CRANFIELD UNIVERSITY

COLLEGE OF AERONAUTICS

Department of Air Transport

PhD THESIS

Andy Jefferson

THE FEASIBILITY OF MAINTAINING REGIONAL AIRLINE ACCESS TO CONGESTED EUROPEAN AIRPORTS.

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This thesis is dedicated in memory of my father and grandmother. Without their support and encouragement, during my earlier life, none of this would of been possible. I hope they will be justly proud.

ABSTRACT

At present runway congestion in the airline industry has reached a dangerously high level. The effects of this are very costly to all parties involved; US$5bn per year in Europe in 1989 alone. The problem demands urgent attention to accommodate the expected average growth in air transport of 6% per annum up to the year 2000. It is becoming more and more obvious, however, that the construction of new runways is not a feasible option due to both political, environmental and physical space limitations within Europe. Alternative solutions are therefore required

In 1991 the European Regional Airlines Association, (ERA), produced a document entitled, 'The Vital Link', which outlined a number of ways in which regional aircraft could use there performance differences from the larger jet aircraft to help generate extra runway capacity from existing runways. Whilst the author was a member of the ERA operations committee he developed some of these ideas further. It is the objective of this thesis to examine the ideas developed by the author from both a theoretical and practical point of view to determine the feasibility of implementing them at congested European airports.

Theoretical simulation modelling of Manchester, Zurich and Gatwick airports was undertaken using the FAA SIMMOD airport and airspace simulation model. This produced delay time savings and changes to peak hour movement rates which were used in a cost benefit analysis model to see whether or not the procedure would make a cost saving. The practical side of the thesis focused on an industry questionnaire to regional airlines, major airlines and airports to obtain their views on the new procedures and case studies of the procedures at Manchester and Gatwick airports.

Results of the work show that whilst the procedures can effectively reduce operating delays they have a lessor impact on peak hour movement rates. Optimum use of the procedures is unique to individual airports and depends on the runway operation mode, TMA airspace configuration and the type and variability of the traffic mix. Actual application of the procedures will be dependant on political and environmental restrictions and likely future changes in regional airlines aircraft fleets.

ACKNOWLEDGEMENTS

In the process of carrying out this thesis I have met many people, without whose help I would not be writing this now.

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If I've missed anyone out, and I'm sure I have, then please accept my apologies and thanks.

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NOTATION

ACI	Airports Council International
AEA	Association of European Airlines
APATSI	Airport/Air Traffic Systems Interface
ATAG	Air Transport Action Group
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Transport Movement(s)
BAA	British Airport Authority
CAA	UK Civil Aviation Authority
CBA	Cost Benefit Analysis
CCF	Central Control Function
CFMU	Central Flow Management Unit
DGPS	Differential GPS
DME	Distance Measuring Equipment
DORA	Directorate of Operational Research and Analysis (UK CAA)
DSP	Departure Sequencing Pad
EATCHIP	European ATC Harmonisation and Integration Programme
ECAC	European Civil Aviation Conference
EFIS	Electronic Flight Information System
ERA	European Regional Airlines Association
FAA	Federal Aviation Administration
FAP	Final Approach Point
FMS	Flight Management System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HIRO	High Intensity Runway Operations
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
ILS	Instrument Landing System
JAA	Joint Aviation Authority (European Regulatory Body)
JAR	Joint Airworthiness Requirement
LATCC	London ATC Centre

MATS	Manual of Air Traffic Services (UK CAA)
MLS	Microwave Landing System
MMR	Multi.Mode Receiver
MTOW	Maximum Take Off Weight
NATS	UK CAA National Air Traffic Services
NPR	Noise Preferential Routing
Pax	Passengers
Pax/ATM	Passengers per Air Transport Movement
RAA	Regional Airline Association (US)
RATS	Rapid Access Taxiways
RET	Rapid Exit Taxiway
RNAV	Area Navigation
ROT	Runway Occupancy Time
RPK's	Revenue Passenger Kilometres
RVR	Runway Visual Range
RWY	Runway
SALS	Separate Approach and Landing Systems
SID	Standard Instrument Departure
SIMMOD	FAA Airport and Airspace Simulation Model
STAR	Standard Terminal Arrival Route
STOL	Short Take Off and Landing
TCAS	Traffic Collision and Avoidance System
TMA	Terminal Manoeuvring Area
TORA	Take off Run Available
VFR	Visual Flight Rules
VNAV	Vertical Navigation
V_1	Take Off Decision Speed
V_R	Take Off Rotation Speed
V_2	Take Off Safety Speed
V_S	Stall Speed
V_{AT}	Landing Threshold Speed
V_{FTO}	Final Take Off Speed
VOR	VHF Omni-Directional Radio

CHAPTER 1 : Introduction.

1.1: Scope of the Thesis

The air transport industry is a large, complex, and highly interactive system which is constantly changing and evolving. The components which make up the industry are shown in figure 1.1.

Elements of the Aviation Industry

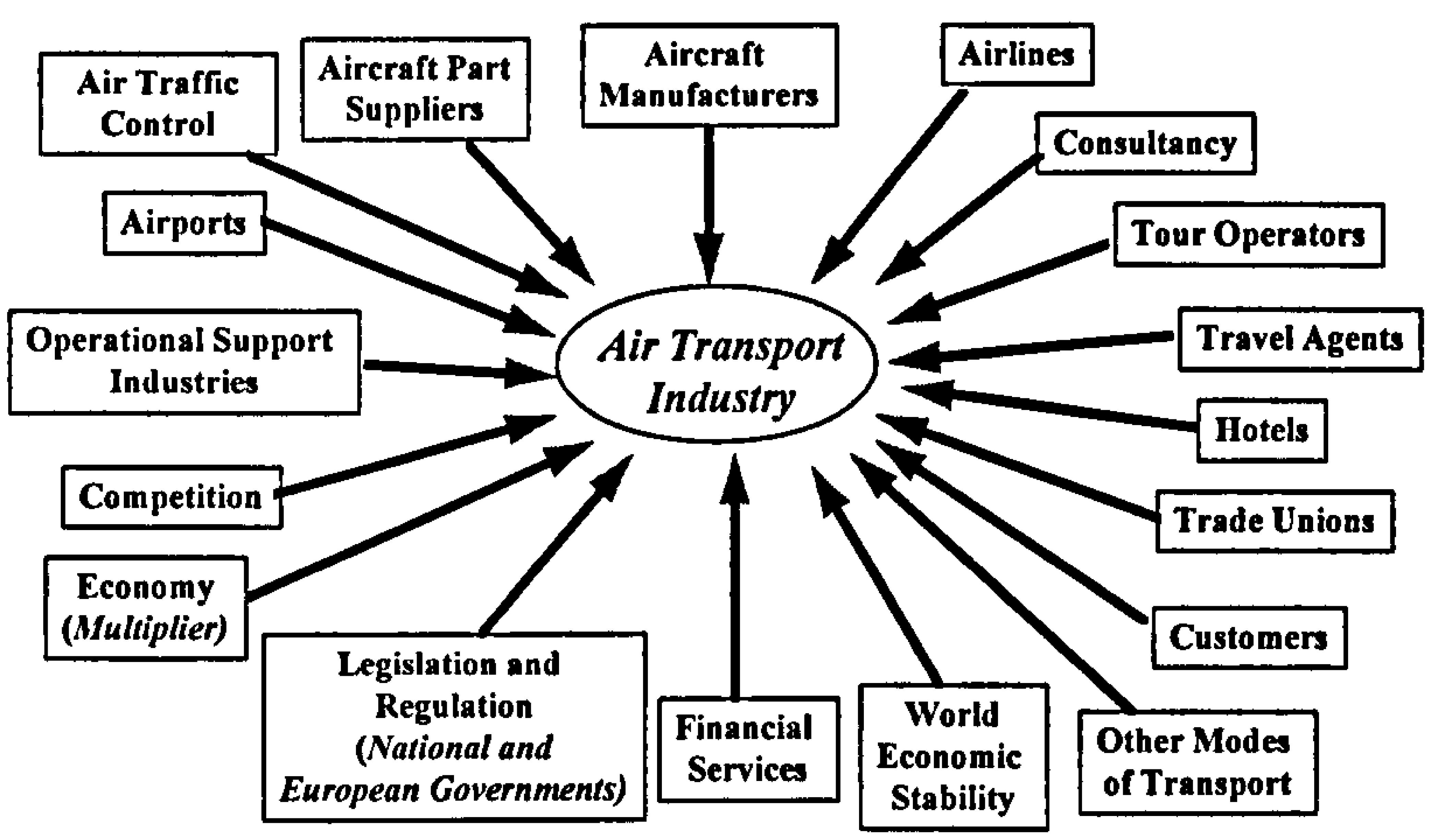

FIGURE 1.1

Some figures, to indicate the size of this industry, were prepared by the Air Transport Action Group, (ATAG), in 1992 which show:

- Over 1.25 billion passengers per year rely on the worlds airlines for business and leisure travel.
- US$230 billion in annual turnover was generated by airlines in 1992.
- Over 3 million people are directly employed by the industry, throughout the world.
- The world's airlines have a combined fleet of approximately 17,000 aircraft which operate a route network of around 15 million kilometres, serving nearly 15,000 airports.

Add to these figures a growth rate of 6% per annum and the scale of this industry begins to emerge. Unfortunately this rate of growth is beginning to test the limits of current aviation infrastructure. No where is this felt more than on the runways of the major international airports. As demand increases due to the factors pushing growth in air transport, (see table 1.1), this pressure on airport runway capacity will only get worse. In addition, growing environmental and political opposition to large scale expansion of airports based on quality of life arguments, are only tending to make this problem worse by enforcing further operating limits on an already critical system.

Factors Driving Growth in Air Transport
1. Falling Real Cost of Air Travel
2. Increasing Economic Activity
3. Intensifying International Trade
4. Increasing Disposable Incomes
5. Political Stability/Instability
6. Relaxation of Travel Restrictions
7. Expanding Ethnic Ties
8. Increased Leisure Time
9. Tourism Promotion
10.Air Transport Liberalisation
11.Emerging Regions and Countries with Low Base Traffic Growth

TABLE 1.1
Source: ATAG, (1993) - The Economic Benefits of Air Transport

Within the European arena this problem is particularly acute and alternative solutions to building new runways are urgently required. In 1991 the European Regional Airlines Association, (ERA), produced a document entitled, 'The Vital Link'. It presented results of various studies which showed 24% of major European carrier's flights in Europe, were delayed by 15 minutes or more in 1989, which, according to the London School of Economics, was generating costs to the industry of US$ 19,580 per annum per traveller by 1991. The document then went on to propose a number of possible procedures that regional aircraft could perform utilising their distinct performance characteristics compared to jet aircraft. These focused on early turns after take off, steep approaches, intersection departures and discrete separate arrival routings. This thesis intends to determine by theoretical and practical examination how far airport runway capacity in Europe can effectively be increased by making use of the procedures outlined by the Vital Link as well as the ideas developed by the author whilst attending the ERA operations committee. To achieve this aim we must first determine what is defined as a regional aircraft. For the purposes of this thesis regional aircraft shall be any turboprop or jet engined aircraft capable of carrying out the special procedures of steep approach and early turn after take off which operate on sector lengths of less than 1400nm. Maximum seat sizes for regional aircraft will be 120 which accommodates the BAe 146-300 aircraft. This definition is based on data which will be presented in chapter 3.

The following figures, prepared by the ERA, show the size and scope of regional airlines in Europe:

- A fleet of 655 aircraft, of which 494 are turboprops and the rest jets.
- 1.43 million landings in 1993, an 8.8% increase from 1992.
- 16,000 people directly employed.
- Average passenger growth for 1992-3 was 14.2%, over double that of the major carriers.

- Sector time averages one hour, with forecast for this to reduce slightly in the future.

Given their size, if the procedures can be effectively implemented to all the regional airlines, significant reductions to airport congestion in Europe, it can be argued, could be made.

1.2: Thesis Aims and Objectives

The overall aim of this thesis is to determine to what extent regional aircraft special procedures can effectively reduce airport congestion in Europe and to make recommendations based on the results as to their practical application.

In order to satisfy this aim there are three questions that require answering:

- Can these special procedures reduce airport congestion in Europe?
- If the special procedures can theoretically reduce congestion at an airport, can they realistically be applied? If not, why not?
- Do these special procedures represent a short or long term solution to airport congestion?

A final objective of the thesis, once these questions are answered, is to produce a methodology for airports and airlines to help them optimally apply the special procedures.

1.3: Thesis Structure

In order to answer the questions posed above this thesis has been broken into nine chapters of which this is the first. Chapters two, three and four provide the background to the work and the base knowledge that is required before moving into the more in depth analysis of the special procedures in the remaining chapters.

Chapter two takes a detailed look at the current operating environment in which aviation exists. The aim is to provide the reader with an understanding of the intricacies, complex interactions and conflicts of interest that must be considered when looking at airport congestion. Figure 1.2 gives an indication of the number of factors to be considered and will be expanded on in chapter two. Chapter three provides the reader with an introduction to the principle components that make up aircraft performance and outlines the specific differences that exist between regional and jet aircraft. Chapter four will outline current trends in international aviation before embarking on a detailed examination of European airport congestion, both present and forecast. Analysis will then look at current issues with European ATC and proposed solutions. The chapter will close with a look at current changes occurring in the European airline market.

With the work properly placed in context chapter five will outline in detail the proposed regional aircraft special procedures along with the background and current practical applications of the procedures. Chapter six will then outline the methodology that the author intends to use to evaluate the special procedures. This will focus on a theoretical simulation modelling of certain European airports using the FAA SIMMOD simulation model, and application of these results to a cost benefit

Factors Affecting Aviation Congestion.

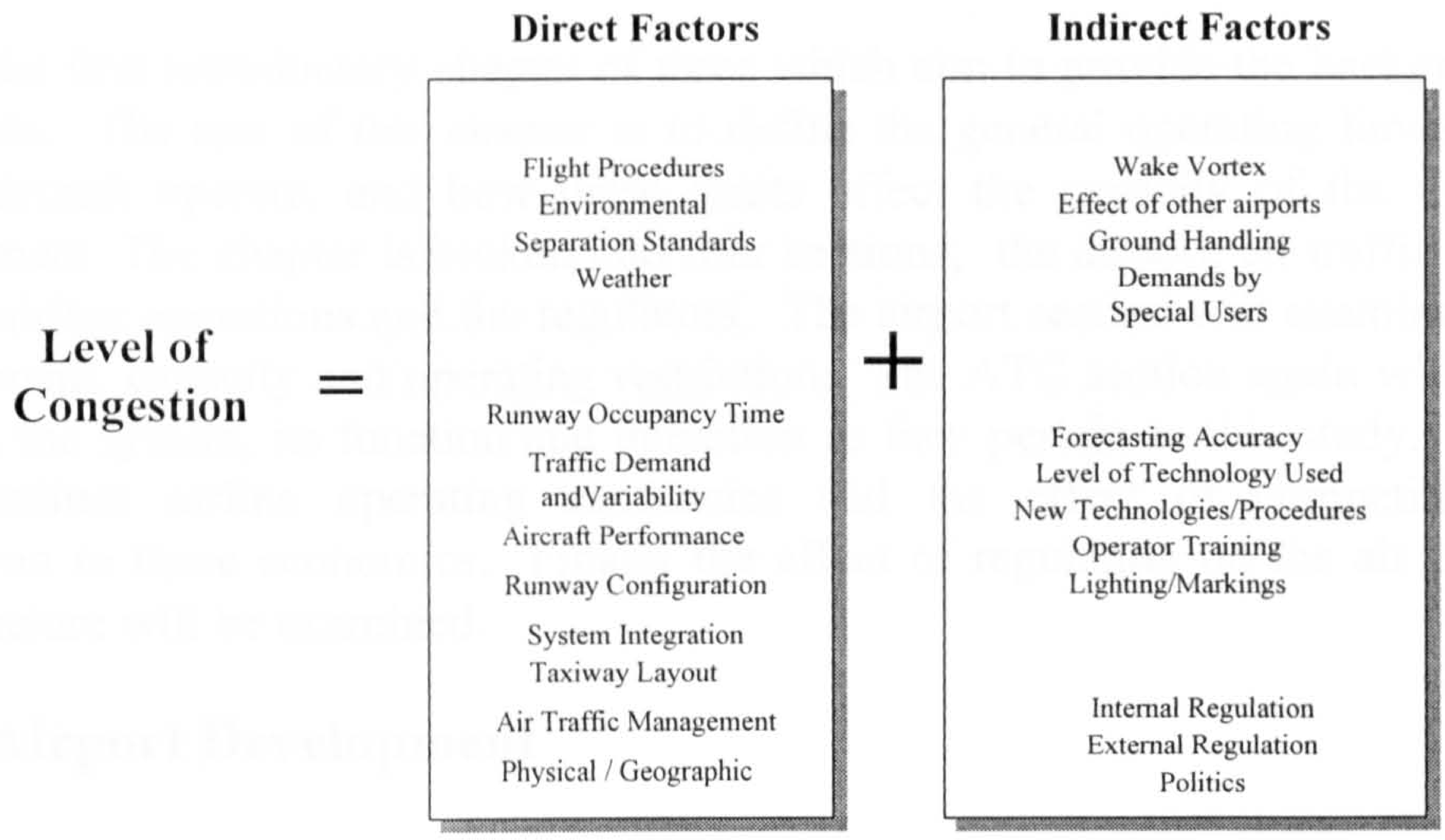

FIGURE 1.2

analysis model. Chapter seven will present the results of this methodology whilst chapter eight will discuss what the results mean on a more practical basis and outline possible areas of application within Europe. Finally chapter nine will present the conclusions of this work by referring back to the questions asked in this chapter and the discussion made in chapter eight.

1.4: Summary

This brief chapter set out to place the work of this thesis in context within the scope of the aviation industry. In doing so, it has touched upon the magnitude and severity of the problem of airport congestion. It then moved on to outline the aims and objectives of the work and defined how the task will be tackled.

Obviously, there are many ways to tackle a problem such as airport congestion and it must be stated that this thesis only touches upon a small but significant part of the whole problem. It is, however, one the author feels can be done by academic study and one, which it is hoped, will prove of value to the aviation industry.

CHAPTER 2 : The Operating Environment

2.1: Introduction

This is the first introductory chapter of three which aim to provide the background to this thesis. The aim of this chapter is to define the general operating limits within which aircraft operate, and how these limits affect the capacity of the operating environment. The chapter is broken into four sections; the airport, air traffic control, (ATC), airline operations and the regulators. The airport section will examine airport development, capacity and operating restrictions. The ATC section again will briefly describe the system, its function and operation as they pertain to this study. Section three outlines airline operating economics and the effect of competition and congestion to these economics. Finally the effect of regulation on the air transport infrastructure will be examined.

2.2: Airport Development

The development of any airport may vary in scale and time compared to other airports, but will be driven by the same factors. These are the demand from passengers, airlines and other associated companies for the airport to provide adequate facilities to satisfy the users. For the airport this covers three areas; landside, terminal, and airside developments. Due to the nature of this thesis, airside developments only will be considered.

Unfortunately the development of airside facilities are not as straight forward as they could be, due to ever increasing economic and financial considerations. Figure 2.1 shows how an airport tries to plan development to meet demand, whilst remaining competitive and profitable. Both an excess or dearth of supply are regarded as an inefficient use of resources and a potential loss of revenue. An airport, therefore, must try to operate in a constant state of equilibrium. This, however, is very difficult as to provide extra facilities at an airport involves substantial planning and building phases. These can cost huge amounts of money, (US$170 million for the second runway at Manchester[1]), and take considerable time to complete, (30 years for Munich2 from conception to operation). As a result of this problem an initial dearth of facilities followed by an excess occurs, (figure 2.1), as airports must plan not just for now but for the next 5-10 years.

In figure 2.1 the grey blocks demonstrate the available level of facilities at the airport at any one time. These facilities over time become fully utilised and then fail to meet user requirements. At this point, or preferably before, a decision to expand is made and the available facilities jump to a new level, where the process described repeats itself. Before these facilities come on line however, there will be a period where demand is greater than available capacity, with congestion and delays likely.

[1] Airports International (1993) World Development Survey, pg 23

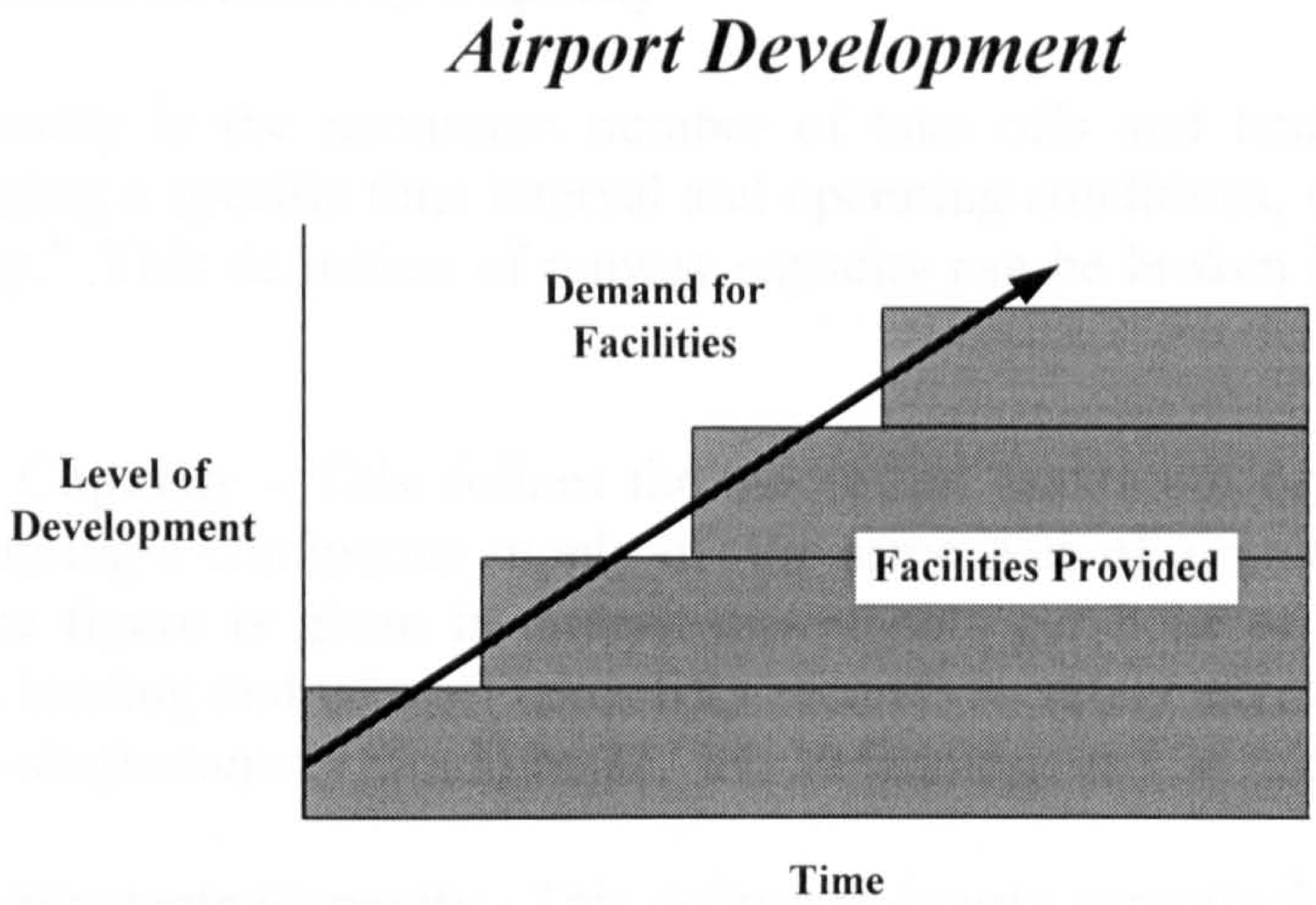

FIGURE 2.1

2.3: Airport Capacity

The assessment of airport capacity will focus on airside, rather than landside areas of the airport, due to the nature of this thesis. The three parts of the airside, (runway, taxiway, apron), each have a capacity limit. Apron capacity is relatively fixed and easy to define by the number of parking stands available at an airport. It will vary with aircraft mix, as large aircraft may occupy more than one parking stand, and also the location of the stands, as this may prohibit some aircraft from using them due to nearby buildings. Taxiway capacity can limit the capacity of an airport where there is limited taxiway construction, either causing aircraft to backtrack along an active runway, or where airport terminal growth has reduced available taxiways, as at London Heathrow for instance. There are various types of taxiway, defined by the size and weight of aircraft they can handle.[2]

Whilst the two previous capacity limits are worthy of mention, it is runway capacity that is the most variable aspect of airport capacity, and this is therefore the focus for the thesis. In the following discussion, it should be remembered that the aims of capacity management are to provide a set level of service for users and to meet set delay criteria. These delay criteria vary greatly from airport to airport, and from airline to airline. 'Acceptable Delay' or tolerated delay, is what is perhaps more important, and as a general rule 15 minutes delay per movement could be classed as acceptable[3], although this is very subjective. Acceptance of a residual delay in the system though does allow airports to make economic use of the capacity. For an airport to have no delays at all would require huge investments to provide sufficient capacity to cope with peak demand traffic, which would be unused during off peak periods.

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[2]Types of Taxiways are defined in ICAO Annex 14 - 'Aerodromes'

[3]Source: ECAC (1993) Feasibility Study for a European System to Monitor Air Traffic Delays - Coopers & Lybrand.

2.3.1: Definition of Runway Capacity

Runway capacity is the maximum number of take offs and landings that can be processed during a specific time interval and operating conditions, with an acceptable level of delay.[4] This definition of runway capacity can be broken into four principal sections:

Theoretical Capacity - This defines the theoretical maximum capacity of a single runway, assuming a continuous supply of the same type of aircraft for take off and landing. The figure is given in aircraft movements per hour of operation. If we assume each landing and take off takes fifty seconds to safely execute, the theoretical capacity of a single runway would be 72, i.e. 36 landings and 36 take offs per hour.

Practical or Strategic Capacity - This defines an hourly capacity for a runway taking into account actual traffic patterns, mixes and assumed operating restrictions in perfect weather. ICAO has laid out figures for, 'achievable runway capacities', in its Airport Master Planning document. The US FAA gives, 'declared target capacity rates'. These figures are combined in table 2.1 below:

Runway Capacities

Runway Configuration	ICAO Capacity Figures	FAA Capacity Figures	FAA Realistic Capacity*
Single	50-59	53	58
Dual (to 760m)	56-60	53	63
Close Parallel (to 1300m)	62-75	74	115
Independent Parallel (above 1300m)	99-119	106	116
Intersecting	56-60	n/a	n/a

* Figures from the FAA are broad potential runway capacity targets as a result of new techniques and procedures.
Source: SH&E/Cranfield Report to APATSI Board - August 1993

TABLE 2.1

Declared Capacity - This is the hourly capacity declared by the airport and air traffic control authority. It represents what capacity the authorities feel is safe to handle in poor weather conditions, and is based upon the practical capacity. It takes into account any other restrictions which may be imposed on the airport. It is used by the IATA scheduling committee at slot constrained airports, to equate airline demand with available supply. The current declared capacities of the 'best in class', runways in Europe are given in table 2.2.

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4 Source 'A Guide to Runway Capacity for ATC, Airport and Aircraft Operators' - CAA CAP 627

The differences in the figures shown in the two tables above reflect the effects of weather, aircraft, pilot, and ATC controller performance, plus airport operational restrictions.

Optimum Runway Capacities

Runway Configuration	Movements per Hour*	Airport**
Single	42	LGW
Dual	68-70	FRA,CPH
Close Parallel	70-78	ORY,LHR
Independent Parallel	76-80	CDG,AMS
Intersecting	60	STO,ZRH

* The airport figures represent those of normal operating procedure even though the airport may have more runways than the figures suggest.

** Airport Codes are standard IATA three letter codes.

Source: SH&E/Cranfield Report to APATSI Board - August 1993

TABLE 2.2

Sustainable Capacity - If an airport operates at its declared capacity for greater than a few hours, delays generally start to build and 'firebreaks', or periods of reduced runway movements are required to clear any backlogs of aircraft, and provide an acceptable level of service and delay. This variation in capacity leads to sustainable capacity. It is usually quoted as changes in the capacity of an airport per hour. London Heathrow is a good example. In 1992 DORA, the CAA's operations research department, set the sustainable capacity shown in table 2.3.

The four definitions of capacity given above can be depicted together by comparing hourly movement rate to incurred delay, (figure 2.2).

Hourly Declared Capacity at London Heathrow

Time Interval	Arrivals	Departures	Total
First Six Hours	37	38	75
Next Two Hours*	34	34	68
Next Two Hours	36	38	74
Next Three Hours	38	39	77
Last Hour	38	38	76

* This represents the firebreak to provide an acceptable level of delay.

Source: Sharpe, A. et al (1991) Heathrow and Gatwick Runway Capacities for Summer 1992 - DORA Report 9152, CAA.

TABLE 2.3

Figure 2.2 clearly demonstrates that if you operate a runway above a set declared capacity, a penalty of increased delay per movement is incurred. The diagram also shows that as the movement rate increases, the delays per movement incurred increase at an exponential rate, tending towards infinity as the absolute capacity is reached. Finally, it does not define where delays become unacceptable, as this is subjective and varies depending on whether you look at it from an airline or airport point of view, and how important it is for you to remain at the congested airport. Airlines are more likely to accept higher delays at strategic airports in their network than at less important ones. For the purpose of this thesis however, declared capacity will mark the limit of acceptable delays and sustainable aircraft movement rates.

Levels of Airport Capacity

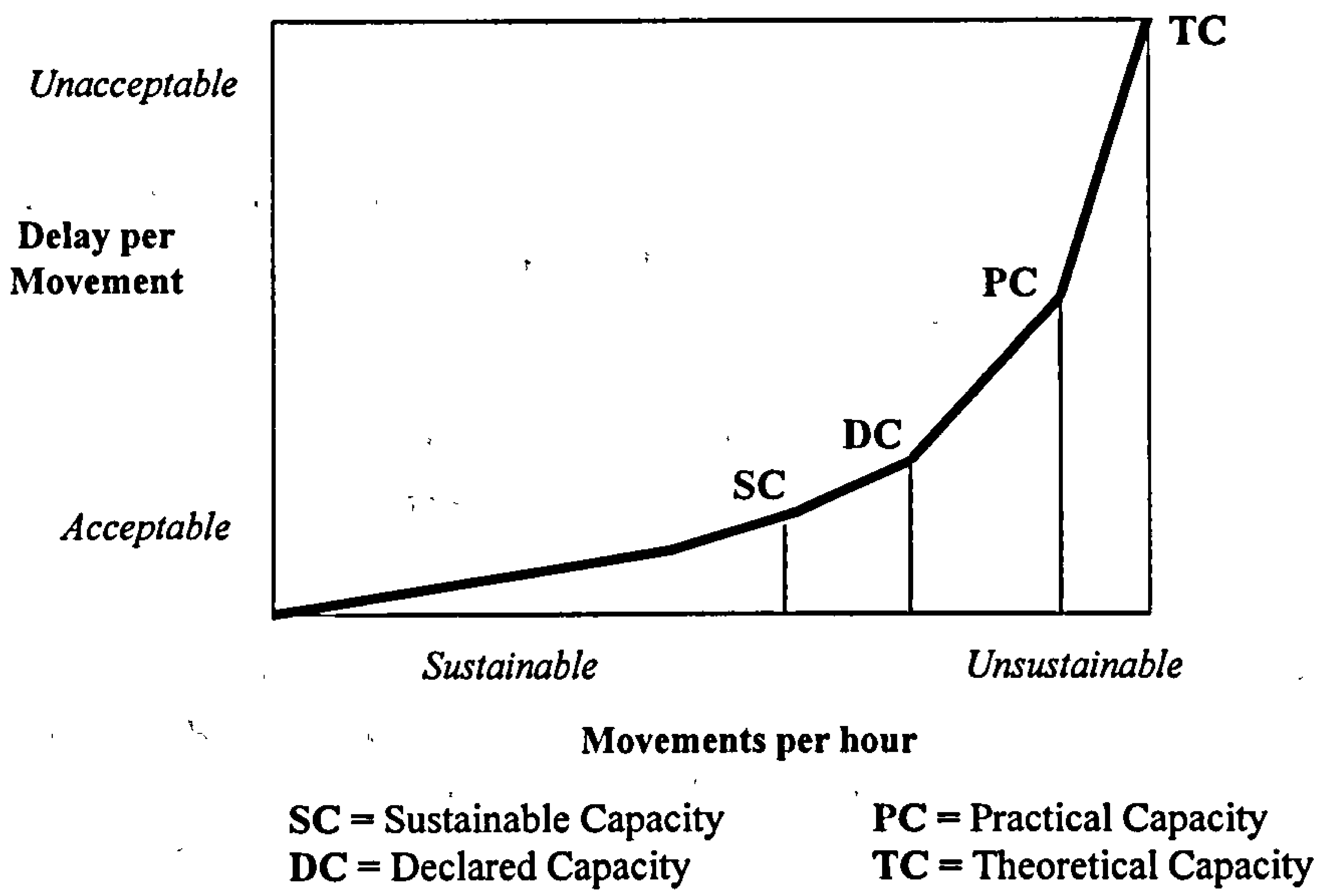

FIGURE 2.2

2.3.2: Factors Affecting Runway Capacity

Runway Geometry

The pavement strength, width and length of the runway will determine the size of aircraft that can be handled by it. The presence of stopways and clearways will assist in increasing allowable aircraft take off weights for the runway. Finally, the location of obstructions on the approach or departure track from the airport, could limit the maximum weight the aircraft can safely land or take off at, which in turn may limit the maximum payload the aircraft can carry.[5]

Rapid Exit Turnoff's (RETS)

The location, type and number of runway turnoffs will significantly affect runway capacity by influencing runway occupancy time. An RET is an angled turnoff from the runway to allow aircraft to exit the runway at a speed higher than possible on 90°

[5]Definitions for all the aspects raised in this section along with recommended standards can be found in ICAO Annex 14 - Aerodromes Vol. 1 Aerodrome Design and Operations - July 1990

turnoffs. The actual speed aircraft can exit on these RET's depends on the angle of the turnoff, its length for deceleration, and manoeuvring required at the other end of it. A. A. Trani, et al (1990 & 1992) from the Virginia Polytechnic Institute & State University Centre for Transport Research, Blacksbury, Virginia, has carried out detailed research into the optimum design of RETS for runway capacity improvement.[6] Results of their research showed firstly, that aircraft using existing RETS do so 10-15 knots below the design speeds of the RET. In addition with the use of three, four, or five optimally located RETS, a 7% to 18% reduction in runway occupancy time could be made Optimal exit angles for RETS range from 17° to 30°. Further work showed, that for a single runway, a 15% reduction in runway occupancy could be achieved with optimally placed 20° angle RETS. Maximum entry speeds to the RETS were demonstrated to be 35m/s or 78mph. More work was needed to assess the issues of aircraft landing gear tolerance to higher exit speeds, and the impact of new RETS on already complex runway and taxiway interactions.

Rapid Access Taxiways (RATS)
These are defined by ECAC Airports Bureau special working group, APATSI, as taxiways constructed at an angle to the runway to permit expeditious line up and/or rolling take off.[7] They could quite conceivably be RETS in the opposite direction and as such, should help reduce runway occupancy time and so increase capacity as the aircraft are already moving when they enter the active runway.

Departure Sequencing Pads (DSP's)
These are paved areas located at the departure end of the runway, large enough to allow aircraft to be held without blocking other taxiways and permit aircraft to pass one another. The primary benefit of DSP's is their ability to assist the air traffic controller generate the optimum departure sequence of traffic, minimising wake vortex and track separation standards.[8] In combination with the above two runway modifications delay reductions, and runway capacity increases may be possible depending on traffic mix and patterns.

Runway Occupancy
The time an aircraft spends on the runway for take off and landing determines the movement rate of the runway. It can be altered by the addition of the previous three modifications. In addition the performance of the pilots and air traffic controllers will affect the occupancy. The effect of slow pilot reactions to take off clearances is demonstrated, when it is considered that an average saving of 5 seconds for each aircraft movement per hour would create another one, to one and a half movements in that hour.[9] The UK CAA recommendations to pilots include completion of cockpit checks before take off and nomination of preferred RETS in the landing brief. ATC performance is measured by their ability to sequence traffic to minimise the separation restrictions. The complexity of this task is appreciated when Heathrow departures are

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6A. A. Trani, et al (1990) Runway Exit Designs for Capacity Improvements Demonstrations Phase 1 Algorithm Development - DOT FAA/RD 90-32 1. Followed up in 1992 with phase 2 - Computer model development.

7Source ECAC Airports Bureau 'APATSI Draft Document on Mature Air Traffic Control Procedures' 1993.

8These separation restrictions will be explained under the air traffic control procedures section.

9Source 'A Guide to Runway Capacity for ATC, Airport and Aircraft Operators' - CAA CAP 627 considered to offer the controller over 500 route combinations, each with their associated rules.

Air Traffic Mix and Patterns

Traffic pattern and mix are more important than all the factors already discussed in relation to runway capacity, which is unfortunate, as both of these factors are relatively unpredictable. A traffic pattern looks at the variations in the flow of arriving and departing aircraft at the airport during the day, whilst traffic mix is concerned with the variations in aircraft types operating in and out of the airport. The principal problem with traffic mix, is that poor traffic sequencing can cause unnecessary wake vortex separations, hence reducing capacity. This shall be examined in more detail later.

Traffic patterns are slightly more predictable than traffic mix and it is the peaks in traffic per hour which are of most interest to airports, as they must decide how much capacity of the peak traffic demand they are prepared to provide. The decision will be made by the capacity management aims of the airport. Methods of describing peaking at airports are currently related to passenger flows through the airport.[10] These principles can also be applied to runway capacity. The first of five methods is 'the standard busy rate', which is defined as the 13th highest hour of traffic flow, or the flow rate surpassed only 29 hours throughout the year. This level of flow sets the capacity requirements and is used in the UK and the rest of Europe. Obviously, the more hours of operation a year that an airport has, the lower the percentage of total operation, the 29 hours will be, consequently this method applies more readily to high, rather than low, operation airports.

The above problem led to the development of the 'busy hour rate', which represents the hourly rate above which 5 percent of the traffic at the airport is handled. The FAA have also developed a measure of peaking called, 'typical peak hour passengers', which gives a recommended flow figure as a percentage of annual flows and total annual passengers. The simplest method is the 'busiest timetable hour', and is self explanatory. It is, though, subject to errors such as rescheduling by airlines. The final method is the 'peak profile hour', which assesses the average hourly volume for an average peak day, using data from the peak month. The result is similar to the standard busy rate.

Effect of Other Runways

So far we have considered a single runway airport. More than one runway can cause restrictions on operations off other runways. There are three factors which will affect capacity. The runway configuration and runway separation, as demonstrated by table 2.1, and runway stagger. The latter can help improve the runway capacity of two closely spaced parallel runways by reducing the effect of wake vortex separation for arrivals and departures. This permits clearances to depart to be given earlier after an arrival than without the stagger, (See ATC section).

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[10] Source Ashford,N et al (1991) Airport Operations Pitman Publishing

Runway Mode of Operation
With more than one runway the method of operating the runways can be different than for a single runway, which must allow for 'mixed mode operation', or arrivals and departures on the same runway. Other modes of operation are 'segregated mode', where a runway is used purely for arrivals or departures, or 'dependent mode', where two closely spaced parallel runways must co-ordinate their arrivals and departures, even though they are on different runways. Each of these operating modes will affect final runway capacity.

This section has clearly defined runway capacity as well as methods of assessing it and the factors that need considering by airport planners when setting the airport's capacity. There are two points to note in conclusion. Firstly, the closer an airport operates to it's finite limit the greater will be the delay for the users. Secondly, operating an airport close to the capacity limits will increase the chances of aircraft go-arounds, due to blocked runways. This latter point needs to be contrasted with the fact that an airport operating close to its capacity is operating in its most cost efficient manner!

2.4: Airport Operational Restrictions

The purpose of this section is to examine operational restrictions preventing airports from operating to their optimum potential we have discussed so far. The restrictions covered are those which the airport management has little scope to remove themselves. The section covers two areas, firstly environmental restrictions followed by political ones.

2.4.1: Environmental Restrictions

Weather
There are four aspects of weather that can reduce runway capacity. Visibility is perhaps the most important and restrictive form of bad weather. The precise limits of operation in poor visibility are given in appendix 2.1.

The level of precision navigation equipment installed on a runway will depend on the regularity of severe weather conditions, and the demand of the airlines to maintain access to the airport in all weather conditions. At London Heathrow for example, the likelihood of category II or III conditions is less than 2% of total operations, however the large demand to use Heathrow 365 days a year from the airlines, justified the BAA investing in Category IIIC systems for both its parallel runways. This decision would not have made sense for smaller regional airports with lower traffic demand. The effect of low visibility conditions on runway capacity can be significant, as the runway occupancy time (ROT) tends to increase, due to arriving aircraft exiting at slower speeds from the runway and reduced ability to optimise the runway exit. Departure ROT also tends to increase as aircraft ground movement is slower and restricted by ATC. In addition departures have to hold short at a distance further from the runway threshold, than in visual conditions, as the ILS landing aid needs a protection zone either side of the runway, clear of obstacles, to provide an uninterrupted high integrity signal. The precise effect on ROT will depend on such factors as taxiway lead in lighting, aircraft systems, pilot and ATC performance and clarity of surface markings. If we consider the theoretical capacity situation for a mixed mode, single runway, and an increased ROT of ten seconds, from 50 to 60 seconds, the hourly runway capacity would decrease from 72 to 60 movements. A loss of 12 movements an hour. The cost of this reduced ability to handle traffic can be huge, with aircraft delayed in the air and ground, or diverted to alternative airports. The above example is not unrealistic when compared to actual operations at Heathrow,. where under 'average' winter conditions, average separations between arrivals increase by about 5 seconds to allow for increased ROT.[11] At Amsterdam ATC limit the landing capacity of the airport to 12 per hour during CAT III conditions, compared to 60 per hour during good visibility.[12] As a consequence they expect delays to increase from less than 2 minutes in good visibility to over 45 minutes during CAT III conditions.

Wind, heavy precipitation and lightning can also affect runway capacity. Excessive cross winds, (greater than 30 knots with a dry runway), can close primary runways and force traffic onto sub-optimal runways due to safety constraints on aircraft operations. Departure runways that have tailwinds also reduce capacity by necessitating longer take off runs. Finally, blustery wind conditions with rapid changes in wind speed and possibly direction, lead to pilots landing at higher speeds to allow for sudden drops in wind speed, which could bring an aircraft's true airspeed close to stall. This higher speed will result in longer landing runs though. Wet or contaminated runways can reduce runway capacity, as aircraft breaking actions on the ground are reduced, which could result in increased arrival ROT's if RETS are insufficient or inadequately located. Snow or slush on the runway can also reduce aircraft acceleration rates and increase take off runs. Lightning and thunder are the last aspect of the weather to consider. Their activity around airports also reduces runway capacity for the time they pass close to the airport, due to the severe downdraughts of air that flow out from the thunder cells. These downdraughts, known as 'windshear', can cause aircraft landing accidents as the downward pressure of the air forces the aircraft below the glidepath, even under full engine power settings! Clearly this can reduce runway capacity by effectively shutting the airport while it is overhead.

Noise

This is perhaps the most well known and understood problem associated with airports. It certainly appears to be the primary issue inhibiting airport development. ICAO Annex 16 to the Convention on International Civil Aviation provides international guidelines for noise control at airports. The intensity of nuisance caused by noise can be shown to depend on three separate factors, firstly; by the duration of the sound, then by its repetition and finally by the time of day it occurs. Actual methods of noise measurement are diverse and beyond the scope of this thesis, except to note the effect of noise control strategies on runway capacity.[13]

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[11] From 'A Guide to Runway Capacity for ATC, Airport and Aircraft Operators' - CAA CAP 627

[12] As defined in the Dutch Aeronautical Information Publication from the Dutch Civil Aviation Authority.

[13] Those wishing to examine noise measurement techniques should consult Annex 16 to the ICAO Convention

Clearly, airports located close to industrial or low habitation areas are less likely to be restricted than those next to high density residential areas. Noise preferential runways and minimum noise routings (MNR), are used to control noise around airports. They involve a limited number of fixed departure routes from the airport on preferred departure runways up to a specified altitude to reduce the geographic area affected by noise. Runway capacity is limited, as aircraft are forced to follow one another along the limited MNR's. This forces ATC to impose strict wake vortex and time separation restrictions to prevent conflicts.

Runway operations are also affected by noise restrictions such as the use of de-rated take off thrust and minimal use of reverse thrust on landing. Capacity restrictions occur as ROT's tend to increase due to slower acceleration and deceleration rates. Finally, the airport may have restricted hours of runway operation during night time, when the airport is forced to shut to prevent noise disturbance as local residents try to sleep. If the airport is not shut, a strict limit is set on the number or type of aircraft that can use the airport during a specified time interval. These curfews are greatly dependent on local government, location, and traffic volume handled by the airport.

2.4.2: Political Restrictions

Due to the large economic impact of airports, both positive and negative, on the local and national economies, any development tends to be restricted by large planning processes which include planning applications, government reviews, public enquiries and re-submissions. This requires large investments in time for all parties involved, with the associated opportunity costs of that lost time. This time lag can lead to periods where an airport is unable to adequately handle traffic demand. Where this occurs, governments can impose traffic distribution rules to set artificial capacity limits at the airport. In addition preferential operating fees at uncongested airports can be offered to attract demand away from the limited airport. The best example of this was the UK government's policy towards London's airports, where traffic was encouraged to use Stansted airport, north of London, instead of Heathrow or Gatwick.[14]

The aforementioned measures represent enforced restriction on runway capacity, and taken with the environmental restrictions, their impact on an airport can be severe, resulting in inefficient use of a resource and potential loss of revenue.

The restrictions also make the already complex issue of runway capacity even more intricate. The current implications of these issues to Europe, and how they are dealing with them, will be examined further in chapter four. The next 3 sections will discuss the other key parts of the infrastructure system affecting runway capacity, Air Traffic Control.

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14 Source: HMSO (1985) Airports Policy HMSO.

2.5: Functions of Air Traffic Control

The primary function of Air Traffic Control, (ATC), is to prevent the collision between aircraft in flight and between aircraft and any obstructions moving, or stationary on an airport. In addition to this, ATC also aim to provide a fair and efficient flow of traffic from origin to destination.[15]

The job of an ATC controller it must be stated is not an easy one. It has often been described as three dimensional chess as they have to move aircraft around a country in the vertical as well as horizontal plane, within limited airspace. A fourth dimension of time could be argued to be integral to this job, as well due to the need for aircraft to enter and leave the system at set time intervals.

To help controllers carry out their task, the airspace aircraft operate in is structured, as indicated in appendix 2.2. This allows the controllers to focus their work into dealing only with aircraft operating in the controllers allotted airspace segment. The controller is helped in this task by the many systems developed over the years. These are laid out in appendix 2.3. Once the aircraft passes beyond the limits of the controllers airspace it is handed off.

From the discussion in the appendix, it can be clearly seen that co-ordination between different sectors of the ATC system are crucial and can affect the number of aircraft each can handle quite significantly.

2.6: Factors affecting Airspace Capacity

2.6.1:Separation Standards

These are the greatest restriction on airspace capacity, but they are unavoidable if the aims of ATC to provide a safe, orderly flow of traffic are to be met. Aircraft are separated using two methods, vertical and horizontal separation. The latter method is broken into three sections; lateral, longitudinal and radar separation. The separations used are the minimum safe distances that should be maintained between aircraft, as defined by ICAO, assuming instrument flight rule, (IFR), conditions. Vertical separation minima are 1000ft between aircraft flying below flight level[16], (FL), 290, and 2000ft above FL 290. Vertical separation is used en-route to reduce horizontal separation and at the holding stacks on the edge of TMAs. On climb and descent vertical separation may be lost due to high traffic densities in the TMA. Where this occurs the aircraft must be separated horizontally. Obviously, individual aircraft rates of climb and descent will be used where possible by a controller to expedite an arrival or departure and optimise the traffic mix.

[15] From 'A Guide to Runway Capacity for ATC, Airport and Aircraft Operators' - CAA CAP 627

[16] A Flight Level is the altitude under the standard pressure setting of 1013.2 millibars which all aircraft operate. Altitudes are reported using the first three figures, e.g. FL 290 is equivalent to 29,000ft.

Horizontal separation will depend on an aircraft's track, speed and weight. Lateral separation is applied to prevent aircraft on different tracks interfering with the others track. Separation distances vary if the aircraft are on diverging or converging tracks depending on the angles between the two aircraft tracks. Details of the restrictions can be found in the UK CAA Manual of Air Traffic Services (MATS) - Part 1, which is based on ICAO guidelines.[17] Minimum separations will take into account the navigational accuracy of the navigation device, the pilot competence and a safety buffer. Longitudinal separation is applied to cover two aircraft following each other on the same track and altitude. Separation is determined either using time or distance. Time separation for en-route aircraft is 10 minutes for all scenarios, but can be reduced if the lead aircraft is moving quicker then the trail one. Departing aircraft are subject to minimum time separations to provide a continuous, safe and orderly flow of traffic from the TMA into en-route sectors, as well as to satisfy wake vortex restrictions. Times vary from 1 to 10 minutes depending on the speed and track of the aircraft, (see UK MATS Part 1). The reliability of time based separation depends on the accuracy and frequency of aircraft position reports, and estimated arrival times at the next reporting point. As previously, a safety buffer is applied to the minimum separation. Distance separation can be used by the controller in airspace which has a high quality of frequently renewed aircraft position information. Specific separations again are given in MATS Part 1. The minima applied will be dependent on accuracy of position information, the age of information displayed on the radar screen, elapsed time between radar updates, and the safety buffer. If an aircraft is within the coverage of a radar minimum separation can be reduced to 3 nautical miles, (nm), provided the aircraft is below FL 245 and has been identified. In all other cases the separation is 5nm. Appendix 2.4 describes how these separation minima are developed and may be reduced.

2.6.2: Wake Vortex Separation[18]

This factor concerns specific approach, arrival and departure separations imposed by an aircraft's wake turbulence. Every aircraft in flight generates an area of unstable air, aft of the wings, known as wake turbulence, as a by-product of lift. Detailed explanations of vortex formation can be found in Kermode, (1972) and Barnard and Philpott, (1989). The strength of the wake vortex depends on the weight, airspeed, wing shape, and attitude of the aircraft. Maximum vortex generation occurs with heavy and slow aircraft on take off and landing. The vortex duration commences on take off and ends as the aircraft's wheels touch down again. In the air the vortex will sink at 500ft per minute to 900ft below the aircraft's altitude and then dissipate. The latter is aided by strong winds which help destroy the vortex.

Wake vortices are potentially very dangerous to aircraft and in some cases cause structural damage to airframes, particularly when light or small aircraft follow heavy ones. Loss of lift can also be due to heavy wake vortex, and finally control problems can occur with small aircraft encountering uncommanded roll and pitch. The situation

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17 Source: ICAO (1987) Procedures for Air Navigation Services - Rules of the Air and Air Traffic ICAO

ICAO (1986) Procedures for Air Navigation Services - Aircraft Operations ICAO

18 Information taken from CAA (1993) Wake Turbulence - UK Aeronautical Information Circular 178/1993.

is most critical on take off and landing as aircraft airspeed is close to the stall. Table 2.4 defines the required separations between differing aircraft classes for arrival, due to wake vortex.

Table 2.4 clearly demonstrates the problems that a controller faces in sequencing arriving traffic. In the worse case of a single mode arrival runway, if a light aircraft followed a heavy, a separation of 8nm would be required. This equates to about 180 seconds when the aircraft are on final approach, if one assumes the aircraft are both travelling at 160kts. If the time for the heavy aircraft to land and clear the runway is 70 seconds, then there are 110 seconds, almost two minutes wasted due to wake vortex separation.

Arrival Wake Vortex Separations

Leading Aircraft	Following Aircraft	Minimum Distance
Heavy (e.g. B747-B757)	Heavy Medium Small Light	4 nm 5nm 6nm 8nm
Medium (e.g. A320-F100)	Medium Small Light	3nm 4nm 6nm
Small/Light (e.g. ATR72-J31)	Medium or Small Light	3nm 4nm

Source: UK CAA MATS Part 1.

TABLE 2.4

This lost time will result in reduced runway capacity that hour and, if the system is operating at capacity, increased delays. This scenario does assume the runway is used in segregated mode for arrivals only. Bearing this in mind, the controller is tasked with optimising the traffic mix to minimise these wake vortex restrictions. This is done by attempting to bunch aircraft of similar types. The advantage of this approach can be demonstrated below in a simple sum.

3nm 4nm 3nm 5nm 4nm

1. Bunching Small⇒Small⇒Medium⇒Medium⇒Heavy⇒Heavy = Total Separation Required of 19nm

3nm 6nm 3nm 3nm 6nm

2. Random Medium⇒Small⇒Heavy⇒Medium⇒Small⇒Heavy = Total Separation Required of 21nm

The saving of 2nm in the example above would relate to 45 seconds at 160kts approach speeds, from a total time of 472 seconds for random arrival to 427 seconds for bunching. To accomplish the above traffic mix, controllers radar vector aircraft within the TMA off the holding stack to the final approach path, (FAP). As aircraft approach the FAP they are turned on to an intercept course at different distances to optimise the sequence, (see figure 2.3).

There is one further factor which will also affect this traffic sequence and that is aircraft approach speed variability. Different aircraft types will have different final approach speeds, a Shorts 360, for example has a landing speed of 106kts, whilst a Boeing 747 will land at 153kts.[19] This means that as well as requiring standard wake vortex separation, extra separation is required to prevent a wake vortex separation infringement as the aircraft travel down the FAP. Optimum separation would result with only the wake vortex separation existing between the two aircraft as the leading aircraft lands. Obviously, the likelihood of achieving this optimum on every landing is slim at best, but will increase with controller experience.

ATC Final Approach Sequencing
(The Fanning Method)

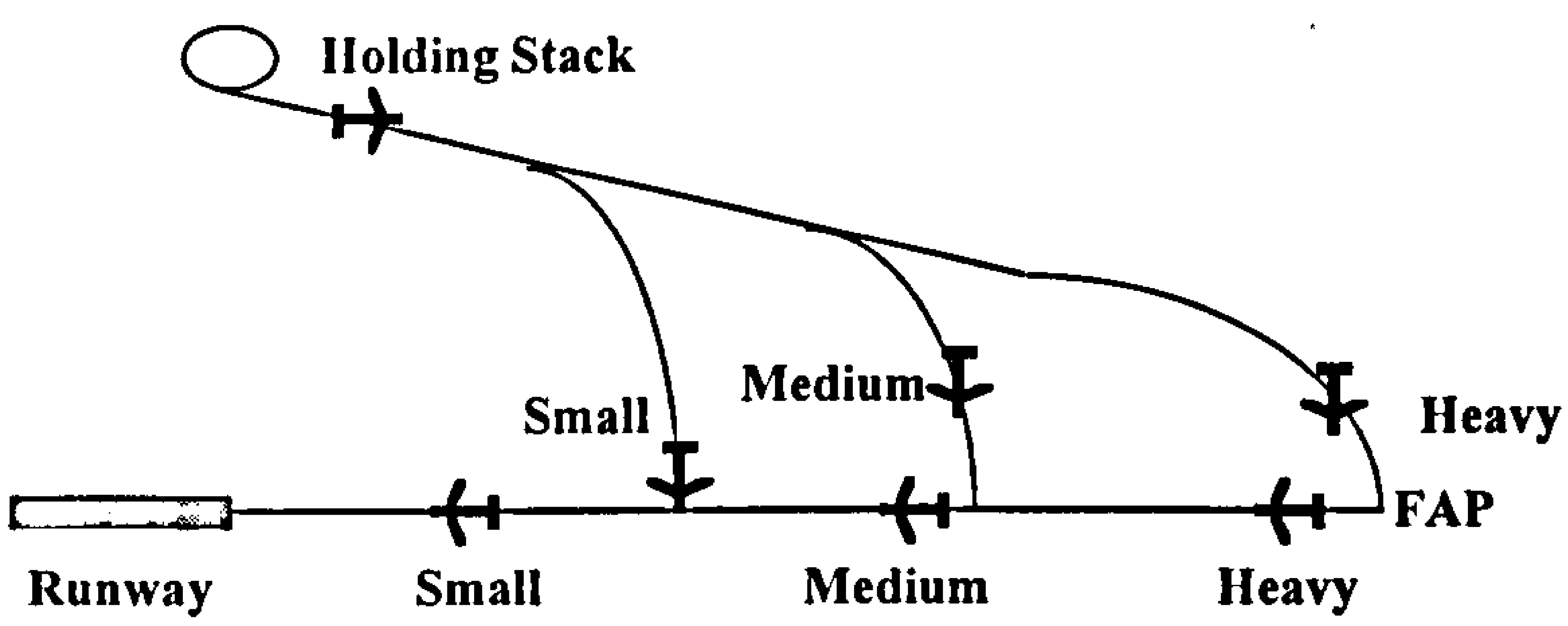


FIGURE 2.3

Wake vortex must also be considered on departure and the specific restrictions are given in table 2.5. Unlike arrivals the traffic mix is not the critical issue, here the point where the take-off run is commenced and the aircraft's departure track are more significant. This time separation may be increased to account for aircraft accelerating at different rates along the same track if they can not be separated vertically. This will be particularly relevant to a jet following a turboprop on the same route. The separation can be reduced to 1 minute between two successive departures, however if the aircraft's tracks diverge by 45° or more immediately after take off, (see UK MATS Part 1). As with the arrival situation the sequence of departing traffic needs careful management to prevent faster aircraft catching up a slow one, and infringing the separation standards. The arrangement of departures which avoid two successive departures along the same track is also preferred.

The above cases can be taken one step further by considering operations on a mixed mode single runway. The aim from the arrival situation was to bunch aircraft of the same weight categories to minimise separation. If that works correctly, there will be a

[19]Source: Flight International -Regional and Commercial Aircraft Directory 1993

run of aircraft separated by 3-4nm, or 68 to 90 seconds respectively, assuming 160kts approach speed.

Departure Wake Vortex Separations*

Leading Aircraft	Following	Aircraft	Minimum Spacing at time aircraft are airborne
Heavy	Medium Small Light	Departure from the same take-off position	2 minutes
Medium or Small	Light	Departure from the same take-off position	2 minutes
Heavy - Full Length Take-off	Medium Small Light	Departure from an intermediate take-off point	3 minutes
Medium or Small	Light	Departure from an intermediate take-off point	3 minutes

* Applies to aircraft departing from the same runway or from a parallel runway less than 760m apart.

Source: UK CAA - MATS Part 1.

TABLE 2.5

If it is assumed that the optimum use of a single runway is a sequence of arrival, departure, arrival, it can be demonstrated that, if an arrival and a departure each take a minimum of 50 seconds, 68 seconds will not permit a safe operation of this sequence. This poses yet another complication to the ATC controller, who must now increase arrival separations to create a departure slot in between two arrivals. This could be partly managed by re-arranging the arrival mix of aircraft, but will also lead to reduced runway arrival movement rates.

A final aspect of wake vortex concerns the tactics to avoid it. Strong winds are the vortices worst enemy, especially turbulent winds, which can break them up sooner than still air. A problem can be induced by this however, as the vortices could be blown onto a parallel runway. Early deployment of flaps or slats and landing gear can also help degrade vortices, as can engine power adjustment and high air density. On departure if an aircraft can aim to rotate and climb above the track of the preceding aircraft it will be free from the vortices.

In summary, wake vortex is the largest restriction on optimising runway capacity and whilst a number of strategies have been developed to alleviate the severity of the restrictions, one is unlikely to ever be rid of the problem.

2.6.3: Airspace Geometry

As the complexity of controlled airspace increases due to new airways, airports and TMA's, etc. the efficiency of the earlier system can be degraded, as more convoluted routes in and out of the airport are developed to avoid conflict with surrounding airports. In the UK, the London TMA is the prime example of this complexity. Coping with arrivals and departures into five closely located airports has led to a highly complex series of routes, which looks like spaghetti from above. Problems arise as the controllers have to sequence traffic from different airports together through bottlenecks, which in this case, are where the TMA routes cross or link to the airway system. The absolute effect on capacity will be determined by controller experience and decision making ability, radar accuracy, and the number of intersections along routes where co-ordination of aircraft is required. In the London TMA, NATS attempted to reduce some of these problems by introducing the Central Control Function, (CCF).[20] This envisaged the development of discrete and independent 'tunnels in the sky', linking each airport in the area, to the airways. Practical application of this was limited however and the focus has now shifted to improving controller co-ordination between the five airports and the TMA.

This section has discussed many factors that define airspace capacity and demonstrated the complexity of the task in hand. The final ability to handle the aircraft rests with the ATC controller though, and it is that person's ability to cope with the workload, that will determine the final capacity of any airspace sector. Appendix 2.5 discusses some aspects of controller workload in more detail.

2.7: ATC Management of Multiple Runways

The discussion of ATC has so far focused on aircraft operations on a single runway. Modifications to the rules outlined apply when multiple runways are used. These are detailed in the ICAO air traffic services planning manual with the relevant operating restrictions highlighted in appendix 2.6.

When ATC have more than one runway to use it can effectively double the complexity of the system, as both runways could potentially be operated in mixed mode. In general though, one runway is used for arrivals and one for departures. In this situation, the need to optimise traffic mix is the key to minimising the limits of wake vortex separations. Multiple runways also tend to increase the problems of airspace geometry discussed previously.

This concludes the discussion of ATC operations. It has been the intention to detail the rules and methods by which aircraft are controlled. The depth of the coverage reflects the subject's prime importance to this thesis. The latest developments and concerns of ATC within Europe will be returned to in chapter four.

2.8: Airline Operations

Following the previous discussions of airport and ATC operations, it is now relevant to examine airline operations to highlight what factors drive airlines, what concerns them, how they deal with these concerns, and how their actions may put pressure on airport and ATC capacity.

20 Source: CAA (1990) CCF- Handling London's Air Traffic in the Nineties. CAA

Airlines exist due to the public's desire to travel, either on business or leisure. In providing a service to the public, the airlines aim to operate an efficient route network, with the right sized aircraft to ensure they satisfy the public's requirements for the niche market they have decided to operate in, Also they must make a sound financial return on any investments. Achieving this relatively simple aim is complicated by the operating environment in which they operate as well as by competition from other airlines.

2.8.2: Aspects of Airline Economics and Competition

Whilst airlines control the routes they fly and the aircraft they operate, it is how they deploy these resources that will determine their fate. When considering routes to fly the airline must gather information regarding operating restrictions on the route, such as airspace and airport slot restrictions, existing operators on the route, nature and type of passenger demand, (business or leisure) and forecast future change in passenger demand on that route. Once these jobs are complete, the right aircraft must be acquired to operate the route. This will be dependent on the route length, passenger demand, crewing requirements, airfield performance, aircraft operating costs and availability, predicted average load factors and the aircraft's ability to accommodate future possible growth capabilities or route structure changes. Decisions will be based on the aircraft's payload range potential as indicated in figure 2.4.

Typical Payload Range Chart

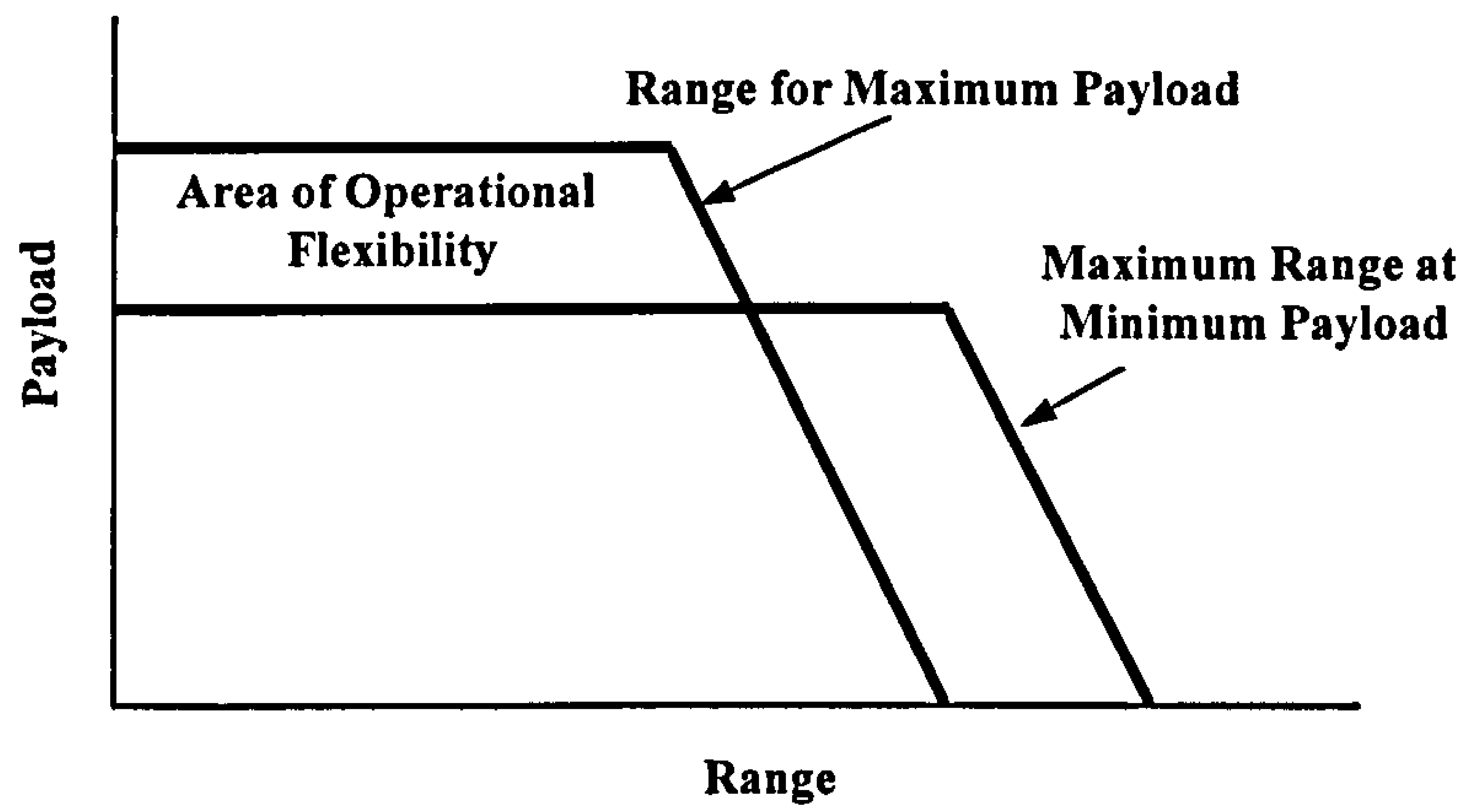
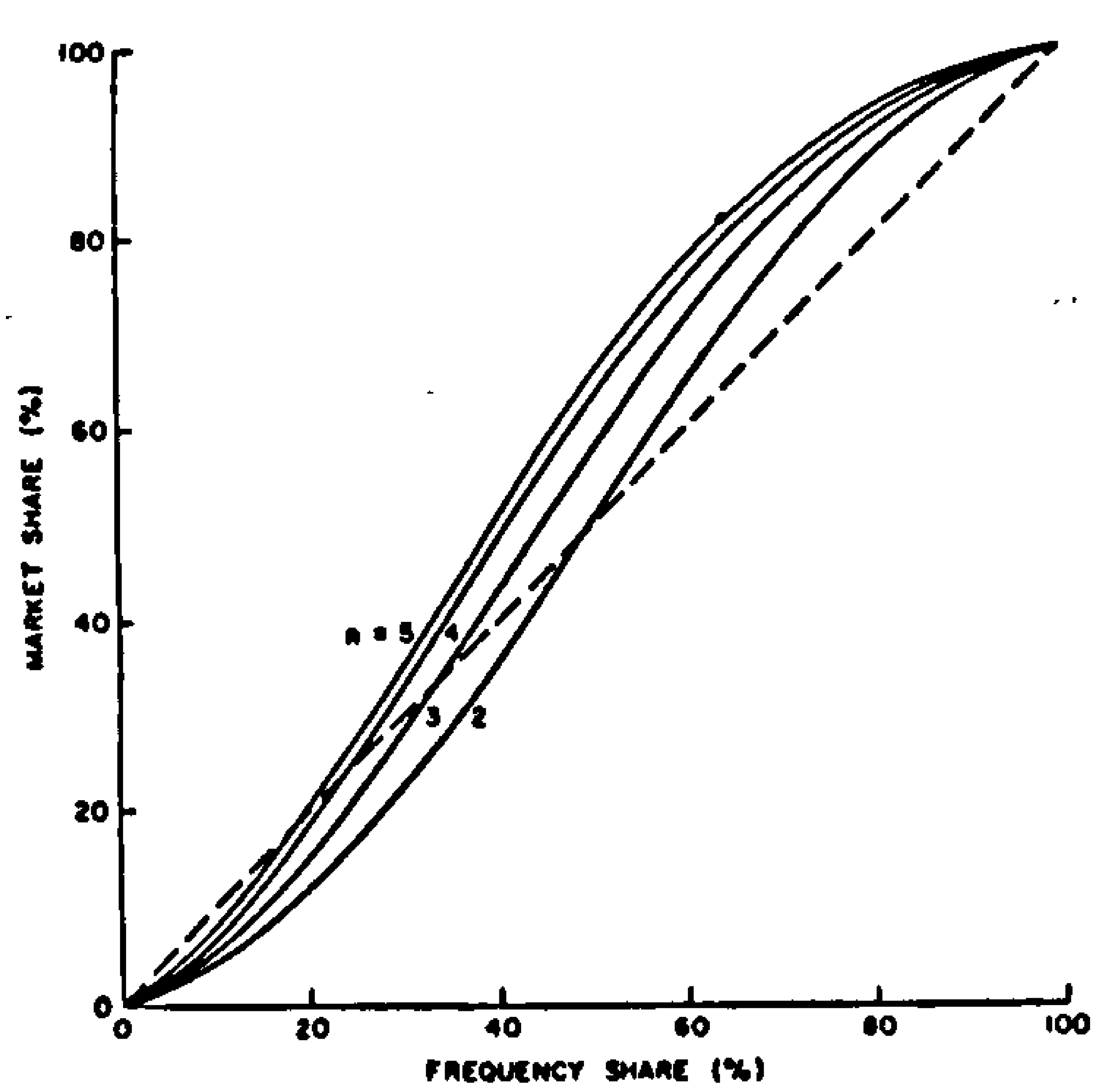


FIGURE 2.4

Absolute payload range figures will vary for each route depending on the departure and arrival airport. The reasons for this will become apparent in chapter three.

Once these factors are decided, the scheduled operating times need finalising, along with the route operating costs and finally, the service is marketed to the general public at set fares. The ultimate aim of this process must be to see a positive return on investment within a specified time interval. Success will depend on the airline's ability to fill the aircraft with sufficient business and/or leisure passengers to cover costs. Once a route is launched, careful monitoring is required to ensure that if external circumstances change, the airline can react by modifying its service to balance demand with supply. In achieving this airlines must ensure they remain competitive compared to other carriers. There are four factors which airlines use to accomplish this. The first is timing of flights. A new airline competing with an existing one must try to match or improve on the latter's timings, to effectively make any impact on the business passenger market. This causes bunching of flights around peak demand times, usually early morning and evening. Secondly, work by Taneja, (1988) has shown that the percentage of flight frequencies an airline operates on a route compared to its competitors, can directly be related to the percentage of the business market share attained. His classic S-curve is shown in figure 2.5. Obviously the absolute effect of extra frequencies will be dependent on the size and composition of the market, but it does encourage airlines to continually increase frequency to capture the business market share which, if done within busy time periods, can put a strain on infrastructure capacity.

The final methods are promotional fares or fare undercutting by the new entrant to attract passengers and the use of passenger loyalty schemes, such as frequent flyer points. The former option can be effective in the leisure market, if airlines have sufficient cash reserves to accommodate lost revenue during the promotion, whilst the latter option is focused on the business market and usually only made available by larger airlines, due to the greater incentive for passengers to take part in a scheme with a large route network, compared to a small one. In addition it is easier for a larger airline with greater access to cash reserves to implement this, than a smaller airline with tight cost margins. The issue of airline size will be returned to shortly.



Note: n = Number of competitors in the market.

FIGURE 2.5

Source: Taneja, N.K. (1988) The International Airline Industry, pg. 144

In summary then, if an airline wants to attract the business passenger it must offer the right combination of flight timings and frequency on a route, whilst if they are trying to attract the leisure market, the key must be to capture as much market share as possible and offer the lowest fare to the customer.

2.8.3: Congestion and Airline Economics

In economic terms congestion would be seen as an imperfection in the market as it serves to restrict competition to the detriment of the consumer. The two significant aspects which congestion forces on airlines are increased flight times, and restricted airport access. In the first case, an increase in flight delays will increase flight operating costs, decrease passenger satisfaction and lead to missed connecting flights and knock on delays. The impact of delays will vary dependant on route length. On short sectors, delays will represent a larger percentage of total flight time due to an increased percentage of the flight operating in the restrictive departure and arrival TMA's compared to a long haul flight. This can also affect operating costs on shorter sectors, as aircraft tend to fly around at sub-optimal flight levels in busy TMA's for a greater percentage of the time than long haul flights. It can lead to sector distances well in excess of the direct track distance.[21] In addition the ability to make up for delays on a shorter flight is less than for longer sectors for the same reason. This is especially relevant for regional airlines which tend to operate the shorter routes, with slower aircraft than the larger airlines, but with the same published time schedules to provide an acceptable level of service to the passenger. In addition once an aircraft has been delayed, it will tend to have a knock on effect to the rest of the daily schedule for that aircraft, although the airline's operation department will do their best to avoid this. Again it is harder for regional airlines to achieve this, due to generally tighter aircraft schedules and less spare aircraft than the larger airlines.

The second issue caused by congestion is slot control of an airport. These slots effectively restrict access to the airport during busy periods to prevent excessive delays. From a competitive point of view, unless an airline can obtain a slot to operate from the airport during these busy times their flight timings will be uncompetitive compared to established carriers which will make the task of attracting passengers to the new airline that bit harder.

Basically, the slots prevent full exploitation of market demand and consequently, lost potential revenue to the airlines.

2.8.4: Effects of Airline Size

The size of an airline will significantly affect how it reacts to competition from others as well as problems such as congestion. If we consider a large airline with many different route networks, the effect of disruption on one of its routes will be

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21 On Air UK's flight planned routes significant variations can occur between track distances flown versus the great circle distance between two airports. On the Edinburgh-London City route, for example, Air UK fly 409nm, whilst the great circle distance is only 294nm. The additional distance is due to an extended STAR for London City which vectors the aircraft around from the north west of London, over Stansted and out over the Thames estuary before turning back into the airport. This is due to the very limited airspace around London.

proportionally less than an airline with a few key routes. This holds true as long as the larger airline has not co-ordinated routes together to provide passengers for other routes - the hubbing philosophy. The larger airline will also work from a greater money reserve, allowing it to cross subsidise poor revenue generating routes.

The factors outlined produce possible barriers to market entry for smaller airlines, unless they can make friends with a large airline themselves and gain from the latters position in the market. This can be achieved by a buy out, codeshare or franchise agreement and have become more prevalent recently.

This concludes the discussion on airline operations which has focused on the economic impact of competition and congestion on them. It is now time to consider the final part of the operating environment, air transport regulation.

2.9: Air Transport Regulation

Regulation of air transport has always been the responsibility of national governments through acts passed in parliament. There are two types of regulation, either technical or economic. The former covers aircraft, airport and ATC operating standards whilst the latter concern regulation of airport and airline growth and competition. During the last few years there has been a push to reduce the level of regulation imposed on aviation, which was led by the deregulation of the domestic air transport market in the US. This section aims to analyse the development and change of regulation in Europe and the consequences of this change on the capacity of the aviation operating environment.

2.9.1: European Regulation

Regulation affecting aviation in Europe is split into a number of separate organisations each affecting the industry in different ways. Appendix 2.7 defines the separate sections of the regulatory system and the work they are currently involved with.

The predominant drive by the EU, during the last fifteen years, has been that of liberalisation in air transport. The process of liberalisation is the reversal of the bilateral agreements proposed by ICAO and aims at increasing competition between airlines by removing restrictions against new airlines entering the market. As a consequence they hope this will generate reduced air fares for the consumers. The concept originated from the US which began domestic deregulation in 1978 following complaints by airlines and consumers over the lack of choice of operators on routes, poor level of service and barriers to market entry. The result of the deregulation was an initial growth in the number of airlines followed by a later decline as the less efficient airlines went out of business. The result forced airlines to intensify their competition, improve services and marketing for the customer and become generally more cost efficient in all areas of their operation. The effect was to remove excessive monopoly profits, a success for free market economics, but more importantly to this thesis, it led to increased congestion at major airports as the new airlines tried to squeeze their services into the peak hour periods. Further effects of US deregulation can be found in Doganis, (1991).[22]

The economic success of deregulation in the US meant it was only a matter of time before it was tried in Europe. Unfortunately though, unlike the US, Europe is a collection of very different and individual countries, whose opinions and cultures have conflicted with one another over a long time period. For this reason, attempting to reach agreements is at best difficult and at worst impossible. If liberalisation was to work a slow and careful approach would be required. Initial changes came with the re-negotiation of bilaterals in the mid to late 1980's following the outlining of the EU's nine air transport objectives in March 1984.[23] New styles of bilateral agreements were developed permitting more than one airline access to more than one route. Capacity control was removed and fares had to be rejected by both governments to prevent it being implemented. Doganis, (1991), indicates that when the UK-Netherlands bilateral was re-negotiated in the above format, the number of airlines operating on the London - Amsterdam route doubled. The effect on other routes was much less dramatic however. Liberalisation continued despite these poor early results with the ruling of the European Court of Justice in April 1986, that articles 85-90 of the Treaty of Rome regarding competition, did apply to air transport.

These rules prevented airlines agreeing fares to reduce competition, giving commissions to travel agents promoting the airline, misusing computer reservation systems for their gain, manipulating airport arrangements to create disadvantages to competitors and using predatory pricing to force competitors out of a market. Breach of these rules would result in considerable fines. By 1987 these rules had led to airlines forming alliances, or merging with others to circumnavigate these restrictions. The EU's response came in December 1989 with a regulation that any merger would be investigated if the combined turnover of the two companies exceeded 5 billion ECU. The final process of liberalisation was three packages passed by the EU to open up further the European market. The detail of these packages are defined in table 2.6. A good summary of the Liberalisation process and the effect it subsequently had can be found in the 1997 EU Single Market Review.

The table clearly shows the lifting of operating restrictions but it is two points in the last column that are of most importance. Firstly, regulations are still imposed at airports considered as congested, which aims to prevent unrealistic aspirations of new airlines flying anywhere they want. Secondly, and more importantly though, April 1997 is the date when total domestic deregulation in Europe occurred. This mirrors the situation in the US, and allows any airline of any country in the EU to fly on any route in the EU. This is likely to encourage growth in air transport which will then tend to put a strain on existing airspace and airports which are already noticing capacity limits or those close to it but not protected by being currently classed as congested.

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22 A good source of information on US Deregulation is Buton, K.J. (1989) The Degregulation of US Interstate Aviation: An Assessment of Causes and Consequences Transport Reviews, Vol 9, pg 189-215

23 These are defined in Doganis, (1991) Flying Off Course - The Economics of International Airlines. p82-83

European Liberalisation Schedule

1st Liberalisation Package 1st January 1988	2nd Liberalisation Package 1st November 1990	3rd Liberalisation Package 1st January 1993
Creation of a fare zone to allow generation of discount fares	Range and scope of fare zone extended	Free pricing regime for air fares
Equal sharing of capacity abandoned 45% to 55% allowed from Jan 1988. Extended to 60% by Oct 1989.	If 60% limit had been reached, the airline was allowed to increase it at 7.5% in the following two years	Open market access - Freedom to fly between any two points in different community states. Restrictions for safety, environmental, congestion, and preservation of public service obligations were not lifted
Traffic rights between regional and main airports created	Multiple designation on all community routes with more than 140,000 pax. per annum	Common airline operators licence - Complete harmonisation of all regulations
Allowed second carrier on intra-Community routes once traffic passed a certain level	Exemptions granted to airports on congestion grounds were withdrawn	Right for a foreign airline to operate between two points in another country restricted until April 1997
Fifth freedom rights granted for airlines on routes between two other Community states (30% of seats on the route only)	Fifth freedom rights increased to 50% of seats offered on the service	
	All bilateral limits on capacity to be abolished by 1 January 1993	
	Double disapproval of air fares on all intra-community routes by 1 January 1993	

TABLE 2.6

Source: EU (1997) The Single Market Review Subseries II - Impact on Services Vol II - Air Transport

2.9.2: Consequences of Regulation

Whilst before liberalisation, airlines complained about the restrictive access of markets, and the development of a few large airlines who exploited their monopoly positions. It did enable the governments to protect their national airlines, their local community services, and let them manage the balance of demand with supply at airports. It prevented the system from operating at its economic optimum by artificially restricting supply and consequently there was a loss of potential revenue. Free market competition, on the other hand, leads to new entrants and price cutting. Consequences of price cutting can be serious for jobs and the local community if it leads to airlines going out of business. Finally regulation prevents the loss of key routes for the general public, which would disappear if airlines were allowed to remove unprofitable routes without consultation, especially those to small remote settlements, where the traffic generated is too small to finance a private air service by itself.

In conclusion regulation and liberalisation both have their advantages and disadvantages and the move from one to the other will result in some sort of opportunity cost. Within Europe though, the trend is for liberalisation which, by encouraging new airlines, new routes and frequencies, will do little to ease pressure on already congested airports and, it could be reasonably argued, will lead to increased congestion problems. Reasons for this are due to the problem of an imperfect operating market as, whilst the airlines are free to operate in the deregulated market, the airports and ATC are not, and passenger demand is therefore focused at a few principle airports, rather than at many smaller ones.

2.10: Summary

This chapter has outlined how the capacity of the aviation system is derived, and the number of restrictions, direct and indirect, that exist within the operating system. Table 2.7 outlines the factors that contribute to the system capacity and which player in the system is principally responsible for them.

Table 2.7 provides not only a useful summary of the factors affecting congestion, but is also useful in looking at how different parts of the operating system should deal with conflicts of interest. Delays to a flight arriving at an airport could be the airline's fault for a late departure, air traffic's fault for en-route delays, or the airport's for lack of arrival slots or ground congestion. This approach is quite logical, assuming each party is responsible for managing their portion of the operating system, but consider, if the system is operating at capacity, then no matter how any part of the system is managed, reduction in delays will be impossible. In this case the only solution lies with the regulators who are the only party capable of increasing or expanding existing resources, by providing finance or less strict regulations to the other parties, which could enable them to increase capacity.

System Capacity Responsibilities

Airports	Air Traffic Control	Airlines	Regulators
Rate of Airport development	Separation standards	Runway occupancy	Environmental restrictions, esp. noise
Apron size and number of stands	Wake vortex separation	Aircraft performance	Airport development restrictions
Number and type of taxiways	Sequencing of traffic mix	Flight frequency and timing	Liberalisation of air transport
Runway configuration	Airspace integration and management	Flight routing	Control of available airspace
Number and location of RETS	Controller workload and experience	Hubbing flights	Protection of consumer and general public interests
Number and location of RATS	Mode of runway operation		Political agendas
Slot Allocation	Multiple runway management		
Number and size of DSPS	Air traffic flow management		
Category of runway operation			

Factors beyond control:	Weather, Physical environment
Factors all are responsible for:	Use of latest technologies and development of accurate forecasts

TABLE 2.7

In conclusion the operating system is established and maintained by airports and air traffic control to permit the airlines to satisfy the public's demand to travel. However, the absolute capacity limits on the system are controlled by the regulators. An appreciation of this point by the airlines, airports and air traffic control, and the need to work in collaboration to achieve meaningful results, will be the key to optimum future capacity improvements.

This thesis will now turn to examine the technical aspects of aircraft performance which permit the regional aircraft to carry out special procedures.

CHAPTER 3: Regional Aircraft Performance Characteristics

3.1: Introduction

The aim of this chapter is to outline and explain the aspects of aircraft design and performance that permit regional aircraft[1] to carry out the special procedures which will be defined in chapter five.

The chapter will be broken into six sections. The first section will set the background to aircraft performance. The basics of aircraft performance followed by a brief discussion on the regulations that affect performance will complete the general part of the chapter. The remaining sections will focus on regional aircraft specifically looking at aircraft speed flexibility, initial climb and low level turning ability, and finally the ability of aircraft to carry out steep descents.

3.2: Background

Each aircraft has a unique set of performance characteristics which are determined by its physical shape and design. The design is usually focused at producing an aircraft capable of effectively competing with other aircraft in a specific operating market. The final design will be a result of the consultation between aircraft manufacturer and airlines over the required performance limits for such factors as aircraft operating range, payload uplift, speed, rates of climb and descent, fuel efficiency and manoeuvrability. There tend to be two types of compromise that occur before the aircraft is finally built which are design compromise and economic compromise.

If the aircraft is designed with one particular performance characteristic in mind it is likely that the remaining characteristics may be compromised. For instance, if an aircraft is designed for maximum speed, fuel efficiency and operating range may be poor. On the other hand, an aircraft designed for maximum payload uplift may have slow rates of climb and descent or poor speed flexibility. The final design is likely to be a compromise in performance terms to prevent excessive degradation of a particular characteristic.

The design of the British Aerospace 146 jet is an example of an economic compromise.[2] Due to the bankruptcy of Rolls Royce in 1970, the engine the designer had anticipated to use on the 146 was no longer available. Instead they turned to Textron Lycoming who offered the ALF502 which was the best alternative engine available at that time. Unfortunately, it only offered 6,500lb of thrust which meant

[1] The term regional aircraft is that defined in chapter 1 of this thesis.

[2] Source: Hardy, M. (1991) Modern Civil Aircraft 11 - BAe 146 Ian Allen Ltd.

four engines would be required instead of the two originally expected. This caused higher relative fuel burns compared to the twin engine competitors which came at the same time as rising fuel prices following the Arab-Israeli Yom Kippur war of October 1973. The advantage though was that four engines helped the aircraft meet it's original design philosophy of offering a jet replacement for the Viscount and Fokker 27 capable of operating without restriction from airfields up to 5000ft and temperatures of ISA+20. This was due to less restrictive penalties for engine failure on a four engined aircraft compared to a two engined aircraft.

Taking the above argument one stage further it can be deduced that an aircraft is designed to meet specific requirements at a specific time. However, in the future these specific requirements may no longer be relevant. In the case of the BAe 146, its ability to operate like a turboprop in and out of short fields has now meant it can be considered as a regional aircraft and those earlier performance requirements can now be used to help reduce congestion at busy major airports. It is this approach to utilising previous performance characteristics in a new environment that this thesis is built on and the specifics of these characteristics will be explained in more detail in further sections of this chapter.

3.3 Aircraft Performance Principles

Prior to discussing the specific performance characteristics that differentiate the regional aircraft from the jets, it is worth covering a few of the principles of aircraft performance. Figure 3.1 shows the four basic forces acting on any aircraft.

Basic Forces Acting on an Aircraft

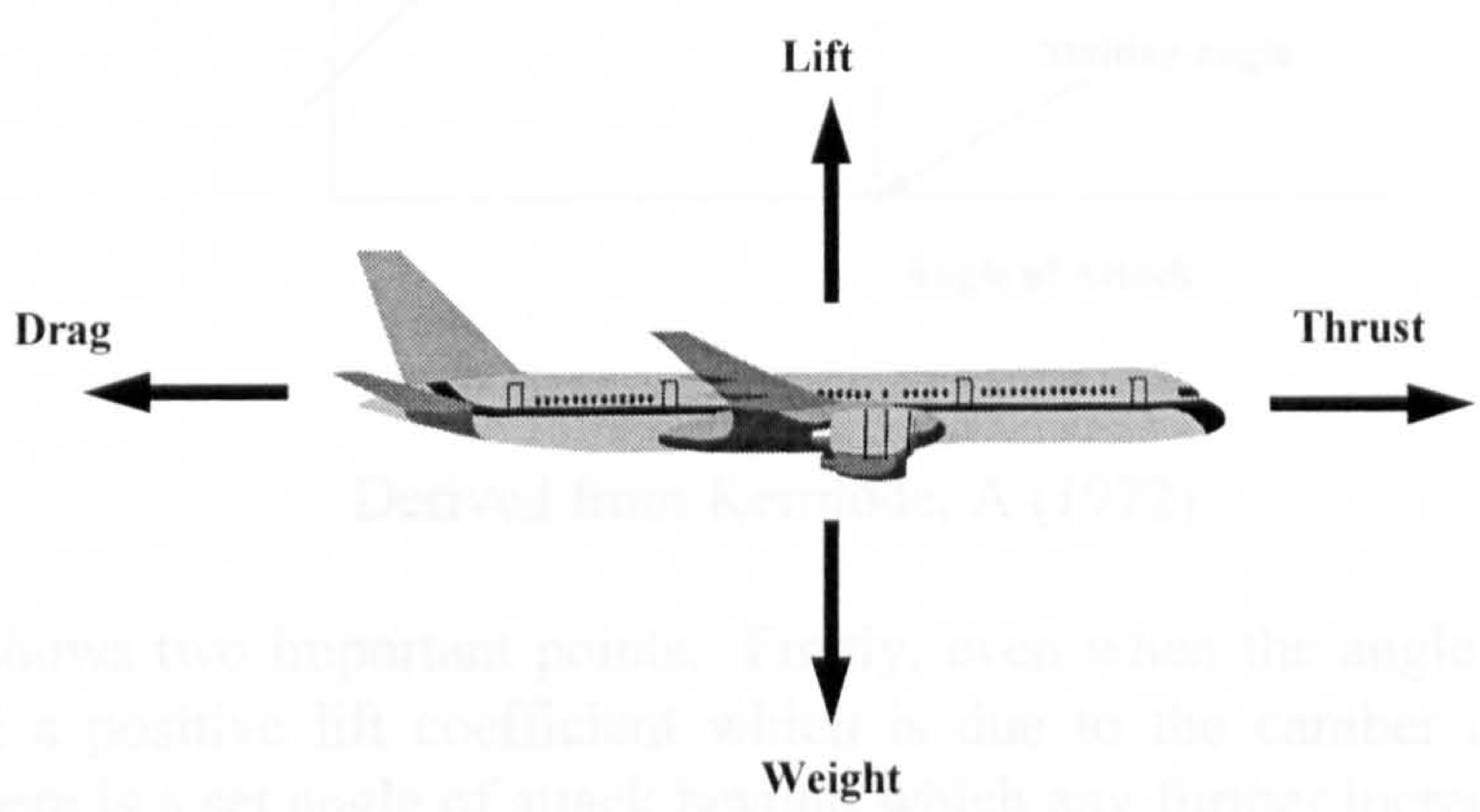

FIGURE 3.1

The figure shows all the forces as balanced which is applicable when the aircraft is in straight and level flight at constant speed. This is not always the case though and an appreciation of how these forces interact together and vary is crucial to understanding the rest of this chapter.

Lift

This force acts at right angles to the direction of the airflow.[3] Almost all the lift on a conventional aeroplane is generated by the wing. In terms of physics, lift is generated by producing a greater pressure under the wing than above it. Precisely how much lift is generated by a wing depends on it's design, the speed of the aircraft and the air density. Mathematically the lift force is defined using the following equation:

$$\text{Lift}^{4} = C_L \times \tfrac{1}{2}\rho V^2 \times S$$

C_L = Lift Coefficient S = Plan Area of Wing (m^2)
ρ = Air Density (kg/m^3) V = Aircraft True Airspeed (Kts)

Source: Kermode (1972) pg. 85

These factors are relatively self explanatory with the exception of C_L. The lift coefficient is dependant on the shape of the aerofoil, (i.e. thickness and curvature/camber), and it alters with the angle of attack of the wing, (i.e. the angle the wing makes with the aircraft flight path). This basic relationship is shown in figure 3.2.

Lift Coefficient and Angle of Attack Relationship

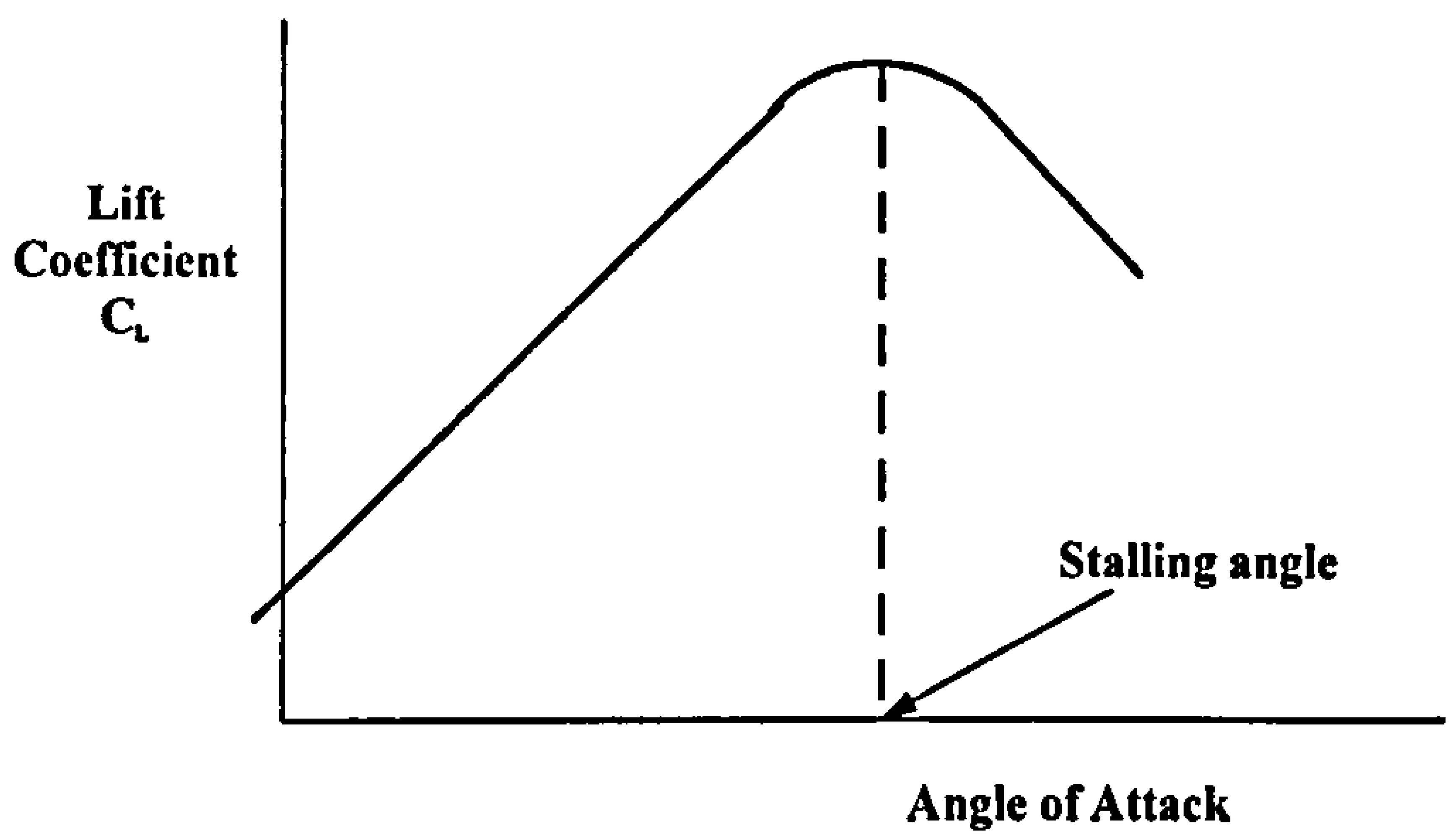

FIGURE 3.2
Derived from Kermode, A (1972)

The figure shows two important points. Firstly, even when the angle of attack is 0° there is still a positive lift coefficient which is due to the camber of the aerofoil. Secondly, there is a set angle of attack beyond which any further increase in the angle of attack will result in a loss of lift. This is the stalling angle of the wing and will always occur at this angle almost irrespective of speed.

To increase the lift generated by any wing the following changes can be made:

[3] Source: Kermode, A (1972) Mechanics of Flight pg 72.
[4] Source: Kermode, A (1972) Mechanics of Flight pg 85.

Increase Wing Camber - This is the most significant change that can be made and will lead to the same increase in the lift coefficient compared to uncambered wings at all angles of attack but it will reduce the maximum speed of the aircraft due to increased drag. To optimise the high lift properties of a highly cambered wing with the speed advantage of a lower cambered wing, flaps and leading edge devices are used. These can vary the wing camber and consequentially permit operations at lower speeds than would of been possible with a fixed camber wing. The precise effect of specific high lift devices will vary from aircraft to aircraft but general effects are outlined in Kermode (1972).

Increased Aircraft Speed - Simply the faster an aircraft flies the greater will be the lift generated other things being constant. This statement only applies whilst the wing is unstalled.

Increase the Aspect Ratio - This the ratio of the wing span to the wing cord, i.e. it tells us whether the wings are long and thin or short and fat. A high aspect ratio wing will provide a better lift to drag ratio, i.e. the lift is increased with a lower increase in drag, than a low aspect ratio one.[5]

Increase Air Density - The denser the air, the greater the lift generated by a wing and vice versa. This means that operations from a hot airport at a high elevation will be more limited due to the lower relative air density than ones from a cold and low airport.

Increase the Wing Area - This can be achieved by putting out the flaps at slower speeds. Any other changes are only possible by major structural change and are unlikely to occur once the aircraft has been designed.

Increase in Wing Thickness - Thicker wings generate more lift and are best a low speeds and for weight uplift whilst thinner wings are better for higher speed.

Increased Wing Incidence - This has already been covered in figure 3.2.

Graphically, the effects of high aspect ratios and high lift devices on the lift coefficient compared to plain wings is shown in figure 3.3.

The high aspect ratio wing offers an improved rate of increase in the lift coefficient with angle of attack compared to the plain wing, but reaches the stalling angle at a lower angle of attack. It does, however, achieve a greater C_L Max. High lift devices offer a fixed increase in the lift coefficient with angle of attack compared to the plain wing and also an improved stalling angle.

Drag

This force acts in parallel to the direction of the airflow and represents the air resistance felt by the aircraft as it moves through the air. Effectively it opposes the motion of the aircraft. The factors that determine the drag are similar to lift, however

[5] Source: Kermode, A (1972) Mechanics of Flight pg 104-109.

drag is not just generated by the wings but the whole aircraft including the fuselage, tail plane and engines.

Effect of High Aspect Ratio and High Lift Devices to the Lift Coefficient

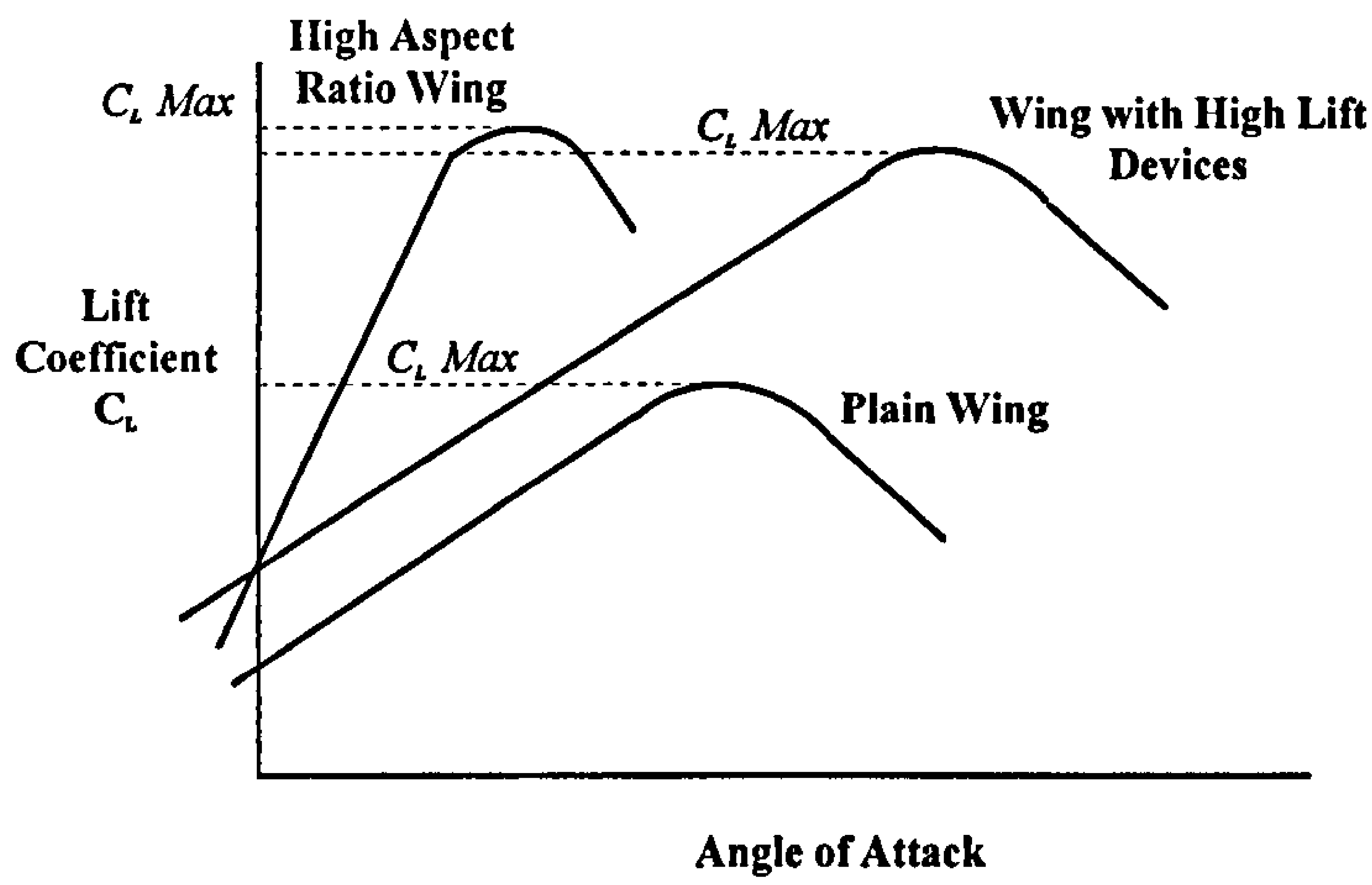

FIGURE 3.3
Derived from Kermode, A (1972)

There are three principle types of drag.[6] Parasitic drag is the drag created by the pressure change of the air as it passes over the aircraft and has three parts. Skin friction drag is caused by the disruption of the air as it passes over the aircraft skin. Form drag is created as the airflow separates from the aircraft surface and can be reduced by streamlining. Finally, interference drag is drag created by the flow interference caused at the junction of various surfaces on the aircraft, i.e. the wing and fuselage junction.

Induced drag is the second principle type of drag. This is drag caused by the wing vortices which represent a by product of lift generation, i.e. Wake vortices as already mentioned in chapter 2. It can be reduced by having a wing with a high aspect ratio. This drag is increased as aircraft weight and lift generation increase. It decreases as the aircraft speed increases however, which is the reverse of parasitic drag which increases with aircraft speed.

Finally drag can be varied during flight to permit the aircraft to operate in conditions it would otherwise not be capable of. This is done by the use of flaps and high lift devices, lift dumpers or spoilers, clam shell doors and a variable pitch propeller. This point is especially important to this thesis and the reasons will be explained later.

The mathematical equation for drag is almost the same as for lift:

[6] Source: Thom, T (1988) The Air Pilots Manual Vol. 4 - The Aeroplane Technical. Airlife.

$$\textbf{Drag}^7 = C_D \times \tfrac{1}{2}\rho V^2 \times S$$

C_L = Lift Coefficient S = Reference Area of Aircraft (m^2)
ρ = Air Density (kg/m^3) V = Aircraft True Airspeed (Kts)

Source: Kermode (1972) pg. 85

The relationship of these factors to drag is not the same as lift though, and the relationship between lift and drag is not constant. The lift force is generally 10-15 times greater than the drag force, although this diminishes with increased wing angle of attack as drag increases at a faster rate than lift.[8] The relationship between the drag co-efficient and the angle of attack is shown below in figure 3.4.

Drag Coefficient and Angle of Attack Relationship

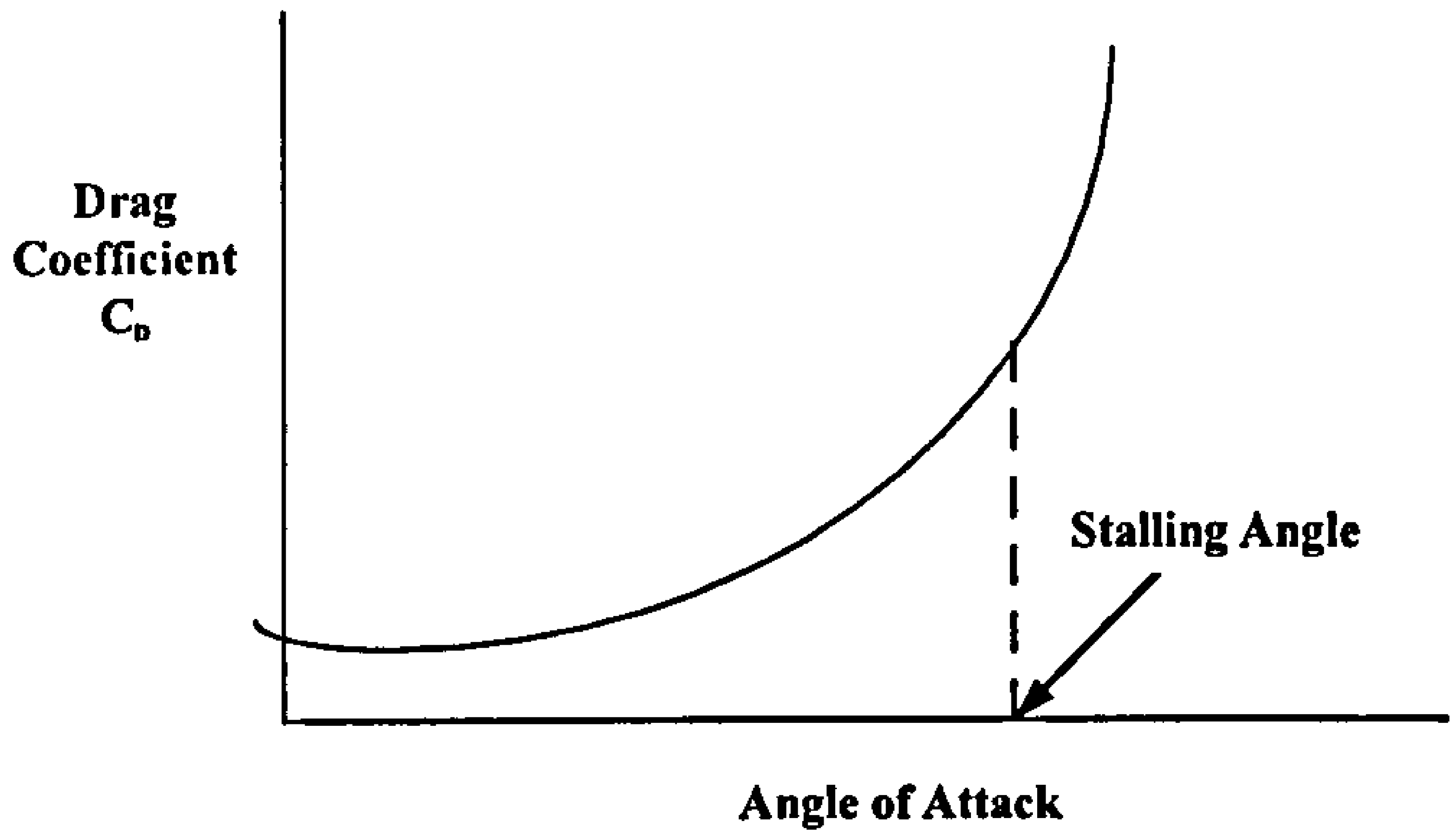

FIGURE 3.4
Derived from Kermode, A (1972)

If this figure is compared to figure 3.2 we can see that as the lift coefficient increases so does the drag coefficient but initially at a lower rate. As the angle of attack approaches the stalling angle though the drag coefficient will increase at a greater rate than the lift coefficient. This relationship between lift and drag is very important in determining the optimum angle of attack for the aircraft during climb, cruise and descent and the design of the wing and it can be appreciated that a compromise between lift generation and drag must be made in every aircraft designed.

Thrust
This is the force generated by the aircraft engine which opposes the drag and moves the aircraft forward. The size of the thrust is proportional to the mass of air moved by the engine and the degree of acceleration imparted to that air.[9]

[7] Source: Kermode, A (1972) Mechanics of Flight pg 85.
[8] MSc Air Transport Course Notes (1995-96) Cranfield University
[9] MSc Air Transport Course Notes (1995-96) Cranfield University

For level, unaccelerated flight, thrust must equal drag, whilst for an aircraft to accelerate or climb the thrust must exceed the drag. During climb the greater thrust is required to support a proportion of the aircraft weight acting with drag against the thrust.

The thrust on most commercial aircraft these days is either generated by a turboprop or a turbofan engine.

If we consider the turboprop first we can see that the thrust is generated by a propeller on the front of the engine pushing a large volume of air back over the wing. In this case the propeller is basically driven by a jet engine with a compressor, combustion chamber and turbine[10]. Gearing is then introduced on the propeller drive shaft to reduce the rotation speed, allowing the propeller to turn at manageable speeds. The basic layout of the turboprop is shown in figure 3.5 which is a breakdown of the Fokker 50 Pratt and Whitney PW125B engine.

A Cross Section of a Turboprop Engine

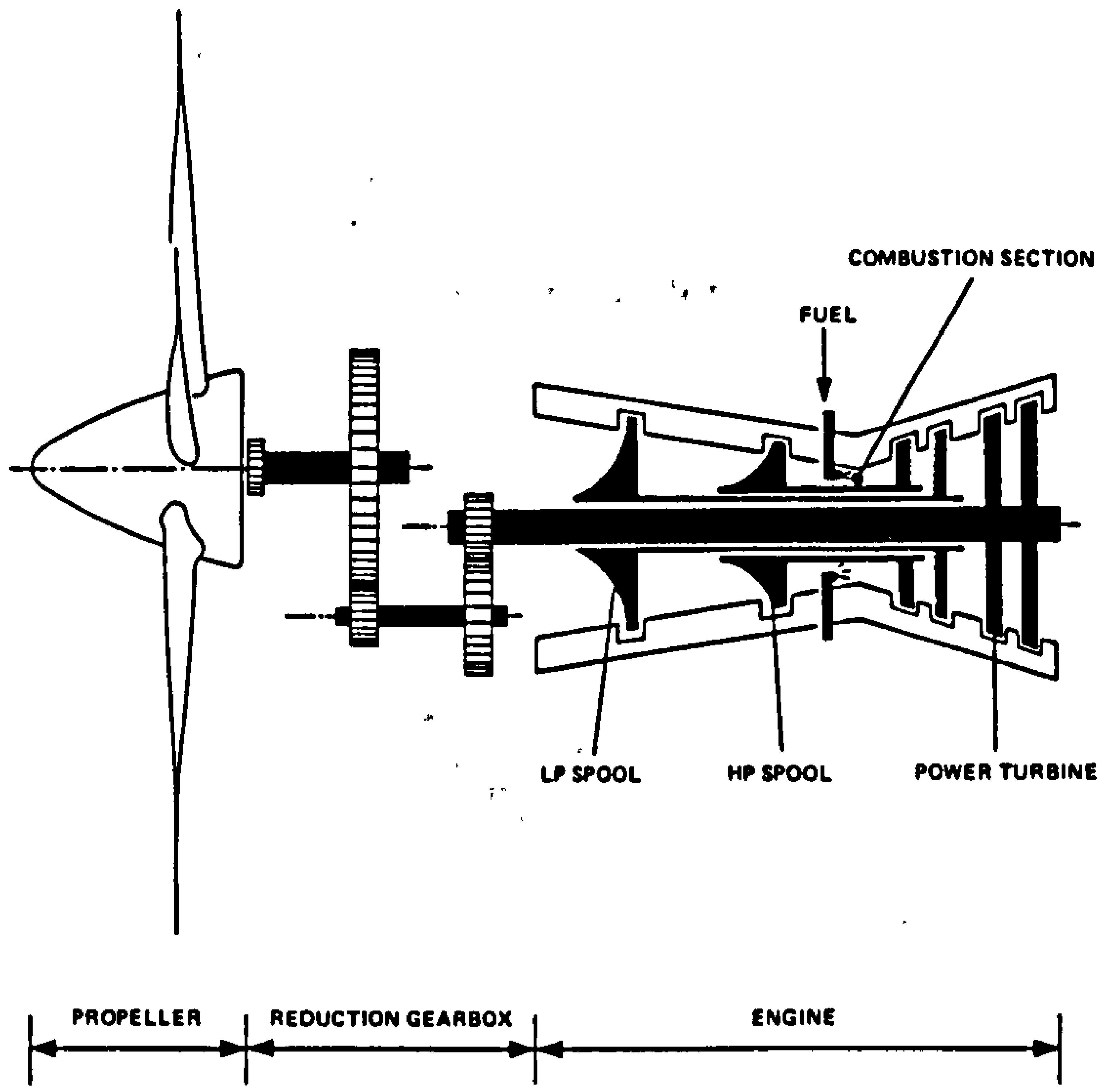

FIGURE 3.5
Source: Fokker (1988) Fokker 50 Aircraft Operating Manual

[10] A detailed description on the operation of turboprop and turbofan engines can be found in: *Rolls Royce (1986) The Jet Engine Rolls Royce.*

From the diagram it can be seen that the engine has both a low pressure, (LP), spool and high pressure, (HP), spool. These compress the air before it is mixed with the fuel and burnt. The exhaust from this accelerates the air through the turbine which in turn drives both spools and the propeller, through the reduction gearbox.

