737-200 adv	-	1 07	-
B727-100	-	1 07	-
L-1011	-	1 07	1 0192
DC-8-71	-	1 07	1 0303
HS 748	-	1 07	1 0273

[a] Takeoff field length

B737-200	-	1 07	1 0298

Table A.14

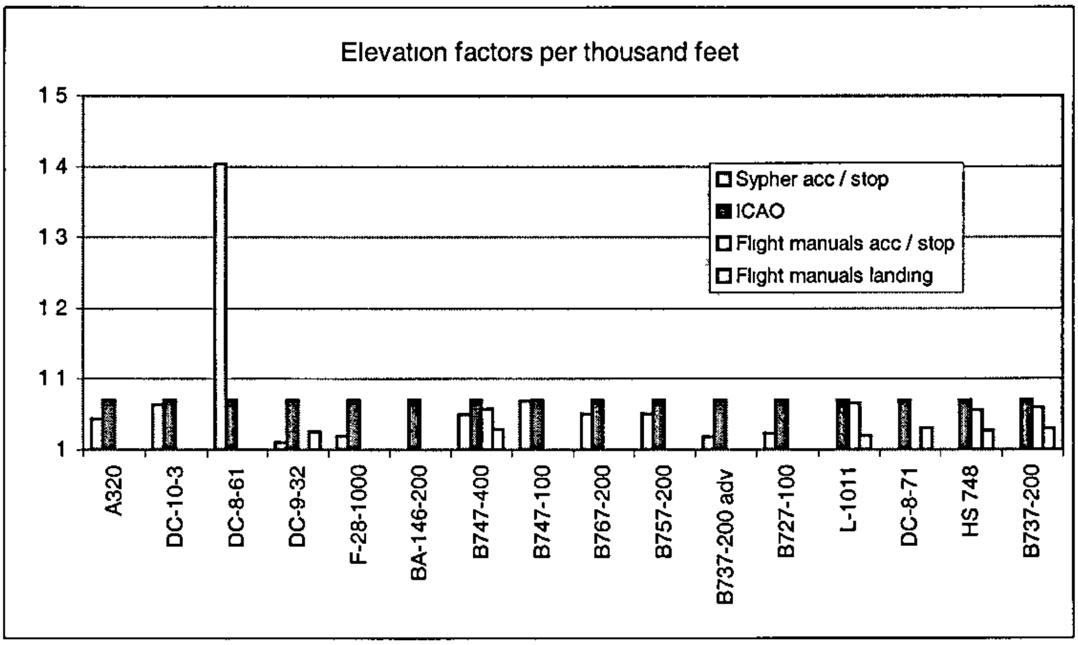

Figure A.1

The elevation factors for the accelerate stop distances taken from the flight manuals are all relatively similar and not vastly different from the ICAO figure of 1 07 The factors quoted by Sypher Mueller have a greater variability The landing factors, where calculated, are relatively consistent and appear to be approximately half to one third of the suggested ICAO factors

Tailwind factor per kt			
Aircraft	Sypher	ICAO	Flight Manuals
Accelerate / stop			
A320	1 018	-	-
DC-10-3	1 002	-	-
DC-8-61	-	-	-
DC-9-32	1 0157	-	1 0164[b]
F-28-1000	1 0167	-	-
BA-146-200	1 0194	-	-
B747-400	-	-	1 0195[b]
B747-100	1 014	-	-
B767-200	1 017	-	-
B757-200	1 017	-	-
B737-200 adv	1 01	-	-
B727-100	1 0121	-	-
L-1011	-	-	1 0223
DC-8-71	-	-	1 0136
HS 748	-	-	1 0268
B737-200	-	-	1 0218
Landing			
A320	-	-	-
DC-10-3	-	-	-
DC-8-61	-	-	-
DC-9-32	-	-	1 0165
F-28-1000	-	-	-
BA-146-200	-	-	-
B747-400	-	-	1 0151
B747-100	-	-	-
B767-200	-	-	-
B757-200	-	-	-
B737-200 adv	-	-	-
B727-100	-	-	-
L-1011	-	-	1 0142
DC-8-71	-	-	1 0153