The thrust developed by the turboprop is determined by the propeller rotation speed and pitch plus the number and shape of the blades. Figure 3.6 shows that each propeller blade is shaped in the same fashion as the wing aerofoil. As the propeller rotates then a lower static pressure is generated ahead of the blade than behind it and it is this pressure differential that creates the thrust force, effectively pulling the aircraft along.

The blade angle shown in figure 3.6 is a combination of the blade angle of attack, which is similar to that discussed for a wing, and the pitch or helix angle. This pitch angle is the angle between the resultant velocity of the propeller blade and the plane of rotation of the propeller.[11]

Almost all modern turboprop engines are what are termed, '*Variable Pitch Constant Speed Propellers*'. This means that the pitch angle of the propeller blade is varied to ensure the engine is generating thrust at optimum efficiency as the aircraft speed changes. The speed the propeller is rotating though is not changed except for take off and go-around. The Fokker 50 for instance has a fixed cruise propeller revolution per minute, (RPM), which is 85% of maximum RPM.[12] This is changed to 100% of maximum RPM for take off and go-around.

The Propeller

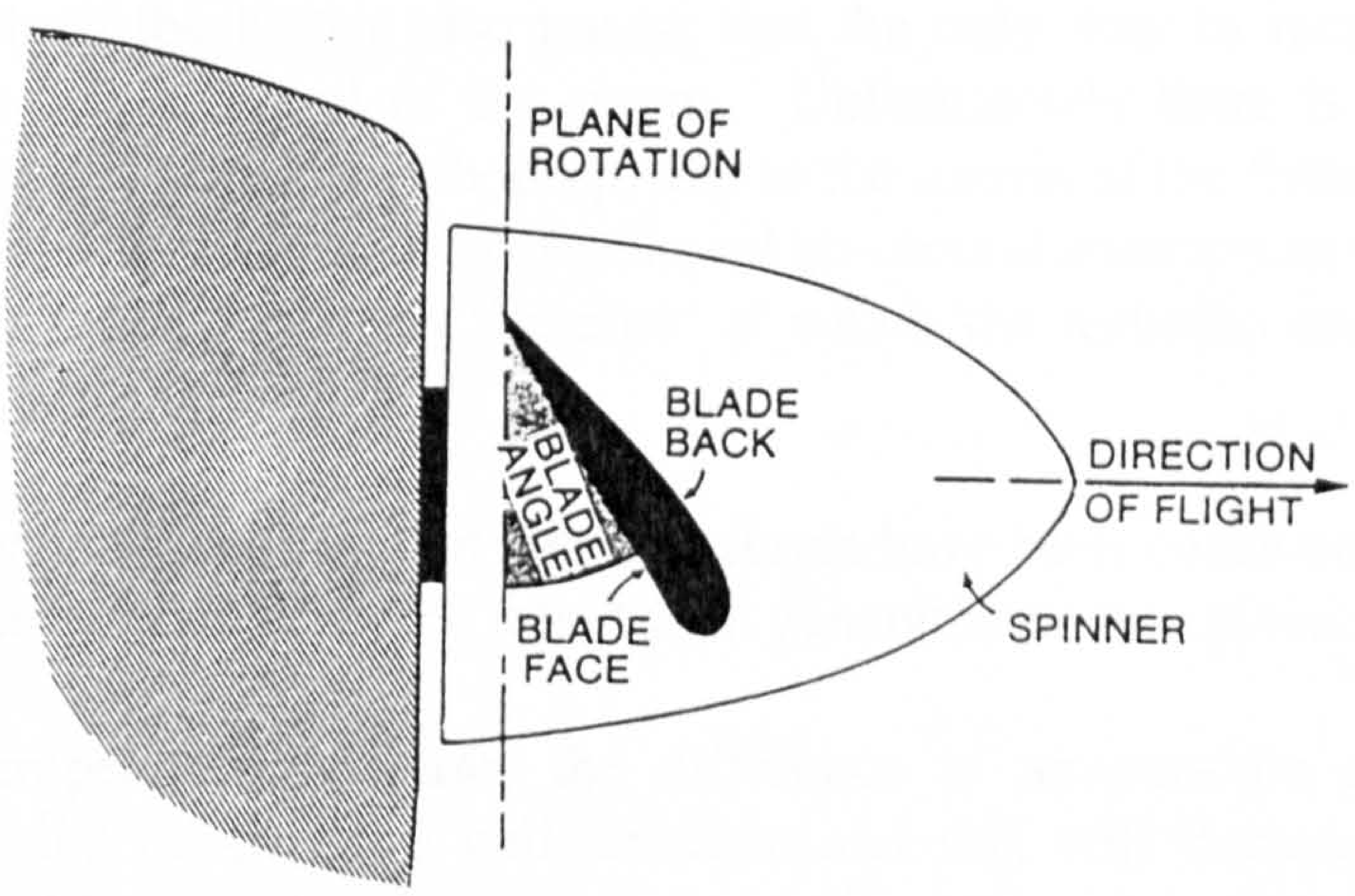

FIGURE 3.6
Source: Thom, T (1988) The Air Pilots Manual

[11] Source: Thom, T (1988) The Air Pilots Manual Vol. 4 - The Aeroplane Technical. Airlife.
[12] Fokker (1989) Fokker 50 Aircraft Operating Manual Fokker.

At low speeds the blade angle needs to be small for the angle of attack to be optimum and this is known as, *fine pitch.* As the aircraft speed increases, the blade angle needs to increase to optimise the angle of attack, this time it is called, *Coarse Pitch.* This coarsening of the blade pitch will also serve to minimise the drag of the propeller during high speed flight. The blade angle on the Fokker 50 for instance varies from 12° for approach and landing to approximately 45° for high speed flight.

Two further developments have occurred with the development of variable pitch. Firstly, if the engine fails the propeller blade can now be *feathered.* This is where the blade is turned beyond the normal fully coarse position, until the blade lies along the direction of flight. This minimises the drag and prevents windmilling of the propeller. The second development was to use the propeller as an air brake on the ground to aid deceleration. It is achieved by turning the blade beyond the fully fine position so generating a reverse thrust force.

The principle advantage of the variable pitch propeller over a jet turbofan is that it can give an almost instantaneous response to demands for variation in thrust which makes the aircraft easier to manoeuvre and accelerate or decelerate. This advantage will be returned to later.

If we now look at the turbofan engine, there a few specific points that need making. Firstly, the engine is physically different from the turboprop as the propeller has now effectively been enclosed within the engine casing and further blades have been added to make it the first fan section of the engine compressor. The important point to make is that now all the blades are fixed in pitch because they are enclosed. Use of variable pitch blades inside the casing would only serve to rip the casing due to the higher rotation speed and minimal blade tip clearance.

The fixed pitch of the blades also means that the only way to increase thrust is to increase the rotational speed of the engine. Unfortunately there is a spool up time involved with this, unlike the turboprop, due to the inertia of the front fan. This needs careful accounting for during an approach and go-around situation as slower responses to demands for thrust can delay the point at which the turbofan can begin to climb away from the airfield.

Now the two types of engines that generate thrust have been considered it is important to note what factors can affect the total thrust generated on any given day.

As ambient temperature increases the difference in temperature compared to the internal jet engine temperature will decrease and this will decrease the maximum thrust that can be generated by the engine. An increase in the ambient pressure however will increase the maximum thrust generated. Finally the difference in speed between the ambient airflow and the jet exhaust airflow will determine the magnitude of the thrust that can be generated and consequentially, as the aircraft accelerates, so the thrust begins to decrease.

Weight
This is the final and most simple force acting on the aircraft. Put simply this is the force which must be overcome to enable the aircraft to get off the ground and fly. The force always acts vertically downwards to the ground, irrespective of the aircraft's flight path. This means that during climb a proportion of the weight will act in the same direction as drag so necessitating higher thrust settings than in cruise. During descent the reverse is the case as the weight proportion now acts in the same direction as the thrust which encourages the aircraft to accelerate.

This concludes the discussion on the basic forces acting on an aircraft and it should be remembered that is it not necessarily the magnitude of the force that is important but how the forces relate to each other and work in union or opposition. It is no use having a hugely powerful engine if the airframe weighs a ton and the drag created exceeds any thrust the engine can provide. This relationship of forces is particularly relevant during descent, where the descent glide angle is determined as:

$$\text{Sin}\,\gamma = \frac{T - D}{W}$$

Where: T = Thrust, D = Drag, W = Weight, γ = The Descent Glide Angle

Source: Campbell, R. D. (1985)

This will be discussed further when looking at steep descents. Inevitably however the final design of the aircraft will be a compromise of all the factors discussed above.

3.4: Aircraft Performance Requirements

This topic is a very weighty matter and the author only intends to point out a few relevant points that affect this thesis, however a useful reference for this topic is Wagenmakers (1991) which outlines the requirements aircraft are expected to meet regarding performance along with observations on how this affects airlines.

Today all public transport category aircraft on a countries register are certified in performance groups based on weight and whether or not they have performance for an engine failure. Aircraft listed in class 'A' should not need to make a forced landing if an engine fails at any time during the flight and concerns aircraft with a maximum authorised take off weight in excess of 5700kgs. This definition applies to all the regional and jet aircraft that will be considered in this thesis. To satisfy the requirements stated aircraft in this group must have detailed performance charts covering four distinct areas, take off, net take off flight path, en-route and landing. In addition the aircraft must achieve maximum gross climb gradients of 2.4% for twin engined aircraft and 3.0% for four engined aircraft after engine failure which is assumed to occur at, 'V_1', the take off decision speed, i.e. the worst possible moment[13]. To achieve this the twin engined aircraft needs to be significantly more overpowered than the four engined aircraft due to the greater impact of a failed engine. The advantage of the twin engined aircraft over the four engined aircraft in terms of performance though when all engines are operating is significant because of this restriction, and gives the twin aircraft a comparative advantage or unique performance characteristic which can be utilised.

3.5: Special Performance Characteristics for Regional Aircraft

Following the introduction to aircraft performance above, it is now time to look at some specific aspects of performance in more depth, to determine specific differences in performance that exist between regional and jet aircraft. The discussion will be based on figures presented in the appendices to this chapter.

3.5.1: Aircraft Speed Flexibility

Take Off

Figure 3.7 combines the take off speeds and field lengths of a selected number of regional and jet aircraft. From this a number of points can be made. Firstly it can be seen that whilst no distinct break occurs in take off speed between the regional and jet aircraft there is a clear upper limit for the regional aircraft which in turn forms the base level for the jets. This occurs at approximately 120 kts where the jet speed increases to 180 kts. There is one anomaly to this, the Fokker 100, which although its take off length ranks it as a regional aircraft, its take off speed falls into the jet category. For this reason the author will assume that the Fokker 100 is a jet aircraft. This is also based on the limited ability of the Fokker 100 to carry out steep approaches.

A similar picture can be made for take off field length with regional aircraft requiring field lengths of less than 5000ft whilst the jets require 5000ft or more. A final interesting point to note in the graph is that whilst take off speed has a general increasing trend from left to right, it does not directly mirror the increase in field length. This can be explained by the differing acceleration rates for individual aircraft which reflect the difference in the thrust to drag ratio compared to the aircraft's weight but is ultimately due to the aircraft's stall speed which, as previously explained, is due to the aircraft weight and wing design. The exception is the BAe 146-300 which has a comparatively high take off field length for its take off speed. This is due to the aircraft having four engines and consequentially lower thrust requirements from each engine due to the less significant penalties of a single engine failure compared to twin engined aircraft. This, though, results in a slower acceleration than the twin engined aircraft.

The reasons for the differences outlined between the regional and jet aircraft are two fold. Firstly, regional aircraft generally have a higher aspect ratio wing than the jets. This provides the regional aircraft with a lower stalling angle of attack and speed as

[13] MSc Air Transport Course Notes (1992-93) Cranfield University

Comparison of Take Off Speeds and Field Lengths for Selected Aircraft at Maximum Weight

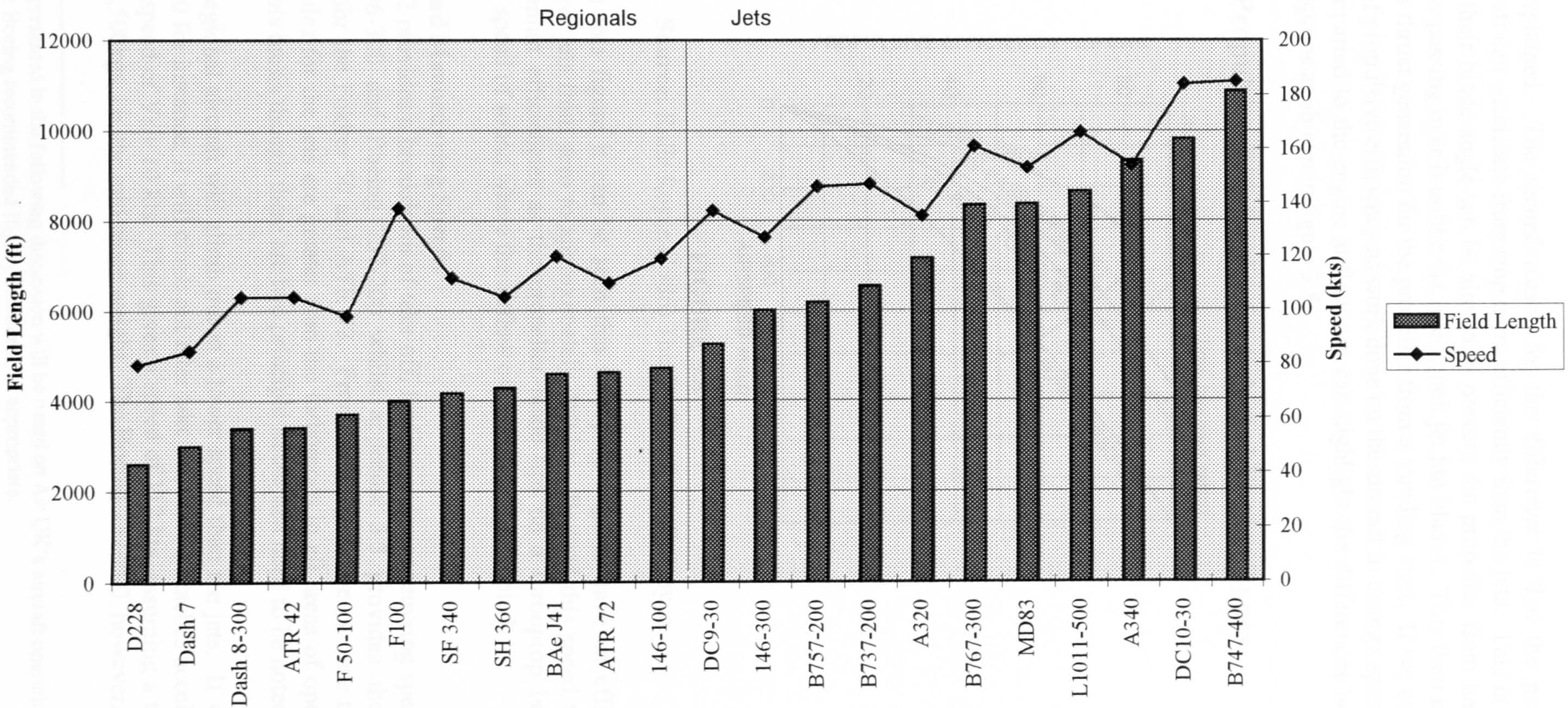

FIGURE 3.7

Source: See Appendix 3.1

previously explained. The second reason for the difference is that the propeller engined aircraft can accelerate from stop more efficiently than the jets. This is due to the fact that their blade angle can be altered to prevent the propeller from having a stalled airflow passing over it unlike the fixed pitch jet fan blades. This then enables instantaneous thrust generation for the propeller from a standing start. If we consider the concept of propulsive efficiency as work done on the aircraft to change speed over the energy imparted to the engine airflow, we can highlight the differences between jets and turboprops as shown in figure 3.8.

Propulsive Efficiencies for Selected Engine Types

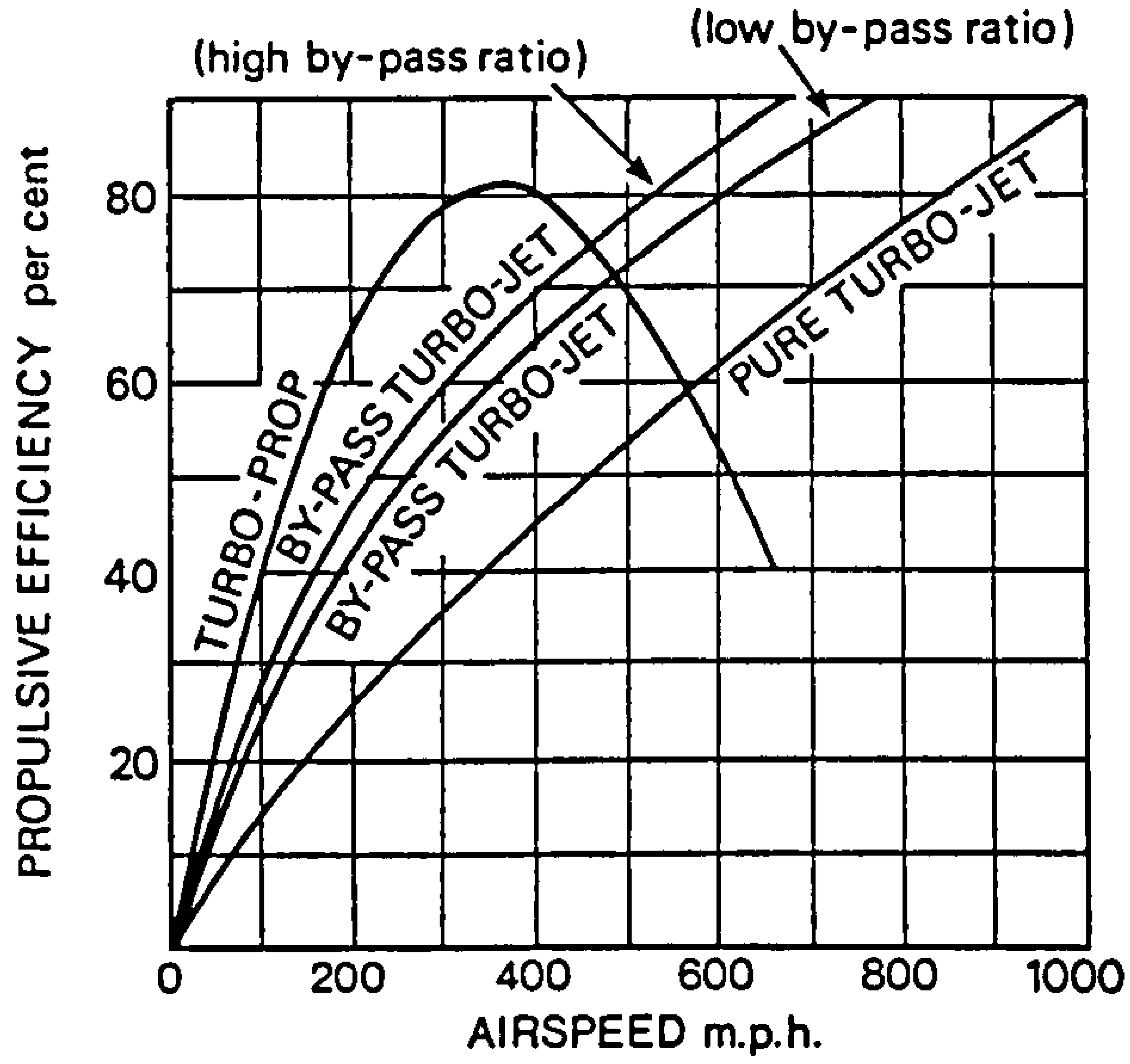

FIGURE 3.8
Source: Rolls Royce (1986) The Jet Engine. Rolls Royce

Clearly from this figure it can be seen that turboprop engines have an efficiency advantage over jets from zero to approximately 450 kts. Beyond this speed the jets achieve optimum efficiencies as the propeller blade tips on a turboprop begin to approach the speed of sound where the airflow over them gets disrupted.

Approach and Manoeuvring Speeds

Appendix 3.2 provides a breakdown of take off, landing and manoeuvring speeds for the BAe 146-300 and Boeing 737-200 whilst appendix 3.3 provides the same information for the Fokker 50 and ATR 72. From these tables we can see that the speed schedules for the jets are greater than the turboprops in all areas of operation. In terms of this thesis though there are two principle issues that need to be noted.[14]

Firstly, the regional aircraft will climb out at a lower speed than the jets. If we take the Fokker 50 for instance, it will climb out after take off, until it reaches acceleration altitude at a speed of V_2 + 10 kts. This gives a speed of 112 kts, assuming a take off weight of 17,500kgs, i.e. the mid range weight. The Boeing 737-200, however, has an

[14] Information presented in the following discussion will be based on Air UK's aircraft operating procedures or Boeing recommended flight procedures, as appropriate.

initial climb out speed of V_2 + 20 kts which gives a speed of 163 kts at it's mid weight of 45,000 kgs. The importance of this variation in speed will be returned to later as it will affect the turning radius of the aircraft. For comparison the BAe 146-300 climbs out at V_2 + 10 kts, which at it's mid weight of 35,000 kgs, gives a speed of 140 kts.

Whilst these slower climb out speeds for the regional aircraft may be useful for early turns after take off, they can be restrictive in a busy airport environment if they slow remaining jet traffic. The significance of this can be seen if V_{FTO} speeds are compared. The Fokker 50 mid weight speed will be 108 kts compared to 190 kts for the Boeing 737-200. This speed differential will require careful aircraft departure sequencing to prevent excessive aircraft separation delays. When this problem is linked with the need for jet engined aircraft to accelerate as soon as possible to achieve optimum engine efficiency, there is a clear advantage to the segregation of regional aircraft from jets on departure.

The second point to make concerns the approach speeds. Generally regional aircraft have a greater ability to vary their approach speed to fit in with other airport traffic than the jet aircraft. This is possible by the turboprops due to the near instantaneous thrust available from the propellers as previously discussed, compared to the delayed spool up time of the jet engines. The variable pitch also enhances the flexible speed control on approach by permitting rapid thrust variations and slight increases in drag as the blades are moved to the fine position, again not possible with jet engines. The BAe 146 aircraft, whilst having jet engines, has a very effective aft fuselage, clam shell door, air brake which allows the aircraft to mimic the rapid drag variations possible in turboprop aircraft. Following a flightdeck jumpseat trip by the author on a Boeing 737 it was brought home just how difficult it was to maintain approach speed in this aircraft. Due to the relatively slippery profile of the aircraft, any attempt to increase the rate of descent beyond the optimum glide path would result in an increase in speed which could not be counteracted by increasing drag. For this reason the aircraft had to be approach speed stable a long way out from the runway, (on average 10nm from the threshold). This is not the case with regional aircraft. The Saab 340 operated by Business Air for instance could vary flight speed from 210 kts to 160 kts in the approach phase up to the outer marker, (approximately 6nm from the runway threshold) to suit traffic and ATC requirements. Once past this point the speed was rapidly reduced to a final approach speed of 110 kts. The Fokker 50 operating with Air UK, optimally passes the outer marker at 160 kts and 10° of flap. This however can be increased to 210 kts if absolutely necessary, although it does make the final deceleration to final approach speed quite heavy on both the airframe, engines and passengers. The Boeing 737 has no choice but to be established at around 160 kts well before the outer marker. Obviously the benefit of being able to modify your approach speed can be very useful to ATC in preventing excessive separation of aircraft.

Landing

Figure 3.9 shows the landing speeds and field lengths for the same group of aircraft considered in figure 3.7. As with the take off graph, there is no clear break between regional and jet aircraft, however there is an upper limit to the regional aircraft which forms the base of the jet aircraft parameters. For landing speeds regional aircraft vary

Comparison of Landing Speeds and Field Lengths for Selected Aircraft at Maximum Weight

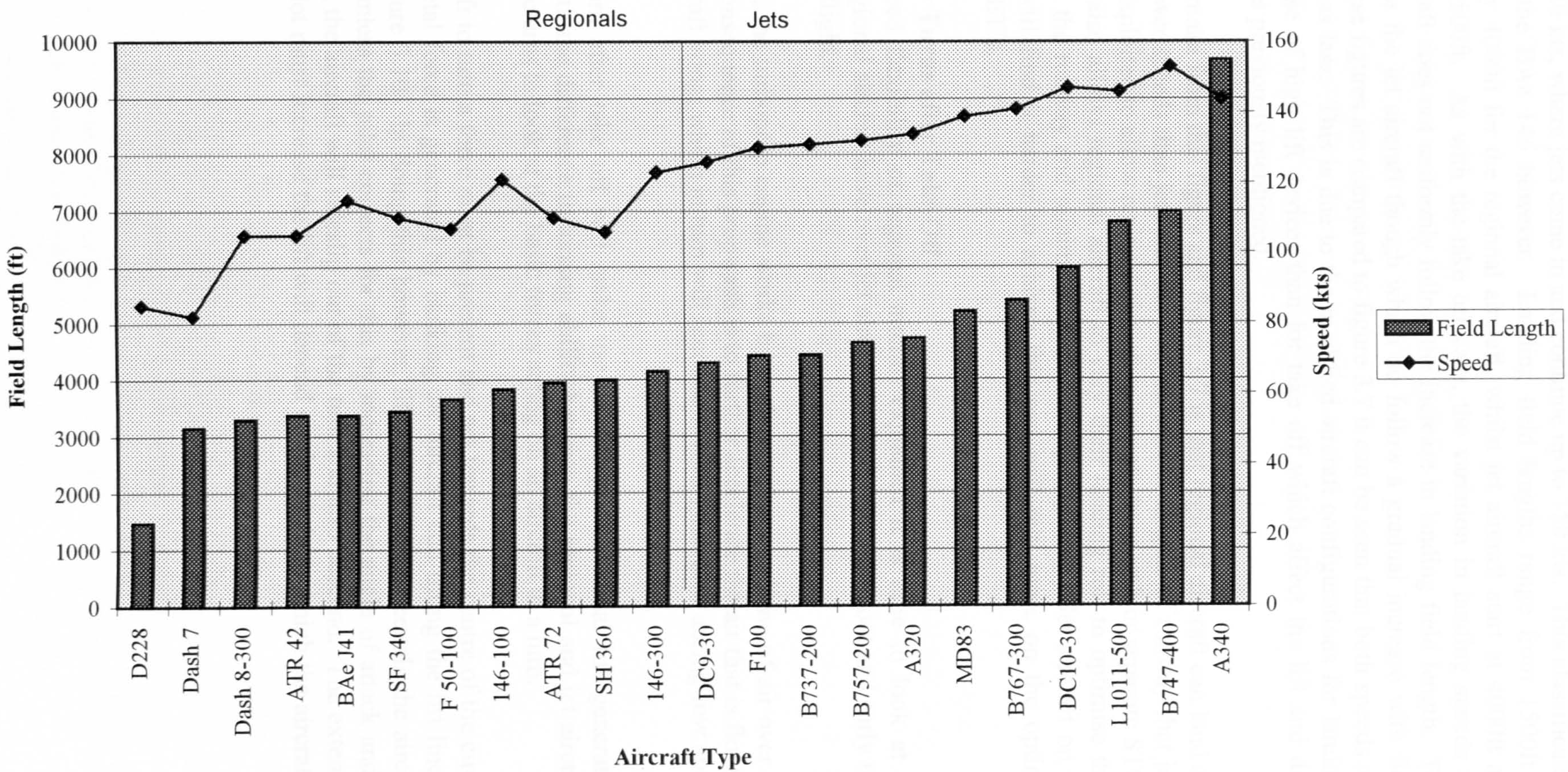

FIGURE 3.9

Source: See Appendix 3.1

from 80 to 120 kts, where jets come in and continue up to 150 kts. This classification does ignore the BAe 146 however. Landing field lengths range from 1500ft to approximately 4000ft for the regional aircraft, whilst jet aircraft start at 4000ft and increase to 9500ft. As with the take off case, the variation in landing speeds for regional aircraft does not uniformly follow the increase in landing field length. This is not true for the jet aircraft though which do follow a gradual increase with field length. If these figures are compared to figure 3.7 it can be seen that both speeds and field lengths as less. This is due to the modified aircraft configurations for landing, i.e. greater use of high lift devices than for take off which affect the lift and drag coefficients as previously mentioned.

The point to make from this figure and figure 3.7 is that regional aircraft can land and take off at lower speeds than jets and can land on shorter lengths of runway that jets. This can be exploited to allow regional aircraft to operate from stub or separate STOL runways. It also allows regional aircraft to vary their landing roll to optimise their exit point on the runway and minimise runway occupancy time. Jet aircraft on the other hand will find it harder to achieve this and will rely more on the optimal location of RET's.

3.5.2: Early Turns after Take Off

With the speed flexibility of regional aircraft explained it is time to look at the advantage regional aircraft have over jet aircraft in the initial climb out and early turn phase of the flight.

As discussed, the turboprop engine works by pushing a large volume of air over the aircraft. A consequence of this propwash is to further accelerate the air that is flowing over the aircraft wing, which in turn will increase the lift generated during low speed flight.

The early turn after take off will make use of this greater initial lift generation combined with the difference in turning ability between the regional and jet aircraft. Figure 3.10 returns to look at the basic forces acting on an aircraft in a turn.

For an aircraft to turn a force must be present and act towards the centre of the circle. This centripetal force is generated by banking the aircraft and tilting the lift line as shown in figure 3.10. In doing this however, lift now no longer equals the aircraft weight and unless the pilot corrects for this by increasing the angle of attack and so the lift force, the aircraft will sideslip out of the turn and also descend. The extent to which the pilot must increase the lift will depend on the angle to which the aircraft is banked.

Forces Acting on an Aircraft during a Turn

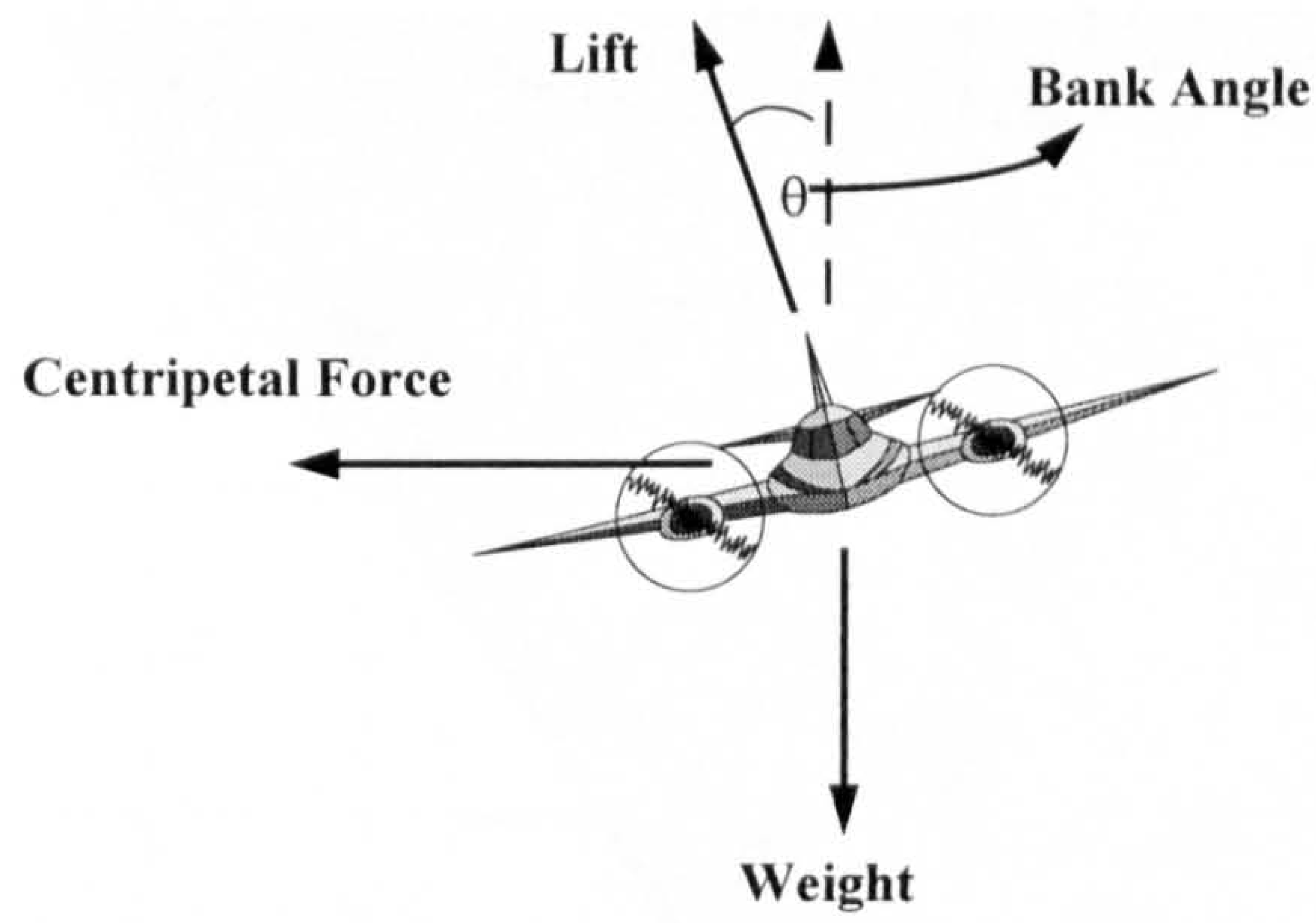

FIGURE 3.10
Source: Derived from Kermode (1972)

At 60° for instance the lift force required is twice the weight of the aircraft.[15] In addition, as the aircraft's angle of attack is increased and the aircraft weight is effectively increased, the stalling speed will also increase during a turn. The increase will depend on the bank angle with the increase being relatively small at bank angles below 30°, but becoming more significant above this angle. In terms of this discussion, however, if an aircraft is entering a turn a relatively slow speed after take off the pilot will have to be careful not to put the aircraft into a stall when entering an early turn. These days standard operating procedures and speeds should prevent this situation arising. It will become critical however if an engine were to fail during the turn.

The radius of turn an aircraft will follow varies with the bank angle and the speed flown during the turn. The following equation is used to calculated the turn radius:

$$\text{Turn Radius (ft)} = \frac{\mathbf{V^2}}{\mathbf{g \tan \phi}}$$

V = Turning Speed (ft/sec)
g = Freefall Acceleration (32.2 ft/s)
ϕ = Bank Angle (°)

Source: Kermode, A (1972)

From the equation it can be seen that the smallest turn radius possible is achieved when the aircraft turns at the stall speed for the nominated bank angle. This however would be quite foolish for the reasons already stated. Figure 3.11 demonstrates how the turn radius will increase with aircraft speed if the bank angle is fixed at 25° and is based on figures calculated in appendix 3.4, table 1.

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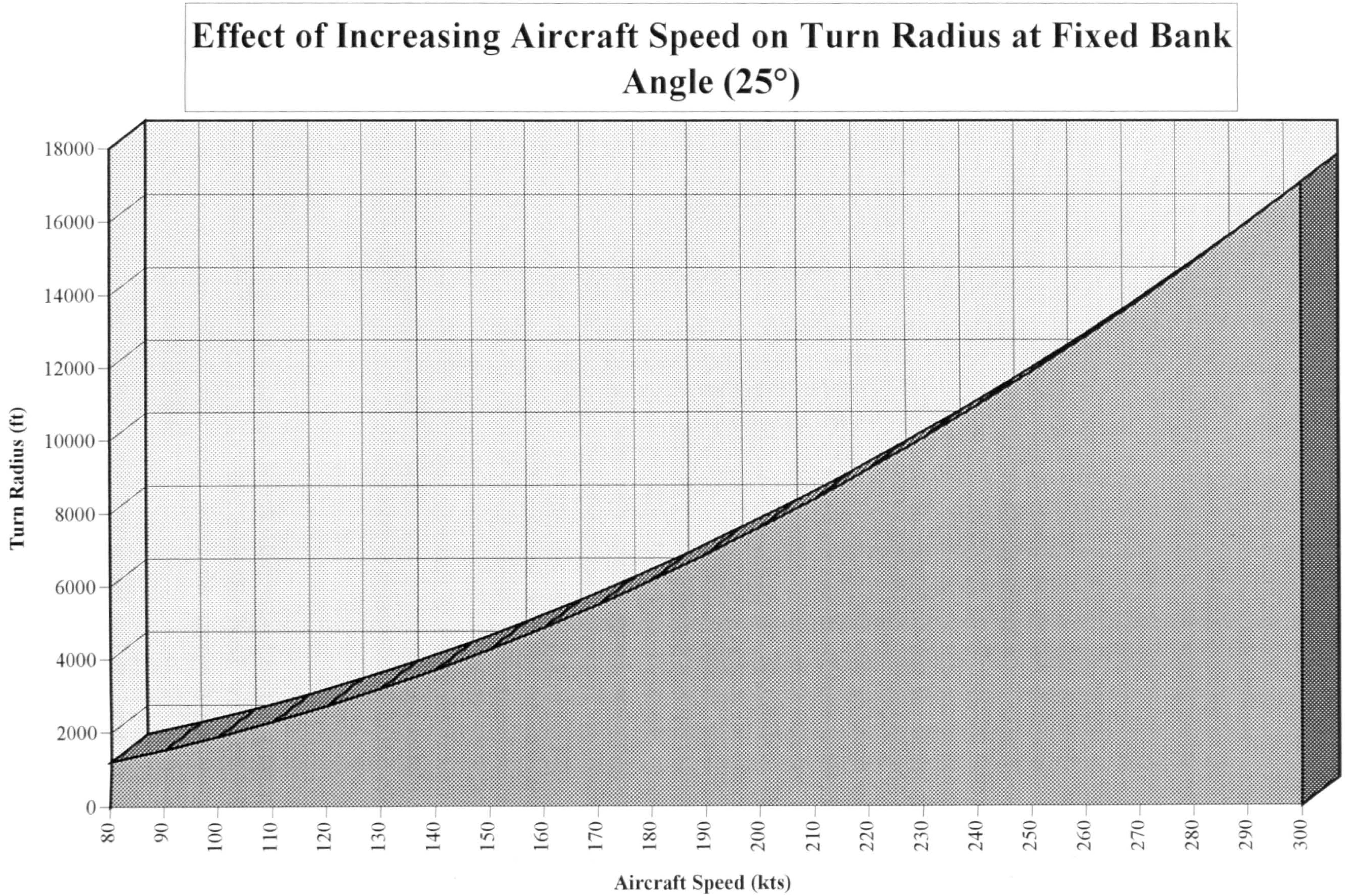
[15] Source: Kermode, A (1972) Mechanics of Flight pg249.



Effect of Increasing Aircraft Speed on Turn Radius at Fixed Bank Angle (25°)
Turn Radius (ft)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
Aircraft Speed (kts)

FIGURE 3.11

If we use the climb out speeds of the Fokker 50 and Boeing 737-200 discussed under the approach and manoeuvring speeds section, we can see that the turn radii vary from 2299 ft for the Fokker 50 to 4863 ft for the Boeing 737-200. This, in turn, relates to a turning circle increase of 2.65nm or 16,112 ft. This proves that regional aircraft, by achieving lower climb out speeds, can out turn the jet aircraft significantly and highlights a potential to use this improved turning ability close into the airport to segregate the two aircraft types. Figure 3.11 also shows that this differential between turning radii increases at higher speeds. A regional aircraft cruising at 260 kts for instance will have a turn radius of 12842 ft compared to a jet turning radius of 17097 ft. cruising at 300 kts, a difference of 4255 ft!

Whilst the preceding discussion has highlighted a potential to exploit differential aircraft turning abilities there are some practical restrictions that currently limit the full application as mentioned. Due to safety reasons the aircraft discussed all limit bank angles to less than 15° below 500ft and require speeds of $V_2 + 10$ or $V_2 + 20$ kts before bank angles can be increased further. In addition as all modern commercial aircraft are flown on automatic pilot these days, bank angle limits are imposed. The limits still apply when pilots fly manually as they must fly using the flight director. For the Fokker 50 this limits bank angles to 27.5° with the figure decreasing to 25° for the BAe 146-300. Similar figures apply to the Boeing 747-400 although the bank angle limit can be changed from 5° to 25° or set on automatic. If bank angles beyond 25° are required the autopilot must be disengaged which goes against current recommended practices of airline operations, it is not, however, impossible. The final practical limit concerns ATC. Most airport departure routes assume the aircraft will follow standard flight profiles. These include rate 1, (3° per second), turns and turns to intercept fixed navigation beacons. Whilst these limits are not too far removed from the optimum jet flight profiles they do limit the regional aircraft. Table 2 in appendix 3.4 shows how bank angle varies with aircraft speed, assuming the turn radius is constant. The effect on a regional aircraft can be seen if we compare the bank angle of a jet turning at 180 kts to a regional turning at 140 kts. A 7.5° difference in bank angle is required. In this situation then the regional aircraft is forced to fly like a jet which takes no account of its differing performance capabilities.

This discussion on turning abilities will form the basis of future discussion on the early turn after take off procedure and it is hoped that the increased flexibility of the regional aircraft over jets in this area has been clearly demonstrated in the preceding discussion.

3.5.3: Steep Descents

In a descent the aircraft approach gradient will be determined by the, (thrust minus drag), to weight ratio, (see earlier equation), plus the head wind or tail wind component. A head wind for instance will make the approach gradient steeper assuming all other factors remain constant.

The flight crew will have the means to vary the thrust and the drag to alter the approach gradient. The drag is altered by the use of the flaps and the air brakes although the latter is unlikely to be used on the final approach. The BAe 146 is an exception to this rule and makes specific use of large air brakes at the rear of the aircraft during steep descents.

Once the aircraft configuration has been set, the flight crew will control the descent gradient using the elevators to maintain the correct speed, corresponding to the aircraft weight, whilst rate of descent is controlled by varying the thrust. The descent gradient usually used for commercial passenger aircraft is approximately 3°, and this is the angle to which the ILS glide paths are set.

Up to now we have been considering standard descent profiles. More recently, however, there has been an increasing need for aircraft to approach airports located within difficult terrain which necessitate the use of a steep approach. In a consultative document by the UK CAA to the JAA, a steep approach is defined as any approach where the final glide angle is greater than 4.5°.

Today this steep approach is applied at a number of European airports but most famously London City airport in the UK. The type of aircraft that can currently carry out steep approaches are BAe 146, Fokker 70, Fokker 50, ATR 72, ATR 42 and Dash 8. The Fokker 100, whilst it has completed landing trials at London City is not currently operated there. The turboprops achieve this steep approach by making increased use of the propeller blade variable pitch which allows the thrust minus drag force to be rapidly altered, i.e. minimum thrust and slightly increased drag. The regional jet aircraft have clam shell door air brakes to achieve the similar thrust minus drag force increase, as previously discussed. Other modifications that are required to the aircraft are the suppression of the ground proximity warning system, (GPWS), to prevent nuisance warnings with the increased rate of descent, and the strengthening of the undercarriage to accommodate the heavier landings.

In terms of operating steep approaches there are a number of operational considerations that need to be taken into account. Firstly steep approaches require flight deck simulator training as the approach procedure is different than normal. This requires different piloting techniques compared to the standard approach with higher landing minima, i.e. the point at which a missed approach must be executed if the runway can not be seen, shorter landing flares and rapid deceleration using all braking means. In Air UK the actual steep approach into London City is flown on the autopilot down to decision height. Specific instructions for carrying out a steep approach with the BAe 146-300 in Air UK are contained in appendix 3.5 which is an extract from the Air UK operations manual. As the brief notes, speed control during the approach is crucial to a successful landing and an increased awareness of windshear and gusts is required as the aircraft is more susceptible to drift and stall than a standard approach due to the lower thrust settings and higher drag configuration.

The discussion on steep approach has highlighted another asset of regional aircraft which makes them distinct from standard jet aircraft and potentially provides ATC with another tool to help segregate regional and jet traffic. There is one final area also worthy of note however.

3.5.4: Noise Footprints

Noise is an ever critical factor for aircraft designers today. Aircraft noise comes from two sources, the engines and displacement of air by the airframe. A comparison of the noise footprints for regional and jet aircraft is given in figure 3.12. It can clearly be seen that the modern regional turboprop and jet generate a considerably smaller noise footprint than the larger jets. This fact has the potential to be exploited by ATC to enable different routings for turboprops compared to jets and make them more acceptable to noise environmentalists.

Comparison of 90 PNDB Noise Footprints for Varying Aircraft Groups

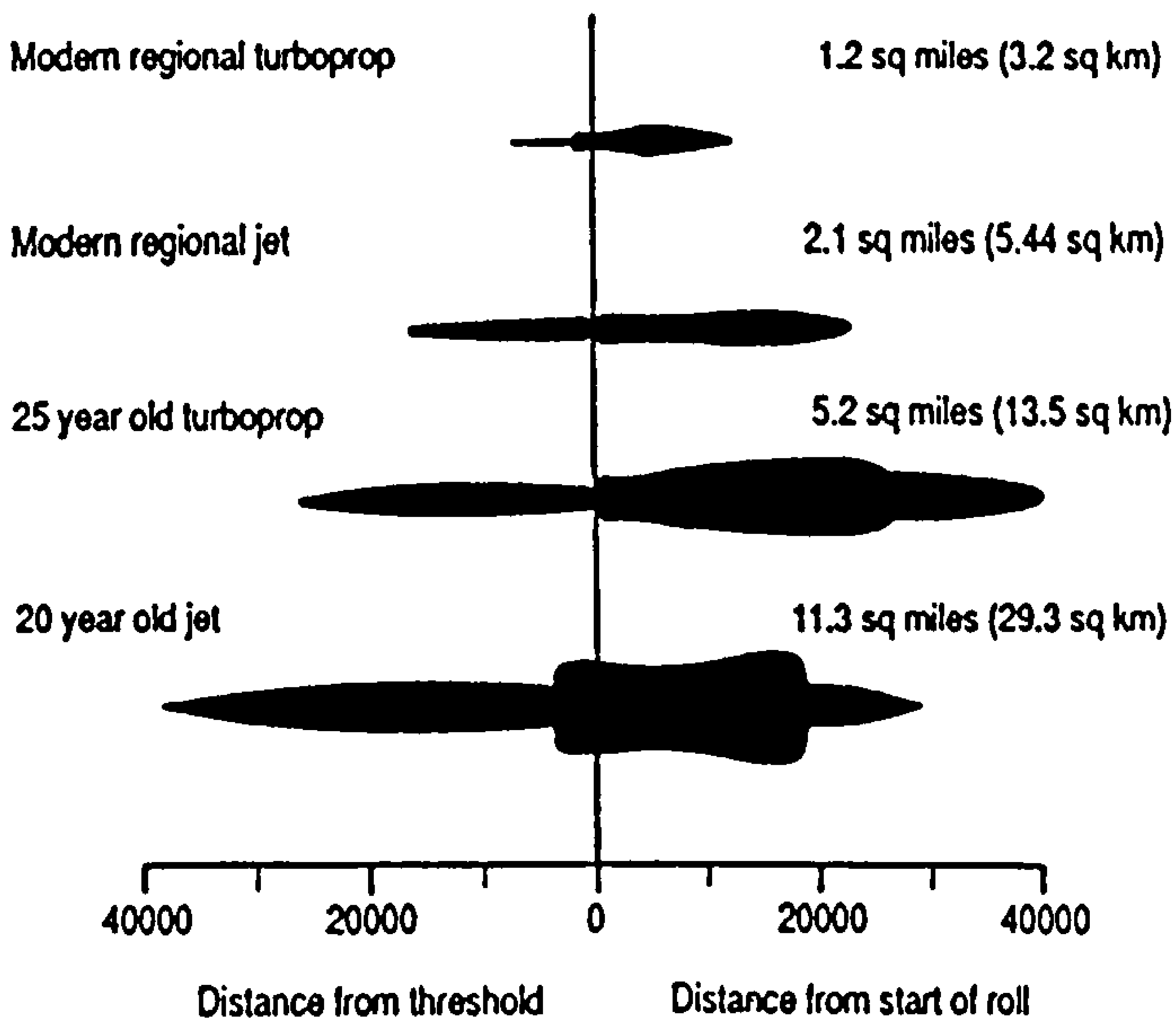


FIGURE 3.12
Source: ERA (1991) The Vital Link

3.6: Summary

This chapter has sought to explain the basic aspects of aircraft performance in order to demonstrate the differences between jet and regional aircraft. Clearly from the discussions there are distinct performance advantages available to the regional aircraft that are not found on standard jet aircraft. It is these specific characteristics that this thesis intends to exploit in order to permit regional aircraft to carry out special procedures and consequentially help reduce airport congestion.

Now the tools with which regional aircraft special procedures can be constructed have been presented it is time to take a closer look at the arena in which this thesis intends to apply the concepts, before describing in detail each of the proposed special procedures in chapter five.

CHAPTER 4 : European Airport and Airspace Congestion.

4.1: Introduction

This is the final introductory chapter and aims to focus some of the issues raised in chapter two into a European arena. The chapter begins with a brief analysis of the current trends, issues and forecasts in the international aviation environment which affects all aspects of the European operation. Focus will then be put on the airports, air traffic and airlines within Europe, looking at their current status, operational problems and proposed solutions.

4.2: Trends in International Aviation

4.2.1: The Current Situation

In 1991 two factors came together to reverse the boom growth of the industry during the late 1980's, namely the Gulf War and fear of terrorism, and a general worldwide recession. The combined effect of these events was critical, resulting in the operating profit for world scheduled airlines turning into losses of $3 billion US dollars during 1991, from profits of $7 billion US dollars during 1990.[1] These losses were more as a result of previous actions than the current world economic situation as Doganis, (1993) explains. 1980 to 1991 had been a period of deregulation in the US and liberalisation in Europe which had encouraged airline growth, combined with a period of falling fuel prices from 1980. The industry forecasts also anticipated world air transport growth following a growth in revenue tonne kilometers of 6% per annum (p.a.) during the 1980's.[2] These factors led to airlines planning huge capacity expansions to cope with expected increases in demand for air travel in the form of more aircraft and route frequencies. Unfortunately, this demand reduced instead of growing, which left the airlines with massive over capacity problems and reducing revenue, so they cut fares in an attempt to fill seats and stimulate demand. During the boom phase the situation was made worse, as the airlines faced with increasing competition let passenger yields fall, and additionally became relatively inefficient at controlling and recovering costs, as profits at that time were almost guaranteed. This only served to amplify the lost revenue problems during 1991. The response that was required from airlines to this dip in demand should have been rapid capacity and cost reduction. Unfortunately, the size, lethargy, and arrogance of some airlines gave them the idea that they were invincible.[3] This proved almost, if not completely fatal for some airlines, such as Pan Am, TWA, Continental, US Air, Air Canada, Air France, Iberia, Olympic, and Alitalia. British Airways was the only European airline to

1 Source: Boeing Current Market Outlook 1995 - World market demand and airline supply requirements.

2 Source: Doganis, (1991) Flying off Course - The Economics of International Airlines

3 Source: Doganis, (1993) Dinosaurs or Pterodactyls - European Airlines after Liberalisation - Inaugural Lecture at Cranfield University

remain profitable following 1991, but paid for it by the loss of 6400 jobs in 1991, the cutting of it's routes, and the development of low cost subsidiary operations.[4] The Asia Pacific region fared better than Europe and America due to a booming economic market in that region.

The airports at this time were forced to turn to other sources of revenue than just aeronautical, so developed their secondary services outlined in chapter two. Air traffic control on the other hand had some of the pressure on it removed, as air traffic services were cut and frequencies reduced. Regulation was also reducing as liberalisation progressed, but governments were being forced more and more to consider the environmental obligations of air transport, During the last few years the environmental movement has developed into a powerful political group, heavily influencing air transport development. The three final factors occurring during this time, were the breakdown of socialism in the USSR and eastern Europe, the development of the Chinese market and the rapid expansion of the air transport market in Asia, in contradiction to the US and Europe.

Since 1991 there has been a return to growth in the market, and in the US and Europe the emergence of rationalized and stable airline growth with profits again being seen. Unfortunately, due to the relaxed attitude of governments with regard to developing airport and ATC infrastructure during the recession, and their focus on liberalisation and environmental concerns, a serious problem of capacity now exists within the industry, which is having to deal with a recovering, expanding and newly liberalised airline industry operating on a limited and in some cases out of date infrastructure.

4.2.2: Future Forecasts

The primary sources of reference for this section are the Airbus, Boeing and McDonnell Douglas global market forecasts for the industry, and an open mind is required concerning the figures as they represent the manufactures justification for selling aircraft. The forecasts can be broken into five principle sections.

World Economy and Airline Growth

Boeing's forecast covers the period 1995-2014 predicting an average world economic growth rate of 3.2% compared with airline traffic growth of 5.1%. They expect the recovery from the recession to be slow and led by the US and Europe. Airline growth is expected to continue following the world economic trend. The Association of European Airlines, (AEA), reported a 9% growth in member airlines in 1994, with the figure being 9.4% in Asia and 4.6% in the US. Boeing indicate that the pace of recovery is currently being set by individual countries, but expects this to eventually lead to an increasingly integrated world with a truly global trading system. McDonnell Douglas's forecast is equally optimistic, expecting the world economy to grow at higher rates over the next two decades than the past decade, with Asia/Pacific markets continuing to out perform the other regions. The report states that the airline

[4]Source: Doganis, (1993) Dinosaurs or Pterodactyls - European Airlines after Liberalisation - Inaugural Lecture at Cranfield University

industry growth is positioned at the beginning of its next growth cycle, which is expected to end at the turn of the century. Airbus Industrie forecast for airline passenger traffic growth is the same as that given by Boeing at 5.1%.

Airline Performance

Boeing outlines improving profit performance for the top 25 airlines by examining dollar sales between 1989 and 1994. McDonnell Douglas examine airline passenger yields. They show that, in real terms, yields have dropped annually by 1.5% per annum, (p.a.), for the last 20 years. This has been offset with reductions in airline operating costs, improvements in aircraft efficiency, other technological advances, longer average passenger trips and economies of scale. They expect these efficiency improvements to be achieved at a lower rate in the future, as passenger yields will decline at a slower rate, around 1% p.a. between 1993 and 2013 due to airline productivity improvements.

Future Airline Strategies

Boeing argues two substitutes to air travel, high speed rail in Europe and tele, or video conferencing will have limited impact on the airlines. They indicate that if the Community of European Railway's master plan is fully implemented, it would take 50% of travel in Europe by 2010. However they doubt the plan will ever be fully implemented due to high investment costs. They also expect airlines will recover some of the traffic through a more liberalised operating environment. Boeing expects fuel price, regulation, infrastructure and capacity to be favorable to airlines in the future, although the premise of this thesis does not agree with this latter statement. In addition they consider that the problem of too many seats for too few people has been solved during the first half of the 1990's.

When the above points are combined with an expected easing of legal, political and regulatory roadblocks, along with promotion of smaller airlines and low cost carriers, Boeing indicates future success will rely on airlines providing increased value for passengers at lower costs. Political pressures on airport capacity are expected by Boeing, who forecast a rise in new non-stop flights and one stop, on-line connecting services, combined with increased hubbing by large airlines. Flight frequencies are expected to increase to a minimum of three a day on short to medium range markets, and at least once a day on long haul routes. In the long term airlines will shape their strategy to take account of the changing mix of travelers, and deploy their fleets on the routes they can serve most profitably. McDonnell Douglas supports this scenario adding that they expect fuel prices to remain constant, in real terms, at 60 cents per gallon. Airbus adds to the scenario two factors:. firstly, it sees the potential for increasing frequency to be greatest on thinly traveled, long distance routes; secondly they anticipate that airline market concentration will be little changed by 2014, with the top 12 airlines share of the world fleet only having dropped from 45% to 37%.

Aircraft Size Trends

Airbus expect aircraft size to increase in high-density, high-volume route structures where airports and terminal area air traffic management systems are close to saturation. They forecast a 34% increase in average aircraft seat capacity for world airlines over the 20 years from 1995-2014. Figure 4.1 from the Airbus forecast links expected increases in aircraft seat size with increases in flight frequencies, and breaks this down by geographic region. It clearly demonstrates that forecast increases in passenger demand will not be met by increasing aircraft size alone.

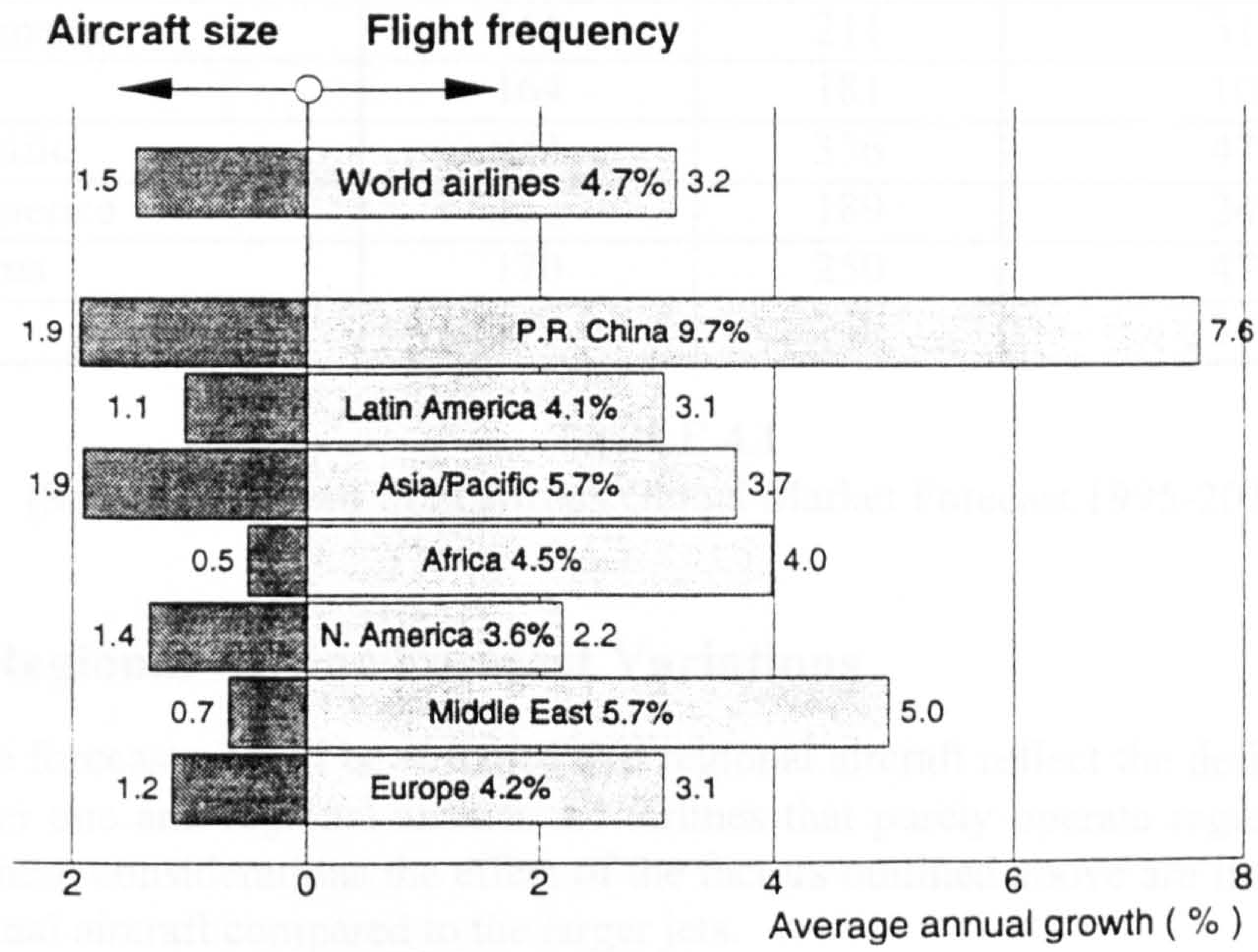


FIGURE 4.1

(Source: Airbus Global Market Forecast 1995-2014)

Table 4.1 provides average seat size demands for the seven regions. It clearly indicates the upward trend in aircraft size and the significant differences in growth that occur in separate regions. These can be explained by the lack of airport capacity in the US and Europe, and the huge growth prospects of the Asia Pacific market. Focusing on the capacity problem, airports are encouraging the use of larger aircraft with the increasing use of landing charges independent of aircraft weight, but related to operation during congestion times. Further issues of this nature will be returned to when looking at European airports in more detail.

Variations by Geographic Region

All the forecasters indicate that the Asia Pacific market will become the second largest in size and grow at a faster rate than any other, with the exception of the Peoples Republic of China. The North American market they argue has reached maturity and will grow at a slow rate around 4% p.a., whilst remaining the largest in size. Europe will remain the third largest market and will soon mature following liberalisation with growth rates only slightly greater than America. Finally, African, Latin American and the Middle East markets are expected to see significant growth, although from a lower base.

Aircraft Size Trends

Geographic Region	Average seats per aircraft		Percentage increase in seat size from 1994
	1994	2014	
Europe	179	225	26%
Middle East	210	240	14%
North America	161	211	31%
Africa	164	181	10%
Asia Pacific	243	356	47%
Latin America	153	189	24%
P.R. China	170	250	47%
World	179	240	34%

TABLE 4.1
(Source: Derived from Airbus Global Market Forecast 1995-2014**)**

4.2.3: Regional Airline Forecast Variations

For these forecasts it will be assumed that regional aircraft reflect the definition given in chapter one and regional airlines are airlines that purely operate regional aircraft. Due to these considerations the effect of the factors outlined above are likely to differ for regional aircraft compared to the larger jets.

Growth on the short haul routes is lower than long haul ones, according to Fokker. World average growth on intra-regional scheduled traffic will decrease from 4.2% to 3.8%, although the exact change will vary from region to region, (see appendix 4.2). Fokker also predict that route sectors between 400nm and 1500nm will represent 50% of the future market with virtually no growth on sectors less than 200nm. Increased concentration is also expected following deregulation. The top 35 regional airlines account for 70% of the available seat mile production in 1994 compared to 45% in 1984 say Fokker, which is due to code-sharing, as regionals fly under major airline liveries, in the US and Europe. Fokker expect this concentration to peak at 80% as code-sharing increases. Regarding the hub and spoke operation, Fokker indicate this has already reached its peak in the US and is showing signs of decreasing. They expect the original turboprops used on these services to be replaced with larger aircraft types and possibly regional jets. The other suggestion is that hub bypass may be accomplished with regional jets in the US, in future. The development of hub operations at other locations in the world, Fokker argue, will be dependent on the availability of uncongested airports. They point to the reduction of turboprop services at London Heathrow, a congested airport, compared to a rise at Amsterdam, (uncongested), between 1984 and 1994.

These points are supported by Jetstream Aircraft and Bombardier Regional Aircraft although they both add a further point. Jetstream argue regional airlines have been more profitable than the majors during the recession and are following the trend towards larger aircraft. They offer three arguments to support the growing aircraft size, the growth in passengers carried following code-sharing, increased airport and airway congestion, and the extension of regional airlines onto longer routes. Bombardier forecast a continued, strong and stable growth in the regional airline market, averaging 3.6% p.a. to 2012 as airline code-sharing increases. The trend in aircraft size is also clearly illustrated by Bombardier as can be seen in figure 4.2.

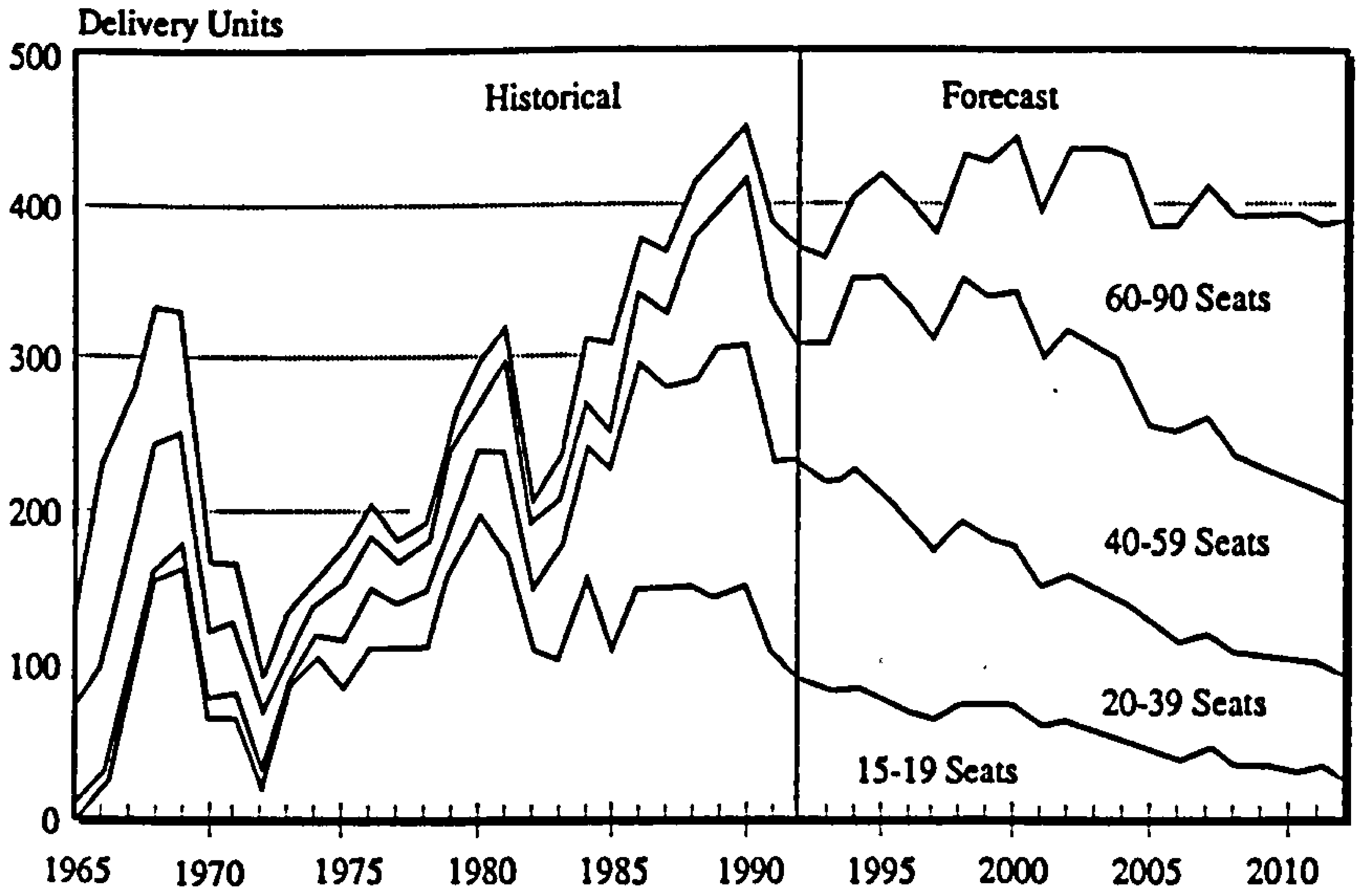


FIGURE 4.2

(**Source:** 1993 Bombardier World Regional Market Demand Forecast)

The chart clearly shows that Bombardier expect the 15-19 and 20-39 seat markets to diminish towards 2012, with an initial growth in the 40-59 seat market up to the turn of the century followed by its demise to the 60-90 seat market. British Aerospace also predict this scenario in their world civil market forecast covering 1992-2011.

Turning to growth forecasts for specific regions, (appendix 4.2), Jetstream forecast that the largest growth will come from Asia, as do the others, with Fokker indicating that it will become the largest market by the end of the 21st century, overtaking North America. Jetstream also predict the fastest growing regional aircraft type in all markets will be the 70 seat turboprop, along with the 50 seat jet in the US and Europe. The growth rates provided by Jetstream do seem significantly higher than those of Fokker and the other major industry forecasts which does bring them into question.

These are the main variations in forecasts and conclude this first section looking at future trends in the air transport industry. All the figures given in the forecasts have a number of assumptions buried in them and consequentially, the exact result will only be known with time. Bombardier does list eight useful points which represent what they feel will be the key market drivers in shaping the future. These are:

1. A stable long term economic environment covering GDP growth, fuel prices and interest rates
2. Continued strong regional growth
3. Major/regional airline route re-distribution
4. Governments encouraging greater competition
5. Industry consolidation and globalisation
6. Significant aircraft retirements for economic, and/or noise and emission restrictions
7. Lower real airline yields
8. Continued airport and airway congestion.

The inclusion of the last point demonstrates the importance of this subject to the industry, both now and in the future with the increases in growth and flight frequencies that are predicted in all forecasts.

4.3: European Airports

This section will cover aspects of historical and current airport performance and congestion followed by an analysis of plans that are being made to overcome some of the problems.

4.3.1: Historical Background

Lack of capacity has long been the concern of those dependent on airports in Europe. The first major report to confront the problem was by the Association of European Airlines, (AEA), in November 1987. They analysed airport congestion by forecasting passenger and aircraft movement growth at 42 European airports under three scenarios. The scenarios represented differing levels of growth from 3.2% in the low growth case through 5.1% in the medium case, to 7.0% in the high case. They classed a runway as being at saturation point when 70% of available slots were being used, which they considered very conservative as all peak slots would of been utilized long before this point. The findings of their work are collated in appendix 4.3. Significant points were the expectation that by 1995, 30% of European runways, under the medium growth case, would have reached saturation outside the night period. By the year 2000, under the medium scenario 24 out of 46 main European airports were expected to be heavily congested which would rise to 31, if the growth rate followed the high scenario. They argued that the increased flight times due to the congestion would result in the loss of air services to surface competition and necessitate the use of larger aircraft. The effect of deregulation in Europe and the development of hub and spoke operations it stated would only make pressure on key airports worse. Finally, they indicated that the problem had no simple solutions and success would depend on the combined co-operation of public authorities, airport management and the airlines. The building of new runways was seen as unlikely, although improvements in existing runway capacity were expected as technology advanced. This shall be demonstrated to have occurred in the following chapters. Restriction of airport access to small aircraft and charter traffic was suggested as were new pricing policies to discourage use of the airport at peak times. Airlines, they argued, should be encouraged to increase aircraft size, promote off-peak travel and increase traffic between secondary airports, not affected by congestion.

Unfortunately this report had little effect and in 1990 the SRI report provided figures to show that during the period from August 1987 to August 1989 the percentage of flights delayed by at least 15 minutes rose from 13.7% to 20.7% on a worldwide basis. In 1987 Lufthansa reported 5,200 holding hours over Frankfurt, Munich and Dusseldorf alone, which led to knock on costs of DM50 million. In September 1987 IATA established a task force on airspace and airport congestion. The aim of the group was to seek co-operative solutions to congestion problems. By late 1988 European congestion was the worst in the world, and IATA's executive committee commissioned a study to assess options to improve the situation. The result came in 1990 with the SRI International consultative report entitled, "A European Planning Strategy for Air Traffic to the Year 2010." The work was approached from five sides, an airport capacity assessment, demand forecasts, airway capacity assessment, economic analysis and institutional overview. The first three aspects of the work were used to generate initiatives which were combined with the last two pieces of work to generate the recommendations and action plan. The report showed that western European economic activity attributable to the provision or use of commercial aviation approached $75billion annually, whilst providing 2.5 million jobs. At that time the governments were spending $1.5 billion to provide the supporting infrastructure to the industry which SRI argued was inadequate to support the system of the time or allow growth. They concluded that this constraint of growth would cause annual losses to national economies of almost $10 billion by the year 2000. Of the 27 major European airports identified by the SRI, they concluded that by the year 2000, 16 would be capacity constrained, as figure 4.3 shows.

The chart was countered with the argument from SRI that, if a commitment to timely implementation of existing airport development plans and adoption of procedural changes available in the next decade were made, the worsening airport congestion could be postponed until 2010, except at several critical locations. Using this idea they demonstrated Madrid and Barcelona could accommodate demand until 2000 although little improvement would be found at Frankfurt and London. Individual airport graphs showing runway development plans and their ability to absorb demand were produced, and similarly to the AEA report, estimates of achievable runway capacities by 2010 were made. A summary of their results are presented in appendix 4.4. The final part of the report was an eleven stage action plan, (see appendix 4.5), presented to the industry as the way forward.

The dire picture of European aviation that these two reports presented must be seen in context. From their point of view they had the expanding influence of liberalisation with a growth in airline movements and forecasts indicating this trend would continue, if not increase its rate, as references. They could not have foreseen the effects of the Gulf War or the world-wide recession in 1991. The dip in traffic caused by this was significant, but as IATA demonstrated in an updated forecast to the SRI report in 1992[5], this would only be short term, with the long term consequences of inaction remaining the same. The forecast did predict a decrease in the growth of flights from 4.5% between 1995 and 2000 to 3.0% between 2005 and 2010 though, due to expected increases in aircraft size. In addition, analysis of appendices 4.3 and 4.4 show that the SRI report expects airports to reach capacity at a later date than the earlier AEA report. For example the AEA report shows London Heathrow to be at capacity in 1986, where as the SRI report extends this to 1991. These differences can be explained by greater then expected efficiency improvements by ATC and the airport as well as increases in published declared capacities at many airports. Five additional movements per hour at Amsterdam and Brussels were generated according to information in the appendices.

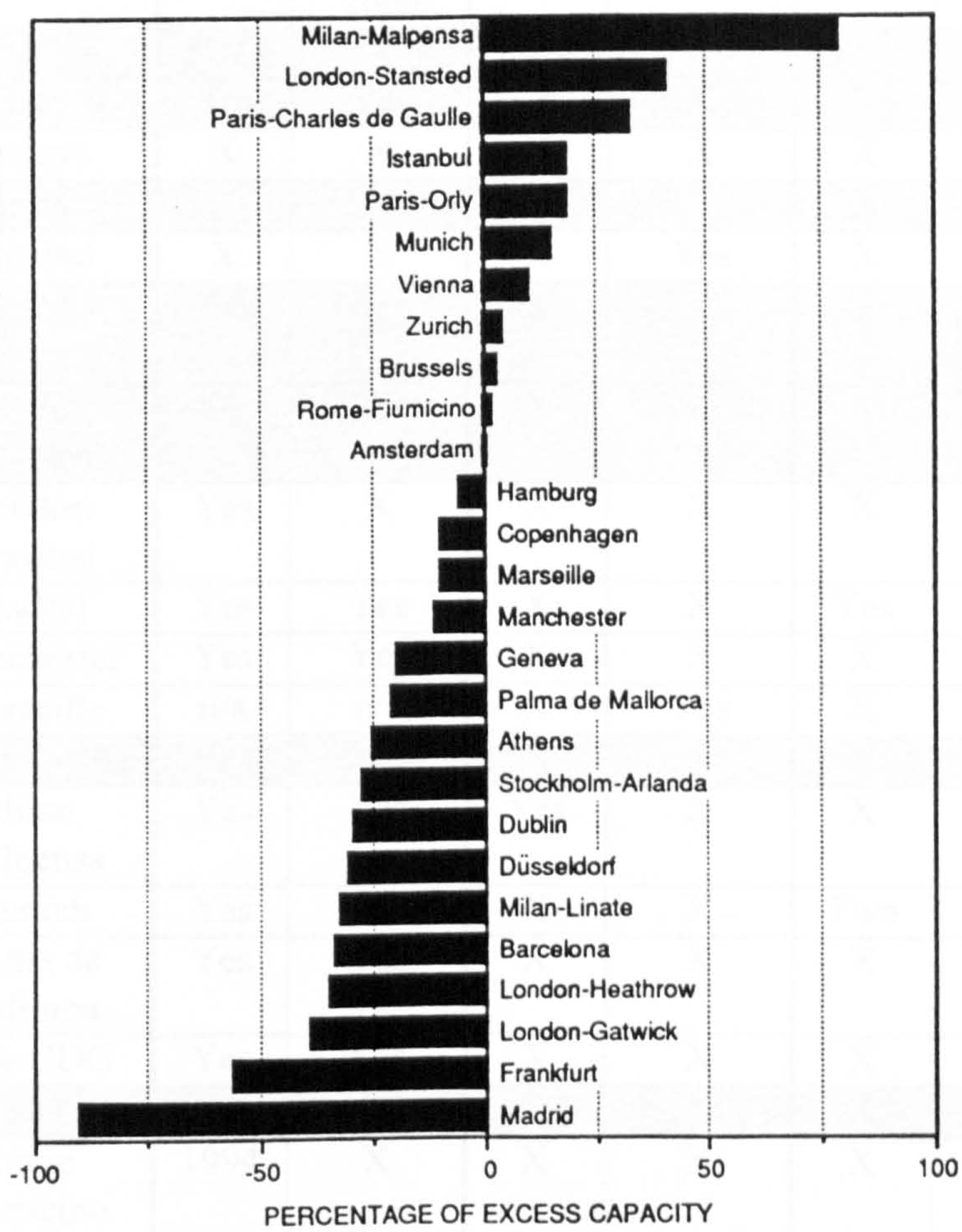


FIGURE 4.3

(Source: SRI International Report 1990**)**

The level of airport development since the SRI report, up to 1996 is given in appendix 4.6. A summary is in table 4.2.

5Source: IATA (1992) European Traffic Forecasts 1991-2010. In association with the Air Transport Action Group, (ATAG).

Summary of European Taxiway and Runway Developments since 1990.

Airport	Taxiway Extensions		Runway Extensions		New Runways	
	Built	Planned	Built	Planned	Built	Planned
Amsterdam	X	X	X	06/24	X	X
Athens	X	X	X	X	X	Two
Barcelona	X	X	X	X	X	07/25
Brussels	1994	X	X	X	X	X
Copenhagen	X	X	X	X	X	X
Dublin	X	up to 2000	X	10/28	X	X
Dusseldorf	1993	X	X	X	1993*	X
Frankfurt	Yes	Yes	X	X	X	X
Geneva	X	X	X	X	X	X
Hamburg	X	X	X	X	X	X
Istanbul	X	X	X	Yes	X	X
London Gatwick	Yes	Yes	X	X	X	X
London Heathrow	Yes	Yes	X	X	X	X
London Stansted	Yes	X	X	X	X	X
Madrid	Yes	Yes	X	X	Yes	Yes
Manchester	Yes	Yes	X	X	X	Yes
Marseille	n/a	n/a	X	Yes	X	X
Milan Linate	Yes	Yes	X	X	X	X
Milan Malpensa	Yes	Yes	Yes	X	X	X
Munich	Yes	Yes	X	X	Two	X
Palma de Mallorca	Yes	Yes	X	X	X	X
Paris CDG	Yes	Yes	X	X	X	Yes
Paris Orly	Yes	Yes	X	X	X	X
Rome Fiumicino	1994	X	X	X	X	X
Stockholm Arlanda	X	Yes	X	X	X	Yes
Vienna	n/a	n/a	X	X	X	X
Zurich Kloten	Yes	Yes	X	X	X	X

* Runway was a 2,700m reliever runway to main 05/23 not officially a new runway.
** X = Not considered..
Source: Same as Appendix 4.5

TABLE 4.2

As can be seen from the table, only two airports, Madrid Barajas and Munich 2, have built new runways since 1990, although a further five intend to build ones in the near future. The largest work has been on taxiway modifications which include anything from new departure sequencing pads and RETS to new links between new terminals and existing taxi-ways.

These problems were examined by the Comite de Sages in their report, 'Expanding Horizons', made to the European Commission in January 1994. The purpose of the report was to assess the future of aviation in Europe as an essential tool for economic and social development. The views of the industry and other related organisations were sought. Their primary conclusion stated that the root cause of Europe's problem was it's heritage with countries developing independently to one another, which caused the development to be at differing standards. The problem was made worse by overly enthusiastic managers, tradition and national pride, which led to irrational commercial and economic decisions being made. The ability to successfully reconcile this enthusiasm with rational and economic decision making was seen as the solution to the problems. Regarding the airports, the report recommended that, " *as a matter of utmost urgency, infrastructure bottlenecks must be removed*". They argued that this could only be achieved if airports were developed within a European context instead of by local authorities. The success of this report was limited, and in October 1995 the members of the Comite des Sages attacked the EU over it's inaction.[6]

4.3.2: Current Status

The status of European airports will be examined in four sections:

1. the scale of individual airport's operations will be assessed;
2. an assessment of the extent to which hubbing has influenced them;
3. a look at current levels of congestion;
4. aeronautical charges and ownership patterns.

Scale of Operations

Figure 4.4 shows the annual air transport movements, (ATM's) and average passengers per ATM, (Pax/ATM)[7] for the top thirty European airports, ranked by annual passenger movements, (Pax's). Looking at the ATM's it can be seen that their magnitude does not always reflect those of the Pax's, although there does appear to be a general downwards trend from left to right. London Heathrow clearly dominates the other airports in both ATM's and Pax's followed by Frankfurt and Paris Charles de Gaulle. Amsterdam Schiphol comes next in terms of ATM's, where a drop in level occurs to Zurich Kloten, Copenhagen Kastrup, Stockholm Arlanda and Brussels. Another drop to the rest of the airports occurs after these to the 200,000 annual ATM mark. The importance of these variations are made more clearly when attention is

[6]Source: Odell, M (1995) None the Wiser - Airline Business October 1995 p28-33

[7]Pax/ATM is simply calculated by dividing the total annual Pax's by the total annual ATM's. (Raw data in appendix 4.7

Comparison of Annual ATM's and Pax/ATM for the Top 30 European Airports Ranked by Annual Passenger Movements (1994)

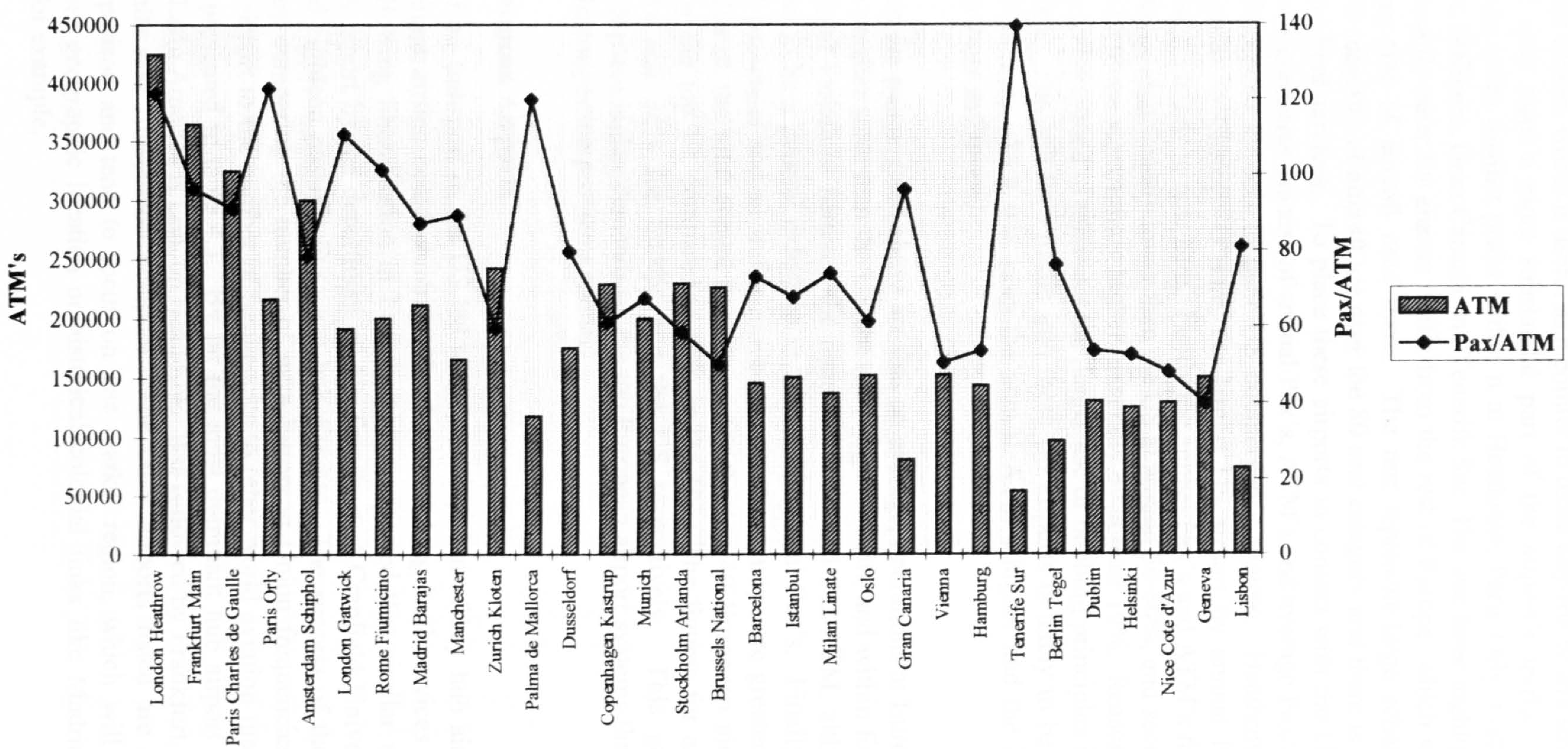


FIGURE 4.4

(Source: ACI Worldwide Airport Traffic Statistics 1994 turned to the Pax/ATM line. This gives a very rough indication to the size of aircraft that are using each airport, which is useful as a pointer to those airports where smaller, regional aircraft may form a more substantial part of the airport's traffic. The Pax/ATM line has seven distinct peaks within it at Heathrow, Paris Orly, Gatwick, Lisbon, Palma de Mallorca, Gran Canaria and Tenerife Sur. The last three highlighted airports predominantly cater for charter traffic from the rest of Europe, which would explain the larger size of aircraft used there. The rest represent large scheduled airports where the majority of aircraft are over the 80 seat category and there is more likelihood of long haul services. To place these airports in context with the United States appendix 4.8 compares the size of annual Pax's, ATM's and average Pax/ATM for the top 40 European airports to their US counterpart's figures. Heathrow for instance is compared to Chicago O'Hare, the largest US airport by annual Pax's. There are two distinct trends to note here. Firstly the annual Pax's and ATM's for the European airports are significantly lower than the US at around 50-60%, and secondly the average Pax/ATM are significantly higher, generally by at least 10%. Reasons for these variations can be argued to represent the larger use of hubbing principles in the US than in Europe. The hub feed traffic into these US airports is likely to be with smaller regional aircraft, which will keep the annual ATM's higher and the Pax's figure lower than those in Europe.

Conclusions from the points noted above are that on average, operations at European airports are on a smaller scale than the US but with larger aircraft, and within Europe there are significant variations between the annual ATM's and Pax/ATM, although there does appear to be a general reduction in them with annual Pax's. Finally, the concentration of passenger and air traffic movements within Europe are greater than the US, with 52% of the total annual passengers for the top 40 European airports being handled by the top 10, compared to 45% in the US. The figures for annual ATM's are 41% and 36% for Europe and the US respectively. This greater concentration will place higher demands on the top European airport systems than the US, and highlight congestion problems sooner!

Hubbing at European Airports

De-regulation of air transport in the US led to the development of key hub airports where the dominant airline could combine it's short and long haul services most efficiently. Following liberalisation in Europe it was expected that similar trends would occur. A report by the department of Air Transport at Cranfield University, (1995) identified eighteen possible European hub airports. The success of the hub was measured by comparing the number of intra European Union frequencies that occurred at the airport to the number of frequencies to other world aviation markets. The results are presented in table 4.3. By far the most dominant hub airport in all markets except Latin America is London Heathrow. It is followed by Frankfurt, Paris Charles de Gaulle and Amsterdam Schiphol. The other airports listed are much smaller in comparison and tend to focus on one market region, which will be a function of either geographic location or historical colonial links like Madrid and Latin America for example.

Dominance of Major Route Markets for Eurpoean Hub Airports 1995

Hub Airport	Route Destination (% of total route frequencies)*							Notes
	European Union	Rest of Europe	North America	Latin America	Africa	Middle East	Asia and Pacific	
London Heathrow	20	19	41	13	22	39	39	Dominant Hub Airport in Europe for most routes
Paris CDG	12	12	11	23	17	13	15	Dominant hub airport for Latin Am.
Amsterdam	9	9	10	14	10	10	10	Thrid largest hub airport in Europe
Frankfurt	8	12	16	15	14	13	21	Fourth largest hub airport in Europe
Copenhagen	7	11	2			2	4	Second largest hub for rest of Europe
Madrid	7	2	3	20	4	1		Second largest hub for Latin America
Brussels	6	5	2	2	9	1		None
Barcelona	4	1			2	1		None
Rome	4	4	2	3	10	7	3	None
Milan Linate	4	1				1		None
Munich	4	4	1	1	2	1	1	None
Zurich	4	8	3	2	3	4	5	None
Dusseldorf	3	2	1	2	1			None
London Gatwick	3	2	6	3	2	2		None
Athens	2	2	1		3	3	1	None
Manchester	2	1	1				1	None
Vienna	2	4			1	2	1	None
Lisbon	1			2	1			None

Note:

1. 'Shaded areas represent the dominant route which the aiport acts as a hub for.

* Figures for hub are calculated by multiplying the number of frequencies into the airport from Europe and the number of frequencies to the specified market region. The percentage figure is the calculated by dividing the preceeding figure by the sum of all frequency values for the 18 airports.

Source: Dept. Air Transport, Cranfield University (1995) Competition and Airport Financing in the EU
- Study for European Commission, DGVII

TABLE 4.3

Current Levels of Congestion

Figure 4.5 is compiled by the author to provide an updated version of the 1990 SRI chart on available runway capacity at European airports.[8] In the production of this chart actual annual ATM's for 1994 were compared to a calculated annual runway capacity. This latter figure was calculated as shown below:

Annual Runway Capacity = Declared Hourly Capacity x 18 Hours x 365 Days

18 hours instead of 24 was chosen to take account of possible ATC firebreak periods, night curfews, quota restrictions and other environmental restrictions, which would reduce the declared hourly capacity for the night period. In fact the figure may, in some cases, be an optimistic value, as due to the points highlighted above, airports may be unable to continuously maintain their declared hourly capacity from 0500 to 2300 each on every day. For the purpose of this thesis and due to limited access to information for hourly variations in declared capacity, this approach will be maintained in further examination of runway capacity.

Runway utilisation was calculated as follows:

$$\textbf{\% of Runway Utilised} = \frac{\textbf{Annual ATM's}}{\textbf{Annual Runway Capacity}} \textbf{ x 100}$$

Finally available runway capacity was calculated by subtracting the percentage of runway utilised from the 70% limit, beyond which significant congestion occurs, according to the 1987 AEA report.

From the above approach figure 4.5 identifies that during 1994[9] seven of the 27 European airports studied in the 1990 SRI report were congested. London Heathrow was the most seriously affected, followed by Frankfurt and Dusseldorf. Vienna, Dublin, Geneva, and Barcelona also appeared to lack sufficient capacity, whilst Gatwick and Brussels had less than 5% of spare capacity. At the other end of the scale London Stansted and Milan Malpensa had over 40% of space capacity. The figure for Stansted is misleading though, as it currently operates under strict aircraft movement limits of 78,000 a year,[10] whilst the chart assumes no operating limits. In conclusion, however, the chart clearly shows that there is more than adequate capacity when all the airports are combined, so the problem is not lack of resources, but lack of adequate distribution of resources and capacity at the right airports.

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8 Raw Data in Appendix 4.9 (with Forecasts until 2010)

9 Traffic data taken from ACI Worldwide Airport Traffic Statistics 1994 whilst declared capacities were taken from 1993 APATSI report - These represent the latest, readily available, figures.

10 The Times 18/1/96 Focus on Stansted Airport.

Available Runway Capacity for Selected European Airports for 1994.

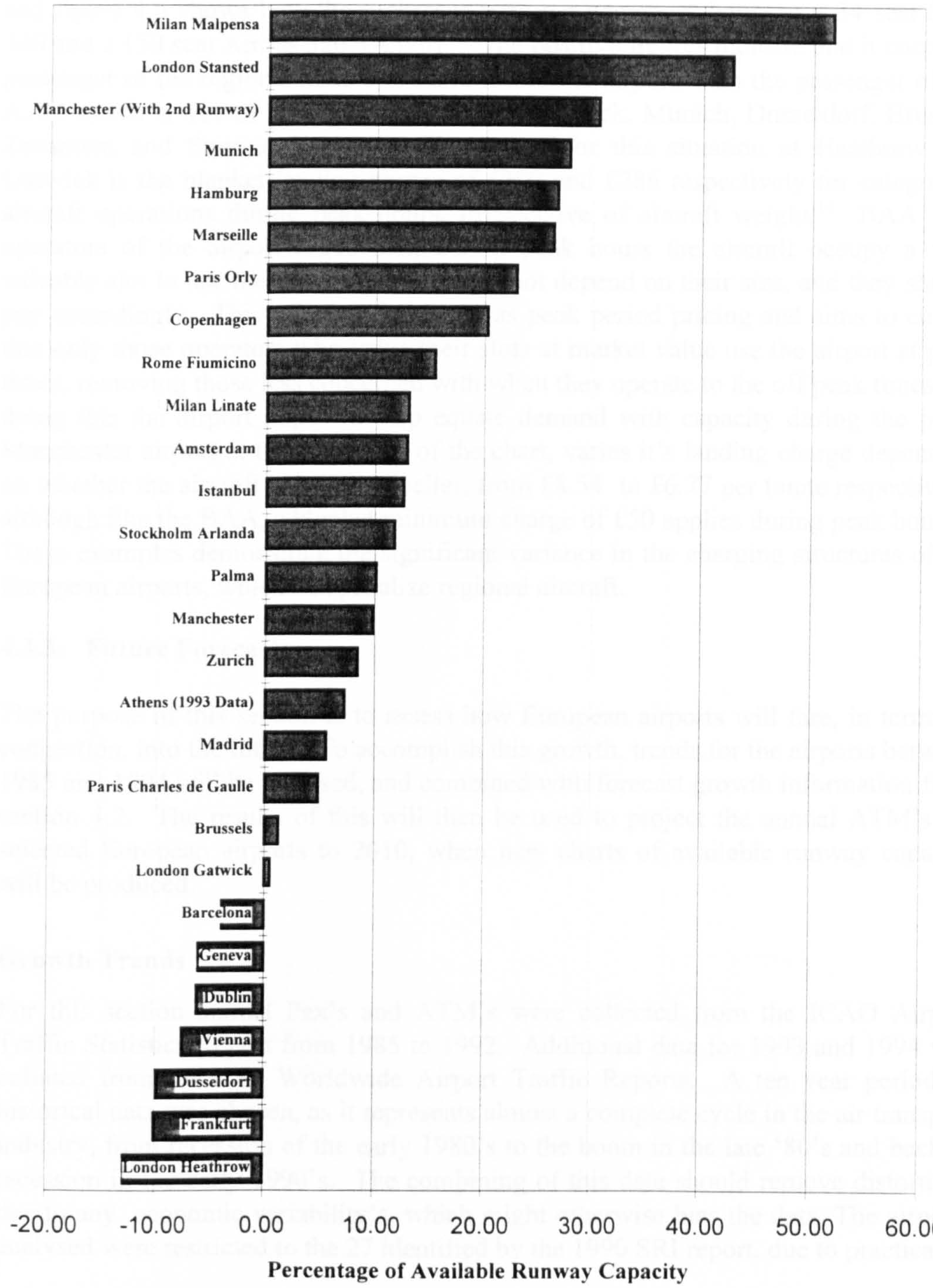

FIGURE 4.5

Source: Data Derived from ACI Worldwide Airport Traffic Statistics 1994 and APATSI Report 1993

Aeronautical Charges and Patterns of Ownership

Information for this section comes from the Department of Air Transport, Cranfield University report, (1995). As indicated in chapter two of this thesis, airports can set a number of operating charges for passenger handling, aircraft parking, runway use and use of local navigation services. Combined these are known as aeronautical charges and figure 4.6 shows how these charges vary per passenger between a 34 seat Saab 340 and a 150 seat Airbus 320, (A320).[11] The positive figures indicate that it costs the passenger of the regional Saab 340 more to use the airport, than the passenger of the A320 which is true of London Heathrow and Gatwick, Munich, Dusseldorf, Brussels Zavantem and Stuttgart airports. The reason for this situation at Heathrow and Gatwick is the blanket landing charge of £390 and £286 respectively for category 3 aircraft operations during peak hours, irrespective of aircraft weight.[12] BAA Plc., operators of the airport argue that, during peak hours the aircraft occupy a very valuable slot to use the runway, which does not depend on their size, and they should pay accordingly. This principle is known as peak period pricing and aims to ensure that only those operators who value their slots at market value use the airport at peak times, removing those less concerned with when they operate to the off peak times. In doing this the airport hopes to help equate demand with capacity during the peak. Manchester airport at the other side of the chart, varies it's landing charge depending on whether the aircraft is jet or propeller, from £8.54 to £6.77 per tonne respectively, although like the BAA, a blanket minimum charge of £50 applies during peak hours.[13] These examples demonstrate the significant variance in the charging structures of the European airports, which can penalize regional aircraft.

4.3.3: Future Forecasts

The purpose of this section is to assess how European airports will fare, in terms of congestion, into the future. To accomplish this growth, trends for the airports between 1985 and 1994 will be assessed, and combined with forecast growth information from section 4.2. The results of this will then be used to project the annual ATM's for selected European airports to 2010, when new charts of available runway capacity will be produced.

Growth Trends

For this section annual Pax's and ATM's were collected from the ICAO Airport Traffic Statistics Report from 1985 to 1992. Additional data for 1993 and 1994 was collated from the ACI Worldwide Airport Traffic Reports. A ten year period of historical data was chosen, as it represents almost a complete cycle in the air transport industry, from recession of the early 1980's to the boom in the late '80's and back to recession in the early 1990's. The combining of this data should remove distortions due to any economic variability's, which might otherwise bias the data. The airports analysed were restricted to the 27 identified by the 1990 SRI report, due to practicality

11 Derivation and presentation of this data is given in appendix 4.10 along with Airport ownership information.

12 BAA Airport Charges from 1st April 1995.

13 Manchester Airport - Fees and Charges 1st April 1995.

Difference in Aeronautical Charges per Passenger between a Saab 340 and A320 for Selected European Airports

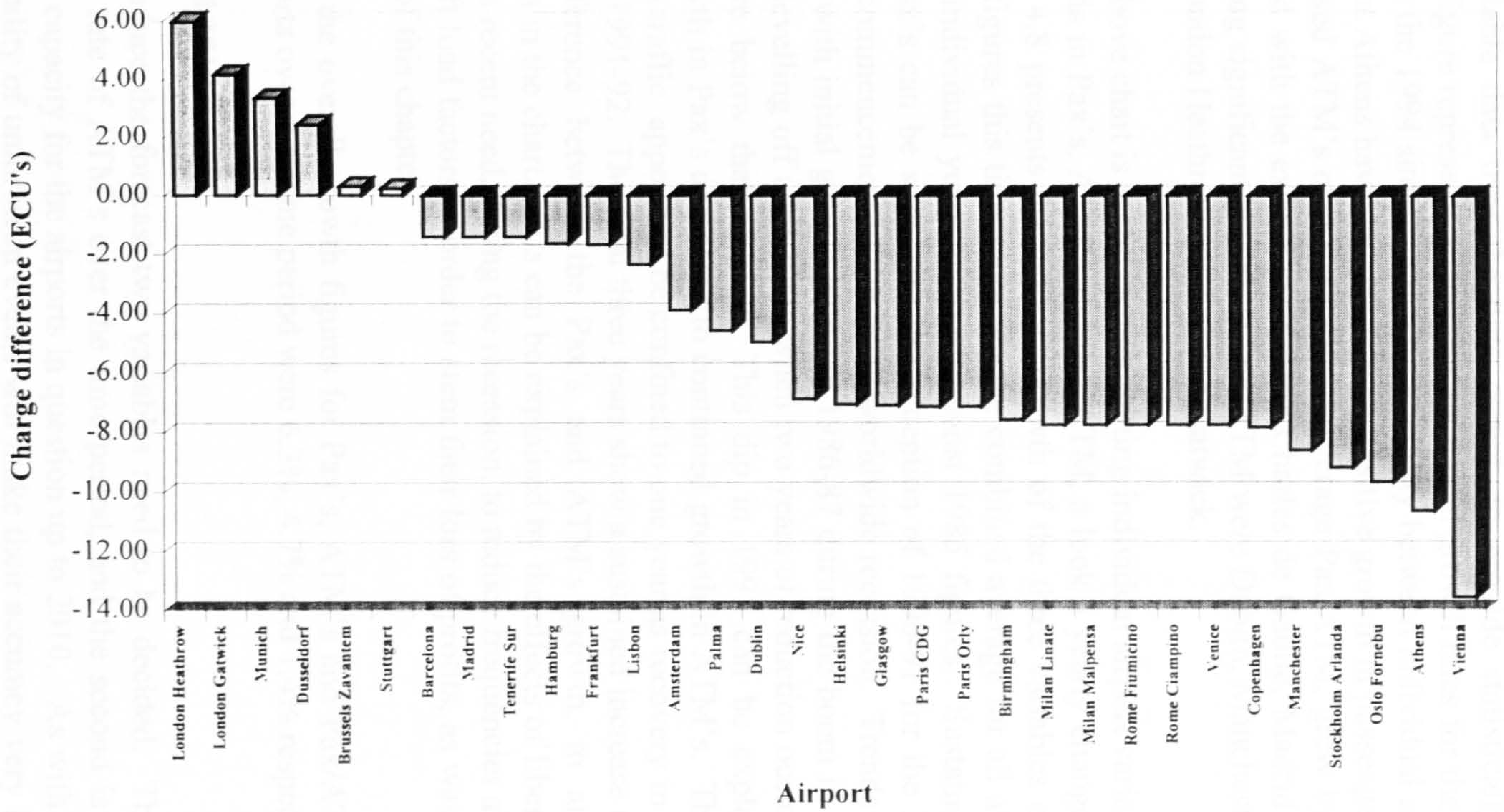

FIGURE 4.6

Source: Dept. Air Transport, Cranfield University (1995) Competition and Airport Financing in the EU - Study for European Commission, DGVII of data handling and, as these airports represented a known benchmark against which to compare the forecasts. The raw data used in the forecasts is given in appendix 4.9. In addition to the primary data retrieved, annual average Pax/ATM's were also calculated over the ten year time period. Figure 4.7 shows the variation in growth rates in Pax's, ATM's and Pax/ATM's for the selected airports between 1985 and 1994. Istanbul and London Stansted are omitted from this chart due to lack of sufficient available data over the time period, to provide statistically significant figures. Each figure represents an average of annual growth rates for the airports. As was noted with the 1994 situation, much variability between individual airports exists although, all but Athens have demonstrated a positive growth in passenger traffic, and all have increased ATM's over the period. Average Pax/ATM, grew by at least 1% over this period with the exception of Paris Charles de Gaulle, Madrid and Athens. Airports showing significant growth in Pax/ATM were Dublin, Manchester Hamburg, Amsterdam, London Heathrow and London Gatwick.

Although the above chart is useful in highlighting individual airport variations, to help assess the trends in Pax's, ATM's and Pax/ATM, a look a yearly changes is of more value. Figure 4.8 presents the indexed growth of the three variables over the time interval. The figures this time represent the combined average for all airports in the study, for the individual years, indexed against 1985 figures. Sustained growth in ATM's and Pax's can be seen with the exception of 1990-91 for the Pax's, which represents the commencement of the latest worldwide recession. Trends in Pax/ATM are interesting with initial growth between 1986-87 during the boom in air transport, followed by a levelling off until 1989, when two years of reduction occurred bringing the 1991 figure below that of 1985. This dip in 1991 can be explained by the decreased growth in Pax's compared to continued growth in ATM's. The severity of the 1991 dip in traffic appears to be confined to one year as recovery in Pax's occurs rapidly during 1991-92. The final three years show a sustained increase reflecting the increasing difference between the Pax's and ATM's growth, to an extent not previously seen in the chart. This can be explained by the effects of liberalisation and also the airlines recent need, during the recession, to reduce frequencies and attempt to increase aircraft load factors in order to stem their loss of profits, as was discussed at the beginning of this chapter.

In conclusion, the overall growth figures for Pax's, ATM's and Pax/ATM for those European airports over the same period were 6.3%, 4.7% and 1.4% respectively.

Forecasts until 2010

In order to produce the forecast two variables need to be decided. The first is the annual growth rate of ATM's over the time period, and the second is the declared annual runway capacity for the airports in question up to 2010. As with any forecast, the unpredictability of unforeseen events will make their accuracy very limited. For this reason, plus the limited availability of resources and time in this thesis, the forecasting methods employed will be relatively simple.

The examination of market forecasts in section 4.2.2, placed the growth of world airline passenger traffic up to 2014, at 5.1% p.a., and an average of 4.2% p.a. for intra-European passenger growth. This is at least 1% lower than the growth figures given

Comparison of Annual Average Pax, ATM and Pax/ATM Growth Rates for Selected European Airports (1985-1994)

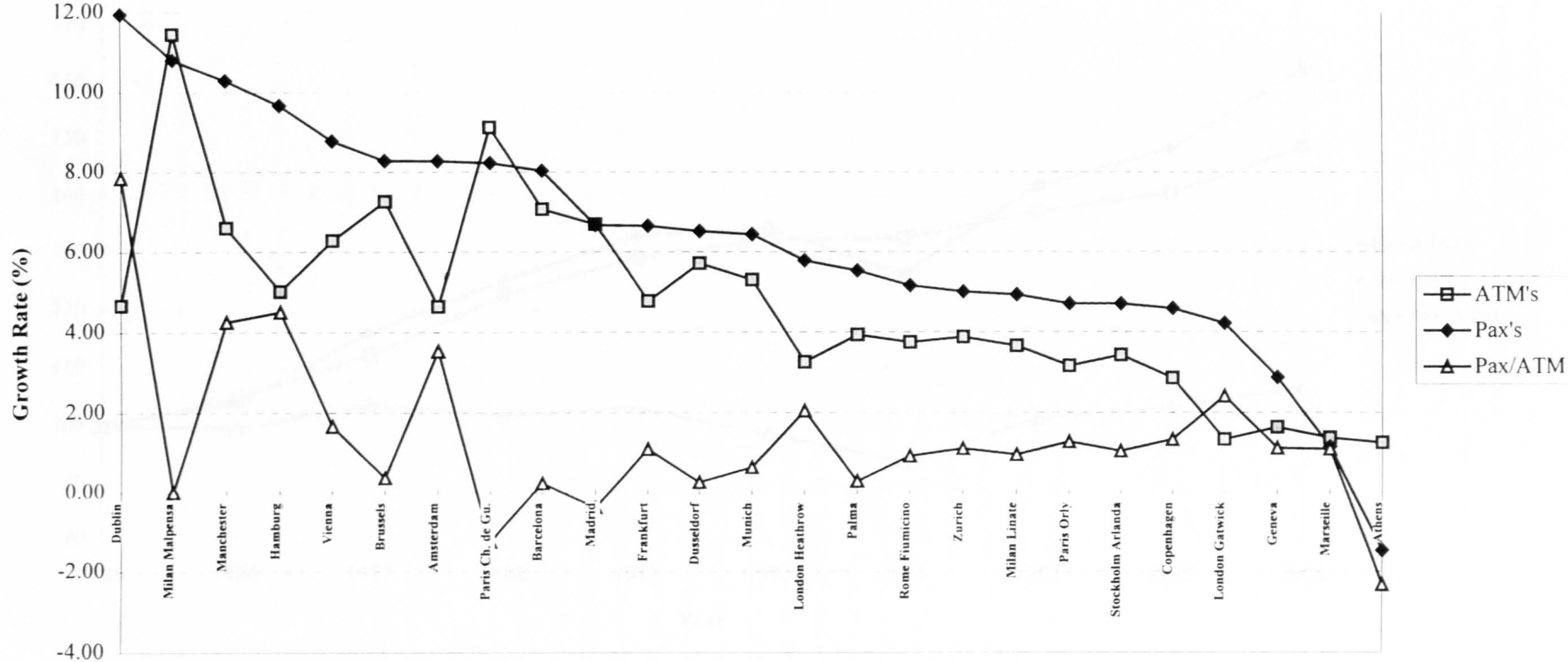

FIGURE 4.7

Source: Derived Data from ICAO and ACI Airport Traffic Statistics 1985-1994

Indexed Annual Average Changes in ATM's, Pax's and Pax/ATM for Selected European Airports.

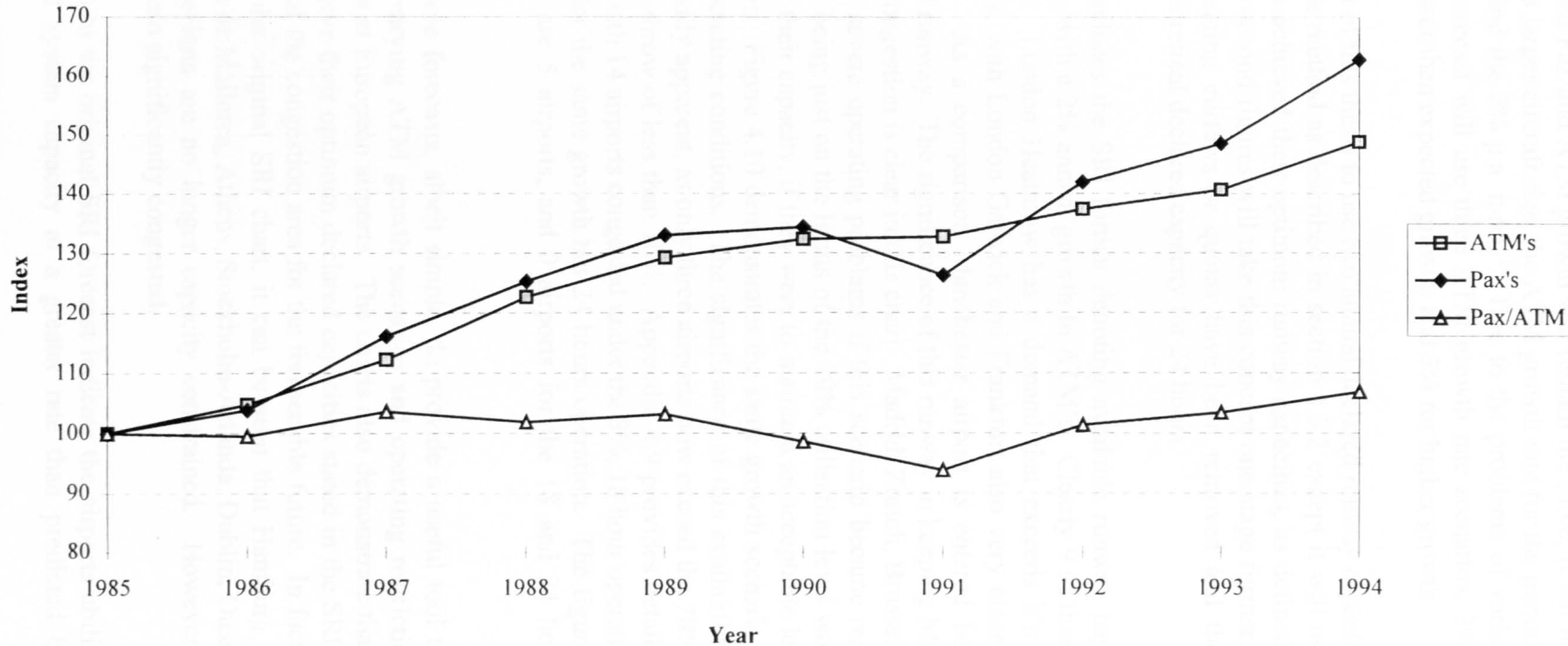

FIGURE 4.8

Source: Data Derived from ICAO and ACI Airport Traffic Statistics 1985-1994 between 1985-94. If one assumes that, in addition to this fact, the magnitude of the difference between Pax and ATM growth will remain the same, if not increase due to the trend towards larger aircraft size, the ATM growth rate for the period until 2010 is likely to be around the 2% p.a. mark.[14] Due to the problems of variability already discussed, this forecast will use three ATM growth rate scenarios, 2% as the most likely, 1% for lower than expected growth, and 3% for higher growth.

It is the intention of this thesis to use two annual declared runway capacities. The first will use the same method as described in section 4.3.2 except it will assume that all the airports have achieved their optimum runway capacities, as defined by the 1990 SRI report. The second figures will take this concept one stage further, by assuming that current operating curfews or quotas have been removed and the airport can operate at it's theoretical declared capacity for 24 hours.

Figures 4.9 reproduces the SRI format denoting available runway capacity for the airports by 2010, with a 2% annual growth in ATM's. Clearly 9 of these airports are lacking capacity. London Heathrow has a demand that exceeds it's total runway capacity by 4.4%, with London Gatwick and Frankfurt also very close to the 100% utilisation level. As a comparison Manchester airport is entered both with, and without a second runway. The significance of this runway in keeping Manchester free from excessive congestion is clear in this chart. Madrid, Zurich, Brussels and Geneva also would have severe operating problems if this scenario became reality. Vienna and Copenhagen being just on the limits of the 70% utilisation level would also need to be developing their capacity, if they were to maintain an acceptable level of service to their customers. Figure 4.10 demonstrates the same growth scenario, but this time with 24 hour operating conditions. The significance of this availability in reducing congestion is readily apparent, as only three airports now exceed the 70% limit, with a maximum at Heathrow of less than 10%. Appendix 4.9 provides details of the other scenario results with 14 airports congested under the 3%, 18 hour operation, compared to 6 airports under the same growth but 24 hours operation. The figures for the 1% growth scenario are 5 airports, and 0 airports for the 18 and 24 hour operations respectively.

In conclusion these forecasts, albeit simple, do provide a useful tool to analyse the implications of varying ATM growth scenarios and operating restrictions on future congestion levels at European airports. The charts also demonstrate that, if the listed airports can achieve their optimum declared capacities stated in the SRI report, many will remain out of the congestion area for the foreseeable future. In fact, if figure 4.9 is compared to the original SRI chart, it can be seen that Hamburg, Copenhagen, Marseille, Palma de Mallorca, Athens, Stockholm-Arlanda, Dublin, Dusseldorf, Milan Linate, and Barcelona are no longer capacity constrained. However, nine of the airports will remain significantly congested.

This comparison to the original SRI forecast indicate the airports ability to increase their operational system capacity at a greater rate than predicted by the earlier

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[14] 2% ATM growth is the figure given in the ICAO long term forecast 1995-2003 - ICAO Journal Dec 1994.

Forecast of Available Runway Capacity for Selected European Airports by 2010 (2% Growth p.a.)

18 Hours Operation

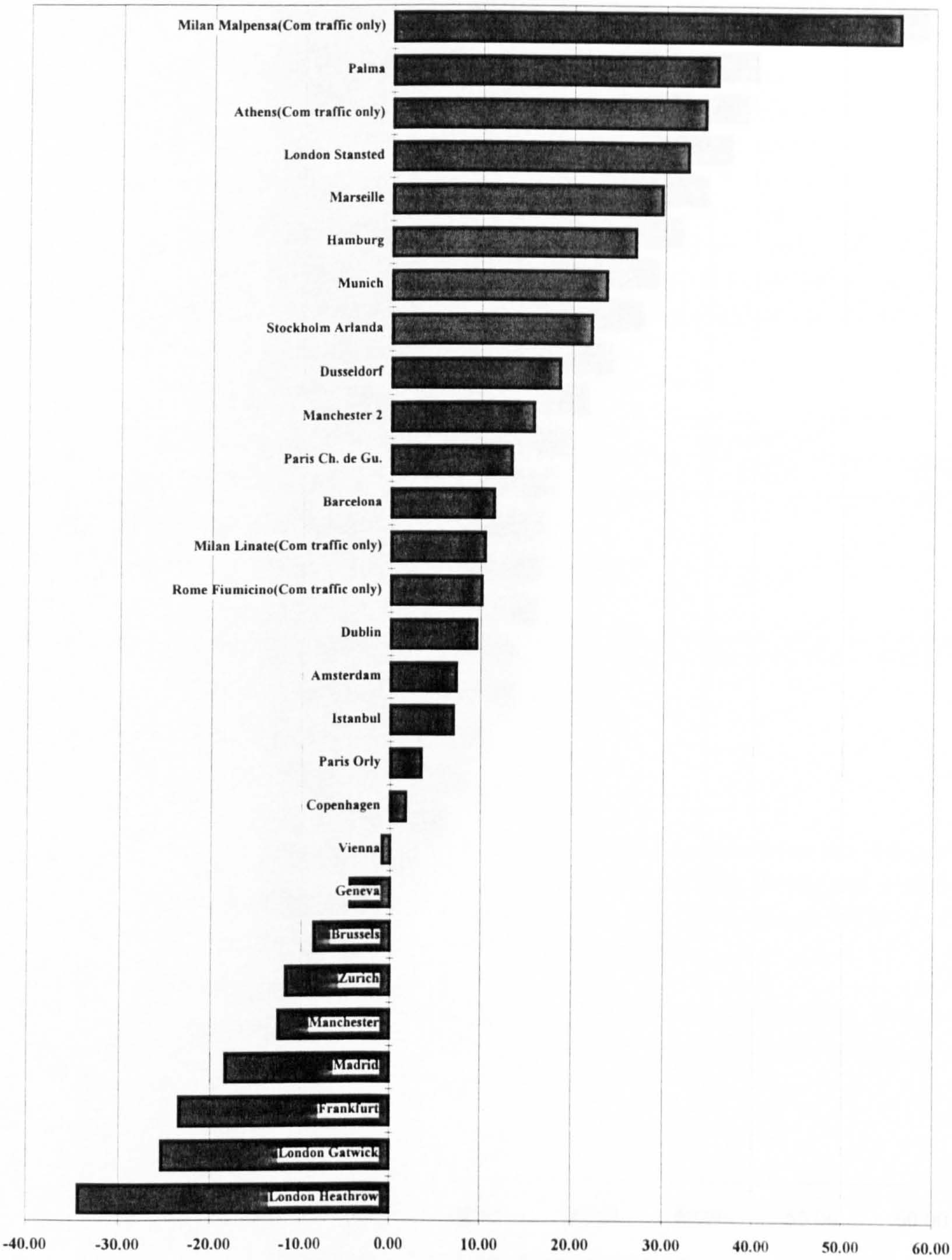

FIGURE 4.9

Forecast of Available Runway Capacity for Selected European Airports by 2010 (2% Growth p.a.)

24 Hour Operation

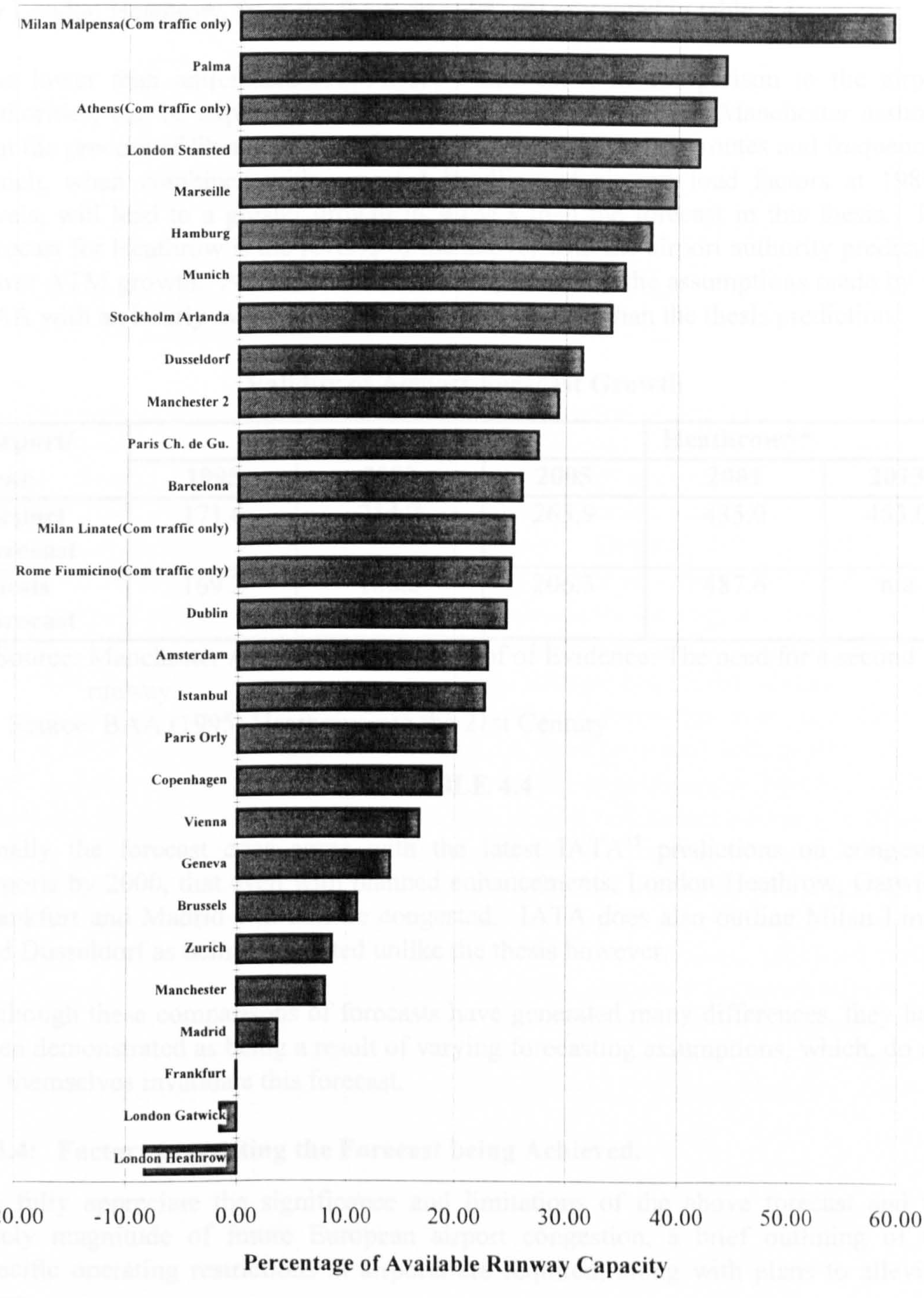

FIGURE 4.10

forecast. The two major limitations of the forecast are in assuming that ATM growth for each airport are the same, and the airports can maintain their optimum declared runway capacities over 18 or 24 hours, without a firebreak from 1995. When the forecast ATM figures are compared to individual airport forecasts differences can be seen. Manchester airport produced a series of ATM forecasts in 1994 as part of it's proof of evidence for a second runway. This comparison, along with similar forecasts for London Heathrow, from the BAA, in 1995, are presented in table 4.4.

The lower than anticipated ATM's for Manchester, in comparison to the airport authorities, can be explained by the assumptions of the latter. Manchester assumes that the process of liberalisation will lead to an increase in new routes and frequencies which, when combined with expected levelling of aircraft load factors at 1980's levels, will lead to a greater growth in ATM's than the forecast in this thesis. The forecast for Heathrow is the reverse of the above, with the airport authority predicting lower ATM growth. As before this can be explained by the assumptions made by the BAA with an hourly average movement rate of 78, less than the thesis prediction.

Validity of Airport Forecast Growth

Airport/	**Manchester***			**Heathrow****	
Year	**1995**	**2000**	**2005**	**2001**	**2013**
Airport Forecast	171.6	214.7	263.9	435.0	453.0
Thesis Forecast	169.2	186.8	206.3	487.6	n/a

* Source: Manchester Airport Plc (1994) Proof of Evidence: The need for a second runway.

** Source: BAA (1995) Heathrow into the 21st Century

TABLE 4.4

Finally the forecast does agree with the latest IATA[15] predictions on congested airports by 2000, that even with planned enhancements, London Heathrow, Gatwick, Frankfurt and Madrid will still be congested. IATA does also outline Milan Linate and Dusseldorf as being congested unlike the thesis however.

Although these comparisons of forecasts have generated many differences, they have been demonstrated as being a result of varying forecasting assumptions, which, do not by themselves invalidate this forecast.

4.3.4: Factors preventing the Forecast being Achieved.

To fully appreciate the significance and limitations of the above forecast and the likely magnitude of future European airport congestion, a brief outlining of the specific operating restrictions at airports are required, along with plans to alleviate them.

[15] Data taken from F. Ligi (1995) Airport Slot Allocation in Europe - Msc thesis, Cranfield.

Slot Allocation

The initial concepts of slot allocation were discussed in chapter two. The specific problems affecting European airports will be covered here. As Ligi, (1995), states, the use of this approach should be seen as a last resort and only regarded as a short term solution to congested airports. The principles of the IATA Scheduling Procedures Guide has fallen foul of a number of criticisms recently. Ligi, (1995), identifies four main concerns, firstly overbooking where allocated slots are not utilised and other airlines are unable to use them. Secondly, giving new entrants 50% of remaining slots, once the historical slots have been allocated, does not give sufficient scope for a successful new entrant it is argued. Problems with bilateral agreements have also arisen as country A's airline operates to country B's uncongested airport, whilst country B's airline has restricted access to country A's congested airport. Finally, an economic row has recently arisen over the IATA procedures and their fairness. Opponents of the system argue that it is a closed shop operated by and for airlines, which contravenes the competition rules of the Treaty of Rome. This last problem has resulted in the US disallowing the system for anti-trust reasons.

The problem of slot allocation, however, is more severe in Europe than the US as, according to a report in 1992, only three out of 24 main European airports were not slot coordinated, compared to only four slot coordinated airports in the US.[16] During the early 1990's the most hotly contested slot allocation issue in Europe has been that of historical precedence, or, 'Grandfather Rights'. Doganis, (1992), explains that when a carrier controls 30-50% of total available slots at an airport, they exert more or less monopoly power at those airports. Understandably the largest complaint to this has been from new entrant airlines and those wishing to expand at a congested airport. In the UK this has been demonstrated by Virgin Atlantic and British Midland trying to break what they see as the monopoly hold British Airways has over slots, (39% of total in 1992[17]), at London Heathrow. British Midland presented data, in 1990, that by 1995 demand for runway slots at Heathrow would exceed supply by 65-120,000.[18] The basic argument, however, is that this lack of slots will reduce access to congested airports and prevent the free market competition between airlines, by severely limiting the addition of route frequencies for airlines. Figure 4.11 clearly demonstrates this for London Heathrow where, for all but four hours during the day, demand for the slots significantly exceeds availability.[19] During 1993 British Midland produced further statistics to demonstrate that Heathrow was the most congested European airport with 99.5% of slots occupied during peak times. The figures for Paris Charles de Gaulle, Amsterdam and Frankfurt were 73%, 66% and 97% respectively.[20] The figure for Frankfurt, although high, was expected to fall as the US military removal freed up more slots.

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[16] Source: Reed, A (1992) Grandfather is well and living in Europe - Air Transport World, 5/1992, p65-67.

[17] O'Toole, K (1993) Searching for a slot - News Analysis - Flight International 27/1-2/2/1993, p14.

[18] Reid, A (1990) The case for additional runway capacity at Heathrow - Paper in Royal Aeronautical Society One Day Conference entitled, "New Runway Capacity in the South East - Solutions and Impacts." p9.1-9.7

[19] See Appendix 4.11 for Raw Data and London Gatwick figures

[20] Source same as footnote 19.

Comparison of Hourly Variations in Demand and Supply of Total Slots at London Heathrow (Summer 1994)

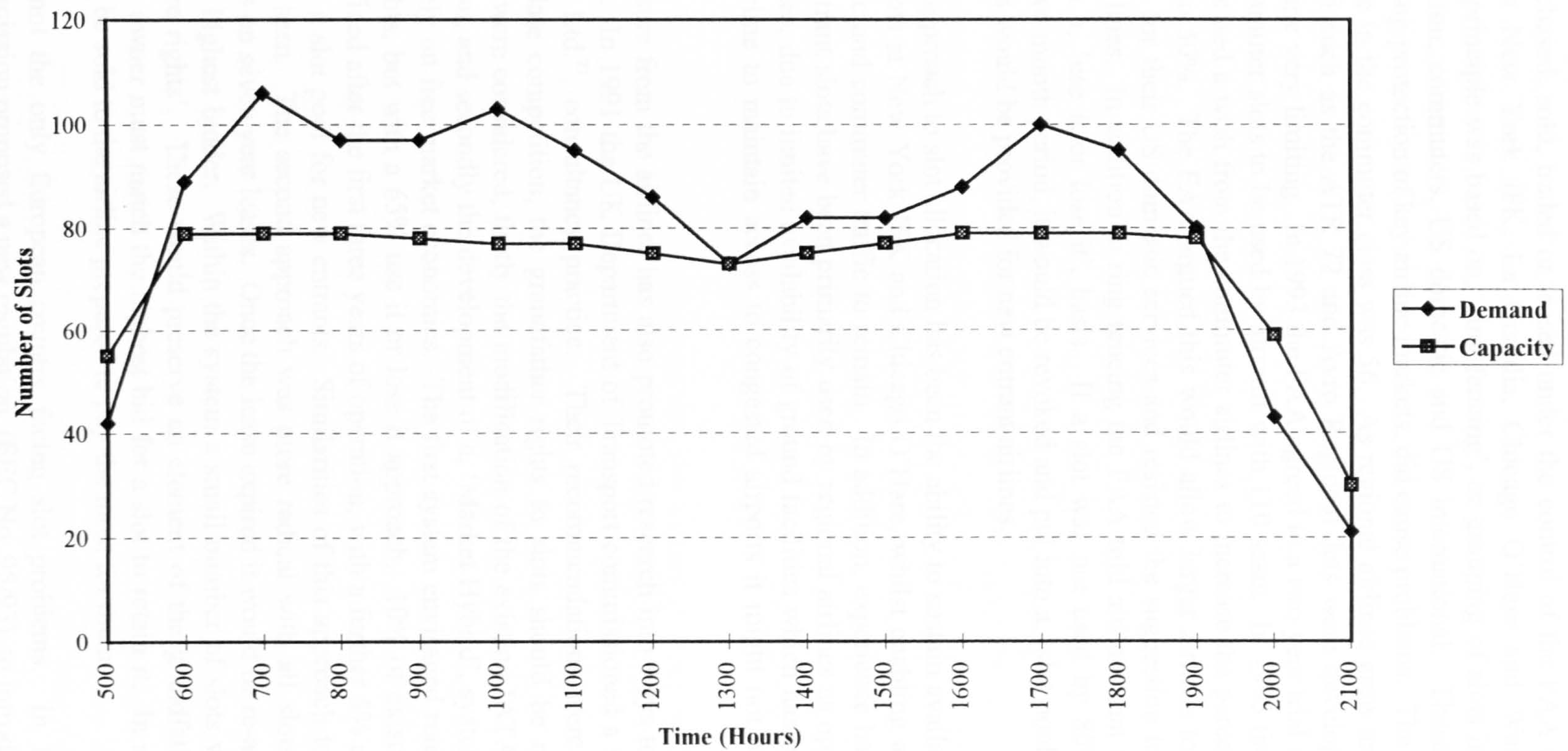


FIGURE 4.11

Source: CAA (1995) CAP 644 Slot Allocation: A Proposal for Europe's Airports

Solutions to this problem are many and varied. Following the US ruling on the IATA scheduling procedures the FAA introduced a buy-sell rule for slots. This allowed slots to be purchased, sold, traded or leased under the control of the FAA and was implemented at New York JFK, La Guardia, Chicago O'Hare and Washington National. The principle was based on, 'ring fencing', or grouping of slots into three types of operation, commuters, US domestic and US international. These fences, although allowing protection of key airline markets, did cause problems. The limit on aircraft seat size in the commuter class was 56. As regional airlines grew and larger regional aircraft such as the ATR 72 and Avro Regional Jets were developed, this restriction became very limiting. In 1993 the FAA agreed to a two year trial allowing 25% of the commuter slots to be used by aircraft with 110 seats. In 1995 the review of the trial indicated a wish from the commuter airlines to increase the percentage of 110 seat slots to 50%. The FAA argued this would allow larger airlines to use the commuter slots for their US domestic services and resisted the suggestion to protect the regional airlines. In addition to ring fencing the FAA told airlines that the slots were issued on a, 'use it or lose it', basis. If a slot was not used by 80% of its potential in a two month period, it would be revoked and put into a, 'slot pool', where 25% of the slots would be provided for new entrant airlines.

Results of this approach to slot allocation has been the ability to sustain availability of international slots at New York JFK and Chicago O'Hare, whilst enabling a healthy mix of domestic and commuter traffic to remain. In addition, experience has shown that the new entrant slots have been primarily used by regional airlines as opposed to the larger airlines, due to limited availability of ground facilities which has permitted the regional airline to maintain access to congested airports it might not otherwise been able to do.

In Europe pressure from the airlines has also promoted research into ways to change the slot system. In 1991 the UK Department of Transport commissioned a study by the SD-Scicon Ltd.[21], consultancy practice. Their recommendations were that, in order to stimulate competition, the grandfather rights to slots should be removed. Two scenarios were considered, firstly the modification of the existing IATA system of full regulation, and secondly the development of a, 'Market Hybrid', system which would rely solely on free market economics. The first system envisaged retention of grandfather rights, but with a 65% use it or lose it approach. 10% of existing slots would be sacrificed after the first three years of operation, with a further 5% after five years, to create a slot pool for new entrants. Similarities of this approach to the US system can be seen. The second approach was more radical with all slots sold at market auctions on seven year leases. Once the lease expired it would be re-auctioned and sold to the highest bidder. Within the system a small number of slots would be classed as, 'core rights'. These would preserve an element of the grandfather right system, but the owner must match the highest bid for a slot to retain it. In summary the slots would be sold to the airline prepared to pay the most for them.

The UK was not the only European country facing slot problems. In 1993 the European Commission proposed a new regulation, (EEC No. 95/93), to introduce a set

21 Source: Hulet, J, et al. (1991) Study on Airport Slot Allocation - Final Report. UK Department of Transport

of common rules on slot allocation. This followed previous regulation on the IATA procedures to exempt them from articles 85 and 86 of the Treaty of Rome. Details of the proposal are given in appendix 4.12. Variations from the IATA system include the introduction of slot exchange between airlines, the use it or lose its rule, and the generation of a slot pool for unused slots, although grandfather rights remain. In terms of regional airline operations, the ability to protect certain routes is good, although it depends on the political stance of member countries.

This EU proposal is currently under review by all interested parties, with a final decision on the regulation planned for 1 July 1997. The UK CAA presented it's views on the proposal in CAP 644, Slot Allocation: A proposal for Europe's Airports. The report reviews the effectiveness of the new regulation at Heathrow and Gatwick, and proposes modifications to the EU regulation following this experience. The CAA argued that the objective of facilitating competition and encouraging new entrants had not been successful, with only five out of fourteen new entrants at Heathrow and only two of those being on intra-EU routes. New slots generated were being used to increase frequency on existing routes rather than introducing new ones. The figures for Gatwick were slightly better, with four new entrants starting up, three on intra-EU routes. The proposed regulation is criticised in its lack of guidance over how to distribute the slots from the slot pool. They protest that to provide effective competition on key European routes, three or four daily frequencies are required, usually beyond the scope of a financially strapped new entrant. They also argue that the airlines best able to finance effective competition to the major airlines, for example in the UK: British Midland at Heathrow; and City Flyer Express and Jersey European at Gatwick, are not eligible for new entrant status.

Following these criticisms, the CAA proposes that slot trading for money should be allowed, so long as the transactions are made public knowledge. Objectives of the regulation should be to further the interests of the users, maximise the use of slots, encourage the use of larger aircraft, and promote new entry and route competition, although it is recognised that the goals of these objectives are not all consistent with each other. In terms of slot allocation, the CAA, propose that allocation to routes should be based on route density, with preference to the denser rather than lighter ones. Slot allocation to airlines must be unbiased with pool slots going to airlines offering a frequency sufficient to compete effectively with the incumbents, or flag carriers. Subjective decisions by the coordinator should be avoided by increased operating guidelines, and 'paper airlines', or those not properly in existence at the time the slots are allocated, should only be granted slots if they have passed defined, 'milestones', such as achievement of an air operators certificate. Regarding airline alliances, the CAA suggest that new entrant airlines gaining slots under their own name at the slot conference, should return these to the slot pool when they develop code sharing agreements or shared flight numbers with an incumbent carrier. Finally, regarding the 'use it or lose it', rule, any airline not actually serving a route for a year would not only be forced to surrender their slots but disqualified for three years from obtaining pool slots at that airport.

Although this response is British biased, it does represent a well respected voice in European regulation. For regional airlines it also highlights areas of concern for their future. The CAA, in their arguments, do not support the protection of smaller regional routes and would actively discriminate against them. The ability for regional airlines to enter the slot constrained airport as a new entrant would also be reduced if the CAA implemented its policy of giving preference of pooled slots to larger competing carriers. Finally, if slot trading were legalised and permitted without restriction, slots would go to the airlines prepared to pay the most money for them. This may well penalise the regional carriers because, although they may value a slot very highly, they may not have sufficient financial resources to meet the price, whereas a major airline is less likely to face this problem.

Further comments to the EU regulations from the airlines was obtained by Ligi, (1995) who received questionnaire responses from 101 European airlines and 28 others. Results of the questionnaire showed that although virtually all airlines supported the concept of grandfather rights, most felt the definition of new entrant needed refinement, although how was not commonly agreed. Most airlines did not want to see an increase in the percentage of pooled slots going to new entrants, or an increase in the 80% use it or lose it rule either. Generally, they were satisfied with the transparency and neutrality of European airport coordinators, although they all felt regulation should be added to prevent an airline abusing it's dominant position. Dominant being defined as an airline holding 40% or more of an airports total slots. Finally, when asked to consider who should own the slots, all agreed it should be the airlines.

This represents the current situation regarding slot allocation within Europe. As has been shown, this issue is more directly debated between the airlines and regulators, but it is the airport that is left at the front line to either expand capacity or mediate between these parties to solve the problems. The implications to the regional airlines have been mentioned, especially the potential problem of *equitable* slot trading. The issue of slot pricing was seen by most airlines as a bad idea. Future developments considered by the Toronto Consumer Policy Institute include slot lease with grandfather rights, or an airline condominium, where airlines run the airside facilities at an airport. Dispossession has also been considered, whereby carriers have to relinquish 10% of their grandfather slots each year for the slot pool. This would benefit the smaller carriers in their competition with the incumbents, although only 11% of these carriers supported the concept in Ligi's questionnaire.

In summary we can see that airport slots can quite severely restrict free airline access to an airport. This thesis aims to demonstrate that by employing special regional aircraft procedures, regional airlines can expand the potential capacity of an airports runway. This in turn should help alleviate some of the misery inflicted by slot allocation

Geographic Limitations

The discussion on slot allocation could be avoided if airports were allowed to expand facilities in line with demand. Unfortunately this is rarely possible for a variety of reasons. Physical availability of space has become an ever increasing factor in this reasoning. Population densities can be used as an indicator of the likely effect, of airport expansion on the surrounding population. The United States has a population density of 26 people per square kilometer, whilst European and Asian countries have densities of at least 50. Specific European countries, where expansion would be difficult, are the Netherlands, Belgium, Germany, and the UK which all have densities over 200.[22] In addition to population density, airports also suffer from being centres of economic attraction due to their ease of access. This in turn leads to business, commercial and residential developments close to the airport, which will further limit its expansion options. In many cases airports will purchase land surrounding them if it is available in order to prevent some of the problems associated with airport expansion. In Europe the only airports that seem to have adequate spare land for expansion are the new green field airports, such as Paris Charles de Gaulle, Munich 2, and Amsterdam Schiphol, although all face problems gaining planning permission to change existing land use into taxiways or runways. This permission for changes in land use into taxiways or runways will also be much harder if existing land use is residential or high value commercial land, which is more likely in high population density areas, than if it is agricultural or waste land. Taking the above reasoning into account, the ability to expand airports in Europe is lower than the United States. It will also make changes to arrival and departure routes harder over high population density areas due to increased noise disturbance.

Environmental Restrictions

Environmental restrictions on airports are very significant. The issue in Europe is more significant than other regions the Airports Council International, (ACI), argues, with increased exposure of the population to aviation waste products, such as noise and air pollution, due to the high population densities, and passengers' preference for airports closest to centres of population. A report by ACI in 1995[23] points out that there tends to be a correlation between an increase in noise complaints and protests associated with increasing air traffic and standard of living.

The current impact of environmental regulations on European airports was summarised in the 1995 ACI Environmental Handbook. The purpose of the report was to ensure that future growth was not constrained by environmental issues, and that environmental capacity was not reached before infrastructure capacity. The investment made in environmental issues at airports was already significant ACI argued, with 20 out of 104 airports in the region having specific environmental departments, 36 had noise monitoring systems, of which 86% were used for enforcement of noise limits or zones. In terms of land use planning around the airport, only 55% of those questioned had any say in the planning process, which may well cause future problems as available land in the vacinity of the airport is used for industrial or residential purposes, limiting airport expansion options. Noise optimised flight routes were used at 75% of the airports questioned, with 50% also applying the noise preferential runway scheme. In an attempt to gain recompense for all the environmental costs the airport faces, 29% of European airports now have a noise

22 Source: Readers Digest (1989) Atlas of the World

23 ACI (1995) Environmental Handbook. ACI Europe

charge for aircraft which vary in absolute cost. Of these, 17 apply charges to propeller aircraft greater than 9,000kg, which includes most regional aircraft.

The effect on regional aircraft will be limited to jet aircraft at present, although the likelihood of increased restrictions on turboprops at a later date cannot be ruled out, and the number of airports already charging regional aircraft for exceeding noise limits is proof of this theory. From an airport point of view the increase in environmental restrictions is worth the expense, if it satisfies the local population, and facilitates future land acquisition. Airlines on the other hand will be financially disadvantaged by the measures, particularly if different standards are made for separate world regions.

This issue has been presented as a limiting factor to airport expansion, and consequentially an artificial cap on capacity. If environmental restrictions increase in the future, as they are forecast to do, the capacity restriction will increase. Assuming airlines still demand to use key airports, this will lead to greater congestion and pollution, so destroying the purpose of the restrictions, (55,560 tonnes of fuel burnt by British Airways aircraft airborne holding at Heathrow and Gatwick during 1994-95[24]).

European Liberalisation

With the fundamentals of liberalisation defined in chapter two, it is the intention here to outline the results of the liberalisation process as they relate to the impact on the current airport operating environment. Doganis, (1993) provided a good review of the changes since liberalisation began in his inaugural lecture to Cranfield University. Put simply, the anticipated effects of a rapidly increasing airline demand for slots, due to increased new entrant start-up and increased competition, has not occurred. This has been put down to both the 1991 recession and the significant barriers to entry for new start ups or smaller airlines, which include lack of sufficient airport infrastructure. By far the largest trend since liberalisation has been the growth of airline alliances or marketing agreements between the major European carriers and the smaller regional airlines. British Airways has led the way with agreements involving City Flyer Express, Brymon Airways, Maersk Air, Manx Airlines, and Loganair in the UK, and Deutsche BA and TAT in Europe. This has enabled BA to provide more frequencies and destinations in its route network, as well as provide more feed traffic for its longer haul services from Heathrow and Gatwick. It also now means that BA dominates its domestic market with 63% of the total market share by RPK's.[25] More importantly however, it has allowed BA to operate these services at a much reduced cost than would have been possible using its own aircraft, due to its higher operating costs. Similar agreements stand with KLM, Alitalia, Air UK, Braathens Safe and Eurowings, and Lufthansa and British Midland.

The results of liberalisation then, rather than leading to expanded growth have led to increased market concentration for European airlines, specialising in their own niche markets, with agreements with other airlines to feed traffic for their services. No

24British Airways (1995) 1995 Annual Environmental Report. British Airways.

25 Nat West Securities (1995) Strategic Assessment - British Airways Further to Fly.

major new entrant has emerged since liberalisation to compete with the existing carriers, due to the steep barriers to entry, especially due to the marketing and purchasing power of the current major carriers, which allow them to achieve lower operating costs than the new entrant. However, the emergence of new low cost operators are just beginning to be seen in the UK, with the growth of Easy Jet, Ryanair and Debonair. These are all built on the philosophy developed by Southwest Airlines in the US as a low fare, 'no frills', operation, providing passengers with point to point flights, avoiding the hassles associated with transiting through one of the major airlines hub airports.

This stagnation then since liberalisation, and the increased ties between airlines has prevented the huge growth expected in aircraft movements, and allowed the European airports a breathing space to improve their existing infrastructure, which they have been doing, albeit slowly.

Future growth due to liberalisation is expected to grow rapidly, following the emergence of the airlines from the recession, increased new entrants and total domestic deregulation in January 1997. It is then that the plans of the airports during the last few years will be tested, and the true results of European liberalisation are discovered.

Political Interference

The best example of this problem is the UK government's inability to make a decision regarding the construction of a new runway in the South East of England. In 1985 a government policy paper indicated that serious problems would occur by 1995 if capacity in the London area failed to grow in line with demand. The government decided that more information would be required before a decision could be made. The UK CAA suggested improvement to the existing runway operation to increase capacity. This idea was not developed in CAP 570 however, which presented a comprehensive examination of the UK's traffic distribution, future airspace and airport capacity prospects. CAP 570 stressed the importance of an early decision on the location of the new runway to avoid unnecessary congestion. Instead of making a decision though, the government set up a working committee called RUCATSE, (Runway Capacity in the South East). They examined the social and economic impacts of the new runway sites proposed in CAP 570, and concluded that to construct a new runway at the commercially preferred airports of Heathrow and Gatwick would be too costly. If Luton and Stansted were developed further, this decision on a new runway could be postponed a further three years.

This is what occurred and, in 1992, this left the UK CAA no choice but to issue CAP 615, which was a consultative report called 'Access to Congested Airports for Regional Services'. The report concluded that the CAA were not in a position to assist in maintaining regional services at congested airports, unless authorised to do so by the government. Obviously, this represented the first attempt to control further growth at major UK airports to prevent excessive congestion developing. In January 1995 Brian Mawhinney, the then government Transport Secretary, announced that, following consideration of the RUCATSE report, neither of the Heathrow or Gatwick runway options would be possible, although further work should be carried out on to assess the feasibility of a close parallel runway at Gatwick, given the advancements in ATC knowledge. In over ten years then, the government have still not made a decision regarding a new runway for London. This indecisiveness may well cost London its position as the international transfer capital of the world to either Amsterdam or Paris, not to mention cause airlines operating from Heathrow and Gatwick increased delays, costs and restrictions, and loss of revenue for the airports.

Summary

This concludes the discussion of the current status of European airports. The discussion has been comprehensive due to the author's intention to prove to the reader that firstly, congestion at European airports is a significant problem which is likely to get worse in the future. Secondly, due to the many operating restraints at the airports, the scope for major infrastructure improvements at existing airports are very limited. Both points support the need for application, where feasible, of low cost, low impact changes to existing operating procedures. The author will demonstrate in the following two chapters that special regional aircraft procedures offer the low cost solution required to reduce present and future airport congestion.

Before moving on it is necessary to discuss the current European ATC situation due to the direct interaction it has on airport capacity.

4.4: European Airspace

Problems with lack of capacity in European airspace were recognised in the summer of 1987, following excessive delays due to ATC strikes throughout Europe. Controllers argued that they were being put under too much pressure by being forced to accommodate volumes of air traffic movements far in excess of the design specifications of their systems, as well as attempting to coordinate traffic within Europe with incompatible ATC equipment between separate countries. Lange, (1989), calculated that ATC inefficiency in 1988 cost the airlines and users over US$5bn. The breakdown of this cost is given in table 4.5. It is the purpose of this section to examine what measures have been undertaken since that time to ease airspace congestion and reduce controller workload.

4.4.1: Background

Attempts to co-ordinate ATC in Europe go back to 1960 with the setting up of Eurocontrol. The aim was based on a semi-open sky policy, following the US system, and wanted to establish total control of all ATC facilities and operations in the upper airspace of member states. National sovereignty fears have largely prevented this idea becoming reality, however Eurocontrol has been involved in many other research projects, in particular EATCHIP and flow management.

The Cost of ATC Inefficiency

Cost Element (in US$ million)	User	Airline	Other	Total
Delay	540	970		1500
Inefficient Routing	510	1270		1800
Non-Optimal Flight Profiles		650		650
Lower ATC Productivity			600	600
Macroeconomic cost to European Community			400	400
TOTAL	**1050**	**2890**	**1000**	**5000**

Source: Lange, (1989) The Crisis of European Air Traffic Control: Costs and Solutions

TABLE 4.5

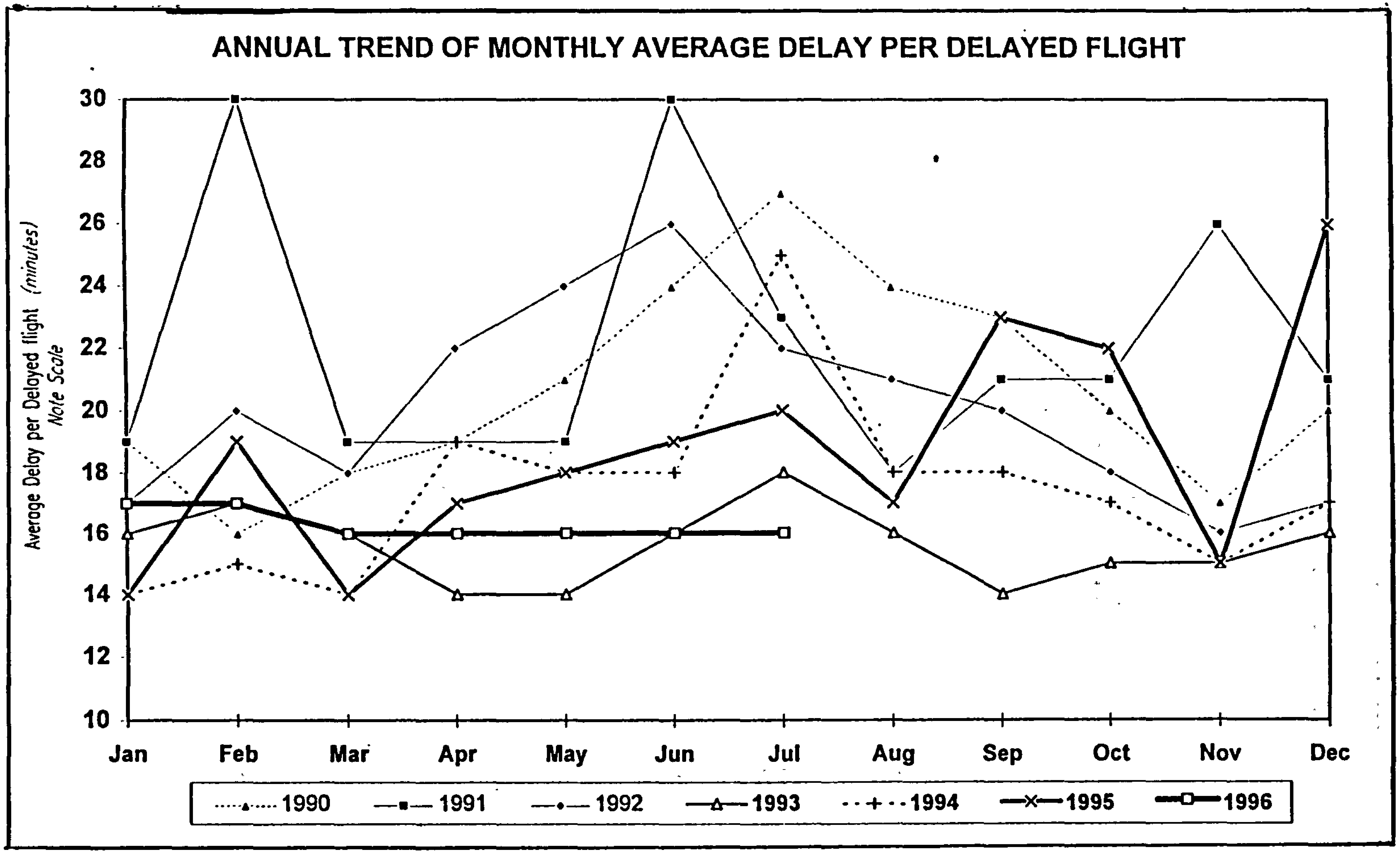
With the horrendous delay problems in 1987, the European members decided that action must be taken to improve existing ATC service. In April 1990 transport ministers representing 23 ECAC countries launched an, 'ECAC Strategy for the 1990's', for ATC in Europe. The aim of the strategy was to ensure that the en-route ATC airspace would be able to cope with the forecast increase in air traffic, whilst maintaining a high level of safety. As a result of the strategy the European Air Traffic Control Harmonisation and Integration Programme, (EATCHIP), was established, which would be funded and controlled by Eurocontrol from Brussels. The goals were to harmonise some 51 air traffic control centres which used 31 different computing systems, introduce a standard en-route radar separation of 5nm, develop closer civil/military coordination of airspace use, and promote research into airspace congestion alleviation.

The current four phase EATCHIP programme plans to create the future European Air Traffic Management System, (EATMS) by 2000. This envisages standardisation of all ATC centres with automatic data exchange and full exploitation of current and future aircraft navigation and communication systems, such as RNAV and datalink.

In addition to the launch of EATCHIP in the ECAC Strategy for the 1990's, they also appreciated that the en-route system only represented part of the total ATC system. With this in mind, the Airport and Air Traffic Systems Interface, (APATSI), project was launched. Detailed discussion of the work of this group will be presented after examination of European delay statistics.

4.4.2: European Delay Statistics

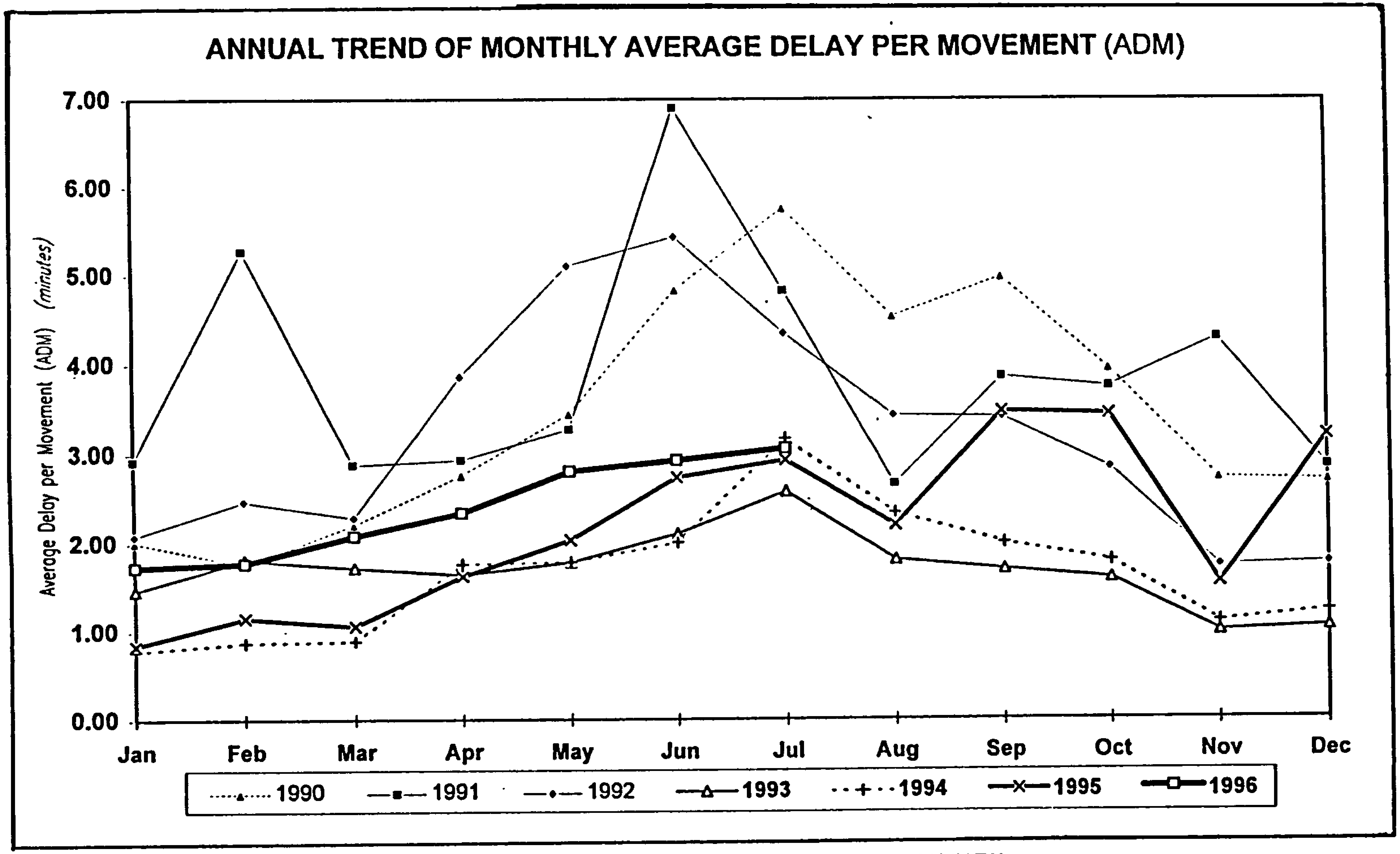
Figures 4.12 and 4.13 show the IATA European ATS delay statistics for the last six years, given by 16 of IATA's member airlines. The delay figures are calculated from delay codes used by the airlines attributed to air traffic services and ATC/Ground Movement Control, with the delay only being reported if it is greater than four minutes. Figure 4.12 shows two interesting patterns, firstly, that the magnitude of the annual trend of monthly average delays per delayed flight has decreased over the time



Source: INTERNATIONAL AIR TRANSPORT ASSOCIATION (IATA)

(based on European ATS delay data - [codes 81/AT 89/AM] - as reported by 16 IATA member airlines)

FIGURE 4.12



Source: INTERNATIONAL AIR TRANSPORT ASSOCIATION (IATA)

(based on European ATS delay data - [codes 81/AT 89/AM] - as reported by 16 IATA member airlines)

FIGURE 4.13

period. Secondly, the monthly variability in the figures has also fallen demonstrating increased consistency in delays.

Figure 4.13 shows the yearly trend of monthly average delay per movement. It shows that during 1993-1996 the average delay per movement has increased for each comparative month. This indicates that the peak airspace delays have been reduced by spreading the delays across the board, which was the aim of ATC flow management. In this case then it appears that efforts at delay reduction have been successful, especially when compared to the early 1990's where delay figures were substantially greater.

It is now time to examine specific ATC projects in operation in Europe and how they aim to reduce delays. The focus will be on TMA related projects due to their more direct bearing on the work of this thesis.

4.4.3: Airspace Delay Alleviation Projects

En-Route Projects

Flow Management - This affects both en-route and TMA airspace. In the early 1980's Eurocontrol was asked to create a central data bank to regulate data on air traffic demand for long term planning. At the same time 12 national flow management units, (FMU), were established to ensure optimum use was made of available airspace. Unfortunately due to the differing levels of ATC equipment and experience, each FMU had different capacity levels, and whilst traffic flowed reasonably within individual states, major bottlenecks were appearing at state FIR borders, with demand exceeding capacity. To overcome this, in the late 1980's the 12 FMU's were reduced to five, namely London, Paris, Frankfurt, Rome and Madrid and the Central Flow Management Unit, (CFMU) was established to co-ordinate slot availability and allocation throughout Europe. Departure slots were issued to restrict departure times, if necessary, to ensure demand at critical points in the system did not exceed supply.

The CFMU is now effectively the central data bank containing flight plan information from all airlines operating through Europe. The total investment cost of the CFMU was 75.6 million ECU between 1989 and 1993, with annual operating costs of about 42 million ECU.

Flexible Use of Airspace Concept, (FUA) - As part of the EATCHIP programme this hopes to remove the designation of airspace as either military or civil, creating a continuum which can be used flexibly on the basis of daily need. The first phase was introduced on 28 March 1996 with the progressive establishment of flexible airspace structures and procedures. Wide spread application of the FUA concept will take place following implementation of phase two from 26 February 1998.

The concept works by generating new routes, based on RNAV capabilities using three levels of availability. Conditional route one's are new routes an airline can flight plan on a regular basis. Conditional route two's are daily available routes notified to airlines which may be used on that day. Finally, conditional route three's are variable routes available to ATC for flight routing on a short term basis.

Reduced Vertical Separation Minimum, (RVSM) - Also part of EATCHIP, RVSM is planned to be implemented from October 2001. It envisages reducing vertical separation between flight levels 290 and 410 from 2000ft to 1000ft. This will dramatically increase upper airspace capacity, but potentially cost airlines significantly, as some aircraft will need airframes re-skinning around the static ports to meet altimeter accuracy standards.

Area Navigation, (RNAV) - By the 29 January 1998 all aircraft operating within Europe should be capable of meeting the new basic RNAV, (BRNAV), requirements of a track keeping accuracy of +/- 5nm for 95% of the flight time. This makes use of the advancements in aircraft equipment technology and will enable reduced separation between routes freeing up valuable airspace, as well as being a pre-requisite for the previous two concepts of RVSM and FUA. Due to the advancement of aircraft RNAV systems, precision RNAV, (PRNAV) rules will be implemented in time, which will require aircraft to achieve a track keeping accuracy of +/- 1 nm for 95% of the time. As with BRNAV, this should release valuable airspace and allow for the development of more direct routings from flight origin to destination.

There are concerns among current European airlines that these specifications, whilst welcomed for existing RNAV equipped aircraft, will impose significant cost penalties for older aircraft to be equipped with RNAV.

European Air Traffic Management System, (EATMS) - This is the final phase of the EATCHIP programme and is based on the integration of the airborne and ground based components such as RNAV, datalink, satellite communication, and radar returns. It envisages standardisation of all the ATC centres with automatic data exchange by the year 2000. The requirement for this system was strongly lobbied for by IATA, AEA and ERA, with the joint publication of their wishes in a document entitled, 'The Need for a Single Air Traffic Management System in Europe'. In the document they outlined what they would expect from the system, stating that it should be safe, reliable, and flexible, capable of providing enough capacity to meet demand, whilst promoting optimum cost efficient flight profiles. Above all costs was the need for common standards and specifications for the ATM systems. In addition they argued that national government involvement should be limited to the broad policies only, leaving the day to day management to separate ATC management organisations.

This concept will require significant investment in both ATC and aircraft infrastructure. Current areas of development include discussion of the free flight concept, where aircraft are free to fly any route they wish, so long as they meet navigation requirements. Linked to this is research into four dimensional control of aircraft using RNAV and vertical navigation, (VNAV), in addition to strict time control for aircraft to be overhead waypoints. The proposals plan to further improve traffic flow, with the basic concept that the more accurately ATC know the position of each aircraft, the greater can be the reduction in imposed vertical and horizontal separation, and the greater will be the increase in airspace capacity. Within these proposals, important human factor issues need to be resolved, especially who will be responsible for accurate navigation and terrain clearance, what problems with the man-machine interface are likely to occur, and how these can be solved. Due to the problems outlined with these current proposals, it is unlikely that we will see significant use of them before the end of the century.

The only en-route system that has really developed recently is the, 'Future Air Navigation System', (FANS), which has been developed for long range operations outside normal ATC radar coverage. It has significantly increased capacity on the Pacific routes and is now being assessed for implementation on the North Atlantic tracks. Implementation of FANS within European airspace is currently limited due to current inflexibility in the airspace system and relatively few properly equipped aircraft.

TMA Projects

All work in this area is now being coordinated by the APATSI project set up in 1992 through ECAC. The initial report on mature ATC procedures, commissioned to SH&E consultants and Cranfield University, in which the author was involved, was presented to the ECAC commission in August 1993. The report outlined two main objectives:

1. To encourage member states of ECAC to consider implementation of certain ATC procedures which can improve capacity at airports and in surrounding airspace.
2. To encourage ECAC states to apply certain existing procedures in a standardised, and therefore safer way.

Under the first objective twelve mature procedures were outlined. In the report a mature procedures was described as:

"A procedure which has been implemented in one or more states, and which has been evaluated by APATSI and judged suitable for implementation at airports in Europe which meet the conditions associated with the procedure."

For each procedure the concept was described, followed by conditions of application. Present ICAO provisions and proposed additions were added next, along with possible candidate airports, concluding with current implementation and status of the procedure. The procedures were endorsed by the Director General Civil Aviation ECAC States in May 1994.

Appendix 4.13 describes each of the procedures along with their applicability to European airports. Further information can be found by consulting the APATSI manual from the ECAC Airports Bureau.

There are a number of points to make regarding this project. Firstly this project should be commended for its approach in attempting to harmonise TMA ATC procedures and reduce operating delays. Looking at the twelve procedures discussed in the appendix it can be seen that the success of each greatly depends on the close co-operation of the airlines, the airport and ATC. This fact further complicates the ease in applying the procedure successfully, more so than in the en-route phase.

Looking at the procedures from the point of the regional airline, use of special regional aircraft procedures are not covered and regional aircraft are only taken into account with the use of intersection departures, multiple line ups and HIRO. In June 1994 though APATSI accepted an addition to the procedures called the 'Modified Departure Procedure for Propeller Driven Aircraft'. This accommodated the early turn after take off procedure, which will be discussed fully in chapter five.

The other major benefit of this APATSI project is the development of co-operation between the three separate parts of the aviation industry. This co-operation is now becoming crucial to the success of these procedures.

Other Projects

In addition to the APATSI project, there are three other TMA based projects which are concerning Europe.

The ILS/MLS/GPS Debate - Due to FM radio interference it was realised in the late 1960's that the instrument landing system, ILS, would be unable to maintain required levels of accuracy by the late 1990's. A plan adopted by ICAO in 1985 called for a transition from ILS to the new microwave landing system, MLS, by 1998. MLS, at that time, was the best replacement system. The microwave beam, which offered a vertical scan angle of 0.9° to 15° and a lateral sweep of 40° either side of the runway centreline, was initially marketed on allowing curved approaches to congested airports, allowing ATC controllers greater routing flexibility to avoid noise sensitive areas and improve traffic sequencing. Another advantage of MLS was that it was not fixed to a line of sight radio beam and was not affected by reflections from nearby obstacles. In short it offered the perfect solution to ILS in the 1980's. MLS was initially tested in the US at the New York airports. At this stage problems in accurately defining and executing the curved approaches with MLS were discovered and through trial it was discovered that if aircraft used their own curved approaches with MLS, although reducing ATC communication congestion, the efficiency of traffic sequencing for final approach reduced. Since that time straight in approaches have been focused on with the ATC controller using the radar to vector aircraft onto the MLS in the same way as with ILS. Current trials in Europe include Heathrow, Amsterdam, Munich, Paris CDG and Frankfurt. MLS is now proven to provide European operators with the CAT III approach capability they require.

The problem with MLS is that it is currently being superseded by the global positioning system, (GPS). This is based on 24 US military satellites which can give pin point accuracy of any object anywhere on the Earth's surface. It entered the replacement landing system debate in the late 1980's. The system works by the triangulation of at least three satellite beams to obtain a position. The information is passed from the satellites to a ground station for processing, returned to the satellite and then passed to the aircraft. For GPS use as a landing aid, a secondary ground station close to the airport is required to correct the signal for position errors, to provide adequate accuracy for landing. This is known as a differential GPS system, (DGPS). There are problems with the system, the major one being that the US satellites are currently controlled by the US Department of Defense, who degrade the accuracy of the information given to civil users and also have the power to turn the system off when they like. In addition to this is has been proven that the signal can be interrupted by anyone on the ground with a simple blocking device. Current GPS landing trials have been undertaken in the US. In April and June 1995 a series of DGPS CAT III trial were undertaken using a Wilcox GPS system. Preliminary results showed that 95% navigation sensor accuracy's of 0.9m lateral and 1.3m in the vertical. Total system error was 6.4m laterally and 3.7m vertically. The first DGPS trial in Europe was with Crossair using their Saab 2000's at Lugano, a short field runway in the Italian Alps. Commencement of the trial was delayed due to unintentional signal blocking in Italy. Use of the GPS approach for Crossair enables them to make a direct approach from Switzerland, instead of having to approach from the Milan TMA, considerably reducing the track distance. The trial is still in its early phase but, if a success, Crossair intend to equip all its aircraft with GPS for CAT II and III landings.

Guidance on which landing system will be approved in the future was addressed at the 1995 ICAO Special COM/OPS meeting. Three issues were examined:

1. The substantial improvement in ILS performance, not forecast.
2. Failure of MLS to deliver all the benefits originally promised, in particular curved approaches.
3. The rapid rate of development and almost universal availability of satellite navigation systems.

The results of the meeting led to a modification of the transition plan from ILS. The following recommendations were made:

1. Continuation of ILS operations where operationally feasible to the highest level of service which can be maintained.
2. Implement MLS where operationally required.
3. Encourage the use of MMR to maintain interoperability.
4. Validate the use of GNSS for non-precision use and CAT I
5. Develop and implement CAT II/III where possible.
6. Redefine regional transition plans with the above in mind.

Within Europe there was a strong urge, by the major airlines, for the implementation of MLS as this was the only system proven to provide existing CAT III operations. Transition will begin in 1998 with the major airports using the two systems for as long as ILS integrity can be maintained, to give operators time to modify aircraft to handle MLS signals.

In closing this section on future landing systems, other landing aids under development should be mentioned. There are three principle future systems. The first is increased use of the Head Up Display, (HUD), concept where an artificial runway symbol is presented to the pilot through the HUD. The perceived benefit of HUD's is that the pilot is looking out of the window so making the adjustment from instrument to visual references less dramatic than the current head down operation. Alaskan Airlines in the US has been using HUD's since 1989 to gain FAA decision heights and visibility credits. The first operational CAT IIIa landing of a HUD equipped Bombardier Canadair Regional Jet was performed by Tyrolean Airways at Graz in Austria on 10th October 1996.

The Autonomous Precision Approach and Landing System, (APALS), has been developed by Lockheed Martin Marietta from a cold war precision bombing tool. They aimed to certify APALS as a CAT II landing system in early 1997 and CAT III later in 1997. APALS offers ILS performance without the need for ground radio aids. APALS works by comparing stored radar images of the terrain around an airport with that received by the aircraft's radar. Differences in position are indicated to the pilot through the flight director. Below 100ft accuracy's of +/- 1.5m are achieved. The first demonstration system was tested in September 1994. Lockheed Martin saw a large potential in Europe for APALS but unfortunately had to cancel the system in early 1997 due to lack of interest.

Finally, there is the Transponder Landing System, (TLS), which offers a low cost, high tech landing based precision aid, originally developed for the general aviation market. The system can be installed at any airport and uses existing on board aircraft avionics to provide precision CAT I approaches. The system works by the ground based TLS interrogating the aircraft's transponder. When the aircraft replies, ground monitoring sensors measure the time delay and send that information to a central processor. This then calculates the aircraft's position by comparing the time delays received by sensors located in separate locations. The system has yet to be fully trailed at a major commercial airport.

ATC Approach Sequencing Aids - There have been a number of developments in the final approach sequencing radar's used by ATC in Europe. The idea is to help reduce controller workload in the final approach stages of the flight as well as help improve aircraft sequencing to optimise wake vortex separation restrictions and increase arrival capacity. Computers assess the pattern of traffic entering their area and compute estimated arrival times. This information is then used to plan optimum, conflict free approach sequences. Systems in use in Europe are Computer Orientated Metering Planning and Advisory System, (COMPAS) in Germany, MAESTRO in France, Zone of Convergence, (ZOC) with Eurocontrol and TCSDG in the UK. Principle operational problems are due to the computers inflexibility. This led initially to many controller overrides of the system. This is now improving as the system is developed. Future development envisages four dimensional traffic sequencing aids, where aircraft trajectories are controlled in time as well as position. A final sequencing aid is the ability to mirror approaching aircraft on converging arrival runways on each arrival track. This ability will permit use of converging arrival runways in IFR conditions, not currently possible.[26] Issues over who becomes responsible for the flight and ability to override the system are also areas that need further evaluation.

Precision Runway Monitors - This is a system developed by Allied Signal. It is designed to offer a high update tracking system for monitoring aircraft arrivals on closely spaced parallel runways. Alarms are made when an arrival deviates from the runway centreline towards the other parallel runway. Benefits of the system are given as its ability to permit increased use of close parallel operations in poor visibility, so increasing capacity and safety due to the higher system update than the standard surveillance radar. Precision approach monitoring equipment is now installed at London Heathrow and Gatwick.

This concludes the discussion of current issues in European ATC. Predominantly the systems discussed provide more accurate information to the pilots and ATC controllers during IFR conditions. It is this improved information which could potentially help reduce aircraft radar separation minima and consequently increase airspace capacity.

4.5 European Airlines

Due to the nature of this work the focus of this section is to outline what current trends exist in European regional airlines and how they are responding to the challenges placed on them by the restrictions outlined in the previous two sections.

An excellent review of European regional airlines was done by the Economist Intelligence Unit in 1995 entitled, 'Regional Airlines in Europe - Strategies for Survival'. A summary of the main points from this report will make up most of this section.

Figure 4.14 demonstrates that European regional airlines grew at a faster rate than all other airline markets between 1989 and 1993. Survival during the recession was due, the ERA argues, to investment in modern aircraft, exploitation of strong business markets, withdrawal of major carriers from regional routes due to restructuring, and greater response flexibility of the regional airlines to changes in the market.

Due to the lack of state aids and ability to cross subsidise poor revenue generating routes, regional airlines have had to keep operating costs as low as possible. This has no been easy in the relatively expensive operating environment of Europe. Figure 4.15 shows the difference, especially in user charges between Air UK, British Airways and the average ERA result.

26 Source: Mundra, A. (1989) New Display aid for Controllers could improve Airport traffic Capacity ICAO Bulletin Sept. 1989 pg37-38

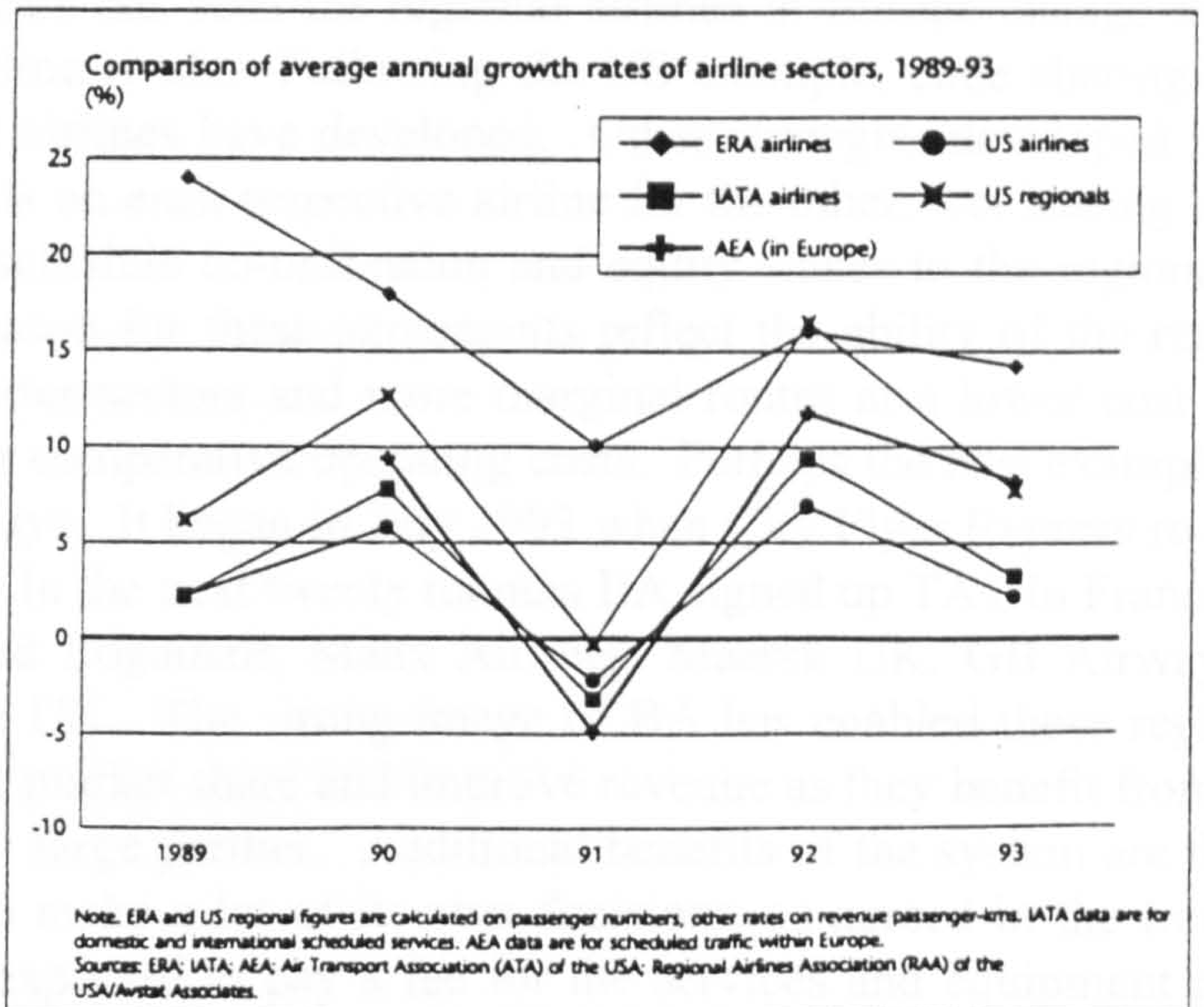


FIGURE 4.14

Source: EIU (1995) Regional Airlines in Europe

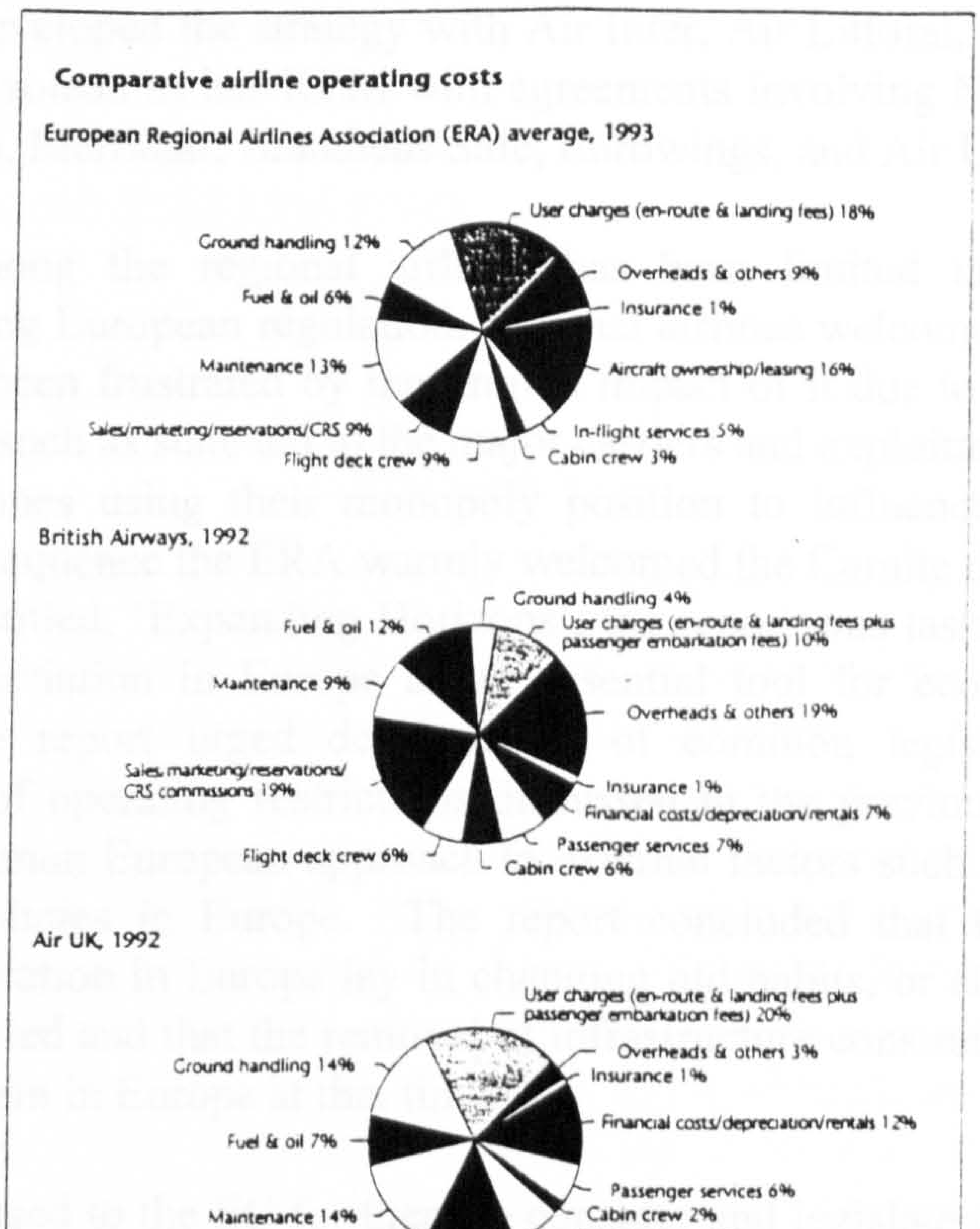


FIGURE 4.15

Source: EIU (1995) Regional Airlines in Europe

The last ten years has seen the regional airlines in Europe change their approach to their major airline rivals. Following the US example, code sharing and franchising with the major airlines have developed. Other strategies developed have been block booking of seats on each respective airline for the other, wet leasing of aircraft to the major airline, schedule co-ordination and equity stakes in the regional airline by the major. The reason for these agreements reflect the ability of the regional airline to operate on shorter sectors and more marginal routes at a lower cost than the major, due to its lower comparative operating costs. Perhaps the best example of franchising is British Airways. It began in July 1993 when City Flyer Express re-painted its fleet in BA colours. In the next twenty months BA signed up TAT in France, Deutsche BA in Germany and Logainair, Manx Airlines, Maersk UK, GB Airways and Brymon Aviation in the UK. The strong image of BA has enabled these regional airlines to strengthen their market share and improve revenue as they benefit from the economies of scale of their large partner. Additional benefits of the system are that the regional airline is left to make a lot of its own decisions, as agreed in the franchise contract. They also are expected to pay a fee for the services and equipment provided by the major airline, although one may argue at a preferential rate. Significant problems lie in the 'what if the agreement is withdrawn' scenario. Other cases like this include Lufthansa's agreements with British Midland, SAS, Lauda, Lufthansa Cityline, Adria Airways, Air Dolomiti, Cimber Air, Contact Air, Eurowings, and Business Air. Air France has also developed the strategy with Air Inter, Air Littoral, Brit Air, Crossair, Eurowings and Tyrolean as has KLM with agreements involving Northwest Airlines, Alitalia, Transavia, Martinair, Braathens Safe, Eurowings, and Air UK.

Consolidation among the regional airlines has been limited unlike their major partners. Regarding European regulation, regional airlines welcome the liberalisation process but have been frustrated by the limited impact of it due to the imperfections within the system such as state aid to the major carriers and exploitation of the process by the major airlines using their monopoly position to influence the direction of change. As a consequence the ERA warmly welcomed the Comite des Sages report in January 1994. Entitled, 'Expanding Horizons', the report was tasked with reflecting on the future of aviation in Europe as an essential tool for economic and social development. The report urged development of common legislation throughout Europe, removal of operating restrictions discussed in the previous sections of this chapter and a common European approach to external factors such as US application for open skies policies in Europe. The report concluded that the key to future development of aviation in Europe lay in changing old habits, or at least recognising that old habits existed and that the removal of infrastructure constraints was the single most critical problem in Europe at that time.

The report was passed to the EC for them to consider and legislate upon if they felt it necessary. As for the regional airlines it showed a strong commitment to maintain regional services and ensure fair play in the liberated European market.

With these issue resolved in favour of the regional airlines they now had to turn to other pressing issues. The implementation of JAA regulations, mandated by the end of 1997, has led to regional airlines facing large restructuring and procedure standardisation costs. They also face problems reaching common agreements regarding new JAR OPS legislation for new flight crew licensing and duty limitations.

Two final areas of concern to the regionals now are fleet modifications and coping strategies for the present infrastructure limitations. With the growth in average regional aircraft size in Europe as demonstrated in figure 4.16, regional airlines are now reaching the stage of considering whether to stay with turboprops or make the change to jet for some routes.

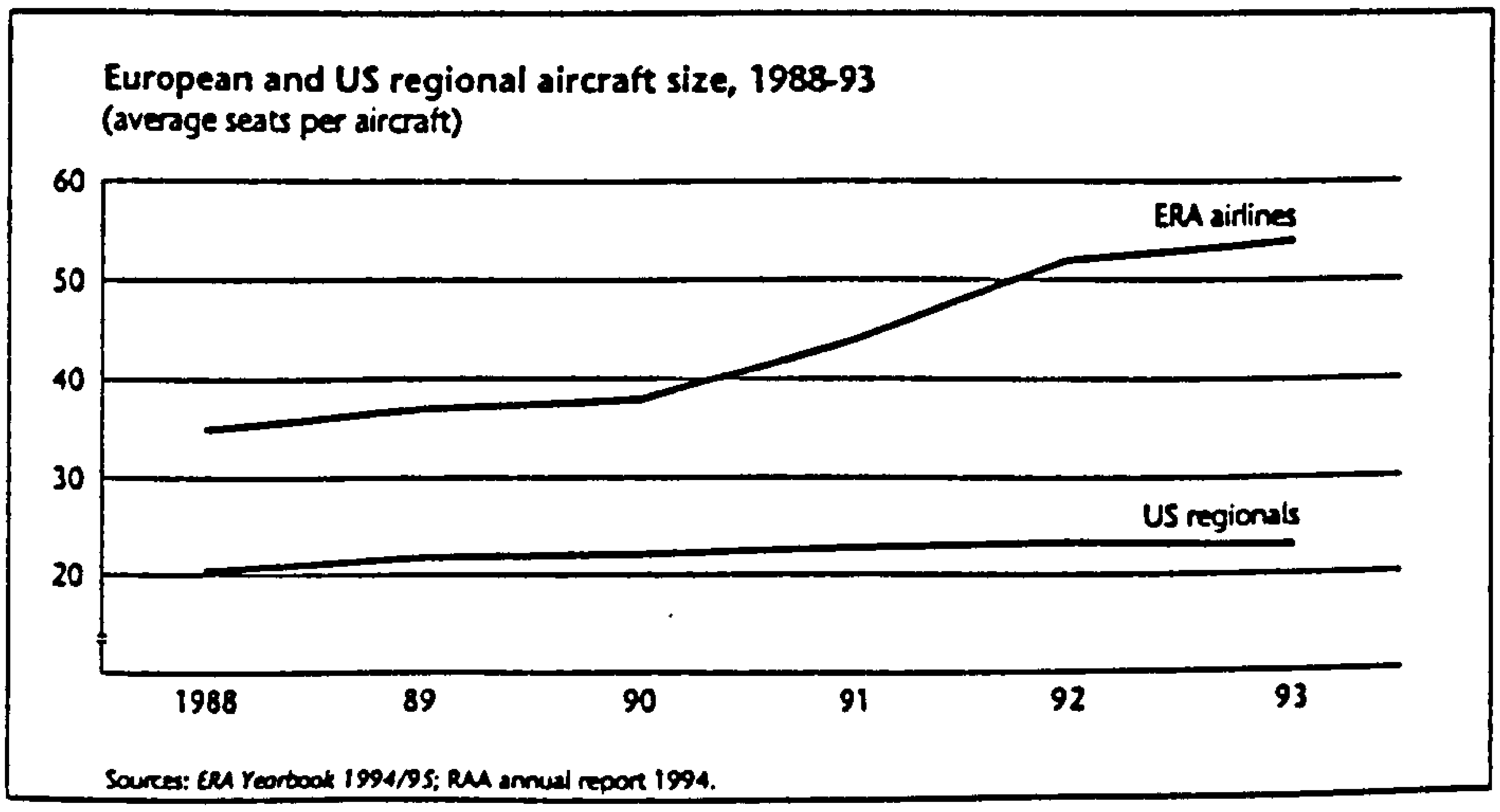


FIGURE 4.16

Source: EIU (1995) Regional Airlines in Europe

The decision is being brought forward with the development of new regional jets with 50 seats, namely the Canadair Regional Jet and the Embraer 145. The latter offers jet performance at considerably lower costs than normally expected. The decision is made more complicated with the development of new turboprops such as the Saab 2000 and Dornier 328, which offer higher cruising altitudes, enabling the aircraft to climb above the worst weather and fly faster, offering performance closer to the regional jets but at turboprop costs. Whichever the regional airlines choose, it will be sure to significantly alter the existing service levels offered, and with the longer possible route stages they may well approach the lower end of the majors route service. This may lead to increased franchising from the majors, or increased competition.

The infrastructure problems pose the regional airline with a more difficult problem than new aircraft types. They realise they must invest in new equipment to alleviate the existing constraints, however, there will be limited if no financial reward for this investment. In 1994 the ERA gave a conference in Brussels to discuss the use of

RNAV operating procedures and their potential impact on infrastructure capacity. The conference reaffirmed the airlines commitment to exploiting new ways to tackle capacity constraints, as well as pushing for the need to introduce RNAV procedures in the TMA environment. where it could be used to allow regional aircraft to efficiently enter and exit the area using their performance advantages. In addition to RNAV the ERA are also concerned with the increasing mandatory requirement for new avionics equipment such as TCAS and MMR's.

To conclude this section it is clearly evident that regional airlines in Europe are rapidly evolving, but feel greatly threatened by the old existing major carriers. Agreements by some regionals with the majors removes this insecurity but leads to new challenges. Due to the tight cost margins in the regionals they are vulnerable to enforced changes but at the same time they must change to remain competitive. In addition this requires the regional airline to maintain access to the congested hub airport to deliver the feed traffic to the major airline. How the regional airlines cope with this change over the next few years as liberalisation stabilises in Europe will truly determine their role in the future.

4.6 Summary

This chapter has covered a wide range of topics but has presented the reader with a clear assessment of the current issues facing aviation operations in Europe and how these are likely to change in the future. Many of the problems with airport and airspace capacity have been discussed along with new ways in which the industry is reacting to them and attempting to find solutions. In addition to outlining the problems and their proposed solutions this chapter has also attempted to demonstrate the significant role that government and European regulation is placing on the system, both in a positive and negative light.

This chapter completes the broad introduction to this thesis, and it is now time to look in depth at the regional aircraft special procedures proposed which offer a way around some of the infrastructure problems discussed here, for the regional airlines.

CHAPTER 5 : Solutions to Airport Congestion for Regional Aircraft.

5.1: Introduction

It is the purpose of this chapter to outline possible solutions available to reduce airport congestion using regional aircraft. In each case the theories will be put forward along with historical, current and potential applications at European airports.

5.2: Separate Approach and Landing System, (SALS)

SALS is a more general term for any special arrival routing, i.e. not along a pre defined STAR, into a congested airport. SALS utilises a number of the performance advantageous of the regional aircraft over the jets, identified in chapter three, namely better field performance, reduced turn radii, greater speed flexibility, faster engine response, smaller noise footprints and a steep approach capability. These factors allow initial high speed approaches followed by rapid descent and speed reduction with tight turns to line up with a short or stub runway. A 3D area navigation system is also required to provide accurate track positioning between arbitrary waypoints once off the standard arrival. This was required for two reasons. Firstly, the routing would be close to conventional arrival routes requiring precision navigation to stop path confliction and, secondly, as the new routes would expose new built up areas to noise, tightly restricted flight paths were compulsory. The SALS routing aims to segregate the regional aircraft from the jets and bring them in on a separate or stub runway, ensuring that they stop short of a primary runway intersection. By accomplishing this, improvements in ATC approach flow management can be made enabling the controller to reduce wake vortex separation. Also improvements could be made in controller workload if the track keeping ability of the regional aircraft is proven to be high, with the use of area navigation equipment.

SALS was first introduced in the United States in 1968 with a combined trial by McDonnell Douglas and Eastern Airlines.[1] A Douglas 188 aircraft was used fitted with a Decca 3D Area Navigation System. Over 160 CAT I approaches to Boston, La Guardia and Washington National were carried out. Following these demonstrations, it was not until 1977 that Ransom Airlines, later to become Pan Am Express, then TWA Express and now USAir Express, took up the concept on a commercial basis at Washington National. Ransom turned to the idea following experience of excessive operating delays there. Together with Bill Hubbard, National's ATC tower chief, Ransome developed the discrete approach routing using the de Havilland Dash 7 shown in figure 5.1. Each section of the route was defined by RNAV waypoints using vertical navigation, (VNAV), as well to control the descent profile. A DAC-7000 3D

[1] Source: Williamson, K. (1989) Right of Way - Commuter World Oct-Nov 1988 pg 18-22

de Havilland (1979) Hub Airport Access - An Air Traffic Alternative

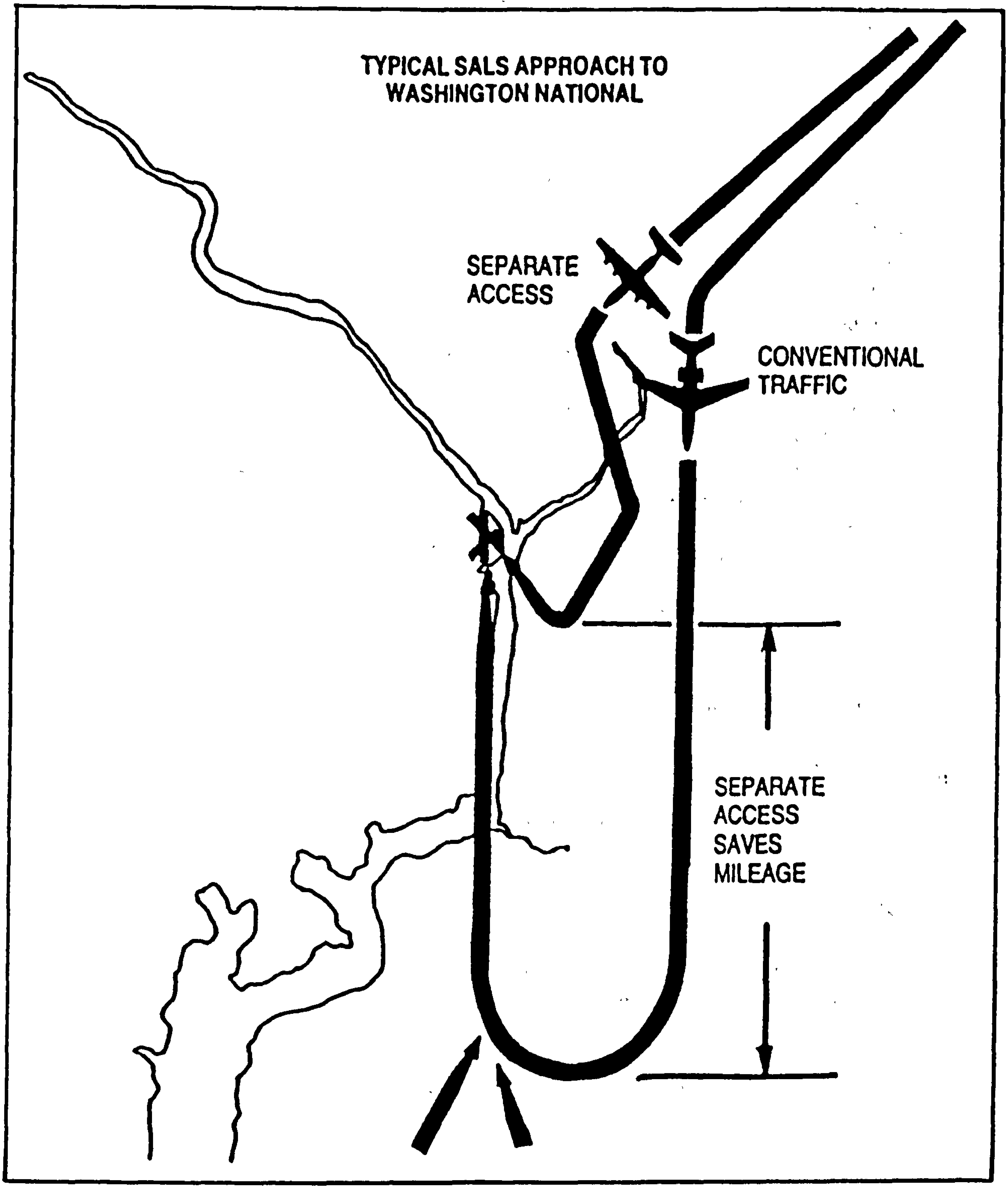


FIGURE 5.1

Source: Williamson, K. (1989) Right of Way Commuter World, Oct-Nov 1989

RNAV, coupled to a Sperry SPZ-700 automatic flight control system was used. The route was displayed to the pilot on a RCA Primus 400 digital colour radar screen. Deviations

from course were displayed on the primary flight display flight director in the same fashion as with an ILS. Basically, the routing gave Ransome access to runway 33 at National, when the jets were using runway 36 and runway 21 when runway 18 was prevailing. The routing incorporated a steep final approach and tight turns to ensure the aircraft maintaining a safe flight profile. This was important in expanding capacity, as it removed the need for ATC to create gaps in the jet arrivals for the regional aircraft, due to wake vortex and aircraft approach speed variations. The result was a creation of extra possible jet movements along the conventional routing, in addition to the regional aircraft movements on the SALS route.

The initial missed approach point, (MAP), for the SALS route was set at the end of the downwind leg to the stub of runway 33. Operating limits were established at a 1000ft cloud ceiling and three nautical mile visibility. These were later reduced to a MAP along the final approach path to runway 33, with a ceiling of 200ft and two nautical mile visibility. Without visual contact at the MAP, an immediate climbing turn to the right was mandated. This prevented any interference with missed approaches from runway 36. Special balked landing procedures were also created for runways 33 and 21 at National, specifically for the Dash 7. Using this procedure Ransome achieved over a 90% completion rate on runway 33.

In 1984 Ransome presented results that demonstrated it was saving 15,000 gallons of fuel or 16% each month. It was estimated a saving of approximately 10% of block fuel per flight occurred. The route also lead to considerable time savings, due to reduced routing and reduced holding time. Benefits were also derived for the airport as the average hourly movement rate could be increased by one or two movements an hour.

The success of this route, which was operational for over ten years, was also attributable to the enthusiastic approach it received from ATC at National. Due to the ability of ATC to achieve a more homogeneous traffic mix and a reduced need for radio communication required by the SALS route, not only controller workload was reduced, but airport capacity was dramatically increased.

Due to the success of the Washington National routing and the rise of Ransome as part of Pan Am Express, a SALS procedure was drawn up for New York JFK.[2] Ransome proposed to the FAA controllers an arrival procedure for runway 4L, holding short of runway 31L. This would involve simultaneous operations on intersecting runways, which was not previously available for this runway configuration. The procedure was built on the experience of Washington National and offered Ransome a 3,100ft landing strip on runway 4L for either its Dash 7 or ATR 42 services. As at National, the FAA and ATC tower chief at JFK were involved from

2 Source: Anderson, D. (1993) TW Express to Fly curved MLS for Separate Access to New York's JFK - Aviation International News, pg 69-75

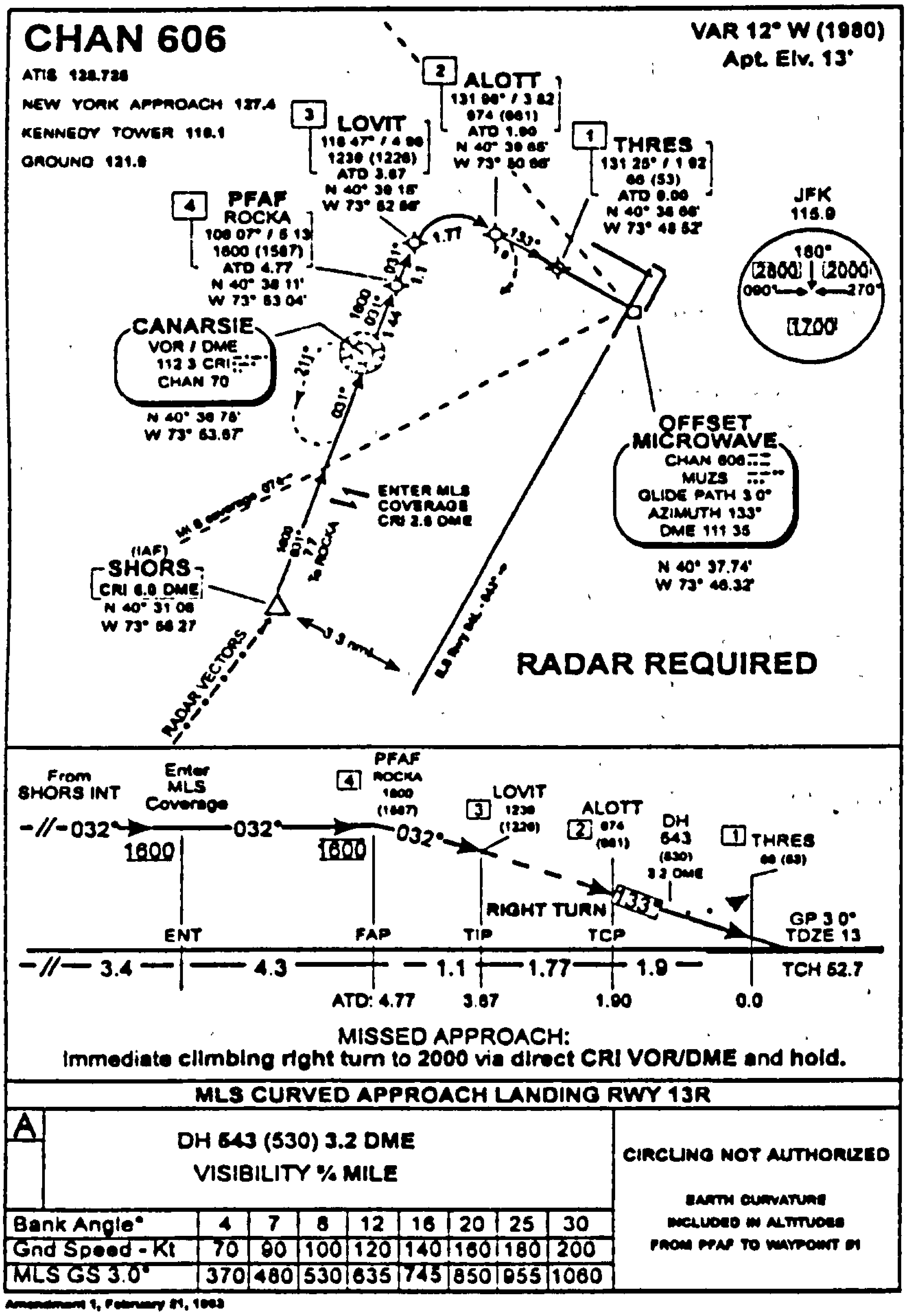
TRANS WORLD EXPRESS, INC.

FMS/MLS FLIGHT CREW NOTEBOOK DASH 7

MLS APPROACH PROCEDURE TO 13R AT JFK

TW Express NEW YORK/JOHN F. KENNEDY INTL (JFK)

MLS/CP RWY 13R NEW YORK, NEW YORK



PROPOSAL – NOT FOR NAVIGATION

FIGURE 5.2

Source: Aviation International News - Nov. 1993 the onset. In May 1992 the then TWA Express developed another arrival at JFK for runway 13R. This arrival normally conflicted with operations off runway 04-22 at La Guardia airport. Due to the addition of a dual Universal UNS-1B flight management system with VOR/DME, MLS and GPS sensors, however, an RNAV arrival route was defined as shown in figure 5.2. With the MLS they had to define what was known as an 'arc to fix', which described a pure arc in space. This was achieved using the EMS and enabled them to carry out CAT II approaches using this procedure, with an RVR of 1200 ft. As before the missed approach procedure was a climbing right turn to avoid conflict with existing jet traffic off runway 04L.

Use of this procedure led to a partial exemption to the high density rule covering JFK at the time, and generated eight new slots for Pan Am Express between 15.00 and 19.00 each day. At the time the FAA and JFK airport indicated their desire to increase this number of slot exemptions following proof of additional stub runway usage.

Unfortunately neither of these procedures is still in operation today. Stephen Farrow, Vice President, Flight Operations, Piedmont Airlines told the author that the procedures had stopped due to a change in the FAA performance regulations, now demanding that the landing aircraft must complete the landing role in 6/10 of the landing distance available, a change from Dash 7 to Dash 8 aircraft, and increased problems with apparent noise sensitivity for the airports in question.

It was not until 1989 that SALS was discussed in Europe. The ERA presented a paper outlining its possible implementation at Frankfurt airport.[3] The full synopsis of this paper will be discussed later in this chapter. After the paper, Crossair began work on a separate STOL approach to runway 28 at Zurich airport. The work followed experience of significant inbound delays for runways 14 and 16. The procedure they proposed aimed to reduce the required aircraft separation both in trail and between runways. This would reduce the impact of wake vortex separations and runway occupancy times.

The new routing was proposed for the Saab 340 and Dash 7 and 8 aircraft which, in collaboration with ATC, brought the aircraft over the Trasadingen VOR at FL065 with a direct route to Zurich East VOR, (ZUE), passing above the standard arrival tracks for runways 14 and 16.[4] A speed of 160kts is maintained during this stage. At ZUE, with the aircraft level at 6000ft, a turn onto a magnetic heading of 178° is made to intercept the 280 radial from the Zurich Kloten VOR located at the airport. During this base leg the speed is further reduced to 140kts and the flaps lowered to 15°. The altitude is maintained at 6000ft. At 7.9nm from ZUE to final turn is made to intercept the 280 radial. Once the turn is complete the flaps are increased to 20° and the undercarriage lowered. A 6° glidepath is then followed to 2330ft. Speed is reduced to 120kts as the flaps are further lowered to 30°. This gives an initial rate of descent of 1490ft per minute, which decreases to 1277ft per minute at 120kts. The requirement for the steep approach was not due to obstacle clearance, but to three

3 Source: Mihlan, J; Williamson, K. (1989) Methods to Increase Airport Capacity - Frankfurt - ERA

4 Source: Crossair Promotional Video (1994) STOL VOR/DME Approach Runway 28 - Zurich

villages located under the approach path. The measure was for noise abatement reasons only. Once at 2330ft the rate of descent is reduced to give a 3° glidepath, and at 2nm out from the airport the ATC tower is called for landing clearance. Landing speed is 109kts with a required landing distance of 500m. The distance from the 28 threshold to taxiway 'C', the last exit prior to crossing runway 16, is 900m, allowing a safe margin of error. The route is schematically presented in figure 5.3.

In setting up this procedure, Crossair had to meet a number of conditions. Firstly the missed approach procedure had to be proven not to conflict with that of runway 14 or 16. The procedure needed to be demonstrated to the authorities, and required a visibility of 5km or more horizontally and 500ft or more vertically with a dry runway and braking action described as good. In addition clear runway markings and appropriate buffer zones were also required. Even with these conditions, the procedure is restricted to 12 movements per day on runway 28, due to environmental restrictions and noise constraints imposed by the three villages the procedure overflies during the final approach.

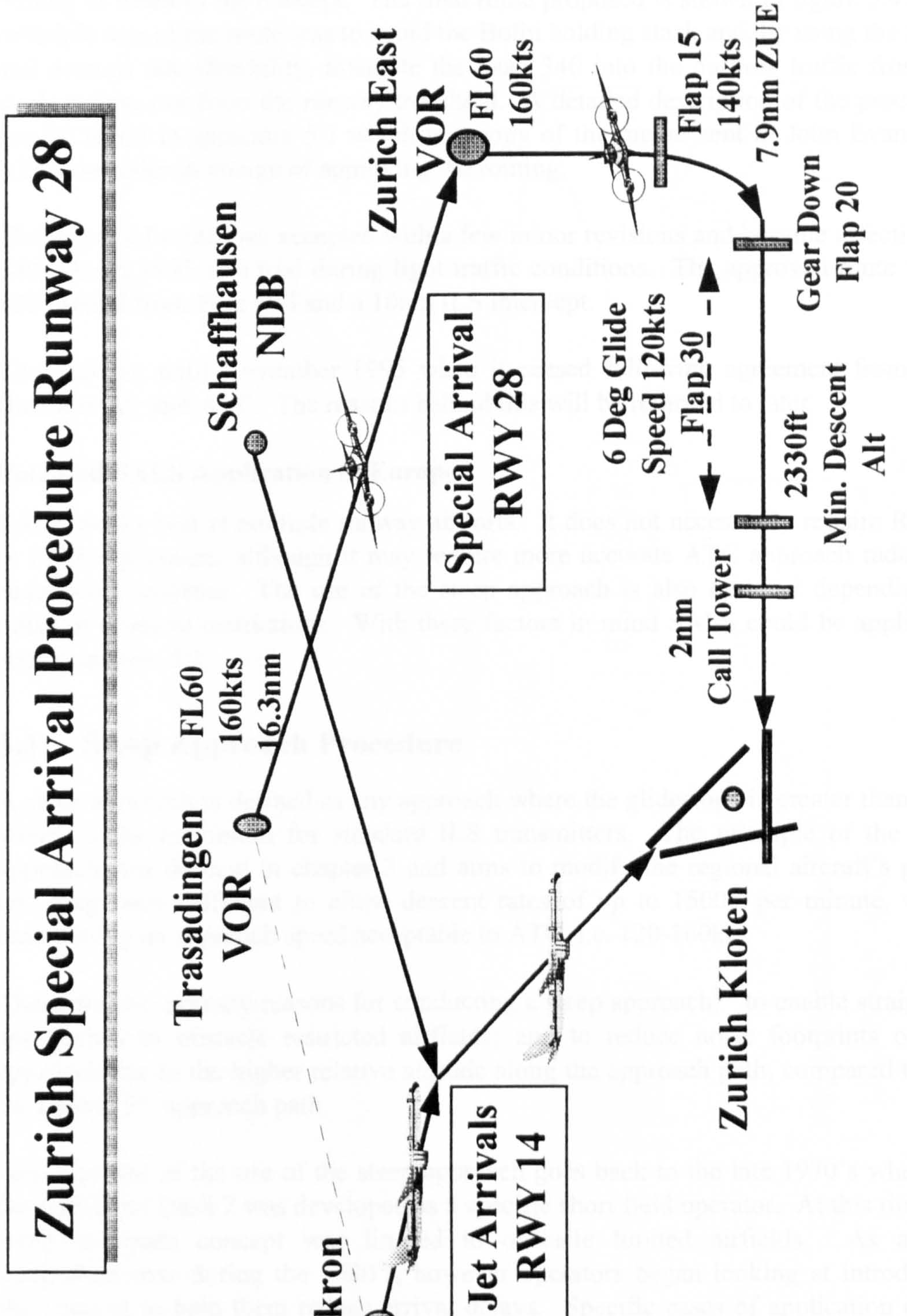
Although this was the first SALS application to be trialed and adopted in Europe, procedures had also been suggested at Heathrow with the use of runway 23, Gatwick with the use of runway 26L and Frankfurt using runway 25L. Unfortunately due to strong lobbying against these proposals, none were either trialed or implemented.

The Manchester Special Arrival Procedure

The only other attempt to develop this SALS concept was at Manchester airport with Business Air. In this case the author was directly involved with setting up and implementing an arrival trial for runway 24 at Manchester, whilst working for Business Air.

During the summer of 1994 Business Air faced severe morning arrival and departure delays whilst operating through Manchester airport. Between 2 May and 31 July nearly 20% of all morning arrivals were delayed by 10 minutes. With the new interline agreement that Business Air had signed with Lufthansa to provide feed traffic for the German airline, these delays represented an unacceptable problem. Following analysis of Manchester traffic demand, it was clear that the delays were due to runway saturation as available runway capacity was exceeded by over 30% during the peak morning hours. The problem for ATC was that to maintain safe runway operations, arrivals had to be held in the stack to ensure, firstly that the arrival flow did not exceed the handling capabilities of the controller, and secondly to help space arrivals later in the morning to allow sufficient time to release departures in between successive arrivals. In doing this, hourly runway movement rates were reaching 55 in the peak hours, 13 more than the published rate of 42.

With this in mind, Business Air and the author approached Manchester airfield operations and ATC to discuss ways to overcome these problems. Four principle meetings were held to discuss the proposal of a separate arrival routing, during which time each of the parties involved gained an improved understanding of the others



Zurich Special Arrival Procedure Runway 28
Ekron
Jet Arrivals
RWY 14
Trasadingen
VOR
FL60
160kts
16.3nm
Schaffhausen
NDB
Special Arrival
RWY 28
Zurich East
VOR
FL60
160kts
Flap 15
140kts
7.9nm ZUE
Gear Down
Flap 20
6 Deg Glide
Speed 120kts
Flap 30
2330ft
Min. Descent
Alt
2nm
Call Tower
Zurich Kloten

FIGURE 5.3

problems and operating constraints. Initial approaches on the subject were not welcomed by ATC, who advised that the procedure would not be feasible during the morning hours. As ATC became aware of the speed flexibility of the Saab 340 and the rapid rates of descent possible, following jump seat trips, they became more willing to listen to the concept. The final route proposed is shown in figure 5.4. The principle aim of the route was to avoid the Bolin holding stack and, by using the speed and descent rate flexibility, integrate the Saab 340 into the outflow traffic from the stack at 6nm out from the runway threshold. A detailed description of the procedure can be found in appendix 5.1 which is a copy of the memo sent to John Evans, the ATC controller in charge of approving the routing.

The proposed route was accepted with a few minor revisions and became effective on 30th March 1995 as a trial during light traffic conditions. The approved route was a 180 Radial from Pole Hill and a 10nm ILS intercept.

The trial ran until November 1995 when it ceased following agreement from both Business Air and ATC. The reasons behind this will be returned to later.

Potential SALS Application in Europe

SALS works best at multiple runway airports. It does not necessarily require RNAV or FMS equipment, although it may require more accurate ATC approach radar and sequencing systems. The use of the steep approach is also optional depending on noise or obstacle restrictions. With these factors in mind SALS could be applied as shown in table 5.1.

5.3: Steep Approach Procedure

A steep approach is defined as any approach where the glideslope is greater than 3.5°, which is the maximum for standard ILS transmitters. The principle of the steep approach was defined in chapter 3 and aims to modify the regional aircraft's power and drag ratio sufficient to allow descent rates of up to 1500ft per minute, whilst maintaining an approach speed acceptable to ATC, i.e. 120-160kts.

There are two primary reasons for conducting a steep approach: to enable straight in approaches to obstacle restricted airfields; and to reduce noise footprints on the approach due to the higher relative altitude along the approach path, compared to jets on a lower 3° approach path.

Development of the use of the steep approach goes back to the late 1970's when the De Havilland Dash 7 was developed as a specific short field operator. At this time the steep approach concept was limited to obstacle limited airfields. As airport congestion rose during the 1980's, however operators began looking at introducing the concept to help them reduce arrival delays. Specific cases of application of the concept in the US are unfortunately not recorded anywhere, as they tended to be used as temporary trials or following specific agreements with local airports and ATC.

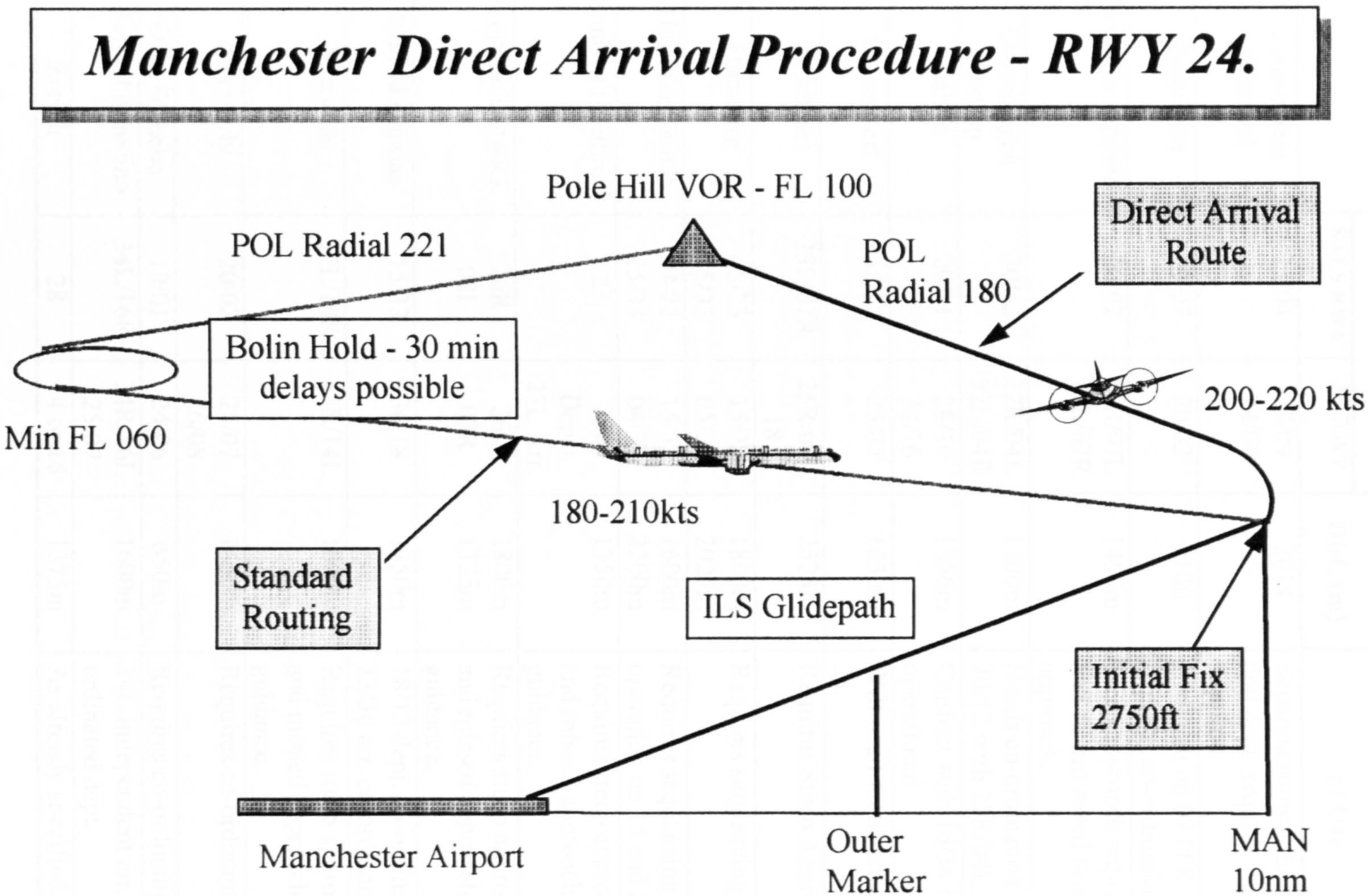

Manchester Direct Arrival Procedure - RWY 24.
Pole Hill VOR - FL 100
POL Radial 221
POL
Radial 180
Direct Arrival
Route
Bolin Hold - 30 min
delays possible
200-220 kts
Min FL 060
180-210kts
Standard
Routing
ILS Glidepath
Initial Fix
2750ft
Manchester Airport
Outer
Marker
MAN
10nm

FIGURE 5.4

SALS Use at European Airports

Airport	Runway Operation		SALS Rwy	Conditions
	SALS RWY	Jet RWY	Dist. (m)	of Use
Amsterdam Schiphol	22/04	27/09 24/06	2014	Separate runway but app. and dept. sequencing required.
Barcelona	25/07	20/02	2100	Arr/Dept on 07 O.K., 25 requires co-ordination
Brussels National	20/02	25R/07L 25L/07R	1450m	Steep approach required and co-ordinated missed approach.
Copenhagen Kastrup	30/12	22R/04L 22L/04R	1300m	Needs co-ordination of 30/12 with 22R/04L.
Dublin	29/11	28/10 34/16	1356m	Conflict with 16/34 if operational.
Dusseldorf	33/15	23/05	1630m	Will need sequencing with 23.
Frankfurt	25L/07R	25R/07L 18	2525m	Requires Steep Approach
Hamburg	05/23 15/33	15/33 05/23	1800m 2025m	Requires sequencing.
Helsinki Vantaa	04/22 15/33	15/33 04/22	1600m 2200m	Requires sequencing if operating on 15 and 22.
London Heathrow	23	27R Depts. 27L Arr.	1350m	Requires steep approach and missed approach guidance.
London Gatwick	26R 08L	26L 08R	1800m 1325m	Requires steep approach and missed approach guidance.
Madrid Barajas	15/33	36/18	1350m	18/15 dept. co-ordination, 33/36 arr. co-ordiantion.
Marseille	32L/14R	32R/14L	1600m	Requires steep approach and missed approach guidance.
Paris Orly	20/02	25/07 26/08	1450m	Requires co-ordination
Oslo Fornebu	19/01	24/06	650m	Requires co-ordination
Rome Fiumicino	34L/16R	34R/16L 25/07	1600m	34L independent arr., co-ordinated dept.
Zurich	28	14 or 16	1375m	As already specified.

TABLE 5.1

The use of steep approach in Europe is currently limited to three airports, Zurich as already discussed, London City and Lugano. It is used at Lugano to permit direct arrivals from the north over the Alps, which would not otherwise be possible, due to the high terrain and obstacles surrounding the airfield. Crossair, who use the procedure, say it saves them considerable flight time by avoiding the need to enter Italian airspace and arrive to the south, as well as considerable fuel savings.

Operations into London City STOLport began in the late 1980's following successful trial landings by Brymon Airways at the King George V Docks. Due to the many building and crane obstructions around the airport, a steep approach is required at 5.5°. Aircraft types currently using this procedure at London City are Dash 7 and 8, Fokker 50, BAe 146 and Avro RJ's. Both the Fokker 70 and 100 have also completed landing trials there.

Apart from these examples, the use of the concept at congested European airports has not been exploited. In 1989 the ERA proposed the use of the concept at Frankfurt[5]. The principle of the proposal was that by the use of a steep approach, the current restriction of independent arrivals to close parallel runway operations due to wake vortex drift constraints could be removed. Figure 5.5 demonstrates what the ERA proposed. The procedure uses the steep approach to keep the regional aircraft above the jets wake vortex on the other runway using the 3° ILS glidepath. The procedure outlined ensures the regional aircraft maintain 1000ft vertical separation from the jets throughout the whole manoeuvre, with the regional aircraft crossing the common threshold at 800ft and touching down 7905ft beyond the threshold of 25L and 8842ft from the threshold of 25R. This threshold displacement ensures that any possible effects of wake vortex from the jet runway are avoided. The ERA recommended with this procedure that the diagonal separation between the two runways could be reduced, although the exact limits would be determined by ATC radar accuracy, with benefits if a precision approach radar were used, and for missed approach procedures. Longitudinal separation could, the ERA argued, be reduced to 2nm in this case from 3nm. Regarding the missed approach, due to the closeness of each aircraft, if a jet executed a missed approach, then the regional aircraft, being above, would also be forced to do so. Unfortunately this proposed procedure was never fully implemented.