[b] Takeoff field length

HS 748	-	-	1 0157
B737-200	-	-	1 0188

Table A.15

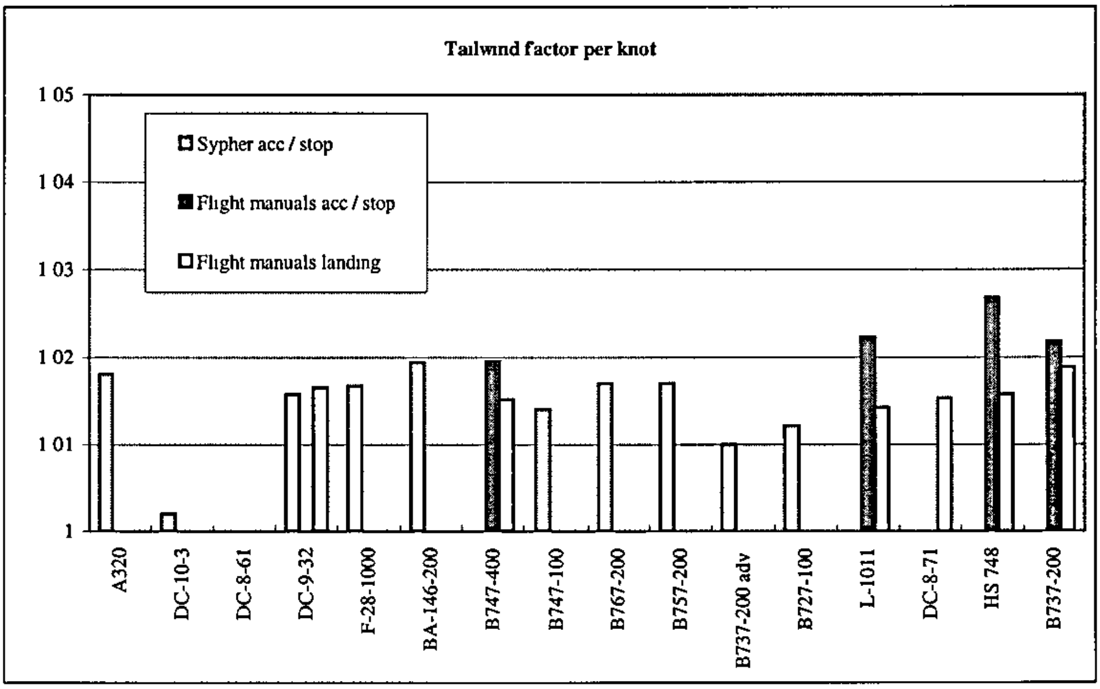

Figure A.2

Most of the factors for the effects of tailwinds are of similar values, with the factors taken from the flight manuals being slightly higher The factor values for effects on landing are slightly lower for those cases where factors have been calculated for both takeoff and landing, although these values are no lower than the values for takeoff calculated by Sypher Mueller

Headwind factor per kt			
Aircraft	Sypher	ICAO	Flight Manuals
Accelerate / stop			
A320	0 9934	-	-
DC-10-3	0 983	-	-
DC-8-61	0 9962	-	-
DC-9-32	0 9959	-	0 9956[c]
F-28-1000	0 995	-	-
BA-146-200	0 9930	-	-
B747-400	0 9958	-	0 9964
B747-100	0 9952	-	-
B767-200	0 9927	-	-
B757-200	0 993	-	-
B737-200 adv	0 9940	-	-
B727-100	0 9953	-	-
L-1011	-	-	0 9946
DC-8-71	-	-	0 9956[c]
HS 748	-	-	0 9878
B737-200	-	-	0 9934
Landing[a]			
A320	-	-	-
DC-10-3	-	-	-
DC-8-61	-	-	-
DC-9-32	-	-	0 9947
F-28-1000	-	-	-
BA-146-200	-	-	-
B747-400	-	-	0 9947
B747-100	-	-	-
B767-200	-	-	-
B757-200	-	-	-
B737-200 adv	-	-	-
B727-100	-	-	-
L-1011	-	-	0 9947

[c] Takeoff field length

DC-8-71	-	-	0 9955
HS 748	-	-	0 9933
B737-200	-	-	0 9939

Table A.16

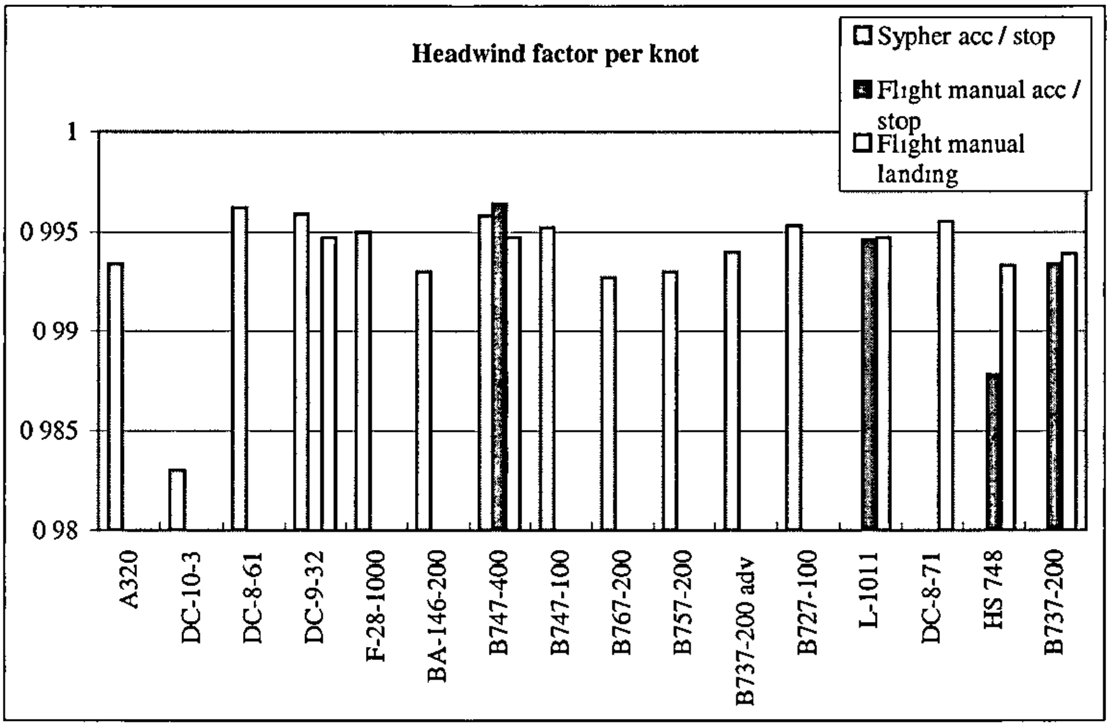

Figure A.3

In figure A 3, because headwind has a negative effect on the required distance, the shorter the column, the more the effect of the headwind As with the effect of the tailwind, most of the values are similar, but with a couple of exceptions such as the DC-10 and the HS748 in the accelerate stop case Also in the three jet aircraft cases where the factor has been calculated for takeoff and landing, the effects are similar for both cases