The conditions that must be met to carry out steep approaches are numerous. For the airline the aircraft will need to be fitted with a GPWS suppression device to avoid nuisance warnings, due to the increased rate of descent on final approach along with a strengthening of the undercarriage. Simulator training and proving flights are mandatory by the aviation authorities, revised minimum equipment lists are required, and special runway markings, PAPI's and glidepath alterations are needed.[6] Using the procedure decision heights only permit CAT I operations, although benefits for published landing performance are possible as the revised screen height is 35ft instead of 50ft.

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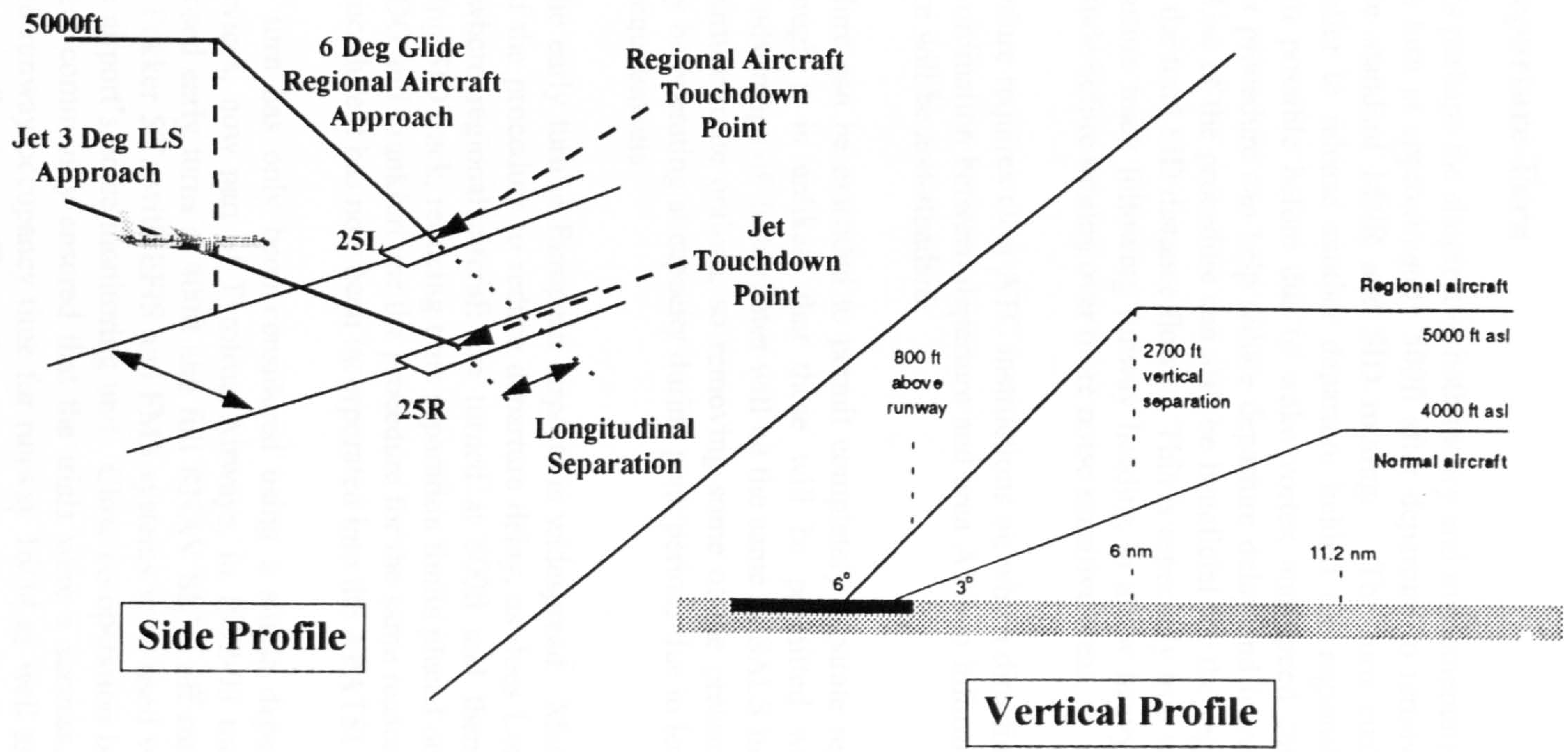
5 Source: Mihlan, J; Williamson, K. (1989) Methods to Increase Airport Capacity - Frankfurt - ERA

6 See Appendix 3.4

Frankfurt Steep Approach Procedure



Source: Homer, M. (1993) MSc Thesis Cranfield

FIGURE 5.5

In theory this procedure could be applied to any runway in Europe, single or multiple mode, where traffic level necessitates.

5.4: Early Departure Turn

This procedure is perhaps the simplest in both theory and implementation. The early turn envisages a turn at approximately 500ft after departure to remove the regional aircraft from the standard MNR and SID routing. The turn enables the ATC departure controller to release another departure behind the regional, sooner than would have been possible before due to wake vortex and speed card restrictions, (table 2.7). This procedure can help reduce departure delay and increase the hourly departure rate. Use of the procedure can also be beneficial for the regional airline if the turn reduces the total SID distance flown. This is especially true where there is a long initial departure track following runway heading to allow heavy jet aircraft to gain enough altitude before turning over more noise sensitive areas.

Use of the procedure requires clear ATC instructions on which direction to turn after take off, and co-ordination between departure and area ATC to inform the latter that the next departure will be non-standard.

Also this procedure can be extended to permit completely separate regional aircraft departures, although it is unlikely that these will be permitted without RNAV equipment. The advantage of these routes will be the same as SALS in that they will add to ATC departure route options, so removing some of the pressure on existing routes which may be operating at capacity during peak periods due to longitudinal and time separation requirements.

Current use of the early turn at European airports is widespread. Manchester make significant use of the procedure to reduce departure delay, as does London Gatwick and Heathrow, where regional aircraft are turned at 500ft and then requested to parallel the existing SID track, reducing time separation limits placed on following jet aircraft. Paris CDG and Frankfurt use the procedure for the same reasons. Due to the success of this procedure it has now been incorporated into the APATSI manual.

So far the early turn has only been considered using a single departure runway. Austrian Air Services, now part of Tyrolean Airways, in 1992-93 took this a step further and proposed early turns at 400ft and full RNAV SID's off runway 16/34 at Vienna airport.[7] Fokker 50's with EFIS and FMS systems were used with the routes monitored by the airport's noise monitoring unit. Close co-operation between pilots, ATC and the local community ensured that the trials were a success. Use of this procedure reduced runway occupancy time for runway 16/34 as well as reducing the time required for co-ordinating traffic on the converging runway 29/11. The trial was postponed when Austrian Air Services and Tyrolean Airways merged. This type of approach is also currently used at Manchester for departures to the North via Pole Hill

[7]Beer, P. (1993) Report on the Test Run based on Specially Standardised Departure Routes for Turboprops using Area Navigation - Unpublished report to ERA Operations Committee

VOR. The early turn off runway 24 is followed by ATC radar vectors until north of Pole Hill.

Application of the early turn procedure can be applied to any European runway where required, although the application of special SID's will depend on local noise regulations.

5.5: Special Regional Aircraft Holding Stacks

This procedure is a relatively new concept although it is beginning to be utilised by some ATC controllers in the UK. The basis of the idea is that current ATC stacks for inbound arrivals are located at quite a distance from the airport to avoid conflicting arriving and departing aircraft and reduce the noise impact of the airport. This idea, which has not yet been introduced even as a trial, looks at introducing unique holding stacks for regional aircraft closer to the airport than current stacks. The reason behind the concept is that at highly congested airports, where runway movement rates are commonly at their maximum, unless a regional aircraft is closely positioned to an airport, a small time slot generated due to departing aircraft missing their slot or arrivals executing a missed approach, will be lost. If the regional aircraft is close to the airport, ATC could feed it into the arrival track to make use of this unpredicted slot.

Due to the nature of this concept it will be highly unpredictable and allowances must be made to provide standard arrival procedures when time gaps do not arise. Routings in and out of these new stacks will need careful construction not to conflict with existing tracks and meet existing noise constraints. New ATC procedures would also need writing to help controllers make optimum use of the stacks. Finally, ATC principles of first come first served for arriving traffic will need re-assessment.

In theory this procedure could be applied to any European airport where TMA airspace allows subject to demand. It is the intention to model this procedure with SIMMOD in an attempt to assess the likely impact on current operating delays.

5.6: Use of Stub Runways

The principles of this procedure have already been touched upon in the SALS discussion and relate to the use of existing runway surfaces at airports, which would not usually be used due to confliction with the prevailing runways in operation. Regional aircraft can make use of these runways in certain cases due to their short field performance. Within the concept it is expected that maximum use will be made of intersection departures, RETS and RATS, with the capacity gains they provide, outlined in the APATSI report. Use of the runways will be limited by many factors but especially flightpath confliction issues with the other runways, impact on noise sensitive areas under the approach and departure paths to the runway, ground taxi limits due to use of the new stub runway, location of new obstacles around the runway and ATC airspace integration problems with regional aircraft operating on this runway.

The procedures at Washington National and Zurich both demonstrate that these issues can be overcome by active participation of ATC, airlines, the airport and the local community. Further application will depend on how far technology can be developed in giving pilots and ATC controllers a precise picture in real time of aircraft location in relation to each other, the airport and restrictive obstacles. This may not be too far away with the development of DGPS and precision approach radar. Work done by Dr. Bernard Lister (1988) on dependent instrument approaches to converging runways demonstrated that simultaneous approaches could be made to converging runways in IFR conditions to a CAT I decision height. Tight controls were placed on missed approach tracks. Dr. Lister concluded that the capacity benefits of using this system would depend on:

1 runway configuration, with runways intersecting close to the threshold of each being the worst;

2 ability of ATC to precisely position aircraft on the approach path;

3 pilot ability to precisely fly the required track in four dimensions.

Work he carried out at many US airports demonstrated that capacity gains of 30-40% over existing levels were possible if the procedure was used to its optimum. Use of this type of operation by regional aircraft can be further exploited by the use of steep approaches, early turns after take off, and tight turn radii to avoid any restrictive obstacles, which would preclude use of the runway in normal conditions.

With the above in mind, application of this procedure in Europe will depend upon the ability of the airlines and airports to provide sufficient equipment, i.e. runway markings and aircraft performance figures, to allow ATC and pilots to achieve the accuracy and safety levels required to operate from the runway. Candidate airports include Amsterdam, Barcelona, Brussels, Copenhagen, Dublin, Hamburg, Helsinki, Heathrow, Madrid, Paris Orly, Oslo and Zurich. It must be borne in mind however that the condition and current state of repair of the stub runway will significantly affect the associated cost of upgrading the facility.

5.7: Short take off and Landing Runways

This concept is now entering the expensive construction levels and considers the possible capacity gains that can be attained from constructing a STOL runway within the current airport boundary. The idea sounds quite dramatic, but the STOL runway could be constructed from old disused runways or taxiways, or other spare space which has limited value or use due to its location or physical shape.

Obviously the concept would involve considerable design and construction challenges, not to mention airspace re-designs and possible new noise issues. Where an airport has a high percentage of regional aircraft operating within its the traffic pattern, and is forced to accommodate them on a single mixed mode runway operation, considerable capacity gains could be achieved by removing these regional aircraft from the existing traffic flows. This would be due to possible significant reductions in wake vortex and the departure separation requirements already discussed.

In 1974 the Canadian government developed this idea in a new way. It funded a trial involving the construction and operation of two STOLports at Montreal and Ottawa.[8] Each was equipped with MLS and served by initially Twin Otters and later Dash 7 aircraft equipped with RNAV. The service could reduce commuting time between the two city centres by 15 to 30 minutes. Unfortunately, due to the many difficulties encountered during the trial and the huge investment costs, the project never made money and when the flight routing had to be extended following construction of the new Mirabel airport at Montreal, the service ceased. The government of the time did conclude however, that if the circumstances has been less severe the trial may well have been a success.

Although use of this idea has not yet been exploited in Europe, application of the concept at some of the less site restricted European airports such as Paris CDG, Munich, Madrid and Rome Fiumicino would be feasible. The conditions of use would be the same as any new runway, and require full analysis of impact on existing operations and affect to the local community, even after the technical feasibility of whether aircraft could safely operate from the runway. In this case significant obstacle are likely to be airport and nearby buildings. As in the previous concept, use of the steep approach, early turn and tight turn radius could be used to overcome these.

5.8: Reliever or Commuter Airports

This is the last proposed solution to current airport congestion problems and envisages the removal of all regional aircraft traffic from the congested airport traffic flows to a nearby overflow airport capable of handling the smaller aircraft. By doing this it is the intention to be able to offer increased capacity at the major airport for the larger aircraft. The solution, it is argued by its supporters, will increase passenger through put at the airport using fewer aircraft movements, so appeasing noise protesters. It is, however, the least favoured solution by the regional airlines as it immediately removes them from the hub airport, and significantly reduces their ability to provide effective feed traffic to the major airlines, due to the distance and journey time penalties that the separate airport enforces. This does appear to be the preferred option of regulatory bodies however, and moves have been made in Germany to provide a reliever airport for Dusseldorf. In the UK proposals for both Heathrow and Gatwick have been made.

Neither of the scenarios proposed have yet been successfully implemented. CAP 570, (1990), examined the construction of a STOL runway at Heathrow, just to the north of the existing runways. The runway would operate separately from the existing airport with a separate manoeuvring area to avoid taxi congestion and runway crossing delays

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8 Plaignaud, J. (1974) An example of a City Centre/City Centre air link: The experimental STOL service of Air Transit Canada between Ottawa and Montreal

with 27R. Separate ATC tower and ground facilities would also be required. With the use of a 5.5° ILS glideslope, it was expected that all regional aircraft would be transferred from existing Heathrow traffic flows to this STOL airport. It was appreciated that ATC controller workload in the Heathrow sector would increase along with the regulated airspace around Heathrow. Northolt operations would also be affected.

In 1993 considerable work was done to asses if Redhill airport, 3.5nm to the north of Gatwick, could act as a reliever airport.[9] Redhill is currently a general aviation airfield situated in the gap in controller airspace between Heathrow and Gatwick. Proposed use of Redhill envisages segregated operation from Gatwick with separate traffic flows and ground facilities. To bring Redhill up to standard, a new VOR and ILS would be required, in addition to the runway being modified to exactly parallel Gatwick, (currently 4 degree difference), and the provision of aerodrome control. As with Heathrow the aim would be to remove all present regional aircraft from existing Gatwick traffic flows and move them to Redhill. Airspace modifications in terms of arrival stacks and existing SID and STAR tracks would also be required.

The final attempt to make use of reliever airports hit the headlines in May 1996 when Dusseldorf airport banned all turboprop flights, irrespective of size, from operating from the airport. Instead they encouraged them to use the recently refurbished general aviation Monchengladbach airport, now majority owned by Dusseldorf airport and renamed Dusseldorf Express Airport. The move was quickly dammed by the ERA, Eurowings, Augsburg Airways and City Flyer Express, with the latter three airlines applying for an court injunction against the airport and seeking compensation. They argued that the 1200m reliever airport incurred a 50% payload penalty for the ATR 72.[10] Monchengladbach is in fact the first operational reliever airport in Europe.

Application of reliever airports in Europe will be limited to those airports which have general aviation airfields close by, and where use of these airfields can technically be achieved, taking into account noise and obstacle limitations. Conditions of application include issues such as modification of SID's and STAR's, increased controlled airspace, restoration of existing airfield, upgrading of airfield navigation aids and ATC, and the necessary regulations to permit operation. Support of the potential users would also be advisable if possible. Finally it must be stated that this proposal represents the most expensive solution out of all those previously discussed, DM25 million was spent by Dusseldorf airport at Monchengladbach..

5.9: Summary

It has been the purpose of this chapter to present the reader with the possible regional aircraft special procedures that may be used to alleviate current European airport congestion. In doing this it can be seen that they are quite varied requiring significantly different levels of investment from airports, ATC and airlines. It should

9 Alan Stratford & Associates (1993) Apollo ATC Simulation Modelling Study - Draft Final Report

10 Flight International (1996) Regionals will Challenge Dusseldorf ban in Court 1-7 May 1996, pg 11

also be noted, in this summary, that at many airports a combination of special procedures are used to solve the problem. Alternative solutions such as reliever airports have also been discussed in order to present all the available options, concerning regional aircraft, that may be used to help reduce airport congestion.

The purpose of the next chapter will be to define a methodology to evaluate these options with the results of that evaluation being presented in the following chapter.

CHAPTER 6 : Evaluation Methodology.

6.1: Introduction

It is the intention of this chapter to define the methodology that will be used to effectively evaluate the theories presented in the preceding chapter. The evaluation process will be broken into two sections. The FAA airport and airspace simulator, SIMMOD, will be used first of all to model specific airport scenarios and traffic mixes that will test the proposals made in chapter five. Results from this work will then be combined with a cost benefit model to help assess the likely feasibility of the theory. The limitations of the methodology and possible solutions will be discussed throughout the relevant sections of the chapter.

The testing of the theories was carried out at two principle airports, Manchester and Zurich. They were chosen for their prior implementation of some of the theories, and for representing two totally different runway configurations and operations. It is appreciated that the results from this approach will not be directly applicable to all airport types, but it is hoped that most of the implementation problems likely to be faced will be brought to light in these two case studies.

6.2: Introducing SIMMOD

History of Development

SIMMOD, the airport and airspace simulation model, was developed from the original FAA airport/airspace delay model in 1978/79. An airfield, and fuel consumption model was added in 1980-82. Between 1987 and 1989 the model was used purely by the FAA before being released to the public sector during autumn 1989. It was marketed as a flexible and powerful tool capable of calculating travel time, delay and fuel consumption. It simulates airfield and airspace traffic operations simultaneously, allowing the investigator to analyse, "what if" scenarios accurately, as well as more safely and cheaply than would be possible in real life. In conclusion it was expected to provide an improved decision making capability for airport planners by enabling examination of a variety of alternatives.

Industry Usage

SIMMOD is currently used at many major airports both in the US and Europe. It was extensively used at Manchester airport for assessing the effects of a second runway. Madrid Barajas is also using SIMMOD for the development of its third runway. Other European airports using SIMMOD are BAA airports in the UK, Frankfurt am Main, Rome, Milan Linate, Athens and ADP Paris airports. Airlines that have used SIMMOD include American Airlines, Northwest, British Airways, Qantas and Federal Express.[1]

[1] Data taken from 'The SIMMOD Flyer' - Information news for FAA SIMMOD Users

SIMMOD has also been used for researching future airport developments, such as the implication of using Redhill as a reliever airport for London Gatwick by Cranfield University[2], and examining new airspace structures and reliever airports for Frankfurt airport by DLR (1994).[3]

Recently there has been a move to consolidate this research from both industry and academia by the setting up of the European SIMMOD Users Group.

SIMMOD then represents an industry wide accepted modelling tool, which also offers the author the flexibility required to effectively model the specific circumstances required to test the special procedures previously discussed.

SIMMOD Operating Principle

SIMMOD is basically an advanced queuing theory model and is classed as a stochastic simulation model using random variables to model random variations in phenomena encountered in the real world. This is accomplished using random linear variables based on user defined probability distributions. These probability distributions are applied to take off and landing runs to simulate pilot variation in performance for similar aircraft types. They are also used in the lateness distributions applied to aircraft entering the system. This randomness creates unique results each time the simulation is run, so to ensure viable figures are obtained, the simulation is run five times, with the combined average result being taken in the end.

In addition to being stochastic SIMMOD is also a discrete event simulation model. This enables a system evolving over time to be simulated using a mathematical model, the state of which changes at discrete points in time. Each point in time is known as an event which is defined to be an instantaneous occurrence which changes the state variables. For example, every movement of an aircraft arriving and departing from a defined point, either on the ground, or in the airspace, is classed as an event. The simulation is also refereed to as event stepped as it moves from one event to another, bypassing an interval in which no events occur. The simulation cross checks each event running in chronological order to determine how it may affect current or subsequent events. The simulation ends once the last scheduled event is completed, or at a specific time defined by the operator. All these events function inside a user defined operating system which can be of any size or level of complexity. Obviously, the ability of the operator to accurately model the real life operating system will determine the validity of simulated results to reality.

Defining the Operating Environment and its Limitations

There are four main data files that are required to run a SIMMOD simulation:

1 Aircraft Data File
2 Airspace Data File
3 Ground Data File

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2 Alan Stratford & Associates (1993) Apollo ATC Simulation Modelling Study - Draft Final Report

3 Platz, K.; Borkof, U. (1994) Optimising Air Traffic Flows at Airports - In 'Advanced Technologies for Air Traffic Flow Management Winter, H.; and Nuber, H.G. (eds), pg 153-190

4 Events Data File

An explanation of each of these can be found in appendix 6.1. These four data files are all written in SIMSCRIPT II, the computer processing language for SIMMOD.

SIMMOD Logic

Some of the logic regarding the landing and take off rolls has already been discussed in Appendix 6.1. The important logic relating to sequencing take offs and landings is known as the, 'interface logic', as it links the ground and airspace data.

Arrivals require two pieces of information to carry out a landing. Firstly, the distance from the airport that departures on the same runway will be disallowed and secondly, a time for the aircraft to land, decelerate and clear the runway. Departures also require the same two pieces of information for a clear take off roll and ensure sufficient separation for wake vortex and radar requirements.

This information is contained in the procedures section of the airspace data file. These procedures are often linked to others in the case of multiple, dependent runway operations or use of intersection departures. In addition the final approach links to parallel runways can be linked to allow either staggered or independent parallel approaches to be made. This is achieved by modifying the aircraft's approach speed and separation times.

Throughout the research it was the procedures that proved the hardest part of the simulation to master as, unnecessary arrival blocking distances or take off and landing times would lead to unrealistic system delays.

Simulation Results Validity

As SIMMOD is a stochastic model, random variables are introduced into each simulation run or iteration, in an attempt to represent a realistic scenario instead of an ideal one. This random element needs to be taken into account when considering the validity of the simulation results and to achieve this a number of separate iterations need to be run to remove any one off results that may otherwise bias the results in the wrong direction.

Due to the time available and the length of the later simulation scenarios, it was decided that five iterations would be used. This value was a compromise and would unavoidably still contain some variability, but at a level that would not dramatically change results if further iterations were run. The same number of iterations are also used by other SIMMOD users in their work.[4]

Allowances for the imperfections of the simulation system also need to be appreciated, although to remove these is not feasible nor the purpose of this thesis. The data validity is determined by all parts of the simulation model but is predominantly affected by the airspace speed vectoring, airborne holding strategies,

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4 Manchester Airport Plc. and Cranfield University Air Transport Consultancy also use 5 iterations for scenario modelling.

separation limits; en-route and final approach, take off and landing roll times and the poor ability of the simulation to think ahead and sequence traffic to prevent excessive separation distances. In this study we shall take the results given by SIMMOD at face value because as each simulation model is exposed to the same problem, by comparing gross results, the same errors can be ignored. Where the author feels that the SIMMOD simulation has been poor in representing reality, or where the results difference between two different simulations is very small, comments over the validity of the data will be made.

Simulation Runs and Post Processing

A considerable amount of time was also spent in correcting and re-running simulations that came up with error messages following runs. Most of these were related to inaccurate data entry, but were also required modification if the operating environment, to prevent unrealistic operations taking place, such as simultaneous take offs and landings on the same runway, take offs before the preceding arrival had cleared the runway or vice versa. These usually involved modifying the procedures program in the airspace file, or restrictions on specific airspace links and nodes.

Once the simulation was running correctly the reports were compiled and results derived. The author edited the data to pick out hourly variations in total, arrival and departure movement travel time, i.e. the time spent by the aircraft traveling through the system and the delay time, i.e. the extra time spent by the aircraft in the system due to congestion. In addition hourly arrival, departure and total runway movement rates were collated.

With the operating methodology of SIMMOD now defined, it is time to look at the scenarios used in the research.

6.3: SIMMOD Case Study Outline

The first stage for each of the three airports used in this analysis was the construction of the airport ground and airspace lattice structure of nodes and links. Racal AERAD charts were used for this task, with the author calculating the latitude and longitude of each node to be entered into the simulation. This was then converted into co-ordinates of X and Y, in feet for the ground file, and nautical miles for the airspace file, from the point of origin, usually in the centre of the airfield. Once this process was complete the data was edited to ensure it would be acceptable to the SIMSCRIPT processing language.

With the ground and airspace data entered the events data was inputted using an actual ATC movement log for events from Zurich, and planned summer schedules for Manchester and Gatwick. The aim in all cases was to give a typical busy day schedule. In the case of Manchester and Gatwick this was a Friday in the summer schedule when scheduled and charter flights were the greatest.

6.3.1: Manchester

Manchester airport was chosen for this study for two principle reasons. Firstly, it was a good example of a single runway, (06/24), mixed mode operation beginning to feel the effects of congestion, shown by the airports current public enquiry for a second runway. This is supported by the information presented by APATSI and the 1990 SRI report already discussed. Figure 6.1 shows a typical busy Friday traffic demand during the 1995 summer season.[5] The figure clearly shows that between 0700 and 0900 the airport was operating at or beyond its optimum runway demand rate of 42 movements per hour. An evening peak was also clearly visible, although to a lessor intensity than the morning peak. Regional aircraft traffic represented 24% of total traffic for this day, and 32% of scheduled traffic.[6] This information is supported by data supplied by Manchester Airport Plc., for maximum annual peak hour movement rates shown in table 6.1. It clearly shows that the peak hour movement rate, excluding 1991, has steadily increased from 49 to 52 movements per hour in 1993. This is way above the 42 movement per hour rate given as an industry benchmark by the SRI for optimum mixed mode, single runway operations. The 30th and 100th busiest hour figures also demonstrate that Manchester is consistently dealing with high movement rates from its single runway.

Manchester Aircraft Movements - Peak, 30th and 100th Busiest Hour 1990-1993

Year	Peak Hour			30th Hour			100th Hour		
	Date	Hour	Movts	Date	Hour	Movts	Date	Hour	Movts
1990	23/5	17.59	49	07/8	17.59	43	27/8	17.59	39
1991	26/4	15.59	45	29/8	7.59	42	09/7	17.59	39
1992	13/5	17.59	48	10/9	8.59	44	20/3	17.59	41
1993	17/9	8.59	52	10/6	7.59	45	09/7	7.59	43

Source: Manchester Airport Plc.

TABLE 6.1

Manchester airport, then, would be used as the primary airport in this study to develop a simulation methodology which could be applied to other airports at a later date. Ten scenarios were developed to test as many of the regional; aircraft special procedures as possible. Each case is defined next, highlighting the aim and problems encountered in setting it up. Figure 6.2 shows the modification to the existing SIDS and STARS for each case. All cases were based off runway 24 as this is the dominant runway operation at Manchester.

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5 1995 UK Airport Timetables

6 Figures deduced from the traffic patterns given in appendix 6.2

Traffic Breakdown per hour for Manchester - 30th June 1995

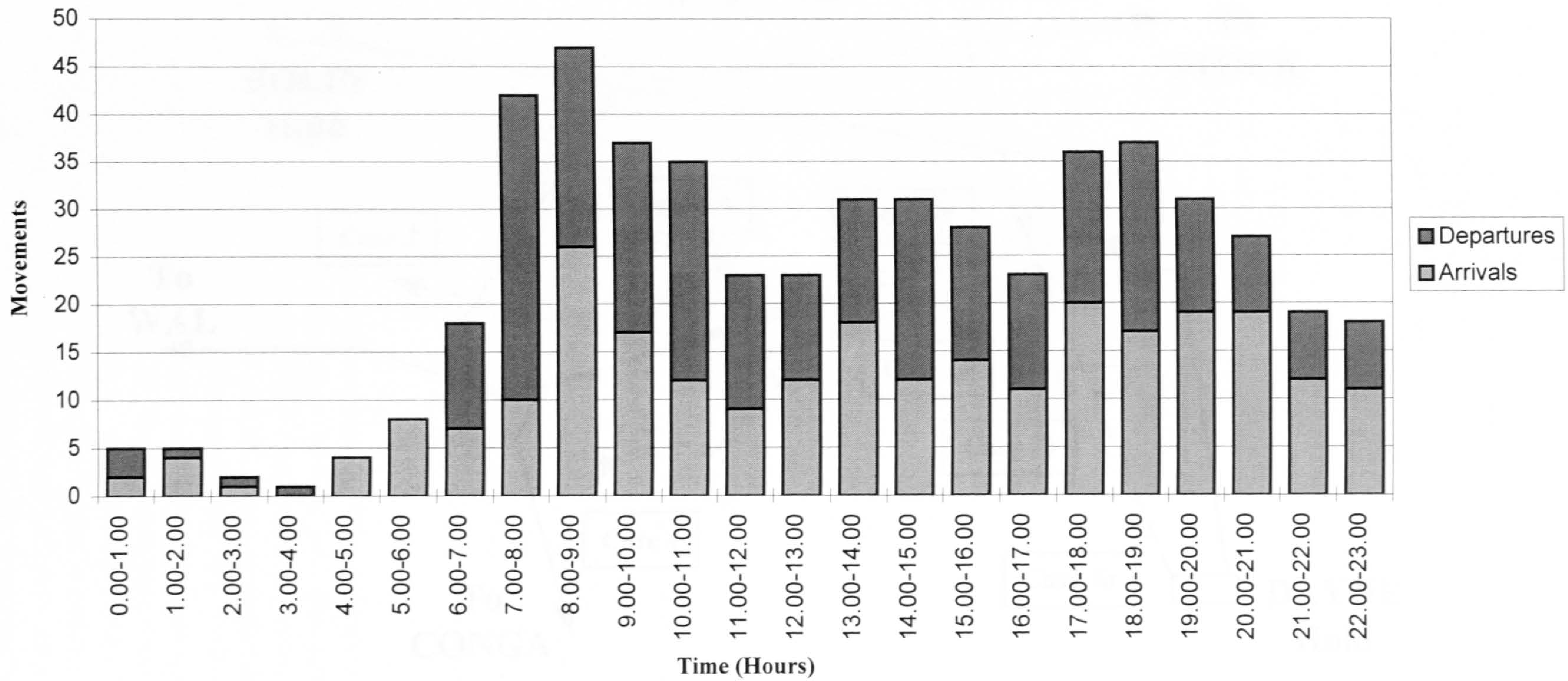

FIGURE 6.1

Source: UK Airport Timetables (1995)

Manchester Airport Case Study Routings

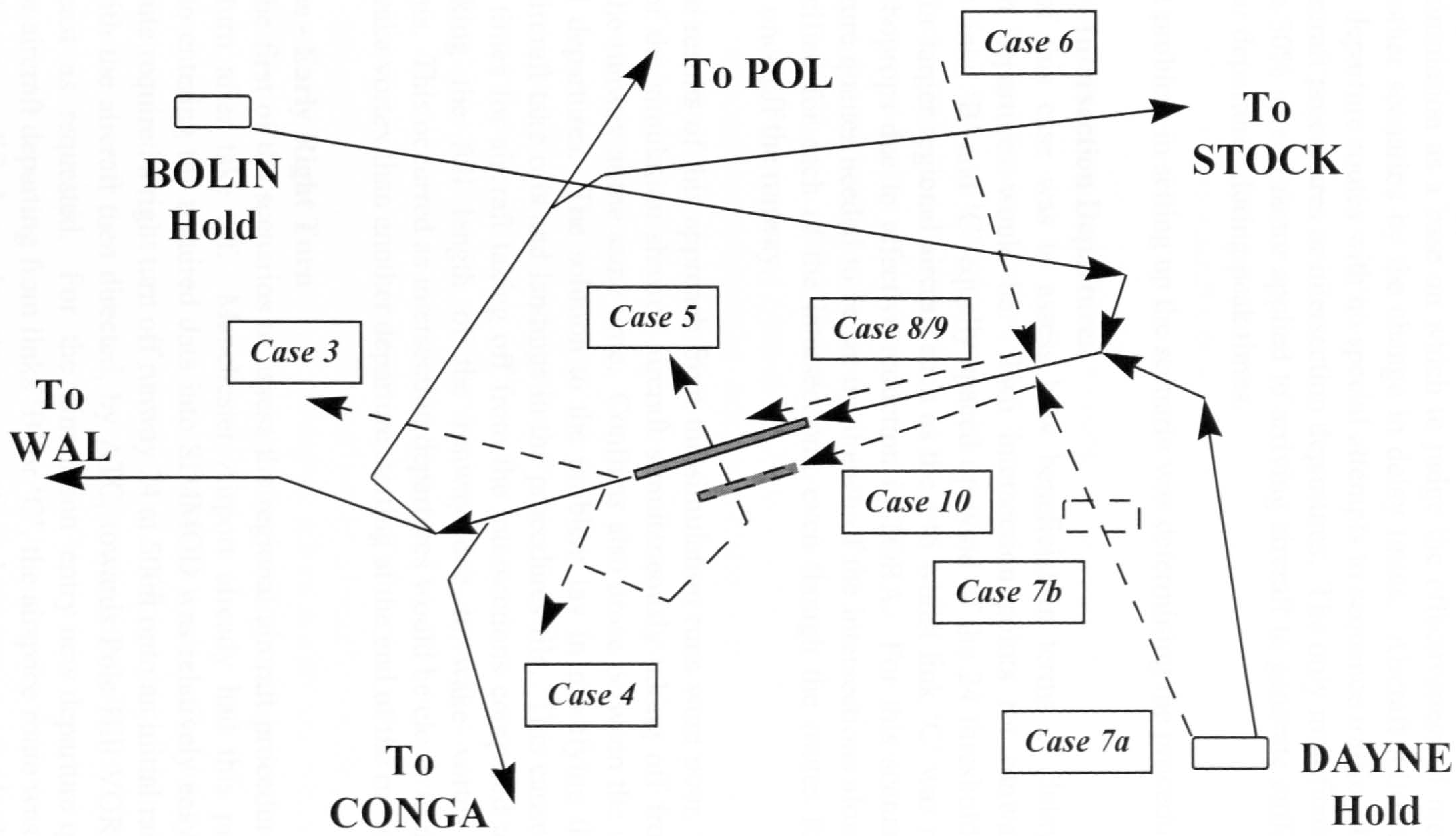

FIGURE 6.2

Base Case
The aim with this case was to provide a basic operating system for the airport based on the current operation of arrivals and departures on runway 24, and the aircraft event data taken from the planned summer 1994 schedule shown in figure 6.1 and presented in full in appendix 6.2. The airfield chart and standard arrival and departure routings are presented in appendix 6.3. It was the intention to use the data received from this simulation as a base on which to judge the effectiveness of modifying the system in other scenarios by the change in delay times. Aircraft followed standard arrival and departure routes with no special attempts to sequence traffic, allow special regional aircraft procedures or intersection departures. The only modification was the setting of a 30% spread factor applied to arriving aircraft to generate sufficient gaps to help clear departures during peak times.

The largest problem in setting up the scenario was determining the procedures.

Case Two - Intersection Departures
The aim of this case was to assess how beneficial in terms of delay reduction intersection departures would be. Two intersection points for runway 24 were inputted at links 'B' and 'C' equally spaced up wind of the 24 threshold. Link 'B' was used for larger regional aircraft such as the 146 whilst link 'C' was reserved for smaller turboprops due to effective reduction in TORA. For this scenario to work new departure queues needed to be set up at each of the intersections along with new routes specified for each of the intersections, even though the routes followed the same track once off the runway.

Initially the results of this approach from the simulation runs were poor. Animation checking of the simulation showed aircraft simultaneously taking off from separate points on the runway at the same time. Conflicts also arose between the arrivals and subsequent departures. The solution to the problem lay in modifying the blocking times for aircraft take offs and landings in the procedures file. This caused increased separation times for aircraft taking off from the intersections compared to departing aircraft taking the full length of the runway due to wake vortex separation requirements. This occurred as intersection departures would be closer to the previous aircraft's wake vortex than another departure starting at the end of the runway.

Case Three - Early Right Turn
This was the first of the scenarios to assess the regional aircraft procedures, namely, the early turn after take off. Manchester Airport already had this procedure in operation so entering the required data into SIMMOD was relatively easy. The new airspace route required a right turn off runway 24 at 500ft onto an initial radar heading of 330°, with the aircraft then directed, by ATC, towards Pole Hill VOR and routes north and east as requested. For the simulation entry new departure queues were required for aircraft departing from links 'B' or 'C', the airspace route was added, and the procedures modified as departure separation between a standard departure, preceded by an early turn departure could be reduced. In this scenario, separation limits for departing aircraft using the early turn were 45 to 50 seconds for the take off roll, with a blocking distance of 0.5nm from the end of the departure runway for departures following from runway 24 threshold, and 1.5nm for aircraft following from

the intersections. This maintained the departure wake vortex separation requirements and allowed the potential benefit of reduced departure separation to be exploited.

The only problems in running this simulation were those associated with obtaining the correct procedure separation, which was a case of experimentation to obtain minimum delay.

Case Four - Early Left Turn

The aim of this case was to build on case three, by adding an early turn for south bound departing regional aircraft to assess how the combination of both early turns at 500ft would reduce departure delays. The format was exactly the same as for case three, using the same departure procedures from the intersections. A new airspace route was added and the events file modified accordingly to allow regional aircraft to use the early turn.

No problems were encountered with the simulation after the data modifications.

Case Five - Early Turns to the Left ONLY

The reason for introducing this case into the simulation scenarios, followed work by the author with Business Air, who were looking at ways to reduce operating delays at Manchester Airport at that time. Previously problems had occurred for Business Air in obtaining regular use of the early right turn, which they needed for their routes back to Scotland. Manchester ATC had indicated that the early right turn would only be offered where traffic sequencing permitted. Business Air felt that if they could carry out early left turns and continue all the way round to the north, this would alleviate the ATC problem. Setting up the simulation was straight forward with modification to the events data to change the early right turn aircraft to early left turns, and minor changes to the airspace route file.

No problems were encountered after running the simulation.

Case Six - Business Air Special Arrival Procedure (Northerly Arrivals Only)

This scenario was developed to test the idea presented by the author and Business Air as described in chapter five. The scenario was modified to include easterly arrivals, as well as to capture all regional arrivals that would normally use the Bolin holding stack. The procedures used were not altered to accommodate the change in arrival structure, as they were just to be integrated into the existing arrival flow.

Without pre-empting the discussion of this case in the results, considerable problems were encountered in trying to remove problems of runway fouling, where departures and arrivals were both active on the runway at the same time. This will be discussed in more depth in the next chapter.

Case Seven - Special Arrivals from the South

The aim of this case was to expand on case six, to segregate all arriving regional aircraft in an attempt to reduce arrival delays. The new routing placed all regional aircraft on a direct join from Dayne to the ILS at 7nm out. It would, as before, offer regionals a shorter arrival track, and hopefully delay reduction, whilst not greatly affecting existing jet traffic. Only the new route string needed adding to the existing model, with the procedures remaining unchanged.

No problems were encountered during the simulation runs. This case was further developed, however, by the introduction of regional aircraft holds close to the final approach path, in an attempt to provide the ATC controller with more sequencing flexibility, as discussed in chapter five. A number of combinations were examined due to problems with simulating the holds correctly. The problems discovered will be discussed in greater depth in chapter seven.

Case Eight - Steep Approach Concept for Runway 24

The idea of this case was to assess how the introduction of a steep approach for regional aircraft onto the existing single runway would affect operating delays. The idea was based on the Frankfurt steep approach idea discussed in chapter five.

Setting this scenario up in SIMMOD posed a considerable challenge. Firstly, a STOL runway had to be added just next to the existing runway, as SIMMOD would not allow more than one arrival point on a runway. This STOL runway was intended to represent regional aircraft use of the existing runway 24, landing beyond the touchdown point of the jet aircraft to avoid wake turbulence problems. Once this was complete, airspace routes were added connecting the STOL runway to the existing arrival routes used in case seven. The final change was in the procedures file, where modification of the blocking arrival and departure times was required to allow safe operation of the jet and regional arrivals and subsequent departures. The blocking time for a regional landing was set at 45 seconds, due to the shorter runway length required, and the use of rapid exit taxiways. Separation between regional arrival and jet arrival was 40 seconds blocking time and 1 nm blocking distance. This would give the minimum separation requirement, assuming no wake vortex separation requirement, i.e. minimum radar separation of 2.5nm taking into account that the jet would be at an average approach speed of 150kts and so catching the regional aircraft up all the time, approaching at an average of 140kts.

Initial results of the simulation runs were poor, with numerous missed approaches. Initial problems showed that as well as simultaneous landings, departures were also commencing before arrivals cleared the runway. The use of the STOL runway also complicated the matter as SIMMOD treated it as an entirely separate runway operation, so arrivals were landing and holding, whilst departures occurred on the other runway. This was solved by increasing the blocking time between STOL arrivals and standard departures. Obviously, this would impact unrealistically on departure delays. The simultaneous landings were solved by the use of final approach stagger control on the last three arrival links for both runways. Other problems were excessive runway occupancy times, which were overcome with increased runway taxi speeds and relocation of the rapid exit taxiways for the STOL runway. Additional nodes were required along the final approach path as these served as update separation controls for the simulation, and enabled correct separation requirements to be maintained. Separation between successive jet or regional arrivals were set at 5 nm, to allow the gap between jet versus regional arrival to be maintained. The next stage of the solution was to increase the time delay that could be absorbed on each airspace link, which aimed to introduce more effectively the ability of the ATC controller to control aircraft speed and maintain separation.

Even with all the modifications applied, above, missed approaches still occurred, albeit less than five for the day's events. At this stage the author decided that any attempt to remove these from the simulation would have imposed excessive delays on the other movements, and rendered the scenario untenable. As a result, a missed approach procedure was introduced, to ensure the aircraft carrying out the missed approaches did so as realistically as possible. With this final change the simulation ran correctly. The principle limitation encountered with SIMMOD in this scenario, was in its inability to properly represent the ATC controller's ability to think ahead and sequence traffic along the arrival track.

Case Nine - Selective Use of Steep Approach
This case modified case eight. The use of the steep approach procedure was limited to peak hours of operation by modifying the events file, and also to re-introduce specific regional aircraft holds to aid traffic sequencing.

The same problem of unavoidable missed approaches were found, as in case eight, but otherwise no problems occurred with the simulation run.

Case Ten - Separate Independent STOL Runway Operation
This was the final case studied. It aimed to simulate the construction of a parallel STOL runway to the south of the existing runway 24. The operation of the STOL runway was classed as independent for arrivals, only using the steep approach concept to remain above the jet aircraft's wake as in the two previous cases. Regional aircraft departures from the STOL runway were not modelled ,due to the problems that would occur with sequencing departures from both runways and between successive STOL arrivals and departures, as well as crossing delays with aircraft crossing the existing runway 24. Obviously, the procedures file needed modifying to allow independent arrivals on both runways as well as changes to the events file.

No problems arose following the simulation run. Further simulations were also carried out using regional aircraft holds to see what benefit, if any, these would generate.

6.3.2: Zurich Kloten

Zurich Kloten airport was developed as the second case study in the SIMMOD simulation strategy for a number of reasons. Firstly, it represented another congested European airport. Figures provided by Zurich Airport Authority for total scheduled movements during the years 1983-93, (figure 6.3), show continued growth, with the exception of 1991, which demonstrate that pressure caused by congestion is likely to get even more serious in the future. Data also provided by the Airport Authority show that 24% of total annual aircraft movements were regional aircraft during 1993. This, as with Manchester, represents a significant proportion of the total traffic, where the

Annual Growth in Total Scheduled Movements for Zurich (1983-1993)

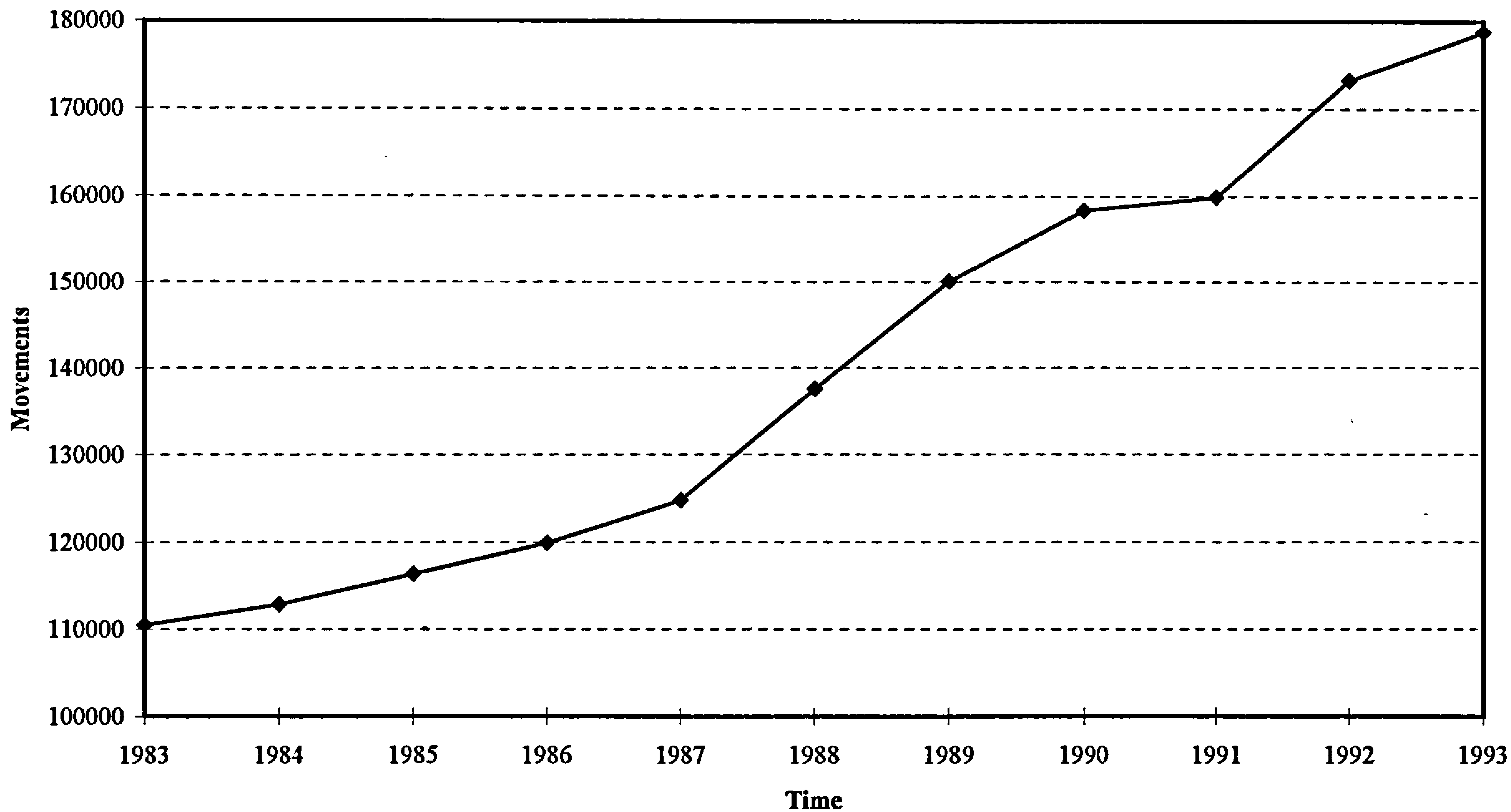

FIGURE 6.3
Source: Zurich Airport Authority

impact of introducing special procedures should yield definitive results as to their effective ability to reduce operating delays.

Considering the planned movements used in the simulation, (figure 6.4)[7], with the APATSI recommended maximum of 60 movements per hour at Zurich, it can be seen that for three hours, from 10:00 to 13:00, Zurich is operating at its maximum.

The final reason for using Zurich in the study was that it represented as good contrast to Manchester, with three runways instead of one, which by default offered a much more complex TMA structure, where introduction of the special procedures would pose more of a problem. It was hoped that the comparison of results from both Zurich and Manchester would broadly cover most TMA structure difficulties that may be found at other European airports.

The evaluation strategy for Zurich incorporated six scenarios, which will be explained below in the same format as used for Manchester. Figure 6.5 shows the modifications to the arrival and departure routes for each scenario, whilst the relevant aerodrome chart and SID and STAR routings can be found in appendix 6.5.

Base Case
As with Manchester, the aim with this case was to set up and simulate the current operation at Zurich. After discussing with Zurich Airport Authority, and looking at runway usage figures for 1994, the system was set up for arrival traffic on runway 14, with departing traffic predominantly using runway 28 for noise abatement reasons, although runway 16 was used as an overspill for departures during peak hours. Each runway in this case would be operating in single mode, with only departures from 28 and 16 requiring co-ordination. Each of the appropriate SIDs and STARs were incorporated into the system and the traffic data for the events file was generated from an ATC log for 16th July 1994 provided by Zurich Airport Authority, (appendix 6.4).

Standard separation for arrivals was set using the ICAO recommended wake vortex separations. Departures were from the threshold of runway 28 only. Initial simulation problems were encountered due to incorrect events data entry and incorrect landing roll distances for the aircraft categories. Arrivals and departures were independent, with no blocking times applied to departures by arrivals.

Following initial de-bugging of data and slight modification of the procedures file, the simulation ran without error.

Case Two - Intersection Departures on Runway 28
The aim of this scenario was to assess how departure delays could be affected by the introduction of intersection departures from runway 28. Two intersection departure points were added, called, 'Bravo', and, 'Charlie'. As with Manchester, new departure
queues and associated routes were inputted. The restrictions on the use of the intersections were the same as links 'B' and 'C' at Manchester. The procedures file

[7] See full schedule breakdown in appendix 6.4

Traffic Breakdown for Zurich per hour - 16th July 1994

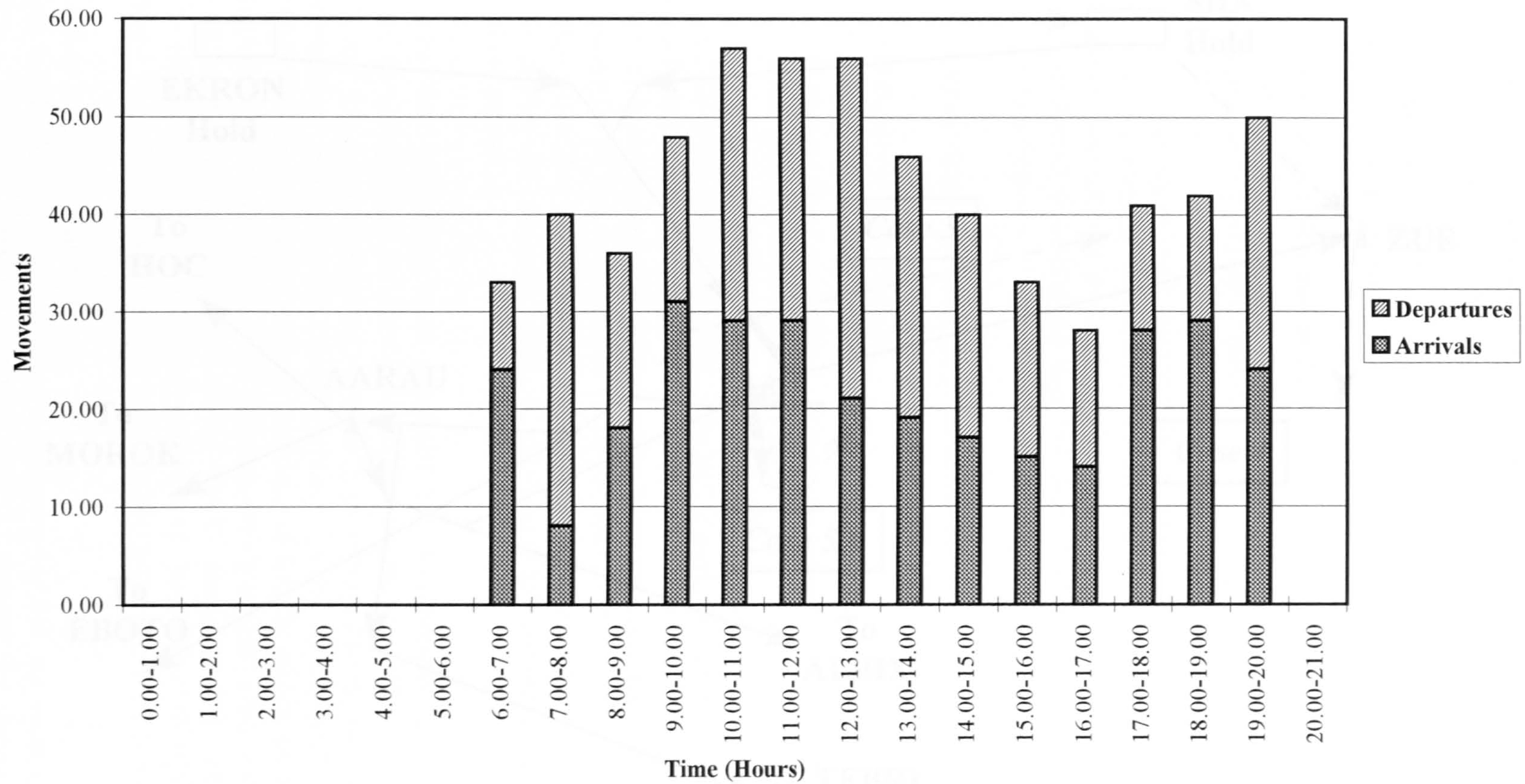

FIGURE 6.4
Source: Zurich Airport Authority

Zurich Airport Case Study Routings

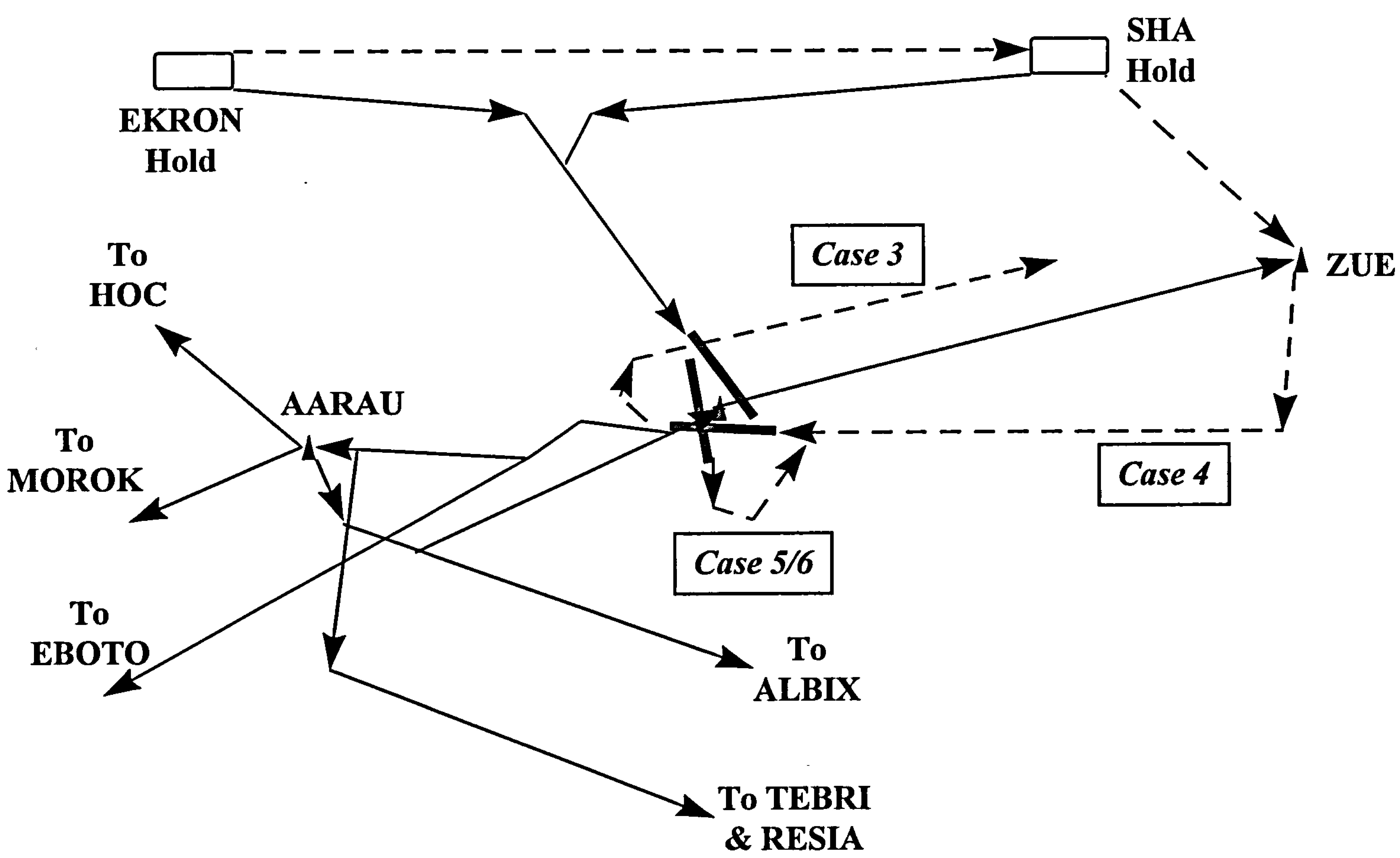

FIGURE 6.5

was also modified to control the departures from the intersections in relation to departures from the threshold. The intersection departures had to wait longer than threshold departures when following a previous threshold departure, due to their closer location to the wake vortex trail.

Due to the experience gained from the Manchester case, no problems were encountered with the simulation runs.

Case Three - Early Turns off Runway 28
This scenario represented an early right turn at 500ft off runway 28, and was applied to all aircraft departing to the north or east of Zurich, through ZUE VOR. Departures to ALBIX, HOCHWALD, MOROK, WILLISAU, EBOTO, TEBRI and RESIA were not affected, as no saving in track distance was feasible and re-integration of early turn traffic, back into existing SID tracks, would only increase delays, not reduce them. For those affected, the procedures file was modified to reduce departure separation for jet aircraft following the regional aircraft, after carrying out an early turn, from 2.5nm to 0.5nm.

No problems were encountered during the simulation runs.

Case Four - STOL Arrival Runway 28
The aim of this case was to simulate the current Crossair procedure used for runway 28, discussed in chapter five, but without movement restrictions. To simulate this scenario case, three airspace data were modified to include a new arrival route for runway 28, incorporating the steep approach. The events file was modified accordingly and then the procedures file. Through experimentation and experience from the Manchester work, the separation used between departures and arrivals for runway 28 was 55 seconds, and a blocking distance of 3 nm. Separation of arrivals on 28 and departures on 16 was not required, as the regional aircraft would stop short of the intersection with the two runways. Finally, a 20% spread factor in arrival separation on runway 28 was introduced, to allow increased departures during the peak hours of the operation.

Results of the first simulation runs presented missed approach problems and departures commencing before the arrival had cleared the runway. The solution lay in adding new RET's to minimise runway occupancy, increasing runway taxi speed and designating standard taxi paths for certain arrivals. A lot of the problems were associated with the simulation variation in landing roll length, which became quite critical when aircraft just missed one RET and then slowly taxied to the next one. In addition ground nodes needed adding just off the runway, along the RET link, as these were used to tell the simulation the aircraft had cleared the runway, so releasing the next departure. The same process had also been applied to the Manchester scenario.

Case Five - New Runway Operation
The aim here was to determine if a change in the pattern of runway operation would reduce delays. The new scenario continued with jet arrivals for runway 14 and regional aircraft arrivals on runway 28, but this time all departures were set on runway 16. Runway 16 was modified to introduce one intersection departure and early turn.

Runway 28 had two intersection departures, but otherwise runway 16 provided a common comparison. It was expected that a delay reduction would be made due to the removal of any need to increase separation requirements for runway 28 arrivals to allow out departures on 28.

Following the modifications to the airspace, ground and events files as required, the initial simulation runs worked well.

Case Six - Case Five with Regional Aircraft Departures on Runway 28
Following on from case five, the aim of this scenario was to segregate the regional air traffic onto runway 28, with jet departures on runway 16 and jet arrivals on runway 14. It was expected that this segregation of regional aircraft would help traffic flows by reducing wake separation requirements and so reduce operating delays.

The data changes were fairly simple, given the current status of the system following case five. The events data was modified to allow regional departures on 28, but from the threshold only. This was to allow the departures to operate with just blocking times for each runway. No blocking distances were applied after departure for departures from the other runway, due to the early turn off runway 28 and diverging track from runway 16. Associated with this was a modification to the procedures file. The simulation runs gave no problems.

6.4 SIMMOD Summary

The previous section has outlined all the simulation problems encountered in running SIMMOD and the limitations encountered with the system. In summarising the section it must be mentioned that in addition to the work for Manchester and Zurich, a model for London Gatwick was also developed, following a proposed project for the BAA to look at possible runway capacity improvement options.[8] Initially eight case studies were planned to assess intersection departures; early turns after take off, steep approach for the emergency runway 26R, and the use of an independent STOL runway within the existing airport boundary. Unfortunately, due to time pressures in setting up and running the SIMMOD system, completion of this part of the evaluation was not feasible. The first stages concerning the use of intersection departures and early turns was completed however, and will be used in the next chapter as a comparison to the Manchester results.

The next stage of the evaluation methodology involved the development of a cost benefit analysis system to assess the overall affect, in monetary terms, of each of the SIMMOD cases outlined above.

6.5: Introducing Cost Benefit Analysis

Up to this point this thesis has focused on the technical theories related to reducing airport congestion with specific relevance to regional aircraft. As the reader will be aware, however, in today's operating environment, every proposed modification to the

[8] For traffic schedule see appendix 6.6 and aerodrome and SID and STAR routings in appendix 6.7

existing status quo requires some sort of validation process, and this process is becoming more and more financially critical. In recognising this point, the author deemed it an integral part of this thesis to attempt a cost benefit analysis, (CBA), of the proposed solutions.

Cost benefit analysis was developed in the 1960's as a way to help investors decide whether or not a specific project would make a financial return on the initial investment. In a way it helped take some of the uncertainty and risk out of the decision. Unfortunately this method focused on purely quantifiable monetary processes, assessing what the costs would be and how quickly a return on that investment would be made, once the project began generating revenue. Returns on investment were calculated using pure accounting methods, whilst attempts to quantify broader implications of the project were not tackled. During the 1960's and 70's, CBA was modified and expanded by all areas of industry and government, as a tool to justify specific projects. Many attempts were made by industry and academia to provide realistic monetary values for such factors as environmental disruption, value of a person's time and other induced effects of a project. Further ties with economic theory were attempted, by putting a value on the multiplier effect of the investment. This related to the knock on effects of a project to the local area industry and community, as well as on a larger scale with effects to the national economy.

The culmination of research, and the trial and error use of CBA over the years, has led to the assessment of costs and benefits under three separate areas: direct, indirect and induced. Direct costs and benefits are those generated directly by the project. Indirect effects are those which are generated to support or accommodate the project. Finally, induced impacts are the economic effects generated in the local and national economy due to the project.

In aviation, the use of CBA has been predominantly used by airport and government bodies in aiding the planning process for construction of new or modified airport facilities. In November 1992 ACI Europe published a document entitled, 'Airports - Partners in Vital Economics'. The aim of the document was to outline the positive benefits to local communities, regions, countries and Europe of the airports. The document also sought to put airports in context, to outline what an airport should and should not be expected to provide.. The strategic significance of airports was assessed along with their ability to act as economic generators. Paris CDG for example employed 2,648 people, whilst supporting 377 other companies at the airport. These companies paid Ffr 9 million in salaries and spent Ffr 7.1 billion on goods and services. Geneva airport calculated that 300 million Swiss Francs were spent in 1980 by passengers staying in hotels around Geneva. The induced impact of Copenhagen airport was calculated in terms of job generation: 14,500 jobs were directly attributable to the airport, 11,500 jobs were indirectly associated with the airport, whilst a further 16,000 were induced in the local community due to the airports presence.

This document led to the publication in March 1993, by ACI, of, 'The Economic Study Kit'. It was developed to help airports accurately present and justify airport developments. Each of the direct and indirect airport impacts were outlined, but the document argued that the induced impact was best calculated by multiplying the sum of the direct and indirect benefits by a factor. This is basically the multiplier effect explained previously. The document warned airports to use caution with using this multiplier in monetary terms due to the difficulty in providing accurate values for some of the effects. Instead it recommended airports outline the effects to show appreciation of the issue, whilst refraining from placing an absolute figure on them. Finally, the document presented further qualitative effects of an airport such as reputation, marketing, innovation and skills effects.

A good summary of the factors contributing to the total economic impact of the air transport system and their relationships are given by ATAG (1993) and presented in figure 6.6.

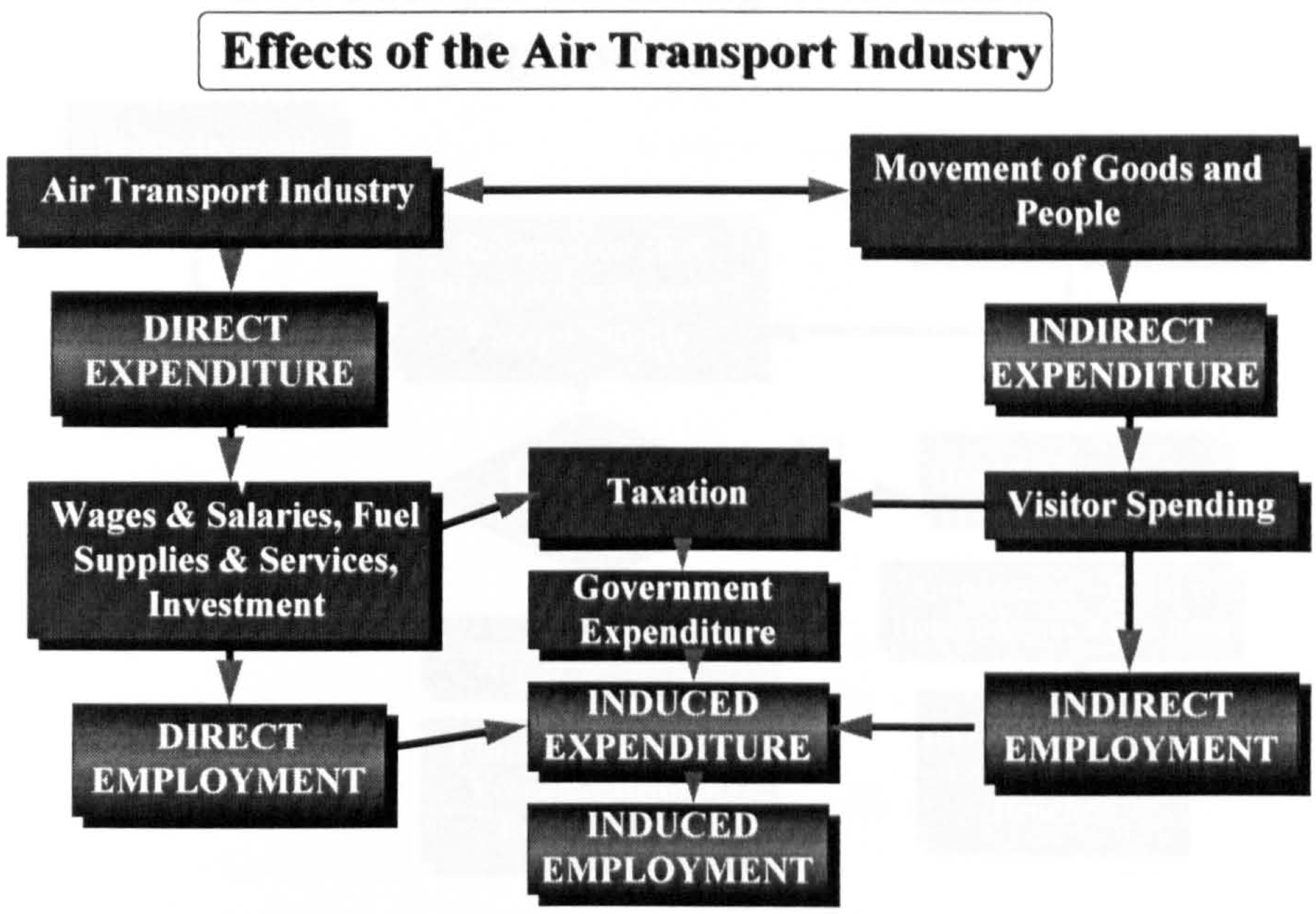

FIGURE 6.6

Source: ATAG (1993) The Economic Benefits of Air Transport

The discussion above has highlighted the principles of CBA, as well as demonstrating its application to the aviation industry. It must be stated that although CBA is used often, many of the actual monetary values for each of the indirect and induced effects are limited at best.

ATAG took this one step further and produced a flow diagram, reproduced in figure 6.7[9], which defines the repercussions of investing in additional infrastructure capacity. The diagram presents a clear cut picture of the consequences for not investing in infrastructure, which help in the determination of the costs and benefits of airport congestion.

[9] **Source:** ATAG (1993) The Economic Benefits of Air Transport

6.6: CBA Criteria and Costings

Taking the above discussion into account, this thesis is specifically concerned with the comparison of separate case studies, using different regional aircraft special procedures, to assess how they effect operating delays. The use of CBA will be to assess if the benefits of introducing the system will cover the costs. The aim will be to detail each of the costs and benefits for each of the SIMMOD case studies, comparing the results to the initial base case of doing nothing. If the new case demonstrates a better benefits to cost ratio than the base case, it will be judged worthy of implementation.

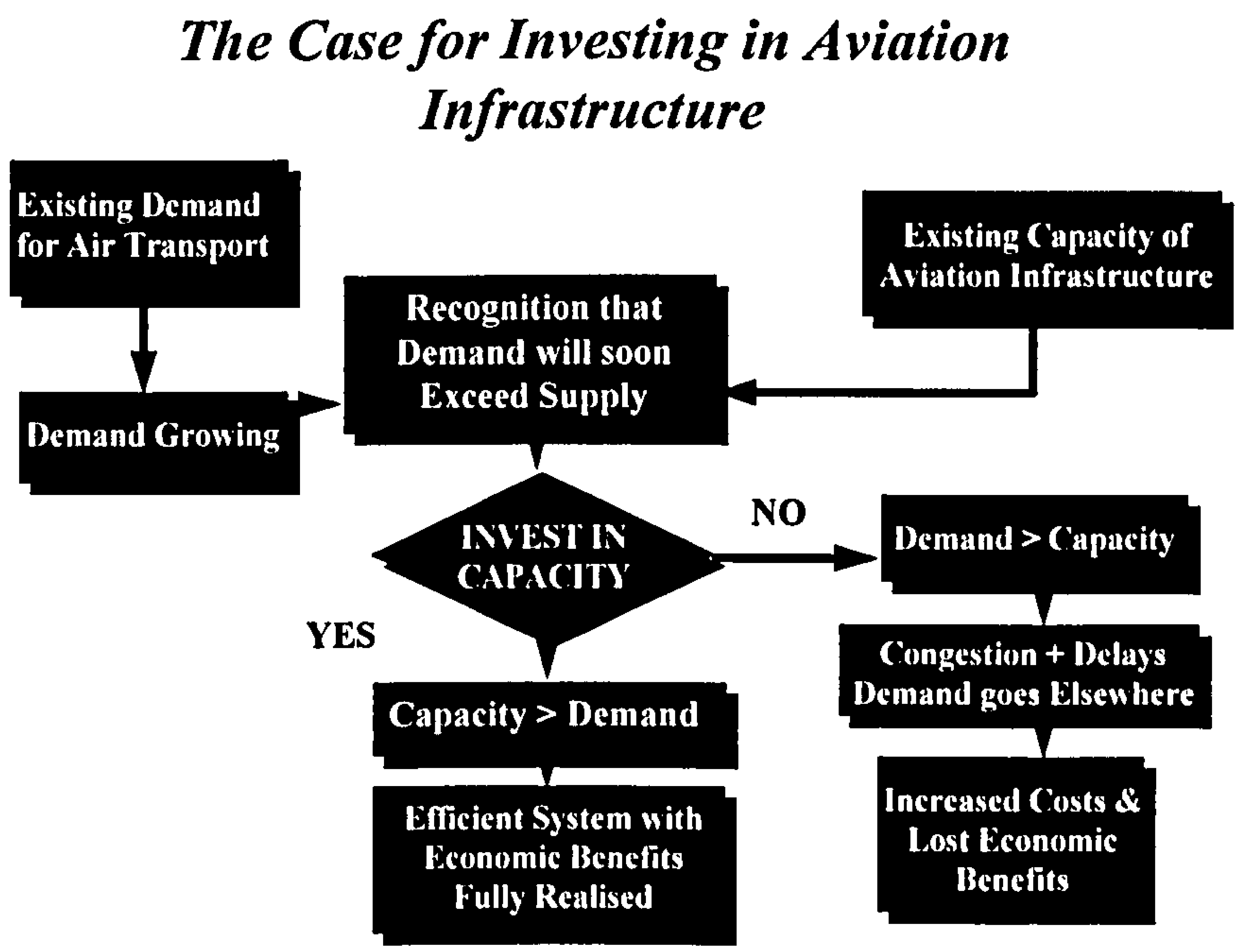

FIGURE 6.7

Source: ATAG (1993) The Economic Benefits of Air Transport

Specific use of CBA for analysing implementation of new procedures is relatively new and scarce. In looking into the issue, the author first began with determining the direct, indirect and induced effects. Help was given from ATAG in this area, who had produced a table assessing, to a limited degree, the penalties of inadequate infrastructure, (Table 6.2).

Although the information in the table is useful, it only presents a general picture of the costs and benefits. The next stage was to outline in as much detail as possible, all the specific costs and likely benefits which would appertain to each special procedure. would make. The results of this phase of the work are shown in appendix 6.8, ranked as direct, indirect and induced costs.

The Penalties of Inadequate Infrastructure

AFFECTED GROUP	NATURE OF IMPACT ON AFFECTED GROUP	ECONOMIC COST TO AFFECTED GROUP	ECONOMIC BENEFITS (TO OTHERS)
1. Airlines	Delays Curtailed Growth	Higher Operating Costs. Loss of Business, (revenues, profit, employment).	Gains by substitutes to air travel
2. Airports	Curtailed Growth	Loss of Revenues	
3. Air Travellers	Delays	Loss of productivity, especially to business people. Higher costs passed on by airlines (loss in real income).	
4. Tourist Industry	Loss of revenue due to curtailed growth	Loss of inbound business.	Increased revenue for other national economies when tourists change country of destination
5. Labour Pool	Fewer jobs due to curtailed growth	Loss of income; personal and social disruptions	
6. Business and Industry	Loss of revenue Higher operating costs	Loss of profit to businesses	Increased business activity elsewhere when businesses relocate
7.Governments	Decreased tax and fee income	Loss of revenues	
8. Aircraft manufacturers	Decreased passenger demand resulting from congestion	Loss of production as fewer aircraft are required in a severely constrained environment	Gain as more aircraft are needed to offset moderate congestion

TABLE 6.2

Source: ATAG (1993) The Economic Benefits of Air Transport

Seven cases were developed as follows:

Case 1	Base Case - no change
Case 2	Maximise current use of existing runway
Case 3	Use of early turn after take off
Case 4	Use of discrete arrival procedure (SALS)
Case 5	Use of steep approach procedure
Case 6	Construction of a STOL runway with existing airport
Case 7	Development of a separate Reliever Airport.

For each case there are common figures which relate to the costing of delays. Value of time is a controversial issue, which attempts to place monetary value to a person's time. In almost all cases it is broken into business time and leisure time. The use of value of time figures has created much debate within users of CBA, as whilst no one doubts that delays during transportation do present a cost to individuals involved, the exact amount of money involved will vary with every individual, depending on their circumstances Value of time is an intangible quantity relating to issues such as time spent with friends and family. Relaxing. It must also take into account time spent in preparing, conducting and reviewing business. Obviously delays during transport will prevent some of these activities taking place or disrupt them. It is this disruption that is used to help assess value of time. The UK CAA values business time at £67 per hour and leisure time at £10 per hour. The figures are corrected to 1996 values take from the RUCATSE report, but date back to work first done for the Roskhill commission examining a site for a new runway in the South East of England. Due to the current application of these figures by the UK CAA, these will be the ones used in this thesis. It must be stated that although these figures represent an industry standard, they do not account for individual variation. A leisure passenger taking his first holiday from work in two years, may value his time much more highly than the business person sat next to him. A business person about to clinch a multi-million pound deal will also value his time at a higher rate than that specified if the plane is delayed and he misses his deal.

The other costs are presented in the appendix, and will be used in examining each of the SIMMOD simulation cases. In each case the author has attempted to provide a source for the figures given, mainly generated through discussion with airlines and airports, or an explanation for the figure or statement written.

6.7: Integrating SIMMOD and CBA Methods

Following the previous explanation of both SIMMOD and CBA, they now need combining to provide meaningful results. From the SIMMOD simulations, data on travel time and delays for each case are recorded by hour. Changes in the runway movement rate are also recorded. Due to the extent of the statistics available, averages are used to help collate the data and make it useable. These average changes in arrival and departure delays for each case are then used in the CBA figures for value of time and airline operating costs. The focus will be on the peak hours, as this is generally where reductions in delays are most significant and effective.

With the SIMMOD delay results entered into the CBA tables for each case, a comparison of available cost and benefit totals is made. Judgment on the accuracy and amendment of these figures will be made in chapter eight, along with whether or not the procedure has positively improved the airport access or not.

6.8: Limitations of Methodology

In general this thesis assumes that each of the procedures trialed is technically feasible using existing levels of navigation equipment, unless otherwise stated. It also assumes that ATC will make sufficient corrections to prevent collisions, except where expressly stated. As the focus is on how can these procedures reduce operating delays, the work does not provide detailed collision risk assessment of each case study, as the author is not an expert in this field. Neither does it provide detailed take off performance assessments of each procedure for each regional aircraft type, to assess its acceptability, due to the same reason as given before. The use of SIMMOD does impose limitations on the accuracy of representing real world scenarios, as previously discussed, however it also represents the best tool available to the author in this work.

Finally, as can be seen by examination of the CBA tables in appendix 6.8, many values are missing. The focus of the work was to provide as detailed a listing of the factors involved as possible, rather than complete monetary values. The author feels this lies with those more experienced in that field.

6.9: Questionnaires[10]

6.9.1: Regional Airline Views on Special Procedures

Due to the limited information that was available regarding the use of these special regional aircraft procedures, the author decided to send a questionnaire to European regional airlines in an attempt to determine exactly what procedures were being used, where and with what success. In addition, a second part was added to the questionnaire to help gauge how regional airlines felt about making use of these procedures. Both parts of the questionnaire are included in appendix 6.9 to this chapter and, as can be seen, the first part is a series of structured questions with space for the airline to express its view directly. It is broken into five sections in an attempt to cover all possible use of the special procedures. Section one asks for basic information on the airline fleet and airports where operating delays are prevalent. Sections two, three and four ask if the airline has ever used special procedures in the past, is using them now, or intends to use them in the future. The final section asked the respondent to give general views on special procedures, how they thought the procedures would ease congestion in the future, and what would be the greatest obstacle to the implementation of possible procedures.

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10 See Appendix 6.9

The second part of the questionnaire was a structured and controlled questionnaire asking the respondent to rate how important he felt a number of statements relate to the use of special procedures.

The questionnaire was mailed to operations directors or chief pilots at 46 European regional airlines making use of the ERA mailing lists. Sixteen were returned representing 37% of the total and are listed below:

Air UK	Hamburg Airline
Avianova	Interot
British Midland	Jersey European Airways
Brymon European Airways	KLM Cityhopper
Business Air	Loganair
Crossair	Lufthansa Cityline
Finnaviation	Olympic Aviation
Gill Aviation	Regional Airlines

Although the return rate seems low, the response does cover operations from nine separate European countries, especially France, Germany, Switzerland, Austria and the UK, where most of the congested European airports are located. The response also covered a broad variety of regional airlines in terms of size and scope of operations.

6.9.2: Major Airlines view on Regional airlines

This was a brief questionnaire aiming to assess the scale of current regional airline franchises or agreements by the major airlines, and how they valued them. This followed an appreciation by the author that major airlines are increasingly using regional airlines to operate their shorter routes which are thin on passenger traffic. This is due to the latters lower operating costs. A high level of commitment to protect these feeder or franchise services would further validate the use of special procedures at major airports.

The last three questions in the questionnaire attempted to evaluate how the major airlines saw the development of these franchises and agreements in the future, and what they felt would be restrictive to their use.

The questionnaire was mailed to 18 of the major European airlines and is included in the appendix.

6.9.3: European Airport views on Special Procedures

This final questionnaire aimed to determine which European airports were currently using any form of special procedure and how they felt special procedures would affect their operation.

Initial questions attempted to evaluate to what extent hub feed traffic affected the airport, and whether the airport viewed the regional aircraft as an asset or liability.

The latter point was forced in question 6 when they were asked to say how they expected regional aircraft traffic to change in the future. The remaining questions asked specific questions on special procedures and how they felt they would or could be used, and why they might be restricted.

The questionnaire was mailed to 24 European airports and is included in the appendix.

6.10: Practical Projects

The aim of this part of the evaluation was to give the author enough exposure to the aviation industry, in order to place the SIMMOD and CBA work in context, adding a realistic element to the theory. The projects also helped cover some of the areas involved with special procedures, not directly covered by previous research. This move was deemed as crucial by the author to help provide results which would be of use to the aviation industry. There were seven separate practical projects undertaken.

APATSI Contract - In March 1993 the author was asked to help the Department of Air Transport, Cranfield University, on a contract for the ECAC APATSI working group. The contract exposed the author to the many procedures that APATSI is examining and involved an in depth review of pertinent articles from Cranfield Library.

SIMMOD Contract - In October 1993 the author again became involved with a Cranfield contract. This time the work was for a group examining the feasibility of developing Redhill airport as a reliever for Gatwick airport. The author was involved in setting up the SIMMOD datafiles to assess the new traffic and airspace patterns proposed by the project. The work enabled the author to gain valuable work experience with SIMMOD.

European Regional Airlines Association (ERA) - From February 1994 to September 1995 the author was asked to represent the Department of Air Transport, Cranfield University, at the ERA operations and maintenance committees. These were held three to four times a year and exposed the author to current concerns and issues of regional airlines operating in Europe, as well as current changes occurring in the European aviation arena.

Business Air Work Experience - Full time for three months in 1994, and for up to a year part time, the author worked at Business Air in Aberdeen in operations planning. This enabled practical experience to be gained in regional airline operations, seeing problems develop and subsequently resolved.

Manchester Airport Project - Whilst working with Business Air, the author was involved with an attempt to reduce arrival and departure delays for the operations of that airline through Manchester. Discussions were held with ATC and the airport and a new trial developed. The work was an excellent opportunity for the author to see at first hand the problems associated with implementing regional aircraft special procedures at a congested airport.

Gatwick Airport Project - The BAA airport authority sponsored the author in 1995 to help provide support for the thesis, looking specifically at Gatwick. Discussions were held with Gatwick and London ATC in addition to the BAA, to evaluate a series of options for use of regional aircraft special procedures. Part of the work was backed up with SIMMOD simulations, specifically the evaluation of the early turn after take off.

This project enabled the author to compare results with Manchester, the same runway configuration and operation, but with differing traffic patterns.

Supplementary Information - In addition to the specific projects outlined above, the author also had the opportunity through Cranfield and the ERA, to gain a general consensus of opinion on regional aircraft special procedures, by discussing the principles with external lecturers at Cranfield and key regional airline personnel, including airline, airport, aircraft manufacturers and associated support industries.

6.11: Summary

This methodology provides the reader with the basic framework used for evaluating special procedures. Whilst appreciating that many gaps still exist in the more detailed aspects, such as take off performance, collision risk assessment and CBA values, the author has attempted to combine the theory with practical advice from the many practical projects covered during work for the thesis. With the above in mind it is now time to examine the results produced and to begin answering the aims of the thesis set in chapter one.

CHAPTER 7 : Evaluation Results.

7.1 Introduction

This chapter will combine the methodology defined in the previous chapter with the work carried out by the author to define the results. The results will be presented in three sections. Firstly, the SIMMOD analysis and results in terms of delay variation from the base case, with comments observed from the simulation, followed by the results of the combined SIMMOD and CBA process. Secondly, an evaluation of the effectiveness of each scenario at reducing congestion will be given. Finally, the results of each questionnaire will be presented. The results of the practical projects will be used to help the discussions on regional aircraft special procedures in the next chapter.

7.2 Manchester Airport

7.2.1: Base Case

As pointed out in chapter six, the purpose of this case was to provide a control level against which to monitor the effect of additional changes in procedures to operational delays and peak hour runway movement rates. Due to the nature of the cases, this case was specifically set at an operational level below that currently used at Manchester. It was assumed that all departures left from the same point on the runway with minimum effort taken to sequence arriving traffic. In addition, no passing was allowed within the departure queue to optimise departure traffic sequence, and arrival spacing was allowed to be increased up to 30% above that scheduled, to help provide sufficient space to let departures out between successive arrivals. Five iterations of this case were run to remove simulation errors, and the results achieved are presented in table 7.1.

Principle points to note, are the delay figures for arrivals and departures and the maximum peak period movement rate per hour. The rest of the cases will be judged by their ability to improve on these figures. The maximum rate of just over 41 movements an hour relates well to the APATSI proposed optimum of 42 movements an hour for a single runway. For this reason and the lack of any undue simulation problems observed during the animation, the author decided to accept this model as a good base to build upon.

The peak period mentioned in the table refers to that outlined in appendix 7.1, which provides more detailed tables of the SIMMOD results in an hour by hour listing. Table 1 gives the movement figures, along with the summary tables, whilst table 2 gives the same information for the delays. From the first table for Manchester, the movement rates demonstrate that the planned and simulated movement rates are greatest during the early morning, from 0700 to 1100 hours. Looking more closely at the peak period movements versus the planned movements, it can be seen that this case achieved 95% of planned movements.

Base Case	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	7723.80	4710.30	
Average Travel Time/Mov. (mins)	28.90	17.60	
DELAY TIME			
Total Delay Time (mins)	976.80	2828.00	
Average Delay Time/Mov. (mins)	3.70	10.30	
PEAK HOUR FIGURES			
Peak Hour for Movements	18-1900	10-1100	
Peak Hour Movement Rate	21.00	23.00	
Peak Hour for delays	08-0900	08-0900	
Peak hour delay/movement (mins)	11.84	22.20	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			41.16
Average Peak Period Mov. Rate/hr.			38.38
Maximum Peak Period Delay per mov./hr (mins)			17.02
Average Peak Period Delay per mov./hr (mins)			13.52

TABLE 7.1

Moving to the delay figures given in the second table for Manchester in appendix 7.1, it can be seen that departure delays per movement are on average double that of the arrivals during the peak period, with the maximum average delay per departure being 22.2 minutes between 0800 and 0900. From the animation it could be seen that this delay led to the development of a substantial departure queue, which was causing taxiway and apron blockage at peak times, especially around the domestic pier and stands.

Turning to the cost benefit analysis, no tables are given in appendix 7.2 for the base case, as the author felt that the focus of this thesis should be to look at how costs varied from this base case. Obviously, if the airport decided to remain in this base case position, there would be associated costs and benefits as outlined in appendix 6.8 in the previous chapter.

7.2.2: Case Two - Intersection Departures

This case built on the base case, by allowing regional aircraft to carry out intersection departures from links 'B' and 'C'. No additional taxiway construction was required. Two additional departure queues needed setting up in the SIMMOD ground file, along with two additional procedures in the airspace file. The procedures had to account for the different departure separations that applied to intersection departures. Departures from link 'B' had a 50 second take off blocking time, and a 2nm airspace blocking distance following departures from the 24 threshold. The figures from link 'C' were 50 seconds and 2.5nm respectively.

Case Two	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	7722.90	4630.60	
Average Travel Time/Mov. (mins)	28.90	16.90	
DELAY TIME			
Total Delay Time (mins)	929.00	2496.10	
Average Delay Time/Mov. (mins)	3.50	9.10	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	07-0800	
Peak Hour Movement Rate	21.00	23.70	
Peak Hour for delays	08-0900	08-0900	
Peak hour delay/movement (mins)	11.74	21.22	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			41.50
Average Peak Period Mov. Rate/hr.			38.63
Maximum Peak Period Delay per mov./hr (mins)			16.48
Average Peak Period Delay per mov./hr (mins)			12.74

TABLE 7.2

Table 7.2 gives the SIMMOD summary results for this case. If these figures are compared to table 7.1, it can be seen that the effect on arrivals has been minimal with no real detrimental effect. The effect on the departures, however, has been substantial. Average travel time per departure has reduced slightly with, on average, an additional minute reduction in delay for departures during the peak period, as well as the whole day.

Looking at simulated movements, it can be seen that the peak hour maximum departure rate has increased from 23 to 23.7, with the average peak hour rate increasing by 0.25. By looking at appendix 7.1 table 1, we can see that as well as the increase in the maximum rate, between 0900 and 1000, the movement rate for departures has increased by 1. Overall, during the peak period 1.01 extra total movements were recorded. This analysis was supported by the animation which showed that, whilst departure delays were reducing, significant departure queues still existed, partly due to the fact that the departure queue logic in SIMMOD had not been changed to allow aircraft passing in the queue. The author had purposely left the restriction in as SIMMOD was unable of assessing which aircraft to move in the queue to provide an optimum departure sequence. In hindsight however, introduction of passing may have further reduced departure delay.

When the above information was put into the cost benefit analysis, (appendix 7.2), it was calculated that the introduction of the procedure would cost £51,534 and yield a benefit of £25,027, not taking into account the multiplier for the reasons given in the table. As this cost represented start up costs only, with no recurrent costs, this procedure would pay back the initial investment in two days, thereafter providing a benefit to the system.

Taking all the above information into account it can be seen that the introduction of this procedure would benefit the system and substantially improve on the existing base case.

7.2.3: Case Three - Early Right Turn to Pole Hill

This case built onto results of case two, and required the addition of two procedures and four routes to the airspace file. The routes were defined to Pole Hill VOR and the second for Stock departures. The routes roughly shadowed the radar vectors given to regional traffic by ATC after the early turn, which was a right turn onto 330° with further right turns to 360° and 020°. As departures were commencing from two intersection departures on runway 24, four routes needed defining, two for each intersection departure point. The two new procedures were introduced to allow reduced separation restrictions for departures following the early turn departures. Distance blocking was reduced from 2nm to 0.5nm for departures from the threshold following departures from link 'B', and from 2.5nm to 1.5nm for departures following from link 'C'. The second procedure applied similar restrictions for departures following departures from link 'C'.

Case Three	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	7711.70	4582.60	
Average Travel Time/Mov. (mins)	28.80	16.70	
DELAY TIME			
Total Delay Time (mins)	943.20	1775.20	
Average Delay Time/Mov. (mins)	3.50	6.50	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	07-0800	
Peak Hour Movement Rate	21.00	25.80	
Peak Hour for delays	09-1000	08-0900	
Peak hour delay/movement (mins)	12.80	16.11	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			42.20
Average Peak Period Mov. Rate/hr.			39.50
Maximum Peak Period Delay per mov./hr (mins)			13.65
Average Peak Period Delay per mov./hr (mins)			10.04

TABLE 7.3

Table 7.3 shows that like case two, little reduction in operating times and delays for arrivals are achieved. Departure delays this time are further reduced by a greater magnitude than with case two. Average delay per departure is 3.8 minutes in this case, less than the base case, with similar reductions in the peak period delay figures.

Average peak period departure delays per movement have decreased from 19.8 minutes in the Base Case to 12.8 minutes, a saving of seven minutes.

Movement rates have also improved for departures. The maximum hourly peak period movement rate has increased from 23 in the base case to 25.8, an additional 2.8 movements. In fact during the peak period 4.5 additional movements were achieved compared to the base case, with improvements achieved for each hour during the peak period.

The cost benefit analysis predicts a cost of £158,665 to introduce this procedure against a perceived benefit of £71,562 per day. This gives a pay back period for the initial investment of 2.2 days ignoring the multiplier effect, and the benefit of additional slot generation. The latter was left out, as the author did not know what value an additional slot at Manchester would fetch. Obviously, if this were included, the pay back period would be much sooner, if not instantaneous. In addition to this there is a daily recurrent cost of £670 reflecting the additional ATC controller workload generated by using this procedure, which will need to be taken into account when calculating benefits once the investment costs are covered.

Given this information, it can be easily concluded that the introduction of this procedure will significantly improve the base case, and case two, with a similar pay back period to case two. As the overall improvement is greater than case two, this represents the optimum solution so far.

7.2.4: Case Four - Early Turns Stage 2

Given the similarity of this procedure to case three, no changes were required to the existing ground files from case three. The events data was altered to allow additional early turns for south bound departures, and two new routes added to simulate the early left turn direct to Conga.

From table 7.4 it can be seen that virtually all the figures are the same as case three. Average total peak period delay per movement is 0.1 of a minute less than case three. This being stated, the reduction in delay compared to the base case is by default the same as case three.

Peak period movement rates are also very similar to case three, although during the peak period an extra 0.2 of a movement is achieved compared to case three, bringing the total to 4.7 additional movements compared to the base case. This improvement is so small that no account should really be made of it, due to the simulation inaccuracies built into the system that are impossible to remove.

The cost benefit analysis for this case shows that costs remain the same, whilst benefits increase by £195, representing the marginal delay reduction. The pay back period is also 2.2 days. Although not included in the cost benefit table, this procedure is likely to cause greater ATC workload than case three. If, for example workload was now 20 hours per day, this would double the cost from £670 to £1340. This would then need taking out of the daily benefits as a recurrent cost.

Given the basic information for this case, it represents no significant improvement from case three, whilst remaining significantly better than the base case. If the workload costs are taken into account however, this case represents a worse case. In the long term, if ATC controllers get used to this procedure, the additional workload may reduce, at which time this case will become the optimum. Until that time case three still represents the optimum solution.

Case Four	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	7710.70	4571.90	
Average Travel Time/Mov. (mins)	28.90	16.70	
DELAY TIME			
Total Delay Time (mins)	943.10	1772.40	
Average Delay Time/Mov. (mins)	3.50	6.50	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	07-0800	
Peak Hour Movement Rate	21.00	25.80	
Peak Hour for delays	09-1000	08-0900	
Peak hour delay/movement (mins)	12.05	16.11	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			42.20
Average Peak Period Mov. Rate/hr.			39.55
Maximum Peak Period Delay per mov./hr (mins)			13.65
Average Peak Period Delay per mov./hr (mins)			9.95

TABLE 7.4

7.2.5: Case Five - Early Turns Stage 3

This case was built on cases three and four and followed results of early discussions with Manchester ATC and Business Air. Business Air had found that their aircraft were not always being allowed early right turns by ATC. This was due to concern by ATC that the aircraft would interfere with standard departures to the north in heavy traffic conditions, and lack of space beneath the Bolin arrival stack, under which the route passed. Business Air wondered if the early turn was to the left, with the turn continuing right back over the airfield, this problem would be removed. ATC indicated that it may, although they could not guarantee the result.

Taking this information on board, the author designed this case to only permit early turns to the left, with north bound departures continuing to turn over the airfield. It was intended to check what effect this would have on existing delays and movement rates. Little change was required to the existing SIMMOD files except the addition of the new north bound early turn route.

Table 7.5 shows that whilst average departure travel time per movement increases slightly, it is offset by a corresponding decrease in average delay time per movement. Other figures in the table remain very close to case four. The case provides a total delay saving during the day of 18.49 hours compared to 18.15 hours for case four. During the peak period the most significant change in average departure delay per movement is from 1000 to 1100, when the figure reduces from 10.22 minutes in case four to 9.73 minutes. As with the movement rate variation mentioned in case four, the validity of this change is subject to discussion and should not be greatly emphasised.

Case Five	**Arrivals**	**Departures**	**Totals**
TRAVEL TIME			
Total Travel Time (mins)	7710.70	4616.80	
Average Travel Time/Mov. (mins)	28.90	16.80	
DELAY TIME			
Total Delay Time (mins)	943.10	1752.30	
Average Delay Time/Mov. (mins)	3.50	6.40	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	07-0800	
Peak Hour Movement Rate	21.00	25.80	
Peak Hour for delays	09-1000	08-0900	
Peak hour delay/movement (mins)	12.08	16.09	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			42.20
Average Peak Period Mov. Rate/hr.			39.60
Maximum Peak Period Delay per mov./hr (mins)			13.64
Average Peak Period Delay per mov./hr (mins)			9.91

TABLE 7.5

Changes in the movement rates reflect the same as case four. The hourly departure rate is increased between 1000 to 1100 by 0.2 of a movement to 23.6. This is 0.4 of a movement greater than case three, but is still not great enough to merit serious consideration. During the peak period this now relates to an additional 4.9 average movements per hour compared to the base case. The other movement figures do not vary from those for cases three and four.

The extra delay savings relate to an increased benefit from £71,757 in case four to £73,103. This does not affect the pay back period. Unlike case four, this case should not lead to extra ATC workload over that accounted for in case three. For this reason and the additional benefits, this case presents a greater optimum position than case three and is now the preferred solution.

7.2.6: Case Six - Direct Arrival from Pole Hill

This case shifted the emphasis from departures to arrivals. The aim of the case was to represent the work of the author and Business Air into the direct arrival procedure discussed in chapter five. New arrival routes were added to the airspace file, and the events file altered accordingly, to allow regional aircraft arrivals from Pole Hill and Stock in the west to use the new routing. The procedures and arrival spacing separation were left the same, although the latter was varied initially to assess its likely impact on delays. Unfortunately it did not improve the overall result so was left unchanged.

Case Six	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	6715.40	4614.00	
Average Travel Time/Mov. (mins)	25.20	16.80	
DELAY TIME			
Total Delay Time (mins)	1273.60	2355.80	
Average Delay Time/Mov. (mins)	4.70	8.60	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	07-0800	
Peak Hour Movement Rate	21.00	24.80	
Peak Hour for delays	08-0900	08-0900	
Peak hour delay/movement (mins)	20.36	20.58	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			43.00
Average Peak Period Mov. Rate/hr.			38.95
Maximum Peak Period Delay per mov./hr (mins)			20.47
Average Peak Period Delay per mov./hr (mins)			13.32

TABLE 7.6

The figures given in table 7.6 above clearly indicate that whilst average arrival travel time has reduced by 3.7 minutes, average delay time per movement for arrivals has increased by 1.2 minutes and by 2.2 for departures. Combined these delay increases all but cancel out the travel time reduction. During the peak period average delays per arrival increased from 7.3 minutes in case five to 8.9 minutes in case six, with the figures for departure being 12.6 and 17.8 respectively. The maximum delay per movement for the peak period has increased by 6.8 minutes.

In addition this case did little to improve peak hour movement rates. Although the maximum peak hour rate shown in table 7.6 does show 0.8 of a movement increase, during the peak period all departure movement rates are reduced by a total of 2.6 movements, whilst arrival totals remain the same compared to case six. The benefit in movement rate for arrivals, is that during the peak period the movement rates between 0800 and 1000 are 21 per hour greater than any previous case.

Whilst studying the animation, it was noted that as well as increasing the departure queues, this simulation also did not accurately represent the ability of ATC controllers to sequence arriving traffic from the new direct arrival route, and the existing standard arrival traffic. This inability to prior plan the arrival sequence led to missed departure opportunities, as optimum use of the wake vortex separation requirements were not made.

Due to the reduced delay saving this case made in comparison to the base case, the benefits were reduced to £11,504. In addition costs of introducing the procedure increased to £114,146. This would require a pay back period of 9.9 days, with additional recurrent costs of £1340 per day.

Taking the preceding information into account it is clear that this procedure, whilst marginally improving arrival traffic flows during the peak period, does not improve on case five and therefore does not represent the optimum solution.

7.2.7: Case Seven - Discrete Arrivals from Dayne and Pole Hill, with and without holding

This case built upon case six with the addition of a direct arrival procedure for regional aircraft from the south. The route was a direct routing from Dayne to 6nm out on the ILS for runway 24. The routing would mean that whilst the regional aircraft were subject to the same holding restrictions other aircraft faced at Dayne, once out of the hold, the routing was a direct one. Apart from the addition of the new routes into the airspace file and the required changes to the events file nothing else was changed.

Case Seven 'a'	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	6640.20	4617.80	
Average Travel Time/Mov. (mins)	24.90	16.80	
DELAY TIME			
Total Delay Time (mins)	1230 50	2213.80	
Average Delay Time/Mov. (mins)	4.60	8.10	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	07-0800	
Peak Hour Movement Rate	21.00	24.80	
Peak Hour for delays	08-0900	08-0900	
Peak hour delay/movement (mins)	20.23	20.67	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			42.40
Average Peak Period Mov. Rate/hr.			39.25
Maximum Peak Period Delay per mov./hr (mins)			20.45
Average Peak Period Delay per mov./hr (mins)			13.36

TABLE 7.7

Due to the sequencing problems discovered in case six, this case was simulated firstly in the same format as case six, and secondly with the addition of regional aircraft holding stacks, just to the north and south of the ILS intercept path. This was achieved in the simulation with a simple alteration to the node holding logic for the specific nodes. For ease of discussion, the results for case seven will be presented as seven 'a' and seven 'b'. The latter will refer to the introduction of regional aircraft holds.

The SIMMOD results are presented in tables 7.7 and 7.8.

Looking at travel times first, both seven 'a' and 'b' show a reduction in arrival travel time, but only on average 0.3 of a minute. Case seven 'a' shows a marginal reduction in average arrival delay time, whilst seven 'b' shows a slight increase compared to case six. Both are still higher than case five.

Case Seven 'b'	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	6647.60	4616.00	
Average Travel Time/Mov. (mins)	24.90	16.80	
DELAY TIME			
Total Delay Time (mins)	1300.10	2186.60	
Average Delay Time/Mov. (mins)	4.90	8.00	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	10-1100	
Peak Hour Movement Rate	21.00	24.40	
Peak Hour for delays	08-0900	08-0900	
Peak hour delay/movement (mins)	19.08	22.18	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			44.00
Average Peak Period Mov. Rate/hr.			39.35
Maximum Peak Period Delay per mov./hr (mins)			20.63
Average Peak Period Delay per mov./hr (mins)			13.46

TABLE 7.8

The average arrival delays per movement during the peak period are 9.4 minutes for seven 'a' and 10.0 minutes for seven 'b'. Both are greater than case six and at least two minutes greater than case five. Average departure delays during the peak are 17.3 and 16.9 minutes for seven 'a' and 'b' respectively. Again both exceed case five by up to 4.7 minutes, but are both less than case six. The total delay saving compared to the base case for seven 'a' is just 0.17 minutes with the figure reducing to 0.06 minutes for seven 'b'.

In terms of movement rates it can be seen by comparing table 7.7 and 7.6 that no change to peak hour movements occurs, and maximum peak period movement rates decrease for case seven 'a'. Case seven 'b' does give a higher peak period rate of 44 movements though. Total peak period departure rates are also higher than case six by

1.2 and 1.6 movements for case seven 'a' and 'b' respectively compared to case six. Neither case however equals the rate achieved in case five for the peak period. The increase in movements to case seven 'b' is to departures, which increase to 23 and 24.4 for the last two hours of the peak period. According to the planned movements however, it is during the first two hours of the peak period that most movements are scheduled. This indicates a reduced ability of this case to provide capacity when required. Total increases in the peak period movements when compared to the base case are 3.5 for seven 'a' and 3.9 for seven 'b'. Both less than case five but greater than case six.

By examining the animation for these cases, the author realised that seven 'a' portrayed similar problems to those outlined in case six. Seven 'b' also disappointed the author, as the simulation imposed holding for all regional aircraft, which led to the reduced ability of regional aircraft to be released as and when traffic flows allowed. This raises potential problems for the use of this idea in real life.

Needless to say, as the movement rate and delays were greater than case five, the cost benefit analysis results also give poorer results. According to the figures in appendix 7.2, the pay back period for case seven 'a' is 4.8 days and 5.7 days for seven 'b'. The increase for seven 'b' being due to increased ATC workload costs and lower delay savings compared to seven 'a'.

Due to the above comments, case seven 'a' and 'b' do not provide better results than case five which remains the optimum.

7.2.8: Case Eight - Steep Approach for Arrivals

Following on from the disappointing results of case seven, this case aimed to combine the direct arrival procedure with a steep approach to see if together they could reduce operating delays. It was the intention to simulate the introduction of a steep approach for arrivals onto a STOL runway section of the main runway, between links 'C' and 'D', a distance of approximately 1600m. The production of this aim posed a few problems for SIMMOD. The largest problem was that the current runway defined in the simulation had just two interface nodes, which meant that arrivals and departures could only enter and leave the ground at those specific nodes. This would not allow two separate arrival points on the same runway. To overcome this, the author had to add an additional runway right next to the existing one in the position the STOL runway would be on the real runway. With this complete, another problem arose. The movements on the two runways had to be coordinated to represent a single runway operation. Departures on the main runway could not occur whilst STOL arrivals were taking place and neither could standard arrivals. This was overcome with the use of the procedures section in the airspace file. A time blocking of 40 seconds for standard arrivals and 45 seconds for departures was introduced, along with a distance blocking of 3nm for departures and 1nm for standard arrivals. The restrictions enabled the simulation to accurately represent the scenario. With additional arrival routes, taxiways for the new STOL runway connecting the rest of the taxiways, and changes to the events file, the simulation was ready.

Table 7.9 gives the results of the simulation. The travel times show the arrival times have increased from case seven, however the average delay per arrival has fallen from 4.9 minutes in case seven to 1.2 minutes. This is better than any previous case. During the peak period the average arrival delay only increases to 2.0 minutes, again better than any previous. Unfortunately when attention is turned to the departure delays the true picture emerges. Average delay per departure has increased by 4 minutes from case seven alone, and by 5.7 minutes compared to case five. Peak hour delay per departure is a substantial 19 minutes greater than case five, which when compared to the corresponding 8.8 minute decrease in arrival delay, demonstrates the real result. Combined peak period delay per movement is now 1.3 minutes greater than the base case.

Case Eight	**Arrivals**	**Departures**	**Totals**
TRAVEL TIME			
Total Travel Time (mins)	6771.80	4610.70	
Average Travel Time/Mov. (mins)	25.40	16.80	
DELAY TIME			
Total Delay Time (mins)	308.90	3323.10	
Average Delay Time/Mov. (mins)	1.20	12.10	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	10-1100	
Peak Hour Movement Rate	22.00	25.50	
Peak Hour for delays	08-0900	08-0900	
Peak hour delay/movement (mins)	3.26	35.06	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			41.33
Average Peak Period Mov. Rate/hr.			38.79
Maximum Peak Period Delay per mov./hr (mins)			19.16
Average Peak Period Delay per mov./hr (mins)			14.85

TABLE 7.9

As with previous cases, movement rate figures closely follow the delay results. The peak hour arrival movement rate is one greater than previous cases with 37 arrivals occurring within the first two hours of the peak period, compared to 31 in case five. Departure movements however, show the reverse with just 40.3 being achieved in the first two hours in case eight, compared to 47 in case five. When combined the movement rate provides 1.7 extra movements compared to the base case.

The benefits of introducing this procedure are calculated to be £11,465 per day compared to costs of £713,585. The latter is high due to the capital investment required by airlines to equip the aircraft to carry out steep approaches. The figures relate to a pay back period of 62.2 days and recurrent costs of £2,010 a day.

Given the cost information for this case, it can be seen that although dramatically improving arrival delays and movement rates, it has an even greater detrimental effect on departures. This is due to the fact that the steep approach effectively reduces arrival separation, which in turn reduces the time gap between successive arrivals to permit departures to take place. This tends to escalate during peak periods resulting in excessive departure delays. For this reason case eight is not the optimum for Manchester. The results do merit consideration by those airports operating a single mode runway operation for arrivals however.

7.2.9: Case Nine - Steep Approach and Regional Holds

This case aimed to take case eight one stage further by adding regional holds to the arrival tracks as in case seven. The aim was to help ease the departure congestion by adding the holds, which would increase the arrival separation that we discovered in case seven 'b'. This was achieved with minor alterations to the airspace files. At the same time, the events file was altered to remove the use of the steep approach procedure outside of the peak periods. Again it was hoped that this measure would help improve the departure flows.

Table 7.10 demonstrates that these aims were not achieved. Average arrival delays per movement remained unchanged, whilst average departure delays increased. Maximum hourly departure delay per movement increased by 5.8 minutes compared to case eight. The difference between the two cases for average departure delay during the peak period was also a 5 minute increase for case nine, whilst arrival delay figures remained the same. Total average delay figures per movement were 3.8 minutes greater than the base case.

Case Nine	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	6782.80	4571.40	
Average Travel Time/Mov. (mins)	25.40	16.70	
DELAY TIME			
Total Delay Time (mins)	321.00	3987.40	
Average Delay Time/Mov. (mins)	1.20	14.60	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	10-1100	
Peak Hour Movement Rate	23.00	26.00	
Peak Hour for delays	08-0900	08-0900	
Peak hour delay/movement (mins)	3.78	40.89	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			40.80
Average Peak Period Mov. Rate/hr.			38.25
Maximum Peak Period Delay per mov./hr (mins)			22.34
Average Peak Period Delay per mov./hr (mins)			17.34

TABLE 7.10

Movement rates support the delay figures. Average peak period hourly departure movement rates decreased from case eight to nine. The total departure movements achieved during the first two hours of the peak period were 38.2 compared to 40.3 for case eight and 47 for case five. This led to the spreading of departures to off peak periods when arrival flows decreased. During the peak period this case achieved 0.5 less movements than the base case.

The cost benefit table clearly indicates that there are no perceived benefits of this procedure, so costs will never be recuperated. For this reason this case represents the least desirable solution.

7.2.10: Case Ten - Use of STOL runway for Regional Aircraft arrivals

As with case seven, this was split into two separate sections. Case ten 'a' looked at the construction of a STOL runway to the south of the existing runway, which commenced parallel to link 'C' and continued to parallel link 'D'. It gave a runway as specified in case eight of 1600m. The two runways were separated by 120 metres. This was less than that specified in the ICAO regulations for independent runway operations, which required a minimum of 640 metres separation due to the 700m runway stagger. The separation was chosen, as it allowed the new runway to remain within existing airport boundaries and although theoretical, it could be argued that use of the steep approach to the STOL runway would remove wake vortex drift problems, which were the cause of the parallel separation limitations in the first place. Case ten 'b' was a repeat of ten 'a' but with regional aircraft holds. The ground SIMMOD file was modified to show the new runway layout from that entered in case eight, whilst the airspace file was altered to remove the procedure limitations affecting independent operations from the two runways.

Case Ten 'a'	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	6795.00	4569.30	
Average Travel Time/Mov. (mins)	25.40	16.70	
DELAY TIME			
Total Delay Time (mins)	241.20	1298.40	
Average Delay Time/Mov. (mins)	0.90	4.70	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	07-0800	
Peak Hour Movement Rate	22.00	25.80	
Peak Hour for delays	08-0900	07-0800	
Peak hour delay/movement (mins)	2.43	15.51	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			46.00
Average Peak Period Mov. Rate/hr.			40.30
Maximum Peak Period Delay per mov./hr (mins)			8.86
Average Peak Period Delay per mov./hr (mins)			5.52

TABLE 7.11

Tables 7.11 and 7.12 show the results of these cases.

The travel times for this case are no greater than previous cases, whilst departure and arrival delay times are slashed. Average arrival times are 2.6 minutes less than case five, the optimum up to this point, whilst departure delays are reduced by a further 1.6 minutes. Average arrival delay during the peak period is 1.7 minutes for case ten 'a' and 1.6 minutes for ten 'b'. The figures for average departure delay during the peak period are 9.4 and 9.5 minutes respectively. These figures represent a saving of 5.6 minutes for arrivals when compared to case five and 3.1 minutes for departures. When comparing the maximum combined average peak period delay per movement, a delay saving of 4.8 minutes is achieved in this case over case five.

Movement rates are also increased in this simulation. Whilst the arrival movement rates remain fairly static, the total peak period departure movements increased by 2.8 when compared to case five and 7.7 movements compared to the base case. Between cases ten 'a' and 'b', it can be seen that the latter case has a slightly reduced peak hour departure movement rate which relates to the higher departure delay figures in this case. Both cases produced a combined maximum peak hour movement rate of 46, 3.8 movements greater than in case five.