Runway slope factor per degree			
Aircraft	Sypher	ICAO[d]	Flight Manuals
Accelerate / stop			
A320	-	1 1	-
DC-10-3	1 078	1 1	-
DC-8-61	1 0585	1 1	-
DC-9-32	1 066	1 1	1 0803[e]
F-28-1000	1 064	1 1	-
BA-146-200	1 021	1 1	-
B747-400	1 0423	1 1	1 0444
B747-100	1 001	1 1	-
B767-200	1 027	1 1	-
B757-200	1 060	1 1	-
B737-200 adv	1 063	1 1	-
B727-100	1 0188	1 1	-
L-1011	-	1 1	1 0098
DC-8-71	-	1 1	1 0401[e]
HS 748	-	1 1	1 0269
B737-200	-	1 1	1 0155
Landing			
A320	-	-	-
DC-10-3	-	-	-
DC-8-61	-	-	-
DC-9-32	-	-	-
F-28-1000	-	-	-
BA-146-200	-	-	-
B747-400	-	-	-
B747-100	-	-	-
B767-200	-	-	-
B757-200	-	-	-
B737-200 adv	-	-	-
B727-100	-	-	-

[d] It is stated in the ICAO Aerodrome Design Manual that the runway slope factors should be applied when the basic runway length determined by takeoff requirements is 900m or over

[e] Takeoff field length

L-1011	-	-	0 9848
DC-8-71	-	-	-
HS 748	-	-	0 9783
B737-200	-	-	0 9853

Table A.17

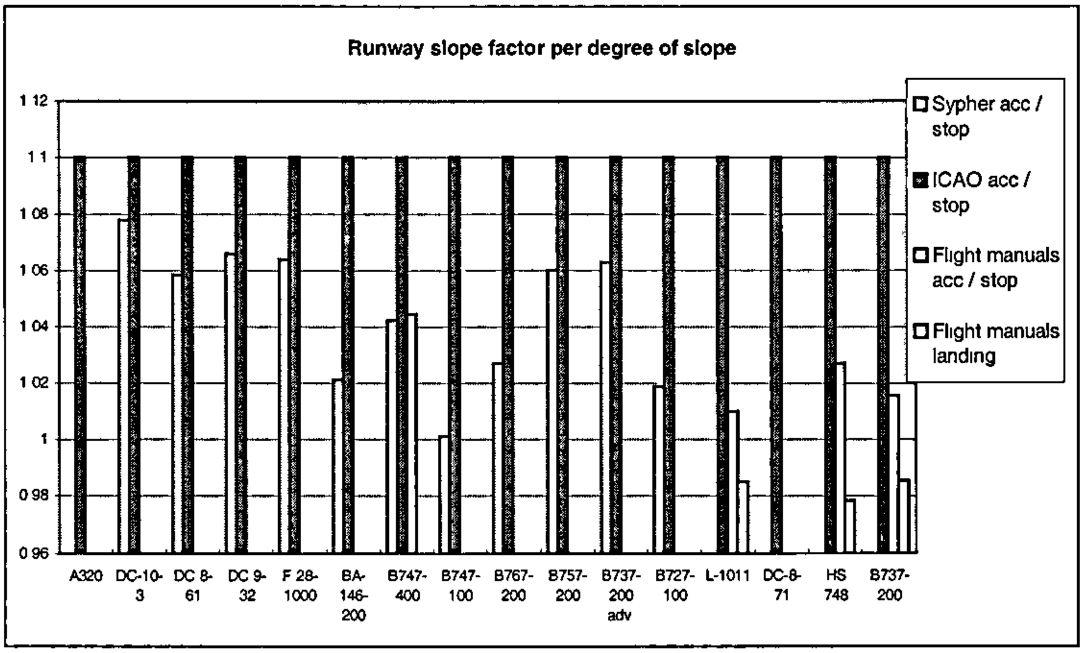

Figure A.4

Figure A 4 shows the factor changes per degree of slope The factors vary somewhat, but in all cases the accelerate stop distances increase with an upslope and decrease with a downslope In all three landing cases this is reversed, with an increase in distance occurring on a downslope The landing cases do not seem to be as variable as the takeoff cases The factors calculated by Sypher Mueller have a greater variability than those of the flight manual study

Temperature factor per degree Celsius			
Aircraft	Sypher	ICAO	Flight Manuals
Accelerate / stop			
A320	1 0050	1 01	-
DC-10-3	1 0017	1 01	-
DC-8-61	1 0038	1 01	-
DC-9-32	1 0002	1 01	1 0033[g]
F-28-1000	1 0021	1 01	-
BA-146-200	-	1 01	-
B747-400	1 0048	1 01	1 0033
B747-100	1 0034	1 01	-
B767-200	1 039	1 01	-
B757-200	1 0019	1 01	-
B737-200 adv	1 0038	1 01	-
B727-100	1 0022	1 01	-
L-1011	-	1 01	1 0032
DC-8-71	-	1 01	1 0033[g]
HS 748	-	1 01	1 0045
B737-200	-	1 01	1 0035
Landing			
A320	-	1 01	-
DC-10-3	-	1 01	-
DC-8-61	-	1 01	-
DC-9-32	-	1 01	-
F-28-1000	-	1 01	-
BA-146-200	-	1 01	-
B747-400	-	1 01	-
B747-100	-	1 01	-
B767-200	-	1 01	-
B757-200	-	1 01	-
B737-200 adv	-	1 01	-
B727-100	-	1 01	-
L-1011	-	1 01	1 0022[h]

[g] Takeoff field length
[h] Advisory only

DC-8-71	-	1 01	-
HS 748	-	1 01	1 004
B737-200	-	1 01	1 0035[h]

Table A.18

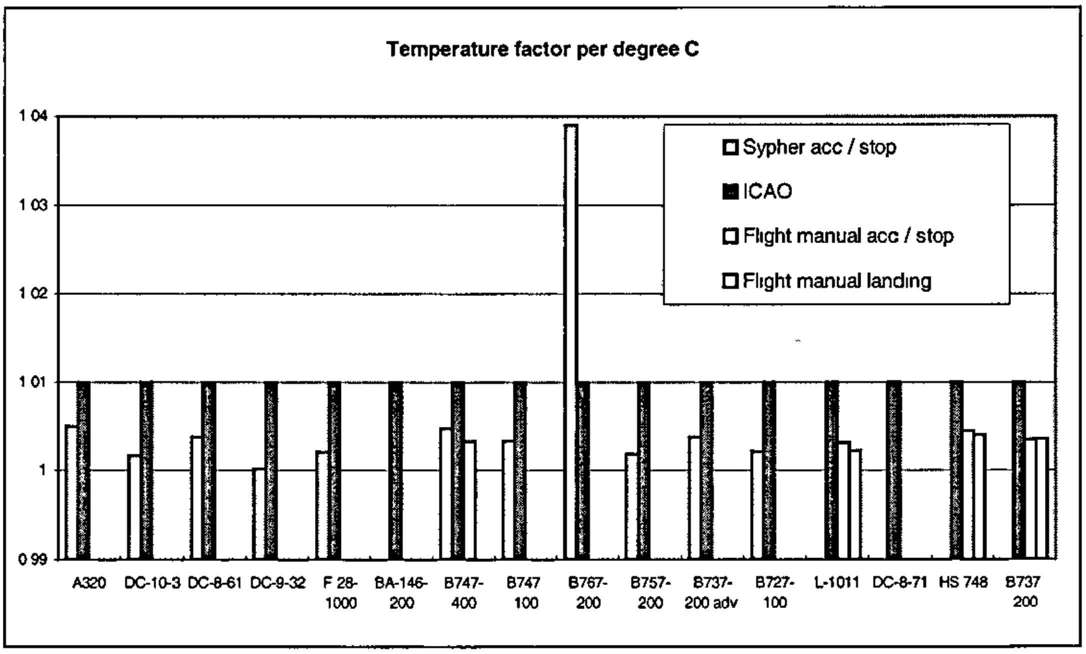

Figure A.5

All of the factors calculated for the effects of temperature are similar, except for the factor calculated by Sypher Mueller for the B-767-200 The factors calculated from the flight manuals are similar to the other factors calculated by Sypher, and the factors for takeoff and landing are also similar All of the factors except that for the B-767 are less than those suggested by ICAO

Runway surface condition factors							
Aircraft	Sypher		ICAO	Flight Manuals			
	Wet	Slush[i]		Wet	v wet/icy	Flooded	Icy
Accelerate / stop							
A320	1 15	1 67	-	-	-	-	-
DC-10-3	1 15	1 9	-	-	-	-	-
DC-8-61	1 15	1 65	-	-	-	-	-
DC-9-32	1 15	1 65	-	1[j]	-	-	-
F-28-1000	1 11	1 64	-	-	-	-	-
BA-146-200	1 16	1 9	-	-	-	-	-
B747-400	1 18	1 51	-	-	-	-	-
B747-100	1 18	1 51	-	-	-	-	-
B767-200	1 15	1 9	-	-	-	-	-
B757-200	-	-	-	-	-	-	-
B737-200 adv	1 15	1 9	-	-	-	-	-
B727-100	1 15	1 9	-	-	-	-	-
L-1011	-	-	-	1	1 3854	-	-
DC-8-71	-	-	-	1[j]	-	-	-
HS 748	-	-	-	1	-	-	-
B737-200	-	-	-	1	1 3877[k]	-	-
Landing							
A320	-	-	-	-	-	-	-
DC-10-3	-	-	-	-	-	-	-
DC-8-61	-	-	-	-	-	-	-
DC-9-32	-	-	-	1 15	-	-	-
F-28-1000	-	-	-	-	-	-	-
BA-146-200	-	-	-	-	-	-	-
B747-400	-	-	-	-	-	-	-
B747-100	-	-	-	-	-	-	-
B767-200	-	-	-	-	-	-	-
B757-200	-	-	-	-	-	-	-
B737-200 adv	-	-	-	-	-	-	-

[i] 6mm The Sypher study also includes values for compact snow but all but the values for the B747 and A320 have been estimated

[j] Takeoff field length

[k] Low braking coefficient conditions

B727-100	-	-	-	-	-	-	-
L-1011	-	-	-	1	1 3944	-	-
DC-8-71	-	-	-	1 15	-	-	-
HS 748	-	-	-	1	-	1 3	1 7
B737-200	-	-	-	-	-	-	1 3317