The costs benefit analysis clearly demonstrates that although movement rates and delays have improved significantly in this case, it has been achieved at substantial cost. The major costs represent the costs of constructing the new runway and taxiways although the author did keep this to a minimum, with taxiways just being added at each end of the runway, connecting to the existing links 'C' and 'D'. Total costs for both cases were calculated to be £8.3 million excluding the addition of optional extras

Case Ten 'b'	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	6797.00	4568.80	
Average Travel Time/Mov. (mins)	25.50	16.70	
DELAY TIME			
Total Delay Time (mins)	234.90	1310.20	
Average Delay Time/Mov. (mins)	0.90	4.80	
PEAK HOUR FIGURES			
Peak Hour for Movements	08-0900	08-0900	
Peak Hour Movement Rate	21.00	25.00	
Peak Hour for delays	08-0900	07-0800	
Peak hour delay/movement (mins)	2.14	15.53	
PEAK PERIOD FIGURES (0700-1100)			
Maximum Peak Period Mov. Rate/hr.			46.00
Average Peak Period Mov. Rate/hr.			40.30
Maximum Peak Period Delay per mov./hr (mins)			8.72
Average Peak Period Delay per mov./hr (mins)			5.55

TABLE 7.12

such as RNAV or DGPS. As case ten 'a' produced greater overall delay savings, its benefit were expected to be greater than ten 'b'. Total benefits were calculated as £149,446 and £149,05 respectively. Although this was by far the greatest benefit figure of any of the previous cases, due to the substantially higher costs, the pay back period, ignoring the multiplier effect was 56 days.

7.2.11: Manchester Summary

In conclusion, case 10 represents the greatest benefits for expanding airport capacity, but does so at a large start up cost. If the land were available to the airport and it was felt that regional traffic would continue to play a large part of the airport's traffic mix, this solution may well be the optimum.

If not however, and the airport was looking for quick, short term solutions, case five represents the best solution for Manchester, given the figures used in this thesis.

Figure 7.1, 7.2 and 7.3 summarise the delay savings for combined totals, arrivals and departures. It is interesting to note that in cases six, seven and eight the total time savings are due more to reductions in travel time than delays. It can also be clearly seen that each cases three, four and five had the largest effect on departure delays, if we exclude cases 10a and 10b. This pattern will be interesting to compare to Zurich with its different pattern of traffic.

7.3: Zurich Airport

7.3.1:Base Case

As with Manchester, this case was set up to be the control against which the subsequent cases would be judged, and was set below the current operational situation at Zurich. It assumed that all departures left from the 28 threshold, with all arrivals occurring on runway 14. Aircraft were allocated routes built in the airspace file, and the procedures were set up for arrivals runway 14, which required no co-ordination with runway 28 departures, and also certain departures from 28 which required co-ordination depending on aircraft type. Arrival and departure procedures were split into three types, with different blocking times and distances to reflect the controllers' use of arrival and departure time restrictions for wake vortex and aircraft speed variations. For arrivals a blocking time of 45 seconds was programmed for regional aircraft, with additional blocking distance separation of 2nm. The figures for small jets were 55 seconds and 2nm, increasing to 65 seconds and 2nm. For departures, the separations were a blocking time of 45 seconds and distance blocking of 2nm for regional aircraft following regional aircraft, increasing to 55 seconds for small jets following regionals, also with a 2nm blocking distance. For regionals following the larger jets, a time separation of 50 seconds was imposed with 2nm distance blocking.

Initial results of the simulation showed that substantial arrival airspace congestion was occurring during peak period. This related to arriving aircraft being directed into holding stacks at Schafhausen and Ekron and subsequently sequenced for arrival along the final approach path, which was a converging path from each holding stack

Comparison of Arrival Travel and Delay Time Variation from the Base Case for Manchester

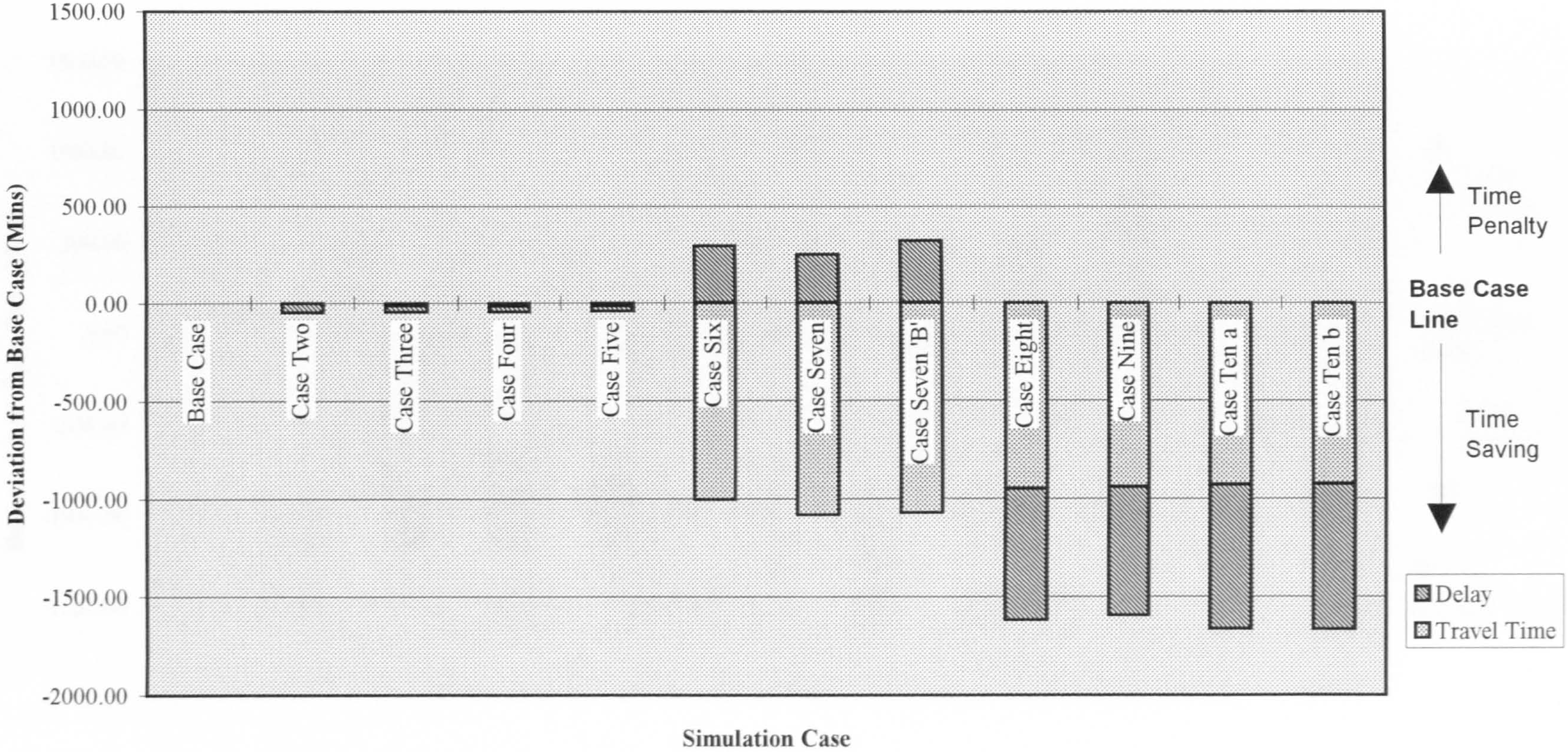

FIGURE 7.1

Comparison of Departure Travel and Delay Time Variation from the Base Case for Manchester

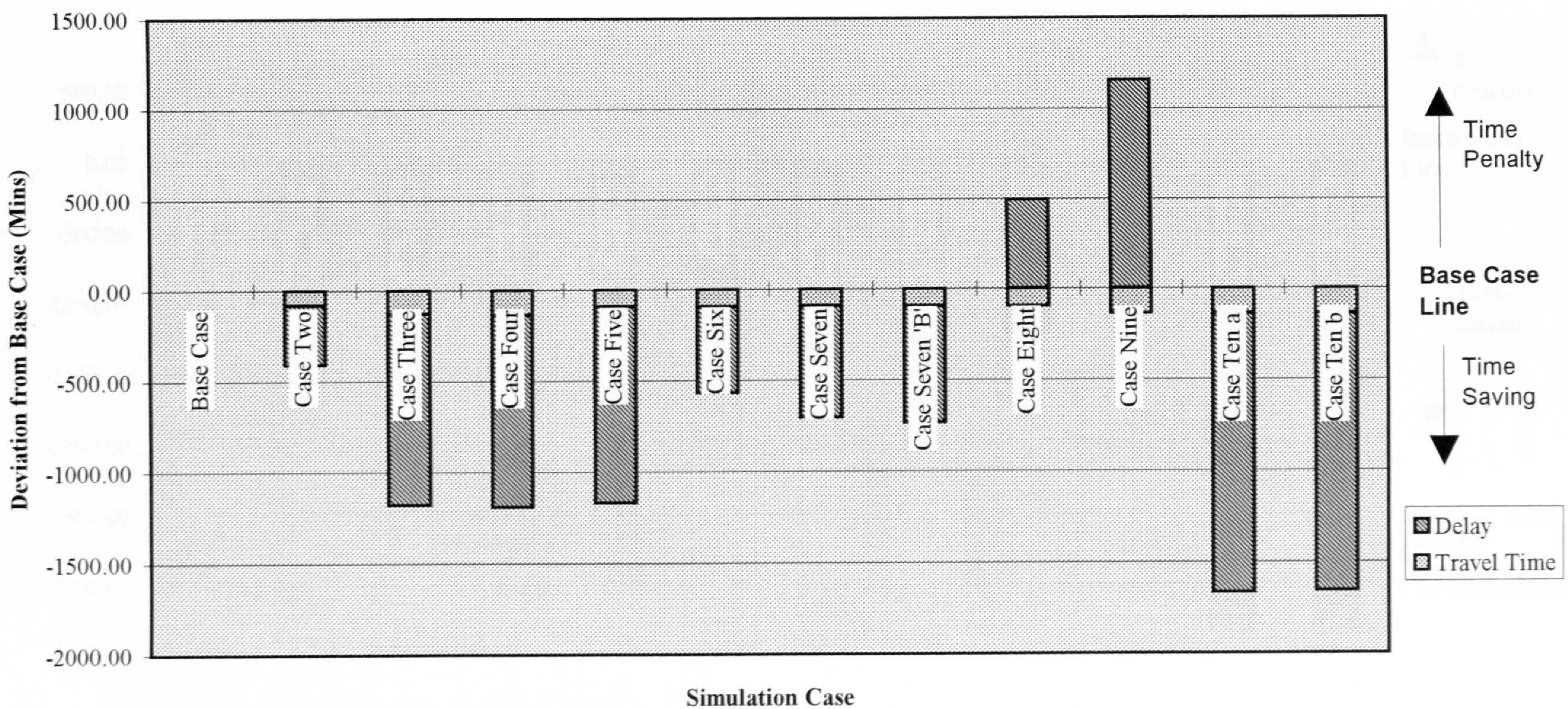

FIGURE 7.2

Comparison of Total Travel and Delay Time Variation from the Base Case for Manchester

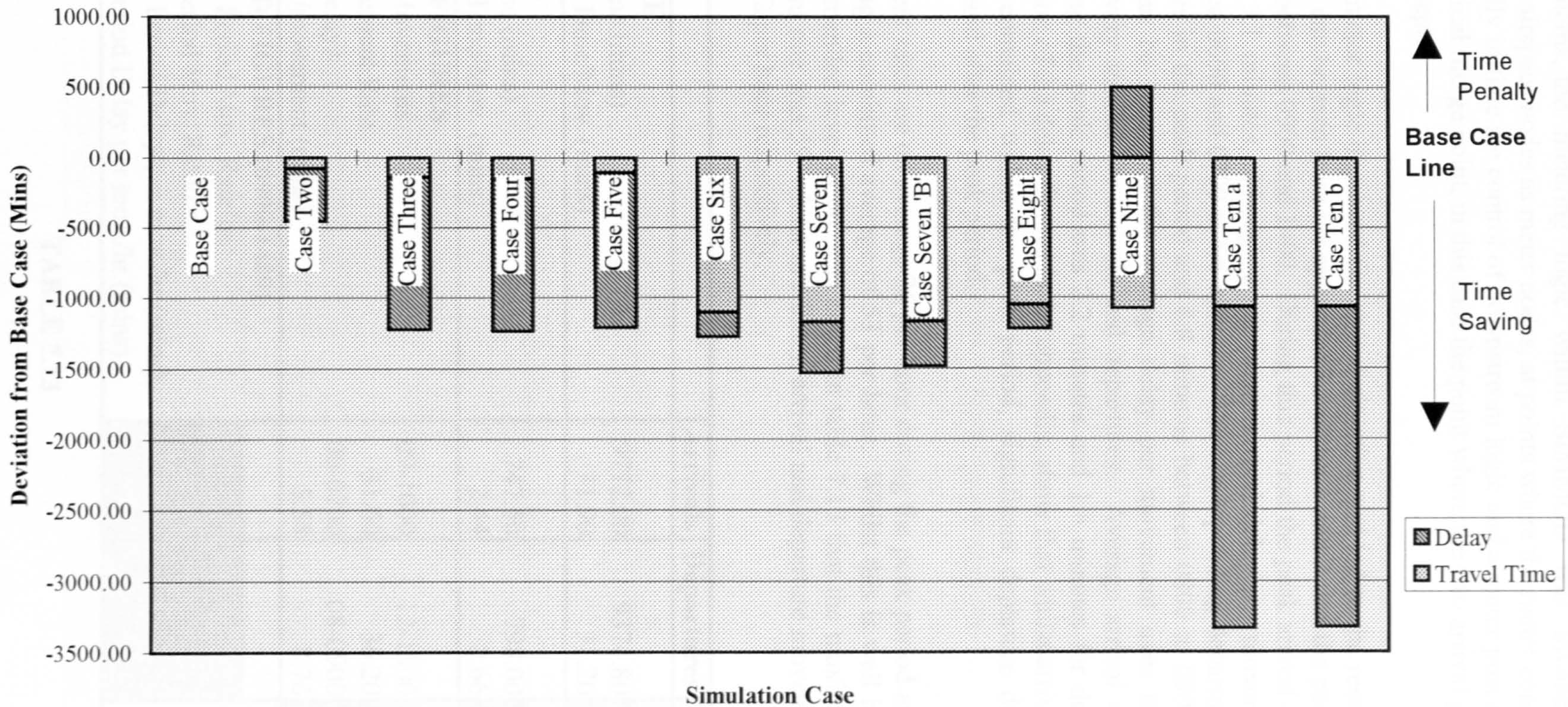

FIGURE 7.3

onto the ILS intercept. In an attempt to help the simulation overcome some of these congestion problems, the metering logic within SIMMOD was invoked. This defined certain airspace nodes as meter nodes, at points where the meter control logic could successfully initiate the control of downstream logic and a meter post node was set up at the critical merge point, in this case the point where the two arrival paths met at the ILS intercept.

The use of this meter logic improved the arrival situation and led to the results given in table 7.13. It can be seen from the appendix 7.3 tables 1 and 2 that the peak period for Zurich was between 0900 and 1400. During this period the peak arrival delay per movement was 3.1 minutes, although a maximum arrival delay per movement was achieved between 0600 and 0700 at 5.6 minutes. The corresponding departure delays were 3.1 minutes in the peak period and 8.8 minutes between 0800 to 0900. From table 7.13 it can be seen that the average delay per movement over the whole simulation are very similar for arrivals and departures. Average arrival delay per movement during the peak period was 2.2 minutes and 1.6 minutes for departures. Close examination of the delay figures in the appendix, show that whilst arrival delays are reasonably contained within the peak period, significant departure delays are incurred before and after the peak period.

Arrival movement rates are on average 26 per hour during the peak period and 27 for departures giving a combined average of 53 per hour. Whilst this is well below the APATSI recommended level of 60, it is noted in table 7.13 that the maximum peak period movement rate was 59, whilst maximum arrival and departure movement rates were 31 and 36.2 per hour respectively.

Base Case	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	9772.00	9374.80	
Average Travel Time/Mov. (mins)	31.90	31.20	
DELAY TIME			
Total Delay Time (mins)	747.50	798.00	
Average Delay Time/Mov. (mins)	2.44	2.66	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	12-1300	
Peak Hour Movement Rate	31.00	36.20	
Peak Hour for delays	06-0700	08-0900	
Peak hour delay/movement (mins)	5.58	8.76	
PEAK PERIOD FIGURES (0900-1400)			
Maximum Peak Period Mov. Rate/hr.			58.60
Average Peak Period Mov. Rate/hr.			53.20
Maximum Peak Period Delay per mov./hr (mins)			4.74
Average Peak Period Delay per mov./hr (mins)			1.92

TABLE 7.13

These figures set the standard on which the following cases aimed to improve. As with Manchester, a cost benefit analysis of the base case was not undertaken, as the focus is with variations from this case.

7.3.2: Case Two - Intersection Departures

As with Manchester, this case was developed from the base case with the introduction of two intersection departures for runway 28. One additional taxiway needed adding 300m from the 28 threshold, along with a new departure queue and associated routes. The second intersection departure was for regional props only and utilised part of the existing taxiway link 'B' taxiway, from the apron to runway 32 threshold. This taxiway placed the props 550m upwind of the 28 threshold. As before this required a departure queue adding and associated routes. The final modification required was to the procedures file. Related procedures for these new intersection departures were set up so that departures from link 'B' were blocked for 50 seconds and 2.5nm following a departure from the 28 threshold, and 50 seconds and 2.2nm for departures from the first intersection following threshold departures. Departures from link 'B' blocked threshold departures by 55 seconds and 2nm, the same as departures from the first intersection followed by threshold departures. These procedures would ensure that wake vortex and speed variation separations were observed. In addition to these procedures, a limited number of departures were allowed from runway 16 during the peak periods to help ease congestion on runway 28. As runways 28 and 16 intersected, a time blocking of 50 seconds was introduced for departures from either runway following a departure from the other runway. As the departure paths diverged once airborne, no distance blocking was used.

Case Two	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	9774.40	9264.50	
Average Travel Time/Mov. (mins)	31.90	30.90	
DELAY TIME			
Total Delay Time (mins)	736.47	709.60	
Average Delay Time/Mov. (mins)	2.40	2.36	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	12-1300	
Peak Hour Movement Rate	31.00	37.00	
Peak Hour for delays	06-0700	08-0900	
Peak hour delay/movement (mins)	5.56	7.46	
PEAK PERIOD FIGURES (0900-1400)			
Maximum Peak Period Mov. Rate/hr.			58.40
Average Peak Period Mov. Rate/hr.			53.08
Maximum Peak Period Delay per mov./hr (mins)			4.08
Average Peak Period Delay per mov./hr (mins)			1.49

TABLE 7.14

The results for this simulation are given in table 7.14, which show that average total delay times per movement for arrivals and departures have marginally improved. These improvements are unfortunately very small, being around 0.2 of a minute. The greatest delay reduction appears to be for departures, which also show a reduction in average travel time per movement. Maximum peak hour departure delays per movement have fallen by 1.3 minutes whilst remaining the same for arrivals. Average peak period delay figures support those already given.

The movement figures further support the delay figures. The peak hour movement rate for arrivals compared to the base case has remained the same, whilst the departure rate has increased by 0.8 of a movement. Departure movement rates during the peak period are marginally higher for the hours of 1000 to 1100 and 1200 to 1300 compared to the base case.

Given the above results, it can be seen that the improvements are focused on departures and relatively insignificant, especially when the SIMMOD validity issue is considered. A cost benefit analysis was undertaken, (see appendix 7.4). Costs were calculated to be £157,204, higher than Manchester due to the construction costs of the new intersection. Benefits were only £8,063 which gives a pay back period of 19.5 days.
Whilst this case appears to improve on the base case, the very marginal differences outlined may well be due to programming errors. In which case this simulation would represent no improvement.

7.3.3:Case Three - Early Turns After Take Off on runway 28

Following the poor results of case two, early turns after take off were introduced for regional aircraft departing from runway 28. As with Manchester, the introduction of this procedure in SIMMOD required the addition of new departure queues and airspace routes. The procedures file was altered to reduce the blocking distance for threshold departures following early turn traffic, from 2nm to 0.5nm. Obviously departures, following previous early turn departures along the same routing, were restricted to the same 2nm departure separation requirement.

Table 7.15 clearly shows that total average departure delays per movement have decreased by 1.5 minutes. The arrival figure remains unchanged from the base case however. The maximum peak hour departure delay is 6 minutes less than the base case. The difference between the average departure delay per movements for this case and the base case was 0.8 of a minute. This reduction hides the fact that departure delay per movement during the peak period was less on all occasions than the base case.

Movement rates for departures are also increased during the peak period in this case. The peak hour figure given in table 7.15 shows an increase of 1.8 movements over the base case. Arrival movement rates remain the same however. Outside the peak period the hourly departure rate between 0700 and 0800 increased by 2.8 movements compared to the base case. Finally by looking at the tables in appendix 7.3 it can be noted that this case has achieved more departures during the peak times, with less spreading of departures until later, as was seen in previous cases.

Case Three	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	9770.70	9201.80	
Average Travel Time/Mov. (mins)	31.90	30.70	
DELAY TIME			
Total Delay Time (mins)	743.90	338.60	
Average Delay Time/Mov. (mins)	2.43	1.13	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	12-1300	
Peak Hour Movement Rate	31.00	38.00	
Peak Hour for delays	06-0700	07-0800	
Peak hour delay/movement (mins)	5.54	2.76	
PEAK PERIOD FIGURES (0900-1400)			
Maximum Peak Period Mov. Rate/hr.			59.00
Average Peak Period Mov. Rate/hr.			53.10
Maximum Peak Period Delay per mov./hr (mins)			3.04
Average Peak Period Delay per mov./hr (mins)			1.48

TABLE 7.15

Not surprisingly the cost benefit analysis reflects this improved system efficiency. Whilst total costs increase £1,340 from case two to allow for increased ATC controller workload, to £158,544, the benefits increase by £29,436 to £37,499. This gives a pay back period of just over 4 days.

The results of this case clearly show an improvement over the base case unlike case two, and as such represents the optimum solution for Zurich so far.

7.3.4: Case Four - Case 3 with Steep Approach runway 28

The aim of this case was to simulate the STOL arrival procedure at Zurich discussed in chapters five and six. In addition to this scenario new RET's were added to runway 28 before the 28/16 intersection, to help reduce the arrival runway occupancy time.

The results given in table 7.16 make interesting reading. Average arrival travel times increased by 0.5 minutes per movement, which relates to the longer routing for arrivals using runway 28. Unfortunately arrival delay per movement also shows an increase of 1 minute compared to the base case. Departure delay per movement has also increased compared to case 3 by 0.5 minutes. Peak hour delays for arrival are greater than the base case by 2.3 minutes, whilst departure figures show a slight improvement over case three. Maximum combined peak period delays were 1.6 minutes greater than case three. During the peak period hourly movement delays for arrivals were greater than the base case for the whole period, with departure figures being greater than case three for the whole period.

Case Four	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	9908.50	9199.10	
Average Travel Time/Mov. (mins)	32.40	30.70	
DELAY TIME			
Total Delay Time (mins)	1047.30	504.50	
Average Delay Time/Mov. (mins)	3.40	1.68	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	12-1300	
Peak Hour Movement Rate	30.00	37.20	
Peak Hour for delays	11-1200	12-1300	
Peak hour delay/movement (mins)	7.87	2.49	
PEAK PERIOD FIGURES (0900-1400)			
Maximum Peak Period Mov. Rate/hr.			59.20
Average Peak Period Mov. Rate/hr.			52.80
Maximum Peak Period Delay per mov./hr (mins)			4.62
Average Peak Period Delay per mov./hr (mins)			2.67

TABLE 7.16

Hourly arrival movement rates were less than the base case for the first three hours of the peak period and greater for the last two, as the simulation attempted to compensate for the earlier lower movement rates. A similar situation is found for the departure movement rates. The maximum peak period combined movement rate shows a slight improvement over case three, but a lower average rate over the whole peak period.

Due to the fact that this case resulted in increased delays from the base case, the author felt that there was no point in conducting a cost benefit analysis, as the costs would have been even greater than case three due to the need to add steep approach modifications to the regional aircraft. What is very interesting to note from this case is that the aim of reducing arrival delays was not achieved in spite of introducing this new procedure and RET's. In addition departure delays were increased, which can be explained by the need to increase departure separation to permit arrivals. This problem was also noted with Manchester. Unfortunately due to the inflexibility of the SIMMOD take off run and landing roll variation, the blocking time that is applied to movements may be excessive, but is required to account for the time a movement uses excessive landing roll or take off run time. This may well account for the lack of apparent movement rate increase, even following the addition of the RET's.

7.3.5: Case Five - New Runway Operation Pattern

This case was an attempt to assess if a new runway operation pattern would improve operating delays. The new operation envisaged all jet arrivals on runway 14, as previous, but this time with all departures off runway 16 and regional aircraft arrivals on runway 28. This case was to represent the new base case with use of intersection departures on runway 16 from link 'F' for regional aircraft, which would then carry out an early turn. In setting up the SIMMOD files, alteration was required to the procedures file. The new operation allowed independent arrivals for 14 and 28 to continue, as in case four, but now also allowed independent departures from runway 16. Blocking times and distances for intersection departures following threshold departures on 16, were 50 seconds and 2nm for smaller jest and 55 seconds and 2.5nm for larger jets respectively. Threshold departures were blocked by 55 seconds and 0.5nm following intersection departures carrying out the early turn. In addition to these changes, a new departure queue was added at the 16 intersection and new departure routes off 16 added for jets and early turn traffic.

From table 7.17 it can be seen that this case has reduced average arrival travel time by 3 minutes compared to case four, and 2.5 minutes from the base case. Departure travel time has unfortunately increased by 3.3 minutes on average from the base case, due to the longer taxi distance now involved. Total delay times per movement are no better for arrivals, whilst departures have increased from case four and are now 0.8 minutes greater than the base case. The peak hour departure delay per movement is now 14.4 minutes, a massive 5.6 minutes greater than the base case. This in turn relates to greater combined peak period delays, on average 2.6 minutes greater than the base case, all related to increased departure delays.

Departure movement rates also failed to meet the base case standard. The peak hour departure rate was 4 movements below the base case and 5.8 movements below case 3. Arrival peak hour rate was also one movement below the base case. During the peak period 2 less arrivals and 4 less departures were achieved compared to the base case. The consequence of this lower movement rate was increased movement spread into the off peak periods.

Case Five	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	9007.40	10361.30	
Average Travel Time/Mov. (mins)	29.40	34.50	
DELAY TIME			
Total Delay Time (mins)	1029.50	1062.90	
Average Delay Time/Mov. (mins)	3.40	3.50	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	13-1400	
Peak Hour Movement Rate	30.00	32.20	
Peak Hour for delays	11-1200	13-1400	
Peak hour delay/movement (mins)	7.80	14.41	
PEAK PERIOD FIGURES (0900-1400)			
Maximum Peak Period Mov. Rate/hr.			59.00
Average Peak Period Mov. Rate/hr.			52.00
Maximum Peak Period Delay per mov./hr (mins)			7.74
Average Peak Period Delay per mov./hr (mins)			4.45

TABLE 7.17

As with case four, due to the lack of delay savings over the base case there was no point conducting the cost benefit analysis. It is clear that in all cases, except the arrival travel time, this case represents the worst so far. The reduction of intersection departures from three to two and the condensing of all departures to the same runway may account for this increased departure delay, but the rest must be due to the SIMMOD operation restrictions.

7.3.6: Case Six - Case Five with Regional Departures on runway 28

As a follow up to case five, the author decided to see what would happen if regional aircraft departures were now permitted on runway 28 along with regional arrivals. Departures were scheduled to go from the 28 threshold to minimise their effect on the arrivals and used the existing procedures, including the early turn, from case four to prevent conflict with existing runway 16 departures.

Table 7.18 shows that compared to case five, the average arrival travel times have increased by 3 minutes whilst departure figures have decreased by 1.4 minutes. Average arrival delay times remain the same as case five, but departure delays have decreased by 1.8 minutes. If these travel time and delay variations are added up the result is no gain at all. Peak hour figures do show a distinct improvement in average delay per departure of 8.8 minutes over case five, 3.2 minutes better than the base case. Arrival delay for the peak hour increased from the base case by 2.4 minutes. All these results are supported by the peak period delay figures, which show a reduction from case five but still above the base case.

Case Six	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	9907.60	9995.20	
Average Travel Time/Mov. (mins)	32.40	33.10	
DELAY TIME			
Total Delay Time (mins)	1050.50	510.10	
Average Delay Time/Mov. (mins)	3.43	1.70	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	12-1300	
Peak Hour Movement Rate	30.00	33.20	
Peak Hour for delays	11-1200	13-1400	
Peak hour delay/movement (mins)	8.02	5.62	
PEAK PERIOD FIGURES (0900-1400)			
Maximum Peak Period Mov. Rate/hr.			58.20
Average Peak Period Mov. Rate/hr.			52.40
Maximum Peak Period Delay per mov./hr (mins)			4.62
Average Peak Period Delay per mov./hr (mins)			3.13

TABLE 7.18

Movement rates show that arrivals are unaffected during the peak hour whilst departures increased by one movement compared to case five, but still were three movements short of the base case. During the peak period the combined movement totals for this case were 3.8 short of the base case.

Case six then, whilst improving on case five departure movements, still under performs in all other areas and therefore provides no tangible financial benefits compared to the base case.

7.3.7:Zurich Summary

As with Manchester, the combined results for each case discussed above are given in figures 7.4, 7.5 and 7.6 for total, arrival and departure delay variation from the base case. Looking at figure 7.4, it can be clearly seen that case three represents the optimum solution in terms of delay time reduction. Figure 7.5 indicates that all the cases did not significantly improve arrival delays, with the last three making the situation worse. Figure 7.6 on the other hand does show that departure delays fluctuated depending on the case quite substantially. Case five is clearly the worst case, as both travel time and delay times increased, whilst the improvement of case six on this is clearly evident.

If we compare figures 7.4 and 7.1, we can see that the magnitude of the base case variations between Manchester and Zurich are quite different. The maximum time improvement for Zurich is case three at approximately 600 minutes. The best Manchester scenario however achieves improvements of approximately 3300 minutes. From this, it can be seen that use of regional aircraft special procedures at Manchester gives greater time benefits than at Zurich. It does not mean that Zurich cannot achieve the larger time savings, just that the results of the case studies in this thesis would not permit this.

7.4: Gatwick Airport

As mentioned in chapter six, SIMMOD work was also carried out for London Gatwick, but to a lesser extent than the previous airports studied. Results from this work will be presented very briefly as a comparison to the first Manchester cases. As demonstrated in chapter four, Gatwick represents the busiest single runway, multi mode operation in Europe. This simulation began with the setting up of the current Gatwick airfield and airspace layout, taking information from the British Airways AERAD charts. Once this was constructed the events data was added, using the same source as Manchester.

Three cases were completed for Gatwick. The base case assumed the same as previous ones, with departures all commencing from the beginning of the starter strip for runway 26L, with no arrival or departure traffic sequencing. Case two introduced intersection departures for regional traffic from holds 'B' and 'C', 300m and 700m respectively from the beginning of the starter strip, with changes to the procedures file to maintain separation requirements. Case three was split into three sub sections looking at the effect of introducing early turns after take off for regional aircraft. Case three 'a' introduced an early right turn for all Gatwick departures with southbound departures turning back later on, climbing above the standard jet departure routes.

Comparison of Total Travel and Delay Time Variation from Base Case for Zurich

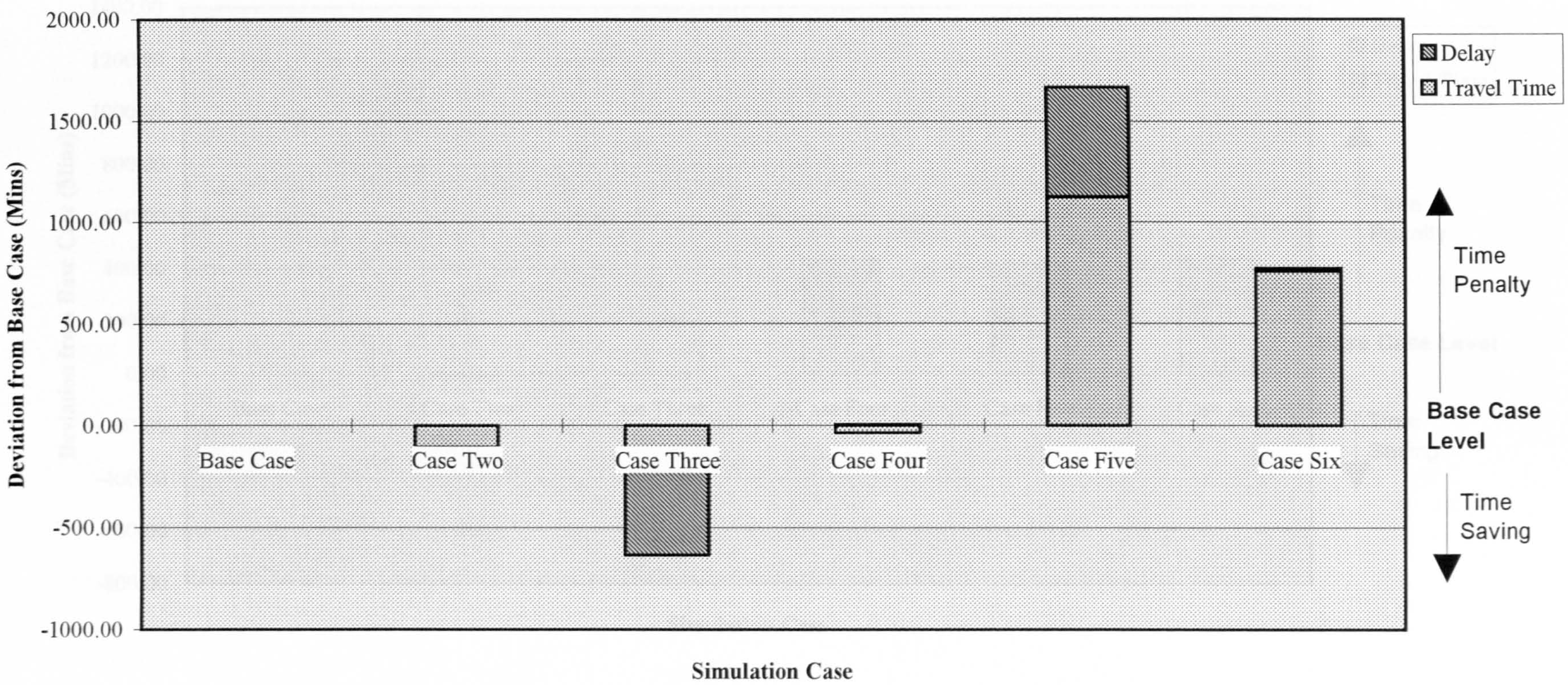

FIGURE 7.4

Comparison of Arrival Travel and Delay Time Variation from the Base Case for Zurich

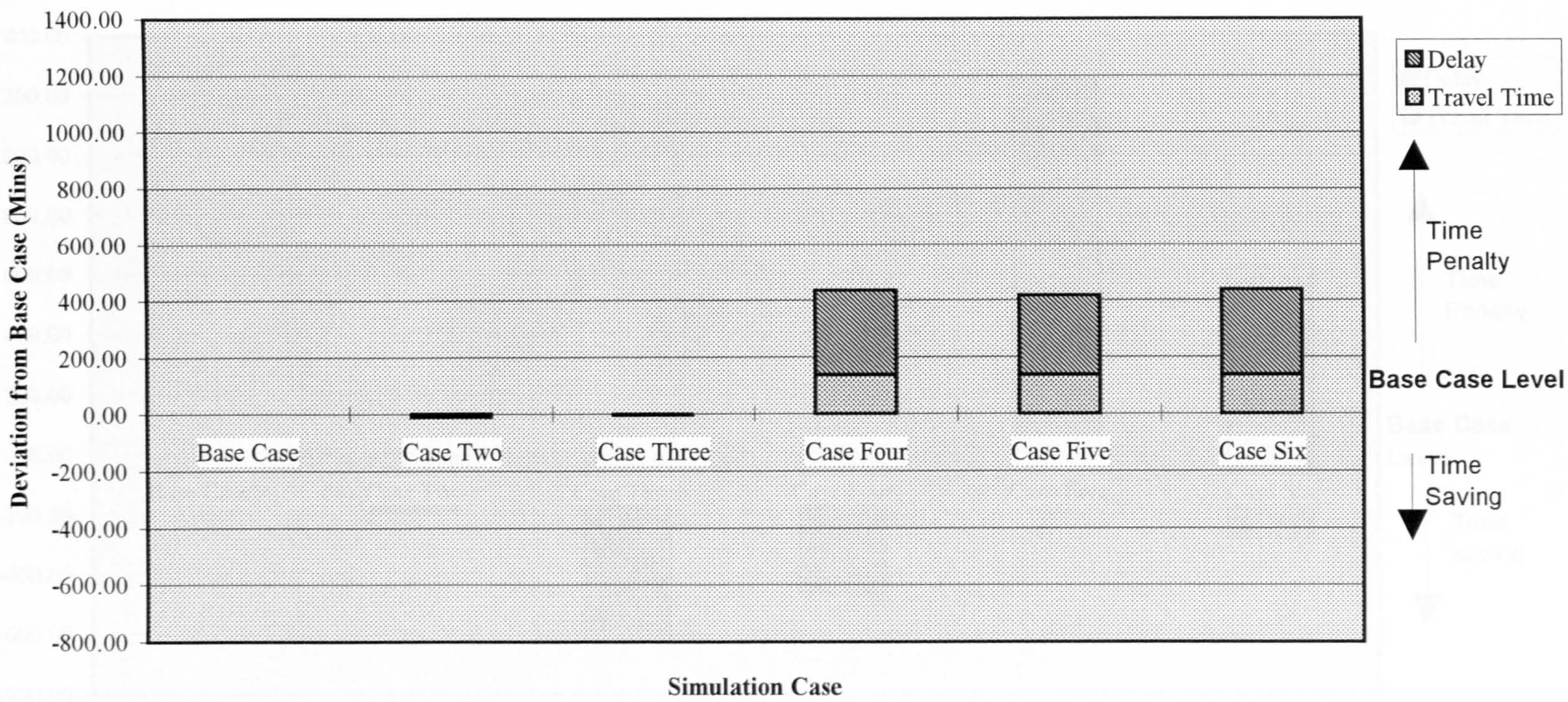

FIGURE 7.5

Comparison of Departure Travel and Delay Time Variation from the Base Case for Zurich

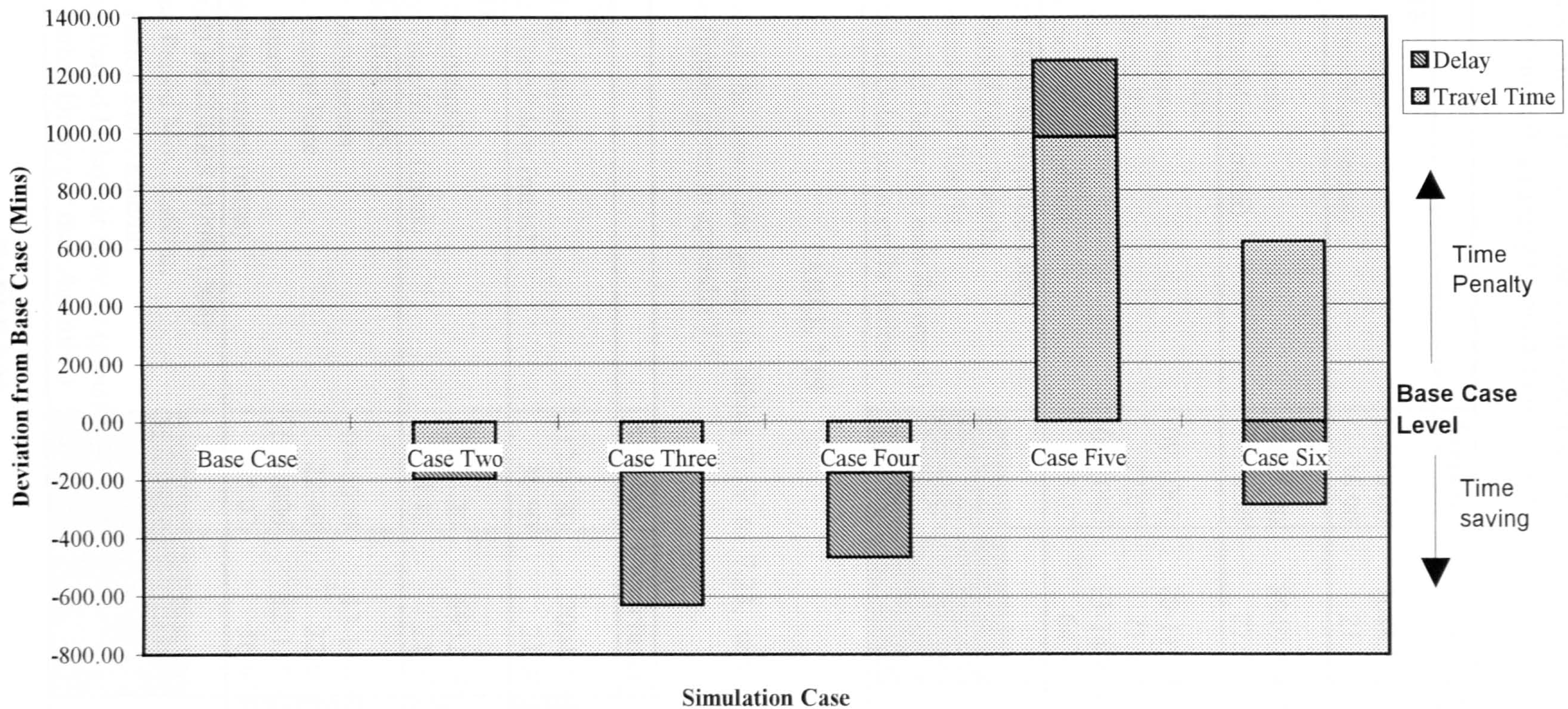

FIGURE 7.6

The case only allowed regional turboprops to carry out the early turn. Case three 'b' allowed regional jets to carry out the early turn and case three 'c' permitted early left turns for all regional aircraft departing Gatwick to the south.

Base Case	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	11250.00	7088.50	
Average Travel Time/Mov. (mins)	36.90	21.80	
DELAY TIME			
Total Delay Time (mins)	2611.00	8949.60	
Average Delay Time/Mov. (mins)	8.56	27.54	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	10-1100	
Peak Hour Movement Rate	22.67	21.17	
Peak Hour for delays	09-1000	13-1400	
Peak hour delay/movement (mins)	35.02	64.75	
PEAK PERIOD FIGURES (0700-1300)			
Maximum Peak Period Mov. Rate/hr.			43.00
Average Peak Period Mov. Rate/hr.			39.30
Maximum Peak Period Delay per mov./hr (mins)			34.35
Average Peak Period Delay per mov./hr (mins)			21.13

TABLE 7.19

Results for each of the cases are given in tables 7.19 to 7.23, with a detailed breakdown of the figures given in appendix 7.5

Case Two	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	11249.80	7094.70	
Average Travel Time/Mov. (mins)	36.90	21.80	
DELAY TIME			
Total Delay Time (mins)	2568.20	6932.70	
Average Delay Time/Mov. (mins)	8.42	21.33	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	13-1400	
Peak Hour Movement Rate	22.40	22.60	
Peak Hour for delays	09-1000	12-1300	
Peak hour delay/movement (mins)	35.07	56.60	
PEAK PERIOD FIGURES (0700-1300)			
Maximum Peak Period Mov. Rate/hr.			43.40
Average Peak Period Mov. Rate/hr.			39.80
Maximum Peak Period Delay per mov./hr (mins)			32.82
Average Peak Period Delay per mov./hr (mins)			20.35

TABLE 7.20

Comparison of the base case and case two show that whilst arrival delays remain fairly static, average departure delay per movement has decreased by 6.2 minutes, with a reduction in peak hour departure delay per movement of 8.2 minutes. These delay savings come between 1000 and 1200, at the peak departure times.

Movement rates also reflect this story with little change to arrival rates, departure movement rates during the peak hour have increased by 1.4. During the peak period a total of 2.8 extra departure movements are achieved.

The cost benefit analysis figures for Gatwick in appendix 7.6 clearly show that this case caused an increase in costs compared to the base case of £52,204. Benefits gained however are just over three times the cost at £161,798. Compared to Manchester, the total delay figures for arrivals and departures are greater, but the increase in movement rates during the peak period are also greater, with greater total time savings from the base case, which consequently relates to the greater benefits. This is the first case where benefits have been greater than costs and relates to a pay back period of just under a third of a day!

Case Three 'a'	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	11251.00	7075.10	
Average Travel Time/Mov. (mins)	36.90	21.80	
DELAY TIME			
Total Delay Time (mins)	2546.60	6364.80	
Average Delay Time/Mov. (mins)	8.35	19.58	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	13-1400	
Peak Hour Movement Rate	22.40	22.80	
Peak Hour for delays	09-1000	12-1300	
Peak hour delay/movement (mins)	34.81	55.60	
PEAK PERIOD FIGURES (0700-1300)			
Maximum Peak Period Mov. Rate/hr.			43.20
Average Peak Period Mov. Rate/hr.			39.90
Maximum Peak Period Delay per mov./hr (mins)			32.58
Average Peak Period Delay per mov./hr (mins)			19.99

TABLE 7.21

The results presented for case three indicate further improvements from the base case. Within the three sub sections to this case, it can be seen from the tables that little variation occurs between each, with no overall improvement in peak period delay or movement rates. Combined to the base case however, this case has further improved delay per movement for arrivals and departures on average, although the peak hour figures remain the same as case two. Total movements achieved during the peak period are also an improvement on case two, although only by 0.5 of a movement. Again this raises the concern of data validity from SIMMOD. The combined total delay and travel time variations for the Gatwick cases are presented in figure 7.7.

Comparison of Total Travel and Delay Time Variations from Base Case for London Gatwick

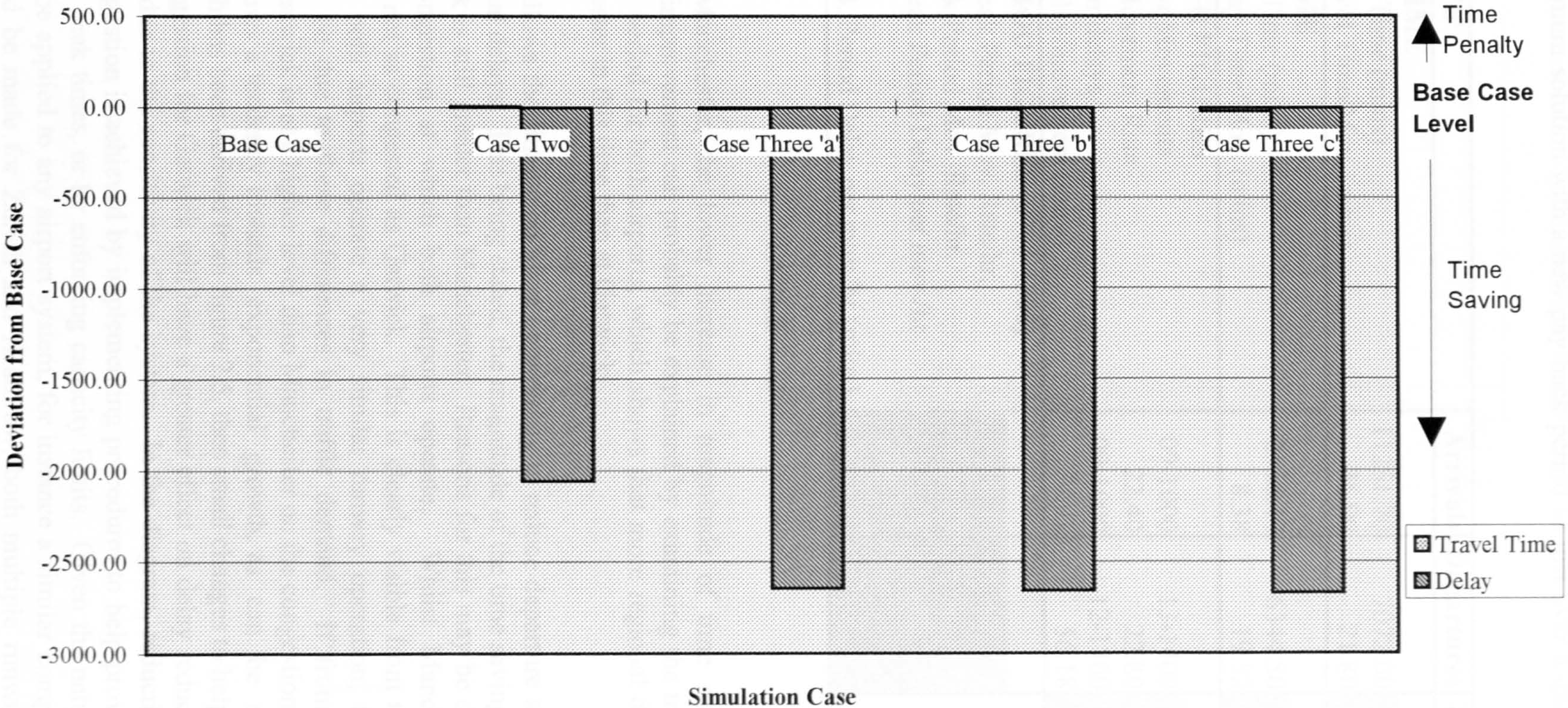

FIGURE 7.7

This supports the preceding findings. The cost benefit figures also show this case to present the optimum solution with a new pay back period of just over a quarter of a day.

Case Three 'b'	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	11251.70	7072.00	
Average Travel Time/Mov. (mins)	36.90	21.80	
DELAY TIME			
Total Delay Time (mins)	2556.40	6344.50	
Average Delay Time/Mov. (mins)	8.38	19.52	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	13-1400	
Peak Hour Movement Rate	22.40	22.80	
Peak Hour for delays	09-1000	12-1300	
Peak hour delay/movement (mins)	34.91	56.18	
PEAK PERIOD FIGURES (0700-1300)			
Maximum Peak Period Mov. Rate/hr.			43.80
Average Peak Period Mov. Rate/hr.			39.90
Maximum Peak Period Delay per mov./hr (mins)			32.94
Average Peak Period Delay per mov./hr (mins)			19.98

TABLE 7.22

Compared to Manchester, the lower increase in magnitude of time saving and movement rate improvement can probably be explained by examining the traffic mix during the peak period for both airports, which shows that more regional departures occur at Manchester in this time than at Gatwick.

This therefore allows the simulation more opportunity to reduce departure separation and consequential delays. This being stated, the magnitude of the time saving for case three at Gatwick is still greater than Manchester. Reasons for this may be due to the intensity of congestion at which both airports operate. Whilst Manchester is congested, it is not as congested as Gatwick. This is clearly visible from the traffic schedules. As both airports operate a very similar runway operation, the delay variations must be due to these differences in traffic demand. If from this we speculate that Gatwick is at a higher level than Manchester on the congestion line, and that the line shows a tendency towards exponential growth, as can be see from figure 7.8, which has been derived from figure 2.5, then small changes to help ease the intensity of congestion for Gatwick will have a greater effect on delay reduction than at Manchester, due to the sensitivity of the system. In the diagram, reduction in the intensity of congestion is achieved by implementing procedures to help provide more capacity during peak times, or by enforcing capacity limits. Given the nature of the diagram it can be applied to any airport system, for instance a similar comparison to that given could be made for Zurich and Heathrow, both multiple runway, single mode operations, but Zurich at the lower end of the congestion scale to Heathrow. Further implications of this diagram will be returned to in the next chapter.

Case Three 'c'	Arrivals	Departures	Totals
TRAVEL TIME			
Total Travel Time (mins)	11251.00	7064.60	
Average Travel Time/Mov. (mins)	36.90	21.70	
DELAY TIME			
Total Delay Time (mins)	2555.90	6330.00	
Average Delay Time/Mov. (mins)	8.38	19.48	
PEAK HOUR FIGURES			
Peak Hour for Movements	09-1000	13-1400	
Peak Hour Movement Rate	22.40	23.20	
Peak Hour for delays	09-1000	12-1300	
Peak hour delay/movement (mins)	34.91	56.18	
PEAK PERIOD FIGURES (0700-1300)			
Maximum Peak Period Mov. Rate/hr.			43.80
Average Peak Period Mov. Rate/hr.			39.90
Maximum Peak Period Delay per mov./hr (mins)			32.94
Average Peak Period Delay per mov./hr (mins)			19.98

TABLE 7.23

Impact of Changes in Airport Congestion to Changes in Total Delays

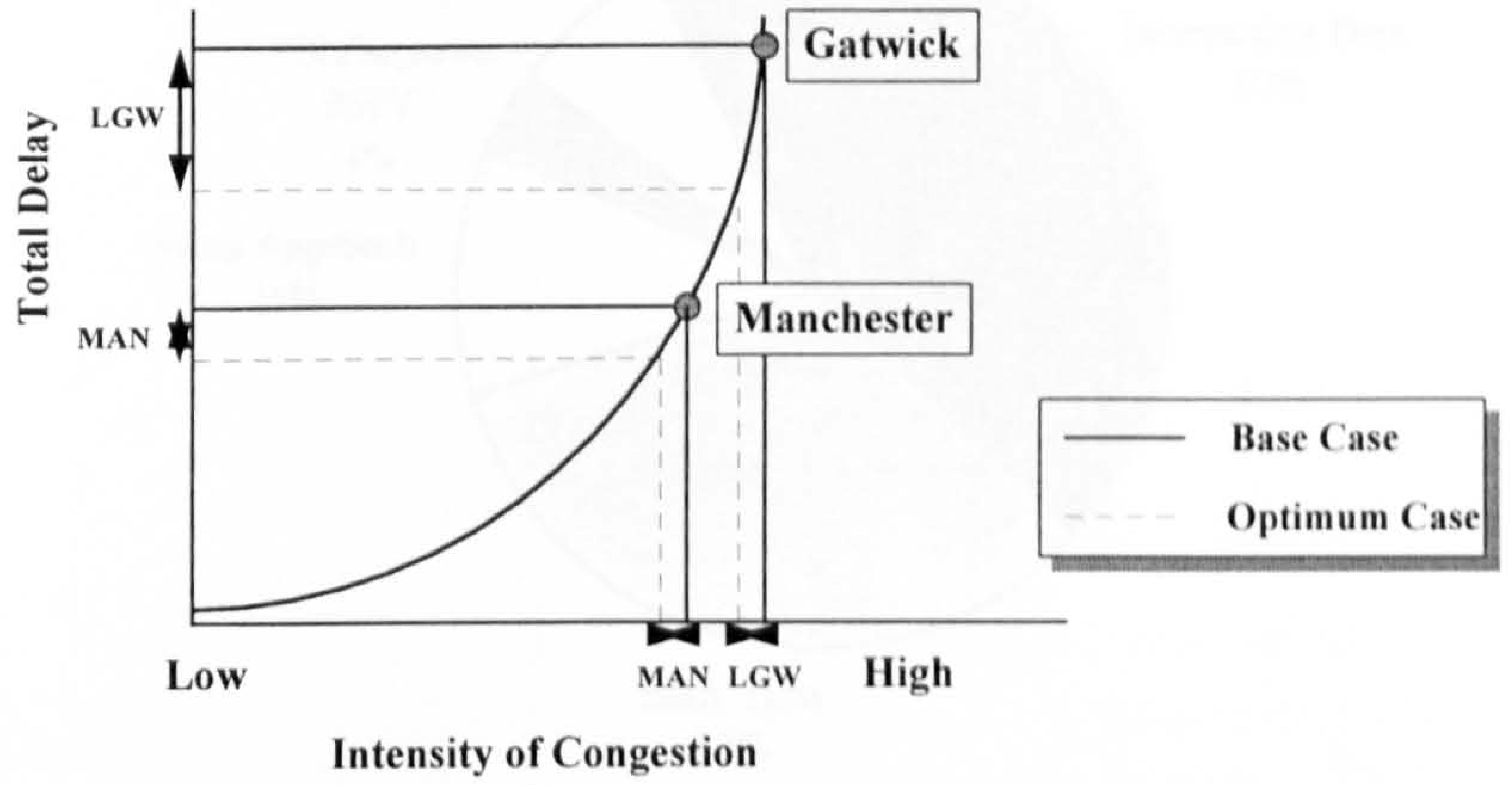

FIGURE 7.8

This concludes the presentation of the SIMMOD and cost benefit analysis results for the airports in question. The final section of this chapter will present the findings of the questionnaires.

7.5: Questionnaire Results

7.5.1: Regional Airlines Questionnaire

The results of this questionnaire are contained in appendix 7.7. The results will be presented in two sections.

The first section will analyse the tables listed in the appendix. Of the 21 airports listed as causing operational delays, 14 have been highlighted by the regional airlines as ones which they feel could make use of special procedures. Of particular note are Amsterdam, Gatwick, Heathrow, Manchester, Milan Linate, Rome Fiumincino and Zurich, which also were outlined as having both inbound and departure delay problems. The three UK airports and Amsterdam also, reinforce the issue by being mentioned by more than one airline in their responses.

Figure 7.9 shows the current percentage use of special procedures by the respondents. Intersection departures and early turns are clearly the favourites, commanding over two thirds of the total usage. Three of the airlines currently use steep approach procedures, whilst use of STOL runways and separate arrival and departure tracks are of limited use. In addition to this it was noted that none of the procedures had been certified.

Percentage Breakdown of Special Procedures Currently in Use

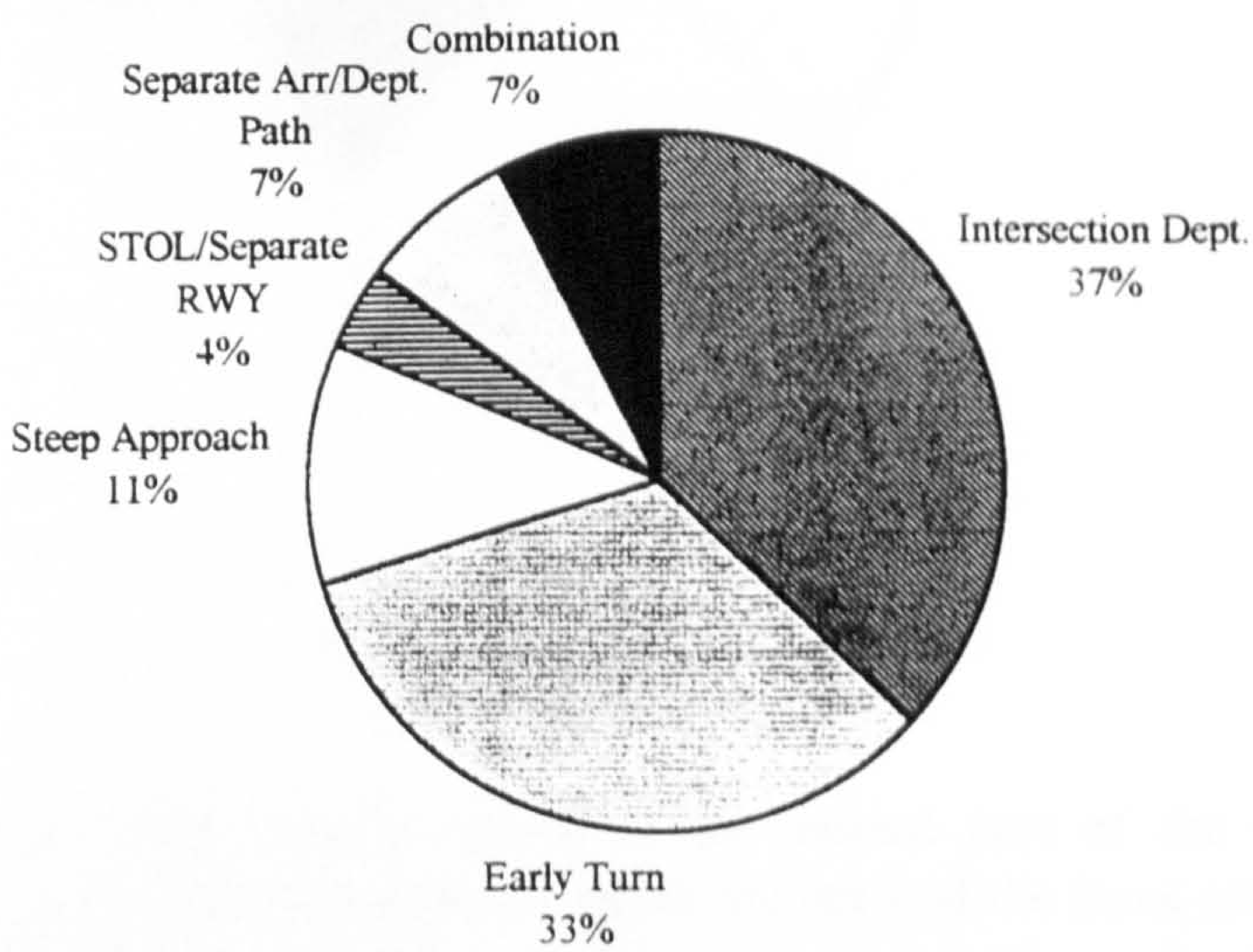

FIGURE 7.9

When the airlines were asked to give their opinion on the ability of the procedures described to help solve airport congestion, they seemed uncertain as to whether the procedures represented a short term or long term improvement, although a slight majority for short term did prevail.

Finally, figure 7.10 gives the percentage breakdown of which obstacles the airlines felt existed to special procedures. Responses were fairly well spread, although airport and/or government restrictions, and ATC restrictions, were the largest. It is interesting to note that the problem of poor communication between affected parties, rates nearly as high as problems with local pressure groups. This confirms results discovered by the author whilst working with Business Air and the arrival trial into Manchester airport. At the other end of the scale, the respondents did not really feel that they were being blocked in terms of their entry and exit to congested airports by the major airlines.

Percentage Breakdown of Factors Restricting Use of Special Procedures

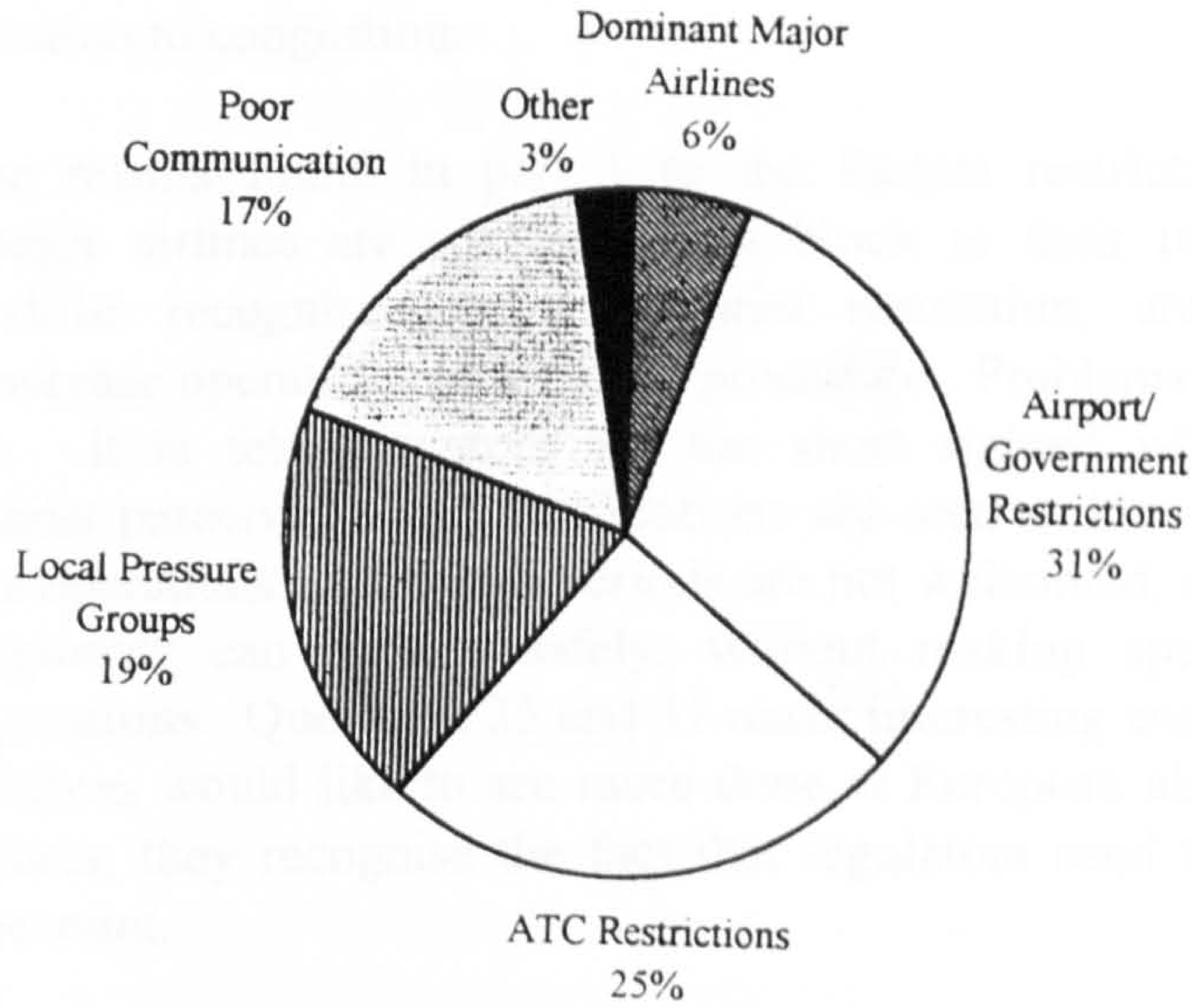

FIGURE 7.10

The second section of the results relates to the second part of the questionnaire. Appendix 7.8 shows the questionnaire on which are marked the most common answer in each case, along with a breakdown of responses per question. To make sense of these results, the questions have been grouped to cover certain issues. ATC issues are covered by questions 1, 18, 19, 30 and 33. For question 1 the feeling was that ATC workload would not increase with the introduction of special procedures. This leads onto question 18, where they also feel sufficient spare airspace exists to introduce the procedures. They were uncertain whether or not these routes should be self-sufficient from ATC or not, which fits with the response given to question 30, where they would like to see co-ordination of the procedures between themselves, the airport and ATC.

With all this being said, they did feel that ATC controllers were not given the flexibility to use special procedures. The overall conclusion to make from this is that ATC operating restrictions are not thought to be a problem and it is felt that sufficient slack exists in the system at present to absorb regional aircraft special procedures, if required.

The need to maintain access to congested airports was covered by questions 4, 11, 17, 23, 26, 29, and 38. From the responses given to these questions came a strong feeling that regionals should maintain access to the congested airports, and strongly resist the attempt to move them to reliever airports.

General perceptions of special procedures were covered with questions 2, 6, 16, 20, 22 and 27. From the responses, it can be concluded that they do not expect the regional aircraft size to grow and remove the potential of special procedures. They indicate that not enough use of the regional aircraft performance capabilities are made, which is related to lack of knowledge. The issue is seen as a runway capacity problem, but not limited to airports with more than one runway. Finally the procedures are seen as a long term solution to congestion.

Comparing the results found in part 1 to the factors restricting the use of the procedures, major airlines are not seen as a block to their use. Environmental restrictions, whilst recognised as a potential restriction, are not expected to significantly increase operating costs for the procedure. Problems with regulations do arise however. It is felt regulators are too short sighted when it comes these procedures, whilst perceived safety implications are seen as low. Attempts to move regional airline operations to off peak periods are not welcomed, as it is felt larger jet traffic and regionals can operate safely, without making special allowances in commercial operations. Questions 35 and 37 make interesting comparisons as, whilst the regional airlines would like to see more done at European airports to implement special procedures, they recognise the fact that regulators need to take every users' interests into account.

Finally this section asked for opinions on landing charges, accuracy of navigation and costs associated with the use of the procedures. There was a strong response indicating that landing charges were unfair to regionals. A feeling also comes across that they felt that introduction of GPS and RNAV would be a major part of the new procedures. The costs to introduce the procedures however, were not expected to be a limiting factor.

Discussion on the implications of these results will be made in the next chapter.

7.5.2: European Airport Questionnaire

50% of mailed questionnaires were received with a total of 13, (appendix 7.9). The varied types of airports that responded is reflected in the answers given. The variation in figures given for the percentage of regional traffic in the total traffic mix was high, from 4% to 50%. As it was the purpose of this questionnaire to target airports with a high percentage of regional aircraft movements, the author was partially successful.

The type of regional traffic the airports received though showed a split between point to point and hub feed. Airports which did receive the regional hub traffic were Copenhagen, Stockholm Arlanda, Heathrow, Amsterdam and Frankfurt. Airport charges were all very similar. All the airports used aircraft weight related charges for landing, but did not for passengers. Parking charges were also predominantly aircraft weight related. This would indicate that differences in regional aircraft weights compared to larger jets was accounted for, although how the exact fees vary during peak operation periods was not discussed. This shall be returned to in the next chapter.

The second aim of the questionnaire to target congested European airports was successful with 8 out of 13 showing they were congested. 7 of the 13 airports detailed runway and taxiway enhancements, but only Manchester and Stockholm planned to build new runways. Most of the airports expected regional traffic to increase in the future, but three did expect it to decrease.

Of the airports using special procedures, the majority were early turns after take off. Nearly all felt these procedures helped improve capacity, although Zurich indicated that use of the STOL arrival procedure on runway 28 increased departure delays. The largest concern over the use of these procedures was environmental and political. Comments attached to this expressed concern over the future environmental problems with the conflict being well expressed by Manchester's statement which highlights the concern over possible environmental restrictions hindering large scale future use of regional aircraft special procedures.

Of those airports not using special procedures, the primary reasons were no demand and environmental. From this group only two felt there was a need to develop special procedures.

Finally and in apparent contradiction to the regional airlines, the airports felt these special procedures represented a short term solution. However Frankfurt does openly support the procedures as long term. The other comments attached to this response do make interesting reading, especially those which point to the removal of regional traffic to reliever airports. It seems in conclusion that the use of special procedures will be determined by the airline demand and their relative importance at the airport in question.

7.5.3:Major European Airline Questionnaire

Although this questionnaire was targeted, the response rate was still low, (appendix 7.10). The aim of discovering the importance the major airlines placed on the regional hub feed can however be speculated from the responses.

Six out of the seven respondents had a franchise agreement with regional airlines, with the majority of these rating the importance of their agreement highly. Problems with German airports were highlighted, along with Oslo Fornebu, Copenhagen and Stockholm Arlanda. The airlines appeared uncertain over the question of future changes in regional aircraft size, although they felt it unlikely that regionals would be moved to reliever airports. Their expectation was that improved technology would enable regional aircraft to remain at the primary airport. Finally a few comments were made which have been added at the end. These appear to be fairly abstract with some airlines expecting high speed trains to replace some regional traffic, whilst others expect technological advances to remove some of the current congestion problems. Increasing aircraft size is also anticipated which may render the regional aircraft special procedures antique.

7.6: Summary

This chapter has made some interesting discoveries by the looking at the results produced. Interesting comparisons between the SIMMOD results for Manchester, Zurich and Gatwick were made, with brief speculations as to the cause of these variations.

The questionnaires, whilst all having a fairly low response rate, have nevertheless brought to light some interesting points, and helped the author to appreciate the intricacies of applying special procedures from other points of view. They have also given the author a feel for the perceived importance of regional aircraft special

CHAPTER 8 : Research Recommendations.

8.1: Introduction

This chapter will discuss the extent to which the regional aircraft special procedures, outlined in chapter five, are applicable for implementation in Europe. The arguments put forward will, whilst taking into account the results evaluated in the previous chapter, take a wider view when considering potential application. This will be based on the experience gained by the author during the practical projects undertaken at Manchester and Gatwick airports. This is to take account of factors the specific research could not cover.

8.2: Intersection Departures

The SIMMOD results presented in chapter seven for Manchester, Zurich and Gatwick airports, all showed that the introduction of this procedure reduced operating times and especially departure delays. Table 8.1 below provides a summary of the SIMMOD results. The figures given reflect changes from each airport's base case and use the best simulation results for the particular special procedure.

Time and Movement Changes due to introduction of Intersection Departures

Airport	Travel Time Saving (mins)	Delay Time Saving (mins)	Total Time Saving (mins)	Chg. in Peak Hour Dept. Rate from Base Case
Manchester	80.6	379.7	460.3	+ 0.7
Zurich	107.9	99.4	207.3	+ 0.8
Gatwick	-6.0	2059.7	2053.7	+ 1.4

TABLE 8.1

As can be seen in this table, whilst improvements for all the airports are visible, compared to their respective base cases, there is a marked difference in the magnitude of the changes between the airports. Zurich shows the lowest improvement, with a total time saving around ten times smaller than that of Gatwick, and roughly half Manchester's total. Changes in the peak hour departure movement rates whilst almost identical for Manchester and Zurich, are nearly double for Gatwick.

The reasons for these differences are due to two factors, level of runway congestion and runway operation mode. Whilst Manchester and Gatwick are both mixed mode runway operations, Zurich is single mode. As the mixed mode runway reaches saturation with a heavy arrival traffic flow, the number of required time gaps is reduced between successive arrivals to allow a departure out. This leads to increased departure delays, as aircraft wait for an appropriate time gap to appear. If the situation gets sufficiently congested, ATC restrict arrivals to allow departures out. At Manchester for example, arrivals are spaced at 6nm intervals, which relates to approximately 160 seconds. Allowing 60 seconds for an arrival to land and exit the runway, and 60 seconds for the following departure to go, this spacing allows for a 40 second buffer to account for slower than expected reaction times and exit times from the runway.[1] The actual use of this procedure however, will be affected by the number of pending arrivals, current size of the arrival holding stacks, and level of traffic congestion in the surrounding TMA airspace. If for instance there are a large number of arrivals over a short period of time, the ATC controller will tend to clear the arrivals in with minimum spacing, which will restrict departures, but then allow a longer gap before the next arrivals, to allow out more departures. Departures may also be left restricted by arrivals if the departure routes are congested. The effect on a mixed mode runway is to lead to an increased departure delay per movement in comparison to a single mode runway, as if an aircraft does not have a sufficient time gap between two arrivals, then it must wait until after the next arrival has landed and cleared the runway. A single mode runway only has the restriction of the departure speed tape explained in chapter two, which although it enforces dead time restrictions where no runway movements occur, it will guarantee departure clearance once the wake vortex time separation expires. This helps explain the reason behind Zurich's relatively low reduction in departure delay as all departures go off the same runway, along with the fact that the total system is operating at a lower level of saturation than either Manchester or Gatwick. At lower levels of system saturation, it is much harder to further reduce delays than at higher levels. This was discussed in figure 7.8 in chapter seven.

The use of intersection departures was closely witnessed by the author at both Manchester and Gatwick from the ATC tower, through discussions with the airport authorities and on the flight deck with Business Air at Manchester. The following discussion reflects the experience gained during this time.

Manchester

At Manchester, the author undertook many jumpseat trips with Business Air in and out of the airport[2]. Departures from both 06 and 24 runways were experienced from both the runway ends and intersections. Each runway had two possible intersection departure points, link 'B' and 'C' for 24 departures, and 'F' and 'E' for 06 departures. The distance of each of these intersections from the runway ends are listed below:

Link 'B' =	300m from 24 runway end	TORA[3] =	2700m	**(Same as threshold dept for wake vortex separation)**
Link 'C' =	810m from 24 runway end	TORA =	2186m	

1 Source: NATS (1994) Reduce Delays by Not Wasting Time on the Runway - Briefing Paper on Manchester Runway Occupancy for Pilots operating at the airport.

2 For reference refer to the Manchester aerodrome chart in appendix 6.3

3 TORA = Take Off Run Available

Link 'F' =	250m from 06 runway end	TORA =	2793m	**(Same as threshold dept. for wake vortex separation)**
Link 'E' =	580m from 06 runway end	TORA =	2456m	

It was standard practice for all aircraft departures to go from the runway ends due to noise abatement restrictions, although departures from 06 were more restricted by this than 24. Intersection departures were given to Business Air, both when traffic levels were high in the morning and also in lighter periods in the afternoon. The move was welcomed by Business Air, which had 47.5% of its departures from Manchester delayed 10 minutes or more between 2 May - 31 July 1994. The absolute effect of the intersection departures was not always a reduction in departure delay. On bad days, when the weather was poor and the airport limited to full IFR procedures, departure delays for Business Air were recorded at around 30 minutes, even with the intersection departure. On these days aircraft were stacked up at all three departure points for the runway, as well as queuing up along the taxiway. Start up clearances were also delayed to prevent aircraft departing from stand and further blocking the taxiways. As the taxiways became more congested, it became harder for the controller to sequence departing traffic due to the lack of passing places. This was more significant for runway 06, which did not have a departure sequencing pad at the time, unlike runway 24. The consequence of this was to hinder the controller's ability to sequence departures depending on the departure SID. Due to the configuration of Manchester's SID's, north and south bound departures followed the Pole Hill and Conga SID's respectively, which diverged from the other departure tracks by 90° at 2nm from the departure point. This enabled controllers to release the next departure sooner than would have been possible if both aircraft had been following the same SID. Unfortunately when the taxiways were blocked, this sequencing was not possible and departure time separations increased, so increasing delays.

In addition to the jump seat rides, the author also discussed the use of intersection departures with the ground and tower controllers at Manchester, and the ATC management staff there. Following the discussions, three further concerns were raised over the use of intersection departures at Manchester. As was discussed previously, a 40 second time buffer was placed on arrival separations to allow for slow pilot reactions either by the arriving or departing aircraft. In the briefing paper ATC issues to pilots using Manchester, it was noted that a reduction of 7-8 seconds in average arrival-departure-arrival spacing, through reduced runway occupancy, would allow one extra arrival and departure per hour on Manchester's runway. The paper went on to explain that this could be achieved by arriving aircraft targeting the earliest suitable exit and expeditiously vacating the runway, whilst departures should line up promptly and start the take off roll immediately when cleared. The departure case was the most frustrating for ATC controllers, as once they cleared the aircraft for take off, it was taking on average 11 seconds before the aircraft started to move. This was due to pilots completing final checks, but that affected the tight time separation between the next arrival. In certain cases, delay times between clearance and roll were as much as

30 seconds. Relating this problem to intersection departures, if Business Air took off from link 'C' on runway 24, the company operations manual dictated that the take off engine power must be applied, whilst remaining on the brakes, to ensure maximum acceleration. The restriction was directly related to take off run availability, which from this intersection was limiting. This process of increasing engine power whilst on the brakes, meant slower response times to the take off clearance than would have occurred had the aircraft departed from link 'A' or 'B'. Assuming similar restrictions applied to other airlines, depending on aircraft performance, there would be an unavoidable time delay between ATC clearance and commencement of the take off roll.

ATC also raised two further problems that they had with intersection departures. In order for ATC to provide a fair service, they are obliged to deal with aircraft on a first come first served basis. With intersection departures, it can occur that an aircraft at an intersection can fit into a slot between two successive arrivals, but is restricted from doing so by ATC, as it would place the aircraft ahead of other aircraft at the threshold that had arrived there earlier, therefore having a greater priority for departure. This conflicts with the departure sequencing plans of ATC, with the solution being an unquantified compromise. If for instance the intersection departure aircraft is not excessively down the departure list compared to the aircraft waiting at the threshold, and the threshold departing aircraft will be cleared for take off shortly after the intersection aircraft, then the intersection departing aircraft can be cleared first, for take off. If these conditions are not met, then generally, the intersection departure must wait its turn. The situation is also affected by the direction each aircraft wishes to go, as was previously explained. Finally it was pointed out to the author, that the ability to accurately separate arriving traffic by 6nm depended very much on ATC controller experience. Due to the nature of the shift working patterns of controllers, it would be impossible to avoid situations where relatively inexperienced controllers were on in high traffic levels. This would affect the efficiency of the runway mixed mode operation, as inexperienced controllers tended to increase separation above 6nm to avoid possible go-arounds, and give themselves an increased margin of safety to play with should anything go awry. A lot of this was due to the controllers lack of confidence in the pilot's ability to consistently deliver minimum runway occupancy times.

The final restriction on the use of intersection departures was due to a time problem for Business Air. When taking intersection departures from link 'C' for runway 24, there was insufficient time for the cabin attendant to complete the pre-flight safety brief to the passengers, before the aircraft was ready for take off, assuming no delays from ATC at the intersection hold. This was due to the fact that Business Air parked at the end stands of the domestic pier at Manchester, right next to link 'C'.

In summary intersection departures, whilst used at Manchester where applicable, are restricted by a number of factors which tend to be of a human nature and hard to remove. These factors, generally, could not be accounted for in the SIMMOD model, which would tend to suggest that the SIMMOD figures for intersection departures at Manchester were overly optimistic. Business Air's departure delays did however, appear to improve in 1995 compared to 1994 as delays of 10 minutes or more only affected 41.5% of departures between 1 April - 13 August 1995. This will be returned to when early turns after take off are discussed, as the improvements were not due to the use of intersection departures alone.

Gatwick

The same problems with the use of intersection departures at Manchester, were also faced at Gatwick but on a greater scale, as the airport was operating at its peak capacity for a longer period than Manchester. In addition, Gatwick faced much greater restrictions on the airspace surrounding it. The need to sequence traffic from Heathrow, Stansted, Luton, as well as Gatwick, through the same airspace, meant that often departures from Gatwick would be held up until the airspace, through which the aircraft wished to fly, was able to take an extra movement. This required much tighter co-ordination between the tower controller at Gatwick and the area controller at West Drayton, which would handle the departure almost as soon as the aircraft left the ground at Gatwick.

The author had the opportunity to discuss the use of special procedures at Gatwick, as part of a project sponsored by the BAA Plc. Discussions were held with Ian McBean, Manager ATC at Gatwick, and Mike Wildin, a group supervisor at NATS, West Drayton and previously an ATCO at Gatwick. Visits were also made to the visual control room at Gatwick and the CCF control room at West Drayton.

As with Manchester, Gatwick has intersection departure points at both ends of 26L and 08R. Departures from 26L have the option to depart from either link 'A' at the end of the runway or link 'B'. Link 'C' can also be used for smaller aircraft when traffic permits, but is not generally used in heavy traffic periods. For 08R links 'D' and 'E' can be used. The distances of these intersections from the runway end, and associated TORA values are as follows:

Link 'A' =	0m from end of 26L	TORA=	3098m
Link 'B' =	280m from end of 26L	TORA=	2894m
Link 'C' =	580m from end of 26L	TORA=	2438m
Link 'D' =	400m from end of 08R	TORA=	2786m
Link 'E' =	0m from end of 08R	TORA=	3159m

Due to the relative closeness of links 'A' and 'B', ATC can treat departures from both intersections as the same point for wake vortex separations. Unfortunately, this is not the case for links 'D' and 'E', although an additional intersection is expected to be built for 08R to allow the same concession as 26R by Spring 1997. At the time, the author visited the visual control room, Gatwick was conducting a wake vortex avoidance trial for departures. This enabled the controller to reduce the departure separation between successive departures from a minimum of 2 minutes, to 40 seconds if the wind was either a 7kts crosswind or more, or greater than 15kts in any direction. This was allowing for the effect of the wind in dispersing the wake vortices. The benefits for departures are obvious with a 80 second time saving if the procedure could be applied, i.e. an extra movement. In addition the ATC controllers also demonstrated frustration with pilots runway occupancy on landing, especially on runway 08R, mirroring the problems faced at Manchester.

The effectiveness of tight co-ordination between the tower and area controllers, was also observed by the author at Gatwick. This being said, gaps were still present in the system when runway occupancy time was lost due to either departure restrictions or poor consolidation of arrival traffic. This latter problem was more apparent as traffic levels began to ease in the early afternoon and arrivals began to arrive at a lessor rate. This led to the removal of the need for large holding stacks, with a direct arrival route. Unfortunately, for the tower controller, this coincided with the peak departure period, which was harder to control with arrival separation being more variable. Although not considered in this study, it may well be worth considering, if it is not already the case, holding arrivals for an additional period to help aid the area arrival controller in providing optimum separation, by consolidating arrivals and helping minimise departure separation. Obviously, there would be a compromise in terms of arrival versus departure delay to be made in this case.

As can be seen from this look at Gatwick, many of the problems found at Manchester are repeated, as are the attempted solutions which focus on departure sequencing depending on departure route; north bound versus south bound at Gatwick; use of intersection departure points close enough to the runway end to prevent increased separation requirements; and a shaky trust by the ATC controllers in the pilots to maintain required separation distances. More detailed developments are used at Gatwick which reflect its greater level of congestion. In both cases the intricate methods employed by ATC in this area, were not modelled in the SIMMOD simulations, which suggest the time savings achieved by SIMMOD may be either an over estimate of actual conditions, or even possibly an under estimation, if actual controllers can more accurately predict traffic flows and adapt accordingly. SIMMOD does though give a general picture of any possible outcome.

Use of Additional Systems

Taking the above examination into account, possible system additions that could help improve some of the problems highlighted now merit discussion. The principle issue concerning the use of intersection departures, is the accuracy with which ATC controllers can separate arriving aircraft, with the associated problems of poor pilot reaction to clearances leading to unnecessarily high runway occupancy times.

To help the ATCO's accurately separate aircraft, many approach sequencing aids have been developed, as discussed in chapter four. When these are linked to precision runway monitors, they should enable the controller to more confidently know the exact position of each aircraft. The success of this will depend on improving controller confidence in the systems, and provision of sufficient monetary funds to put the systems into operation. The aim of the introduction will be to reduce the buffer applied to arrival separation.

The ability to solve the problem of controller mistrust in a pilot's ability to precisely follow speed and altitude restrictions within a set time frame is harder to achieve. In a busy arrival stream, the controller will have a mental plan of how they see the traffic arriving. The largest concern for the controller is with speed reductions as aircraft slow at variable rates. This could be due to either high cockpit workload at the time of the request, adverse weather or just slow reactions. With the consequence of reduced separation between the aircraft ahead, assuming the previous aircraft reacted quickly to the speed reduction, the importance of improving the reaction time is evident. The best solution probably lies with greater education between the controllers and the pilots. The pilots need to appreciate the necessity to quickly and accurately respond to the controllers' requests, and the controllers need to appreciate the demands on the flightdeck at certain stages of the flight. Hopefully with increased co-operation from both sides and possible procedural modifications, the problem could be reduced.

The final area where the author feels that improvements could also be made, is in the ATC tower and ground controller co-ordination, as regards sequencing traffic for the DSP. Solutions to this could be recommended by a computer traffic optimising system and displayed to both controllers to help them sequence traffic. This would need accurately updating with aircraft departure routes and current status of the departure queues, as well as arrival traffic patterns.

Restrictive Regulations

As was seen at Manchester, the largest restriction on the use of intersection departures is from noise restrictions. In using intersection departures, aircraft will take off further up the runway, resulting in the aircraft being lower over the first built up areas upwind of the departure runway, than it would of been had the aircraft departed from the end of the runway.

The use of noise preferential routes also adds to the problem, as they restrict the number of departure options available to ATC, so reducing their ability to make use of reduced separation based on diverging aircraft tracks.

Given the current focus on environmental issues in Europe, the relaxation of these regulations is very unlikely. Instead it is more likely that the restrictions become more stringent at existing airports and applied to airports currently unrestricted.

Other Concerns with the Procedure

For airlines to use intersection departures, new performance figures are required to account for the reduced TORA and the fact that the aircraft will be closer to the departure obstacles. With changes in take off techniques, crew training is also required, as discussed with Business Air at Manchester. From discussions with airlines at the ERA operations meetings, attended by the author, there was a mixed response to intersection departures. Some welcomed the idea, while others were more cautious, especially if they had many young and inexperienced flight crews. Concern was also expressed with engine fatigue, as intersection departures generally required higher engine power settings compared to departures from the threshold.

Finally, airports generally welcomed the use of intersection departures in reducing departure delays but expressed concern over any increases in noise emissions.

Applicability to Europe

Taking into account the above discussion and the figures provided by the SIMMOD simulation it can be stated that the use of intersection departures does reduce departure delay without significantly increasing arrival delays. The procedure has been demonstrated to be applicable to both single and multiple runway operations and could be applied relatively cheaply to all European airports with sufficient traffic demand and taxiway construction. Table 8.2 breaks the applicability into two sections, those airports which currently have runway intersections less than 300m from the departure threshold and those that do not and would require additional taxiway construction to do so.

Applicability of Intersection Departures at European Airports

Intersections Available	Intersections Requiring Construction
London Heathrow	Barcelona
London Gatwick	Madrid (Rwy - 33)
Manchester	Palma
Glasgow	Marseilles
Birmingham	Nice (Rwy - 23L)
Alicante	Paris Orly
Madrid (Rwys - 36, 15, 18)	Lisbon
Lyons (Rwy - 18R)	Athens
Nice (Rwy - 05R)	Munich
Paris Charles de Gaulle	Milan Linate
Amsterdam (Rwys - 01L, 24, 22)	Milan Malpensa
Brussels (Rwys- 25R, 02)	Rome Fiumicino
Cologne Bonn (Rwys- 14, 32R)	Geneva
Dusseldorf (Rwy - 23L)	Zurich
Frankfurt (Rwy - 18)	Helsinki
Hamburg (Rwys - 23, 33)	Stockholm Arlanda
Vienna (Rwys - 29, 16, 34)	
Copenhagen (Rwys - 22R, 04R, 12)	
Oslo (Rwys - 24, 16)	

Source: Derived from British Airways AERAD Charts

TABLE 8.2

As can be seen from the table the scope for application is significant. Application of the procedure could be expanded if use of the land after procedure was employed, mentioned in the APATSI report, with arrivals being given landing clearance based on the aircraft currently completing its take off roll. This would work well if the time gap between successive arrivals was too small to permit a departure from the threshold, but may also work if a regional aircraft, with a shorter take off roll time, commenced departure from an intersection further up the runway.

To summarise, application of intersection departures will be most advantageous for currently congested, mixed mode, single runways due to the sequencing restrictions explained. The application on single mode, multiple runway, systems will be dependent on the runway usage, configuration and traffic pattern. In all cases simulation of the system will be required to determine if the potential time saving will justify changes to the system. Finally, in it's favour it represents the most heavily used special procedure currently in use with regional airlines in Europe at 37%.

8.3: Early Departure Turn

The combined SIMMOD results are given in table 8.3. It can be clearly seen that all airports achieve an improvement in delay time saving and improved peak hour movement rates compared to both the base case and the results for the intersection departure, with the use of this procedure. As before though, considerable variation exists in the improvements between the three airports.

Compared to the base cases, Gatwick reaps the largest reward, twice the time saving of Manchester and over four times greater than Zurich. The total time savings for Gatwick are around 600 minutes, (10 hours), when compared to the intersection departure results with the figures for Manchester and Zurich being around 750 minutes, (13 hours), and 420 minutes, (7 hours), respectively. So whilst the largest delay time saving occurs at Gatwick for the use of the early turn procedure, the greatest improvement compared to the intersection departure case goes to Manchester, which also achieves the best peak hour movement rate improvement. Finally, for Manchester and Gatwick the best of the variations in use of the early turn, are cases four and three 'c' respectively.

Time and Movement Changes from Base Case due to introduction of Early Turns

Airport	Travel Time Saving (mins)	Delay Time Saving (mins)	Total Time Saving (mins)	Chg. in Peak Hour Dept. Rate from Base Case
Manchester Cs3	139.8	1086.4	1226.2	+ 2.8
Manchester Cs4	151.5	1089.3	1240.8	+2.8
Manchester Cs5	106.6	1109.4	1216.0	+2.8
Zurich	174.3	463.0	637.3	+ 1.8
Gatwick Cs 3a	12.4	2649.2	2661.6	+ 1.6
Gatwick Cs 3b	14.8	2659.7	2674.5	+1.6
Gatwick Cs 3c	22.9	2674.7	2697.6	+ 2.0

TABLE 8.3

The reason for these time savings and increased movement rates reflect the operating systems increased flexibility to deal with departures as defined in chapter five. The results clearly support this theory although the variations mentioned above are interesting. It is clear that the improvements on single, mixed mode runways exceed those on single mode runways. This is for the same reasons as discussed for intersection departures. Differences between Manchester and Gatwick are due to the differences in traffic patterns. Gatwick has a higher concentration of traffic and a reduced arrival time gap as more of the arriving aircraft are of the same wake vortex category. This means that standard separation between two successive arrivals is more commonly 3nm than at Manchester, which leaves too little time to release an early turn departure after an arrival, before the next arrival reaches the threshold. It is these factors which explain the lower peak movement rate improvement than at Manchester. The larger reductions in delay times at Gatwick than Manchester are due to the situation explained in figure 7.8.

Variations between the Manchester and Gatwick early turns prove that the more flexibly the early turn is used the greater will be the time delay saving, as was proven at Manchester in the changes between only early turns in one direction for cases three and five and turns in both directions after take off in case four. This enables ATCO's to maximise the use of the departure sequencing speed tape reductions. At Gatwick case three 'c' also reflects the use of early turns left and right after take off whilst the previous cases had restricted use of the procedure to right turns only. It should, however, be noted that the difference in the time saving between these sub cases is very small, so if restrictions do exist with turns in one direction, use of the turn in the opposite direction may not significantly reduce the procedure's ability to reduce delays. This will be expanded on below.

Manchester

Use of the early turn at Manchester was discussed in chapter five. Following the author's experience of the procedure at Manchester and further discussion with ATC there, additional points of interest were found. Firstly, for operation of the early turn, close co-ordination was required between the tower and area controllers, due to the radar vectoring the aircraft required to stay clear of existing departures and arrival traffic vectoring from the Bolin holding stack as shown in figure 8.1. Once clear of conflicting traffic zones direct headings were given to position the aircraft back on track to the north of Pole Hill. Due to the traffic conflicts this procedure caused at times of high traffic demand, each departure would have to receive special ATC clearance prior to being released.

Discussions with the Business Air pilots indicated that the procedure did not generate any undue problems for them or the aircraft. This being said, the instruction to the pilots from ATC in carrying out the early turn was, '*Cleared to turn at your discretion....*', which did tend to cause pilots to turn a heights above 500ft. Much of this was due to the need to carry out immediate cockpit checks and raise the landing gear before commencing the turn, during which time the aircraft was often climbing above 500ft. The turn was then completed with flaps at the take off setting to prevent stalling should an engine fail, with a full clean up once clear of the turn.

Due to noise complaints the procedure was restricted to turboprop aircraft smaller than the BAe ATP, and only permitted for right turns at ATC instruction. In addition, it would only be used by ATC during heavy traffic periods where its use would help reduce departure delays.

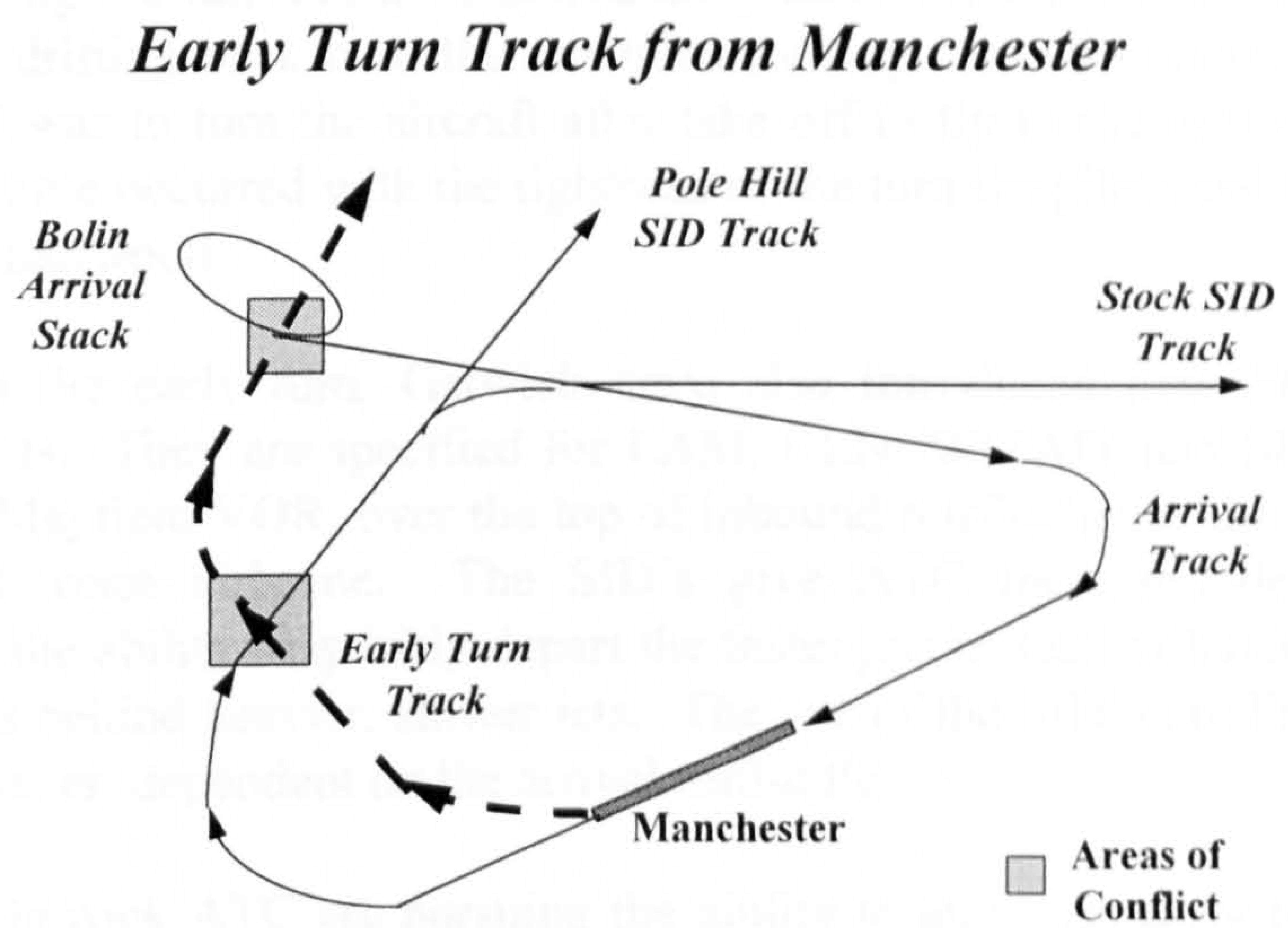

FIGURE 8.1

Gatwick

Due to existing exemptions to the NPR's for turboprop aircraft with MTOW's less than 17,000kgs, (i.e. Jetstream 31 and 41, Dash 8, Dornier 228 and 328, Banderante, Brasilia, Saab 340 and Shorts 360) and the Dash 7 in the UK AIP, the use of early turns has been used for some time at Gatwick. Unfortunately the most common regional aircraft movement at Gatwick today is the ATR 42 and 72 of City Flyer Express. Neither of these aircraft are exempt from the NPR's which means they have to follow the published noise routes.

An allowance for the ATR 42 has been made by ATC to permit a turn of 50° off the runway centreline track after take off at 0.5 nm on the ILS DME. After the turn traffic is handed to LATCC and radar vectored as required to intercept its intended final track. Use of the procedure is limited to fine weather conditions as the pilots must maintain separation visually. Use of the procedure saves 2-3 minutes in departure delays the Gatwick tower controllers argue.

The procedure could not be applied to the ATR 72 although ATC wish this it could. This is due to vociferous and influential airport noise campaigners. There are three key built up areas that restrict possible operations; Charlwood, (North West of Gatwick), Crawley, (South West of Gatwick) and Horley, (North East of Gatwick).

Unfortunately these three areas account for 75% of optimum early turn options at Gatwick. Off runway 26L turns and headings of 210° or 230° are given or 040° or

030° off runway 08R. The aim after the turn is to climb to 3000ft as soon as possible to extradite the aircraft from the NPR restrictions and allow radar vectors to be given.

Due to the number of departures from Gatwick heading north and east, the restriction at Charlwood is the most significant. Two trials were conducted by ATC with the first turning the aircraft onto a heading of 300°, flying to the west of Charlwood before continuing the turn north. Unfortunately due to weather conditions this often led to aircraft drifting back onto the extended runway centreline track. The second option on trial was to turn the aircraft after take off to fly to the east of Charlwood. Problems this time occurred with the tightness of the turn for pilots and the drifting of aircraft over Charlwood.

In addition to the early turn, Gatwick have also introduced new SID's for high performance jets. They are specified for LAM, CLN, WIZAD, and SFD departures and route via Mayfield VOR, over the top of inbound traffic, hence the need for high rates of climb once airborne. The SID's give ATC increased departure route flexibility and the ability to quickly depart the faster jets instead of having them fly at reduced speeds behind heavier, slower jets. The use of the SID's are limited to ATC discretion however, dependent on the arrival traffic flows.

In the future Gatwick ATC are pursuing the ability to authorise early turns for ATR 72's and easterly departure clearances to climb above the Biggin Hill stack for Heathrow. Restrictions on the Southampton departure flows are also being sought, currently limited by route saturation from Heathrow at peak periods.

Additional Improvements

As can be seen from the questionnaire results and preceding discussion, the use of early turns is currently fairly limited. To help increase their use more accurate and reliable track keeping will be required from the aircraft to help overcome some of the noise issues. This will require PRNAV to be fitted to the aircraft and improved radar accuracy. Track making could be given using a DGPS system integrated into the PRNAV system. Whilst this sounds expensive and a long way off, as was mentioned in chapter 4, BRNAV will be mandated in Europe by 29 January 1998, which should permit improved use of early turns up to a point. Finally, some account of the weather is required due to the problems discussed at Gatwick. Improved radar updates will also enable controllers to see and respond to apparent aircraft deviations from track sooner than at present.

Restrictive Regulations

Obviously noise is once again the primary issue stopping use of this procedure. Also of concern is the flight safety aspect, with the presence of built up areas or significant terrain under the early stages of the turn. This will require a full performance analysis prior to use of the procedure by each aircraft type, to assess the critical effect of turns at low level with an engine failure at the crucial moment. At multiple airport systems such as London and Paris, airspace restrictions will also need taking into account as mentioned at Gatwick to prevent aircraft infringing other airport's airspace.

Other Concerns
Effective use of this procedure will require airline crews to be trained to carry out the procedure, while ATC controllers will need clear guidelines as to the available and likely times to use early turns. Accurate definition of these operating procedures will take time, but are the best way to ensure optimum use under the current regulatory, operating environment in Europe. Any procedure that is drawn up must be careful to provide enough flexibility in it, to allow the early turn to be used at the spur of the moment when sufficient gaps in the arrival traffic permits.

Applicability to Europe
Results of the SIMMOD simulation and current use prove that use of the early turn does significantly reduce departure delays and in doing so provides the best solution to improve operating delays during the peak periods short of building or operating a STOL runway. Unfortunately its use is tightly restricted and the absolute effect of the procedure is largely dependent on traffic mix and flows, with greatest benefits accruing for mixed mode runway operations.

With these points taken into consideration, this procedure could be applied to any European airport without the need to alter either the current airport infrastructure or aircraft avionics initially. Optimally the use of this procedure would be combined with intersection departures. In addition if the early turn in one direction can not be made, it is worth considering a turn in the opposite direction that continues all the way round to the desired flight heading. This was discussed at both Manchester and Gatwick.

Finally where restrictions do block use of the early turn in one direction, the possibility of turning the other way, with a continued turn back over the airfield, should also be considered. Whilst it may increase the total track distance compared to a standard departure, the departure delay savings should be more beneficial.

8.4: Discrete Arrivals (SALS)

As before the combined SIMMOD results are given in table 8.4. This time it can be seen that whilst time savings were made for both airports compared to the base case, excluding cases 5 and 6 for Zurich, they are nowhere near the magnitude of the previous procedures. It is also clear that of the two airports, Manchester clearly achieves a more significant time saving than Zurich. In addition the predominant time saving was the travel time, reflecting the shorter arrival routings for regional aircraft that this procedure permits. For Zurich the delays are even greater than the base case, with the maximum peak hour arrival rate reduced by one. Peak hour departure rates are reduced for both airports compared to the early turn case, with significant reductions in delay time savings using SALS compared to just early turns, as a consequence of the departure movement rate reduction. The figures for the revised runway usage at Zurich clearly demonstrate that use of SALS has not helped ease the congestion there.

Time and Movement Changes from Base Case due to introduction of SALS

Airport	Travel Time Saving (mins)	Delay Time Saving (mins)	Total Time Saving (mins)	Chg. in Peak Hour Rate Arrival	Departure
Manchester Cs 6	1104.7	175.4	1280.1	0.0	+1.8
Manchester Cs 7a	1176.1	360.5	1536.6	0.0	+1.8
Zurich Cs 4	39.2	-6.3	32.9	-1.0	+1.0
Zurich Cs 5	-221.9	-546.9	-768.8	-1.0	-4.0
Zurich Cs 6	-756.0	-15.1	-771.1	-1.0	-3.0

TABLE 8.4

The reason for these poor results is due to the interaction of a less optimised arrival sequence on a mixed mode runway, resulting in a reduced number of required departure intervals between successive arrivals. This could clearly be seen during both Manchester and Zurich animation's, which showed increased departure queues. The greater time savings for Manchester compared to Zurich, reflect the higher percentage of regional aircraft in the total traffic mix for the airport, with greater flight path reductions possible at Manchester.

The limitation of modelling this procedure in SIMMOD was the inadequacy to represent the ability of the ATC controller to predict and sequence arrival traffic, accounting for the new procedure. This will need accurate modelling in order to determine the exact effect of this procedure, as better sequencing would reduce the effect on departing traffic. By how much, will depend on how optimally the arrival traffic can be sequenced and how the procedure will effect controller workload.

Practical Studies

The results discussed above, reflect those found at Manchester with the Business Air direct arrival procedure as discussed in chapter 5. The largest area of concern to ATC in this trial was the lack of time the procedure gave them to sequence the direct arrival with aircraft arriving along the standard route. In addition, introduction of this procedure during peak times was ruled out, due to the results of the trial and expectations of significant increases in controller workload in arrival sequencing due to the increase in arrival points on to the extended ILS that needed resolving. The consequence of this ATC predicted was a reduction in the runway movement rate during peak times.

They suggested that if Business Air had been able to conduct steep approaches, the procedure may have been more successful, as the SALS traffic and remaining traffic could of remained separated like the Frankfurt procedure described in chapter 5. Unfortunately this was not feasible, so it was agreed in November 1995 to cease the trial. Whilst the trial had not proved a success, during the time spent at Manchester, both ATC and the airport became more appreciative of the need for Business Air to maintain punctual arrival times, due to its interline commitments, as well as the performance capabilities of the Saab 340. This is clearly visible in figure 8.2, which shows the reduction in the percentage of departures from Manchester delayed over 10 minutes, for the 1994 and 1995 summer period. The overall result then, whilst disappointing in the fact that the trial could not be applied during peak periods, was, in the author's opinion, a success. It became apparent during the project at Manchester that ATC were already offering as flexible a system as they could, with minimum separations and direct routings to the ILS as soon as traffic levels permitted. If the SALS procedure had been formalised it may have limited the previous flexibility of the controllers. This does not negate the attempt however, due to the improved knowledge everyone involved gained of each others operation, which hopefully will be considered by each in future proposed procedure developments.

Similar results to Manchester were found at Zurich, where ATC stressed to the author that use of the STOL arrival for runway 28 had led to a drop off in the departure movement rate, due to the need to increase the time interval between successive departures to permit arrivals to land and clear the runway. Case 5 and 6 figures indicate that even if runway 28 was reserved purely for regional aircraft, the situation does not improve where you have arrivals and departures off the same runway.

The use of SALS at Manchester and Zurich did not lead to a significant improvement in system efficiency, in fact it led to a reduction. SALS was successful at Washington National and New York JFK though. The problem was that Manchester and Zurich were both attempts to introduce SALS onto existing operational runways, whilst the examples in the US had been using previously closed runways, which had no conflicting approach paths. At Manchester and Zurich a degraded departure movement rate was the result both times, due to the complexity of fine tuning a sensitive mixed mode runway operation. It is the author's opinion that for SALS to be a success in Europe, a separate or purely single mode arrival runway is needed. Improved ATC approach sequencing aids and RNAV equipped aircraft will also aid successful implementation of this procedure, as was the case in the US. The other key to look at with the use of SALS is to examine where the regional traffic is segregated to commence it's approach. Must all traffic go through the same holding stack? If traffic is segregated earlier, will this affect other airport's arrival and departure routes? These are questions that still require answers and it is the authors belief that where you segregate traffic will be specific to each airport due to local operating restrictions. Finally, as has already been touched upon, the use of the steep approach may also benefit the procedure, but this will be discussed in more depth next.

Operational restrictions will be noise based and careful evaluation of new built up areas being over-flown will be required.

With these points taken into account, application of SALS in Europe, whilst relatively cheap to implement has relatively limited application at present and will require a change in operating philosophy by ATC and encouragement from the airlines before much ground is gained. It is also dependent on airports operating a single mode arrival runway.

Percentage Breakdown of Air Traffic Departure Delays for Business Air at Manchester during the Summer Period for 1994 and 1995.

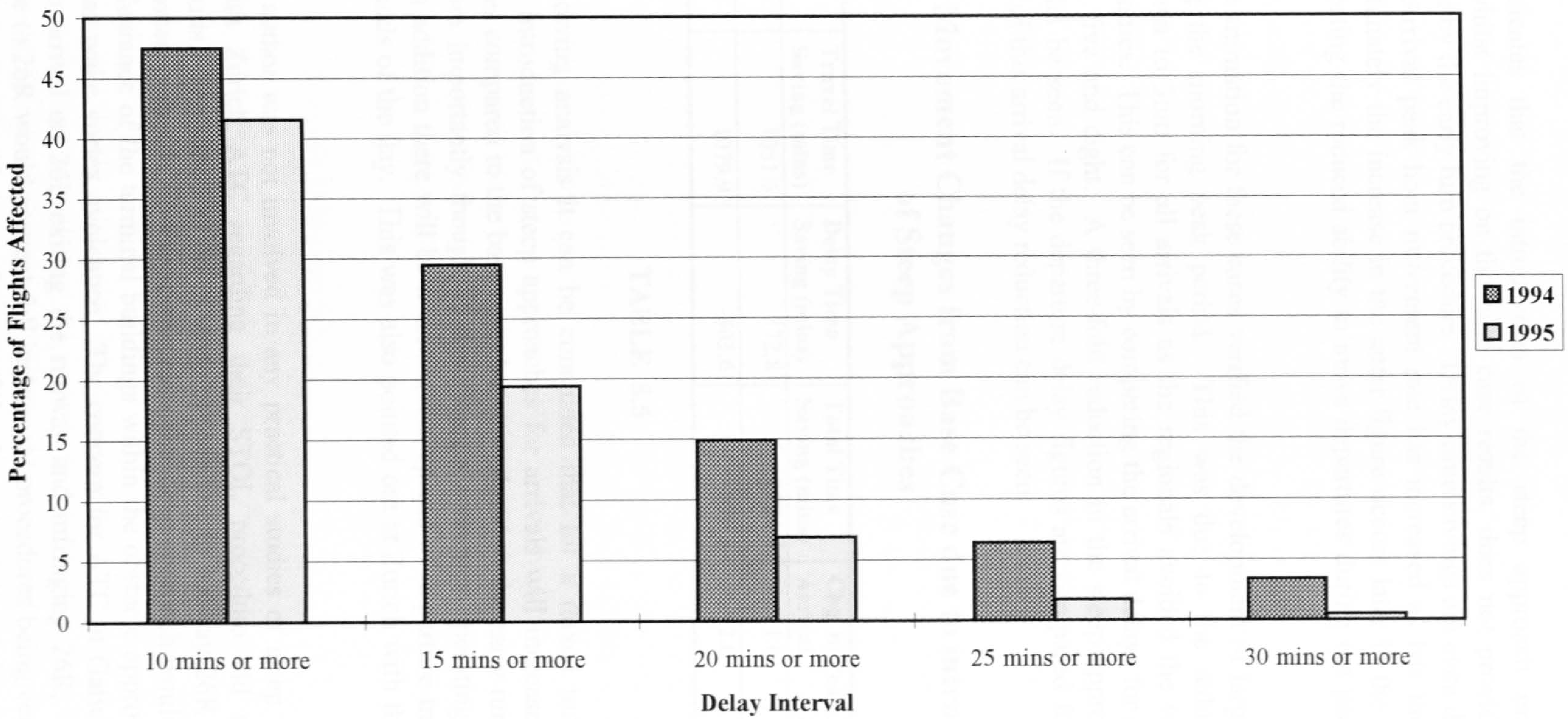

Figure 8.2

8.5: Steep Approach Concept

Table 8.5 indicates that the introduction of the steep approach procedure at Manchester, whilst improving on the base case results, does not provide the time savings offered by the early turn procedure. Delay time savings are even down on the SALS case. Arrival peak hour movement rate has increased as has the departure figure. Unfortunately the increase in the latter figure occurs later in the morning at 10-11.00, reflecting the reduced ability to move departures during the peak morning hours.