Table A.19

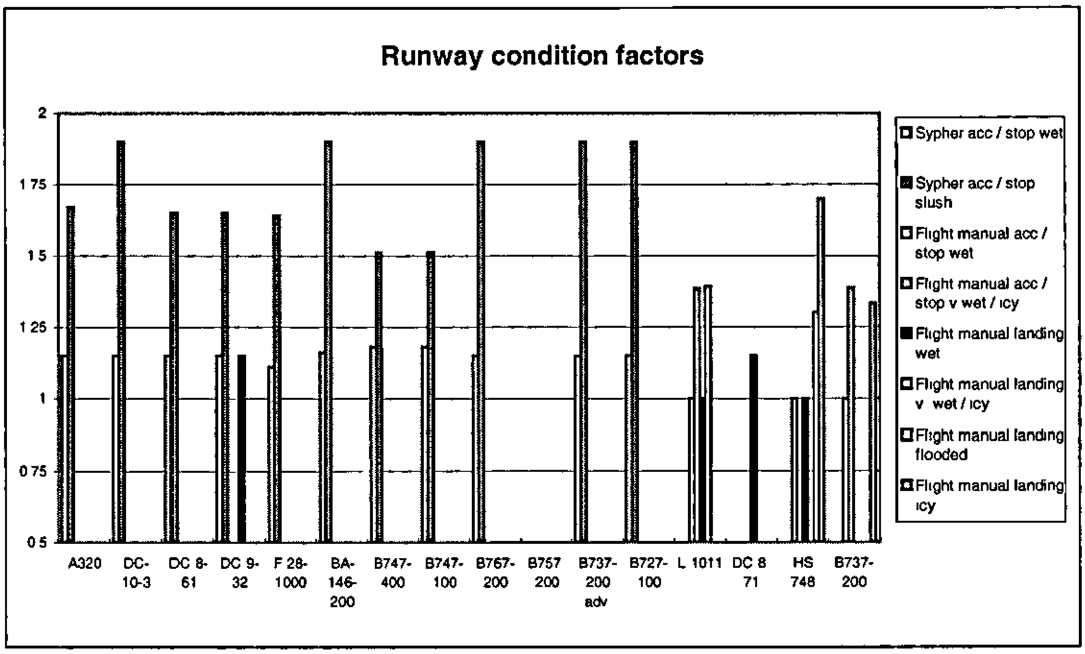

Figure A.6

The above chart shows the factors that have been calculated for various runway conditions It is apparent that the factors are not consistent among aircraft To a large extent this will be due to the differing certification rules that are applied to aircraft operated from different parts of the world For example, to operate on a wet runway, aircraft certificated to FAR 25 have to add 15 percent to the demonstrated dry runway landing distance The L-1011, however, in accordance with the BCAR reference landing distance requires the same landing distance on a wet or dry runway Unfortunately, the Sypher Mueller report does not state the rules under which the aircraft in the study were certificated

It is not usually required for the manufacturer to demonstrate distances when operating on contaminated runways so information for these conditions is only given as advice, and varies greatly between aircraft

For example, it is advised that the landing distance of the B-737-200 is increased by 30 percent on an icy runway, while that of the HS 748 is increased by 70 percent

It is not clear whether the differences between the factors given by Sypher Mueller for wet and slush covered runways result from differences between the way the aircraft reacts to these conditions, or from differences in calculation methods For example, the factor increases were estimated for the B747 from simulator results and from supplementary material to the aircraft flight manual, for the A320 from the flight manual computer program, for the BAe 146 from the appendix to the flight manual, and for the F-28 from a carrier's operating procedures For the other types the factor was estimated from carriers operating procedures, or calculated using the take off weight or V1 corrections stipulated in operating procedures Where approximately the same values were found for 6mm of slush for a number of aircraft types using this method, a common average value was used

A 4 Application

The difficulty now arises in how this information can be applied to the overruns in the database With such a range of values, is it reasonable to apply an average value to all of the cases, or would it be better to split the factors into one value for small aircraft, one for large, one for jets, one for turboprops etc? This does not seem appropriate, as the values do not appear to conform to this kind of pattern If the factors more closely match the groups of certification requirements, it would not seem appropriate to use these factors at all, as they would not be representative of the effects of the runway condition on the performance of the aircraft, as presumably the actual effects would be the same regardless of which set of rules the certification followed As regards runway conditions a more realistic way of applying factors for different conditions may be to use excepted friction values for different surfaces, or values taken from data recorders of those aircraft that have experienced overruns However, this route would also involve having to make estimates of deceleration due to air resistance and from reverse thrust

As regards the factors for the other characteristics, it may be reasonable to take average values, as they do not seem to vary quite as much as those for runway conditions and probably do not suffer as much from the vagaries of different certification rules All of the factors taken from the flight manuals and the majority of those stated in the Sypher study are less than those advised by ICAO

In order to provide a uniform and simple method of normalisation, the ICAO factors will be utilised to normalise for altitude, runway slope, and temperature The choice of factor from the three sources of factor may not actually affect the results of the normalisation by a great amount This is because although it is important to examine the effects of elevation, slope and temperature, it is terrain beyond the runway end that affects most of the overruns and has the greatest affects upon wreckage location

The proportions of overruns that have occurred at extreme values of elevation, and temperature are small Approximately 5 percent of the overruns have occurred at aerodromes of over 2000 ft in elevation, and approximately 1 percent of the overruns have occurred in temperatures of over 30 degrees Celsius.

The methodology for terrain condition normalisation is as described in chapter 4

Appendix B Statistical tests

Table B contains information on the significance tests that were conducted on the data in Chapter 6 and 7 A significance level of 0 05 was chosen This level was chosen because this is an accepted convention for work in the field of aviation safety (see Flight Safety Foundation, 1998), and in many other areas of scientific research (see Field, 2000) The choice of this level of significance will ensure that the maximum numbers of occasions where the null hypothesis is rejected, when in fact it is true, is less than one in twenty, and a significant result is one in which there can be a satisfactorily high degree of confidence that the result is not due to chance

Paragraph	Characteristic	Test
6 2 8 1	UK landing overrun rates of November and December	Fisher's exact
6 2 8 1	UK takeoff overrun rates of August and September	Fisher's exact
6 2 8 2	UK air transport / non-air transport overrun rates	Fisher's exact
6 2 8 3	UK passenger and cargo overrun rates	Fisher's exact
6 2 8 3	Global passenger / cargo overrun rates	Chi-square
6 2 8 4	UK operators / foreign operators	Fisher's exact
6 2 9	Australian GA, Charter / Scheduled	Fisher's exact
6 2 10	Canadian / Australian rates	Chi-square
6 3 1	Means of weights as percentage of maximum weight	Independent samples t-test
6 3 1	Standard deviations of weights as percentage of maximum weight	Levine's
6 5 1	Damage by phase	Mann Whitney U
6 5 2	Damage by flight type	Kruskal Wallace
6 5 5	Runway exit speed versus damage	Mann Whitney U
6 5 6	Damage and numbers of obstacles	Kruskal Wallace & Mann Whitney U
6 5 7	Aircraft weight and number of obstacles	Kruskal Wallace
6 5 8 1	Fire by phase	Fisher's exact
6 5 8 2	Weight by flight phase	Mann Whitney U
6 5 8 3	Runway exit speed by phase	Mann Whitney U
6 5 8 5	Obstacles struck by phase	Mann Whitney U
6 5 8 6	Incidence of fire by obstacles struck	Mann Whitney U
6 5 8 7	Separation of phase and obstacles struck	Mann Whitney U