A study of the animation for these cases verified the development of large departure queues during the morning peak period. This was due to the reduced arrival separation, down to 3nm for all arrivals as the regionals avoided the wake vortex separation penalties. This can be seen by comparing the arrival delays for Manchester between cases five and eight. A three-fold reduction in the steep approach arrival delay figure can be seen. If the departure delay figures are compared for the same cases, the cost of this arrival delay reduction can be seen.

Time and Movement Changes from Base Case due to introduction of Steep Approaches

Airport	Travel Time Saving (mins)	Delay Time Saving (mins)	Total Time Saving (mins)	Chg. in Peak Hour Rate Arrival	Departure
Manchester Cs 8	1051.6	172.8	1224.4	+1.0	+2.5
Manchester Cs 9	1079.9	-503.6	576.3	+2.0	+3.0

TABLE 8.5

From the following analysis it can be concluded that for a mixed mode runway operation, the introduction of steep approaches for arrivals will increase peak hour movement rates compared to the base case, but not related to the early turn after take off case. More importantly though, it significantly increases operating delays for departures. In addition there will be a consequent spread of departure traffic to less congested periods of the day. This was also pointed out at Zurich with the results of case 4.

Although the author was not involved in any practical studies of steep approaches, discussion with Zurich ATC regarding their STOL procedure did support the SIMMOD results. The introduction of steep approaches to runway 26R at Gatwick was also discussed with ATC there. In this case, the steep approach would be needed for obstacle clearance of the terminal buildings within the obstacle approach cone of 26R, as well as wake vortex avoidance. The concern for ATC at Gatwick was the scenario of an arrival on 26L exiting the runway and infringing 26R. In addition buildings close to 26R would prevent full instrument procedures being certified. Use of 26R would also restrict the use of some of the domestic gates at the terminal, and use of the taxiway to the north of 26R due to limited wing tip clearance. The combined result of these problems was a reduction in capacity at peak times according to studies previously done by ATC. They showed more interest in developing the steep approach for 26L in combination with existing arrival streams. The need for a separate landing aid, probably MLS or GPS with PAPI's was crucial though and interference issues between the two landing aid signals would have to be overcome. Very accurate controller approach sequencing aids and precision approach radar would also be a prerequisite for this type of operation. Finally, missed approach procedures would also need very careful definition to make it clear to pilots what each aircraft must do, depending on which aircraft executed the missed approach. Generally, it would be the regional aircraft that must go-around if the aircraft on the lower approach path commenced the missed approach. An indication to the controller of possible conflict and likely resolutions would also be useful, similar to that being developed with the precision runway monitor systems and non-transgression zones. Due to these strict limitations, the procedure would not work well in poor visibility and would probably be restricted to visual flying conditions. Much more work is required to be done with this procedure before significant benefits can be made to runway capacity and it must be borne in mind that as more and more technical monitoring systems are introduced to validate the procedure the benefits of introducing it may be overcome by the costs.

To summarise, the application of the steep approach procedure in order to avoid wake vortex separation restrictions will only be successful if the arrivals occur on an independent single mode runway at major airports. Use of the procedure on a mixed mode runway could be applied if sufficient bunching of arrival streams occurred with later departure streams, but not if both streams occur at the same time, i.e. Manchester case 9.

With this in mind, application will be limited to those European airports meeting this requirement, which are not many, and those that are feasible like Amsterdam, then tend to have significant environmental limitations which may kill the implementation altogether. Further research with SIMMOD at different airports is required in addition to a list of what extra monitoring equipment will be demanded by ATC to operate the procedure. Collision risk modelling of the likelihood of go-around problems is also necessitated to accurately deduce realistic runway capacity benefits of using steep approaches. All these current issues relating to this procedure explain it's current limited use.

8.6: Regional Aircraft Holding Stacks

Analysis of this procedure, as previously mentioned, was undertaken by the author following discussions with ATC at the London ATC centre, (LATCC). Table 8.6 shows the results of the SIMMOD work at Manchester.

As previously explained, the application was based on the direct arrival case 7a and the STOL runway case 10a of regional aircraft holds for Manchester SIMMOD simulations. In both cases the aim was that through introduction of the holding stack regional aircraft could be more optimally sequenced with existing arrival traffic, thus helping to reduce arrival gaps. Table 8.6 clearly shows that whilst savings were made compared to the base case, in reality the introduction of the holds made the system less efficient in both operating time reduction and movement rate improvement. The effect on movement rate was more severe for case 10 than case 7, whilst the effect on operating time was greater for case 7.

Time and Movement Changes from Base Case due to introduction of Regional Aircraft Holding Stacks

Airport	Travel Time Saving (mins)	Delay Time Saving (mins)	Total Time Saving (mins)	Chg. in Peak Hour Rate Arrival	Departure
Manchester Cs 7b	1170.5	318.1	1488.6	0.0	+1.4
Manchester Cs 7b*	-5.6	-42.4	-48.0	0.0	-0.4
Manchester Cs10b	1068.3	2259.7	3328.0	0.0	+2.0
Manchester Cs10b*	-1.5	-5.5	-7.0	-1.0	-0.8

*Figures show difference in results from cases 7a and 10a respectively.

TABLE 8.6

The explanation for the greater effect on movement rate for case 10, is due to the fact that the holds would restrict the regional aircraft arrival flow onto the separate STOL runway. In this scenario, regional aircraft holds would not provide a benefit as the arrival flow has already been segregated. The increased operating times incurred in case 7b reflect SIMMOD's inability to accurately model the controller thinking when using holding stacks and sequencing arrival traffic. In reality the regional aircraft holds would be located close to the ILS approach path and as a gap in arrival traffic appeared, the controller would release a regional aircraft from the stack to fill the arrival gap. In order to achieve this, the controller must have placed a regional aircraft in the hold, while appreciating that an arrival gap would form by observing the flight progress strips and the radar screen. By default, the production of these arrival gaps would be unpredictable and thus require rapid response from the regional aircraft to ensure effective use of the gap. SIMMOD failed to permit rapid exits from the holds or adequate sequencing of the regional aircraft release from the hold. More complex modelling techniques will need to be applied before a satisfactory answer to the use of regional aircraft holds is determined. Results here can only be used to say that this modelling technique did not prove their usefulness, but this does not rule out their potential.

As far as the author is aware, regional aircraft holds are not currently used in a published procedure at any European airport, there are instances where they have been used by ATC however as and when traffic conditions allow. This tends to be very difficult to track though and if the procedure is to be applied more successfully, clear written instructions and transparency of use is required. Successful implementation will also depend on investment in controller approach sequencing aids, along with RNAV equipped regional aircraft capable of holding at any point required by ATC. Noise related issues of the new holding stacks and arrival routes would also need evaluating. Obviously in a more complex arrival airspace system, such as London or

Paris, location of these holding stacks would require very careful consideration and studies into their likely impact on existing traffic flows would be required.

Mindful of the above discussion, it is clear that further research into regional aircraft holds is required to validate their ability to help improve runway capacity. From the work here, it is clear that they are best suited to unsegregated regional and jet arrival traffic, and will be strongly dependent on the ability of the ATC controller to effectively recognise arrival gaps and exploit them. Help with sequencing aids will be required to achieve this. Applicability of the procedure in theory is unrestricted by any current European airport operation, assuming the preceding points are taken into account and can be introduced at a relatively low cost reflecting the time spent designing any airspace alterations to accommodate the new holds and subsequent pilot training.

8.7: Use of STOL Runways

As indicated in chapter 7, this option represents one of the most expensive in terms of required investment by the airport. Due to this, significant time savings and movement rate improvements will be expected. Table 8.7 shows the results for Manchester case 10a, which modelled the use of a STOL runway for regional aircraft arrivals operating independently from jet arrivals, with all departures from the main runway.

Time and Movement Changes from Base Case due to introduction of a STOL Runway

Airport	Travel Time Saving (mins)	Delay Time Saving (mins)	Total Time Saving (mins)	Chg. in Peak Hour Rate	
				Arrival	Departure
Manchester Cs 10a	1069.8	2265.2	3335.0	+1.0	+2.8

TABLE 8.7

As can be seen, a significant increase in the operational time saved has occurred. A total of 55.6 hours less total time than the base case. In addition both arrival and departure movement rates are increased in comparison to the base case. Compared to Manchester case 5, the optimum early turn simulation, the arrival movement rate has increased by 1 and the total operating time reduced by 2119 minutes or 35.3 hours.

Clearly then this STOL runway has significantly improved the operating system at Manchester, but is that not to be expected? The question to ask here, is does the improvement achieved merit the investment and construction disruption costs involved in building the STOL runway? For Manchester this would involve the demolition of listed buildings, disruption to current operations during building works, destruction of wildlife habitats, service road re-routing and a host of other associated costs. The answer lies in how the STOL runway will alleviate Manchester's runway capacity problems in the longer term. By its very nature and length, it will only be able to handle the current generation of regional aircraft. Will this be satisfactory, or will the type of aircraft flown by regional airlines in the future change? Will this change reduce the ability of the STOL runway to handle regional air traffic? If the answer to this last question is yes, then the construction of the STOL runway in the first place must be seriously questioned.

In addition to the preceding questions, the level of investment in landing aids for the STOL runway will need defining, as they will tend to vary for each proposed location. The cost benefit table in appendix 6.8 could be used as a base for this. In complex airspace structures, the need for accurate flight paths within a limited space will require aircraft to be fitted with RNAV, precision approach radar and an MLS or GPS landing system. Covering the costs of these aids may not be possible from the benefits of introducing the runway. Success will depend on long term sustainable regional aircraft traffic demand, in sufficient numbers to cover costs. Obviously this will depend on each airport in question. For current European airports, the largest problem of introducing STOL runways, even if they could be justified, lies in the lack of physical space around the airport site. Noise issues related to increased noise footprints over new areas will also need addressing.

Given the above discussion, the use of STOL runways to reduce airport congestion forces the airport and probably the regional airline to make much more serious financial commitments and offers an unpredictable benefit. Taking this into account, the use of this procedure is not recommended, unless the return on investment can be satisfactorily resolved. Additional research is also required in this area, to help define what level of improvement in operating time and movement rate must be achieved to enable successful application.

In this discussion the author has assumed that the candidate airport does not have a suitable landing strip currently not utilised. If this were the case then the procedure could succeed, as the level of investment would be much lower. This was the case at Washington National. For European airports, there are runways not utilised but this is due to strict operational rules which would have serious cost implications to remove. Examples include those outlined in table 5.1, all of which could technically be made into STOL runways with the introduction of steep approaches, sequencing aids, MLS or GPS and RNAV equipped aircraft. However, the author believes that, due to the political and environmental constraints at these airports, combined with the possible effect introduction of the STOL runway would have on existing traffic flows, they may not, realistically, be viable.

8.8: Use of Reliever Airports

Although no simulation work was carried out on reliever airports by the author, there has been a push in recent years in Europe to make increased use of them for regional air traffic. For this reason they merit discussion here.

In 1993 Cranfield University, and the author, participated in a consultancy project evaluating the likely effect of introducing up to 15 million passengers per annum through a reliever airport called Apollo for Gatwick.[4] In fact this Apollo airport simulated the possible development of Redhill.

A SIMMOD simulation was set up using the current Gatwick operation as a base with improved departure routes from Gatwick. Movements to the reliever airport were based on new traffic, as opposed to relocation of existing regional traffic at Gatwick. Three scenarios were run using the reliever airport with 4, 8 and 15 million passengers per annum. Results of the simulations showed that average air travel times for Gatwick in each case increased by about two minutes for arrivals and departures. Average departure delays however reduced by 3.3 minutes. These changes were largely attributed to London TMA re-organisations rather than the Apollo development. Average flight times for the Apollo operation varied depending on the variety of traffic mix, but had average flight delays comparable or less than Gatwick. The report concluded that on the basis of the results derived, Apollo did not create significant problems in terms of extra airspace delays to Gatwick traffic. The simulations were based on westerly operations, so further work would be required to determine the impact on easterly operations. In addition, it was recognised that use of Apollo would increase ATC controller workload, although it was felt that this would be offset by technical advances such as RNAV and MLS. Finally, it is significant to note that Gatwick peak hour movement rates were not greatly affected by the use of Apollo.

It can be argued that as reliever airports are situated further away from the main airport than any STOL runway, their impact on the main airport of increasing regional traffic will be relatively small, as approach and departure paths will have less chance of conflict. This in turn should reduce controller workload in two ways. Firstly, the traffic mix at each airport should be more homogeneous, thus helping reduce wake vortex separations; secondly segregated traffic flows should be more easily manageable. Unfortunately in a highly complex, multiple airport TMA, the ability to provide conflict free traffic flows will be virtually impossible which, consequently, could lead to increased controller workload. In many cases, movements from the reliever airport will need coordinating with the primary airport. This will remove the potential benefits of the reliever airport if its movements are slot restricted by the major airport. This would be necessary at Redhill and Gatwick for instance. Additional dangers exist with the use of reliever airports in restricted airspace areas. The addition of another arrival and departure point, with associated connecting routes to the airways, will add to the complexity of the system and possibly increase the risk of flight path conflicts. Further research is required to validate the seriousness of this issue. The other issues relating to the use of reliever airports have already been mentioned in chapter five, which includes the reduced ability of regional airlines to satisfy passenger demands to carry them to and from the primary airport; reduced ability of regional airlines to meet their interline agreements with major airlines due to connecting passengers arriving at the wrong airport; and lastly environmental issues relating to the operation of a new airport.

[4] Source: Alan Stratford and Associates (1993) Apollo ATC Simulation Modelling Study - Draft Final Report

Taking the preceding discussion into account one must ask the question, will reliever airports help solve airport congestion in Europe and if so by how much? The answer to the first part of the question is a reserved yes, with the absolute affect on present congestion depending on the ability of the reliever airport, to relieve traffic from the major airport and not overly increase TMA airspace complexity and controller workload. Theoretically then they could work but practically all attempts so far within Europe have not been successful[5]. This reflects the current economic climate affecting regional airlines, which are being used more and more by the major airlines to provide feed traffic to their long haul services as was proven by the returned comments in the questionnaire. This is not possible from a reliever airport. In the longer run however, it is the author's opinion that reliever airports will develop in Europe to serve those regional airlines that have decided to set up hub bypass routes and specific point to point routes, either independently, or on behalf of a larger carrier. Incentives from local or national governments may also be used to entice regional airlines to use them, along with higher operating charges to remain at the principle airport. This last point will undoubtedly cause much outrage from the independent regionals still requiring access to the hub airport. The largest practical problem will be finding the space to accommodate these reliever airports on the ground and in the air. Further research is needed to define solutions to this problem.

Finally it must be stated, that whilst the author feels that reliever airports will develop, he feels more can be gained by focusing at the hub airport, as even if radar and landing aid upgrades are required, this still adds up to less than effectively building a new airport. In this area much more research is still required.

8.9: Summary

This chapter has consolidated the results presented in chapter seven, with the author's experience at Manchester, Gatwick and Zurich airports, European regional airlines and discussions held with ATC. A number of practical implementation problems have been identified which are very airport site specific. It is clear that runway usage, location of other airports within the same TMA, specific traffic mixes and patterns are the dominant controlling factors on congestion. The interrelation of these factors determines which special procedures can be applied to optimally improve the situation. Table 8.8 is an attempt to summarise and aid airports to decide which special procedures they should apply.

Prior to discussing the implications of table 8.8 it is worth taking the reader through one line of the table to ensure a clear understanding of what has been presented. If SALS are used, as the example, it can be seen that initially their use is preferred on a single mode runway operation, as opposed to a mixed mode runway operation, for the reasons discussed in section 8.4. They also better suit operations in a single airport TMA, than a multiple one, due to the reduced possibility of arrival and departure track confliction. Finally, the real benefit of introducing SALS will occur during peak periods with a large traffic mix than during quieter periods. By this example it can be

[5] Referring to the attempt by Dusseldorf airport to re-locate regional traffic to Monchengladbach airport - See Chapter 5.

seen that where a, *'no'*, is written in the table it does not necessarily mean the procedure can not be applied. Instead it indicates that there will be difficulties in introducing the system and use of the procedure, in this situation, may not yield the optimum improvement in current airport capacity.

Special Procedure Application Matrix

Special Procedure	Runway Usage		TMA Structure		Traffic Mix and Pattern	
	Mixed Mode	Single Mode	Single Airport	Multiple Airport	Large + Peaky***	Small + Stable****
Intersection Departures	Yes	Yes	Yes	Yes	Yes	No
Early Turns	Yes	Yes	Yes	No	Yes	No
SALS**	No	Yes	Yes	No	Yes	No
Steep Approaches	No	Yes	Yes	Yes	Yes	No
Regional A/C Holds	No	Yes	Yes	No	Yes	No
STOL Runways*	Yes	Yes	Yes	No	Yes	No
Reliever Airports*	Yes	Yes	Yes	Yes	Yes	No

* Note serious cost implications

** Responses based on a single mode runway operation

*** Peaky traffic flows represent distinct periods where traffic is at or beyond the current airport capacity limit

**** Stable traffic patterns represent a constant drip feed of traffic below the current airport capacity limit

TABLE 8.8

In general then, table 8.8 demonstrates that in simple airport/airspace environments, like Manchester, all procedures can be applied so long as a sufficient traffic mix exists to make use of the variations in wake vortex separations. Maximum restrictions on the use of special procedures come into play with multiple airport, mixed mode runway environments such as London Gatwick. London Heathrow, Paris CDG and Paris Orly come in between as single mode runways in multiple airport TMA's. In these cases early turns, SALS and regional aircraft holds may well be overly restricted by lack of free airspace and path conflictions with nearby airports.

The absolute effect each of these procedures has on reducing congestion and delay depends on the intensity of the congestion as previously explained in figure 7.8 in addition to specific operating restrictions imposed at each individual airport.

In closing, it must be stated that whilst this work has produced recommendations on which special procedure to use where, and the possible savings that can accrue from using them, much more work is required to define boundaries on the three principle influencing factors outlined above. What level of traffic mix and percentage of regional traffic movements will produce the best reduction in congestion, and how will this vary depending on each airport's specific operating circumstances? What is not in question however, is that regional airlines want to make more use of the procedures and this thesis has demonstrated that the procedures can help reduce current operating delays.

CHAPTER 9 : Conclusions.

9.1: Introduction

In concluding this research, it is the author's intention to address three issues. Firstly, to answer the hypothesis set at the beginning of the work; secondly to define a methodology for applying this work on special regional aircraft procedures; and finally to define the potential next steps that need research in this area.

9.2: Answering the Hypothesis

In chapter one the author set the scene for this work, by posing the question over whether the ability of regional aircraft special procedures could help to reduce airport congestion at major European airports. The next chapter set out to inform the reader that, due to the complexity of the operating environment within which airlines operate, and the conflicting interests of airports, ATC and airlines, airport congestion was a highly complex and inter-related problem. In addition, the problem is heightened by legislative and regulatory bodies, which restrict the ability of the system to flexibly respond to the problems of congestion. Chapter three examined aspects of aircraft performance which permit the regional aircraft to carry out the special procedures.

Chapter four was the last of the scene setting chapters and focused the reader on the European operating environment. The chapter was broken into four principle sections, which assessed forecast growth potential for the industry, current status of European airports, highlighting those facing congestion problems now and those likely to suffer congestion in the future. A review of recent developments in ATC and European airlines made up the second part of this chapter. It soon became clear from this chapter, that within Europe there was a marked development of airline alliance, which either had or was likely in the future to encourage the development of key hub airports. This was directly tied to the liberalisation in Europe, but was likely to cause significant congestion problems, especially at 16 European airports by 2010, as highlighted by the 1990 SRI report. The author then expanded the work, demonstrating a revised forecast of 9 congested airports by 2010. Closer examination of this problem, revealed that the primary cause of lack of airport capacity in Europe was due to the lack of physical space, as well as environmental and political expansion restrictions. This lack of capacity was highlighted during peak periods around the early morning and evening. Focus of the thesis on the peak hour reflected airline need to match aircraft supply to passenger demand. The nature of passenger demand in Europe for regular frequencies at the right time had only put further pressure on limited airport capacities, as all the airlines attempted to fly in and out of the airports at the same times. In certain cases, the poor ability on the part of ATC to handle high peak hour movement capacities, compared to other airports in Europe with the same runway configuration, made congestion at the airport artificially worse than it need have been. The APATSI report had been developed to address this latter problem specifically. The chapter closed by examining a number of technical systems that could be used by the airlines and ATC in an attempt to remove some of the limitations currently placed on their operations.

Thus the first four chapters were aimed at explanations on the complexity of problems causing airport congestion, together with a discussion on the current congestion situation in Europe. The main purpose was to demonstrate that many of the changes occurring there, would have a significant potential to make the congestion problems worse. What was clear from this evaluation was that, whilst attempts had been made to apply certain mature ATC procedures, little had been done to exploit the differences in aircraft performance and flight techniques that existed between the jet and regional aircraft types.

Chapter five defined a number of special procedures which could be used by regional aircraft to possibly help reduce the impact of airport congestion. Given the severity of congestion within Europe defined previously, it was felt that these procedures more than warranted serious study to determine their specific ability to reduce operating delays. Due to the limited availability of resources available to the author, the evaluation of these special procedures was initially relatively theory based, using computer simulation techniques with associated application of a cost benefit analysis model. The latter model was used to reflect the increasing industry need to justify any infrastructure investments on monetary grounds.

It was always appreciated by the author, however, that application of these special procedures could only really be achieved by practical studies. This was achieved thanks to the generous help of Business Air, Crossair, Manchester, Zurich and Gatwick airports and the European Regional Airlines Association. The experience gained from the practical exposure to the implementation problems associated with these special procedures, enabled the author to re-evaluate certain parts of the initial computer modelling process to validate the results presented in chapter seven. It also made the author aware of the limitations of the computer model which was also highlighted in chapter seven. Chapter eight placed the theoretical modelling results in context, with the limitations imposed by the real world which culminated in a matrix summary table of special procedure against three airport operating variables. It was argued that this table could be used by airport planners to help them decide which special procedure could be applied to their airport.

The first question posed, 'Can these special procedures reduce airport congestion in Europe?' The answer is yes! The scale of each special procedures impact on an individual airport's delay figures is, however, highly variable. Evidence, from the simulation models and practical studies, does indicate that the use of early turns after take off and use of intersection departures has a more substantial impact on reducing departure delays; whilst use of steep approaches, SALS and regional aircraft holds does not greatly improve arrival delays and often hinders departure delays off a mixed mode runway. This conclusion is represented in the current application of the procedures, from the airport questionnaire, with eight cases of early turn against only three arrival procedures. The search for an optimum application of special procedures has not produced a simple answer, as an optimum solution is airport site specific, due to subtle variations in operating restrictions such as noise preferential routes, density of built up areas, terrain limitations and effect of other airports, all of which was explained in chapter two.

The next question asked, 'If the special procedures can theoretically reduce congestion at an airport, will they practically be used, and if not, why not?'. The answer to this question depends on a number of factors. Application of the cost benefit analysis is a primary determinant, as previously explained. For an airport however, the weighting given to specific factors may well vary from those given in this research. More emphasis will probably be placed on the ability of the procedure to increase peak hour runway movement rates, due to their ability to more accurately place costs and benefits on extra movements, instead of time savings. The approach is also more likely to focus on pure market economics as opposed to welfare economics, as the airport must satisfy any shareholders that a satisfactory return on investment can be made in monetary terms. Expanded multiplier effect benefits to the local economies may be all well and good in theory, but will not directly help the airport pay for the investment made. This same rational will apply to required investments for ATC and airlines. The significance of regional aircraft traffic at the airport will also affect the likelihood of a procedures application as, where regional aircraft represent a higher percentage of total traffic, they are likely to produce a more favourable outcome, especially if the regional airlines involved co-operate together. The level of technology required to carry out the procedure, compared to the existing aircraft and ATC systems, will also have an affect. Again this returns to the cost problem. Finally, and perhaps most important, either airlines, ATC or the airport will need to be aware that special procedures are available, can be applied, and if necessary must communicate this to the other parties.

The final question asked, 'Would these special procedures represent a short term or long term solution to airport congestion?'. To answer this question, one must look towards the future and the likely changes that will occur in airlines, airports and ATC. For the regional airlines, there has been a recent tendency for increasing aircraft size and a switch from turboprops to jets on the hub feed routes. Jets are also being used more frequently on the thin point to point routes. Many of these new jets, such as the Embraer 145 and Canadair regional jet, do not have the performance characteristics required to carry out these special procedures. Airports also are changing, with the improvement of current runway capacities being achieved as ATC adopt the APATSI recommendations. Plans for new runways in Europe are still limited however, so congestion must still be expected. Within ATC much has been done in recent years to improve the en-route traffic flows, with more recent attempts to integrate this en-route traffic into the TMA. New approach and conflict resolution systems are also increasingly helping ATC. To surmise then, regional airlines are reducing the ability of the special procedures to work in the long term, whilst airports still need them and ATC are becoming more capable of dealing with them. It is the author's opinion that, as the systems develop, special procedures, whilst effective in the short term, will eventually be replaced by new procedures along similar lines to those discussed, but more applicable to all aircraft types. What is definitely certain, is that this problem of maintaining access to airports during congested peak periods will only get worse unless new procedures can be implemented!

9.3: A Methodology for Application

Throughout the research it was evident that, whilst the use of special procedures had been known about for a while, little attempt had been made to implement them, or where they had been implemented, there had been no exchange of information with other airports. This, the author believes is due to lack of evidence to validate the claims, combined with no recommendations or definitions given on how the procedure might be implemented. It has been the purpose of this thesis to answer as far as possible these two issues. The first part has been discussed already, from which can be deduced the following six step plan for introducing special procedures.

Step 1: Determine cause of airport congestion.
Use of these procedures will only help a runway and TMA congestion problem where there is a significant percentage of regional aircraft operations. Modelling of the current airport operation will help assess the main congestion points. A distinction should be made, however, between arrival and departure congestion problems, which will help to determine the correct special procedures to apply.

Step 2: Decide which special procedures will be of use.
Table 8.8 should be used as a guide here, backed up with modelling of the procedure, focusing on possible delay time improvements and increased peak hour movement rates.

Step 3: Discuss ideas with relevant Airlines and ATC.
The purpose here is to assess how feasible the procedures evaluated in step 2 can practically be achieved. For effective discussion, all parties must be fully briefed and understand the procedures and results of the modelling studies. The aim will be to decide which procedure to implement, if any.

Step 4: Carry out a detailed cost/benefit analysis of chosen procedure.
This will have to take account of any investment required by the airport, ATC or airline and then compared to the opportunity cost of remaining at the present position, whilst of course being prepared to accept increased congestion problems.

Step 5: Develop detailed Implementation Plans.
Provision of a trial period will probably be required, with the need to define specific success criteria, time periods, lines of communication between all parties and clear boundaries of responsibility. In the case of system up-grades, flexibility in terms of cancelling the procedure will need defining to prevent unnecessary investment. Initial plans should be passed to all parties for comment and revision before fixing the final schedule.

Step 6: Maintain regular review and feedback meetings.
This is the most important part of the process to ensure that a successfully introduced special procedure remains in operation. All parties must communicate any operating problems that they discover, attempting to solve them wherever possible. It is essential that the use of any relevant changes and up-dates to systems or procedures must be passed on to all those involved, as it may affect the ability of the procedure to

achieve its goal. With this pro-active and constructive feedback the procedure should remain a success.

This six step guide has universal applicability, and is recommended as a result of the work carried out and experience gained by the author during the course of this thesis. A seventh step should also be added which involves the dissemination of information regarding the use of the procedures to other airports.

One of the largest constraints involved with this guide, however, is the time and manpower it requires to function effectively. Following practical experience, the author is well aware that both of these resources are limited at the best of time, however, given the potential reward, the author feels, it is justifiable.

9.4: Limitations of Research

The majority of these have been discussed within the preceding chapters, however, there are larger underlying limitations that need raising. Due to the limited resources and time available to this study, a truly comprehensive answer has not been possible to all the questions that were asked in the introduction. Through researching this problems, the author has become aware that the scale of the problem is much larger than first appreciated, which is only made more complicated because application of the procedures is unique to individual airports. This work focused primarily on Manchester, Zurich and Gatwick airports, taking the lessons learnt from these and generalising as to their applicability to other European airports. Much further work is required on other specific airports to validate the conclusions made here. This is especially true when looking at varying runway configurations. How effective are steep approaches on parallel runways? For crossing and converging runways is there an optimum configuration to maximise the benefits of introducing special procedures? How will future traffic patterns vary and how will this affect the use of the special procedures?

The cost benefit analysis employed during this research is also in need of a more in depth study and evaluation. The importance of getting this area correct can never be understated, given the very tight cost structures of regional airlines and an ever increasingly cost conscious industry. Airline operating costs need better definition, along with specific monetary benefit figures for increasing the peak hour movement rate. Both of these costs will be airport specific, but are crucial to accurate cost benefit analysis.

Thirdly, the routes studied in the modelling exercises were not examined from a technical aircraft performance feasibility point of view. This remains to be comprehensively assessed, but is crucial to prove the procedures feasibility. Considerable work is also required to define specific procedures for engine failure during execution of a special procedure, missed approach and balked landing, as well as restrictions for wet and contaminated runway operations. Will special procedures be permitted in the case of an engine failure, if not can different single engine SID's be developed for regional aircraft?

The final area mentioned regularly in this thesis is system accuracy requirements. It is beyond the capabilities of this work to define these, but they must be able to ensure safe operation of the procedure and set any necessary route boundaries required in already limited TMA airspace. It requires navigational track keeping accuracy definitions, from which individual system accuracy can be deduced for landing aids, RNAV equipment and approach radar. Within this, redundancy requirements also need accurate definition, as this is likely to significantly affect any procedure costing if duplication of systems are required. A lot of the system requirements will depend on whether the procedure is defined for VFR or IFR operation. The former will require less investment but provide a less reliable tool for effective use.

These are the principle limitations that the author believes exist with this work and prompt a number of areas of future research mentioned. There are further areas however which the author feels require analysis.

9.5: Areas of Future Research

There are seven further areas of research the author has identified following work on this thesis. The first concerns the effect of current changes occurring in regional airlines in terms of increased use of larger aircraft and regional jets on thin longer routes and alliances with major airlines. Research is required to determine how these changes will affect the applicability of special procedures. Can new procedures be developed or will the use of turboprop aircraft cease in the longer term? Will the alliance with the major airline restrict the regional airline's flexibility to accommodate special procedures?

The second area of required research, concerns how the new technologies such as GPS, RNAV, 4D ATC approach aids, and aircraft FMS systems can be integrated to help optimise and improve the special procedures. It is the author's feeling that success in this area is critical to the success of many of the arrival special procedures discussed. As part of this as well, the current philosophy used by ATC of first come, first served, must be reassessed to determine if improvements in final arrival sequencing can be made and so reduce the impact of wake vortex arrival separations. Finally, further research into wake vortices must be encouraged wherever possible, as it is the single largest restriction on runway capacity.

Research into the effect of liberalisation in Europe on peak hour airport capacity demands also merits attention. There is currently a conflict between the aim of liberalisation to increase competition between airlines and an airport's duty to provide adequate capacity. The only way for effective competition for airlines is to provide a comparable number of flight frequencies and timings. Unfortunately this leads to bunching of arrivals and departures at an airport around peak periods. The dilemma for the airport, is that if they expand to accommodate traffic demand during the peak period, they face large time periods outside the peak, where resources are significantly under utilised. The current proposed solution is peak period charges to operators wishing to operate during the busy times. Is this the best solution or are there alternative solutions? Should competition be limited to help match airport capacity with traffic demand at congested airports? To what extent should airports build to accommodate the peak period demand? How far do special procedures go into reducing the requirement for airports to expand capacity?

The limitations discussed above raised the issue of track accuracy requirements. In addition, and especially, in multiple airport TMA's, there is a need to assess any safety risk associated with increasing the number of arrival and departure options. This requires collision risk modelling which has been used widely by the UK CAA[1] and attempts to assess the number of times ATC controllers will not spot a possible collision induced by either pilot error or failure of a navigation aid to provide accurate guidance. The model uses both standard deviation distributions and decision event tree methods. Questions such as what are the tolerances within which potential collision risk occurrence may occur using special procedures and the optimum number of separate arrival and departure paths allowed per airport system need answering.

The human factors for both ATC controllers and pilots in using these special procedures also needs evaluating. How far will the special procedures increase present workload for both parties? Is there an optimum solution to minimise workload? This could be combined with the collision risk modelling.

Political and environmental issues and their effect on airport congestion has been touched upon in this research, but the author believes much further research into the influence these factors have, both now and in the future, is required. In the political arena, issues as far and wide as airline state aid, planning permission procedures, airport operating restrictions and political bias, all need assessment to determine their effect on airport congestion. From an environmental point of view, it appears that all forms of air transport should be stopped due to noise and air pollution damage. How far is this justified? It has already been proven that compared to road transport, air transport's environmental impact is minimal. Noise impact has also been significantly reduced in the last 20 years, with increased usage of chapter three aircraft. What is the opportunity cost of restricting air transport? How far will environmental restrictions go in the future? Will they prevent usage of special procedures, or will they welcome special procedures as a way to increase flexibility in arrival and departure routes? All of these questions need answering.

The final area of research to consider is perhaps the largest. This concerns the potential application of the results of this work, and special procedures in general, to the Asia/Pacific air transport market. An ATAG report in 1991 highlighted the potential problems in airport capacity that may occur in Asia by the turn of the century. With predicted growth rates of 7.5% p.a. between 1995-2000, the regions share of worldwide scheduled passenger traffic is expected to grow from 25.2% in 1995 to 51.1% in 2010. It is also expected that the ability of airlines to respond to increased passenger demand by increasing load factors, aircraft seat densities and aircraft size will be limited. More of the new capacity, ATAG predict will come from an increased number of flights. Traffic will be focused at seven hub airports, namely Seoul, Tokyo-Narita, Osaka, Taipei, Bangkok, Singapore and Hong Kong, which,

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1 Source: CAA (1991) CAA Paper 91010 - Outline of a method for the determination of separation standards for future air traffic systems. CAA

with current curfews, will lead to significant increases in congestion during peak hours. Given that, in addition to the above, short haul traffic is expected to grow faster than long haul routes, can special procedures be effectively employed to help reduce peak period congestion at the seven hub airports? How will application methods vary from those employed in America and Europe, if at all?

9.6: Summary

This research has successfully answered the questions posed at the start of this work by closely scrutinising the existing and potential future operating conditions in Europe. Application of special procedures can significantly help reduce delays during peak periods relatively cheaply, although changes to the peak hour movement rates are limited. Much still requires to be studied however before a complete answer can be given to application of individual procedures to individual airports. In addition there is much more work to be done to fully evaluate all technical and safety issues related to special procedures. Finally, there is a significant potential application of this work in the Asia/Pacific area.

In closing it must be stated that the author feels that many of the obstacles presented with the use of special procedures resulted from either fear of change or ignorance of the possibilities. Only with clear and effective exchange of information between all parties can real success be obtained.

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Appendices

Appendix to Chapter 2

2.1: Runway Operating Limits in Poor Visibility
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Appendix 2.1

Runway Operating Limits in Poor Visibility

Runway Category	RVR Limits	Other Comments*
Non-Instrument Runway	>2600ft	Can only use in VFR Conditions
Instrument Approach Runway	>2600ft	Visual and non-visual aids for straight in approach guidance
Precision Approach Runway - Category I	Down to 2600ft	ILS and Visual Aids with decision height of 200ft
Precision Approach Runway - Category II	2600ft to 1200ft	ILS and Visual Aids with decision height of 100ft
Precision Approach Runway - Category IIIA	1200ft to 700ft	ILS and Visual Aids with decision height of 0ft using visual aids to land
Precision Approach Runway - Category IIIB	700ft to 150ft	ILS and Visual Aids with decision height of 0ft using visual aids in taxiing
Precision Approach Runway - Category IIIC	150ft to 0ft	ILS and Visual Aids with decision height of 0ft No reliance on visual cues for landing or taxiing

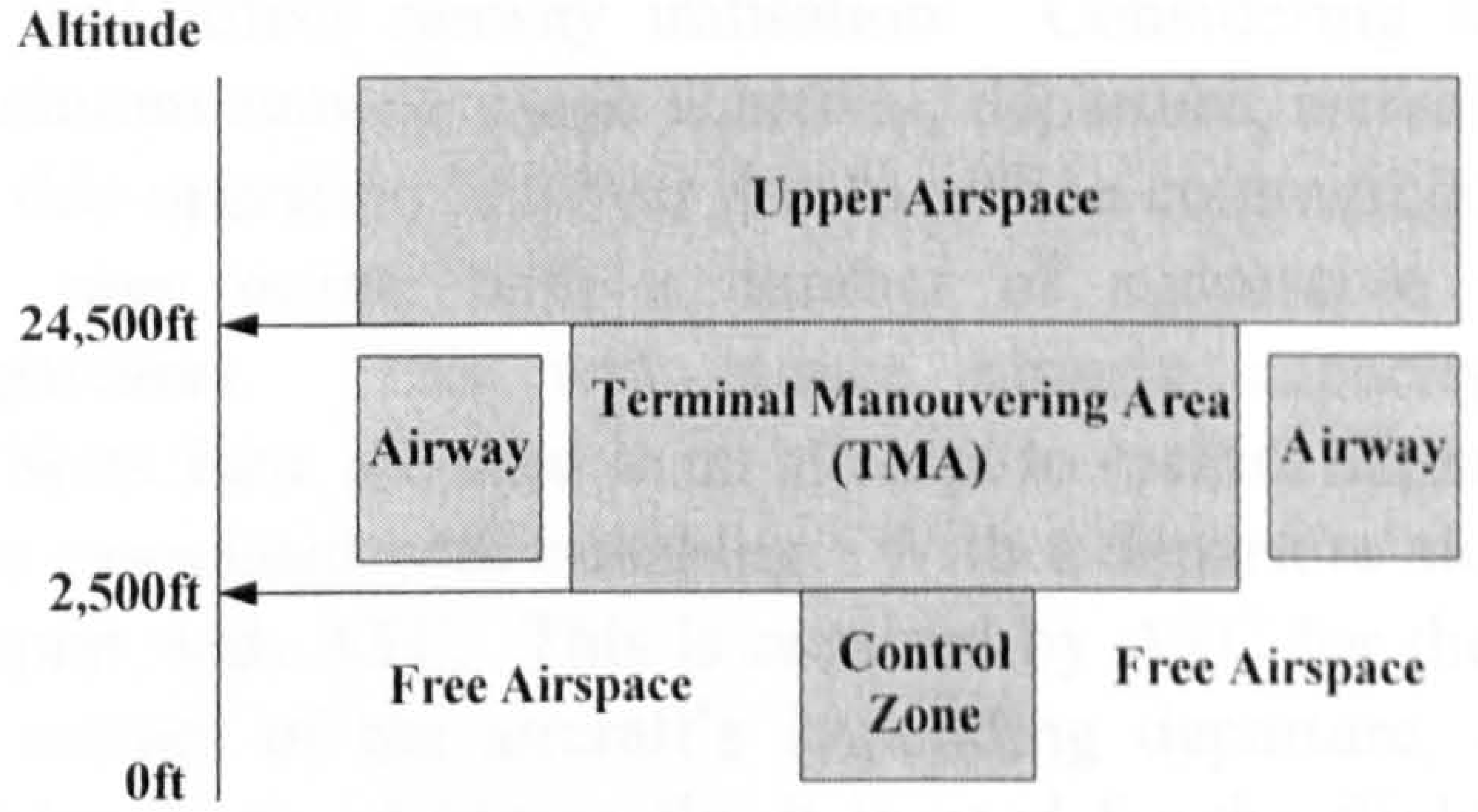
Source: Ashford, N., et al. (1991) Airport Operations

Appendix 2.2

The ATC Operational System

A country's airspace is restricted in its size and use to accommodate demand for general aviation, military training and commercial operations. Consequently, the airspace is broken up into a series of sections to facilitate its management. The vertical structure of the UK's airspace is given below.

The Vertical Division of Airspace



(Source: CAA (1993) London Air Traffic Control Centre**)**

The combined grey areas represent the controlled airspace, which is managed by ATC for licensed aircraft and pilots, and is primarily used for commercial aircraft. The surrounding free or uncontrolled airspace is used for private flying and military traffic, although some of this airspace is restricted purely for military traffic.

The integration of the controlled airspace can be demonstrated by looking at a standard arriving aircraft. Due to the complexity of the whole ATC system, the focus will be in handling aircraft within the terminal manoeuvring area, (TMA), which is the focus of this thesis The arrival would appear en-route to its destination, either in the upper airspace, or on an airway. If on the upper airspace descent guidance would be given to the pilot onto the most appropriate lower airway for his destination. The pilot would then be given further descent and heading guidance along the airway, or corridor, to join the standard arrival route(STAR), to the destination TMA. As the aircraft approached the TMA boundary speed would be reduced, and if TMA capacity was full, the aircraft would be put in a holding stack with other aircraft, with the area controller handing over to the TMA controller. The aircraft would then be required to fly a circular race track to allow the controller time to deal with existing traffic in the TMA. Descent within the stack would occur in 1000ft steps as available. Final release would be on a first come first served basis. Once free of the stack, the aircraft would be radar vectored by one or more TMA controllers or directors, with speed, heading and descent guidance to line the aircraft up on the extended centreline of the runway for final approach. Control of the aircraft would be handed over here to the tower controller at the airport, who would issue the aircraft's landing clearance. Once on the ground, guidance would be given, by the ground controller to the aircraft, to find its alloted gate at the terminal building. For this thesis the sections of airspace that are relevant are the terminal manoeuvring area ,and the control zone which are closest to the airport. The need for close ATC controller liaison between separate sections of controlled airspace is crucial to ensure optimum traffic flows.

When considering departures the situation is basically the reverse of the above situation. Firstly a departure slot needs to be acquired which defines a specific time interval during which the aircraft is able to depart. The purpose of this is to help ATC manage the traffic flow and limit demand during peak hours to the airports sustainable capacity. At congested airports the peak of departures is very important in relation to arrivals, as it will affect runway utilisation. Considering a single mixed mode runway, the optimum runway usage is arrival, departure, arrival. The traffic demand may not allow this operation however due to airline commercial pressures a situation of, 'bunching' may occur, with a number of successive arrivals followed by successive departures. This will reduce runway capacity due to separation requirements. Slots then, are used in an attempt to restrict demand, and remove some of the problems associated with bunching. With a departure slot the aircraft requests clearance to depart with ATC. This is required by ATC for them to inform separate ATC airspace sectors of the aircraft's impending departure, and ensure it can be accommodated by them. Additionally, it is used for the flight crew to obtain their flight routing. The clearance will initially give the departure runway, the standard instrument departure (SID), routing along the preferential noise routing, and primary altitude and speed restrictions. On receipt of clearance the aircraft taxies to the runway for take off. Once airborne the aircraft is handed from the tower controller to departure controller, who monitors the aircraft as it follows the SID restrictions for noise reasons. The SID will take the aircraft to the edge of the TMA, and altitude is usually restricted to 6000ft until clear of the inbound arrival stacks. The controller may instruct the pilot climb or increase the speed of the aircraft along the SID to expedite the departure, or help traffic flow, but can not deviate the aircraft off the SID track until above 6000ft. Once the aircraft reaches the end of the SID, either in altitude or track, it is passed on to the area controller who is responsible for aircraft's climb to its assigned en route cruise level along the airway and up into upper airspace if appropriate.

Source: Derived from Paylor, A. (1993) Air Traffic Control Today and Tomorrow - Ian Allen

Appendix 2.3

Tools Available to an Air Traffic Controller

System	Description
Radio	Used to communicate with the aircraft. There are two types, VHF and HF. The former is of higher quality and used over land, the latter used over sea.
Primary Radar	Uses reflected radio beams to highlight dense objects. Provides spatial location of aircraft to controller on a screen. This primary radar was a line of sight instrument that could not positively identify aircraft without them turning at ATC instruction.
Secondary Radar	Updated the primary radar. Requires a transponder on an aircraft to interrogate for identity, and with a mode C transponder, altitude information is provided as well. Both types of radar are required in busy airspace to identify all aircraft with or without transponder.
Multi radar Tracking	The use of many radars has resulted in areas of overlap. Multi radar tracking combines radar returns of the same aircraft to remove irregular returns, and improve location accuracy.
Precision Approach Radar	This is a high accuracy radar which is used to talk aircraft down a final approach path for landing - azimuth and elevation. It is used infrequently when ILS systems are not available or feasible due to terrain.
Datalink/Mode S Transponder	Mode Select, (Mode S), is an advanced aircraft transponder that is selectively addressed and can improve overall surveillance accuracy by a factor of up to four. In addition messages can be passed from ATC to aircraft and between other Mode S equipped aircraft.
Radar Display Screen	Displays the radar images. Aircraft are identified using the secondary radar. Modern screens use computers to generate the radar image, which improve resolution and allow additional information such as airspace boundaries, airways, weather, separation requirements, aircraft performance data, etc., to be added.
Non-Directional Beacon (NDB)	The most basic navigation tool regularly used in controlled airspace. It provides a continuous radio signal which, when identified by an aircraft's automatic direction finder (ADF), provides a direction indication of the aircraft from the beacon. They are not limited by line of sight.
Very High Frequency Omni-directional Radio range, (VOR)	A more sophisticated and accurate navigation tool used for airway guidance in controlled airspace, runway centreline guidance and position reporting. It provides 360° bearings from its location with radial tracks for aircraft to follow. This information is presented to the pilot on the horizontal situation indicator (HSI), in the cockpit. It is line of sight restricted.
Distance Measuring Equipment, (DME)	Normally co-located with the VOR it provides slant distance of the aircraft from itself. It is basically a transponder on the ground that the aircraft interrogates and uses the Doppler effect to convert the time delay into distance. Accuracy decreases as cruise aircraft pass overhead with the slant distance measurement.
Runway Visual Range, (RVR)	Provides runway visibility information to ATC and pilots.
Runway Lighting	Provided in varying levels of sophistication depending on the visibility limits of the runways operation. Defined in Annex 14 to ICAO Chicago Convention.

System	Description
Visual Approach Slope Indicators, (VASI)	Three symmetrically positioned banks of lights at the runway touchdown point. Lights are angled to give the correct glidepath for aircraft approaching the runway. Further defined in Annex 14 ICAO.
Precision Approach Path Indicators, (PAPI)	Single row of four lights satisfying the same job function as VASIS, which they are replacing.
Instrument Landing System, (ILS)	This is a high precision approach system. It provides a localiser beam indicating the horizontal direction of the runway centreline and a glideslope or rate of descent indicator to the runway. It is usually calibrated up to 10nm from the airport, although the tolerance of both beams is greater at this distance. Two to three locator markers are placed along the ILS localiser path. The outer marker is located 3.5 to 7 nm from the runway threshold, often with an NDB, the middle marker 3500ft from touchdown and the inner marker closer still. Calibration can allow CATIIIC landings. It is presented to the pilot as two cross bars, usually on the flight director, which if kept crossed in the centre indicate correct heading and glidepath. The glideslope is normally 3° or 800ft per minute but can be recalibrated to any setting required. It is a costly system to install and run. It requires an unobstructed path, limited ground movement nearby and a straight in approach for aircraft.
Microwave Landing System, (MLS)	Developed to replace the ILS. Provides precision landing guidance over an angle of 80° to 120° from the runway centreline with glideslope angles of 0.9° to 15°. It allows curved approaches to be flown to the runway, so getting round some of the ILS problems. Currently on trial throughout Europe.
Global Positioning System, (GPS)	24 satellites operated by the US Dept. of Defence primarily for the military. Service provided for civil operations with downgraded accuracy. Position guidance is achieved with three/four satellites reporting to the aircraft from different locations. Currently used in en route trials especially over oceans, it can also be modified for precision approach guidance and could replace existing navigation systems if proven dependable.
Area Navigation Systems (RNAV)	This is a system on board the aircraft which will enable the aircraft to fly between any two points defined by latitude and longitude by taking references from existing ground based navigation aids. It offers the controller complete flight path routing flexibility but currently has limited applicability due to aircraft/ATC interface problems.
Flight Strips	Paper stripes providing the ATC controller with information for each flight from the ICAO flight plan, filed by the airline. Additional flight clearances added by controllers handling flight. Currently looking at ways to provide flight strips on the computer screen.

Source: Paylor, A (1993) Air Traffic Control Today and Tomorrow - Ian Allen

Appendix 2.4

Determining Radar Separation Minima

In developing the separation minima there are a number of factors that need considering. The ICAO Air Traffic Services Planning Manual, (1984), breaks them into four sections: position factors, control factors, human factors and the buffer. Position factors refer to the accuracy of position indication and the accuracy with which flight progress can be maintained. Errors can occur in any part of the air or ground navigation equipment, in estimating position by dead reckoning, or in operational tolerances of the flight path allowed without ATC notification. Control factors are either communication delays in position reporting for whatever reason, or clock errors either on the ground or in the air. Human factors of the pilots and controllers can also induce errors due to lack of experience or familiarity with the environment, mental attitude, or reaction time. Finally there is the buffer which is defined by the ICAO manual as follows:

> *"The buffer is a minimum physical distance of defined dimensions to accommodate:*
> *a) Variations in an aircraft's flight path due to air movements, etc.;*
> *b) The size of the aircraft;*
> *c) An additional miss distance."*

Once all the separation standards are established, the ICAO manual then discusses the prospect of reducing those minima. Four possibilities are discussed. It is argued that if the navigational accuracy of ground or air equipment, or the pilot, has clearly improved with no increased safety risk, then minimum's could be reduced. Also, if the time interval between position reports can be reduced, the controller will be more certain of the aircraft's exact position and hence capable of reducing minima. This will only be possible if rapid and reliable air to ground communication exists, which, in congested airspace with many aircraft being controlled by the same person, is at present limited. The third possibility is the optimisation of traffic mix along the same track and concerns the rate of closure of a faster aircraft following a slower one. If the faster aircraft can be placed ahead of the slower aircraft, or the rate of closure reduced, then separation could also be reduced. Lastly the way traffic information is presented to the controller significantly limits separation minima. The higher the rate that information is updated the better are the chances of reducing separation between aircraft, as the controller has a more accurate picture of the traffic flows. This remains true up to the point that the display becomes so complex that the ability of the controller to observe, analyse, and make a decision about a situation is reduced.

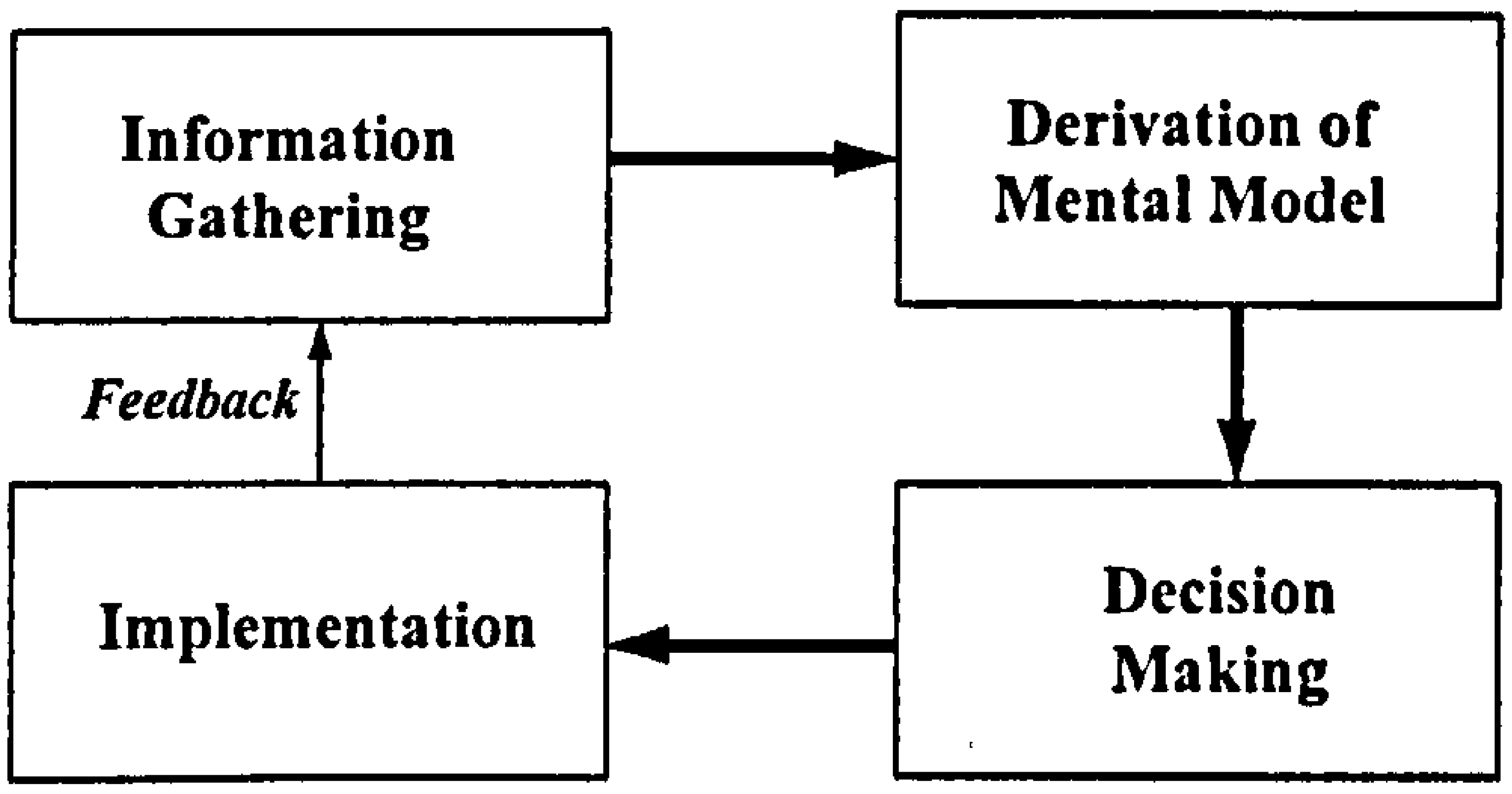
Source: ICAO (1984) Air Traffic Services Planning Manual

Appendix 2.5

Controller Workload

The job of an ATC controller can be broken into four sections as shown below.

ATC Controller Job Functions



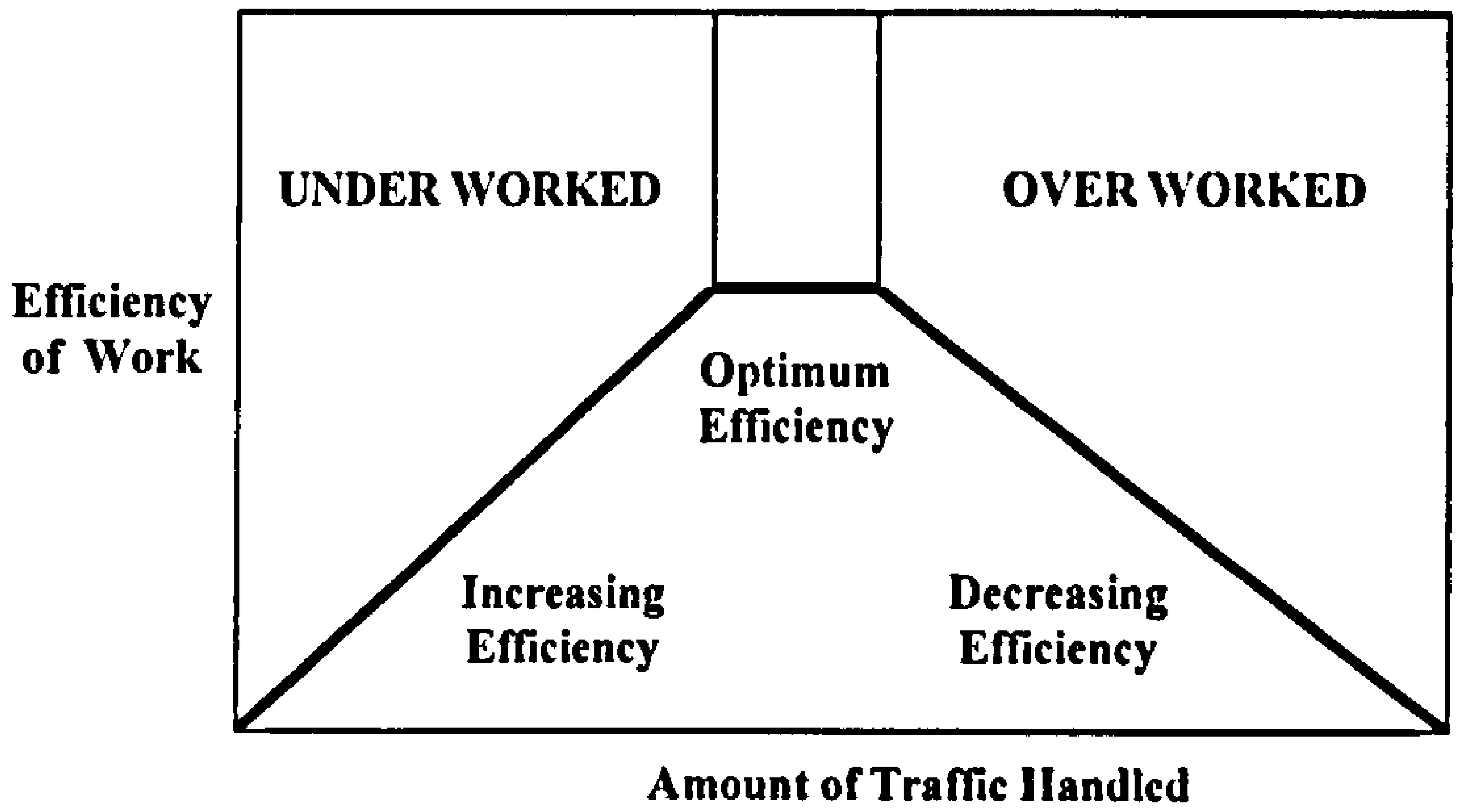
The diagram is relatively straight forward. Information is gathered by the controller from the radar screen, flight strips and communication with aircraft under their control. The next step is the construction of a mental picture in the controller's mind of aircraft position, terrain, airspace structure, etc. The success of the next step depends on the effectiveness of this mental picture in representing reality. The model will be limited by the controllers training, experience and preconceived belief of what the system is supposed to do.[1]

Once the mental model is finalised a decision is made on any action required. In doing this the controller must decide what plan for the air traffic he wishes to follow, and how it can be done with least disruption to other aircraft, within operating laws. Once the decision is made it is implemented. Following implementation, information is fed back to the controller to update the present situation and enable him to formulate the next model and plan.

Obviously, as the level of traffic handled by the controller increases, the time available to the controller to think through decisions will reduce, leading to increased levels of stress. This relationship is shown as follows:.

[1]Mogford, R. (1991) Mental Models in Air Traffic Control - Paper in, 'Automation and Systems Issues in Air Traffic Control - NATO ASI Series 1991, p235-242

Concept of Controller Workload



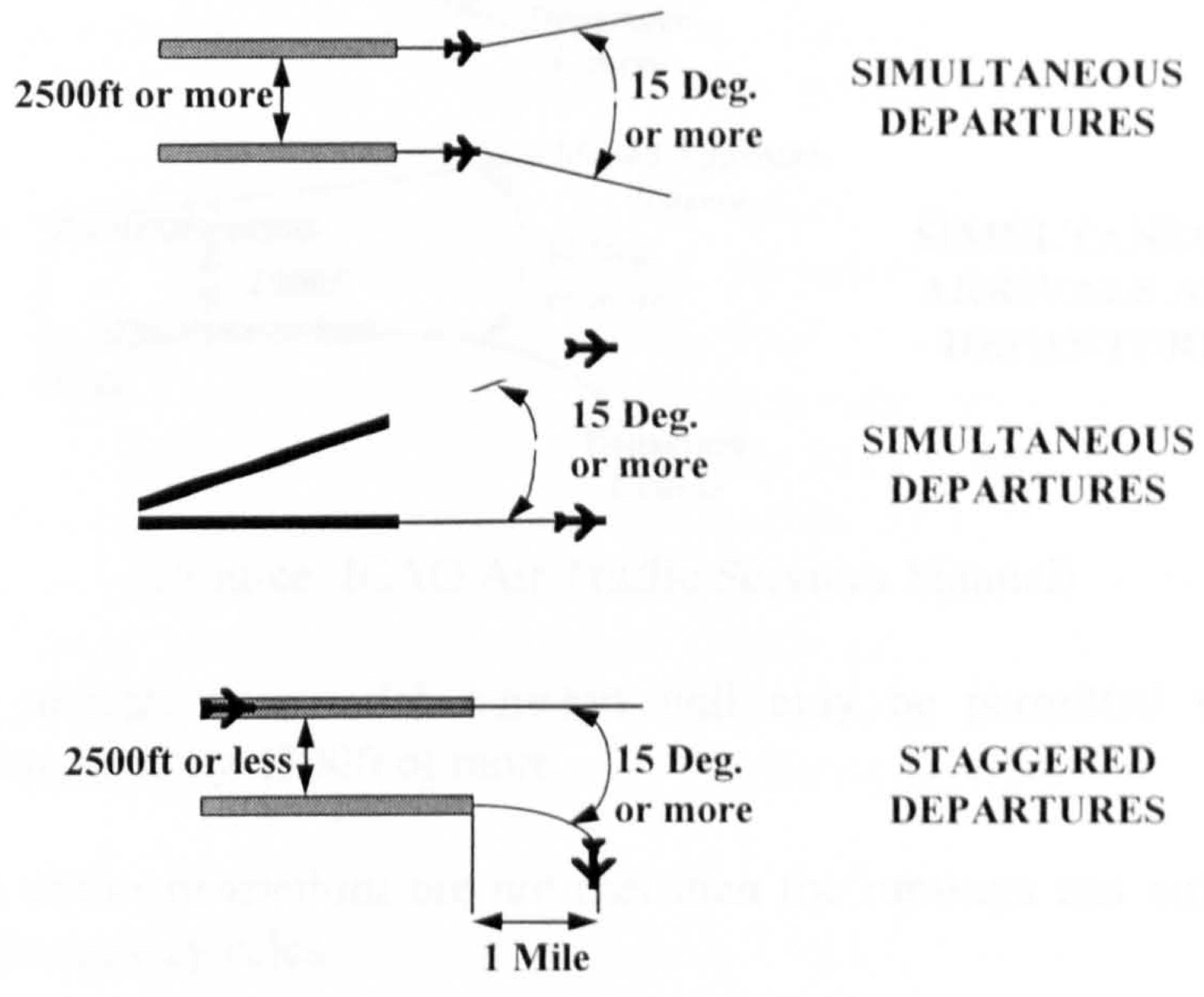
Note: Efficiency of Work can also be interpreted at Stress Level

This indicates that initial increases in stress are beneficial to the system as efficiency is increased, however, once the traffic passes a certain point the stress on the controller becomes detrimental leading to a reduced ability to efficiently handle traffic. If extreme levels of traffic occur safety may be compromised. Jorna, P. (1991) provides a good examination of operator workload as a limiting factor in ATC. They indicate that each person will have their own optimum level, due to their individual personalities and work experience. This level however, will represent the fixed capacity of the airspace under the controller. Intensity and duration of high levels of traffic will also reduce total capacity as controllers tire more rapidly. He also discusses the problem with modern, high technology, systems and the break down in the, 'man-machine interface'. This occurs when a technological advancement in mechanical systems reduce the ability of the worker to do their job. They become, 'out of the loop', or lose touch of the situation. The consequence of this is serious to ATC, as the controller must have clear situational awareness to make decisions. There is concern with present controllers that the increasing demands being placed on the airspace, and technological advances in aircraft systems, which exceed the ability of those on the ground, will force increased technology onto ATC, which may degrade their ability to do their job. What is certain, however, is that the increased level of traffic will only be allowed to operate, if controllers can do so without increasing the safety risk. Careful management of controller stress, workload, and technical aids will be the key to a sustainable ATC system in the future, capable of satisfying traffic demand.

Appendix 2.6

Multiple Runway Operating Restrictions

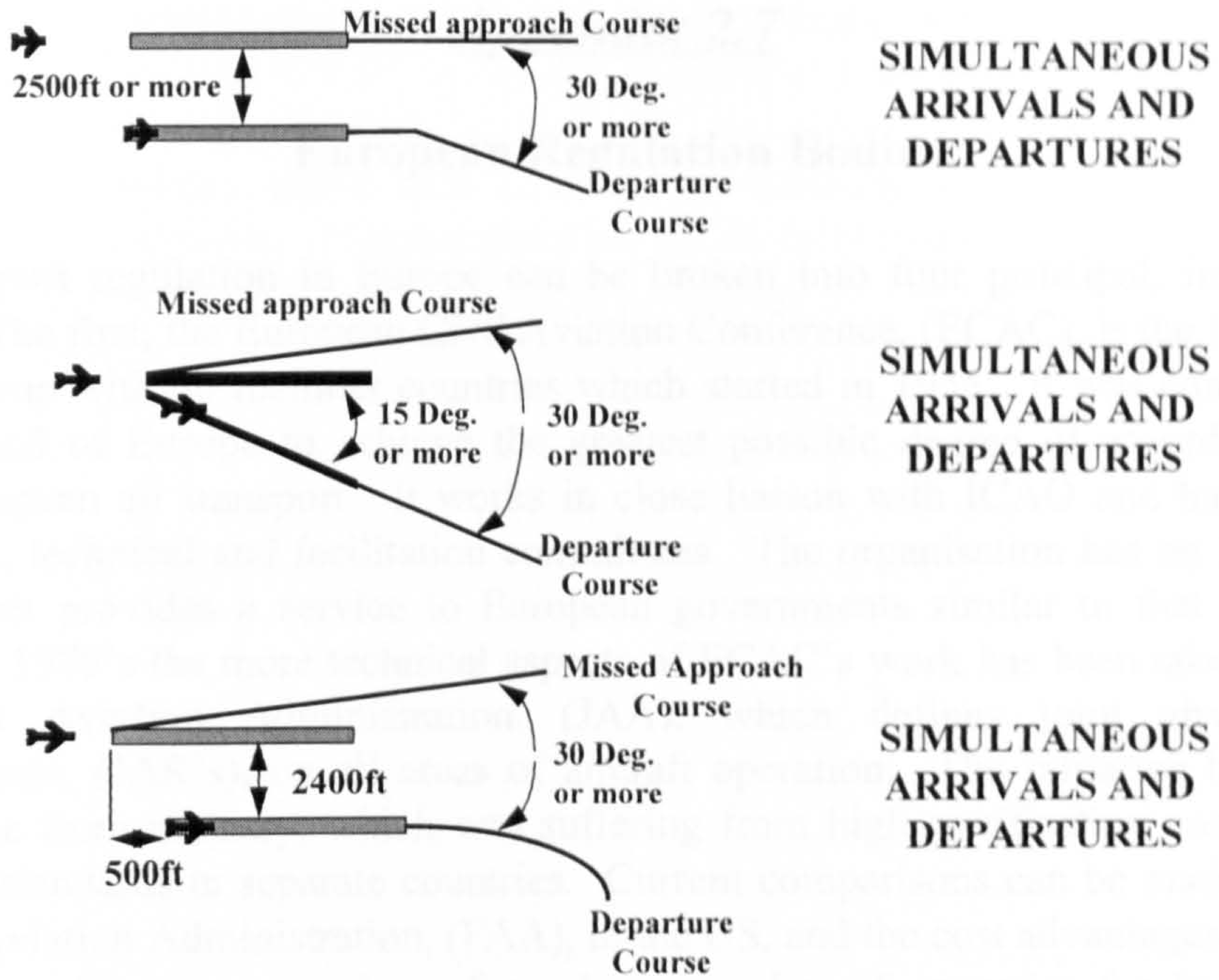
Simultaneous departures from parallel or diverging runways are allowed if the track of two successive departures diverge by 15° or more, and the parallel runways are greater than 2500ft apart. If the parallel runways are less than 2500ft apart, the departures must be separated by 1 mile in addition to the above restrictions.



(Source: ICAO Air Traffic Services Planning Manual)

Simultaneous arrivals and departures to airports with more than one runway are limited depending on the runway separation, stagger and missed approach procedure. The exact limits are defined below. For the staggered runway example every reduction in runway separation of 100ft requires a stagger of 500ft between active thresholds. The diverging runway example only applies if the two thresholds do not touch.

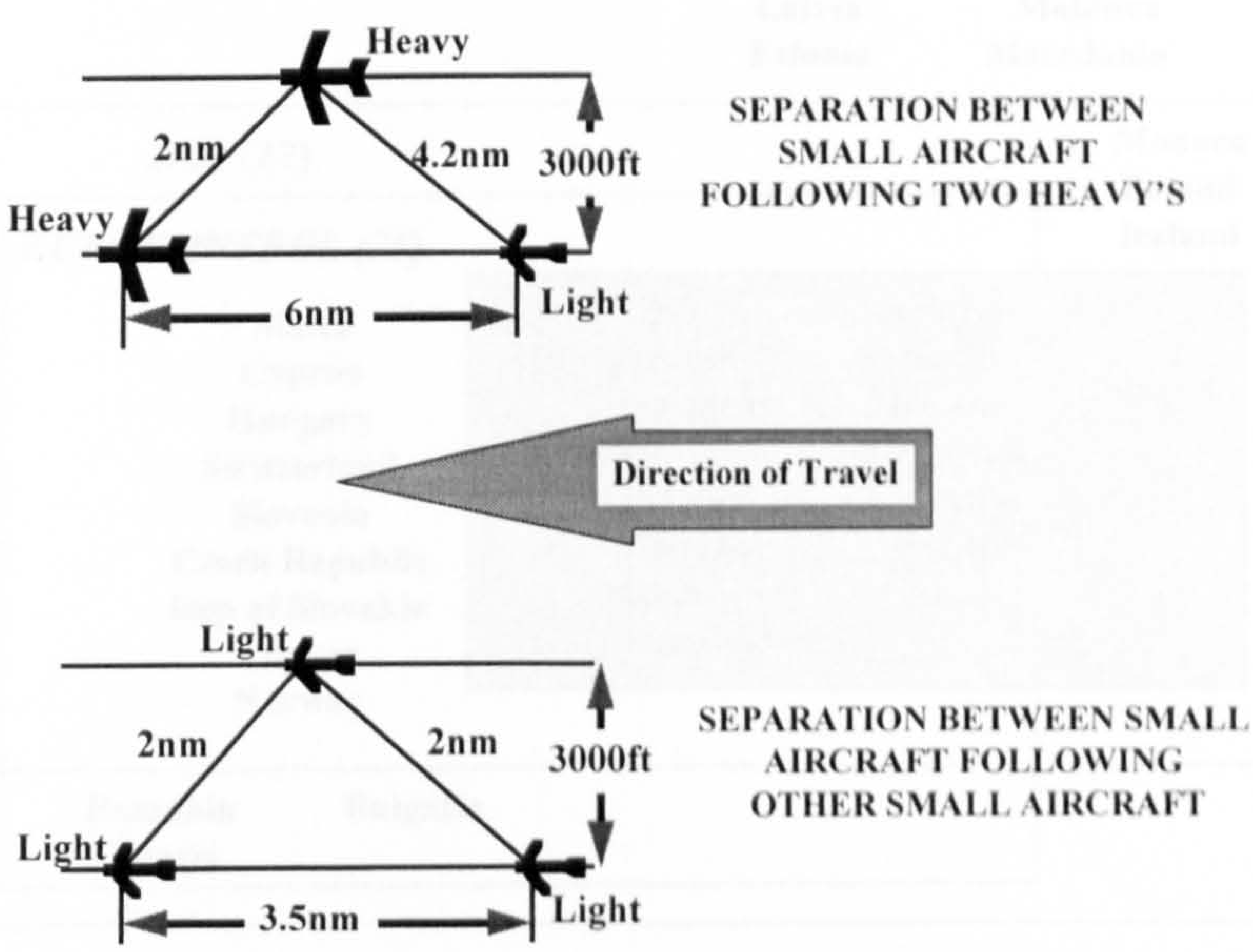
The final scenario is using multiple runways for arrivals only. Separation standards already discussed apply with additional ones due to the close proximity of the runways. The final diagram details some of these restrictions. In addition to this, the missed approach procedures must not conflict and during the turn on to the FAP aircraft separation must be maintained at either 1000ft or 3nm. As the aircraft descends, with the ILS, controllers must ensure the aircraft do not impinge the no-transgression zone, which is the area between the two approach paths.



(Source: ICAO Air Traffic Services Manual)

Simultaneous arrivals to parallel runways will only be permitted when the two runways are separated by 4300ft or more.

Finally, if the above restrictions are not met then the runways can only be operated under the single runway rules.

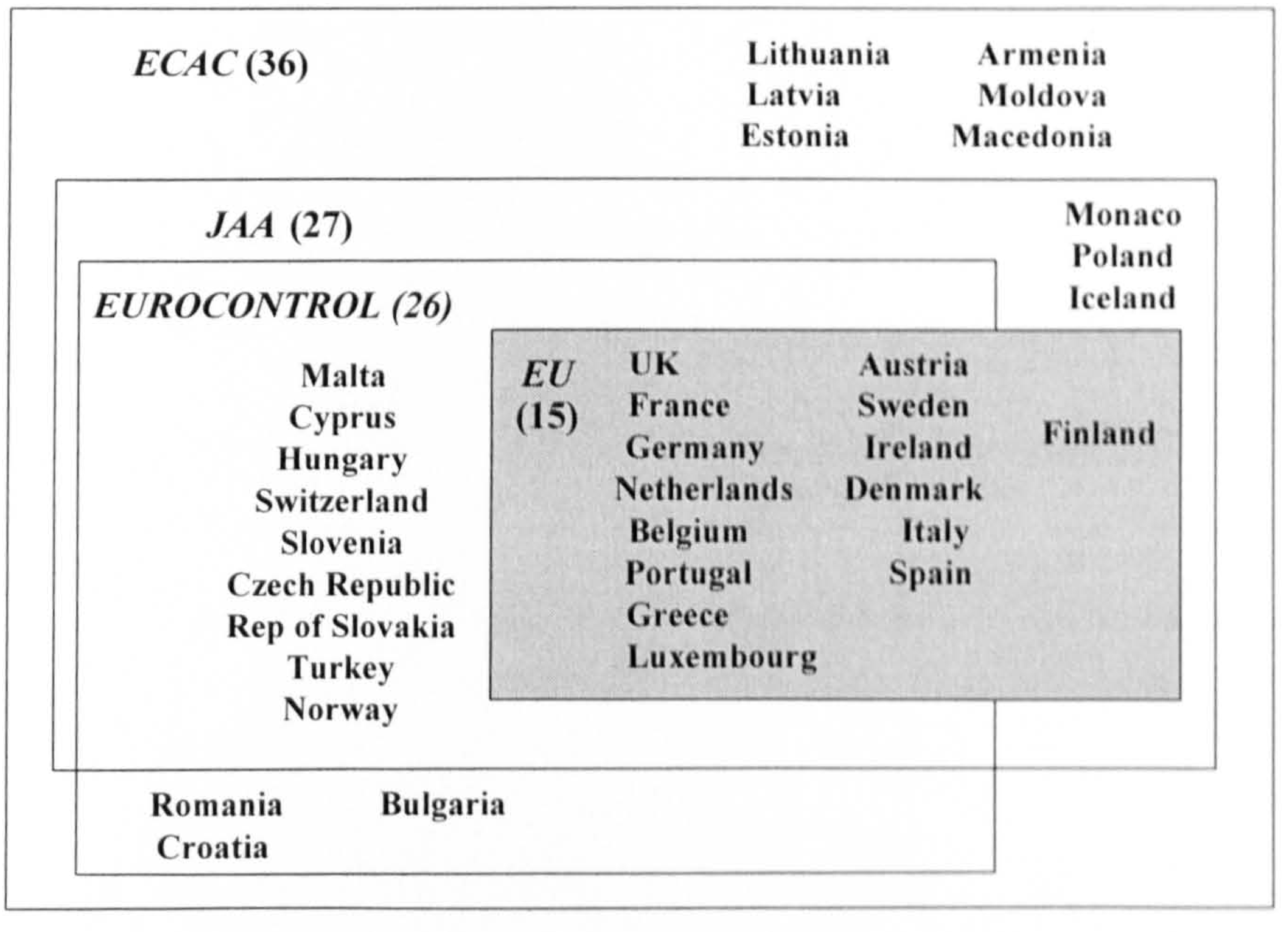


(Source: ICAO Air Traffic Services Manual)

Appendix 2.7

European Regulation Bodies

Air transport regulation in Europe can be broken into four principal, inter-related groups. The first, the European Civil Aviation Conference, (ECAC), is the largest and oldest group with 36 member countries which started in 1955. It was conceived by the Council of Europe to achieve the greatest possible degree of co-ordination of intra-European air transport. It works in close liaison with ICAO and has separate economic, technical and facilitation committees. The organisation has no legislative powers but provides a service to European governments similar to that of ICAO. Since the 1970's the more technical aspects of ECAC's work has been taken over by the Joint Aviation Administration, (JAA), which defines joint airworthiness requirements, (JAR's), on all areas of aircraft operation. The initiative behind the JAA came from industry, which was suffering from high certification costs, due to differing standards in separate countries. Current comparisons can be made with the Federal Aviation Administration, (FAA), in the US, and the cost advantages of having common certification procedures for a large number of countries for both aircraft manufacturers and airlines can be significant, as it allows easier operation and transfer of aircraft between participating countries. Many of the JAR's have now been completed, although problems with flight crew licensing standards still remain. In addition, the JAA has not yet attempted to harmonise regulations on airports or ATC.



Source: ATM MSc Course Notes 1996/97

The third largest country co-operation in Europe is Eurocontrol, consisting of 26 members. Eurocontrol was developed in 1960 to provide ATC in the upper airspace above 25000ft. Currently upper airspace control is only provided for the Netherlands, Belgium, Luxembourg and the northern half of Germany by its centre in Masstricht, Netherlands. The issue of ATC integration in Europe is not an easy one as there are at least 51 air traffic control centres in the ECAC area using 31 different systems, using 18 different computer types, with 22 different operating systems and 33 different programming languages. This compares to just 22 fully integrated centres in the US, an area of equivalent size. Eurocontrol is attempting to develop a standard operating system for Europe to overcome this problem, which undoubtedly increases congestion problems. Finally, it is attempting to co-ordinate separate flow management centres in Europe through its headquarters in Brussels. In conjunction with this work Eurocontrol is required to analyse and propose future development recommendations of ATC systems, which it does through its experimental centre at Bretigny-sur-Orge in France.

The final and most powerful regulatory group in Europe is the European Union, (EU), which consists of 15 member states and was formed to create a common trading market in the 1970's. Aviation regulation is controlled through DG IV and DG VII of the EU. Currently they have adopted the JAR's and recommended adoption by member states governments to harmonise regulations. A number of environmental regulations on air and noise pollution have also been passed for adoption by members affecting airport and aircraft operations.

Appendix to Chapter 3

3.1: Aircraft Performance Characteristics
3.2: Jet Operating Speeds - BAe 146-300 and Boeing 737-200
3.3: Turboprop Operating Speeds - Fokker 50 and ATR 72
3.4: Turn Radius variations with Speed
3.5: Extract of Air UK BAe 146 Operations Manual on Steep Approaches

Appendix 3.1

AIRCRAFT PERFORMANCE CHARACTERISTICS (Flight Int. 27/10-2/11/93 and 21-27/4/93)

A/c Type	Speeds			Long Range Cruise			Payload		Field Lengths - Take Off			Field Lengths - Landing			Weights				Seat Cap.	Turn	360 Deg Turn
	V_2 (kts)	Vat (kts)	Vs (kts)	Max Cru Spd (kts)	Cru Alt. (ft)	Fuel Consump Kg/hr	Max Pld (kgs)	Max Rng Pld (Kgs)	ISA SL (ft)	ISA +20C (ft)	ISA+5000ft (ft)	ISA SL (ft)	ISA +20C (ft)	ISA+5000ft (ft)	MRW (Kgs)	MZFW (Kgs)	MTOW (Kgs)	MLW (Kgs)	Max	Radius (ft)*	Distance (ft)
Jets																					
DC9-30	137	126	97	503	35000	4050	14000	3560	5248	6560	9643	4297	4297	4871	49500	39500	49000	45000	115	1441	9056
A319				487	37000	3150	17400	7745	5740	6822	7741	4428	4428	5018	64400	57000	64400	61000	153		
B767-200	142	136	105	492	39000	5370	33974	8797	5806	6298	7400	4799	4799	5448	152861	114759	151953	126099	290	1679	10551
BAC 1-11			109	459	35000	2748	9648	4279	5897	7200	9033	4726	4726	5451	41958	34021	41721	39463	89	1823	11454
B737-500	134	130	100	492	35000	3574	15530	6389	6009	6570	7596	4467	4467	5028	52620	46490	52390	49900	132	1534	9640
MD87	141	133	102	499	35000	3924	17619	5478	6117	7088	8669	4759	4759	5294	63950	53524	63500	58000	139	1606	10090
B757-200	146	132	102	505	39000	5350	26090	8460	6166	6921	8692	4641	4641	5232	100245	83400	99792	89800	239	1582	9939
B737-400	159	138	106	492	35000	3307	17740	5241	6347	7688	9617	4940	4940	5560	63050	51260	62820	54880	168	1729	10863
B737-300	148	133	102	491	35000	3890	16030	5902	6360	6918	7977	4579	4579	5169	56700	47630	56470	51710	149	1606	10090
B737-200	147	131	101	485	35000	4005	15710	5347	6527	6658	10929	4428	4428	5297	52620	43092	52390	47600	130	1558	9789
DC9-40	151	131	101	501	35000	3980	14379	3315	6858	7879	12248	4779	4779	5428	52200	42200	51700	46300	125	1558	9789
A320	135	134	103	487	37000	3200	20000	6865	7150	8495	9676	4723	4723	5396	73900	61000	73500	64500	180	1630	10243
A321	150	140	108	487	37000	3550	22900	5685	7200	8102	10529	5182	5182	5888	83400	69500	83000	73500	220	1779	11180
MD81	148	133	102	499	35000	4077	17953	5280	7200	8679	9197	4858	4858	5458	63950	53500	63500	58000	172	1606	10090
A300-600	151	135	104	480	35000	5160	42400	7900	7347	8692		5025	5025	5648	165900	130000	165000	138000	375	1655	10396
MD82/88	153	134	103	499	35000	4077	18802	4941	7459	8567	9197	4920	4920	5517	68270	55340	67812	58970	172	1630	10243
BAC 1-11-500			120	457	34000	2772	12000	3886	7469	7469	11598	4756	4756	5560	45360	36742	45201	39020	119	2209	13882
A310	156	138	106	484	37000	4690	33300	9400	7511	8036	9676	4887	4887	5543	150900	113000	150000	123000	280	1729	10863
L1011-200	165	144	111	512	33000	7938	32395	10040	7698	8597	10598	5799	5799	6547	212281	145150	211374	166922	400	1883	11828
L1011-1	153	138	106	512	33000	8165	37771	9075	7947	9643	9597	5697	5697	6399	195951	147417	195044	162386	400	1729	10863
DC9-50	160	132	102	501	35000	4525	15265	3545	8200	10266	12070	4756	4756	5182	55400	44700	54900	49900	139	1582	9939
B767-300	161	141	108	492	39000	5479	39644	8241	8348	9151		5399	5399	6098	160118	126099	159211	136078	345	1805	11341
MD83	153	139	107	499	35000	4027	18721	5828	8367	10056	10116	5199	5199	5848	73030	55340	72580	63280	172	1754	11021
A330	154	137	105	500	39000	5000		12950	8594	10168		7052	7052		212900	164000	212000	174000	440	1704	10706
B767-200ER	163	140	108	492	39000	5370	35562	11945	8594	10299		4999	4999	5658	180076	117934	179169	129274	290	1779	11180
L1011-500	166	146	112	518	33000	7847	41845	11760	8646	9948	10998	6799	6799	7649	225889	153314	224982	166922	333	1935	12159
B777-200		140	108	499	39000		54450	13060	8790	11513		5609	5609	6363	268550	195050	267600	208650	440	1779	11180
A300 B4	165	137	105	480	33000	6570	37980	7250	9348	13907	12005	5363	5363	6101	165900	124000	165000	134000	345	1704	10706
A340	154	144	111	500	39000	7300	50900	15600	9348	10824	14432	9676	9676		257900	174000	257000	186000	440	1883	11828
MD11	177	148	114	0.87M	31000	8970	55566	15250	9597	10096	11916	6448	6448	7328	285081	195043	283720	207744	405	1989	12495
DC8-72	164	136	105	480	39000	4890	20094	11528	9745	9896	12595	6098	6098	7098	160100	88900	158900	108900	201	1679	10551
L1011-250	172	145	112	518	33000	7620	40025	11853	9797	11198	10998	6698	6698	7498	232239	153314	231332	166922	400	1909	11993
DC10-10	172	138	106	0.85M	31000	9445	41730	10649	9804	12516	13625	5819	5819	6599	200941	151953	199580	164881	380	1729	10863
DC10-30	184	147	113	0.85M	31000	9743	45910	11850	9827	10476	14235	5970	5970	6767	265000	166893	265000	263636	380	1962	12326
B767-300ER	173	145	112	499	39000	5400	44497	10834	9840	13396		5707	5707	6448	187334	133810	186880	145150	345	1909	11993
B727-200	166	137	105	530	33000	4536	37800	6019	9948	11998	12995	4900	4900	5448	95238	63318	95028	72575	189	1704	10706
B747-100	169	141	108	507	35000	12890	69400	13020	10004	10660	12497	6199	6199	6986	341560	238820	340200	255830	550	1805	11341
B747-200	177	152	117	507	35000	12990	92310	13770	10463	11841		6898	6898	7806	379210	267620	377850	285830	550	2098	13179
B747-300	177	141	108	507	35000	12110	68630	13590	10463	11841		6298	6298	7085	379210	242680	377850	260370	660	1905	11341
L1011-100	159	143	110	512	33000	7938	33355	9555	10798	11398	13497	5799	5799	6547	212281	145150	211374	166922	400	1856	11665
B747-400	185	153	118	507	35000	11230	63870	15410	10890	12218		6986	6986	7905	395990	242670	394630	285760	660	2125	13353

Note:
* Using Formula given in Chapter 3

Appendix 3.1

AIRCRAFT PERFORMANCE CHARACTERISTICS (Flight Int. 27/10-2/11/93 and 21-27/4/93)

A/c Type	Speeds			Long Range Cruise			Payload		Field Lengths - Take Off			Field Lengths - Landing			Weights				Seat Cap.	Turn	360 Deg Turn
	V2 (kts)	Vat (kts)	Vs (kts)	Max Cru Spd (kts)	Cru Alt. (ft)	Fuel Consump Kg/hr	Max Pld (kgs)	Max Rng Pld (Kgs)	ISA SL (ft)	ISA +20C (ft)	ISA+5000ft (ft)	ISA SL (ft)	ISA +20C (ft)	ISA+5000ft (ft)	MRW (Kgs)	MZFW (Kgs)	MTOW (Kgs)	MLW (Kgs)	Max	Radius (ft)*	Distance (ft)
Regionals																					
D228	80	85	65	235	10000	320	2200	2582	2608	3395	3608	1476	1574	1706	6430	5940	6400	6100	19	656	4121
D328				335	25000		3450		3608			3313				12260	13640	13230	30		
EMB BANDIT	85	100	77	225	10000	310	1565	1852	4051	4592	4904	4477	4477	5002	5930	5450	5900	5700	19	908	5704
EMB BRASILIA	115	115	88	313	25000	480	2923	3540	4920	5248	5970	4428	4428	4920	11580	10500	11500	11250	30	1201	7544
EMB 145	125	120	92	430	35000	1100	4800	2780	5084	5838	6396	5150	5150	5576	19300	16410	19200	18700	48	1307	8214
CASA 212-300	94	91	70	191	10000	350	2320	1823	2936	3657	3821	1702	1761	1840	7750	7100	7700	7450	26	752	4724
CASA CN-235	94			248	18000	535	4250	4890	4297	4789	5412	2558	2657	2788	15150	14100	15100	14900	45		
SH 330	100	95	73	190	10000	420	2655		3805	4690		3608	3542		10430		10385	10250	30	819	5148
SH 360	105	106	82	215	10000	475	3185	1575	4280	4805	4707	4002	4002	4477	12340		12290	12020	39	1020	6409
SF 340	112	110	85	280	20000	520	3760	3470	4166	4592	5215	3444	3444	3870	13060	11790	12930	12700	37	1099	6902
SF 2000	129	125	96	360	31000	950	5900	3160	4461	4920	5576	4100	4100	4559	22200	19400	22000	21500	58	1419	8913
Dash 8-100	92	95	73	270	25000	580	3810	2843	3083	3477	3772	2985	2985	2985	15740	14060	15650	15375	39	819	5148
Dash 8-200			72	300	25000		3365	2843	3149			2985				14515	16465	15375	39	795	4997
Dash 8-300	105	105	81	285	25000	775	5215	2400	3395	3756	5576	3296	3296	3296	18730	16870	18645	18145	56	1001	6289
Dash 8-400				350					3729			3870				22227	29993	24721	70		
Dash 7	85	82	63	230	16000	860	5160	2870	3001	4100	4362	3149	4723	3542	21360	17700	21340	20430	50	610	3836
CRJ	140	130	100	460	39000	1175	4535	3235	5264	5445	7282	4723	3149	5297	21635	19140	21525	20275	50	1534	9640
IPTN N-250				300	20000		6000	2038	4002			4002				18565	22000	20650	54		
F 50-100	98			282	25000	679	6080	4017	3700	4405	4786	3654	3654	4067	19990	18600	19950	19500	58		
F50-300	98			284	25000	695	6080	3934	3454	3966	4349	3654	3654	4067	19990	18600	19950	19500	58		
F 50-400	102			276	25000	727	7177	3597	4648	5776	6524	4028	4028	4503	22295	20600	22250	21500	68		
F70	126	119	92	461	35000	2391	9302	3487	4562	5038	5691	3962	3962	4385	36965	31975	36740	34015	79	1286	8078
F100	138	130	100	461	35000	2650	11993	4245	4005	6599	6658	4421	6599	6658	46040	36740	45210	39915	107	1534	9640
ATR 42	105	105	81	269	25000	570	4915	4635	3411	4051	4395	3378	3378	3788	16720	15200	16700	16400	50	1001	6289
ATR 72	110	110	85	284	25000	640	7500	4370	4625	5248		3952	3952		21020	19700	21000	20850	74	1099	6902
BAe J31			86	269	25000	361	1902	2277	5123	5865		4474	4474		7400	6500	7350	7080	19	1135	7130
BAe J41	120	115	88	295	29000	565	3040	3125	4592	5215		3378	3378		10485	9390	10435	10115	29	1201	7544
BAe ATP				265	22000		6990		4395	5494		3690	3690		23000	21230	22930	22230	72		
146-100	119	121	93	432	29000	2150	8650	2987	4723	5874	6035	3838	3838	4339	38328	32205	38102	37875	94	1329	8352
146-200	124	122	94	432	29000	2237	11457	2693	5399	6547	6898	3910	3910	4379	42410	35834	42184	38555	112	1351	8490
146-300	127	123	95	432	29000	2310	12059	2108	5999	6947	7596	4149	4149	4599	44266	37421	44225	40413	112	1374	8630
Avro RJ70	119	121	93	432	29000	2150	8650	2987	4723	5874	6035	3838	3838	4339	38328	32205	38102	37875	94	1329	8352
Avro RJ85	124	122	94	432	29000	2237	11457	2693	5399	6547	6898	3910	3910	4379	42410	35834	42184	38555	112	1351	8490
Avro RJ100	127	123	95	432	29000	2310	12059	2108	5999	6947	7596	4149	4149	4599	44266	37421	44225	40143	112	1374	8630
Avro RJ115	127	123	95	432	29000	2380	11265	2459	5999	6947	7596	4149	4149	4599	44266	37421	46040	40143	112	1374	8630

Note:
* Using Formula given in Chapter 3

APPENDIX 3.2

JETS

BAe 146-300 OPERATING SPEEDS

TAKE OFF FLAPS 18					LANDING FLAPS 33
AIRCRAFT WEIGHT (KGS)	V_R (KTS)	V_2 (KTS)	V_{FTO} (KTS)	V_{ER} (KTS)	V_{REF} (KTS)
25000	99	111	141	151	97
26000	102	113	144	155	98
27000	104	115	147	157	100
28000	106	117	150	160	102
29000	108	119	153	163	104
30000	110	121	156	166	106
31000	113	123	158	169	108
32000	115	124	161	171	109
33000	117	126	163	174	111
34000	120	128	166	176	113
35000	121	130	169	179	114
36000	123	131	171	181	116
37000	125	133	174	184	118
38000	128	135	176	186	119
39000	129	136	179	189	121
40000	131	138	181	191	122
41000	133	139	184	194	124
42000	135	141	186	196	125
43000	137	143	189	199	127
44000	139	144	191	201	128
45000	140	145	193	204	129

MANOEUVRING SPEEDS	
CONFIGURATION	SPEED LIMIT
FLAP 0	V_{FTO} + 15 kts
FLAP 18	V_{REF} 33 + 30 kts
FLAP 24	V_{REF} 33 + 20 kts
FLAP 33	V_{REF} 33 + 10 kts
Min Manoeuvering Speed with flaps zero is V_{FTO} + 15	

V_R = Take off rotation speed
V_2 = Take Off Safety Speed
V_{FTO} = Final Take Off Speed - Final Flap Retraction
V_{ER} = En Route Safety speed - Final Climb Out Speed
V_{REF} = Landing Safety Speed

Source: Air UK BAe 146-300 Operations Manual - Take Off Speed Cards

Boeing 737-200 OPERATING SPEEDS

TAKE OFF FLAPS 5				LANDING FLAPS 40
AIRCRAFT WEIGHT (KGS)	V_R (KTS)	V_2 (KTS)	V_{FTO} (KTS)	V_{REF} (KTS)
30000	127	135	190	
32000			190	106
34000			190	110
35000	127	135	190	
36000			190	113
38000			190	116
40000	127	135	190	119
42000			190	122
44000			190	126
45000	136	143	190	
46000			190	129
48000			190	132
50000	146	151	190	135
52000			190	138
55000	154	159	200	
60000	162	167	200	

MANOEUVRING SPEEDS	
CONFIGURATION	SPEED LIMIT
FLAP 1	210-190 kts
FLAP 5	190-170 kts
FLAP 15	150 - V_{REF}
FLAP 25	140 - V_{REF}
FLAP 30	V_{REF}
FLAP 40	V_{REF}
bank angle limit 15° until V_2+20	

V_R = Take off rotation speed
V_2 = Take Off Safety Speed
V_{FTO} = Final Take Off Speed - Final Flap Retraction
V_{REF} = Landing Safety Speed

Source: Boeing 737-200 Quick Reference Handbook

<u>*APPENDIX 3.3*</u>

TURBOPROPS

FOKKER 50 OPERATING SPEEDS

TAKE OFF FLAPS 5					LANDING FLAPS 25
AIRCRAFT WEIGHT (KGS)	V_R (KTS)	V_2 (KTS)	V_{FTO} (KTS)	V_{ER} (KTS)	V_{REF} (KTS)
15000	93	96	101	105	94
15500	94	97	103	107	94
16000	95	97	104	108	94
16500	97	99	106	110	96
17000	98	100	107	112	97
17500	100	102	109	114	98
18000	101	103	110	115	99
18500	103	105	112	117	101
19000	104	106	113	118	102
19500	106	107	115	120	104
20000	107	108	116	121	105
20800	110	110	119	124	107

MANOEUVRING SPEEDS	
CONFIGURATION	SPEED LIMIT
FLAP 0	140 kts
FLAP 10	130 kts
FLAP 20	120 kts
FLAP 25	110 kts
bank angle limit 15° below 500 ft	
Normal turns are rate 1 with a maximum bank angle of 30°	
Normal manoeuvring speed after take off is V_2 + 10 after flap retraction	

V_R = Take off rotation speed
V_2 = Take Off Safety Speed
V_{FTO} = Final Take Off Speed - Final Flap Retraction
V_{ER} = En Route Safety speed - Final Climb Out Speed
V_{REF} = Landing Safety Speed

Source: Air UK Fokker 50 Operations Manual - Take Off Speed Cards

ATR 72 OPERATING SPEEDS

TAKE OFF FLAPS 15				LANDING FLAPS 30
AIRCRAFT WEIGHT (KGS)	V_R (KTS)	V_2 (KTS)	V_{FTO} (KTS)	V_{REF} (KTS)
14000	104	107	112	90
15000	104	107	116	94
16000	104	107	120	97
17000	104	107	124	100
18000	104	107	128	103
19000	104	107	132	106
20000	107	110	135	110
21000	110	112	138	113
22000	112	115	142	115

MANOEUVRING SPEEDS	
CONFIGURATION	SPEED LIMIT
FLAP 0	180 kts
FLAP 15	150 kts
FLAP 30	135 kts
Minimum turn speed with bank angle greater than 15° = V_{FTO} +10 kts	

V_R = Take off rotation speed
V_2 = Take Off Safety Speed
V_{FTO} = Final Take Off Speed - Final Flap Retraction
V_{REF} = Landing Safety Speed

Source: Air UK ATR 72 Operations Manual

APPENDIX 3.4

Effect of Turning Speed on Turn Radius

Aircraft Speed (Kts)	Aircraft Speed (ft/s)	Bank Angle (deg)	Turn Radius (ft)*	Circular Path Distance (nm)**
80	135	25	1216	1.26
90	152	25	1539	1.59
100	169	25	1900	1.96
110	186	25	2299	2.38
120	203	25	2735	2.83
130	220	25	3210	3.32
140	236	25	3723	3.85
150	253	25	4274	4.42
160	270	25	4863	5.03
170	287	25	5490	5.67
180	304	25	6155	6.36
190	321	25	6858	7.09
200	338	25	7599	7.85
210	355	25	8377	8.66
220	372	25	9194	9.50
230	388	25	10049	10.38
240	405	25	10942	11.31
250	422	25	11873	12.27
260	439	25	12842	13.27
270	456	25	13848	14.31
280	473	25	14893	15.39
290	490	25	15976	16.51
300	507	25	17097	17.67

TABLE 1

* Calculation is made using formula presented in Chapt. 3

** Calculated using the formula $C=2\pi r$ assuming 1nm = 6080ft

APPENDIX 3.4

Effect of Turning Speed on Bank Angle assuming a Fixed Turn Radius

Aircraft Speed (Kts)	Aircraft Speed (ft/s)	Bank Angle (deg)	Turn Radius (ft)*	Circular Path Distance (nm)**
80	135	4.1	8000	8.27
90	152	5.1	8000	8.27
100	169	6.3	8000	8.27
110	186	7.6	8000	8.27
120	203	9.1	8000	8.27
130	220	10.6	8000	8.27
140	236	12.2	8000	8.27
150	253	14.0	8000	8.27
160	270	15.8	8000	8.27
170	287	17.7	8000	8.27
180	304	19.7	8000	8.27
190	321	21.8	8000	8.27
200	338	23.9	8000	8.27
210	355	26.0	8000	8.27
220	372	28.2	8000	8.27
230	388	30.4	8000	8.27
240	405	32.5	8000	8.27
250	422	34.7	8000	8.27
260	439	36.8	8000	8.27
270	456	38.9	8000	8.27
280	473	41.0	8000	8.27
290	490	43.0	8000	8.27
300	507	44.9	8000	8.27

TABLE 2

* Calculation is made using formula presented in Chapt. 3

** Calculated using the formula $C=2\pi r$ assuming 1nm = 6080ft

2.9 STEEP APPROACH OPERATIONS

2.9.1 GENERAL

1.1 BAe 146 aircraft are permitted to land from an ILS approach with an approach angle between 4.5° and 6.0° provided all operational requirements are met.

1.2 LIMITATIONS

The following limitations must be observed.

a) The procedure has only been cleared for landing with 33° flap.

b) The decision height must not be less than 200 feet or the OCA/H, if greater.

c) The autopilot may remain engaged down to a height of 160ft RA.

d) Landing with a tailwind component is not permitted.

NOTE: Maximum tailwind component for the 100 series aircraft is 5kts

e) Steep approaches with two engines inoperative have not been demonstrated.

f) BAe mod.HCM50016 (Steep Approach Monitor System) must be fitted.

g) Visual Precision Approach Path Indicators (VASI's of PAPI's) must be serviceable.

2.9.2 LANDING PERFORMANCE

2.1 In order to maximise landing performance, a steep approach procedure has been developed.

2.2 The benefit of the steep approach procedure is that aviation authorities have recognised that a reduction in screen height from 50ft to 35ft is appropriate. This reduction will provide two performance benefits.

1. Less touchdown scatter due to the steeper approach angle.
2. A geometric reduction in airborne distance due to the reduced screen height.

2.3 The actual performance benefit is determined through a number of tests carried out by the relevant civil aviation authorities and result in a correction to the landing distance required (LDR).

2.4 In the case of the UK CAA, the wet runway landing performance benefit has been certified as an increase in landing field length available of:

BAe 146 - 300 143m

BAe 146 - 100 82m

2.9.3 APPROACH PROCEDURE

3.1 Tune and identify the ILS frequency, select the Steep Approach selector to ON by depressing the switch and check the S.APP white annunicator is lit.

3.2 When establishing on the approach select 18° flap and reduce speed V_{REF} 33 + 30 knots. Arm G/S and S.APP (PNF to call "LOCALISER GREEN, GLIDSLOPE AND STEEP APPROACH ARMED" PF to acknowledge.

3.3 After localizer capture, and when glideslope indicator becomes live, select 24° flap and allow speed to reduce to minimum of V_{REF} 33 + 20 knots.

3.4 Approach the glideslope from below. At 1.1/2 dots select landing gear DOWN, select 33° flap and allow the speed to reduce to a minimum of V_{REF} 33 + 5 knots. Confirm the S.APP green annunciator is lit. (PNF to call "STEEP APPROACH GREEN", PF to acknowledge).

3.5 On intercepting the glideslope select airbrake OUT and maintain speed at a minimum of V_{REF} 33 + 5 knots. Initiate the LANDING CHECKLIST.

3.6 Aim to cross the threshold at V_{REF} 33. Commence the landing flare and reduce power to flight idle.

3.7 Do not prolong the landing flare and after touchdown lower the nosewheel to the runway without delay. Select lift spoilers and commence braking.

NOTE: Approach profile is at 2.8.1 page 12.

2.9.4 **BRIEFING NOTES**

4.1 It is essential to maintain the correct speed on final approach.

4.2 Be aware that the more rapid changes of altitude on a steep approach can increase the effects of WINDSHEAR. The higher drag configuration and lower power settings increase the need for anticipation and windshear awareness.

4.3 When gusts are reported, increase approach speeds by up to a maximum of 10 knots. When icing conditions require an increase of all speeds by 7 knots, this speed plus the gust factor must not exceed the basic V_{REF} + 10 knots threshold speed.

4.4 Avoid flying above the glideslope but if this occurs quickly change the attitude to regain the glideslope. With the high drag configuration any resulting increase in speed can soon be corrected.

4.5 On a steep approach, aircraft nose down attitude approximates to glideslope.

4.6 At decision altitude, when achieving visual reference, ie. runway and PAPI's in sight, use the PAPI indications to maintain the correct glideslope. Before commencing the flare transfer to normal visual cues for flare and touchdown.

4.7 The lower attitude on a steep approach necessitates a slightly larger change in attitude both to achieve the landing or to initiate a missed approach.

4.8 An early flare can result in an unnecessary increase in landing distance due to float. A very late flare can result in a heavy landing.

4.9 Landing limitations are changed. For a steep approach, Landing Distance Available may be increased by 143m for the BAe 146 - 300 series and 82m for the 100 series when using Flight manual landing charts.

NOTE Check OM Part C2 as some airports e.g LCY have specific landing weight charts.

4.10 In the event of a go around, pilots must check that the airbrake is retracted as unlike a normal approach, the airbrake will be open at minima.

2.9.5 Steep Approach Monitor System (BAe mod. hcm 50016)

5.1 This modification prevents nuisance sink-rate warnings from the GPWS system during steep approaches.

5.2 The warnings are inhibited when the following conditions are met:

- Aircraft in landing configuration (gear down, flap 33).
- Steep Approach Monitor Select Switch 'ON'.
- Vertical speed less than 1500 fpm.

5.3 The select switch has a white 'S.APP' legend and a green 'S.APP' legend.

When first selected ON, the white legend will illuminate.

When the following conditions are achieved the green legend will also illuminate.

- Gear down and locked..
- Flaps set to 33.
- Weight OFF wheels.

If the switch is selected ON after the conditions are achieved, only the green legend will be illuminated.

5.4 The select switch is mounted either:

Immediately below the Flap Override switch - analogue ac.

or

Immediately to the right of Flap Override switch - EFIS ac.

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Appendix to Chapter 4

4.1: Combined Percentage Traffic Growth Rate Forecasts in Major Airline Markets.

4.2: Regional Aircraft Manufacture's Forecast Industry Growth

4.3: Summary of Findings by 1987 AEA Report on Capacity of Aviation Systems in Europe.

4.4: SRI 1990 European Airport Development Summary

4.5: SRI Action Plan Recommendations

4.6: Summary of European Airport Development 1990-1995

4.7: Top 30 European Airports by Passengers with ATM's - 1994

4.8: Combined Summary Table of Top 40 Airports by Region, Ranked by Pax. Movs.

4.9: Summary Tables of Runway Capacity Forecasts for Selected European Airports.

4.10: Breakdown of Ownership and Aeronautical Charges for Selected European Airports - 1995.

4.11: Heathrow and Gatwick - Slot Capacity vs Demand in Peak August Summer 1994.

4.12: Recommendations of EC Proposal on Airport Slot Allocation

4.13: APATSI Mature ATC Procedures

Appendix 4.1

Combined Percentage Traffic Growth Rate Forecasts in Major Airline Markets

Market Segment	Airbus Forecast (1995-2014)	Boeing Forecast (1995-2014)*	McDonnell Douglas Forecast (1994-2013)*
Intra-Africa	5.2		
Intra-Asia/Pacific	6.3	7.1	9.6
Intra-Europe	4.3	4.2	4.1
Intra-Latin America	5.5		
Intra-Middle East	5.2		
Intra-North America	3.7	3.8	4.0
Intra-P.R. China	10.3		
Asia-Africa	7.3		
Asia-Europe	7.5	7.0	6.5
Asia-Indian Subcontinent	5.9		
Asia-Middle East	6.4		
Asia-North America	7.4	6.5	
Asia-Pacific	6.5		
Europe-Africa	4.3		5.9
Europe-Indian Subcontinent	6.4		
Europe-Latin America	4.7	4.8	
Europe-Middle East	4.2		
Europe-North America	4.3	4.2	4.0
Indian Subcontinent-Africa	3.9		
Latin America-Africa	4.5		
Latin America-Pacific	5.2		
Middle East-Africa	7.2		
Middle East-Indian Subcontinent	6.0		
Middle East-Pacific	4.4		
North America-Africa	4.4		
North America-Latin America	5.3	5.1	6.0
North America-Middle East	3.9		
North America-Oceania	3.7		
Pacific-Africa	3.2		
Pacific-Indian Subcontinent	4.7		
Intra-CIS		5.7	
CIS-Rest of World		6.5	
Charter Airlines	6.4		
World	5.1		5.8**

* Boeing and McDonnell Douglas figures were given in their forecasts in some cases under different region names although they related to the same geographical area.

** Figure ignores former U.S.S.R. domestic market.

Source: Airbus, Boeing and McDonnell Douglas Global Industry Forecasts

Appendix 4.2

Fokker Forecasts of Intra-Regional Scheduled Available Seat Mile Growth (1984-2014)

Geographic Region	Average Growth p.a. Percentage		
	1984-1994	1995-2004	2005-2014
North America	2.4	2.7	2.6
Europe	6.8	3.6	2.6
Asia/Pacific	9.0	7.3	5.8
Latin America	4.0	3.7	2.9
Africa & Middle East	0.4	3.0	2.6
World	4.2	4.2	3.8

Jetstream Regional Market Outlook of Forecast Capacity Growth (1995-2004)

Geographic Region	Growth Rate in Forecast Capacity (%)						
	19 seats T/prop	30 seat T/prop	50 seat T/prop	50 seat Jets	70 seat T/prop	70 seat Jets	Combined Average
North America	-1.8	6.2	7.0	15.8	17.1	5.3	5.9
Europe	-1.1	5.2	5.3	21..3	10.6	5.1	6.6
Asia, Pacific and China	-0.2	15.7	4.3	n/a	17.7	6.6	9.3
Central and South America	-0.6	6.4	3.9	n/a	10.8	2.2	4.3
Africa & the Middle East	n/a	9.8	3.3	n/a	11.2	5.2	5.2
Australasia	-0.8	1.8	11.3	n/a	n/a	5.6	5.7
World	-1.5	6.1	5.6	20.8	15.2	5.2	6.3

Appendix 4.3

Summary of Findings by 1987 AEA Report on Capacity of Aviation Systems in Europe

Airport	Hourly Runway Capacity						Forecast Congestion Year		
	Normal Capacity			Theoretical Capacity			Low Growth Scenario	Medium Growth Scenario	High Growth Scenario
	Depart.	Arrivals	Total	Depart.	Arrivals	Total			
Vienna	15	15	30	18	18	36	>2000	>2000	2000
Salzburg - 1986	6	6	12	10	10	20	>2000	>2000	>2000
2000	18	18	36						
Brussels	20	20	40	30	30	60	1998	1994	1992
Helsinki - 1986	15	15	30	18	18	36	>2000	2000	1996
1995	18	18	36	22	22	44			
Paris-Orly	32	32	64				>2000	1999	1995
Paris-CDG	36	32	68				>2000	>2000	1998
Marseille	14	14	28				>2000	1994	1992
Nice			30				>2000	>2000	1998
Lyon	15	15	30				>2000	>2000	>2000
Frankfurt	48	35	64				>2000	1995	1992
Dusseldorf			35				1993	1991	1989
Munich - 1986	24	24	32				>2000	1996	1993
1992			64						
Hamburg			36				>2000	1995	1993
Stuttgart	10	10	20				1986	1986	1986
Hannover			54				>2000	>2000	>2000
Athens	16	14	30			39	1993	1990	1989
Budapest - 1986	8	8	16	10	10	20	>2000	>2000	>2000
1988	17	17	34	20	20	40			
Keflavik	n/a						>2000	>2000	>2000
Dublin - 1986	18	17	35	20	20	40	>2000	2000	1995
1989	22	21	43						
Rome	25	25	50				>2000	1998	1995
Milan Linate	12	12	24				>2000	>2000	>2000
Milan MXP	15	15	30				Combined with Linate		
Luxemburg	n/a						>2000	>2000	>2000
Amsterdam	35	30	65	42	36	78	2000	1997	1995
Lisbon - 1986	14	13	25	17	15	30	>2000	>2000	>2000
1990	n/a			21	20	39			
Porto	5	4	7	13	11	22	>2000	1998	1997
Copenhagen - 1986	40	33	60	44	36	66	>2000	1998	1994
1989	44	36	66						
Stockholm - 1986	24	30	54			62	>2000	2000	1996
1993			72			76			
Gothenburg	n/a						>2000	>2000	>2000
Oslo	17	13	35				>2000	1994	1991
Bergen	n/a						>2000	>2000	>2000
Stavanger	n/a						>2000	>2000	>2000
Madrid	16	18	34				1996	1992	1990
Palma de Mallorca			30			40	>2000	>2000	>2000
Malaga			25			30	>2000	1998	1996
Barcelona			18			20	1986	1986	1986
Zurich	35	32	67				>2000	1998	1995
Geneva	15	15	30				1989	1988	1988
London - Heathrow	37	35	72	Under Review			1986	1986	1986
London - Gatwick			40			41	1996	1991	1989
London - Stansted - 1986			25			40	2000	1997	1996
1991			40			40			
Manchester	19	18	37				>2000	>2000	>2000
Birmingham	19	18	37				>2000	>2000	>2000
Glasgow	19	18	37				>2000	>2000	2000
Aberdeen	19	18	37				>2000	>2000	1999
Istanbul - 1986	7	13	20				>2000	>2000	2000
1988	12	18	30						
Ankara - 1986	4	6	10				>2000	>2000	>2000
1988	6	10	16						

Table Notes:

1. CDG = Charles de Gaulle, MXP = Milan Malpensa
2. Theoretical capacity figures refer to AEA expectations of future airport development, and the resultant capacity increase.
3. Three scenarios relate to different market growth rates of 3.2%, 5.1% and 7% respectively.

Appendix 4.4

SRI 1990 European Airport Development Summary

Airport	Forecast Capacity Limit		Declared Capacity (1990)	Development Plans and Recommendations
	Without Mods.	With Mods.		
Amsterdam Schiphol	2000	>2010	70	With independent parallel operations runway capacity could increase to 84 by 1995. Plans to build a 5th runway if demand is sufficient giving capacity of 100 mov. per hour.
Athens	1993	2000	30/32	No planned capacity improvements. Need to improve ATC operations to 42 movs. per hour to accommodate demand till 2000.
Barcelona	1995	2010	28	ATC improvements would allow mov. rate of 50 to 55. No planned capacity increases.
Brussels Zavantem	2001	>2010	45	Computer aided ATC centre for 1990 plus taxiway enhancements should accommodate demand.
Copenhagen Kastrup	1997	2007	60	Expect mov. rate of 62-65 by 1990. 70-80 mov. per hour possible with runway configuration and improved ATC management and training
Dublin	1994	>2010	25	ATC improvements possible to give 40-45 mov. per hour. Need to divert general aviation, (GA), traffic.
Dusseldorf	1992	>2010	34	New runway planned for 1991. Mov. rate increases to 64. Very politically sensitive location. Reliever airports for GA and traffic diversion to Cologne/Bonn considered.
Frankfurt	1991	1992	64	Capacity limit of 120 movs. in 2 consecutive hours. 70 mov. per hr. possible with runway config by 1995, 80 mov. per hr. by 2000 with procedural/equip. enhancements. GA and commuters to reliever airport would help. Severe expansion restrictions.
Geneva	1995	1995	35	42 movs. per hr. possible. High GA and business traffic restrict growth; relocation suggested. French ATC traffic integration problems.
Hamburg	1990	1990	36	45 mov. per hr. possible if ATC improves. 55 movs. feasible with runway config. GA traffic relocation suggested. Growth limited by physical space.
Istanbul	2005	>2010	40	700m runway extension. Rate of 50 mov. per hr. possible if ATC improve
London Gatwick	1992	1996	41	Best in class for single runway. 48 mov. per hr. possible if use is made of 2nd runway.

London Heathrow	1991	1997	72	Best in class. 85 mov. per hr. possible if independent parallel operations on runways were allowed.
London Stansted	>2010	>2010	20	If ATC constraints were lifted 42 mov. per hr would be possible. Diversion traffic from LHR and LGW could cause capacity problems later.
Madrid Barajas	1992	1997	30	ATC limits runway capacity. 42 mov. per hr. possible.
Manchester	1997	2000*	39	42 mov. per hr. possible. Capacity by 1997 unless second runway is built. If not traffic will need reliever airport.
Marseille	1996	>2010	28	ATC and stand improvements would allow 52 mov. per hr.
Milan Linate	1994	2001	26	Capacity limited by poor use of slot allocation, physical space and GA traffic. Plan to move traffic to Malpensa in 1993.
Milan Malpensa	>2010	>2010	30	Increase mov. rate to 50-54 required to handle Linate traffic.
Munich	late 1980's	>2010	34 (72 Muc2)	Capacity problems will be absorbed by new Munich 2 airport in 1992.
Palma de Mallorca	1996	>2010	30	72 mov. per hr. possible with improved ATC, taxiways, and independent parallel operations on runways.
Paris Charles de Gaulle	>2010	>2010	72	82 mov. per hr. possible with improved ATC management. Room for 3rd and 4th runways. No real capacity problem.
Paris Orly	2006	2007	66	No expansion plans due to highly developed land surrounding airport.
Rome Fiumicino	2000	>2010	50	ATC improvements expect 70 mov. per hr. Should reach 80 movs. eventually. No airport expansion plans at present.
Stockholm Arlanda	1993	>2010	57-60	Third runway 1994 will give 84 mov. per hr. 4th and 5th runway under consideration. No real capacity problems.
Vienna	2004	>2010	35	45 mov. per hr. possible on taxiway and runway improvements. Airport plan will prevent lack of capacity.
Zurich Kloten	2002	2003	60	62 mov. per hr. possible with reduced longitudinal separation. GA/Business traffic relocation suggested. Expansion very limited by political and environmental pressures.

Source: SRI International (1990) A European Planning Strategy for Air Traffic to the Year 2010.

Note: The second and third columns in the table indicate the year when SRI expect the airport to reach capacity. The second column is without and changes to the present system whilst the third column indicates differences following changes to the system.

Appendix 4.5

SRI Action Plan Recommendations

- Continue current efforts to improve ATC and airport functions.
- Undertake ATS Capacity Enhancement Program.
- Convene European Air Traffic Assembly.
- Evaluate economic impacts of commercial aviation.
- Provide airport development subsidies to foster economic development.
- Expand Data Bank Eurocontrol.
- Develop comprehensive airport master plans.
- Implement best in class enhancements.
- Seek Heathrow Terminal 5 and an additional London runway.
- Seek Frankfurt airport expansions.
- **Seek reliever airports.**

Appendix 4.6

Summary of European Airport Development 1990-1995

Airport	Development up to 1995 and future plans
Amsterdam Schiphol	Plans to extend runway 06/24 by 250m. Other work focused on terminal modifications and extensions, including a regional aircraft pier completed in 1994. Rail link to high speed rail station expected to be complete by 1995.
Athens	Planning a new, $2.3bn private, airport 25km from Athens to begin operation in 1998 with two runways and a capacity of 16 million. Existing airport, Hellenikon, will be closed and re-developed.
Barcelona	Declared capacity of 28 exceeded by ATC improvements. Terminal expansion to 17 million was made by 1992 for Olympic Games, further expansions planned. Considering a new parallel runway to 07/25 to allow closure of 02/20 which causes flights to cross a densely populated area on approach.
Brussels Zavantem	All work has focused on new terminal work which was opened on 11th December 1994.
Copenhagen Kastrup	Due to severe lack of space, airport noise and environmental issues are very sensitive. No new runways planned. All development has been to upgrade and expand terminal capacity.
Dublin	Runway 10/28 opened in 1989 following soil deterioration on previous main runway. Airport operates to single runway levels even though it has four. New masterplan set in 1993 to the year 2000 outlines terminal and apron expansions with a 300m extension to 10/28 to handle long haul traffic. Work expected to be complete by 1997. Political limitations on Aer Lingus long haul traffic having to route via Shannon.
Dusseldorf	Airport operation severely regulated by local government. All modifications must have state authorisation. A 2700m reserve runway to 05/23 was built in 1993. Motorway and rail links have also been put in place. Regulations limit aircraft movements to approx. 150,000 a year with encouragement for traffic to use Cologne/Bonn airport. Considering relocation of regional traffic to reliever airport, either Monchengladbach or Essen-Mulheim both 20-30km outside Dusseldorf. Move resisted by regional commuters.
Frankfurt	Second most important airport in Europe severely limited by physical space, USAF base on south side of airport, very effective local opposition to any growth and political ownership of airport causing constant conflict between what the airport needs and local residents want. Large use of technology including Departure Co-ordination system, (DEPCOS), Computer Orientated Metering Planning and Advisory System, (COMPAS), Precision Runway Monitoring, (PRM-EScam) and MLS replacement of ILS. Significant work also done on wake

Frankfurt (Cont..)	vortex and SALS trials. Taxiway modifications carried out where DEPCOS indicates the need for them. Relaxation of night curfew also sought. Hoped these approaches will increase annual movements to 366,000 a year by 2000 increasing declared capacity to 80. Removal of regional traffic to Weisbaden-Erbenheim also considered.
Geneva	All airport developments need to meet approval from strict, environmentally conscious, Swiss law courts. Noise restrictions prevent increases in aircraft movements. 5 movements an hour given to GA restrict growth even further. Subsequently, all recent work focused on terminal enhancements.
Hamburg	Restricted runway operations due to noise. Capacity limited by apron stands and lack of space to expand. Runway expansions not feasible. Plans to build a new airport at Kaltenkirchen failed in 1984. Recent developments have been in the terminal. Relocation of GA to Finkenwerder suggested.
Istanbul	Proposed extension of runway 06/24 to 2700m. Ten remote stands added in 1994 with second terminal proposed to enter service in the late 1990's.
London Gatwick	Much work by RUCATSE and UK CAA has been carried out on a proposed second runway, north and south of existing airport boundary. Significant land purchase costs, local council agreements and strong local opposition have prevented permission for new runway. CAA work also carried out regarding regional services and possible relocation to Redhill reliever airport. Actual airport developments include terminal redevelopment and expansions and taxiway modifications. Government policy encouraging traffic redistribution to Stansted limiting further expansion.
London Heathrow	Site for a new runway outlined by RUCATSE report although construction and relocation costs prohibited development. Currently in planning enquiry for a 5th terminal for operation in two phases from 2002 and 2016. Runway capacity increased to 377,000 movs. by mid 1992. 2.5nm arrival separation trials in use. Discussion of mixed mode runway operation still unresolved. 1992 runway capacity enhancement group set up. Report in 1994 indicated mixed mode could raise declared capacity to 92 although problems of ground capacity would arise and also the noise footprint of LHR has decreased significantly. Currently use peak period pricing to regulate demand during peak periods. MLS trials are also being carried out. Future plans include terminal redevelopment and taxiway and RET extensions.

London Stansted	Currently under-utilised. Fastest growing UK airport. Expansion of terminal capacity completed in 1994. Currently attempting to remove movement limit on the airport of 78,000 per year. Expects to handle 8 million pax's by 2000 and 15 million by 2007 due to redirection of LHR and LGW traffic.
Madrid Barajas	32% of all flights were affected by delays during 1991. All aspects of the airport lacked capacity. ATC problems existed from lack of experience and staff. AENA was placed in charge in 1991 and developed a new masterplan incorporating in depth simulation of future traffic demands with the FAA. From this a plan to add three parallel runways to the existing 36/18 was made. The runways will be built in phases with the first expected to be completed by 1997, 4000m long and used mainly for take offs. The plan is expected to satisfy demand till 2030. Increasing use of intersection departures on 36 is planned following a shortening of runway 33 and taxiway construction.
Manchester	Declared capacity increased to 42 through additional RET's and holding bays for single runway. Current plans include an additional passing bay for 06, an additional RET for 06 and a second runway. Public enquiry for last plan complete during late 1995, still awaiting response. Terminal redevelopment and extensions also planned. Also being trailing SALS procedures and FMS departures. TMA re-structured in 1995/6.
Marseille	Capacity limited by French ATC. Two plans for runway extension were under consideration, 14R/32L could be extended to 3000m increasing declared capacity to 52, or a new runway increasing capacity to 60-72. The latter faces severe environmental problems and neither have planning permission. Current terminal expansion expected to be complete by 1996.
Milan Linate	Constrained in all areas of the airport and lack of space to expand or allow a second runway. Capacity restricted by 6 reservations for GA activity an hour. Plan is to divert all international and intra Europe flights to Malpensa, with a 50:50 split in traffic by 2000.
Milan Malpensa	Seen by SEA, the operating authority, as Italy's new hub airport. Consists of two parallel runways, one principal one, one for GA. Malpensa 2000 project sees upgrade of GA runway to CATIII and dependent parallel operations for commercial traffic, new road and rail links and a new terminal. First phase of terminal expected to be open by 1998. Changes to the design and fraud charges delayed project by two years. Bergamo airport being developed as a possible reliever airport to Malpensa and Linate in the future.

Munich	Congestion problems at Munich Reim were removed when it shut in 1992, following the opening of the new Munich2 airport which provided an extra runway and much needed terminal space. New airport took 30 years from conception to operation.
Palma de Mallorca	Lack of ATC experience means the independent parallel runways can not be used. Instead the airport is restricted to one runway. Airport receives support of local population! Work in the last few years has focused on completion of the first terminal in 1995 and start of work on the next one the same year.
Paris Charles de Gaulle	Master plan for CDG already has provision for 3 more runways and another terminal. 1994 saw the completion of a high speed rail interchange at the airport. Third runway expected to be operational by 1997 although delays occurred in getting government approval. Integration of traffic from Orly and CDG can cause some problems for ATC.
Paris Orly	Originally the French domestic airport it was opened up to intra European flights in 1993. Expansion limited by available space. As CDG develops it would be expected to handle more of Orly's traffic.
Rome Fiumicino	Terminal, apron and taxiway extension made in 1994. Airport not capacity limited by space, more by ATC ability.
Stockholm Arlanda	Third runway and parallel taxiway planned to begin in 1996 and complete by 1999. Rail link to Stockholm also scheduled to open in 1997.
Vienna	Focus has been on terminal development rather than runway changes.
Zurich Kloten	Faces same severe restrictions as Geneva. Also as arrivals cross German border, a restriction that a third off all landings have to be on runway 16 exists. Airport 2000 masterplan details taxiway and apron extensions. A special SALS arrival procedure has been used with limitations by Crossair since 1990. Severe noise and environmental restrictions, as well as lack of space limit runway extensions and additions.

Source: Homer, M (1993) Congestion in Europe - An Opportunity or a Threat to Regional Jet Operations - Msc Thesis Cranfield.

Airports International - World Development Surveys December Edition various years.

Flight International - Airports Special - Flight 19-25 October 1994 - p 35-47

Appendix 4.7

Top 30 European Airports by Passengers with ATM's - 1994 (also includes growth rates from 1993).

Airport	Total Passengers	% Change since 1993	Pax Euro Rank	Pax World Rank	Total ATM's	% Change since 1993	ATM Euro Rank	ATM World Rank	Avg. Pax/ATM
London Heathrow	51717918	8	1	4	424551	3.3	1	19	122
Frankfurt Main	35122528	7.9	2	7	364716	3.6	2	24	96
Paris Charles de Gaulle	29630222	13.5	3	11	324944	4.8	3	34	91
Paris Orly	26617556	4.9	4	17	216314	2.1	9	61	123
Amsterdam Schiphol	23559456	10.7	5	23	299712	4.1	4	38	79
London Gatwick	21212117	5.2	6	29	191644	3.8	13	74	111
Rome Fiumicino	20316058	5.4	7	36	200479	3.6	11	69	101
Madrid Barajas	18427086	5	8	39	211380	3.7	10	64	87
Manchester	14814299	10.7	9	45	165910	6.9	15	87	89
Zurich Kloten	14506865	7.4	10	46	242498	3.7	5	50	60
Palma de Mallorca	14142035	13	11	48	117924	11.7	29	145	120
Dusseldorf	14003365	7.3	12	49	175631	5.3	14	85	80
Copenhagen Kastrup	13955178	9.3	13	50	228509	3.1	7	54	61
Munich	13497041	6	14	52	199845	4	12	70	68
Stockholm Arlanda	13420693	6.9	15	53	229180	1.4	6	53	59
Brussels National	11342172	11.3	16	63	225662	7	8	55	50
Barcelona	10642335	6.5	17	65	145583	6.4	21	117	73
Istanbul	10216788	7	18	67	150627	7.8	19	111	68
Milan Linate	10134307	7	19	68	136888	2.3	23	126	74
Oslo	9344638	13.8	20	76	152235	9.8	18	106	61
Gran Canaria	7764819	11.2	21	90	80923	12.7	43	197	96
Vienna	7729844	7.8	22	91	152730	6.8	17	105	51
Hamburg	7693436	4.8	23	93	143134	0.6	22	119	54
Tenerife Sur	7562710	7.2	24	95	54185	5.1	73	257	140
Berlin Tegel	7334031	3.8	25	96	96316	3.3	38	169	76
Dublin	6980983	17.6	26	97	130031	10.1	25	131	54
Helsinki	6566472	7.1	27	103	124754	2.1	27	135	53
Nice Cote d'Azur	6197464	4.3	28	109	128869	2	26	132	48
Geneva	5986279	3.9	29	111	149811	3.1	20	113	40
Lisbon	5950899	5.4	30	112	73563	1.2	51	213	81
Glasgow	5594929	8.2	31	117	95442	-7.7	39	170	59
Malaga	5548160	13.2	32	119	54889	7.1	71	254	101
Stuttgart	5543730	8.1	33	120	133409	-0.2	24	128	42
Birmingham	4948968	17.6	34	127	161966	1.9	16	91	31
Marseille	4831369	1.1	35	130	100267	-1	36	161	48
Lyon	4257509	6.1	36	136	77099	6.1	46	205	55
Cologne	3952884	3	37	139	120496	2.5	28	143	33
Hannover	3890857	13	38	141	98574	1.2	37	164	39
Lanzarote	3722956	8.6	39	145	33721	9.4	108	328	110
Milan Malpensa	3679408	3.4	40	147	40460	-4 3	93	298	91

Source: *ACI 1994 Worldwide Airport Traffic Statistics.*

Appendix 4.8

Combined Summary Table of Top 40 Airports by Region, Ranked by Pax Mov's. (1994)

United States

Rank	Airport	Pax	ATM's	Pax/ATM	% of US Pax	% of US ATM's	% of US Pax/ATM
1	Chicago O'Hare	66468229	883062	75.27	100	100	100
2	Atlanta Hartsfield	54093051	715920	75.56	100	100	100
3	Dallas DFW	52601125	840406	62.59	100	100	100
4	Los Angeles	51050275	689888	74.00	100	100	100
5	San Francisco	34643095	422190	82.06	100	100	100
6	Denver	33133428	530839	62.42	100	100	100
7	Miami	30203269	557680	54.16	100	100	100
8	New York JFK	28806638	343252	83.92	100	100	100
9	Newark	28020482	436686	64.17	100	100	100
10	Las Vegas	26850488	495942	54.14	100	100	100
11	Detroit	26800951	485306	55.22	100	100	100
12	Phoenix	25626132	490015	52.30	100	100	100
13	Boston	25195005	470318	53.57	100	100	100
14	Minneapolis	24471944	454723	53.82	100	100	100
15	St Louis	23362871	479943	48.68	100	100	100
16	Honolulu	22995976	359569	63.95	100	100	100
17	Houston	22526299	355694	63.33	100	100	100
18	Orlando	22392412	337573	66.33	100	100	100
19	Seattle	20972819	353052	59.40	100	100	100
20	Toronto	20863922	308901	67.54	100	100	100
21	Charlotte	20751628	462994	44.82	100	100	100
22	La Guardia	20730467	337737	61.38	100	100	100
23	Pittsburgh	19490709	442376	44.06	100	100	100
24	Salt Lake City	17564149	392570	44.74	100	100	100
25	Philadelphia	17274871	402984	42.87	100	100	100
26	Washington National	15517470	306529	50.62	100	100	100
27	Cincinnati	13686349	336895	40.62	100	100	100
28	San Diego	12952015	221040	58.60	100	100	100
29	Baltimore/Washington	12817192	295413	43.39	100	100	100
30	Tampa	12042518	265687	45.33	100	100	100
31	Washington Dulles	11561290	284874	40.58	100	100	100
32	Cleveland	11131526	268141	41.51	100	100	100
33	Vancouver	11059254	301416	36.69	100	100	100
34	Fort Lauderdale	10571364	234000	45.18	100	100	100
35	Portland	9905248	272603	36.34	100	100	100
36	Chicago Midway	9561983	271804	35.18	100	100	100
37	Kansas City	9360968	203070	46.10	100	100	100
38	Raleigh-Durham	9189443	276564	33.23	100	100	100
39	Nashville	8738378	294617	29.66	100	100	100
40	Oakland	8345725	472810	17.65	100	100	100

Europe

Rank	Airport	Pax	ATM's	Pax/ATM	% of US Pax	% of US ATM's	% of US Pax/ATM
1	London Heathrow	51717918	424551	121.82	77.81	48.08	161.84
2	Frankfurt Main	35122528	364716	96.30	64.93	50.94	127.45
3	Paris Charles de Gau	29630222	324944	91.19	56.33	38.67	145.69
4	Paris Orly	26617558	216314	123.05	52.14	31.35	166.29
5	Amsterdam Schiphol	23559456	299712	78.61	68.01	70.99	95.80
6	London Gatwick	21212117	191644	110.69	64.02	36.10	177.33
7	Rome Fiumicino	20316058	200479	101.34	67.26	35.95	187.11
8	Madrid Barajas	18427086	211380	87.18	63.97	61.58	103.88
9	Manchester	14814299	165910	89.29	52.87	37.99	139.16
10	Zurich Kloten	14506865	242498	59.82	54.03	48.90	110.50
11	Palma de Mallorca	14142035	117924	119.92	52.77	24.30	217.16
12	Dusseldorf	14003365	175631	79.73	54.64	35.84	152.46
13	Copenhagen Kastrup	13955178	228509	61.07	55.39	48.59	114.00
14	Munich	13497041	199845	67.54	55.15	43.95	125.49
15	Stockholm Arlanda	13420693	229180	58.56	57.45	47.75	120.30
16	Brussels National	11342172	225662	50.26	49.32	62.76	78.59
17	Barcelona	10642335	145583	73.10	47.24	40.93	115.43
18	Istanbul	10216788	150627	67.83	45.63	44.62	102.25
19	Milan Linate	10134307	136888	74.03	48.32	38.77	124.63
20	Oslo	9344638	152235	61.38	44.79	49.28	90.88
21	Gran Canaria	7764819	80923	95.95	37.42	17.48	214.08
22	Vienna	7729844	152730	50.61	37.29	45.22	82.45
23	Hamburg	7693436	143134	53.75	39.47	32.36	121.99
24	Tenerife Sur	7562710	54185	139.57	43.06	13.80	311.95
25	Berlin Tegel	7334031	96316	76.15	42.45	23.90	177.63
26	Dublin	6980983	130031	53.69	44.99	42.42	106.05
27	Helsinki	6566472	124754	52.64	47.98	37.03	129.56
28	Nice Cote d'Azur	6197464	128869	48.09	47.85	58.30	82.07
29	Geneva	5986279	149811	39.96	46.71	50.71	92.10
30	Lisbon	5950899	73563	80.90	49.42	27.69	178.47
31	Glasgow	5594929	95442	58.62	48.39	33.50	144.44
32	Malaga	5546160	54869	101.08	49.84	20.47	243.48
33	Stuttgart	5543730	133409	41.55	50.13	44.26	113.26
34	Birmingham	4948968	161966	30.56	46.81	69.22	67.64
35	Marseille	4831369	100287	48.19	48.78	36.78	132.61
36	Lyon	4257509	77099	55.22	44.53	28.37	156.97
37	Cologne	3952864	120496	32.81	42.23	59.34	71.16
38	Hannover	3890857	98574	39.47	42.34	35.64	118.79
39	Lanzarote	3722956	33721	110.40	42.60	11.45	372.23
40	Milan Malpensa	3679408	40460	90.94	44.09	8.56	515.20

Rest of World

Rank	Airport	Pax	ATM's	Pax/ATM	% of US Pax	% of US ATM's	% of US Pax/ATM
1	Tokyo Haneda	42245667	202990	208.12	63.56	22.99	276.49
2	Seoul	27333241	183292	149.12	50.53	25.60	197.37
3	Hong Kong	25948789	161893	160.28	49.33	19.26	256.08
4	New Tokyo	23745240	125466	189.26	46.51	18.19	255.76
5	Singapore	21644677	159521	135.69	62.48	37.78	165.36
6	Bangkok	21009259	160178	131.16	63.41	30.17	210.14
7	Osaka	20368293	118618	171.70	67.43	21.27	317.02
8	Mexico City	18889256	347326	54.38	65.57	101.19	64.80
9	Sydney	17483193	Data not a	n/a		n/a	n/a
10	Sapporo	15093583	72466	208.29	56.21	14.61	384.71
11	Fukuoka	14475617	96606	149.84	54.01	19.91	271.33
12	Taipei	13349468	83409	160.05	52.09	17.02	306.04
13	Jakarta	12664575	141133	89.74	50.27	30.01	167.51
14	Melbourne	11679818	157797	74.02	47.73	34.70	137.54
15	Kuala Lumpur	11499243	137871	83.41	49.22	28.73	171.34
16	Manila	10046085	132971	75.55	43.69	36.98	118.13
17	Bombay	9956487	90127	110.47	44.20	25.34	174.44
18	San Juan	9533138	178016	53.55	42.57	52.73	80.73
19	Jeddah	9409147	77088	122.06	44.86	21.83	205.47
20	Naha	8611361	95328	90.33	41.27	30.86	133.74
21	Brisbane	8452938	Data Not A	n/a	40.73	n/a	n/a
22	Riyadh	8378853	72962	114.84	40.42	21.60	187.09
23	San Jose	8350030	14430	578.66	42.84	3.26	1313.37
24	Nagoya	8230902	97058	84.80	46.86	24.72	189.54
25	Cheju	7846842	56288	139.41	45.42	13.97	325.20
26	Kaohsiung	7783352	104444	74.52	50.16	34.07	147.21
27	Sao Paulo	7701414	123069	62.58	56.27	36.53	154.04
28	Pusan	7677126	51626	148.71	59.27	23.36	253.78
29	Caracas	6855703	100239	68.39	53.49	33.93	157.63
30	Cairo	6773816	66688	101.57	56.25	25.10	224.10
31	Santafe be Bogota DC	6653395	185044	35.96	57.55	64.96	88.60
32	Auckland	6553866	121311	54.03	58.88	45.24	130.14
33	New Delhi	6533615	64315	101.59	59.08	21.34	276.87
34	Dubai	6299179	92861	67.83	59.59	39.68	150.15
35	Tel Aviv	5917889	40872	144.79	59.74	14.99	398.48
36	Kahului	5748600	179227	32.07	60.12	65.94	91.17
37	Columbus	5439820	196760	27.65	58.11	96.89	59.98
38	Guadalajara	5283470	140257	37.67	57.49	50.71	113.37
39	Osaka	5070534	28338	178.93	58.03	9.62	603.27
40	Denpensar-Bali	4529351	54205	83.56	54.27	11.46	473.39

Source : ACI Worldwide Airport Traffic Statistics

Appendix 4.9

Summary Table of the Operating Position for Selected European Airports for 1994.

Airport	1994 ATM's	ATM Growth 1985-94 (%)	1994 Pax	Pax Growth 1985-94 (%)	1994 Pax/ATM	Pax/ATM Growth 1985-94 (%)	1993 Declared RWY Cap.	Annual Cap. 1993	Current Capacity Utilisation	% Available 1994
Athens (1993 Data)	120000	1.25	9414000	-1.47	78.45	-2.23	30	197100	62.71	7.29
Marseille	100267	1.38	4583378	1.15	45.71	1.09	35	229950	43.60	26.40
Geneva	149811	1.64	5788261	2.87	38.64	1.11	30	197100	76.01	-6.01
London Gatwick	191644	1.33	21051044	4.21	109.84	2.41	42	275940	69.45	0.55
Copenhagen	228509	2.86	13955178	4.59	61.07	1.33	70	459900	49.69	20.31
Stockholm Arlanda	229180	3.43	13314753	4.70	58.10	1.04	60	394200	58.14	11.86
Paris Orly	216314	3.16	26496531	4.70	122.49	1.28	70	459900	47.04	22.96
Milan Linate	119571	3.66	10025086	4.93	83.84	0.95	32	210240	56.87	13.13
Zurich	242498	3.88	14044483	5.01	57.92	1.11	60	394200	61.52	8.48
Rome Fiumicino	200479	3.75	19910771	5.16	99.32	0.92	56	367920	54.49	15.51
Palma	117924	3.93	14073193	5.53	119.34	0.28	30	197100	59.83	10.17
London Heathrow	424551	3.26	51362251	5.78	120.98	2.05	78	512460	82.85	-12.85
Munich	188371	5.30	13251839	6.43	70.35	0.64	68	446760	42.16	27.84
Dusseldorf	157252	5.71	13863527	6.52	88.16	0.26	30	197100	79.78	-9.78
Frankfurt	357565	4.77	34472872	6.65	96.41	1.09	68	446760	80.04	-10.04
Madrid	211380	6.69	18209895	6.67	86.15	-0.38	50	328500	64.35	5.65
Barcelona	145583	7.07	10296709	8.03	70.73	0.23	30	197100	73.86	-3.86
Paris Charles de Gaulle	324944	9.12	29312772	8.23	90.21	-1.25	76	499320	65.08	4.92
Amsterdam	299712	4.64	23069365	8.27	76.97	3.53	80	525600	57.02	12.98
Brussels	225662	7.26	11237582	8.28	49.80	0.37	50	328500	68.69	1.31
Vienna	152730	6.28	7524328	8.77	49.27	1.66	30	197100	77.49	-7.49
Hamburg	113633	5.01	4435501	9.67	39.03	4.50	40	262800	43.24	26.76
Manchester	165910	6.60	14344868	10.29	86.46	4.26	42	275940	60.13	9.87
Milan Malpensa	35808	11.46	3231451	10.81	90.24	0.00	30	197100	18.17	51.83
Dublin	130031	4.66	6926432	11.95	53.27	7.84	26	170820	76.12	-6.12
Istanbul	150627	n/a	10088622	n/a	66.98	n/a	40	262800	57.32	12.68
London Stansted	75257	n/a	3257949	n/a	43.29	n/a	42	275940	27.27	42.73
Manchester (With 2nd Runway)	165910	not relevant	14344868	not relevant	86.46	not relevant	64	420480	39.46	30.54
Averages		4.72		6.31		1.36				

Notes:

1. Istanbul and Stansted Growth rates are not included due to insufficient data for the period.
2. Annual runway capacity is calculated by multiplying declared hourly capacity by 18 hours and 365 days.
3. Available Runway Capacity = Difference of capacity utilised and the 70% runway congestion level indicated by the 1987 AEA report.

Appendix 4.9

Forecast of Available Runway Capacity by 2010 for Selected European Airports - Summary Table

Airport	2010 and 18 Hrs Operation						2010 and 24 Hrs Operation					
	2% Growth % Cap Used	%Capacity Available	1% Growth % Cap Used	%Capacity Available	3% Growth % Cap Used	%Capacity Available	2% Growth % Cap Used	%Capacity Available	1% Growth % Cap Used	%Capacity Available	3% Growth % Cap Used	%Capacity Available
London Heathrow	104.36	-34.36	89.14	-19.14	121.99	-51.99	78.27	-8.27	66.86	3.14	91.50	-21.50
London Gatwick	95.34	-25.34	81.44	-11.44	111.45	-41.45	71.51	-1.51	61.08	8.92	83.59	-13.59
Frankfurt	93.39	-23.39	79.77	-9.77	109.17	-39.17	70.04	-0.04	59.83	10.17	81.88	-11.88
Madrid	88.33	-18.33	75.45	-5.45	103.26	-33.26	66.25	3.75	56.59	13.41	77.44	-7.44
Manchester	82.54	-12.54	70.50	-0.50	96.48	-26.48	61.90	8.10	52.88	17.12	72.36	-2.36
Zurich	81.72	-11.72	69.81	0.19	95.53	-25.53	61.29	8.71	52.35	17.65	71.65	-1.65
Brussels	78.59	-8.59	67.12	2.88	91.86	-21.86	58.94	11.06	50.34	19.66	68.90	1.10
Geneva	74.53	-4.53	63.66	6.34	87.12	-17.12	55.90	14.10	47.75	22.25	65.34	4.66
Vienna	70.92	-0.92	60.57	9.43	82.90	-12.90	53.19	16.81	45.43	24.57	62.17	7.83
Copenhagen	68.21	1.79	58.26	11.74	79.73	-9.73	51.16	18.84	43.70	26.30	59.80	10.20
Paris Orly	66.47	3.53	56.77	13.23	77.70	-7.70	49.85	20.15	42.58	27.42	58.27	11.73
Istanbul	62.95	7.05	53.77	16.23	73.58	-3.58	47.21	22.79	40.32	29.68	55.19	14.81
Amsterdam	62.62	7.38	53.49	16.51	73.20	-3.20	46.97	23.03	40.12	29.88	54.90	15.10
Dublin	60.38	9.62	51.57	18.43	70.58	-0.58	45.28	24.72	38.68	31.32	52.93	17.07
Rome Fiumicino(Com traffic only)	59.84	10.16	51.11	18.89	69.95	0.05	44.88	25.12	38.34	31.66	52.46	17.54
Milan Linate(Com traffic only)	59.49	10.51	50.81	19.19	69.54	0.46	44.61	25.39	38.11	31.89	52.15	17.85
Barcelona	58.50	11.50	49.97	20.03	68.38	1.62	43.87	26.13	37.48	32.52	51.29	18.71
Paris Ch. de Gu.	56.58	13.42	48.33	21.67	66.14	3.86	42.44	27.56	36.25	33.75	49.60	20.40
Manchester 2	54.17	15.83	46.27	23.73	63.32	6.68	40.62	29.38	34.70	35.30	47.49	22.51
Dusseldorf	51.34	18.66	43.85	26.15	60.01	9.99	38.50	31.50	32.89	37.11	45.01	24.99
Stockholm Arlanda	47.89	22.11	40.90	29.10	55.98	14.02	35.91	34.09	30.68	39.32	41.98	28.02
Munich	46.31	23.69	39.55	30.45	54.13	15.87	34.73	35.27	29.66	40.34	40.60	29.40
Hamburg	43.17	26.83	36.87	33.13	50.46	19.54	32.38	37.62	27.66	42.34	37.85	32.15
Marseille	40.29	29.71	34.41	35.59	47.10	22.90	30.22	39.78	25.81	44.19	35.32	34.68
London Stansted	37.44	32.56	31.98	38.02	43.77	26.23	28.08	41.92	23.98	46.02	32.82	37.18
Athens(Com traffic only)	35.52	34.48	30.04	39.96	41.93	28.07	26.64	43.36	22.53	47.47	31.45	38.55
Palma	34.22	35.78	29.23	40.77	40.00	30.00	25.67	44.33	21.92	48.08	30.00	40.00
Milan Malpensa(Com traffic only)	13.86	56.14	11.83	58.17	16.20	53.80	10.39	59.61	8.88	61.12	12.15	57.85

Source: Forecasts extrapolated from ICAO and ACI Airport Traffic Statistics 1985-1994

Appendix 4.10

Breakdown of Ownership and Aeronautical Charges for Selected European Airports 1995

Airport (Ranked by difference in Saab 340 and A320 charge per pax.)	Airport Ownership (%)				Aeronautical Charges (ECU)					% of total Airport Revenue from Aeronautical charges
	National Government	Local Government	City/Town Authority	Private Sector	Saab 340	Saab Charge per Pax.	Difference in Saab and A320 charge	A320	A320 Charge per Pax.	
London Heathrow				100	499	22.68	5.98	1637	16.70	35
London Gatwick				100	358	16.27	4.17	1186	12.10	30
Munich	28	51	23		570	25.91	3.36	2210	22.55	54
Dusseldorf		50	50		507	23.05	2.44	2019	20.60	72
Brussels Zavantem	100				477	21.68	0.30	2095	21.38	47
Stuttgart		50	50		467	21.23	0.24	2057	20.99	68
Barcelona	100				185	8.41	-1.43	964	9.84	59
Madrid	100				185	8.41	-1.43	964	9.84	58
Tenerife Sur	100				185	8.41	-1.43	964	9.84	73
Hamburg	26	10	64		444	20.18	-1.65	2140	21.84	97
Frankfurt	33	33	33		487	22.14	-1.70	2336	23.84	79
Lisbon	100				348	15.82	-2.37	1782	18.18	81
Amsterdam	75		24	1	396	18.00	-3.91	2147	21.91	41
Palma	100				95	4.32	-4.60	874	8.92	65
Dublin	100				175	7.95	-4.99	1269	12.95	n/a
Nice	100				203	9.23	-6.91	1581	16.13	39
Helsinki	100				265	12.05	-7.09	1875	19.13	66
Glasgow				100	321	14.59	-7.12	2128	21.71	53
Paris CDG	100				230	10.45	-7.17	1727	17.62	49
Paris Orly	100				230	10.45	-7.17	1727	17.62	49
Birmingham		42	7	51	361	16.41	-7.61	2354	24.02	59
Milan Linate	100				99	4.50	-7.79	1204	12.29	83
Milan Malpensa	100				99	4.50	-7.79	1204	12.29	83
Rome Fiumicino	100				99	4.50	-7.79	1204	12.29	50
Rome Ciampino	100				99	4.50	-7.79	1204	12.29	50
Venice	100				99	4.50	-7.79	1204	12.29	82
Copenhagen	75			25	205	9.32	-7.87	1684	17.18	61
Manchester		45	55		196	8.91	-8.63	1719	17.54	54
Stockholm Arlanda	100				152	6.91	-9.21	1580	16.12	n/a
Oslo Fornebu	100				422	19.18	-9.70	2830	28.88	67
Athens	100				249	11.32	-10.66	2154	21.98	n/a
Vienna	17.4	17.4	17.4	47.8	325	14.77	-13.56	2777	28.34	67

Notes:

1. Aeronautical charges assume a 65% load factor and the sum of runway use charge, pax. levy and security charge, one hour parking charge and local air navigation charge.
2. Saab 340 aeronautical charge is based on a domestic scheduled flight, with 34 seats, MTOW 13,00kg (22 seats filled)
3. Airbus 320 aeronautical charge is based on an intra-EU cross boarder scheduled flight with 150 seats, and 74 tonnes (98 seats filled)

Source: Dept. Air Transport, Cranfield University (1995) Competition and Airport Financing in the EU - Study for Eurpoean Commision, DGVII

Appendix 4.11

Heathrow Slot Capacity vs Demand in Peak August Summer 1994

Hour	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	Total
Arrivals																		
Demand	29	44	59	47	50	52	42	38	32	39	37	45	50	42	44	29	6	685
Capacity	30	39	39	39	38	38	38	37	37	39	39	40	40	39	39	34	15	620
Excess Demand	-1	5	20	8	12	14	4	1	-5	0	-2	5	10	3	5	-5	-9	65
Departures																		
Demand	13	45	47	50	47	51	53	48	41	43	45	43	50	53	36	14	15	694
Capacity	25	40	40	40	40	39	39	38	36	36	38	39	39	40	39	25	15	608
Excess Demand	-12	5	7	10	7	12	14	10	5	7	7	4	11	13	-3	-11	0	86
Total																		
Demand	42	89	106	97	97	103	95	86	73	82	82	88	100	95	80	43	21	1379
Capacity	55	79	79	79	78	77	77	75	73	75	77	79	79	79	78	59	30	1228
Excess Demand	-13	10	27	18	19	26	18	11	0	7	5	9	21	16	2	-16	-9	151

Gatwick Slot Capacity vs Demand in Peak August Summer 1994

Hour	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	Total
All Movements																					
Demand	6	12	34	70	76	76	52	54	54	44	52	42	34	54	64	56	40	28	20	14	882
Capacity	20	20	35	44	46	44	42	42	40	38	42	36	36	44	45	44	38	38	30	20	744
Excess Demand	-14	-8	-1	26	30	32	10	12	14	6	10	6	-2	10	19	12	2	-10	-10	-6	138

Source: CAA (1995) CAP 644 Slot Allocation: A Proposal for Europe's Airports

Appendix 4.12

Recommendations of EC Proposal on Airport Slot Allocation (Council Regulation (EEC) No. 95/93 of January 18,1993)

- A carrier may apply for new entrant slots at an airport provided it has less than four on any one day. Above this limit new entrant status will be lost unless the carrier applies for slots on a non-stop service between two Community airports where, at most, two other carriers operate a direct service between the two Community airports or airport system. However, if the carrier holds more than 3% of total slots available at that airport or more than 2% of the total slots available at an airport system, the carrier shall not be entitled to any new entrant status.

- If a member state designates an airport as coordinated[1], it is responsible to ensue that the coordinator provides to all concerned, all the relevant information regarding co-ordination and to ensure that the principles of transparency, neutrality and non-discrimination are met. Member states are also obliged to carry out airport capacity analysis when air carriers or the airport authorities consider that capacity is insufficient for actual or planned demand or when new entrants encounter serious problems in obtaining slots. Recognised methods must be used conforming to recognised industry standards. All fully coordinated airports must have undergone a capacity analysis by 1995.

- A coordinator for the previous regulation shall be appointed and act in accordance to the regulation, attend international scheduling conferences, be responsible for slot allocation and monitor the use of slots. The coordinator shall also ensure that in that airport, a co-ordination committee is set up to assist and consult the coordinator. This committee must represent all the air transport services as well as local residents and users of the system.

- Airport capacity shall be determined by a competent authority as defined by the member state. This may be the airport assisted by ATC, the airlines or a third party organisation with the appropriate skills and knowledge for this task.

- The IATA scheduling procedures guide is to remain the baseline for slot allocation. Grandfather rights remain valid although permission is given to freely exchange slots between air carriers on a one to one basis. Slots may be exchanged with other slot holding airlines at an airport, without hindrance from the coordinator. The transfer of slot does not restrict the route or level of service that can be offered with the traded slot except in the case of slots given to a new entrant on specific routes.

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[1] At a coordinated airport the coordinator facilitates the operation of the air carriers. Scheduled Movement Advises are required to be sent to the coordinator. The coordinator will not allocate slots and airlines do not have to obtain cleared slots for their schedules. A fully coordinated airport has an appointed coordinator and requires Scheduled Clearances Requests to be sent to the coordinator. In periods where demand exceeds capacity all the schedules shall have slots allocated by the coordinator.

- EU members may declare certain routes to an airport serving peripheral or development regions within the member state as vital for the economic development of a region. In this case slots at fully coordinated airports will be reserved for the designated routes.

- Grandfather slots are defined as slots the carrier operates in a similar fashion and on the same day of the week for a number of weeks. With evidence of this the carrier may claim historical precedence to the slot so long as the slot was operated by at least 80% of the time during it's allocation period. Allowances to this 80% rule are made for grounding of aircraft types, ATC, adverse weather and strikes by ATC or handling agents. Failure to meet these criteria will result in the slot being taken from the carrier and placed in a slot pool. This pool will supply slots to carriers applying for extra

- slots and at least 50% will go to new entrants although this may be reduced if new entrant demand has been satisfied.

- A carrier at a fully coordinated airport may not exchange it's own slots to permit increased operation on a particular route between two EU member states or operate new routes.

- No discrimination must exist between treatment of foreign, (non EC), and Community carriers at any airport. Action to take if this rule is broken is not clearly explained.

- The European Commission must report to the European Council and Parliament on the implementation of this regulation three years after its entry into force. Final responsibility for continuation and revision of this regulation lies with the European Council of Ministers.

Source: Taken from Ligi, F. (1995) Airport Slot Allocation in Europe. MSc Thesis, Dept., Air Transport, Cranfield University.

Appendix 4.13

APATSI Mature ATC Procedures

1. Reduction of Radar Separation on Final Approach

This procedure recommends the reduction of final approach radar separation between aircraft, without wake vortex restrictions, from 3nm to 2.5nm. The procedure requires runway occupancy time of 50 seconds or less and turnoff points visible from the ATC tower. Capacity gains of 3 to 5 arrivals per hour for a single mode runway operation are envisaged following reports of similar procedures in the US. Most major European airports will be candidates for implementation of this procedure.

2. Reduction of Diagonal Separation on Final Approach

For aircraft established on parallel final approach paths to runways separated by at least 760m, diagonal separation may be reduced from 2nm to 1.5nm. The procedure is subject to weather and non conflicting missed approach paths. Capacity gains of 4 arrivals per hour on single mode runways are expected. Candidate airports are Amsterdam Schiphol, Hanover, Heathrow, Berlin Schoenefeld, Cologne-Bonn and Rome Fiumicino.

3. Reduced Runway Separation on the Same Runway

This procedure envisages that under specific conditions of aircraft traffic mix and visibility, aircraft may be cleared to land or depart while a preceding aircraft is landing or departing from the same runway. Specific minimum separation distances along the runway are specified for each case. Capacity gains of two movements per hour are expected off a single runway during peak hours of operation. Candidate airports are Alicante, Barcelona, Copenhagen, Gothenburg, Istanbul, Lyon, Amsterdam, Bordeaux, Geneva, Helsinki, Lisbon, Madrid, Malaga, Marseille, Nice, Paris CDG, Rome Fiumicino, Manchester, Milan Malpensa, Palma de Mallorca, Paris Orly and Stockholm Arlanda.

4. Simultaneous Operations on Intersecting/Converging Runways (SIMOPS)

Under specified weather and visibility conditions an aircraft will be permitted to land whilst another aircraft is simultaneously taking off or landing on an intersecting or converging runway. The procedure is referred to as SIMOPS. Specific ATC clearances are required along with clearly published landing distances and good braking conditions. Use of SIMOPS at Sydney Kingsford Smith airport in Australia has led to an almost complete removal of the need to hold aircraft prior to sequencing. Candidate European airports are Stockholm Arlanda, Hamburg, Amsterdam, Barcelona, Zurich, Dublin, Helsinki, Rome Fiumicino, Lisbon, Madrid and Edinburgh.

5. Visual Approaches

This is an approach by an IFR flight where either part or all of the instrument approach procedure is not completed. Instead the pilot elects for an approach using visual reference to the ground. Obviously, the procedure is dependent on cloud ceiling. Visual approach capacity gains come by reducing aircraft spacing and time to complete the approach in a non-radar environment. The procedure is currently used in Germany and the UK, but could be applied to all ECAC states.

6. Intersection Take Offs

This procedure can be requested by ATC or the pilot. It makes use of runway access points to reduce departure delays by improving traffic sequencing and avoiding unnecessarily long taxi times to the end of the runway. Use of the procedure requires publication of reduced take off distances from the intersections. Specific minimum visibility limits are also applied along with the need for specific marking and lighting aids to ensure safe control and guidance of aircraft towards take off intersections. Specific capacity gains will be dependent on traffic mixes, location of the intersections, and type of traffic demand. This can be applied to any European airport with a fully developed taxiway system. Paris Charles de Gaulle has used this procedure since January 1988. It is also used effectively at Manchester.

7. Multiple Line Ups

This procedure is an extension of intersection take offs. It permits more than one aircraft to line up on the active runway at any one time. By using the procedure runway occupancy time can be reduced due to the lack of any time required for aircraft to move from the holding point to the runway. It can only be used during daylight hours and the aircraft must be within visual range of the ATC tower. Capacity gains of two movements per hour have been put forward by ATC controllers. The procedure can be applied to any European airport with appropriately placed runway intersections. The procedure is currently used widely at Paris CDG and Manchester.

8. Landing Based on Anticipated Separation

This applies where runway separation between an arrival and a preceding arrival or departure does not yet exist, but is expected to exist by the time the arriving aircraft reaches the runway threshold. Landing clearance is given if the controller judges the situation to be acceptable. Capacity gains will come from closer aircraft spacing and the reduced number of missed approaches. All major European airports are candidates for this procedure. The procedure is actively used at Heathrow and Gatwick, with the, 'Land After', procedure being used in France.

9. Modification of Application of Wake Vortex Constraints for Departing Aircraft

This procedure places the responsibility for wake vortex avoidance, on departure, with the pilot of the aircraft. ATC will clear the aircraft to depart indicating the type of aircraft that departed ahead, the time since it departed, surface wind and possibility of wake vortex turbulence. Application of the procedure at Amsterdam Schiphol has demonstrated that invariably the pilot reduced the required separation. The procedure could be applied to any European airport.

10. Displaced Threshold

On intersecting runways, when one is used for arrivals and the other for departures, a reduction in landing and departure clearance can be achieved if the landing or take off threshold is displaced. The displacement will mean that the landing or departing aircraft will cross the intersecting runway earlier than was previous. Obviously, the runway in question will need to be long enough to allow such a displacement. Displacement of the take off runway will only be permitted if the obstacle clearance procedure does not unduly penalise operators. The procedure has been used at Madrid Barajas where the landing runway threshold was displaced towards the intersection. The results were a reduction in the time it took for aircraft to clear the intersection from 35-40 seconds to 10-15 seconds. The procedure will have limited applicability to European airports with sufficiently long intersecting runways.

11. Strategic Deconfliction of Arrival and Departure Routes

This procedure encourages the development of improved SID and STAR co-ordination to promote better traffic flow in the TMA and reduced controller workload. Full exploitation of RNAV equipment is encouraged to avoid unnecessary investment in ground based aids. Obviously, specific implementation of this procedure will be dependent on local operating restrictions and TMA airspace structure. Whilst quite well developed at most major European airports, this procedure can be considered for any European airport where TMA traffic levels warrant. In the London TMA substantial work was done in this field with the development of the Central Control Function, (CCF). This procedure has now centralised all London airport ATC approach controllers with their companion area controllers at West Drayton. In addition stand alone tunnels for arriving and departing aircraft from each airport have been developed to reduce controller workload in climbing or descending aircraft through the busy TMA. The Terminal Radar Approach Control, (TRACON), system has also been developed in the US. Similar approaches have been carried out in the Paris and Madrid TMA's.

12. Operational Factors Affecting Runway Capacity

This procedure focuses on reducing runway occupancy time. It promotes the construction of adequately located departure sequencing pads, rapid exit taxiways and rapid access taxiways. It also encourages pilots to nominate in their approach brief which RET they intend to use, which will minimise their landing run. For departure pilots are requested to complete departure checks prior to lining up and expected to commence their take off roll immediately upon receipt of their take off clearance. The procedure also focuses on the ATC controller, requiring them to improve their final sequencing separation. This is expected to come from improved precision approach radars. Modifications to runway lighting and markings may be required. At Gatwick runway marking were painted as a series of strips with the number of co-located strips decreasing as the next RET was approached. The aim was to help the pilot gauge his speed and distance to the next RET to assist in braking.

The combination of these individual projects was termed, 'High Intensity Runway Operations'. Monitoring of the effectiveness, by both airports and airlines, of the procedure was recommended to help set standard ROT's. The application of the procedure is most relevant to single mode runway operations such as Gatwick and Manchester who now achieve hourly declared runway movement capacities of 42.

Source: ECAC APATSI (1993) Document on Mature Air Traffic Control Procedures. ECAC Air

Appendix to Chapter 5

5.1: Definition of Preferred Arrival Procedure into Manchester Airport for the Saab 340A.

Appendix 5.1

Cranfield University

Memo: 19th September 1994

To: John Evans,
ATC Ops 1,
NATS, Manchester.

From: Andy Jefferson,
Dept. Air Transport,
Cranfield University.

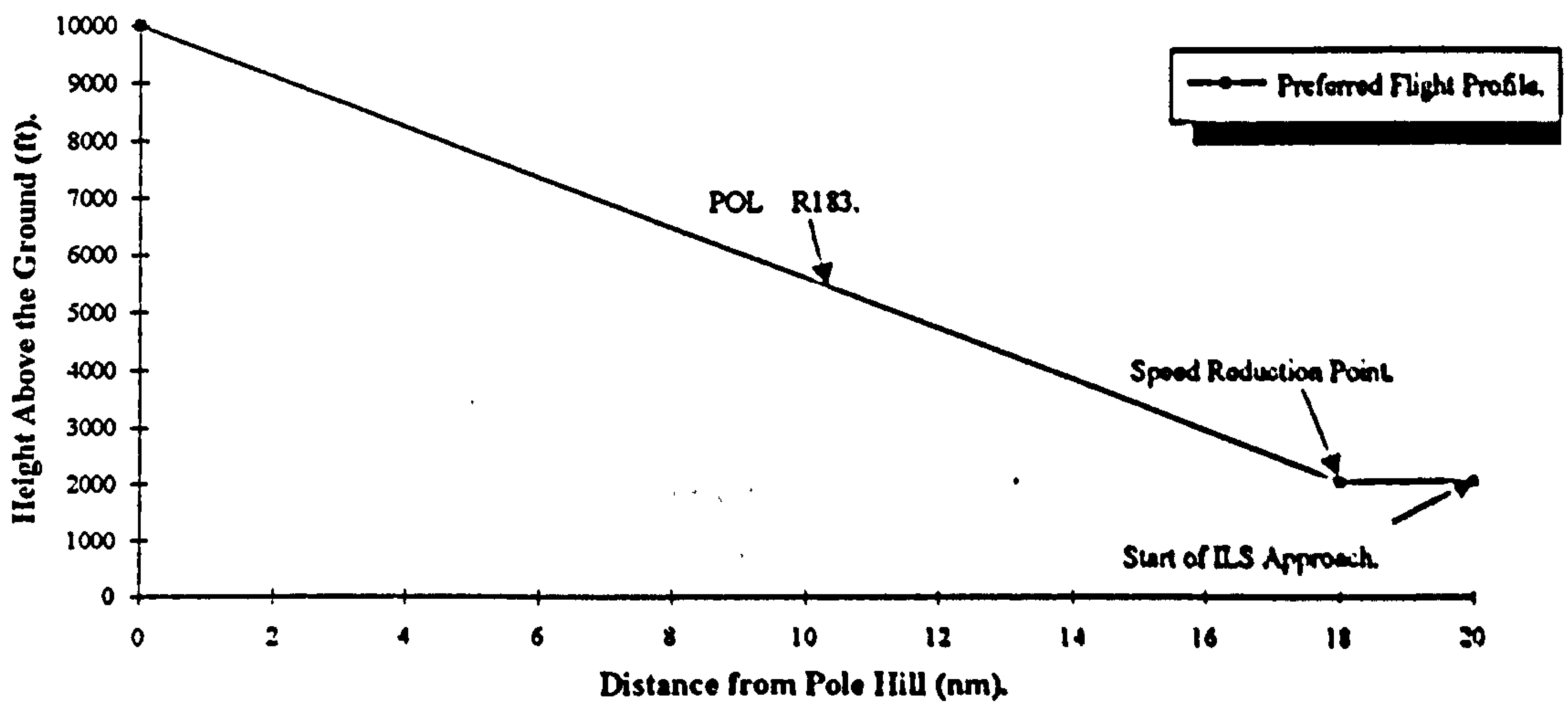
c.c. Bill Hanton,
Chief Pilot,
Business Air,
Aberdeen.

Subject: Definition of preferred arrival procedure into Manchester Airport for the Saab 340A.

PREFERRED ROUTE.

1. **Horizontal Profile.** - (See attached chart) Direct to Pole Hill - To be level at Flight Level 100 overhead the POL. Then out of POL on R183 direct to intercept ILS RWY 24 at 6nm out. Then follow the ILS.
2. **Vertical Profile.** - FL100 at the POL. Then continuous descent at approx. 2000 fpm, to be level 2nm from the ILS intercept to bring speed back.

Vertical Flight Profile Of Proposed Route for Manchester Special Arrival.



3. **Speed Profile. -** Along R183 at 220kts. Then 2nm before ILS intercept reduce speed to 200kts. Then further reduce to 170kts by the outer marker. From then on down to V_{ref} of 115kts by the threshold.

FLEXIBILITY.

Obviously Business Air appreciate the complex and busy airspace that exists within the Manchester TMA and understands that what is proposed above and on the attached chart represent an idealistic situation. As such the following information is added to help plan a realistic routing.

1. **Horizontal Profile. -** As required by ATC with the caution of GPWS warnings if diverted too far to the East at low level.
2. **Vertical Profile. -** Step descent is quite feasible but again caution over rates of descent greater than 2000fpm at 220kts due to GPWS warnings and problems of reducing speed at a later date. If continuous descents are not feasible then descent as soon as possible would be appreciated to help reduce pilot workload and keep within speed ranges at a latter stage. The point 2nm from the ILS intercept is the critical point, beyond which, speed reduction to 200kts will not be possible before intercepting the ILS. Obviously, this point can be made greater than 2nm out, if required.
3. **Speed Profile. -** **a)** Intermediate approach - Speed ranges from 220-200kts.
   b) ILS - Speeds defined are max. possible with the ability to either speed up and slow down very quickly once below 200kts.

OTHER RELEVANT INFORMATION.
Business Air's Saabs are not currently equipped to carry out steep approaches, although this may change if critical to success and if Business Air management feel the costs involved will be recouped.
Business Air are currently undergoing a period of new crew line training as such the best time for them to begin running the trial will be at the end of October.

TRIAL DEFINITION.
Assuming it is decided to go ahead with the trial two areas of concern will need to be satisfied:-

a) Trail start date, length of duration and definition of safety procedures for the new route.
b) Definition and monitoring of success criteria.

Understandably, the latter will vary between the airline, air traffic and the airport, however, to reduce future problems it will be useful to establish these for the next meeting in October.

Best Wishes,

Appendix to Chapter 6

6.1: Characteristics and Properties of the SIMMOD Data Files
6.2: Manchester Airport Typical Busy Day Arrivals and Departures - 30th June 1995
6.3: Manchester Airport Aerodrome Chart and Standard Routings
6.4: Zurich Busy Day Schedule - 16th July 1994
6.5: Zurich Airport Aerodrome Chart and Standard Routings
6.6: Gatwick Airport Typical Busy Day Schedule - 30th June 1995
6.7: Gatwick Airport Aerodrome Chart and Standard Routings
6.8: The Costs and Benefits of Implementing Special Regional Aircraft Procedures
6.9: Regional Airline, European Airport and Major European Airline Questionnaires.

Appendix 6.1

Characteristics and Properties of the SIMMOD Data Files

Aircraft data file
This file provides the simulation with a number of aircraft models each with various takeoff weights depending on trip length. The take off weight is also used to determine the aircraft's weight category. SIMMOD uses four categories defined below:

1.	< 10,000lb	Small Engine/GA
2.	10,000lb-100,000lb	Twin Engine /Small
3.	100,000lb-300,000lb	Commercial Jet/Large
4.	> 300,000lb	Wide Body/Heavy

These categories are also used to determine the aircraft's wake vortex category, enroute minimum separation requirements, holding strategy, speed performance in the air, take off and landing roles and gate servicing times.

This file also contained the aircraft group maximum, nominal and minimum speeds and minimum holding time and speed. Obviously, this grouping of aircraft types into four categories causes limitations by generalising in each of the cases although it is difficult to overcome without making the model impossibly complex.

Airspace data file
The airspace routes are defined as a set of nodes, or points and links, or lines. These in turn are combined to create routes for arrival and departure. The nodes all have a specified altitude and are also used to check aircraft separation. As an aircraft passes the node its separation is checked and either held at the node until minimum separation is re-established and capacity of the next link is not exceeded, or released at reduced speed to ensure separation is maintained between a slower aircraft in front. The node holding strategy is specified as one of three possibilities:

a) Hold if aircraft are holding at next node in route.

b) Hold if the capacity of the next node's holding queue is full.

c) Hold if capacity of next node's hold is exceeded by aircraft at hold and those approaching it.

This check will only take place if holding at the next node exists when aircraft arrive at the preceding node. Where more than one link joins a node aircraft speeds are modified to provide separation at the node. This applies to either merging routes on arrival or crossing routes at the same node. In addition to this specific nodes can be defined as holding stacks with maximum capacity, and minimum entry and exit times. The final node in the airspace file is the interface node which links the airspace system to the ground system.

Links in the airspace file have recommended speeds for aircraft although these can be varied to optimise separation and traffic flow. This is used to model path stretching concepts applied by ATC in real day situations. Links on final approach to the runway can be linked to simulate paired or staggered approach control for close parallel runway operations.

SIMMOD defines three levels of movement control:

a) Node Arrival Control

b) Metering Control

c) Flow Control

Node arrival control is the basic level and broken into three types. Queue first in, first out, (QFIFO), places every aircraft at the back of an arrival queue based on distance from the node. This can lead to large back logs in the system and poorly optimised aircraft flow, especially for wake vortex separation. This problem is attempted to be solved by the next type of control in the base level, namely speed fit node arrival control. Individual aircraft are allowed to modify their speed within the range specified in the aircraft data file to prevent multiple arrivals at a point at the same time. Its effect is optimised if a number of links join one node with many varying aircraft types. SIMMOD will always only adjust the speed of the aircraft by the minimum amount required to achieve the necessary separation. Speed fit also modifies the aircraft's speed when modifying its location in a queue. Multi fit node arrival control is the final modification available in the base level. This extends the previous speed fit system by attempting to fit an aircraft at a specific point by adjusting other aircraft in the queue. As this last strategy most closely resembles real life ATC, it is the one used in this thesis.

The final two levels of movement control build on the base level explained above. The metering strategy provides the option to model the effect of looking ahead, along the route network and modifying present traffic to reduce possible congestion further down track. Flow control strategy aims to provide the optimum control of air traffic in the system by modifying separation distances at nodes on the boundary of the defined airspace. This aims to balance the flow of air traffic into the system to prevent the development of congestion points in the airspace system that cannot reasonably be resolved by node arrival or meter control levels.

In this research the last two levels of movement control were only added into the simulation if excessive congestion occurred. This was due to the processing time penalties that were incurred by adding them to the simulation.

The final section required for this file is the airport information. This data is fairly basic but does also have a spread list which basically gives a percentage figure by which arrival spacing can be increased to help increase departure flow once the departure queue reaches a certain size. Excessive percentage spread will lead to significantly reduced departure delay but increased arrival delay. A healthy balance is needed, which is only determined by experimentation.

Ground data file
As with the airspace file, the airfield is composed of a series of nodes and links. Links are defined as either taxiway or runway sections, whilst nodes can either be departure queues, or terminal gates. Ground links have a variety of data associated with them to determine their characteristics. These include, passing rules and limitations, length, reservation for arriving or departing traffic, or both, aircraft capacity and maximum aircraft size allowed on the link. In addition taxi links from the runway to the taxiway system can be classed as rapid exit taxiways, if required. Specific taxi paths can also be defined to allow preferred routings from the runway to the gate or vice versa. If these preferred routes are not defined the simulation will aim to move the aircraft from the runway to the gate along an optimised taxi path relating to minimum time.

Two final points to consider in the ground file are departure queues and take off and landing rolls. Departure queues are positioned at the end of the departure runway and have defined capacity, beyond which arrival separation is increased to allow more gaps for departures. They also contain a unique departure route list, and passing strategy. The program models well the problems the controller would face in trying to optimise traffic in this departure queue by limiting the ability of aircraft to pass on another. For simulating take off and landing the simulation picks a random distance for the role bounded by the maximum and minimum limits set in the aircraft data file. Again this brings a touch of realism to the model. Limitations with this approach lie in the ability of the operator to accurately input realistic maximum and minimum values. Time for the take off and landing is calculated using the selected distance and the average velocity during the roll.

The final part of the ground file relates to the airport gates and restrictions on their use. As this is not relevant to this thesis it was not utilised in the simulations.

Events data file
This file holds all the data concerning the aircraft that will operate in the system. Data inputted includes, time of entry into the simulation, airline flight number, aircraft model number from the aircraft data file, destination of the flight, route the aircraft will take through the system, taxi path if required, and turnaround data if required, including scheduled re-departure time. Regarding the turnaround again random times are generated within set limits to simulated real day turnaround cases.

The events file also sets all the environmental conditions for the simulation such as runways in use, weather, if inputted and any changes to any of the existing data at set times. Although the runway in use option was used in this research, the other variables were not experimented with for two reasons. Firstly, the case studies had to be run with exactly the same conditions each time to allow effective comparisons to be made, and secondly, it would of significantly increased the simulation time.

APPENDIX 6.2

Manchester Airport Typical Busy Day Arrivals - 30th June 1995

Arr. Time	Flt. No	Aircraft Type	A/c Code	From	Turnaround	Dest.
0.20	AMM301	734	84	ACE/FAO		
0.45	MON5651	AB6	31	ACE		
1.10	AMM273	757	51	DLM		
1.30	AMM123	757	51	MLA		
1.30	AT5220	732	42	TNG	AT5221	TNG
1.50	LEI7348	734	84	ALC		
2.25	DP029	757	52	LCA		
4.05	BY536B	757	51	KGS		
4.10	LEI7682	734	84	LCA		
4.50	BY529B	762	32	POP		
4.55	MON1803	A320	87	LCA		
5.05	BY039B	762	32	ALC		
5.10	BY305B	757	51	HER		
5.10	EXC136	A320	87	GRO	EXC103	MAH
5.20	AIH278	M83	50	LPA		
5.25	BY081B	757	51	PMI	BY439A	ATH
5.30	MON3541	AB6	31	AGP		
5.35	ULE832	763	33	MCO		
5.40	AIH176	M83	50	AGP	AIH251	IBZ
6.10	BA183	763	33	JFK		
6.35	BY144B	762	32	PMI	BY215A	MAH
6.35	CKT116	757	51	MCO/GLA		
6.40	CMM4837	757	52	YVR/YYC	CMM4838	YYC/YVR
6.55	AMM1531	757	51	PMI	AMM384	AGP
6.55	AMM034	757	51	BKK/DHA	AMM106	TFS
6.55	THI110	757	52	KGS		
7.10	AA092	757	52	JFK		
7.25	BA7841	J41	99	RTM	BA7841	ORK
7.30	SQ338	744	83	SIN/BOM		
7.35	BA4402	734	84	LHR	BA4423	LHR
7.40	II551	J31	98	CWL	9R501	MME
7.45	MON3969	A320	87	ZTH	MON3124	MAH
7.45	AA054	M11	85	ORD		
7.50	5W621	J31	98	NWI	5W622	NWI/RTM
7.55	BA5017	732	42	BRU		
7.55	CX261	744	83	HKG/CDG		
8.00	BA7600	ATP	67	BHD	BA7603	BHD
8.00	EI202	143	15	DUB	EI203	DUB
8.05	JE321	ATP	67	IOM	JE322	IOM
8.05	II370	SF340	72	ABZ	II371	ABZ
8.05	5E600	J31	98	EIN/RTM	5E601	RTM/EIN
8.05	AF984	735	84	CDG	AF923	CDG
8.05	LH4034	735	84	DUS	LH4055	DUS
8.05	BA5731	ATP	67	GLA	BA5732	GLA
8.10	II330	SF340	72	BFS	II331	BFS
8.10	II390	SF340	72	GLA	II391	GLA
8.15	9C712	SH6	68	NCL	9C713	NCL
8.15	II380	SF340	72	DND/EDI	II381	EDI/DND
8.15	TIH042	763	33	MCO/GLA		
8.15	LH4058	732	42	FRA	LH4103	FRA
8.15	LH5204	F50	89	HAM	LH5205	HAM
8.20	BA5761	ATP	67	EDI	BA5762	EDI

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8.25	BA2002	732	42	LGW	BA2003	LGW
8.25	CB301	DO8	100	AMS	CB004	CBG
8.35	BA4412	757	51	LHR	BA4433	LHR
8.35	CLI410	742	2	YVR/BFS		
8.35	BA5791	ATP	67	ABZ	BA5734	GLA
8.40	FR550	732	42	DUB	FR551	DUB
8.45	DL064	L1015	23	ATL		
8.50	CB003	DO8	100	CBG	CB302	AMS
8.55	EI661	735	84	ZRH	EI661	DUB
8.55	OOE485	732	42	ZTH	OOE486	DLM
9.00	EI622	735	84	DUB	EI622	CPH
9.05	WA421	J31	98	BLL	WA421	BHX/BLL
9.15	9R115	J31	98	BOH/EXT	9R116	EXT/BOH
9.15	AC840	762	32	YYZ	AC841	YYZ
9.20	FU520	EM2	101	LYS	FU521	LYS
9.25	VM131	J31	98	BOD/NTE		
9.30	BA7731	J41	99	SOU	BA7750	GCI
9.30	BA7602	ATP	67	BHD	BA7723	NOC
9.30	9R502	J31	98	MME	II552	CWL
9.30	TS257	L1011	22	GLA	TS257	YYZ
9.30	BA5281	ATP	67	BFS	BA5284	BFS
9.35	BA4422	757	51	LHR	BA4443	LHR
9.45	BA7822	J41	99	STN	BA7823	STN
9.45	MON5023	757	51	TFS	MON3972	TFS
9.45	BA5763	ATP	67	EDI		
9.45	BA5608	ATP	67	GLA	BA5608	HAJ
9.55	UK151	F100	88	AMS	UK152	AMS
10.00	TZ721	757	52	JFK/GLA	TZ721	JFK
10.15	BA2004	732	42	LGW	BA2005	LGW
10.20	SN7816	732	42	BRU	SN7616	BRU
10.25	BA5025	732	42	AMS		
10.30	AA120	762	32	ORD		
10.30	SK1541	D94	46	ARN/FBU	SK1542	FBU/ARN
10.30	KM202	A320	87	MLA	KM203	MLA
10.35	BA4432	763	33	LHR	BA4463	LHR
10.40	SU249	TU5	90	SVO	SU250	SVO
10.45	AY687	M82	49	HEL/ARN	AY688	ARN/HEL
10.50	BA5003	732	42	CDG	BA5026	AMS
10.50	SK539	D94	46	CPH	SK540	CPH
11.05	BA7842	J41	99	ORK	BA7835	SNN
11.20	AIH112	M83	50	BVA	AIH113	MLA
11.30	II332	SF340	72	BFS	II333	BFS
11.30	FR552	732	42	DUB	FR553	DUB
11.30	IB6916	M87	86	MAD/BCN	IB6917	BCN/MAD
11.35	BA5129	732	42	DUS	BA5130	DUS
11.40	BA7604	ATP	67	BHD	BA7764	JER
11.50	BA5147	732	42	FRA	BA5004	CDG
11.55	CKT1397	L1011	22	MAH	CKT1396	MAH
12.00	BA2006	732	42	LGW	BA2007	LGW
12.00	OK660	735	84	PRG	OK661	PRG
12.15	AMM129	757	51	VRN	AMM222	TFS
12.20	BA5011	732	42	CDG	BA5028	AMS
12.30	LEI7684	734	84	MAH	LEI7683	MAH
12.35	BA5139	732	42	MUC	BA5060	LIN
12.40	BA4452	757	51	LHR	BA4483	LHR
12.45	BY068B	757	51	FAO	BY124AF	NCL

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12.45	EXC104	A320	87	MAH	EXC107	MAH
12.45	BA5285	ATP	67	BFS	BA5286	BFS
12.50	BA8774	SH6	68	LDY	BA8775	LDY
12.55	CLI411	313	34	LGW	CLI411	YVR
13.00	AIH280	A320	87	MAH	AIH279	MAH
13.05	II382	SF340	72	LSI/EDI	II383	EDI
13.05	LEI7602	734	84	MAH	LEI7267	GRO
13.05	BA5060	ATP	67	GLA	BA5764	EDI
13.10	JY574	F2E	67	JER/GCI	JY577	GCI
13.15	BA7751	J41	99	GCI	BA7754	GCI
13.15	AIH144	M83	50	NAP		
13.20	JE325	ATP	67	IOM	JE326	IOM
13.25	AF914	735	84	CDG	AF907	CDG
13.40	AMM385	757	51	AGP	AMM372	NAP
13.40	TIH178	757	52	PMI	AIH179	PMI
13.45	BA5059	732	42	LIN		
13.45	BY201B	762	32	PMI	BY446A	CFU
13.50	BA7763	ATP	67	JER		
13.50	BY257B	757	51	PMI	BY117A	IBZ
13.50	AMM151	734	84	LDE	AMM228	AGP
13.55	CB303	DO8	100	AMS		
13.55	ALT257	A320	87	PVK	ALT254	DLM
14.00	BA118	742	2	ISB	BA118	LGW
14.00	BA7724	ATP	67	NOC	BA7605	BHD
14.05	MON3549	A320	87	NAP	MON3772	AGP
14.20	BA5735	ATP	67	GLA	BA5736	GLA
14.25	EI623	735	84	CPH	EI623	DUB
14.25	FR554	732	42	DUB	FR555	DUB
14.30	EAF2307	B15	37	LDE		
14.35	BA4472	763	33	LHR	BA4503	LHR
14.35	BY215B	762	32	MAH	BY159A	NAP
14.40	UK155	F100	88	AMS	UK156	AMS
14.40	BWL512	143	15	CIA	BWL303	VGO
14.45	BA7836	J41	99	SNN	BA7845	ORK
15.00	SN7812	732	42	BRU	SN7618	BRU
15.10	BA5058	732	42	GVA	BA5006	CDG
15.10	LG445	EM2	101	LUX	LG446	LUX
15.15	9C714	SH6	68	NCL		
15.20	EI206	143	15	DUB	EI207	DUB
15.20	BA5795	ATP	67	ABZ	BA5796	ABZ
15.25	BA7733	J41	99	SOU	BA7734	SOU
15.25	II334	SF340	72	BFS	II335	BFS
15.30	BA2012	734	84	LGW	BA2011	LGW
15.30	BA5027	732	42	AMS		
15.45	AMM309	757	51	CFU	AMM338	MAH
15.50	BA7765	ATP	67	JER	BA7607	BHD
15.50	BA5131	732	42	DUS	BA5020	BRU
15.50	BA5611	ATP	67	HAJ	BA5611	GLA
16.05	BY439B	757	51	ATH	BY075A	RMI
16.20	MON3107	AB6	31	TFS		
16.20	BA5287	ATP	67	BFS	BA5288	BFS
16.25	EI668	735	84	DUB	EI668	ZRH
16.30	BA5005	732	42	CDG	BA5134	DUS
16.30	BA5765	ATP	67	EDI	BA5766	EDI
16.35	BA4492	757	51	LHR	BA4513	LHR
16.35	BA5797	ATP	67	LSI/ABZ	BA5798	ABZ

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16.50	FU526	EM2	101	LYS	FU527	LYS
16.55	II555	J31	98	CWL	9R505	MME
16.55	OOE217	L1011	22	TFS	OOE218	MAH
17.00	BA7755	J41	99	GCI	BA7736	SOU
17.00	BA7824	J41	99	STN	BA7825	STN
17.05	II392	SF340	72	GLA	II393	GLA
17.05	FR556	732	42	DUB	FR557	DUB
17.05	LH4044	735	84	FRA	LH4075	FRA
17.10	BA5029	732	42	AMS	BA5008	CDG
17.15	SK541	M87	86	CPH	SK542	CPH
17.20	BA5019	732	42	FCO/BRU	BA5022	BRU
17.25	AF920	732	42	CDG	AF917	CDG
17.30	BA7606	ATP	67	BHD	BA7609	BHD
17.30	AWD349	A320	87	JSI		
17.35	BA4502	757	51	LHR	BA4523	LHR
17.35	BA5737	ATP	67	GLA	BA5292	BFS
17.45	9C716	SH6	68	NCL	9C717	NCL
17.45	WA425	J31	98	BLL/BHX	WA425	BLL
17.50	BY263B	762	32	MBA		
17.55	5W623	J31	98	RTM/NWI	5W624	NWI/RTM
17.55	9R117	J31	98	BOH/EXT	9R118	EXT/BOH
17.55	DP031	757	52	PFO		
17.55	NG6228	CRJ	94	VIE	NG6229	VIE
18.00	LH4052	735	84	DUS	LH4057	DUS
18.00	LH5200	CRJ	94	MUC	LH5249	MUC
18.00	LH5226	F50	89	STR	LH5217	STR
18.00	LH5248	CRJ	94	HAM	LH5203	HAM
18.00	NG6274	CRJ	94	MXP	NG6275	MXP
18.05	BA2008	732	42	LGW	BA2009	LGW
18.05	CB011	DO8	100	CBG	CB006	CBG
18.15	II396	SF340	72	LSI/GLA	II397	GLA
18.15	II376	SF340	72	ABZ	II377	ABZ
18.15	II336	SF340	72	BFS	II337	BFS
18.15	II386	SF340	72	DND/EDI	II387	EDI/DND
18.20	BA5767	ATP	67	EDI	BA5768	EDI
18.25	5E602	J31	98	EIN/RTM	5E603	RTM/EIN
18.30	BA7846	J41	99	ORK	BA7846	RTM
18.30	AMM107	757	51	TFS	AMM204	TFS
18.35	UK157	F100	88	AMS	UK158	AMS
18.45	9R506	J31	98	MME	II556	CWL
19.00	JE329	ATP	67	IOM	JE330	IOM
19.00	EAF2309	B15	37	LDE		
19.05	BA5061	732	42	LIN		
19.10	BA7608	ATP	67	BHD		
19.10	BA5799	ATP	67	ABZ		
19.20	BA5289	ATP	67	BFS	BA5061	GLA
19.25	TIH202	757	52	ACE	TIH203	HER
19.30	BA2010	734	84	LGW		
19.30	BA5007	732	42	CDG		
19.35	BA4522	757	51	LHR		
19.40	EI208	143	15	DUB	EI209	DUB
19.40	SN619	732	42	BRU	SN622	BRU
19.45	EXC108	A320	87	MAH		
19.45	CKT259	L1011	22	TFS		
19.45	FR558	732	42	DUB	FR559	DUB
19.50	LEI7268	734	84	GRO	LEI7353	ATH

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19.55	SBE487	722	24	DLM	SBE186	TFS
19.55	OOE487	732	42	DLM	OOE488	HER
19.55	BA5769	ATP	67	EDI		
20.00	BA7826	J41	99	STN		
20.00	BY530B	757	51	LCA	BY453A	MLA
20.00	MON5041	757	51	TFS		
20.05	BA7737	J41	99	SOU		
20.05	BA5739	ATP	67	GLA		
20.10	MON3973	757	51	TFS		
20.15	AIH114	M83	50	MLA	AIH285	TFS
20.20	LEI7352	734	84	AGP	LEI7271	HER
20.20	LH5202	CRJ	94	MUC		
20.20	SK1539	M87	86	CPH		
20.25	BA5153	732	42	FRA		
20.25	SR842	M81	48	ZRH		
20.40	BA5021	732	42	BRU		
20.45	AIH284	M83	50	CHQ	AIH147	SKG
20.45	AF942	735	84	CDG		
20.45	BA5293	ATP	67	BFS		
20.50	BA7610	ATP	67	BHD		
20.50	BA5031	732	42	AMS		
20.55	BA5135	732	42	DUS		
21.05	AMM373	757	51	NAP	AMM352	ADB
21.05	AIH180	757	52	PMI	THH315	DLM
21.25	MON3125	A320	87	MAH	MON3524	TFS
21.25	MON3773	A320	87	AGP	MON3718	CFU
21.30	BA5009	732	42	CDG		
21.35	BA4542	757	51	LHR		
21.35	BA5054	732	42	MAD		
21.40	AAN228	313	34	TFS	AAN229	TFS
21.45	BWL304	143	15	VGO		
21.45	AMM229	734	84	AGP		
21.50	BY117B	757	51	IBZ	BY166A	PMI
21.55	AIH252	M83	50	IBZ	AIH253	IBZ
22.00	CY456	A320	87	LCA	CY457	LCA
22.10	BY159B	762	32	NAP	BY250A	PMI
22.20	UK159	F100	88	AMS		
22.20	SN7814	732	42	BRU		
22.25	BA7847	J41	99	RTM		
22.25	MON7713	757	51	LXR/LGW		
22.25	BY446B	762	32	CFU	BY229A	IBZ
22.40	NP401	SH5	68	AMS		
22.40	AMM223	757	51	TFS	AMM242	CFU
22.50	BY075B	757	51	RMI	BY145A	CFU
22.50	AAN206	M83	50	TFS	AAN205	TFS
23.00	AMM339	757	51	MAH		
23.15	SPP3127	M83	50	PMI		

Note - Aircraft Code relates to SIMMOD a/c Data file.

Source: UK Airport Timetables 1995

Appendix 6.2

Manchester Airport Typical Busy Day Departures - 30th June 1995

Dept. Time	Flt. No.	Aircraft Type	A/c Code	Dest.	Turnaround
0.30	MON5022	757	51	TFS	
0.30	OOE484	732	42	ZTH	
0.40	BY144A	762	32	PMI	
1.00	AMM1530	757	51	PMI	
2.40	AT5221	732	42	TNG	y
3.00	NP400	SH5	68	AMS	
6.00	ALT256	A320	87	PVK	
6.05	BY068A	757	51	FAO	
6.35	UK150	F100	88	AMS	
6.40	BA4403	757	51	LHR	
6.40	OOE216	L1011	22	TFS	
6.45	BA2001	734	84	LGW	
6.45	AIH143	M83	50	NAP	
6.45	SN7620	732	42	BRU	
6.55	BA7730	J41	99	SOU	
6.55	BA7821	J41	99	STN	
6.55	SK1540	M87	86	CPH	
7.00	EXC103	A320	87	MAH	y
7.00	BY439A	757	51	ATH	y
7.00	AMM384	757	51	AGP	y
7.00	BA7601	ATP	67	BHD	
7.00	BA5016	732	42	BRU/FCO	
7.00	LEI7601	734	84	MAH	
7.00	LEI7351	734	84	AGP	
7.00	MON3106	AB6	31	TFS	
7.00	AMM128	757	51	VRN	
7.00	BA5280	ATP	67	BFS	
7.00	BA5760	ATP	67	EDI	
7.00	BA5790	ATP	67	ABZ/LSI	
7.05	BA5730	ATP	67	GLA	
7.10	MON7712	757	51	LGW/LXR	
7.10	AF947	735	84	CDG	
7.15	BA5024	732	42	AMS	
7.15	BA5002	732	42	CDG	
7.15	MON3548	A320	87	NAP	
7.15	DP030	757	52	PFO	
7.25	BA5146	732	42	FRA	
7.30	BA4413	757	51	LHR	
7.30	AMM308	757	51	CFU	
7.30	TIH177	757	52	PMI	
7.30	AIH251	M83	50	IBZ	y
7.40	BA5128	732	42	DUS	
7.40	BA5138	732	42	MUC	
7.40	BY257A	757	51	PMI	
7.40	BY201A	762	32	PMI	
7.45	SR843	M81	48	ZRH	
7.55	AIH111	M83	50	BVA	
7.55	LH5251	CRJ	94	MUC	
7.55	BA7841	J41	99	ORK	y
8.00	9R501	J31	98	MME	y
8.00	BWL511	143	15	CIA	
8.15	AWD348	A320	87	JSI	
8.20	BA5058	732	42	LIN	
8.20	AMM106	757	51	TFS	y
8.25	CMM4838	757	52	YYC/YYR	y

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8.30	BY215A	762	32	MAH	y
8.30	BA4423	734	84	LHR	y
8.30	5E601	J31	98	RTM/EIN	y
8.35	5W622	J31	98	NWI/RTM	y
8.35	EI203	143	15	DUB	y
8.35	AMM150	734	84	LDE	
8.35	BA5732	ATP	67	GLA	y
8.40	BA5010	732	42	CDG	
8.45	JE322	ATP	67	IOM	y
8.45	9C713	SH6	68	NCL	y
8.50	AF923	735	84	CDG	y
8.55	MON3124	A320	87	MAH	y
8.55	LH4055	735	84	DUS	y
8.55	LH4103	732	42	FRA	y
8.55	CB004	DO8	100	CBG	y
9.00	BY530A	757	51	LCA	
9.00	II371	SF340	72	ABZ	y
9.00	II331	SF340	72	BFS	y
9.00	II391	SF340	72	GLA	y
9.00	II381	SF340	72	EDI/DND	y
9.00	LH5205	F50	89	HAM	y
9.00	BA5762	ATP	67	EDI	y
9.10	BA7603	ATP	67	BHD	y
9.15	BA2003	732	42	LGW	y
9.15	CB302	DO8	100	AMS	y
9.20	FR551	732	42	DUB	y
9.25	BA5734	ATP	67	GLA	y
9.25	EI661	735	84	DUB	y
9.30	EAF2306	B15	37	LDE	
9.30	BA4433	757	51	LHR	y
9.30	EI622	735	84	CPH	y
9.30	WA421	J31	98	BHX/BLL	y
9.45	SQ337	744	83	BOM/SIN	
9.45	9R116	J31	98	EXT/BOH	y
9.50	II552	J31	98	CWL	y
10.00	BA183	763	33	JFK	
10.00	TIH201	757	52	ACE	
10.00	SBE486	722	24	DLM	
10.00	CX260	744	83	CDG/HKG	
10.00	FU521	EM2	101	LYS	y
10.00	BA7750	J41	99	GCI	y
10.10	BA7762	ATP	67	JER	
10.15	CKT127	757	51	BGR/MCO	
10.15	CKT258	L1011	22	TFS	
10.15	BA5284	ATP	67	BFS	y
10.15	BA7823	J41	99	STN	y
10.20	BA5048	732	42	GVA	
10.25	BY152A	762	32	MCO	
10.30	MON5040	757	51	TFS	
10.30	BA7723	ATP	67	NOC	y
10.30	BA4443	757	51	LHR	y
10.30	BA5608	ATP	67	HAJ	y
10.35	CLI411	742	2	YVR	
10.40	UK152	F100	88	AMS	y
10.45	TIH051	763	33	MCO	
10.45	AA093	757	52	JFK	
10.45	OOE486	732	42	DLM	y
10.55	MON3972	757	51	TFS	y
11.00	AC841	762	32	YYZ	y

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11.00	TS257	L1011	22	YYZ	y
11.00	BA2005	732	42	LGW	y
11.15	SN7616	732	42	BRU	y
11.20	HY238	IL6	9	TAS	
11.25	ULE833	763	33	MCO	
11.25	SK1542	D94	46	FBU/ARN	y
11.25	AY688	M82	49	ARN/HEL	y
11.30	AIH283	M83	50	CHQ	
11.30	TZ721	757	52	JFK	y
11.30	KM203	A320	87	MLA	y
11.35	DL065	L1015	23	ATL	
11.35	SK540	D94	46	CPH	y
11.35	BA7835	J41	99	SNN	y
12.00	SU250	TU5	90	SVO	y
12.10	FR553	732	42	DUB	y
12.10	BA7764	ATP	67	JER	y
12.20	BA5130	732	42	DUS	y
12.30	BA5792	ATP	67	ABZ	
12.30	BA4463	763	33	LHR	y
12.30	BA5026	732	42	AMS	y
12.30	IB6917	M87	86	BCN/MAD	y
12.35	AIH113	M83	50	MLA	y
12.45	BA2007	732	42	LGW	y
12.50	OK661	735	84	PRG	y
13.00	II333	SF340	72	BFS	y
13.00	BA5004	732	42	CDG	y
13.15	AMM222	757	51	TFS	y
13.20	BA8775	SH6	68	LDY	y
13.25	LEI7683	734	84	MAH	y
13.30	AA121	762	32	ORD	
13.30	EK036	313	34	ZRH/DXB	
13.30	BA5286	ATP	67	BFS	y
13.45	CKT1396	L1011	22	MAH	y
13.45	BY124AF	757	51	NCL	y
13.45	BA7754	J41	99	GCI	y
13.50	BA5060	732	42	LIN	y
13.50	BA5764	ATP	67	EDI	y
14.00	EAF2308	B15	37	LDE	
14.00	EXC107	A320	87	MAH	y
14.00	JE326	ATP	67	IOM	y
14.10	BA5028	732	42	AMS	y
14.10	CLI411	313	34	YVR	y
14.10	JY577	F2E	67	GCI	y
14.10	AF907	735	84	CDG	y
14.15	LEI7267	734	84	GRO	y
14.25	9C715	SH6	68	NCL	
14.30	BA4483	757	51	LHR	y
14.30	II383	SF340	72	EDI	y
14.30	AMM372	757	51	NAP	y
14.35	BY446A	762	32	CFU	y
14.55	AIH279	A320	87	MAH	y
14.55	AIH179	757	51	PMI	y
14.55	ALT254	A320	87	DLM	y
14.55	BA5736	ATP	67	GLA	y
14.55	EI623	735	84	DUB	y
14.55	FR555	732	42	DUB	y
15.00	BA118	742	2	LGW	y
15.00	BA7605	ATP	67	BHD	y
15.05	AMM228	734	84	AGP	y

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15.05	MON3772	A320	87	AGP	y
15.20	UK156	F100	88	AMS	y
15.20	BA7845	J41	99	ORK	y
15.40	BY117A	757	51	IBZ	y
15.40	BY159A	762	32	NAP	y
15.40	SN7618	732	42	BRU	y
15.45	LG446	EM2	101	LUX	y
15.50	II335	SF340	72	BFS	y
15.50	BA5042	732	42	MAD	
15.55	BWL303	143	15	VGO	y
15.55	BA7734	J41	99	SOU	y
16.00	BA5152	732	42	FRA	
16.00	BA5006	732	42	CDG	y
16.00	BA5796	ATP	67	ABZ	y
16.15	CB304	DO8	100	AMS	
16.15	BA2011	734	84	LGW	y
16.30	BA4503	763	33	LHR	y
16.40	BA7607	ATP	67	BHD	y
16.50	AMM338	757	51	MAH	y
16.50	BA5288	ATP	67	BFS	y
16.55	VM136	J31	98	NTE/BOD	
16.55	EI207	143	15	DUB	y
16.55	EI668	735	84	ZRH	y
17.00	BA5611	ATP	67	GLA	y
17.00	BA5766	ATP	67	EDI	y
17.10	BY075A	757	51	RMI	y
17.10	BA5134	732	42	DUS	y
17.15	9R505	J31	98	MME	y
17.20	BA5020	732	42	BRU	y
17.30	BA4513	757	51	LHR	y
17.30	FU527	EM2	101	LYS	y
17.30	BA7736	J41	99	SOU	y
17.30	BA7825	J41	99	STN	y
17.35	FR557	732	42	DUB	y
17.40	BA5798	ATP	67	ABZ	y
17.45	BA5030	732	42	AMS	
17.45	LH4075	735	84	FRA	y
17.50	II393	SF340	72	GLA	y
17.55	BA5008	732	42	CDG	y
18.10	AF917	732	42	CDG	y
18.10	9C717	SH6	68	NCL	y
18.15	SK542	M87	86	CPH	y
18.15	BA5292	ATP	67	BFS	y
18.15	WA425	J31	98	BLL	y
18.25	5W624	J31	98	NWI/RTM	y
18.25	CB006	DO8	100	CBG	y
18.30	OOE218	L1011	22	MAH	y
18.30	BA4523	757	51	LHR	y
18.30	9R118	J31	98	EXT/BOH	y
18.35	BA2009	732	42	LGW	y
18.45	II387	SF340	72	EDI/DND	y
18.50	BA5768	ATP	67	EDI	y
18.50	5E603	J31	98	RTM/EIN	y
18.55	BA5022	732	42	BRU	y
18.55	LH4057	735	84	DUS	y
18.55	LH5249	CRJ	94	MUC	y
18.55	LH5217	F50	89	STR	y
18.55	LH5203	CRJ	94	HAM	y
18.55	BA7846	J41	99	RTM	y

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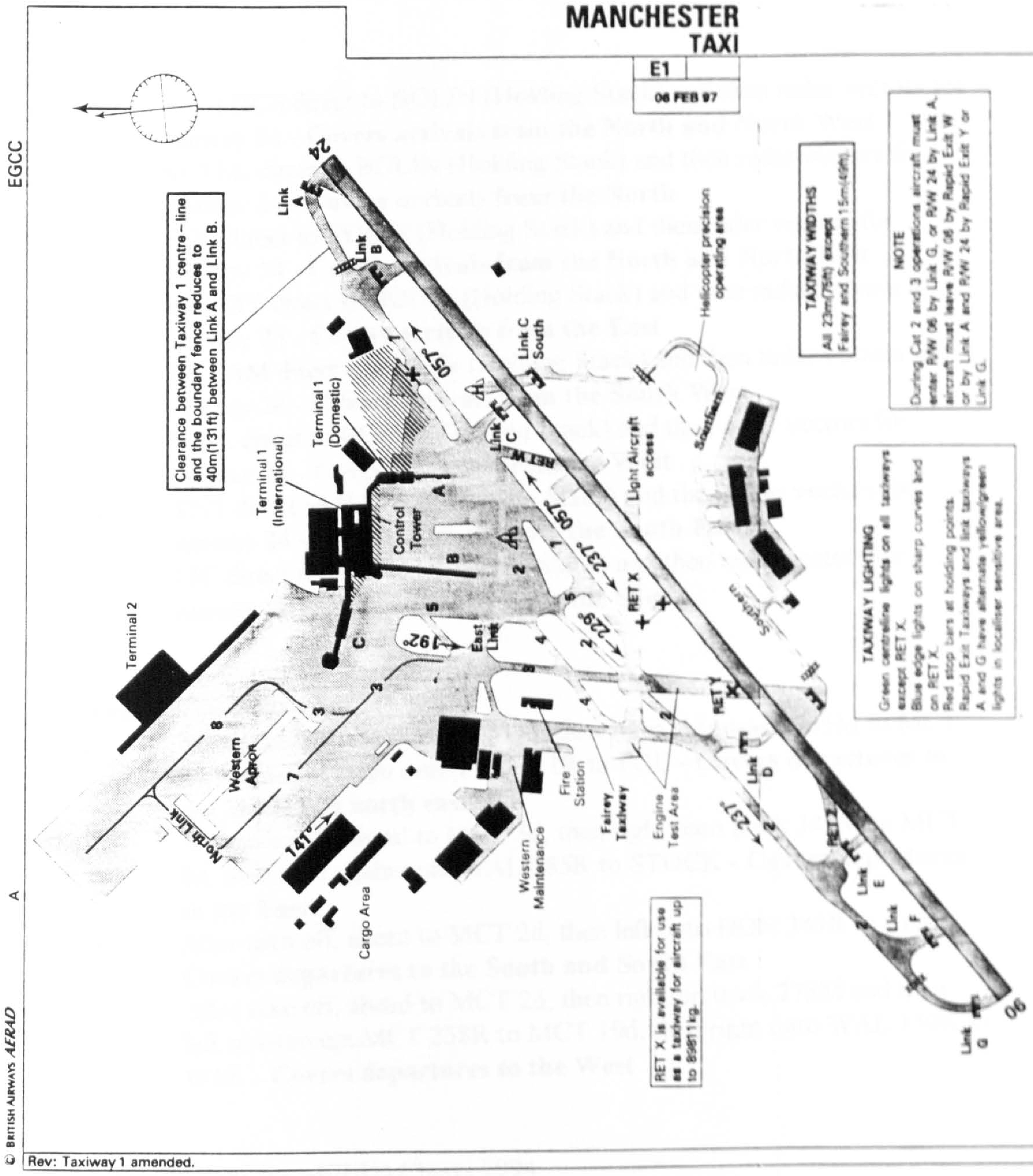
19.00	BA7609	ATP	67	BHD	y
19.00	NG6229	CRJ	94	VIE	y
19.00	II397	SF340	72	GLA	y
19.00	II377	SF340	72	ABZ	y
19.00	II337	SF340	72	BFS	y
19.05	II556	J31	98	CWL	y
19.15	NG6275	CRJ	94	MXP	y
19.15	UK158	F100	88	AMS	y
19.30	AMM204	757	51	TFS	y
19.40	JE330	ATP	67	IOM	y
19.45	AWD324	A320	87	HER	
19.45	BA5061	ATP	67	GLA	y
20.00	AMM1526	757	51	ADB	
20.10	EI209	143	15	DUB	y
20.15	FR559	732	42	DUB	y
20.20	SN622	732	42	BRU	y
20.50	LEI7353	734	84	ATH	y
20.50	SBE186	722	24	TFS	y
20.50	OOE488	732	42	HER	y
20.55	TIH203	757	52	HER	y
21.05	BY082A	762	32	IBZ	
21.20	MON3164	AB6	31	ATH	
21.25	LEI7271	734	84	HER	y
21.30	BY453A	757	51	MLA	y
21.30	AIH285	M83	50	TFS	y
21.50	CKT1288	L1011	22	DLM	
21.50	AIH147	M83	50	SKG	y
22.20	EXC147	A320	87	CFU	
22.20	AMM352	757	51	ADB	y
22.20	TIH315	757	52	DLM	y
22.25	MON3718	A320	87	CFU	y
22.35	MON5608	757	51	ALC	
22.45	MON3524	A320	87	TFS	y
22.50	CY457	A320	87	LCA	y
23.05	AIH253	M83	50	IBZ	y
23.10	AAN229	313	34	TFS	y
23.30	BY166A	757	51	PMI	y
23.30	BY250A	762	32	PMI	y
23.30	AMM242	757	51	CFU	y
23.40	AAN205	M83	50	TFS	y
23.45	BY229A	762	32	IBZ	y
23.59	BY145A	757	51	CFU	y

Note - Aircraft Code relates to SIMMOD a/c Data file

Source: UK Airport Timetables 1995

Appendix 6.3



Source: RACAL AERAD Aerodrome Charts

Appendix 6.3

Manchester Airport Standard Routings

Arrivals

BOL 1A	From DCS direct to BOLIN (Holding Stack) and then radar vectors for runway 24 - **Covers arrivals from the North and North West**
BOL 1B	SETEL direct to BOLIN (Holding Stack) and then radar vectors for runway 24 - **Covers arrivals from the North**
BOL 1C	POL direct to BOLIN (Holding Stack) and then radar vectors for runway 24 - **Covers arrivals from the North and North East**
BOL 1D	DENBY direct to BOLIN (Holding Stack) and then radar vectors for runway 24 - **Covers arrivals from the East**
BOL 1E	REXAM direct to BOLIN (Holding Stack) and then radar vectors for runway 24 - **Covers arrivals from the South West**
BOL 1F	WAL direct to BOLIN (Holding Stack) and then radar vectors for runway 24 - **Covers arrivals from the West**
DAY 1A	TNT direct to DAYNE (Holding Stack) and then radar vectors for runway 24 - **Covers arrivals from the South East**
DAY 1B	LIC direct to DAYNE (Holding Stack) and then radar vectors for runway 24 - **Covers arrivals from the South**

Departures (From runway 24)

POL 5R	After take off, ahead to MCT 3d, then right onto track 345M to MCT 8d, then right again onto POL 221R to POL - **Covers departures to the north and north east**
STO 1R	After take off, ahead to MCT 3d, then right onto track 345M to MCT 8d, then right again onto WAL 085R to STOCK - **Covers departures to the East**
CON 1R	After take off, ahead to MCT 2d, then left onto HON 343R to Conga - **Covers departures to the South and South East**
WAL 1R	After take off, ahead to MCT 2d, then right on track 275M and then left to intercept MCT 258R to MCT 19d, then right onto WAL 130R to WAL - **Covers departures to the West**

Source: British Airways AERAD Charts 1994

Appendix 6.4

Zurich Busy Day Schedule - 16/7/94

Arrivals

Time	Flight No	Aircraft Type	A/C Code	Destination	Turnaround
600	VIM 601	TU5	90	SOF	VIM602
605	SA 274	747	83	CPT	SA274
605	SR 2321	MD81	48	IST	
605	SR 2323	MD81	48	IST	
605	SR 2327	MD81	48	IST	
605	TSW 3515	B737-300	35	AEY	TSW8616
610	BB 3723	MD87	86	ESB	
610	BB 3727	MD87	86	ADB	
610	BB 5353	MD83	50	SCQ	
610	LX 5703	MD81	48	SCQ	
615	BB 3721	MD82	49	ADA	
615	SR 195	MD11	85	DEL	
615	CX 291	747-400	83	HKG	CX291
620	LX 9717	146-300	15	VRN	LX9056
620	SR 171	747-300	82	SEL	
620	SR 183	MD11	85	SIN	
620	SR 2089	MD81	48	IST	
625	SR 265	MD11	85	ACC	
630	LX 580	SF340	72	BSL	LX570
635	SQ 328	747-400	83	SIN	SQ328
635	SR 145	MD11	85	EZE	
635	SR 6971	ARJ85	92	BSL	LX900
640	SR 921	F100	88	GVA	SR506
645	LX 870	ARJ85	92	LUG	
700	BB 3661	A310	34	MIA	
700	TK 4913	A310	34	IST	TK4914
705	SR 6745	SF340	72	SXB	
710	UA 964	767	33	IAD	
720	TG 908	747-200	2	BKK	TG908
730	AOJ 650	Caravell	97	SIR	AOJ650
730	PMK 301A	F100	88	SKP	PMK302
750	SR 923	MD81	48	GVA	
800	BB 3671	A310	34	PUJ	BB3672
800	LX 7011	SF340	72	HAM	LX9134
800	LFA 427	A300	31	IST	LFA428
805	AA 064	767	33	JFK	
805	VER 917	M80	48	HER	VER918
810	OS 241	F50	89	SZG	OS242
815	AA 038	767	33	ORD	AA037
820	AZ 1236	M80	48	LIN	AZ1237
835	LH 4851T	A320	87	FRA	LH4851
845	GA 976	747-200	2	DPS	GA976
845	LH 5524	F50	89	DUS	LH5525
845	RS 410	SF340	72	BTS	
845	FUA 904	737-400	84	PMI	FUA907
850	LH 5592	F50	89	CGN	LH5557

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850	AEA 629	757	51	PMI	AEA628
855	OS 201	M80	48	VIE	OS202
855	TK 4907	727	24	IST	TK4908
855	FUA 964	737-400	84	PMI	FUA965
900	SN 361	737-200	42	BRU	SN362
905	OU 460	737-200	42	ZAG	OU461
905	SR 559	F100	88	MUC	
905	AEA 591	737-300	35	LPA	AEA633
910	AF 2890	A320	87	CDG	AF2885
915	KL 301	737-300	35	AMS	KL302
915	SR 6571	MD81	48	STR	SR490
915	TK 719	737-200	42	IST	
915	TCT 6911	727	24	IST	TCT6912
920	DI 216	SF 340	72	BRE	DI217
920	RO 351	B11	37	OTP	RO352
920	TW 890	767	32	GVA	TW891
925	LX 953	Citation	57	SIR	
925	LZ 7521	TU5	90	VAR	LZ7522
925	OHY 611	A320	87	IST	OHY612
930	LH 5574	CRJ	94	HAM	LH5543
930	OS 217	F 50	89	LNZ	
930	TK 989	A310	34	AYT	TK990
930	AEA 676	757	51	PMI	AEA677
935	LX 903	ARJ85	92	LUG	LX9012
940	AC 878	767	33	YYZ	
940	LH 4586	A 320	87	FRA	LH4589
940	LO 291	737-200	42	WAW	LD292
945	CY 472	A310	34	LCA	CY473
945	OS 223	DH8	64	GRZ	
945	SR 6775	SF340	72	MRS	
950	SR 125	747-300	82	ORD	
955	LX 571	SF340	72	NUE	LX904
955	SR 139	MD11	85	YMX	
955	SR 6425	SF340	72	KLU	
955	TK 919	737-200	42	ESB	TK920
1000	AY 862	M80	48	GVA	AY862
1000	SR 101	747-300	82	JFK	
1005	JP 1662	DC9	40	LJU	JP1663
1005	LZ 491	A320	87	SOF	LZ492
1005	OK 774	737-200	42	PRG	OK775
1010	SR 665	MD81	48	BCN	SR486
1015	SR 121	747-300	82	ATL	
1015	SR 651	F100	88	MAD	SR1690
1015	SR 6771	SF340	72	LYS	SR6974
1020	MA 564	737-200	42	BUD	MA565
1020	SR 6631	F50	89	GOA	
1025	BA 710	757	51	LHR	BA711
1025	SR 3961	MD81	48	BSL	SR426
1025	SR 6611	F50	89	TRN	SR6574
1030	FV 552	737-300	35	AGP	FV553
1030	SR 129	747-300	82	BOS	

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1035	SR 421	MD81	48	HEL	SR554
1035	SR 6873	SF340	72	SXB	SR6992
1040	SK 601	M80	48	CPH	SK602
1045	SK 609	M80	48	FBU	SK610
1045	SR 431	MD81	48	VIE	SR320
1045	SR 443	MD81	48	PRG	SR662
1045	SR 843	A310	34	MAN	SR692
1050	SK 605	M80	48	ARN	SK606
1050	SR 591	F100	88	TXL	
1050	SR 925	MD81	48	GVA	SR686
1055	SR 511	F100	88	DUS	
1055	SR 701	MD81	48	CDG	SR432
1055	SR 801	A310	34	LHR	SR324
1100	SR 507	F100	88	HAM	
1100	SR 551	F100	88	MUC	SR592
1100	SR 883	MD81	48	BRU	SR704
1105	SR 307	MD81	48	ATH	SR792
1105	SR 469	MD81	48	BUD	SR622
1110	SR 333	A310	34	TLV	SR802
1110	SR 621	A310	34	LIN	
1110	SR 791	MD81	48	AMS	
1110	TU 8600	A320	87	MIR	TU8601
1115	OS 225	DH8	64	INN	
1115	SR 533	MD81	48	FRA	
1120	DL 122	A310	34	CVG	DL123
1120	SR 401	MD81	48	CPH	SR308
1125	LX 861	ARJ85	92	BHX	SR6964
1125	SR 6963	SF340	72	BSL	SR6616
1130	EI 664	737-300	35	DUB	EI667
1130	KL 303	737-300	35	AMS	KL304
1130	OS 243	F50	89	SZG	OS244
1130	SR 601	MD81	48	FCO	SR648
1135	IB 3464	M80	48	MAD	IB4475
1140	LX 583	SF340	72	LEJ	SR6422
1140	LX 905	SF340	72	LUG	LX906
1140	TSW 3607	737-300	35	MAH	TSW3600
1145	CY 352	A310	34	LCA	CY353
1145	SR 168	MD11	85	GVA	SR168
1150	SR 6573	MD81	48	STR	SR318
1150	TK 907	A310	34	IST	TK908
1150	AAN 406	M80	48	PMI	AAN409
1155	SR 927	MD81	48	GVA	SR658
1200	LX 581	SF340	72	DRS	SR6874
1200	SU 265	TU5	90	SVO	SU266
1205	SR 6965	146-300	15	BSL	LX854
1205	TK 4915	727	24	IST	TK4916
1210	BB 3477	MD82	49	OLB	
1210	AEA 695	737-300	35	SCQ	AEA696
1215	SPP 227	M80	48	PMI	SPP228
1215	TSW 8617	737-300	35	SKP	TSW3620
1220	AF 3154	F28	39	NCE	AF3145

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1220	LX 9023	ARJ85	92	NAP	SR6928
1220	SR 3671	MD87	86	PMI	SR3670
1225	SR 803	A310	34	LHR	SR332
1235	OA 131	737-200	42	ATH	OA132
1235	SR 929	F100	88	GVA	SR466
1235	AEA 643	757	51	LPA	AEA644
1240	CX 290	747-400	83	FCO	CX290
1240	AEA 639	737-300	35	AGP	AEA605
1240	TAT 4171	F100	88	FSC	TAT4172
1245	SR 6977	SF340	72	BSL	LX9118
1250	AT 8639	DC9	40	HEL	AY8629
1250	AIZ 501	757	52	TLV	AIZ502
1300	BA 5344	737-200	42	BHX	BA5345
1300	TU 8620	727	24	DJE	TU8621
1300	SPP 211	M80	48	PMI	SPP214
1305	AZ 4400	A300	31	FCO	AZ4401
1310	AI 193	DC8	64	BAH	
1310	KE 916	747-400	83	FCO	KE916
1315	FUA 900	737-400	84	LPA	FUA901
1320	TG 909	747-300	82	BRU	TG909
1325	AOJ 651	Caravell	97	SKP	AOJ652
1330	AZ 1440	M80	48	FCO	AZ1441
1330	CLC 422	DC3	71	ZRH	CLC423
1335	LTE 625	757	52	TFS	LTE624
1340	AXX 101	M80	48	SKP	AXX102
1345	AH 2048	737-200	42	GVA	AH2049
1345	AAN 452	A310	34	LPA	AAN453
1350	LX 907	SF340	72	LUG	LX9106
1355	LH 4550	A320	87	FRA	LH4593
1355	OK 768	ATR42	95	GVA	OK769
1355	SR 411	F100	88	ARN	
1400	AF 2866	737-300	35	CDG	AF2891
1400	SR 1311	MD11	85	SKG	
1400	SR 6575	F50	89	STR	SR6568
1405	SR 6967	ARJ85	92	BSL	SR6930
1410	IG 355	DC9	40	OBL	IG356
1410	FLT 797	146	15	EDI	FLT799A
1415	TP 538	737-200	42	OPO	TP538
1430	SR 555	MD81	48	MUC	SR444
1435	SR 6617	SF340	72	TRN	LX9124
1440	BA 714	757	51	LHR	BA715
1440	SR 623	MD81	48	LIN	SR886
1445	SR 6633	SF340	72	GOA	SR6618
1445	TP 522	A320	87	LIS	TP521
1450	AEA 634	737-400	84	MAH	AEA592
1450	KAR 3043	DC9	40	HEL	KAR3044
1450	ZAS 760	M80	48	SSH	ZAS761
1455	OS 245	F50	89	SZG	OS246
1500	BB 3237	MD82	49	HER	BB3366
1500	SR 433	MD81	48	VIE	SR750
1505	MS 809	737-200	42	CAI	MS810

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1510	SR 705	MD81	48	CDG	SR538
1510	FUA 906	737-400	84	ALC	FUA905
1515	LH 5526	F50	89	DUS	LH5527
1515	LX 9135	SF340	72	CTA	LX912
1520	AEA 627	757	52	PMI	AEA632
1525	SR 6931	ARJ85	92	GVA	LX9006
1535	SR 793	MD81	48	AMS	SR938
1545	KL 305	737-300	35	AMS	KL314
1545	SR 6423	SF340	72	KLU	
1550	KAR 3037	DC9	40	HEL	KAR3038
1555	HM 002	767	32	SEZ	HM002
1555	LX 9057	146-300	15	JTR	LX9008
1600	SR 453	F100	88	ZAG	SR516
1600	SR 593	F100	88	TXL	SR968
1600	SR 663	MD81	48	BCN	SR556
1600	VER 911	M80	48	HER	VER912
1605	OS 203	M80	48	VIE	OS204
1610	GA 977	747-200	2	LGW	GA977
1615	SR 603	MD81	48	FCO	
1615	CLC 423	DC3	71	ZRH	
1625	SR 805	A310	34	LRH	SR806
1635	SR 6875	SF340	72	SXB	
1650	AY 8630	M80	48	HEL	AY8620
1650	EK 036	A300	31	MAN	EK036
1650	SR 6937	ARJ85	92	GVA	SR6940
1655	BB 3265	MD83	50	LPA	BB3864
1700	BB 3257	MD87	86	TFS	BB3378
1700	BB 3605	A310	34	MLE	
1700	RG 768	DC10	20	CDG	RG769
1700	SR 107	MD11	85	LAX	
1705	SR 447	F100	88	WAW	
1705	TK 909	737-200	42	IST	TK910
1710	BB 3153	MD87	86	LPA	
1710	LX 843	F50	89	GCI	SR6567
1710	SR 6451	F50	89	LJU	
1710	TU 8612	737-300	35	MIR	TU8613
1710	AXX 105	TU5	90	SKP	AXX106
1715	AAN 408	M80	48	IBZ	AAN407
1720	LX 9013	ARJ85	92	ATH	
1735	AZ 1494	DC9	40	LIN	AZ1495
1735	LX 9119	SF340	72	SOB	
1735	SR 1691	F100	88	LIS	
1740	SR 169	MD11	85	NRT	
1745	BA 718	757	51	LHR	
1745	EI 662	737-300	35	SNN	EI669
1745	KQ 144	A310	34	NBO	KQ145
1745	TU 8610	727	24	DJE	
1745	AEA 606	737	35	PMI	AEA642
1750	IB 4476	M80	48	BCN	IB3467
1755	LH 4556	737	35	FRA	LH4559
1755	LX 913	SF340	72	LUG	