6 5 8 9	Injuries incurred in fires by phase	Mann Whitney U
6 6 1	Wind	Mann Whitney U
6 6 2	Light conditions	Chi-square
6 6 3	Conditions of visibility	Mann Whitney U
6 6 4	Type of prevailing weather	Chi-square
6 6 5	Runway condition	Mann Whitney U
6 7 4	Touchdown point by flight type	Kruskal Wallace
6 7 5 1	Touchdown points in precision approach overruns versus other than precision approach overruns	t-test and Levine's test
6 7 5 2	Approach type overrun rate	Fisher's exact
6 7 5 3 2	Approach type versus distance remaining	t-test
6 7 5 3 3	Type of approach and flight type	Chi-square
6 7 5 3 3	Type of approach and captains experience	t-test
6 7 5 3 4	Type of approach and problems	Chi-square
6 7 5 3 5	Type of approach and wind	t-test
6 7 5 3 5	Weather conditions	Chi-square
6 7 5 3 5	Runway condition	Chi-square
6 7 5 3 7	Quality of approach	Chi-square
6 7 5 3 8	Landing overrun causes and circumstantial factors	Chi-square
6 7 5 4	Overrun and non-overrun touchdown points	t-test and Levine's test
6 8 8	Visibility	t-test
6 8 10	Captain's flight experience	t-test
7 5	Excess distance	t-test
7 6	Takeoff weight	t-test

Table B

Appendix C Database fields

" - " in any box indicates that the information could not be determined

Source

Location from which the information about the accident was obtained

Fields include

Accident report

This is the official accident report published by the agency responsible for the accident investigation

Accident bulletin (UK & Canada)

Also an official accident report published by the agency responsible for the accident investigation, but is usually a much smaller document than the accident report and tends to contain the accounts of accidents / incidents in which there were few injuries or fatalities, or in which the aircraft has suffered minor damage

Accident summary (US)

This is the same as an accident bulletin but in the US it is referred to as an accident / incident summary

Occurrence reports (UK)

These are the reports filed by pilots, air traffic controllers, to the CAA as part of the occurrence-reporting scheme

NTSB Factual report (US)

For many aircraft accidents in the United States a full accident report is not published However, in these cases a *factual report* is available from the National Transportation Safety Board These factual reports contain all the information that was gathered as part of the accident investigation, and often contain more information than the published reports

Category of operation (US)

Aircraft that operate in the United States have to operate according to *Title 14 Code of Federal Regulations* (FAA, 2001) These regulations are divided into parts, which apply to different types of flight The division is mainly on number of seats and type of operation i e commercial / non-commercial Part 121 generally applies to large aircraft and Part 135 applies to smaller aircraft There are other rules for different types of flights, for example, foreign carriers operating in the US have to operate their aircraft according to the regulations set out in Part 129, and maintenance and test flights are carried out under Part 91

Type of flight

Describes the nature of the flight and contains the following options

Freight A flight operated solely for the transport of cargo

Passenger A flight operated solely for the transport of passengers

General aviation A flight not open for public transport

Phase of operation

Describes the phase of flight of the aircraft in which the overrun occurred Overruns can only occur in the takeoff, or landing phase

Report number

The reference number of the report from which the data was collected The format of the number varies with type of report

Date

Date on which the overrun occurred

Country

Country in which the overrun occurred

Airport

Airport at which the overrun occurred

Aircraft

Model of aircraft involved in the overrun

Variant

Model variant of the aircraft involved in the overrun

Engine type

Type of engine fitted to the aircraft The two types are

Turbofan

Turboprop

Registration

Registration mark of the aircraft

Operator

Company or individual responsible for the operation of the aircraft when it was involved in the overrun

Aircraft weight lbs

Aircraft weight at the time of the overrun in lbs

Aircraft weight kgs

Aircraft weight at the time of the overrun in kgs

Weights have been rounded to the nearest pound or kilogram

Cert MGW lbs

Certificated maximum gross weight of the aircraft in lbs, usually only given in U S factual reports

MRW

Maximum ramp weight of the aircraft in pounds

MTOW

The maximum takeoff weight of the aircraft in pounds

MLW

The maximum landing weight of the aircraft in pounds

MRW, MTOW, & MLW have been taken from the accident reports directly where this information is given where not, they have been taken from *Jane's All the World's Aircraft*

Max allowed weight for that runway and conditions

Maximum legal weight for the operation under the prevailing conditions In some cases this information was given in the accident report This was usually given less frequently than the weight relative to the maximum takeoff or landing weight In cases where this information was not reported, it was calculated using a flight manual for the particular aircraft type In some cases the flight manual for the specific certification authority was not available but the UK manual for that aircraft type was available In those cases (6 of 180) the UK weights were used It was the opinion of Graham Skillen, Head of Flight Test at the UK CAA, that the weights calculated by the UK flight manuals would not be appreciably different from those of the applicable manual

Weight as a percentage of max weight (landing or takeoff)

Aircraft weight at the time of the overrun as a percentage of the maximum landing weight if a landing overrun, or takeoff weight if a takeoff overrun

Weight as a percentage of max allowed weight for that runway & conditions

Aircraft weight at the time of the overrun as a percentage of the maximum legal weight for the operation under the prevailing conditions

Aircraft COG %MAC

The position of the centre of gravity of the aircraft at the time of the accident This is usually expressed as a percentage of the mean aerodynamic chord (MAC) of the wing, 0% being at the leading edge of the MAC, 100% being at the trailing edge of the MAC However, many accident / incident reports only state whether the position of the centre of gravity is within the prescribed limits

Forward limit

The maximum legal forward limit of the position of the centre of gravity Expressed in inches or as a percentage of the MAC

Rearward limit

The maximum legal rearward limit of the position of the centre of gravity Expressed in inches or as a percentage of the MAC

Aircraft damage in detail

A brief description of the damage incurred by the aircraft

General damage description

None No damage

Minor Any damage not severe enough to be classified as substantial

Substantial Damage or structural failure that adversely affects the structural strength, performance, or flight characteristics of the airplane and would normally require major repair or replacement of the affected component Substantial damage is not considered to be .

- Engine failure or damage limited to an engine if only one engine fails or is damaged
- Bent aerodynamic fairings
- Dents in the skin
- Damage to landing gear (unless sheared)
- Damage to wheels
- Damage to tires
- Damage to flaps

Destroyed Where the aircraft has been classified in the report as destroyed

Aircraft fire

Whether a fire occurred as a result of the crash

Damage to property

A brief description of the damage that has occurred to property as a result of the overrun

Fatalities

Number of fatalities that occurred to the occupants of the aircraft as a result of the overrun

Serious

Number of serious injuries that occurred as a result of the overrun

Total on board

Total number of passengers and crew that were on board the accident / incident flight

Injuries to others

Injuries caused by the aircraft to people who were not onboard the aircraft

The above four fields do not include injuries sustained in the evacuation and rescue operation

Weather

The weather information may not be the exact weather at the time of the overrun This is because the weather is measured at intervals and in the time between measurement and the overrun the weather may have changed slightly

Wind

Deg M

The closest approximation of the wind direction in degrees from magnetic north at the time the aircraft crossed the landing threshold or started the takeoff roll

Wind spd kt

The closest approximation of the wind speed in knots at the time the aircraft crossed the landing threshold or started the takeoff roll

Direction

Indicates whether the wind is a headwind or a tailwind

Headwind component

The closest approximation to the headwind component of the wind velocity encountered by the aircraft, in knots, at the time the aircraft crossed the landing threshold or started the takeoff roll

Crosswind component

The closest approximation to the crosswind component of the wind velocity encountered by the aircraft, in knots, at the time the aircraft crossed the landing threshold or started the takeoff roll

From

This indicates whether the wind was from the left or the right from the view of the pilot

Visibility

The closest approximation to the visibility in meters, at the time of landing or takeoff

Conditions

A brief summary of the weather conditions at the time of landing or takeoff Clear indicates no clouds "no precipitation" indicates that there was no precipitation falling at the time of the accident but there may have been clouds present

Cloud

Three columns give information on cloud cover, either in oktas at a certain height or a description at a certain height Generally, UK reports quote in terms of oktas, US reports give a description

Dew Point

The closest approximation to the dew point in degrees Celsius at the time of takeoff or landing

RVR

The closest approximation to the runway visual range, in metres, at the time of takeoff or landing

Cloud base

Height of the cloud base in feet above aerodrome level, at the time of takeoff or landing

Airfield elevation

Height of the airfield above mean sea level in feet

QNH

Corrected mean sea level pressure at the airport, in millibars, at the time of the landing or takeoff

QFE

Aerodrome surface pressure, in millibars at the time of the takeoff and landing

Pressure altitude

Height in feet in the international standard atmosphere above the 1013 2 mb pressure level at which the pressure equals that at the elevation of the arrival or starting threshold at the time of the accident / incident If the elevation of the runway threshold cannot be obtained the aerodrome reference elevation is used If actual pressure altitude on the runway is given in the report, it is the figure that is used If pressure altitude is not given, it is calculated based on the altitude of the aerodrome above mean sea level, the QNH if the accident occurred in the U K , or the altimeter setting pressure if the accident / incident occurred in the U S

Temperature

Air temperature in degrees Celsius at the aerodrome at the time of the takeoff or landing

Temp dev.of pressure alt. from ISA (C)

Difference in temperature (degrees Celsius) between that at the aerodrome and that at the same height in the international standard atmosphere

Density altitude (ft)

Height in feet in the international standard atmosphere at which the density equals that at the aerodrome

Gusts

Speed (kts)

Maximum speed in knots of any gusts that were measured at the time of the takeoff / landing

Direction

Direction in degrees from magnetic north, of gusts that were measured at the time of the takeoff / landing

Narrative

Additional comments on the event

Landing distance required (metres)

Landing distance required for the aircraft under the prevailing conditions, as specified in the flight manual for that aircraft As for the maximum legal weight, this was given in the report in many cases, in other cases it was possible to utilise flight manual data from the CAA or the manufacturer for the particular aircraft involved In the small number of cases where a flight manual from a different certificating authority was available it was used

Target threshold speed

Target speed in knots, according to the report, that should be attained at the point of crossing the landing threshold

Actual threshold speed

Actual indicated airspeed, in knots, that was achieved at the point of crossing the landing threshold

Reverse

Notes on any reverse thrust that was used

Spoilers

Notes on any spoilers that were deployed

Slats

Notes on the slat positions

Flaps

Notes on the flap positions

Touchdown point in relation to threshold

Difference in metres along the runway centreline from the threshold to the actual main gear touchdown point.

Early \ Late \ On target

Specifies whether the touchdown was before, on target or beyond the normal touchdown zone

Glide slope touchdown point

Imaginary origination point of the glide slope

Time to initiate braking from touchdown sec

Time in seconds between main gear touchdown and first application of the brakes

VFR Approach/ landing

Type of VFR approach and landing if the landing was conducted under VFR rules

Stabilised approach

An approach was considered stable if by 1000 ft above touchdown in instrument meteorological conditions, and by 500 ft above touchdown in visual meteorological conditions the following conditions were met.

1 The aircraft was on the correct flight path
2 Only small changes in heading and pitch were required to maintain that path
3 The aircraft speed was not more than Vref +20 kts indicated airspeed and not less than Vref
4. The aircraft was in the proper landing configuration
5 Sink rate less than 1000 ft per minute
6 Power setting appropriate for the configuration
7 All briefings and checklists have been performed

Coupled?

Specifies whether the approach was flown by the autopilot

DH ft agl

Height in feet above ground level at which the pilot must be able to see the runway if he is to continue the approach

MDA agl

Height in feet above ground level, which the pilot is not allowed to descend beyond without being able to see the runway

Weather minimums

Minimum requirements of the meteorological conditions in order for the approach and landing to be legal

Above mins

Specifies whether the weather was above the minimum requirements of the meteorological conditions in order for the approach and landing to be legal

Height runway acquired ft agl

Height in feet above ground level at which the pilot was able to see the runway

Type instrument approach flown

Type of instrument approach flown if the approach was flown under instrument flight rules

Glide path indication

Type of visual glide path indication available

Above\below

Specifies whether the aircraft's approach was above or below the glide path that was subscribed by the ILS or the visual aid

ILS\GP angle

Angle of the ILS or visual aid glide path

Take off

Accelerate \ stop distance required

Accelerate stop or emergency distance required for the aircraft under the prevailing conditions, as specified in the flight manual for that aircraft See "landing distance required" for calculation methodology

Flaps

Notes on the flap positions

Anti-ice

Specifies whether the anti-ice system was on or off at the time of the takeoff

Spoilers

Notes on spoiler deployment

Reverse

Notes on the use of reverse thrust during the abort

Speed brakes

Notes on the use of speed brakes during the abort

V1(kts)

V1 speed, in knots, as specified in the flight manual for that particular takeoff

Abort speed (kts)

Speed in knots, at which the abort was actually initiated

VR (kts)

Rotation speed in knots, as specified in the flight manual for that particular takeoff

Rotation (kts)

Speed in knots, at which the rotation was actually initiated

V2

Takeoff safety speed in knots, as specified in the flight manual for that particular takeoff

Time to initiate braking after RTO (sec)

Time that was actually taken in seconds, to initiate braking after the takeoff was aborted

Start of roll from 1st threshold (m)

Distance in metres from the start of the runway, that the aircraft used up whilst lining up with the centreline

Problem

Nature of any mechanical / technical problem with the aircraft

Runway

R/w ID

Identification number of the runway used for the takeoff / landing

Bearing

Bearing of the runway in degrees from magnetic north Where this was not available the runway identification number multiplied by ten was used.

Runway length

The length of the runway in feet

Declared distances (metres)

TORA

Take off run available

ED/ASDA

Emergency distance / accelerate stop distance available, which is usable runway length plus stopway Generally in the U K it is known as the emergency distance, and in the U S A accelerate stop distance

TODA

Takeoff distance available, which is usable runway length plus clearway

LDA

Landing distance available

R/w width (metres)

Width of the runway in metres

Pilot action

Specifies whether the pilot made any kind of steering maneuver after the aircraft overran the runway, either to slow the aircraft down or to avoid any obstacles

R/w slope

Gradient of each quarter of the runway

Runway surface

Surface type

Material from which the runway surface is constructed

Runway surface condition

Condition of the runway surface in terms of standing water or contaminant present at the time of the accident

Depth (")

Depth in inches of any water / contaminant present

Braking action advisory

Nature of any braking action advisory reports current at the time of the accident

R/w surface character

Runway surface character for each four quarters of the runway (i e grooved / ungrooved & type of material)

Friction measurements (Mu) (accident conditions)

Mu readings for each third of the runway, of any friction measurements that were taken after the accident / incident had occurred

Device

Type of friction measuring device that was used to take the readings

Time elapsed

Time in minutes between incident occurrence and friction measurement

Wreckage location in relation to runway (m)

X location

Distance in metres along the extended runway centerline between the aircraft and the end of the runway surface It is usually measured from the main gear, but may also be measured from other points on the aircraft In many reports it is not specified exactly from where it is measured

Y location

Distance in metres, normal to the extended runway centerline between the aircraft and the extended centerline In common with the X location, it is usually measured from the main gear, but may also be measured from other points on the aircraft

From maingear?

Specifies whether the X and Y distances are measured from the main gear

Y L/R

This indicates whether the aircraft came to rest to the left or the right of the centerline as viewed from the runway

X location in relation to 1st threshold

Distance in metres along the extended centerline, between the threshold at the start of the takeoff run or the landing threshold, and the wreckage location

Wreckage location in relation to required distance (m)

X location

Y location

Aircraft location relative to the end of the required landing or accelerate stop distance, while starting the required distance at the takeoff or landing threshold

Normalised required distance

Required distance after being normalised by application of the procedure specified in Chapter 4

X location of normalised wreckage location in relation to normalised required distance

Normalised wreckage location in relation to normalised required distance, while starting the normalised required distance at the takeoff or landing threshold

Source of required distance

Indicates source of required distance information

X (relative to 1st threshold) of stop position assuming infinite length runway (but not normalised for slope, temp, alt.)

Non-normalised point that the aircraft would have come to rest had the runway been of an infinite length This position is measured in metres from the threshold at the start of the takeoff run or the landing threshold Position is taken from report where specified, from the flight data recorder information where given, and by using deceleration model described in Chapter 4

Terrain type of overrun area

Type of terrain over which the aircraft overran, as described in the report Where mentioned the elevation of the wreckage in relation to the runway is contained within this field

RESA

Length in metres of any Runway End Safety Area

Runway exit speed

Groundspeed in knots, at which the aircraft was travelling when it exited the end of the runway

Pilot information

This section contains information on hours flown prior to the accident / incident for the commander, co-pilot, and third pilot It includes information on

Total flying hours
Total hours on type
Total hours flown in the last ninety days
Hours flown on type in the last ninety days
Hours flown in the last sixty days
Hours flown in the last thirty days
Hours flown in the last twenty eight days
Hours flown in the last twenty four hours
Rest before duty on the day of the accident (in hours and minutes)

Different investigating authorities collect slightly different information on the hours flown For example, in the U K hours flown in the last twenty-eight days is recorded, whereas in the U S the number of hours flown in the last thirty days is recorded