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1755	MA 566	737	42	BUD	MA567
1755	SR 467	F100	88	BUD	
1755	AF 2868	A320	87	CDG	AF2867
1800	SR 6635	SF340	72	GOA	
1805	OS 219	F50	89	LNZ	
1805	OS 227	DH7	65	INN	OS228
1815	SR 309	MD81	48	SKG	SR544
1815	SR 463	F100	88	OTP	SR796
1815	SR 649	MD81	48	MLA	SR664
1815	SR 687	MD81	48	AGP	SR436
1820	OS 247	F50	89	SZG	
1820	SK 603	DC9	40	CPH	SK604
1820	SR 693	A310	34	LIS	SR842
1825	SK 607	DC9	40	ARN	SK608
1825	SR 325	A310	34	IST	SR808
1830	SR 491	MD81	48	SVO	SR708
1830	SR 659	MD81	48	MAD	SR420
1835	LH 5548	CRJ	94	HAM	LH5549
1835	SR 303	MD11	85	ATH	
1835	SR 445	MD81	48	PRG	SR942
1835	SR 969	F100	88	BSL	SR624
1840	SK 611	M80	48	FBU	SK612
1840	SR 197	MD11	85	PEK	
1840	SR 487	MD81	48	LED	SR650
1840	SR 751	MD81	48	NCE	SR468
1840	TU 484	727	24	DJE	TU485
1845	SR 321	MD81	48	ESB	
1850	SR 245	A310	34	GVA	
1850	SR 6619	SF340	72	TRN	
1850	TK 993	A310	34	AYT	TK994
1855	AZ 400	M80	48	FCO	AZ401
1855	SR 887	MD81	48	BRU	SR326
1855	TU 602	A320	87	TUN	TU603
1900	MD 053	747-200	2	CDG	MD054
1900	SR 6941	F50	89	GVA	SR6578
1900	SPP 213	M80	48	IBZ	SPP212

Source: Zurich Airport Authority (1994)

Appendix 6.4

Zurich Busy Day Schedule - 16/7/94

Saturday Departures

Time	Flight No	Aircraft Type	A/C Code	Destination
635	BB 3260	MD87	86	LPA
645	TSW 8616	737-300	35	SKP
645	VIM 602	TU5	90	SOF
650	TSW 3608	737-300	35	FAO
655	KL 300	737-300	35	AMS
655	LH 5533	F50	89	CGN
655	LX 580	SF340	72	DRS
655	LX 952	Citation	57	SIR
655	TSW 3602	737-300	35	KGS
700	LH 4563	737-300	35	FRA
705	LX 582	SF340	72	LEJ
705	SA 274	747400	83	MXP
705	SR 400	MD81	48	CPH
705	SR 6770	SF340	72	LYS
710	LX 9056	146-300	15	JTR
710	SR 590	F100	88	TXL
710	SR 6570	MD81	48	STR
715	LX 900	ARJ85	92	LUG
715	SR 430	MD81	48	VIE
715	SR 506	F100	88	HAM
720	SR 600	MD81	48	FCO
725	BB 3256	MD87	86	TFS
725	LX 570	SF340	72	NUE
725	SR 442	MD81	48	PRG
725	SR 790	MD81	48	AMS
725	SR 3960	MD81	48	BSL
730	SR 183	MD11	85	GVA
730	SR 410	F100	88	ARN
730	SR 700	MD81	48	CDG
735	SR 510	F100	88	DUS
735	SR 800	A310	34	LHR
740	SR 882	MD81	48	BRU
740	SR 6610	F50	89	TRN
740	TSW 3606	737-300	35	MAH
745	SQ 328	747-400	83	CPH
745	GBL 953	737-200	42	LGW
750	CX 291	747-400	83	FCO
750	SR 550	F100	88	MUC
750	SR 620	A310	34	LIN
755	BB 3152	MD87	86	LPA
755	SR 532	MD81	48	FRA
800	BB 3264	MD83	50	LPA
800	LX 9022	ARJ85	92	NAP
800	TK 4914	A310	34	IST
805	AF 2849	A320	87	CDG
805	MAK 281	737-200	42	SKP
810	BA 709	757	51	LHR
810	SR 6638	SF340	72	GOA
815	BB 3236	MD82	49	HER
815	IB 3473	M80	48	MAD
815	SR 1310	MD11	85	SKG
820	LX 9134	SF340	72	CTA

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820	TG 908	747-400	2	BRU
820	AOJ 650	Caravell	97	SKP
820	PMK 302	F100	88	SKP
830	BB 3476	MD82	49	OLB
830	SR 920	MD81	48	GVA
830	AXX 104	M80	48	SKP
840	OS 242	F50	89	SZG
900	EI 663	737-300	35	DUB
900	FLT 796	146	15	EDI
905	VER 918	M80	48	HER
910	AZ 1237	M80	48	LIN
915	CLC 210	DC3	71	DIJ
920	LFA 428	A300	31	IST
925	LH 4851	A320	87	FRA
930	LH 5525	F50	89	DUS
935	OS 202	M80	48	VIE
935	QS 411	SF340	72	BTS
945	SN 362	737-200	42	BRU
945	AEA 633	737-300	35	MAH
945	FUA 907	737-400	84	ALC
950	DI 217	SF340	72	BRE
950	SR 6572	MD81	48	STR
950	AEA 628	757	51	PMI
955	SR 922	F100	88	GVA
1000	BB 3672	A310	34	MBJ
1000	KL 302	737-300	35	AMS
1000	LH 5543	CRJ	94	HAM
1000	LH 5557	F50	89	CGN
1010	GA 976	747-200	2	LGW
1015	AA 037	767	33	ORD
1015	AF 2885	A320	87	CDG
1015	OU 461	737-200	42	ZAG
1015	SR 490	MD81	48	SVO
1020	AEA 677	757	52	PMI
1020	TCT 6912	727	24	IST
1025	LX 904	SF340	72	LUG
1025	LZ 7522	TU5	90	VAR
1025	TK 990	A310	34	AYT
1030	BB 3664	A310	34	MCO
1030	LD 292	737-200	42	WAW
1030	LX 9012	ARJ85	92	ATH
1030	RO 352	B11	37	OTP
1035	LH 4589	A320	87	FRA
1040	AY 862	M80	48	HEL
1040	SR 256	A310	34	ABJ
1040	TK 720	737-300	35	IST
1045	CY 473	A310	34	LCA
1045	OHY 612	A320	87	IST
1055	SR 6974	SF340	72	BSL
1055	TK 920	737-200	42	ESB
1055	TK 4908	727	24	IST
1055	TW 891	767	32	JFK
1100	JP 1663	DC9	40	LJU
1100	CLC 422	DC3	71	ZRH
1105	LZ 492	A320	87	SOF
1115	AA 065	767	33	JFK
1115	LX 842	F50	89	GCI

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1115	SR 6962	SF340	72	BSL
1120	OK 775	737	42	PRG
1120	SR 486	MD81	48	LED
1120	SR 1690	F100	88	LIS
1125	MA 565	737	42	BUD
1125	OS 224	DH8	64	GRZ
1125	FUA 965	737-400	84	PMI
1130	FV 553	737-300	35	AGP
1130	OS 218	F50	89	LNZ
1135	BA 711	757	51	LHR
1135	SR 926	MD81	48	GVA
1135	SR 6632	SF340	72	GOA
1140	SR 320	MD81	48	ESB
1140	SR 662	MD81	48	BCN
1145	SR 554	MD81	48	MUC
1145	SR 692	A310	34	LIS
1145	SR 6616	SF340	72	TRN
1150	SR 686	MD81	48	AGP
1155	SR 192	747-300	82	BOM
1155	SR 432	MD81	48	VIE
1155	SR 704	MD81	48	CDG
1155	SR 6574	F50	89	STR
1200	SR 324	A310	34	IST
1200	SR 792	MD81	48	AMS
1200	TU 8601	A320	87	MIR
1205	OS 244	F50	89	SZG
1205	SR 622	MD81	48	LIN
1205	UA 965	767	33	IAD
1210	SK 606	M80	48	ARN
1210	SR 302	MD11	85	ATH
1215	SR 592	F100	88	TXL
1215	SR 802	A310	34	LHR
1215	SR 6422	SF340	72	KLU
1215	SR 6964	ARJ85	92	BSL
1220	KL 304	737-300	35	AMS
1220	SK 602	M80	48	CPH
1220	SR 462	F100	88	OTP
1225	LX 906	SF340	72	LUG
1225	SR 446	F100	88	WAW
1225	SR 602	747-300	82	FCO
1230	EI 667	737-300	35	SNN
1230	IB 4475	M80	48	SCQ
1230	OS 226	DH8	64	INN
1230	SR 452	F100	88	ZAG
1235	SR 126	747-300	82	PHL
1235	SR 262	MD11	85	LOS
1240	SR 120	747-300	82	ATL
1240	SR 308	MD81	48	SKG
1240	SR 648	MD81	48	MLA
1240	TSW 3600	737-300	35	LPA
1245	CY 353	A310	34	LCA
1245	SK 610	M80	48	FBU
1250	SR 138	MD11	85	YYZ
1250	SR 168	MD11	85	NRT
1250	SR 318	MD81	48	LCA
1250	SR 6874	SF340	72	LUX
1250	AAN 409	M80	48	IBZ

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1300	AC 879	767	32	YYZ
1300	SR 100	747-300	82	JFK
1300	SR 106	MD11	85	LAX
1300	SR 658	MD81	48	MAD
1300	AEA 696	737-300	35	SCQ
1305	SR 6928	ARJ85	92	GVA
1310	SR 376	A310	34	AUH
1310	SR 3670	MD87	86	PMI
1310	SU 266	TU5	90	SVO
1310	TK 908	A310	34	IST
1310	TK 4916	727	24	IST
1320	AF 3145	F28	39	NCE
1320	SR 124	747-300	82	ORD
1320	SR 6450	F50	89	LJU
1320	SPP 228	M80	48	PMI
1325	DL 123	A310	34	CVG
1330	LX 854	146-300	15	DUB
1330	OA 132	737-200	42	ATH
1330	AEA 605	737-300	35	PMI
1330	AEA 644	757	51	LPA
1330	TAT 4172	F100	88	FSC
1335	TSW 3620	737-300	35	RHO
1340	AY 8629	DC9	40	HEL
1340	LX 9118	SF340	72	SOB
1345	SR 466	F100	88	BUD
1350	TU 8621	727	24	DJE
1355	SPP 214	M80	48	IBZ
1405	AZ 4401	A300	31	FCO
1405	AIZ 502	757	52	ETH
1410	CX 290	747-400	83	HKG
1410	KE 916	747-400	83	SEL
1410	SR 332	A310	34	TLV
1415	FUA 901	737-400	84	LPA
1420	AZ 1441	M80	48	FCO
1420	TG 909	747-400	83	BKK
1425	AH 2049	737-200	42	ALG
1425	BA 5345	737-200	42	EDI
1425	SR 804	A310	34	LHR
1430	LX 9106	SF340	72	GCI
1430	SR 1322	MD81	48	ESB
1430	AOJ 652	Caravell	97	SKP
1430	AXX 102	M80	48	SKP
1435	OK 769	ATR42	95	PRG
1440	BB 3526	MD82	49	AGP
1440	SR 6634	SF340	72	GOA
1440	LTE 624	757	52	TFS
1445	LH 4593	A320	87	FRA
1445	SR 6930	ARJ85	92	GVA
1450	AF 2891	737-300	35	CDG
1450	CLC 423	DC3	71	ZRH
1500	IG 356	DC9	40	OLB
1500	TP 538	737-200	42	OPO
1500	FLT 799A	146	15	LGW
1510	AAN 453	A310	34	LPA
1515	LX 9124	SF340	72	JER
1525	OS 246	F50	89	SZG
1525	SR 444	MD81	48	PRG

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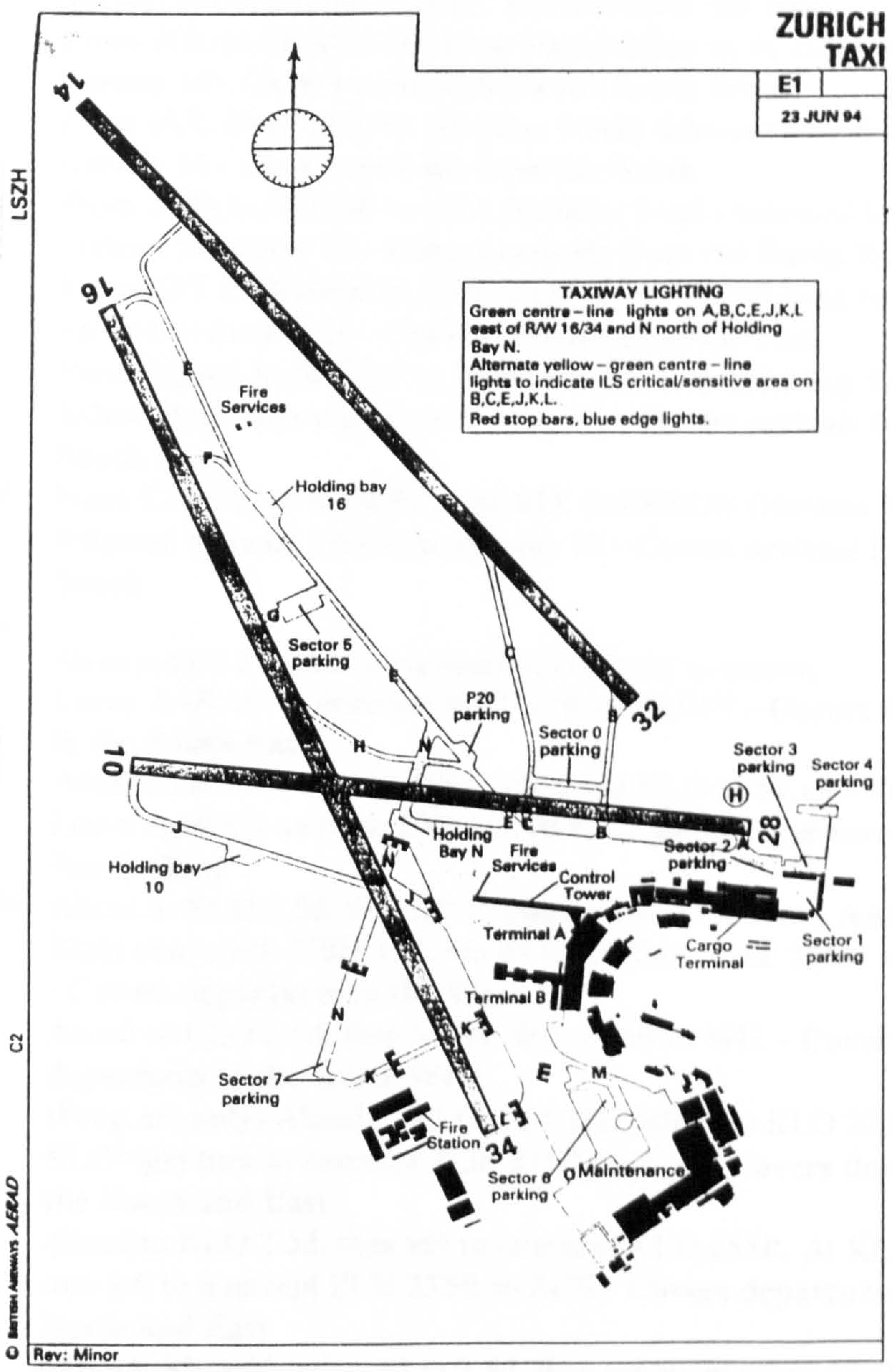
1535	SR 886	MD81	48	BRU
1540	BA 715	757	51	LHR
1540	SR 750	MD81	48	NCE
1540	SR 6568	F50	89	HAJ
1540	AEA 592	737-300	35	LPA
1545	LH 5527	F50	89	DUS
1545	TP 521	A320	87	LIS
1550	BB 3366	MD82	49	ALC
1550	SR 6618	SF340	72	TRN
1550	KAR 3044	DC9	40	HEL
1550	ZAS 761	M80	48	SSH
1600	BB 3234	MD81	48	KGS
1600	LX 912	SF340	72	LUG
1600	LX 9128	SF340	72	OLB
1610	AEA 632	757	52	PMI
1610	FUA 905	737-400	84	PMI
1615	MS 810	737-200	42	CAI
1625	KL 314	737-300	35	AMS
1625	LX 9006	ARJ85	92	MAH
1645	HM 002	767	32	LGW
1645	OS 204	M80	48	VIE
1650	LX 9008	146-300	15	REU
1650	SR 516	F100	88	DUS
1650	KAR 3038	DC9	40	HEL
1655	AI 194	DC8	64	BLR
1700	SR 538	MD81	48	FRA
1700	SR 968	F100	88	BSL
1700	VER 912	M80	48	HER
1705	SR 938	MD81	48	GVA
1710	GA 977	747-200	2	CGK
1715	SR 556	MD81	48	MUC
1735	AY 8620	M80	48	HEL
1740	SR 806	A310	34	LHR
1745	BB 3864	MD83	50	MAH
1745	SR 6567	F50	89	STR
1745	SR 6940	ARJ85	92	GVA
1750	EK 036	A300	31	DXB
1750	SR 404	F100	88	CPH
1800	BB 3378	MD87	86	IBZ
1800	TK 910	737-200	42	IST
1800	TU 8613	737-300	35	MIR
1800	AXX 106	TU5	90	SKP
1805	AAN 407	M80	48	PMI
1820	AZ 1495	DC9	40	LIN
1835	EI 669	737-300	35	DUB
1835	IB 3467	M80	48	MAD
1835	AEA 642	737-300	35	AGP
1840	KQ 145	A310	34	NBO
1845	LH 4559	737-200	42	FRA
1850	AF 2867	A320	87	CDG
1855	MA 567	737-200	42	BUD

Source: Zurich Airport Authority (1994)

Appendix 6.5



Source: RACAL AERAD Aerodrome Charts

Appendix 6.5

Zurich Airport Standard Routings

Arrivals

BLM 1Z	From BSL to GOLKE to EKRON (Holding Stack) followed by radar vectors to runway 14 - **Covers arrivals from the North West**
HOC 1Z	From HOC to GOLKE to EKRON (Holding Stack) followed by radar vectors to runway 14 - **Covers arrivals from the West**
WIL 1Z	From WIL to EKRON (Holding Stack) followed by radar vectors to runway 14 - **Covers arrivals from the South West**
SUL 1Z	From SUL direct to SHA (Holding Stack) followed by radar vectors to runway 14 - **Covers arrivals from the North**
TGO 1Z	From TGO to HEUSE to SHA (Holding Stack) followed by radar vectors to runway 14 - **Covers arrivals from the North East**
KPT 1Z	From KPT to BODSE to SHA (Holding Stack) followed by radar vectors to runway 14 - **Covers arrivals from the East**
RESIA 1Z	From RESIA to SOSON to ALBIX to EKRON (Holding Stack) followed by radar vectors to runway 14 - **Covers arrivals from the South East**
CANNE 1Z	From CANNE to SOSON to ALBIX to EKRON (Holding Stack) followed by radar vectors to runway 14 - **Covers arrivals from the South**

Departures

ALBIX 5W	Ahead to KLO 2.5d, then left to intercept KLO 255R to AARAU. Leave AARAU to intercept HOC 11R to ALBIX - **Covers departures to the South East**
HOC 5W	Ahead to KLO 2.5d, then left to intercept KLO 255R to AARAU. Leave AARAU on track 291M to HOC - **Covers departures to the North West**
MOROK 5W	Ahead to KLO 2.5d, then left to intercept KLO 255R to AARAU. Right onto track 278M to LASON then left on track 266M to MOROK - **Covers departures to the West**
WIL 5W	Ahead to KLO 2.5d, then left on WIL 054R to WIL - **Covers departures to the South West**
ZUE 6Z	**(Prop a/c only)** Ahead to KLO 2.5d, then left onto KLO 223R. At KLO right turn to intercept ZUE 235R to ZUE - **Covers departures to the North and East**
ZUE 6W	Ahead to KLO 2.5d, then left to intercept KLO 255R. At KLO 10d turn left to intercept ZUE 235R to ZUE - **Covers departures to the North and East**
TEBRI 1Y	**(RNAV SID)** Ahead to KLO 2.5d, then left to intercept KLO 255R. Remain within KLO 12d, left turn to OTTAB and TESMA, then right to TEBRI - **Covers departures to the South and South East**
EBOTO 1Y	**(RNAV SID)** Ahead to KLO 2.5d, then left to intercept WIL 054R to BREGO. Then left to BERSU, right to TELNO and right again to EBOTO - **Covers departures to the South West**
RESIA 1Y	**(RNAV SID)** Ahead to KLO 2.5d, then left to intercept KLO 255R. Left to OTTAB and TESMA, then right to KELAP and finally left to RESIA - **Covers departures to the South East**

Appendix 6.6

Gatwick Airport Typical Busy Day Arrivals - 30th June 1995

Arr. Time	Flt. No.	Aircraft Type	A/C code	From	Turnaround	Dest.
0.55	RPX706	HPH	67	STN	RPX707P	STN
1.00	EXS472	HPH	67	LPL		
1.05	GR614	SH6	68	EMA		
2.20	MON3685	AB6	31	LPA		
3.40	AIH494	M83	50	AGP		
3.45	AIH470	M83	50	GRO		
4.15	BA062	742	2	SEZ		
4.35	AMM593	757	51	TLV		
4.40	FD223	SH6	68	CDG		
5.00	BY060B	757	51	PMI	BY222A	CFU
5.05	BY158B	762	32	HER		
5.10	BY291B	762	32	MCO	BY341A	NAP
5.15	BA074	742	2	LOS		
5.25	BY438B	757	51	LPA		
5.30	BY347B	757	51	KGS	BY194A	PMI
5.30	CKT132	D1C	20	MCO		
5.40	LEI6024	734	84	AGP	LEI6227	JSI
6.10	EXC384	320	87	SKG		
6.15	BY375B	757	51	PMI	BY047A	ATH
6.15	TIH048	763	33	MCO		
6.20	BA198	762	32	PIT		
6.20	BA294	742	2	MIA		
6.25	EK007	313	34	DXB		
6.30	BA172	D1C	20	JFK		
6.40	DL012	L15	23	ATL		
6.45	MON5513	320	87	KGS	MON5226	PVK
6.45	DP013	757	52	LCA	AMM450	MAH
6.50	BA194	762	32	BWI		
6.50	BA224	D1C	20	IAH		
6.50	BA192	D1C	20	DFW		
6.50	BA232	D1C	20	BDA		
6.55	Q7001	313	34	DOH		
7.00	CO028	D1C	20	EWR		
7.00	GT821	732	42	FAO	GT888	CFU
7.05	BA226	D1C	20	ATL		
7.10	BA196	762	32	CLT		
7.10	LEI6560	734	84	DLM		
7.15	DB541	AT4	95	RNS	DB542	LEH
7.25	BA8012	AT7	96	ANR	BA8035	JER
7.25	BA8058	AT4	95	RTM	BA8059	RTM
7.25	VD460	M38	50	ORY	VD461	ORY
7.25	VS006	742	2	MIA		
7.30	BA3127	F28	39	LYS	BA3128	LYS
7.30	ZI211	EMB	69	URO	ZI212	URO
7.35	BA8090	AT4	95	DUS	BA8011	ANR
7.35	TW720	741	1	STL		
7.45	BA2411	734	84	BRU	BA2016	ABZ
7.45	BA2001	734	84	MAN		
7.45	LEI6226	734	84	SKG		
7.45	DB943	AT4	95	NTE	DB944	NTE
7.50	HV601	732	42	AMS	HV602	AMS
7.50	VS012	741	1	BOS		
7.55	BA8081	AT7	96	DUB	BA8082	DUB
7.55	BA252	742	2	ANU		
7.55	BA2817	734	84	CDG	BA2472	AGP
7.55	5E463	J31	98	EIN	5E464	EIN
7.55	NW048	D14	21	BOS		
7.55	BA3400	733	35	MUC	BA3401	MUC
8.00	MON7712	757	51	MAN	MON7712	LXR

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8.00	AA174	762	33	RDU		
8.05	CKT5741	757	51	TFS		
8.10	BA8070	AT4	95	NCL	BA8073	NCL
8.10	JY900	F2E	67	GCI	JY903	GCI
8.10	BA2785	734	84	GOT	BA2464	MAD
8.15	JY930	142	15	JER	JY933	JER
8.15	UK510	143	15	EDI	UK511	EDI
8.15	BA2333	732	42	BOD	BA2606	NAP
8.15	MON3005	757	51	ZTH	MON5584	MAH
8.15	NG107	763	33	VIE	NG106	VIE
8.15	VS016	742	2	MCO		
8.20	BA2913	734	84	FRA	BA2654	TLV
8.20	DM101	735	35	BLL	DM102	BLL
8.25	UK480	143	15	GLA	UK483	GLA
8.30	JY961	143	15	BHD	JY962	BHD
8.30	BA2735	732	42	GVA	BA2614	GOA
8.30	BA2015	732	42	ABZ	BA2004	MAN
8.30	BA3203	100	88	MRS	BA3202	MRS
8.35	BA2640	734	84	FBU	BA2640	ATH
8.40	BA2824	734	84	SVG	BA2824	CDG
8.45	BA2691	732	42	VIE	BA2894	OTP
8.45	AA050	M11	85	DFW	AA051	DFW
8.45	AZ1262	M82	49	BLQ	AZ1261	PSA
8.50	BA8122	SH6	68	LBA	BA8123	LBA
8.50	NW044	D14	21	MSP		
9.00	IG3531	141	15	FLR	IG3532	FLR
9.05	BA2595	732	42	VRN		
9.05	AMM425	757	51	DLM		
9.10	BA2613	732	42	GOA		
9.15	DM13	735	35	CPH	DM114	CPH
9.20	BA2605	734	84	NAP	BA2328	MPL
9.20	BA2463	732	42	MAD	BA2334	BOD
9.20	NW032	D14	21	DTW		
9.25	TI777	721	25	RIX	TI778	RIX
9.30	AA138	762	33	BNA		
9.30	TQ031	100	88	ARN	TQ032	ARN
9.30	TS852	L11	22	YYC		
9.35	DL010	L15	23	ATL	DL011	ATL
9.35	FV162	733	35	AGP	FV163	AGP
9.45	CO004	D1C	20	EWR		
9.55	SBE2443	732	42	TFS		
9.55	DL036	L15	23	CVG		
10.00	MON1959	AB6	31	TFS	MON5388	TFS
10.00	CO014	D1C	20	EWR		
10.00	FR112	732	42	DUB	FR113	DUB
10.10	BU585	735	35	FBU	BU596	BGO
10.15	BA2821	734	84	CDG	BA2828	CDG
10.15	BA2003	732	42	MAN	BA2006	MAN
10.20	AF2570	320	87	MRS	AF3589	MRS
10.30	KM140	320	87	MLA	KM141	MLA
10.30	FLT799	143	15	ZRH		
10.35	BA2413	734	84	BRU	BA2518	FAO
10.40	BA8036	AT7	96	JER	BA803	ORK
10.40	CLI410	313	31	YVR	CLI411	MAN
10.45	BA8050	AT4	95	RTM	BA8091	DUS
10.45	DB041	SF3	72	BES	DB042	BES
10.45	NG1409	CRJ	94	SZG	NG1410	SZG
10.50	BA8022	SH6	68	GCI	BA8023	GCI
10.55	UK509	143	15	EDI	UK515	EDI
10.55	MON3053	320	87	MAH	MON7802	TFS
11.00	BA8072	AT4	95	NCL	BA8037	JER
11.00	BA8014	AT4	95	ANR	BA8051	RTM
11.00	TS258	L11	22	YYZ		

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11.05	AZ284	M82	49	VCE	AZ285	VCE
11.10	CKT5129	L10	22	MAH		
11.10	QN742	L10	22	YYZ	QN743	YYZ
11.20	AA078	763	33	DFW	AA079	DFW
11.40	JY965	143	15	BHD	JY966	BHD
11.45	AMM443	757	51	VRN	AMM456	CFU
11.50	BA2737	732	42	GVA	BA2596	VRN
11.50	DB945	AT4	95	NTE		
11.55	NS7608	AT7	96	FMO	NS7609	FMO
12.00	JY938	142	15	JER	JY907	GCI
12.00	UK484	143	15	GLA	UK487	GLA
12.00	BA2005	732	42	MAN		
12.00	BY194B	757	51	PMI	BY243A	MLA
12.00	CMM4511	757	51	YYZ	CMM4512	YYZ
12.05	HV603	732	42	AMS	HV604	AMS
12.15	BA2825	734	84	CDG	BA238	TLS
12.15	BA2017	734	84	ABZ		
12.20	BA2915	734	84	FRA	BA2916	FRA
12.20	FV140	733	35	MAD	FV141	MAD
12.25	JY904	F2E	67	GCI	JY941	JER
12.25	AIH404	320	87	IBZ	AIH403	IBZ
12.30	BA8083	AT7	96	DUB		
12.30	BA8074	AT4	95	NCL	BA8075	NCL
12.30	BA2801	734	84	CPH	BA2801	AGP
12.30	DB111	AT4	95	RNS	DB112	RNS
12.30	IJ3172	F28	39	FSC		
12.45	AZ4280	M82	49	FCO	AZ4279	FCO
12.50	BA2381	732	42	TLS	BA2414	BRU
12.50	BY341B	762	32	NAP	BY187A	MAH
12.50	EXC224	320	87	PSA	EXC311	SSH
13.00	AMM427	757	51	AGP	AMM430	MAH
13.00	TQ033	100	88	ARN	TQ034	ARN
13.05	MON1921	AB6	31	PMI	MON1960	MAH
13.15	DM105	735	35	BLL	DM106	BLL
13.25	AMM451	757	51	MAH	AMM438	NAP
13.25	GV401	732	42	RIX	GV402	RIX
13.40	BA2573	734	84	LIN	BA2012	MAN
13.40	BY222B	757	51	CFU	BY089A	IBZ
13.40	SBE2511	732	42	NAP		
13.45	BA2007	732	42	MAN	BA2738	GVA
13.45	IT4488	733	35	BOD	IT4489	BOD
14.00	BA2615	732	42	GOA		
14.00	BWL554	B15	37	VCE	BWL561	AOI
14.00	BA3205	100	88	MRS	BA3204	MRS
14.15	BA8038	AT4	95	JER	BA8015	ANR
14.15	BY173B	757	51	MAH		
14.15	BA8953	732	42	VLC		
14.20	BA8024	SH6	68	GCI		
14.20	BA2465	734	84	MAD	BA2836	CDG
14.25	MON5585	757	51	MAH		
14.30	BA8052	AT4	95	RTM	BA8053	RTM
14.30	BA8903	734	84	GIB		
14.35	MON3663	733	35	CIA	MON7894	SFA
14.40	LEI6142	734	84	MAH	LEI6371	AGP
14.55	BA2329	734	84	MPL		
14.55	FRO307	AB3	31	TFS		
15.05	BA8045	AT7	96	ORK	BA8045	JER
15.05	BA8092	AT4	95	DUS	BA8077	NCL
15.10	BA2335	732	42	BOD	BA2416	BRU
15.10	GT889	732	42	CFU	GT818	BUD
15.15	JY944	F2E	67	JER	JY913	GCI
15.15	MON5227	320	87	PVK	MON3076	ALC
15.20	BA2695	734	84	VIE		

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15.30	SBE677	732	42	SKG		
15.40	VD466	M83	50	ORY	VD467	ORY
15.40	OOE319	L10	22	TFS		
15.40	ALT151	320	87	TFS	ALT152	MAH
15.45	JY910	142	15	GCI	JY947	JER
15.45	BA2607	732	42	NAP	BA2840	CDG
15.50	JY969	143	15	BHD	JY970	BHD
15.50	BY047B	757	51	ATH	BY264A	RMI
15.55	MON3693	757	51	NAP	MON5236	GRO
16.00	BA2473	734	84	AGP	BA2473	CPH
16.00	LEI6228	734	84	SKG	LEI6565	MAH
16.00	FR114	732	42	DUB	FR115	DUB
16.00	OOE161	L10	22	TFS	OOE134	AGP
16.05	BA118	742	2	MAN		
16.05	UK490	143	15	GLA	UK491	GLA
16.15	BA2833	732	42	CDG	BA2008	MAN
16.15	HV605	732	42	AMS	HV606	AMS
16.20	BA2887	732	42	SVO		
16.25	AIH472	M83	50	CHQ		
16.30	IY748	722	24	ORY	IY749	ORY
16.35	UK520	143	15	EDI	UK521	EDI
16.35	AMM517	320	87	JSI		
16.45	CKT3211	757	51	CFU		
16.50	AIH438	M83	50	ACE		
16.55	AZ4284	D93	40	VCE	AZ4285	VCE
16.55	IB5134	M87	86	SCQ	IB5135	SCQ
16.55	TQ035	100	88	ARN	TQ036	ARN
17.00	BA2415	732	42	BRU	BA2336	BOD
17.10	BU595	735	35	BGO	BU588	FBU
17.15	BA2011	734	84	MAN	BA2010	MAN
17.15	EAF3025	B15	37	LIN		
17.20	AMM359	757	51	TFS	AMM404	GRO
17.25	BA2597	732	42	VRN	BA2740	GVA
17.30	BA8076	AT4	95	NCL	BA8047	JER
17.30	BA3129	F28	39	LYS	BA3120	LYS
17.30	ZI213	EMB	69	URO	ZI214	URO
17.35	BA2519	734	84	FAO	BA2786	GOT
17.40	BA8016	AT4	95	ANR	BA8095	DUS
17.45	BA2917	734	84	FRA	BA2774	FBU
17.45	BA2641	734	84	ATH		
17.45	BA2895	732	42	OTP	BA2618	GOA
17.50	BA8026	SH6	68	GCI	BA8129	LBA
17.50	DB543	AT4	95	LEH	DB544	RNS
17.50	DM117	735	35	CPH	DM118	CPH
17.55	BA8054	AT4	95	RTM	BA8055	RTM
17.55	5E467	J31	98	EIN	5E468	EIN
17.55	DM109	735	35	BLL	DM110	BLL
18.10	BA2383	734	84	TLS	BA2420	BRU
18.10	BA2739	732	42	GVA	BA2598	VRN
18.15	BA8046	AT7	96	JER	BA8017	ANR
18.15	BA2837	734	84	CDG	BA2837	SVG
18.15	FV142	733	35	MAD	FV143	MAD
18.15	PS551	732	42	KBP	PS552	KBP
18.15	RA229	313	34	FRA	RA230	FRA
18.30	BA8087	AT7	96	DUB	BA8088	DUB
18.30	BA2019	732	42	ABZ	BA2020	ABZ
18.30	NG109	734	84	VIE	NG108	VIE
18.40	BA2417	732	42	BRU	BA2698	VIE
18.45	DB941	AT4	95	NTE	DB942	NTE
18.45	VD470	M83	50	ORY	VD471	ORY
18.45	EAF3119	B15	37	LDE		
18.50	JY950	142	15	JER	JY974	BHD
18.50	IG3533	141	15	FLR	IG3534	FLR

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18.50	BA3404	733	35	MUC	BA3405	MUC
18.55	BA8128	SH6	68	LBA		
18.55	JY918	F2E	67	GCI	JY919	GCI
19.05	JY973	143	15	BHD	JY974	BHD
19.10	BA3207	100	88	MRS	BA3206	MRS
19.15	UK524	141	15	EDI	UK525	EDI
19.15	BA2839	734	84	CDG	BA2849	CDG
19.15	AMM431	757	51	MAH	AMM434	TFS
19.15	AZ1260	M82	49	PSA	AZ1263	BLQ
19.20	BA2475	734	84	AGP		
19.25	BA8078	AT4	95	NCL	BA8079	NCL
19.30	FR116	732	42	DUB	FR117	DUB
19.35	BA2009	732	42	MAN		
19.40	MON1961	AB6	31	MAH		
19.40	CKT601	L10	22	MAH	CKT5064	ATH
19.45	HV609	732	42	AMS	HV610	AMS
19.50	BY187B	762	32	MAH		
20.00	UK496	143	15	GLA	UK497	GLA
20.15	BA2841	732	42	CDG		
20.20	AMM439	757	51	NAP	AMM502	ADB
20.25	BY089B	757	51	IBZ	BY376A	CFU
20.30	EXS821	HPH	67	GCI		
20.30	BY243B	757	51	MLA		
20.30	CKT463	L10	22	TFS	CKT3340	DLM
20.35	UK526	143	15	EDI		
20.35	MON5389	AB6	31	TFS	MON7822	ATH
20.35	BWL562	B15	37	AOI		
20.40	GR611	SH6	68	JER	GR613	EMA
20.45	BA8048	AT4	95	JER		
20.45	MON7713	757	51	LXR	MON7713	MAN
20.55	AMM457	757	51	CFU	AM440	CFU
21.00	BY264B	757	51	RMI	BY208A	IBZ
21.00	EXC226	320	87	HRG	EXC237	ATH
21.05	BA2811	734	84	CPH		
21.15	LEI6028	734	84	AGP	LEI6029	ATH
21.25	MON7803	320	87	TFS	MON5206	ATH
21.40	BA2521	734	84	FAO		
21.40	BA2655	734	84	TLV		
21.40	BA2467	732	42	MAD		
21.45	ALT153	320	87	MAH	ALT158	ATH
21.50	LEI6372	734	84	AGP	LEI6231	TFS
21.55	GT959	732	42	MUC		
21.55	AT5202	735	35	AGA	AT5203	AGA
22.00	MON3671	757	51	BJL	MON1158	ATH
22.00	MON5237	757	51	GRO	MON1496	ALC
22.05	LEI6566	734	84	MAH	LEI6457	ATH
22.15	GT819	732	42	BUD	GT804	AGP
22.20	BA8056	AT4	95	RTM		
22.25	MON7895	733	35	SFA	MON3014	ATH
22.30	MON3077	320	87	ALC	MON5288	AGP
22.45	MON1551	757	51	ALC	MON7244	DLM
22.45	AM405	757	51	GRO		
22.50	GT6967	734	84	ALC	GT6944	CFU
22.55	JY977	142	15	BHD		
23.15	BY537B	757	51	FAO		
23.20	BA8907	732	42	GIB		
23.40	OOE135	L10	22	AGP		

Note: Aircraft Code refers to SIMMOD aircraft Data file.
Source: UK Airport Timetables 1995

Appendix 6.6

Gatwick Airport Typical Busy Day Departures - 30th

Dep. Time	Flt. No.	A/c Type	A/c Code	Dest.	Turnaround
0.05	AMM424	757	51	DLM	
0.20	MON3004	757	51	ZTH	
0.45	GT820	732	42	FAO	
0.55	BY375A	757	51	PMI	
0.55	SBE2442	732	42	TFS	
1.05	MON1958	AB6	31	TFS	
1.25	RPX707P	HPH	67	STN	Y
1.40	FD222	SH6	68	CDG	
4.25	GR612	SH6	68	JER	
5.15	EXS820	HPH	67	GCI	
5.30	CKT5128	L10	22	MAH	
6.00	AVB502	CND	57	JER	
6.00	MON3052	320	87	MAH	
6.00	SBE118	732	42	MAH	
6.00	FRO306	AB3	31	TFS	
6.00	OOE318	L10	22	TFS	
6.10	CKT600	L10	22	MAH	
6.10	SBE676	732	42	JSI	
6.35	BY222A	757	51	CFU	Y
6.35	BY194A	757	51	PMI	Y
6.45	BY341A	762	32	NAP	Y
6.55	AMM442	757	51	VRN	
6.55	ALT150	320	87	TFS	
7.00	LEI6227	734	84	JSI	Y
7.00	UK509	143	15	GLA	
7.00	LEI6027	734	84	AGP	
7.00	AMM426	757	51	AGP	
7.10	JY962	143	15	BHD	
7.20	BA2886	732	42	SVO	
7.25	BA8071	AT4	95	NCL	
7.25	BA2002	732	42	MAN	
7.30	BY047A	757	51	ATH	Y
7.30	GT888	732	42	CFU	Y
7.30	BA2820	734	84	CDG	
7.30	SBE2510	732	42	NAP	
7.35	AMM516	320	87	JSI	
7.40	BA2412	734	84	BRU	
7.45	DB542	AT4	95	LEH	Y
7.50	BA2736	732	42	GVA	
7.50	EXC223	320	87	PSA	
7.55	BA8059	AT4	95	RTM	Y
7.55	MON1920	AB6	31	PMI	
7.55	AIH471	M83	50	CHQ	
8.00	MON5226	320	87	PVK	Y
8.00	ZI212	EMB	69	URO	Y
8.00	BA8021	SH6	68	GCI	
8.00	BA2800	734	84	CPH	
8.00	AMM358	757	51	TFS	
8.00	AIH437	M83	50	ACE	
8.10	BA8035	AT7	96	JER	Y
8.10	BA8011	AT4	95	ANR	Y
8.10	BA2914	734	84	FRA	
8.10	BA8902	734	84	GIB	
8.20	DB944	AT4	95	NTE	Y
8.20	5E464	J31	98	EIN	Y
8.25	AMM450	757	51	MAH	Y
8.25	HV602	732	42	AMS	Y
8.30	VD461	M83	50	ORY	Y
8.30	BA3128	F28	39	LYS	Y
8.30	BA2016	734	84	ABZ	Y
8.35	BA3401	733	35	MUC	Y
8.40	BA8082	AT7	96	DUB	Y
8.45	BA2380	732	42	TLS	
8.55	BA8073	AT4	95	NCL	Y
8.55	BA2464	734	84	MAD	Y

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8.55	JY933	142	15	JER	Y
8.55	UK511	143	15	EDI	Y
8.55	BA8952	732	42	VLC	
9.00	BY173A	757	51	MAH	
9.00	MON7712	757	51	LXR	Y
9.00	DM102	735	35	BLL	Y
9.05	BA2572	734	84	LIN	
9.05	UK483	143	15	GLA	Y
9.10	JY962	143	15	BHD	Y
9.10	BA2614	732	42	GOA	Y
9.10	BA2640	734	84	ATH	Y
9.15	BY179A	762	32	MCO	
9.15	MON3662	733	35	CIA	
9.15	MON3670	757	51	BJL	
9.15	JY903	F2E	67	GCI	Y
9.15	MON5584	757	51	MAH	Y
9.15	NG106	763	33	VIE	Y
9.15	BA2004	732	42	MAN	Y
9.20	LEI6141	734	84	MAH	
9.20	BWL553	B15	37	VCE	
9.25	CKT3210	757	51	CFU	
9.30	BA193	D1C	20	DFW	
9.30	EXC225	320	87	HRG	
9.30	BA2606	732	42	NAP	Y
9.30	BA3202	100	88	MRS	Y
9.30	BA2824	734	84	CDG	Y
9.30	BA8123	SH6	68	LBA	Y
9.40	BA2472	734	84	AGP	Y
9.45	BA255	742	2	BGI	
9.45	AZ1261	M82	49	PSA	Y
9.45	IG3532	141	15	FLR	Y
9.55	BA225	D1C	20	IAH	
9.55	MON3692	757	51	NAP	
10.00	BA295	742	2	MIA	
10.00	AA139	762	33	BNA	
10.00	BA2654	734	84	TLV	Y
10.00	BA2894	732	42	OTP	Y
10.00	DM114	735	35	CPH	Y
10.10	BA2694	734	84	VIE	
10.15	TQ032	100	88	ARN	Y
10.30	BA227	D1C	20	ATL	
10.30	CKT077	D1C	20	TAB	
10.35	BA2328	734	84	MPL	Y
10.40	BA173	D1C	20	JFK	
10.40	AA051	M11	85	DFW	Y
10.40	FR113	732	42	DUB	Y
10.45	FV163	733	35	AGP	Y
10.55	BA163	D1C	20	GCM	
10.55	TIH057	763	32	MCO	
10.55	TW721	741	1	STL	
11.00	BA081	742	2	ACC	
11.00	EK008	313	34	DXB	
11.00	DL011	L15	23	ATL	Y
11.00	BU596	735	35	BGO	Y
11.00	BA2828	734	84	CDG	Y
11.00	BA2006	732	42	MAN	Y
11.10	AF3589	320	87	MRS	Y
11.10	BA8036	AT7	96	ORK	Y
11.15	CKT462	L10	22	TFS	
11.15	CO025	D1C	20	EWR	
11.15	VS005	742	2	MIA	
11.15	BA2334	732	42	BOD	Y
11.15	TI778	721	25	RIX	Y
11.15	BA2518	734	84	FAO	Y
11.15	NG1410	CRJ	94	SZG	Y
11.20	BA197	762	32	CLT	
11.20	BA8091	AT4	95	DUS	Y
11.30	BA265	742	2	MBJ	
11.30	AA173	762	33	RDU	

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11.30	TS853	L11	22	YYC	
11.30	KM141	320	87	MLA	Y
11.30	BA8023	SH6	68	GCI	Y
11.35	MON5388	AB6	31	TFS	Y
11.40	CLI411	313	34	MAN	Y
11.40	BA8051	AT4	95	RTM	Y
11.45	NW049	D14	21	BOS	
11.45	DB042	SF3	72	BES	Y
11.45	UK515	143	15	EDI	Y
11.45	BA8037	AT4	95	JER	Y
12.00	CO005	D1C	20	IAH	
12.00	Q7002	313	34	DOH	
12.00	AZ285	M82	49	VCE	Y
12.10	NW045	D14	21	MSP	
12.15	BA199	762	32	PIT	
12.20	JY966	143	15	BHD	Y
12.25	BA195	762	32	BWI	
12.25	MON7802	320	87	TFS	Y
12.30	VS015	742	2	MCO	
12.40	JY907	142	15	GCI	Y
12.40	UK487	143	15	GLA	Y
12.45	NW033	D14	21	DTW	
12.45	BA2596	732	42	VRN	Y
12.50	HV604	732	42	AMS	Y
12.55	JY941	F2E	67	JER	Y
13.00	EAF3024	B15	37	LIN	
13.00	QN743	L10	22	YYZ	Y
13.05	AA079	763	33	DFW	Y
13.05	FV141	733	35	MAD	Y
13.05	BA2801	734	84	AGP	Y
13.10	TS259	L11	22	YYZ	
13.15	AMM456	757	51	CFU	Y
13.15	NS7609	AT7	96	FMO	Y
13.30	BA237	742	2	MCO	
13.30	BA2832	732	42	CDG	
13.30	DL037	L15	23	CVG	
13.30	BY243A	757	51	MLA	Y
13.30	CMM4512	757	51	YYZ	Y
13.45	BA2916	734	84	FRA	Y
13.45	DB112	AT4	95	RNS	Y
13.45	AZ4279	M82	49	FCO	Y
13.45	EXC311	320	87	SSH	Y
13.55	DM106	735	35	BLL	Y
14.00	BA8075	AT4	95	NCL	Y
14.00	TQ034	100	88	ARN	Y
14.05	BA2382	734	84	TLS	Y
14.05	AIH403	320	87	IBZ	Y
14.05	AMM430	757	51	MAH	Y
14.15	BA2414	732	42	BRU	Y
14.15	AMM438	757	51	NAP	Y
14.25	GV402	732	42	RIX	Y
14.25	BA2738	732	42	GVA	Y
14.30	DB946	AT4	95	NTE	
14.30	IJ3173	F28	39	FSC	
14.30	MON1960	AB6	31	MAH	Y
14.30	BA2012	734	84	MAN	Y
14.35	BY187A	762	32	MAH	Y
14.40	CO019	D1C	20	EWR	
14.45	BA8086	AT7	96	DUB	
14.45	BA2018	732	42	ABZ	
14.45	EAF3118	B15	37	LDE	
14.45	IT4489	733	35	BOD	Y
14.50	BA3204	100	88	MRS	Y
14.50	BA8015	AT4	95	ANR	Y
15.00	DL019	L15	23	ATL	
15.00	VS011	741	1	BOS	
15.00	BY089A	757	51	IBZ	Y
15.00	BA8025	SH6	68	GCI	Y
15.00	BA8053	AT4	95	RTM	Y

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15.15	BA2520	734	84	FAO	
15.15	BWL561	B15	37	AOI	Y
15.30	BA2836	734	84	CDG	Y
15.35	MON7894	733	35	SFA	Y
15.45	BA8045	AT7	96	JER	Y
15.50	LEI6371	734	84	AGP	Y
16.00	BA8077	AT4	95	NCL	Y
16.00	BA2416	732	42	BRU	Y
16.20	JY913	F2E	67	GCI	Y
16.25	BA2466	732	42	MAD	
16.25	JY947	142	15	JER	Y
16.30	GT818	732	42	BUD	Y
16.30	JY970	143	15	BHD	Y
16.35	BA2473	734	84	CPH	Y
16.40	SBE2524	732	42	PSA	
16.40	ALT152	320	87	MAH	Y
16.40	FR115	732	42	DUB	Y
16.40	UK491	143	15	GLA	Y
16.50	BY264A	757	51	RMI	Y
16.55	OOE134	L10	22	AGP	Y
17.00	BY537A	757	51	FAO	
17.00	GT6966	734	84	ALC	
17.00	MON3076	320	87	ALC	Y
17.00	LEI6565	734	84	MAH	Y
17.00	HV606	732	42	AMS	Y
17.05	BA2008	732	42	MAN	Y
17.10	MON1550	757	51	ALC	
17.15	VD467	M83	50	ORY	Y
17.15	UK521	143	15	EDI	Y
17.25	MON5236	757	51	GRO	Y
17.30	BA2840	732	42	CDG	Y
17.40	GT958	732	42	MUC	
17.45	IB5135	M87	86	SCQ	Y
17.50	BU588	735	35	FBU	Y
17.55	AZ4285	D93	40	VCE	Y
18.00	BA2608	734	84	NAP	
18.00	FLT792	143	15	ZRH	
18.00	TQ036	100	88	ARN	Y
18.00	BA2336	732	42	BOD	Y
18.10	IY749	722	24	ORY	Y
18.15	BA8047	AT4	95	JER	Y
18.15	BA3120	F28	39	LYS	Y
18.20	BA2786	734	84	GOT	Y
18.25	AMM404	757	51	GRO	Y
18.25	5E468	J31	98	EIN	Y
18.30	ZI214	EMB	69	URO	Y
18.30	BA2010	734	84	MAN	Y
18.30	BA2618	732	42	GOA	Y
18.30	DM118	735	35	CPH	Y
18.35	DM110	735	35	BLL	Y
18.40	BA8055	AT4	95	RTM	Y
18.45	BA8129	SH6	68	LBA	Y
18.50	BA8017	AT7	96	ANR	Y
18.55	BA2740	732	42	GVA	Y
18.55	BA2598	732	42	VRN	Y
18.55	BA2837	734	84	SVG	Y
19.00	DP012	320	87	LCA	
19.00	FRO320	AB3	31	HER	
19.00	BA8095	AT4	95	DUS	Y
19.00	BA2774	734	84	FBU	Y
19.00	BA2420	734	84	BRU	Y
19.00	BA8088	AT7	96	DUB	Y
19.05	BA2918	734	84	FRA	
19.10	NG108	734	84	VIE	Y
19.15	AIH439	M83	50	SKG	
19.15	FV143	733	35	MAD	Y
19.15	PS552	732	42	KBP	Y
19.20	BA2020	732	42	ABZ	Y
19.25	IG3534	141	15	FLR	Y

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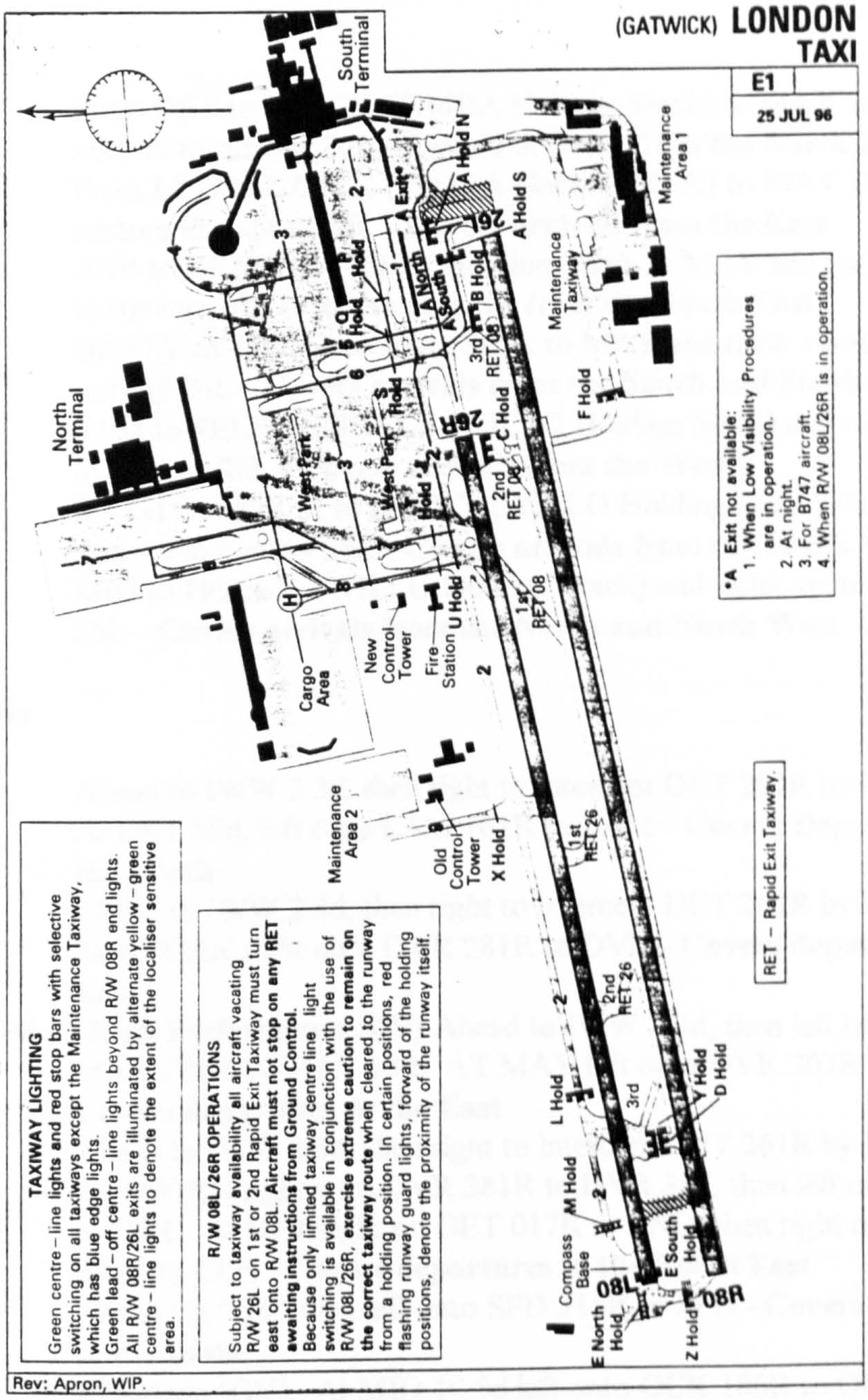
19.30	DB544	AT4	95	RNS	Y
19.30	DB942	AT4	95	NTE	Y
19.30	BA3405	733	35	MUC	Y
19.35	RA230	313	34	FRA	Y
19.35	JY919	F2E	67	GCI	Y
19.45	BA2698	732	42	VIE	Y
19.45	VD471	M83	50	ORY	Y
19.45	JY974	142	15	BHD	Y
19.50	BA2470	734	84	MAD	
19.50	JY955	143	15	JER	Y
19.50	UK525	141	15	EDI	Y
19.55	BA2849	734	84	CDG	Y
19.55	BA8079	AT4	95	NCL	Y
20.00	CKT3812	L10	22	HER	
20.00	BA3206	100	88	MRS	Y
20.00	AZ1263	M82	49	BLQ	Y
20.10	AIH473	M83	50	HER	
20.10	FR117	732	42	DUB	Y
20.15	OOE320	L10	22	DLM	
20.30	HV610	732	42	AMS	Y
20.35	UK497	143	15	GLA	Y
20.50	AMM434	757	51	TFS	Y
20.55	CKT5850	757	51	CFU	
21.00	SD117	L10	22	KRT	
21.25	CKT5064	L10	22	ATH	Y
21.35	MON1574	757	51	HER	
21.35	MON7713	757	51	MAN	Y
21.40	CKT3340	L10	22	DLM	Y
21.45	MON7822	AB6	31	ATH	Y
21.55	BY376A	757	51	CFU	Y
22.00	CKT5102	757	51	AGP	
22.00	AMM502	757	51	ADB	Y
22.00	EXC237	320	87	ATH	Y
22.05	BY208A	757	51	IBZ	Y
22.20	ALT158	320	87	ATH	Y
22.30	GR613	SH6	68	EMA	Y
22.30	MON5206	320	87	ATH	Y
22.30	BY292A	762	32	PMI	
22.40	EXS473	HPH	67	LPL	
22.40	MON3400	AB6	31	TFS	
22.40	LEI6231	734	84	TFS	Y
22.45	LEI6029	734	84	ATH	Y
22.45	AT5203	735	35	AGA	Y
22.50	AMM440	757	51	CFU	Y
22.50	LEI6457	734	84	ATH	Y
23.15	BY313A	757	51	CFU	
23.15	MON1158	757	51	ATH	Y
23.30	MON1496	757	51	ALC	Y
23.30	GT804	732	42	AGP	Y
23.30	MON5288	320	87	AGP	Y
23.30	GT6944	734	84	CFU	Y
23.45	MON3014	733	35	ATH	Y
23.45	MON7244	757	51	DLM	Y

Note: A/C Code refers to SIMMOD Data file
Source: UK Airport Timetables 1995

Appendix 6.7



Source: RACAL AERAD Aerodrome Charts

Appendix 6.7

Gatwick Airport Standard Routings

Arrivals

TIM 1E	From DET to LARCK (TIMBA Holding Stack) to MAY and radar vectors to runway 26L - **Covers arrivals from the North East**
TIM 1F	From LYD to LARCK (TIMBA Holding Stack) to MAY and radar vectors to runway 26L - **Covers arrivals from the East**
TIM 1B	ABB to BEXIL to TIMBA Holding Stack to MAY and radar vectors to runway 26L - **Covers arrivals from the South East**
TIM 1G	HASTY to TIMBA Holding Stack to MAY and radar vectors to runway 26L - **Covers arrivals from the South and South West**
WLO 1A	SAM to SELSI to HOLLY (WILLO Holding Stack) and radar vectors to runway 26L - **Covers arrivals from the West**
WLO 2C	KATHY to SELSI to HOLLY (WILLO Holding Stack) and radar vectors to runway 26L - **Covers arrivals from the South West**
WLO 1B	MID to HOLLY (WILLO Holding Stack) and radar vectors to runway 26L - **Covers arrivals from the North and North West**

Departures

LAM 2M	Ahead to IWW 2.3d, then right to intercept DET 261R by DET 31d. At DET 10d, left onto LAM 161R to LAM - **Covers Departures to the North**
DVR 6M	Ahead to IWW 2.3d, then right to intercept DET 261R by DET 31d. At ACORN right onto DVR 281R to DVR - **Covers departures to the East**
WIZAD 3M	**(High Performance SID)** Ahead to IWW 2.3d, then left to intercept MAY 288R by MAY 13d. AT MAY left onto DVR 263R to WIZAD - **Covers departures to the East**
CLN 4M	Ahead to IWW 2.3d, then right to intercept DET 261R by DET 31d. At ACORN right onto DVR 281R to DVR 31d, then left on DET 188R to DET. At DET right on DET 017R to SND, then right on CLN 229R to CLN - **Covers departures to the North East**
SFD 4M	Ahead via 'GY' then left onto SFD 315R to SFD - **Covers departures to the south**
BOG 1M	Ahead via 'GY'. At MID 10.5d left onto OCK 180R to OCK 28d, then left onto MID 150R to BOGNA - **Covers departures to the south**
SAM 2M	Ahead via 'GY' then left to intercept MID 067R to MID. At MID right onto MID 262R to SAM - **Covers departures to the west and south west**
KENET 2M	Ahead via 'GY' then left intercept MID 067R to MID. At MID right onto MID 262R to MID 10d then right onto GWC 331R to KENET - **Covers departures to the North and North West**

Appendix 6.8

The Costs and Benefits of Implementing Special Regional Aircraft Procedures.

Case 1: Base Case - No Change to Present System

Costs	Value	Benefits	Value
DIRECT		**DIRECT**	
Increased Delay for Business Pax.	£67/hr*	Saving for all parties in planning and testing of new procedures	£67 per (a) person/hr
Increased Delay for Leisure Pax.	£10/hr*	Saving in Airport Investment Budget	Variable (b)
Increased Airline Operations cost	£1313/hr (a)	**INDIRECT**	
Airline Cost of missed interlines	Variable (b)	Increased revenue from landing fees	Variable (c)
INDIRECT		Increased Pax commercial revenue	Variable (d)
Increased Air Pollution (c)	Unquantifiable	Reduce disturbance to local residents	Unquantifiable
Increased Noise Pollution	Unquantifiable	**INDUCED**	
Lost Airport Revenue as Pax demand falls	Variable (d)	Improved level of technology as aircraft and airport work to achieve more from the existing system.	Variable but significant (e)
Increased ATC airspace and workload problems	Variable (e)	Improved efficiency of existing system	Unquantifiable (f)
Cost to airlines as smaller aircraft are banned	Variable but significant (f)		
INDUCED			
Negative Multiplier in local economy	41% direct (g) 7% indirect		
Negative Multiplier on National Economy	41% direct 7% indirect		
Reduction in Airport Reputation	Unpredictable		
Reduction in Airline Reputation	Unpredictable		

Notes:

Costs

* Figures used by the UK CAA in the 1996, developed using a model from the Roskhill report. Last used for the RUCATSE report.

(a) Figure derived from data supplied from Crossair during the 1994 ERA RNAV Conference in Brussels in which they stated, 'a minute of flight time in a typical regional aircraft costs approximately $35. Using an exchange rate of £1:$1.6 and multiplying the resultant by 60, a cost of £1313 per hour was determined.

(b) Absolute cost will depend on the number of interlining passengers, regional airline cost to re-route passengers and inconvenience to other airline.

(c) Increased delays will result in increased exposure to noise pollution over holding areas, and general increase in air pollution. Exact cost implications of these factors is very difficult to quantify and beyond the scope of this author.

(d) If runway congestion leads to a reduced movement rate and excessive delays, airlines may move their flight to alternative airports. If so, the airport will lose their aeronautical and commercial revenue generating opportunity. Some of the cost implication of this is also covered in the loss of airport reputation in the induced section.

(e) As an airport reaches saturation the ATC controller workload will increase exponentially and their efficiency will decrease beyond the optimum level. Costs are very difficult to assess here, as stress related costs vary from person to person. If an additional time factor could be added to the current one to account for the increased workload, a cost could be made in terms of additional hours worked. In addition to the workload problem, costs also need examining as to the effect of congestion on other parts of the airspace; TMA, other airports and en-route.

(f) Costs relate to the loss passengers to the regional airline, loss of feed traffic to the major airline, lower aircraft utilisation costs for the regional airline, legislation costs to impose the ban and loss of airport and airline reputation.

(g) These percentage figures are taken from the proof of evidence given by York Consulting Ltd., to the Manchester second runway enquiry, (May 1994). They relate to the multiplier effect already discussed. Local multiplier in this case reflects the impact of the regional airline to the local community it serves, away from the major airport. The effect on the national multiplier relates changes in the effect of the regionals interline ability to the majors, passenger throughput at the airport and the overall system efficiency.

Benefits

(a) Savings in planning and lobbying costs are related to a saving in a persons time which, being a professional, are rated at £67 per hour. Savings in aircraft testing costs are related to a saving in flight time, rated at £1313 per hour.

(b) Saving relates to the size of the investment budget and the level of investment that would be needed to introduce new procedures.

(c) As landing slots become more scarce, the airport will achieve a monopoly situation and be able to increase slot price accordingly, assuming demand remains greater than supply. The drop off in demand will depend on suitable alternative airports, level of congestion and the strength of desire of the airlines to continue using the airport.

(d) If passengers are increasingly delayed at the airport they may spend more money in the commercial retail outlets.

(e) As congestion begins to bite at the airport, ATC, airlines and the airport will be encouraged to develop and improve existing technology to provide extra capacity from the existing infrastructure.

(f) Similar to 'e' but related purely to the benefit of a system operating closer to its optimum. Obviously, this assumes the system is not already at its optimum working position. If this were the case, increased workload would place the system in a sub-optimal position and related in increased operating costs.

Case 2: Maximise Use of Existing Airfield Layout

Costs	Value	Benefits	Value
DIRECT		**DIRECT**	
Add new Taxiways - RET's, RAT's and DSP's	£70/sq. m (a)	Reduced delays for Business Pax.	£67 per hour
Planning and Lobbying time	£67/hr per person	Reduced delay for Leisure Pax.	£10 per hour
Testing new taxiways	£1313/hr per a/c, £67/hr per person	Reduced airline operating costs.	£1313 per hour
Increased ATC workload	Variable	Possible extra slot generation	Variable (a)
Extra Tower Controller	£22/hr (c)	**INDIRECT**	
Addition of Ground Surface Movement Radar	£ (optional)	Increased aeronautical revenue from landing fees	Variable
Increased ATC airspace and workload problems	Variable	Increased Pax commercial revenue	Variable
INDUCED		Reduce disturbance to local residents	Unquantifiable
Increased Noise Pollution	Unquantifiable	Reduced air pollution	Unquantifiable
		INDUCED	
		Improved level of technology as aircraft and airport work to achieve more from the existing system.	Variable but significant
		Improved efficiency of existing system	Unquantifiable
		Positive Multiplier in local economy	41% direct 7% indirect
		Positive Multiplier on National Economy	41% direct 7% indirect
		Improved Airport Reputation	Unpredictable
		Improved Airline Reputation	Unpredictable

Costs:

(a) Figure passed to the author following discussion with Birmingham airport planning department.

(b) Based on an ATC controller costing £20,000 per annum and £20,000 to train. Working a 37.5 hr week for 47 weeks a year, (= 1762.5 hrs/yr).

Benefits:

(a) Slot costs will vary widely depending on desirability of the airport by airlines. UK CAA CAP 534 (1988) placed the value of additional slots at Heathrow and Gatwick at £180 million and £70 million respectively for a year. Placing an accurate figure on this will prove difficult however due to frequency of use and opportunity cost if another user places a higher value than the one paid for the slot by the user

Case 3 : Early Turn after Take Off.

Costs	Value	Benefits	Value
DIRECT		**DIRECT**	
Planning and testing of concept by airline and airport	£1313/hr per a/c, £67 per person	Reduced delays for airlines	£1313 per hour
Obtaining planning permission to operate new route	£67 per person/hr	Reduced delays for business Pax.	£67 per hour
Increased controller workload to redirect regional aircraft on early turn to join existing airways	£67/hr on top of existing cost (a)	Reduced delays for leisure Pax.	£10 per hour
Airline costs to train flight crews in new procedure and equip a/c	£67 per person/hr £709.5 Sim cost. (b)	Increased slots at peak times at airport	Depends on level of congestion (a)
Costs to retrain ATCO's to provide service for procedure	Uncertain (c)	Increased aeronautical revenue by additional landings	Variable (b)
Safety implications	Unquantifable in this thesis	Increased commercial revenue from passengers	Variable (c)
INDIRECT		**INDIRECT**	
Air pollution over new areas	Unquantifable	Reduced air pollution as delays reduce **(May cancel out with cost)**	Unquantifable
Effect of procedure on existing traffic	£1313/hr per a/c (d)	**INDUCED**	
Increased Insurance costs	Marginal (e)	Positive multiplier to national economy	41% direct 7% indirect
Larger noise footprints over previously unaffected areas	Unquantifable	Positive multiplier to local economy as more revenue is generated by the airport	41% Direct 7% indirect
		Improvement in image of airport by users	Unquantifable
		Improvement in image of airline by users	Unquantifable

Notes:

Costs

(a) Absolute amount will vary depending on existing traffic levels. Cost must account for increased ATC co-ordination required between tower and area controllers.

(b) Simulator cost provided by Crossair based on an hourly charge of Sfr 745. Using an exchange ratio of Sfr 2.1: £1 over two hours - which is the minimum training time required by Crossair before carrying out early turns, the figure is derived.

(c) Could be given by the number of extra hours training required at a set rate per hour, and associated simulation costs, if necessary.

(d) The figure given is for regional aircraft. If jet aircraft were affected, using a cost of $150 per minute, from SAS a figure of £5625 is derived in the same format as with the regional aircraft.

(e) Aircraft hull insurance may be increased if it is shown that the use of this procedure significantly shortens the life span of the aircraft or represents an increased safety risk.

Benefits

(a) As with Case 2, the exact value gained here will be dependent on the value calculated for slots at each airport, a function of demand and alternative resources.

(b) As with 'a' the benefit will depend on how far the airport can increase charges and the number of feasible alternatives.

(c) This value is tentative, dependent on the assumption that the early turn will increase passenger throughput at the airport and, using the law of averages, more money will be spent in the commercial outlets at the airport.

Case 4 : Discrete Arrival Routings

Costs	Value	Benefits	Value
DIRECT		**DIRECT**	
Planning and testing of concept by airline and airport	£67/hr per person	Reduced delays for airlines	£1313/hr per a/c
Obtaining planning permission to operate new route	£67 per person per hour	Reduced delays for business Pax.	£67/hr
Airline costs to retrain flight crews.	£67 per person/hr	Reduced delays for leisure Pax.	£10/hr
Costs to retrain ATC	£67 per person/hr	Increased aeronautical revenue for the airport	Variable
Increased Controller workload to sequence arrival traffic flows	£67/hr above existing cost	**INDIRECT**	
Upgrade ATC Radar	Variable **(a)**	Increased slots at peak times at airport	Variable
INDIRECT		Increased commercial revenue for airport.	Variable
Increases in insurance or aircraft depreciation with new procedure	Marginal	Reduced air pollution as delays reduce. **(May be cancelled by cost poll.)**	Unquantifable
Increased noise pollution over wider area	Unquantifable	Improved interline ability for regional airlines	Variable
Air pollution over new areas	Unquantifable	**INDUCED**	
INDUCED		Positive multiplier to local economy as more revenue is generated by the airport	41% Direct 7% Indirect
Possible effect to existing traffic	Variable **(b)**	Positive multiplier to national economy	41% Direct 7% Indirect
OPTIONS (c)		Improvement in image of airport by users	Unquantifable
Addition of MLS to airport Addition of DGPS to airport Fitting of MMR to aircraft Fitting of RNAV to aircraft Fitting of FMS to aircraft	£? $150,000/ a/c $130,000/ a/c $150-90,000 £ Variable	Improved airline interlines for hub airports	Unquantifable

Notes:

Costs

(a) The upgrade costs of the ATC radar may be required to provide more accurate approach position and guidance to the controller. Frankfurt airport use the COMPAS system for example. Absolute cost will be determined by scale of improvement required and system used.

(b) If use of this procedure delays other traffic from arriving or departing from the airport, then this must be taken into account as a cost. It may be caused by increased arrival separation, sequencing delays, or reduction in departure slots during peak arrival periods.

(c) Figures are taken from Crossair for the DGPS and RNAV installation costs and Air UK for the MMR.

Case 5 : Steep Approach

Costs	Value	Benefits	Value
DIRECT		**DIRECT**	
Addition of 6° PAPI system	Variable (a)	Reduced noise on approach by higher aircraft	Unquantifable
Addition of steep approach modification to aircraft	£3,800 per a/c	Reduced delays for airlines	£1313 per hour
Train ATC in procedure	£67 person/hr	Reduced delays for business Pax.	£67/hr
Planning and testing of concept by airline and airport	£1313 a/c/hr £67 person/hr	Reduced delays for leisure Pax.	£10/hr
Retraining flight crews (b)	£1419 sim cost £67 person/hr	Increased aeronautical revenue for the airport	Variable
Modify runway markings and lighting	Variable (c)	Increased slots at peak times at airport	Variable
INDIRECT		**INDIRECT**	
Increased ATC controller workload	£67 person/hr	Reduced air pollution as delays reduce	£0 per min
Increased a/c maintenance costs	Variable (d)	Increased airport commercial revenue as pax. mov. increases.	Variable
Increases in insurance or aircraft depreciation with new procedure	Variable	Improved airline interline ability	Variable (a)
INDUCED		**INDUCED**	
Effect on existing traffic	Variable (e)	Positive multiplier to local economy as more revenue is generated by the airport	41% Direct 7% Indirect
OPTIONS		Positive multiplier to national economy	41% Direct 7% Indirect
Other Costs for Precision Improved resolution radar Addition of MLS to airport Addition of DGPS to airport Fitting of MMR to aircraft Fitting of RNAV to aircraft Fitting of FMS to aircraft	 £ Variable £ ? $150,000 / a/c $130,000/ a/c $150-90,000 £ Variable	Improvement in image of airport by users	Variable
		Improved airline reputation	Variable

Notes:

Costs

(a) The type of PAPI system chosen will dictate the cost, assuming the system is not already installed as a 3° glidepath approach aid. If so alteration to 6° will be minimal.

(b) Figures are derived from Crossair as in Case 3. In this case however Crossair require 1 hour briefing, 4 hours simulator training and a written test for pilots to carry out steep approaches at Bern, Sion and Lugano.

(c) Absolute cost will depend on scale of changes required which will relate to level of current facilities. London City for instance provide specific lighting throughout the recommended touchdown point.

(d) Use of the steep approach will increase the stresses on the undercarriage which will usually require strengthening. Problems of tyre bursts may also rise due to the tighter round out from the steeper approach angle and resultant limited buffer for pilots to correctly flare before touchdown. This will relate to heavier landings.

(e) The use of the steep approach may negatively affect existing traffic movements by reducing the time between successive arrivals. The cost will be in terms of increased delays for departures. Costs may also arrive due to the increased likelihood of go-arounds from steep approaches due to the higher decision heights enforced by steep approach regulations.

Benefits

(a) Exact benefits will be determined by the number of extra interlines achieved by use of the procedure which will be vary hard to accurately define.

Case 6 : STOL Commuter Runway

Costs	Value	Benefits	Value
DIRECT		**DIRECT**	
Design and planning for new STOL runway	£67 person/hr	Reduced delays for airlines	£1313 per hour
Planning and testing of concept by airline and airport	£1313 a/c/hr £67 person/hr	Reduced delays for business Pax.	£67/hr
Obtaining planning permission to operate new route	£67 person/hr	Reduced delays for leisure Pax.	£10/hr
Retraining flight crews	£1419 sim cost £67 person/hr	Increased aeronautical revenue for airport	Variable
Building new STOL runway, and taxiways	£70 m. sq. (a)	Increased slots at peak times at airport	Variable
Costs to retrain ATCO's to provide service for procedure	£67 person/hr	**INDIRECT**	
Increases in insurance or aircraft depreciation with new procedure	Variable	Increased airport commercial revenue as pax. mov. increase	Variable
INDIRECT		Reduced air pollution as delays reduce	Unquantifable
Increased maintenance costs	Variable (b)	**INDUCED**	
Increased ATC workload operating more runways	£67 person/hr	Positive multiplier to local economy as more revenue is generated by the airport	41% Direct 7% Indirect
Increased noise from STOL runway use	Unquantifable	Positive multiplier to national economy	41% Direct 7% Indirect
INDUCED		Improvement in image of airport by users	Unquantifable
Effect on existing traffic	Variable (c)	Improved airline interlines for hub airports	Unquantifable
OPTIONS			
Other Costs for Precision Improved resolution radar Addition of MLS to airport Addition of DGPS to airport Fitting of MMR to aircraft Fitting of RNAV to aircraft Fitting of FMS to aircraft	 Variable £ ? \$150,000/ a/c \$130,000/ a/c \$150-90,000 £ Variable		

Notes:

Costs

(a) As in case two this figure was derived following discussions with Birmingham airport planning department.

(b) Due to the greater use of maximum power for take offs and full braking methods for landing engine and brake components may require more regular replacement using this procedure.

(c) If the STOL runway intersects with the main runway, interference with departing and arriving traffic may occur. Costs will be related to increases in operating delays. Delays may also occur if arrival paths intersect with each other.

Case 7 : Reliever Airport

Costs	Value	Benefits	Value
DIRECT		**DIRECT**	
Planning and design costs	£67 person/hr	Reduced delays for airlines at main airport	£1313 per hour
Possible Land acquisition and Public Enquiry	£67 person/hr +Land Costs	Reduced delays for business Pax. at main airport	£67/hr
Planning and testing of concept by airline and airport	£67 person/hr £1313 a/c /hr	Reduced delays for leisure Pax. at main airport	£10/hr
Obtaining planning permission to operate new route	£67 person/hr	Increased slots at peak times at main airport	Variable (a)
Building new STOL runway, taxiways and aprons	£70 sq. m	**INDIRECT**	
Providing lighting and markings for runway CAT 1/2/3 Ops.	Variable (a)	Reduced air pollution as delays reduce	Unquantifable
Develop efficient transport links with main airport	Variable (b)	**INDUCED**	
Costs to retrain ATCO's to provide service for procedure	Variable	Positive multiplier to local economy as more revenue is generated by the airport	41% Direct 7% Indirect
INDIRECT		Positive multiplier to national economy	41% Direct 7% Indirect
Less efficient interlines for Pax and airlines	Variable (c)	Improved reputation of main airport and airlines using it.	Variable
Increased ATCO workload to operate two airports	£67 person/hr		
INDUCED			
Effect of new runway on existing airport	Variable (d)		
Increased noise along flight path of new airport	Unquantifable		
OPTIONS	(e)		
Other Costs for Precision Improved resolution radar Addition of MLS to airport Addition of DGPS to airport Fitting of MMR to aircraft Fitting of RNAV to aircraft Fitting of FMS to aircraft	 Variable £ ? $150,000/ a/c $130,000/ a/c $150-90,000 £ Variable		

Notes:

Costs

(a) Costs will be dependent on runway length and level of precision approach lighting required.

(b) Costs will vary depending on type of transport link chosen and distance between each airport. Costs will increase if the link requires special construction methods such as tunneling or bridging.

(c) The costs relate to slower more inconvenient transfer connections between regional and major carrier, larger possibility of missing connections and possible loss of use of interline by passengers.

(d) To be of any effect the reliever airport must be relatively close to the main airport. In a congested TMA airspace the provision of extra arrival and departure routes for the airport will invariably conflict with existing ones, and more than likely those related to the airport it is supposed to relieve. The exact effect will depend on the amount of free airspace and use of other special procedures such as steep approaches.

(e) The costs related to the options listed, although having a specific value, may vary in cost in this study due to subsidies from either national governments, systems developers or airport authorities.

Benefits

(a) The actual value of slots at the main airport may fall due to reduced congestion problems. The actual effect will be offset by perceived importance of the slots by the airlines and expected time duration of reduced congestion period.

Appendix 6.9

1. Regional Airline Questionnaire
2. European Airport Questionnaire
3. Major Airline Questionnaire

College of Aeronautics
Department of Air Transport

Cranfield UNIVERSITY

Cranfield
Bedford MK43 0AL
United Kingdom
Tel +44 (0) 234 750111
Fax +44 (0) 234 752207
Telex 825072 CITECH G

Tel: 44(0)234 750111 ext 2232

Dear Sir/Madam,

24th November 1994

I am currently carrying out a PhD study at Cranfield University to assess the feasibility of specially designed turboprop routes into and out of congested airports. My work, so far, has focused on developing a background understanding of this topic, followed up with current industry exposure through the European Regional Airlines Association, (ERA). A practical study of the concept, applied to Manchester Airport, UK, has also been undertaken.

The principal aim of the questionnaire, is to help develop criteria for assessing the viability of implementing these special routes within Europe, by obtaining opinions regarding them from all sides of the aviation industry.

I would be most grateful if you could take approximately 20 minutes of your time to answer the enclosed questionnaire. I should like to use data from this questionnaire in my final report. If, however, you wish your information to remain confidential, the results will only be presented in aggregate form. If this is the case, could you please indicate this at the beginning of the questionnaire. The questionnaire is hopefully self explanatory, however, if there are any queries concerning it, or anything else, please do not hesitate to contact me at Cranfield.

I intend to produce a summary report from the findings of the questionnaire, so if you are interested, please let me know at the end of the questionnaire.

I take this opportunity to thank you, in anticipation, for your help.

Yours faithfully,

Mr. A. Jefferson.
PhD Researcher.

Professor Rigas Doganis
Head of Department
Direct dial +44 (0) 234 754742

College of Aeronautics
Department of Air Transport

Cranfield
UNIVERSITY

USE OF TURBOPROP SPECIAL

PROCEDURES AT CONGESTED AIRPORTS.

QUESTIONNAIRE

(Part 1)

Instructions:

1. The questionnaire is split into two parts, please complete part 1 before moving onto part 2.

2. Part 1 is split into five main sections, you may not need to answer sections B, C, or D, however, sections A and E need answering by all participants. This part of the questionnaire should take you no longer than 15 minutes, and Part 2, no longer than 5 minutes.

3. During the questionnaire reference will be made to the phrase **'special procedure'**. This phrase is a form of shorthand, and covers any procedure used by a turboprop, or Avro/BAe 146 regional jet to gain access to a congested airport by using, for example, early turns after take off, or steep approaches for landing, etc.

Do you wish this data to be restricted? Please delete as appropriate.	Yes/No

Questionnaire.

Name:______________________________

Airline:______________________________

Position in Organisation:

____

Section A: This section intends to collate information on your current airline's operation irrespective of whether or not your airline is involved in special procedures.

1. Please state your airline's aircraft fleet types and numbers:-

Aircraft Type	Quantity

2. At which, if any, of the airports in your route network do you suffer significant delays?
Could you please tick the relevant box to indicate whether this delay is greatest inbound or outbound.

Airport.	**Inbound delay.**	**Outbound delay.**	**Delayed on both.**

3. Which airports mentioned above, do you feel would benefit from introducing special procedures, and why?

Airport	**Reason for introducing special procedures.**

End of Section.

Section B: This section is intended to obtain information concerning current activities you may be involved in, regarding the use of special procedures with your fleet.

1. Does your airline take advantage of regional aircraft performance to develop special procedures at congested airports?

Yes/No - If yes go to **Question 2**
- If no go to **Section C**

2. Which of the following special procedures do you currently use? Please ring as appropriate.

(a)	Intersection take off	Yes/No
(b)	Early turn after take off	Yes/No
(c)	Steep approach for landing	Yes/No
(d)	Use of a STOL or separate runway	Yes/No
(e)	Separate airspace approach and/or departure route	Yes/No
(f)	A combination of these If yes, please indicate which ones by letter code ____________________ ____________________	Yes/No
(g)	Others. Please specify. ____________________ ____________________ ____________________	

3. Are these procedures,

(a)	On trial	Yes/No
(b)	Certificated	Yes/No

If they are on trial when do you expect them to be certificated?

____

____

4. Is there a clearly defined route in the aeronautical charts for these procedures, and can a copy be enclosed with the questionnaire?

Yes/No - If yes go to **Question 6**
- If no go to **Question 5**

5. Could you briefly explain each of the procedures, stating the route and what means of navigation are used?

____
____
____
____
____
____

6. Are any of your aircraft restricted from using these routes? Yes/No
If yes, Why?______________________________
____
____

7. What were the reasons for introducing these procedures?

____
____
____

8. Can you indicate what these procedures means for your airline in terms of,

(a) Cost Saving, i.e. Fuelburn

____
____

(b) Time Saved from previous operation

____
____

9. Has there been any opposition to these procedures? Yes/No
If yes from where? ________________________
____
____

10. Do you get any incentives to use these routes? Yes/No
If yes, please specify.

____
____
____

11. Do you feel these procedures could be further developed? Yes/No
If yes, please explain how?

____
____
____

End of Section.

Section C: This section analyses any previous experience you may of had with the use of special procedures.

1. Has your airline attempted any of the procedures indicated in question 2, section B in the past?

   Yes/No -If yes, go to **Question 2**
   -If no, go to <u>**Section D**</u>

2. Are there any navigation/route charts available with the past special procedures defined, and can these be enclosed with the completed questionnaire?

   Yes/No - If yes go to **Question 4**
   - If no go to **Question 3**

3. Could you briefly explain what the procedures entailed, stating the route, what means of navigation were used, airports affected, and any operating restrictions?

   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____

4. How did the procedures benefit your airline in terms of cost or time savings?

   ____
   ____
   ____
   ____
   ____

5. Why did the procedures stop?

   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____

End of Section.

Section D: This section enquires whether or not you will be pursuing the use of special procedures in the future.

1. Do you intend to carry out any of these procedures, as indicated in question 2, section B, in the future?

   Yes/No - If yes, go to **Question 2**
   - If no, go to **Section E**

2. Which ones are you considering and why? (Reduce delay, or provide access)

   ____
   ____
   ____

3. Could you indicate when you intend to start operating the routes?

   ____

4. Could you briefly explain the predicted procedures, stating the route, what means of navigation will be used, airports likely to be affected, and possible operating restrictions?

   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____

5. How do you feel these procedures will benefit your airline in terms of cost and time savings?

   ____
   ____
   ____
   ____
   ____

End of Section.

Section E: This part is intended to obtain your opinions in general, on the whole concept of special procedures, and, in addition, any further comments you may have.

1. Are there particular reasons why your airline would not use any of the procedures mentioned in question 2?

   Yes/No

   If yes, please indicate why? ______________________________

   ____

   ____

   ____

2. Do you feel these procedures will alleviate the access/congestion problem for regional airlines or not,

   (a) in the short term? Please explain.

   ____

   ____

   ____

   (b) in the longer term? Please explain.

   ____

   ____

   ____

3. Which of the following issues do you feel will present the greatest obstacle to the implementation of these special procedures at congested airports.
   Please ring appropriate number(s).

   1. Dominant Multinational Airline, trying to reduce competition.
   2. Airport Authority/Local Government, scared of upsetting local residents.
   3. Air traffic unwilling to change current system.
   4. Local pressure groups concerned about noise and safety.
   5. Lack of communication between affected parties, with consequent poor understanding of the problem.
   6. Other. Please Specify.

   ____

   ____

4. If you feel there are areas that have been omitted or need further consideration, please let me know.

____

____

____

____

____

End of Questionnaire Part 1. Please go to Part 2.

College of Aeronautics
Department of Air Transport

Cranfield UNIVERSITY

USE OF TURBOPROP SPECIAL PROCEDURES AT CONGESTED AIRPORTS.

QUESTIONNAIRE

(Part 2)

Instructions.

The purpose of this questionnaire is to obtain opinions regarding statements made concerning the use of turboprop special procedures at congested airports. The statements cover views from a variety of stand points within the industry. It is appreciated that you may not be an expert in all the fields, however, I would very much appreciate if you could answer all the statements. Please answer each question by placing a ring around the appropriate number, indicating how far you agree, or disagree with each statement.

Questionnaire

	Statement	Strongly Disagree	Disagree	Agree	Strongly Agree
1.	Managing special procedure routes will create too much work for the air traffic controller.	1	2	3	4
2.	Aircraft size is growing and this problem will go away.	1	2	3	4
3.	Special allowances for turboprops will create further noise pollution problems around airports.	1	2	3	4
4.	Regional aircraft need access to congested hubs to feed the major carriers.	1	2	3	4
5.	Landing charges are unfair to regional carriers.	1	2	3	4
6.	Too little use is made of regional aircraft performance.	1	2	3	4
7.	Aircraft occupying runway space should be charged the same rate irrespective of their size.	1	2	3	4
8.	Microwave landing systems or GPS will greatly enhance the regional aircraft's ability to access congested airspace.	1	2	3	4
9.	Common practice in the aviation world, such as large carriers dominating airports and squeezing regional airlines out, will mean special procedures will have little effect at the end of the day.	1	2	3	4
10.	Environmental issues make special procedures too costly to consider.	1	2	3	4
11.	Regional aircraft should use reliever airports.	1	2	3	4
12.	The infrastructure costs required to develop these special procedures are too high, giving the ideas no chance of success.	1	2	3	4
13.	Regulation authorities are too short sighted to recognise the benefits of special procedures.	1	2	3	4
14.	The safety issues, related to the special procedures, present too high a risk, making the concepts unworkable.	1	2	3	4
15.	The use of area navigation, (RNAV), routes would improve a regional airlines chance to access congested airports.	1	2	3	4
16.	Too little is known of individual regional aircraft performance capabilities by the aviation community with the result that their potential is not realised.	1	2	3	4
17.	Access to congested airports, for regional airlines; is crucial no matter what the cost.	1	2	3	4
18.	Congested terminal airspace around busy airports allows no room to accommodate the new special routes.	1	2	3	4
19.	The routes will only work if they are totally self-sufficient, requiring minimal air traffic control intervention.	1	2	3	4
20.	These special procedures will only be applicable to airports with more than one runway.	1	2	3	4
21.	High levels of navigational accuracy will be required for these special routings to be considered.	1	2	3	4

	Strongly Disagree	Disagree	Agree	Strongly Agree
22. The problem is not airspace or runway congestion but taxiway, apron, and/or terminal congestion.	1	2	3	4
23. Separate STOL ports are better than trying to fit aircraft into emergency or cross runways at existing airports.	1	2	3	4
24. Special Procedures, such as steep 6° approaches, which involve operating at the edge of an aircraft's performance envelope, present safety implications.	1	2	3	4
25. Making special allowances for regional aircraft will detrimentally affect current commercial operations in terms of safety separation standards and possible longer delays on the ground for other aircraft.	1	2	3	4
26. The procedure would only be worthwhile if extra movements into the congested airport are created and air traffic delays reduced.	1	2	3	4
27. These procedures represent a long term solution to the problems of regional aircraft access to congested airports.	1	2	3	4
28. Regional aircraft should make better use of the off-peak slots and lighter night restrictions, than trying to increase capacity in an already saturated time zone.	1	2	3	4
29. If regional aircraft can be put on separate approaches to STOL/emergency runways at congested airports, while the larger jet aircraft remain on the standard arrival routes for the main runways, there will be a double increase in capacity.	1	2	3	4
30. These special procedures will only work with the co-operation of all airlines, airports, air traffic controllers, and aircraft manufacturers, involved.	1	2	3	4
31. A full cost benefit analysis, taking into account both the direct and indirect effects of the routes would be required, if these routes were to be considered at all.	1	2	3	4
32. Overall the idea is a good one but just not feasible due to the high costs associated with training air crew and air traffic controllers, in addition to infrastructure modifications, etc.	1	2	3	4
33. Air traffic controllers are not given the flexibility to cope with special performance procedures for turboprops.	1	2	3	4
34. United States special turboprop procedures will not be feasible in Europe due to differing operating rules.	1	2	3	4
35. Although some European airports are already doing something towards developing special procedures for regional aircraft, much more could still be done.	1	2	3	4
36. Route operating costs for special procedures will be too high to justify their use.	1	2	3	4
37. Aviation regulators are aware of the problem of commuter access to congested airports but have to take every users interests into account.	1	2	3	4
38. Commuter traffic should not be forced to move to reliever/regional airports, but increase their movements at international hubs to feed the majors'.	1	2	3	4

That completes the questionnaire. Thank you very much for taking the time to fill it in.

Tel: +44 (0) 1234 750111 ext 2232
25 August 1995

Dear

I am currently carrying out research at Cranfield University to assess the feasibility of maintaining regional airline access to congested European hub airports. My work, so far, has focused on developing a background understanding of this topic, followed up with current industry exposure through the European Regional Airlines Association, (ERA), and a practical study of the problems at Gatwick, Zurich, and Manchester airports.

A preliminary result of the research is the catch 22 situation where regional traffic feed to the major airlines is becoming more critical to the formers' survival, whilst their access to the major European airports, to feed the major airline, is becoming more difficult, as congestion increases. The following two page questionnaire aims to see how you, as a major European airport, are coping and plan to deal with regional traffic, and capacity limitations at your airport both now, and in the future.

I would be most grateful, therefore, if you could take a few minutes of your time to answer the attached questions yourself, or pass it on to someone who can. I should like to use data from this questionnaire in my final report. If, however, you wish your information to remain confidential, the results will only be presented in aggregate form. If this is the case, could you please indicate this at the beginning of the questionnaire. The questionnaire is hopefully self explanatory, however, if there are any queries concerning it, or anything else, please do not hesitate to contact me at Cranfield.

With reference to the questionnaire the term, 'regional aircraft', is used regularly. This refers to all aircraft types up to and including the Avro RJ/BAe 146.

I intend to produce a summary report from the findings of the questionnaire, so if you are interested, please let me know at the end of the questionnaire.

I take this opportunity to thank you, in anticipation, for your help.

Yours faithfully,

Mr. A. Jefferson.
PhD Researcher.

Do you wish this information to remain confidential?	Yes/No

Name: **Position:**

Company:

Questionnaire

Please complete the following questions by ringing the appropriate answer or adding any comments where relevant.

1. What percentage of movements at your airport involve regional traffic? [ ] %

2. Would you say this traffic is mainly point to point, or feed traffic?

All Point to Point				**All Feed**
1	2	3	4	5

3. Are the following airport charges weight related?

   1. Landing — Yes/No
   2. Passenger — Yes/No
   3. Parking — Yes/No

4. How would you rate your airport in terms of congestion in peak periods?

Not Congested				**Very Congested**
1	2	3	4	5

5. What plans does the airport have to expand it's capacity in the future?

....

....

....

6. What changes in regional traffic do you expect at your airport in the next 10 years?

[ ] **Reduction** [ ] **No Change** [ ] **Growth**

7. Do you allow any early turns or special arrival procedures for regional aircraft at your airport?

Yes/No If yes, go to question 8. If no, go to question 12.

8. Please specify the types of procedures used.

   1. Early turn after take off
   2. Discrete arrival routing
   3. Steep Approach
   4. Other. Please Specify ....

9. In your opinion, do these special regional aircraft procedures actively enhance your capacity?

Yes/No

Go to Next Page

10. What is the biggest issue concerning the use of these procedures?

1. Environmental Restrictions
2. Physical Limitations - ATC/Runways etc.
3. Political Limitations
4. Other. Please Specify ....

11. Do you think your answer to question 8 will change in the future? **Yes/No**
If yes, how?...
....

Go to Question 14

12. Why do you not use special procedures for regional aircraft?

1. No demand from operators
2. Environmental Restrictions
3. Physical Limitations - ATC/Runways etc.
4. Political Limitations
5. Other. Please Specify ....

13. Do you see a need to develop new regional procedures in the future? **Yes/No**
If yes, what? ....
....

14. In general, do you see these procedures as a short or long term solution to the access situation?
....
....

15. Any other comments? ....
....
....

Many thanks for taking the time to complete this questionnaire

Please return to Andy Jefferson:

By Fax on: **+44 (0) 1234 752207**

By Post to:
Andy Jefferson
Department of Air Transport
Building 115
Cranfield University
Cranfield
BEDS MK43 0AL
ENGLAND

Tel: +44 (0)1234 750111 ext 2232

16th August 1995

Dear

I am currently carrying out a PhD study at Cranfield University to assess the feasibility of maintaining regional airline access to congested European hub airports. My work, so far, has focused on developing a background understanding of this topic, followed up with current industry exposure through the European Regional Airlines Association, (ERA), and a practical study of the problems at Gatwick, Zurich, and Manchester airports.

A preliminary result of the research is the importance of these regional services in providing traffic feed to the larger carriers, whether as part of a franchise agreement or not. The following one page questionnaire aims to see how you, as a major carrier, see this role of regional hub feed developing in the future.

I would be most grateful, therefore, if you could take approximately 5 minutes of your time to answer the attached questions yourself, or pass it on to someone who can. I should like to use data from this questionnaire in my final report. If, however, you wish your information to remain confidential, the results will only be presented in aggregate form. If this is the case, could you please indicate this at the beginning of the questionnaire. The questionnaire is hopefully self explanatory, however, if there are any queries concerning it, or anything else, please do not hesitate to contact me at Cranfield.

I intend to produce a summary report from the findings of the questionnaire, so if you are interested, please let me know at the end of the questionnaire.

I take this opportunity to thank you, in anticipation, for your help.

Yours faithfully,

Mr. A. Jefferson.
PhD Researcher.

Do you wish this information to remain confidential?	Yes/No

Name: **Position:**

Company:

Questionnaire

Please complete the following questions by ringing the appropriate answer or adding any comments where relevant.

1. Does your airline have agreements/franchises with regional airlines to provide feed traffic for your longer haul services? Please ring.

   Yes/No If yes, go to question 2. If no, go to question 4.

2. How important do you feel this feed traffic is? Please ring.

Not Important				Very Important
1	2	3	4	5

3. Is this feed traffic currently affected or restricted by airport operating rules?

   Yes/No

   If yes, at which airports?..

4. What do you think will happen to this feed traffic in the next 5 years? Please rate each scenario on a scale from 1-5, from very unlikely to very likely.

Rating

[ ] a) Regional airlines will have to increase their aircraft size and stay at the main airport.
[ ] b) Regional airlines will move to a reliever/secondary airport and feed traffic will be brought in to the main airport by surface transport.
[ ] c) Better technology and increased flexibility of the Air Traffic Control system will enable regional traffic to remain at the main airport unaffected.
[ ] d) Other. Please specify. ....
....

5. Does your answer to question 4 change when the future time scale is increased to 20 years? If yes, how? ....
....

6. Do the answers you give in questions 4 and 5 represent what you would like to see happen to feed traffic?

   Yes/No

   If not, please specify what you would prefer to see. ....
....

7. Any other comments? ....
....
....
....

Many thanks for taking your time to complete this questionnaire.

Please return by fax or post to Andy Jefferson at the address shown overleaf.

Please return completed Questionnaire:

By Fax on: +44 (0) 1234 752207

By Post to:

Andy Jefferson
Department of Air Transport
Building 115
Cranfield University
Cranfield
BEDS MK43 0AL
ENGLAND

Appendix to Chapter 7

7.1: SIMMOD Manchester Hourly Movement Rate and Delay Results
7.2: Manchester Airport - Cost Benefit Analysis Case Study Results
7.3: SIMMOD Zurich Hourly Movement Rate and Delay Results
7.4: Zurich Airport - Cost Benefit Analysis Case Study Results
7.5: SIMMOD London Gatwick Hourly Movement Rate and Delay Results
7.6: London Gatwick - Cost Benefit Analysis Case Study Results
7.7: Regional Airline Questionnaire Results - Part 1
7.8: Regional Airline Questionnaire Results - Part 2
7.9: European Airport Questionnaire Responses
7.10: Major Airline Questionnaire Responses

Appendix 7.1

Manchester Hourly Movement Rate Arrivals and Departures - Table 1

Time	Planned			Base Case						Case Two						Case Three	
	Arr	Dep	Total	Arr	% of plan	Dep	% of plan	Total	% of plan	Arr	% of plan	Dep	% of plan	Total	% of plan	Arr	% of plan
0.00-1.00	2	3	5	2.00	100.00	3.00	100.00	5.00	100.00	2.00	100.00	3.00	100.00	5.00	100	2.00	100.00
1.00-2.00	4	1	5	4.00	100.00	1.00	100.00	5.00	100.00	4.00	100.00	1.00	100.00	5.00	100	4.00	100.00
2.00-3.00	1	1	2	1.00	100.00	2.00	200.00	3.00	150.00	1.00	100.00	2.00	200.00	3.00	150	1.00	100.00
3.00-4.00	0	1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00
4.00-5.00	4	0	4	4.00	100.00	0.00	0.00	4.00	100.00	4.00	100.00	0.00	0.00	4.00	100	4.00	100.00
5.00-6.00	8	0	8	8.00	100.00	0.50	0.00	8.50	106.25	8.00	100.00	0.50	0.00	8.50	106.25	8.00	100.00
6.00-7.00	7	11	18	7.00	100.00	8.17	74.27	15.17	84.28	7.00	100.00	8.50	77.27	15.50	86.11111	7.00	100.00
7.00-8.00	10	32	42	10.00	100.00	23.67	73.97	33.67	80.17	10.00	100.00	23.67	73.97	33.67	80.16667	10.00	100.00
8.00-9.00	26	21	47	20.83	80.12	20.33	96.81	41.16	87.57	21.00	80.77	20.17	96.05	41.17	87.59574	21.00	80.77
9.00-10.00	17	20	37	19.00	111.76	21.50	107.50	40.50	109.46	19.00	111.76	22.50	112.50	41.50	112.1622	19.00	111.76
10.00-11.00	12	23	35	15.17	126.42	23.00	100.00	38.17	109.06	15.00	125.00	23.17	100.74	38.17	109.0571	15.00	125.00
11.00-12.00	9	14	23	10.00	111.11	22.17	158.36	32.17	139.87	10.00	111.11	22.50	160.71	32.50	141.3043	10.00	111.11
12.00-13.00	12	11	23	11.00	91.67	12.33	112.09	23.33	101.43	11.00	91.67	10.83	98.45	21.83	94.91304	11.00	91.67
13.00-14.00	18	13	31	17.00	94.44	10.50	80.77	27.50	88.71	17.00	94.44	10.83	83.31	27.83	89.77419	17.00	94.44
14.00-15.00	12	19	31	14.00	116.67	14.83	78.05	28.83	93.00	14.00	116.67	14.33	75.42	28.33	91.3871	14.00	116.67
15.00-16.00	14	14	28	13.00	92.86	17.17	122.64	30.17	107.75	13.00	92.86	17.50	125.00	30.50	108.9286	13.00	92.86
16.00-17.00	11	12	23	10.00	90.91	12.50	104.17	22.50	97.83	10.00	90.91	12.17	101.42	22.17	96.3913	10.00	90.91
17.00-18.00	20	16	36	18.00	90.00	15.50	96.88	33.50	93.06	18.17	90.85	15.33	95.81	33.50	93.05556	18.40	92.00
18.00-19.00	17	20	37	21.00	123.53	12.00	60.00	33.00	89.19	20.83	122.53	13.50	67.50	34.33	92.78378	20.60	121.18
19.00-20.00	19	12	31	16.83	88.58	21.83	181.92	38.66	124.71	17.00	89.47	20.83	173.58	37.83	122.0323	17.00	89.47
20.00-21.00	19	8	27	20.17	106.16	8.00	100.00	28.17	104.33	20.00	105.26	7.67	95.88	27.67	102.4815	20.00	105.26
21.00-22.00	12	7	19	13.00	108.33	8.17	116.71	21.17	111.42	13.00	108.33	8.00	114.29	21.00	110.5263	13.00	108.33
22.00-23.00	11	7	18	11.00	100.00	7.83	111.86	18.83	104.61	11.00	100.00	8.00	114.29	19.00	105.5556	11.00	100.00
23.00-24.00	2	8	10	1.00	50.00	6.17	77.13	7.17	71.70	1.00	50.00	6.17	77.13	7.17	71.7	1.00	50.00
24.00-25.00	0	0	0	0.00	0.00	1.83	0.00	1.83	0.00	0.00	0.00	1.83	0.00	1.83	0	0.00	0.00
TOTALS	267	274	541	267.00	**91.30**	274.00	**90.12**	541.00	**94.18**	267.00	**91.27**	274.00	**89.73**	541.00	**94.09**	267.00	**91.26**
Peak Period Totals	65	96	161	65		88.5		153.5		65		89.51		154.51		65	

Source: Data for planned movements from airport schedule
Other data taken from the results of the SIMMOD simulation runs

Manchester Movements Summary Table

Case	Max Mov/Hr	Avg. % Mov	Avg. % Mov. Peak hr.	Diff Max Mov/hr
Base Case	41.16	94.18	96.57	0.00
Case Two	41.50	94.09	97.25	0.34
Case Three	42.20	93.84	99.29	1.04
Case Four	42.20	93.83	99.43	1.04
Case Five	42.20	93.82	99.57	1.04
Case Six	43.00	93.98	97.71	1.84
Case Seven	42.40	93.93	98.55	1.24
Case Seven 'B'	44.00	93.97	99.06	2.84
Case Eight	41.30	93.95	97.44	0.14
Case Nine	40.80	94.18	96.23	-0.36
Case Ten a	46.00	93.36	100.34	4.84
Case Ten b	46.00	93.35	100.32	4.84

Appendix 7.1

Manchester Hourly Movement Rate Arrivals and Departures - Table 1

Time	Case Three				Case Four						Case Five						Case Six			
	Dep	% of plan	Total	% of plan	Arr	% of plan	Dep	% of plan	Total	% of plan	Arr	% of plan	Dep	% of plan	Total	% of plan	Arr	% of plan	Dep	% of plan
0.00-1.00	3.00	100.00	5.00	100.00	2.00	100.00	3.00	100.00	5.00	100.00	2.00	100.00	3.00	100.00	5.00	100.00	2.00	100.00	3.00	100.00
1.00-2.00	1.00	100.00	5.00	100.00	4.00	100.00	1.00	100.00	5.00	100.00	4.00	100.00	1.00	100.00	5.00	100.00	4.00	100.00	1.00	100.00
2.00-3.00	2.00	200.00	3.00	150.00	1.00	100.00	2.00	200.00	3.00	150.00	1.00	100.00	2.00	200.00	3.00	150.00	1.00	100.00	2.00	200.00
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	4.00	100.00	4.00	100.00	0.00	0.00	4.00	100.00	4.00	100.00	0.00	0.00	4.00	100.00	4.00	100.00	0.00	0.00
5.00-6.00	0.40	0.00	8.40	105.00	8.00	100.00	0.40	0.00	8.40	105.00	8.00	100.00	0.40	0.00	8.40	105.00	8.00	100.00	0.40	0.00
6.00-7.00	7.80	70.91	14.80	82.22	7.00	100.00	7.80	70.91	14.80	82.22	7.00	100.00	7.80	70.91	14.80	82.22	7.00	100.00	7.80	70.91
7.00-8.00	25.80	80.63	35.80	85.24	10.00	100.00	25.80	80.63	35.80	85.24	10.00	100.00	25.80	80.63	35.80	85.24	11.00	110.00	24.80	77.50
8.00-9.00	21.20	100.95	42.20	89.79	21.00	80.77	21.20	100.95	42.20	89.79	21.00	80.77	21.20	100.95	42.20	89.79	21.00	80.77	21.00	100.00
9.00-10.00	22.80	114.00	41.80	112.97	19.00	111.76	22.80	114.00	41.80	112.97	19.00	111.76	22.80	114.00	41.80	112.97	21.00	123.53	22.00	110.00
10.00-11.00	23.20	100.87	38.20	109.14	15.00	125.00	23.40	101.74	38.40	109.71	15.00	125.00	23.60	102.61	38.60	110.29	12.00	100.00	23.00	100.00
11.00-12.00	19.80	141.43	29.80	129.57	10.00	111.11	19.60	140.00	29.60	128.70	10.00	111.11	19.40	138.57	29.40	127.83	9.00	100.00	21.60	154.29
12.00-13.00	10.80	98.18	21.80	94.78	11.00	91.67	10.80	98.18	21.80	94.78	11.00	91.67	10.80	98.18	21.80	94.78	15.00	125.00	11.00	100.00
13.00-14.00	11.00	84.62	28.00	90.32	17.00	94.44	11.00	84.62	28.00	90.32	17.00	94.44	11.00	84.62	28.00	90.32	14.20	78.89	10.80	83.08
14.00-15.00	14.00	73.68	28.00	90.32	14.00	116.67	13.80	72.63	27.80	89.68	14.00	116.67	13.80	72.63	27.80	89.68	15.80	131.67	14.20	74.74
15.00-16.00	17.80	127.14	30.80	110.00	13.00	92.86	18.00	128.57	31.00	110.71	13.00	92.86	18.00	128.57	31.00	110.71	11.00	78.57	19.00	135.71
16.00-17.00	12.20	101.67	22.20	96.52	10.00	90.91	12.20	101.67	22.20	96.52	10.00	90.91	12.20	101.67	22.20	96.52	11.00	100.00	11.60	96.67
17.00-18.00	16.00	100.00	34.40	95.56	18.40	92.00	16.00	100.00	34.40	95.56	18.40	92.00	16.00	100.00	34.40	95.56	18.60	93.00	15.40	96.25
18.00-19.00	12.60	63.00	33.20	89.73	20.60	121.18	12.60	63.00	33.20	89.73	20.60	121.18	12.60	63.00	33.20	89.73	21.40	125.88	12.40	62.00
19.00-20.00	20.80	173.33	37.80	121.94	17.00	89.47	20.80	173.33	37.80	121.94	17.00	89.47	20.80	173.33	37.80	121.94	15.80	83.16	21.20	176.67
20.00-21.00	7.80	97.50	27.80	102.96	20.00	105.26	7.80	97.50	27.80	102.96	20.00	105.26	7.80	97.50	27.80	102.96	19.20	101.05	8.20	102.50
21.00-22.00	8.20	117.14	21.20	111.58	13.00	108.33	8.20	117.14	21.20	111.58	13.00	108.33	8.20	117.14	21.20	111.58	13.00	108.33	7.60	108.57
22.00-23.00	7.80	111.43	18.80	104.44	11.00	100.00	7.80	111.43	18.80	104.44	11.00	100.00	7.80	111.43	18.80	104.44	11.00	100.00	8.00	114.29
23.00-24.00	6.40	80.00	7.40	74.00	1.00	50.00	6.40	80.00	7.40	74.00	1.00	50.00	6.40	80.00	7.40	74.00	1.00	50.00	6.20	77.50
24.00-25.00	1.60	0.00	1.60	0.00	0.00	0.00	1.60	0.00	1.60	0.00	0.00	0.00	1.60	0.00	1.60	0.00	0.00	0.00	1.80	0.00
TOTALS	274.00	**89.46**	***541.00***	**93.84**	267.00	**91.26**	274.00	**89.46**	541.00	**93.83**	267.00	**91.26**	274.00	**89.43**	541.00	**93.82**	267.00	**91.59**	274.00	**89.63**
Peak Period Totals	93		158		65		93.2		158.2		65		93.4		158.4		65		90.8	

Appendix 7.1

Manchester Hourly Movement Rate Arrivals and Departures - Table 1

Time			Case Seven 'a'			Case Seven'a'					Case Seven 'B'					Case Eight		Case Eight		
	Total	% of plan	Arr	% of plan	Dep	% of plan	Total	% of plan	Arr	% of plan	Dep	% of plan	Total	% of plan	Arr	% of plan	Dep	% of plan	Total	% of plan
0.00-1.00	5.00	100.00	2.00	100.00	3.00	100.00	5.00	100.00	2.00	100.00	3.00	100.00	5.00	100.00	2.00	100.00	3.00	100.00	5.00	100.00
1.00-2.00	5.00	100.00	4.00	100.00	1.00	100.00	5.00	100.00	4.00	100.00	1.00	100.00	5.00	100.00	4.00	100.00	1.00	100.00	5.00	100.00
2.00-3.00	3.00	150.00	1.00	100.00	2.00	200.00	3.00	150.00	1.00	100.00	2.00	200.00	3.00	150.00	1.00	100.00	2.00	200.00	3.00	150.00
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	4.00	100.00	4.00	100.00	0.00	0.00	4.00	100.00	4.00	100.00	0.00	0.00	4.00	100.00	4.00	100.00	0.00	0.00	4.00	100.00
5.00-6.00	8.40	105.00	8.00	100.00	0.40	0.00	8.40	105.00	8.00	100.00	0.40	0.00	8.40	105.00	8.00	100.00	0.50	0.00	8.50	106.25
6.00-7.00	14.80	82.22	7.00	100.00	7.80	70.91	14.80	82.22	7.00	100.00	7.80	70.91	14.80	82.22	7.00	100.00	8.00	72.73	15.00	83.33
7.00-8.00	35.80	85.24	11.00	110.00	24.80	77.50	35.80	85.24	11.00	110.00	23.60	73.75	34.60	82.38	15.00	150.00	21.50	67.19	36.50	86.90
8.00-9.00	42.00	89.36	21.00	80.77	21.20	100.95	42.20	89.79	20.00	76.92	21.40	101.90	41.40	88.09	22.00	84.62	18.83	89.67	40.83	86.87
9.00-10.00	43.00	116.22	21.00	123.53	21.40	107.00	42.40	114.59	21.00	123.53	23.00	115.00	44.00	118.92	17.00	100.00	24.33	121.65	41.33	111.70
10.00-11.00	35.00	100.00	12.00	100.00	24.60	106.96	36.60	104.57	13.00	108.33	24.40	106.09	37.40	106.86	11.00	91.67	25.50	110.87	36.50	104.29
11.00-12.00	30.60	133.04	9.00	100.00	20.40	145.71	29.40	127.83	9.00	100.00	20.40	145.71	29.40	127.83	9.83	109.22	22.17	158.36	32.00	139.13
12.00-13.00	26.00	113.04	15.00	125.00	11.00	100.00	26.00	113.04	15.00	125.00	10.20	92.73	25.20	109.57	14.17	118.08	11.17	101.55	25.34	110.17
13.00-14.00	25.00	80.65	14.80	82.22	11.60	89.23	26.40	85.16	14.20	78.89	12.20	93.85	26.40	85.16	17.00	94.44	10.50	80.77	27.50	88.71
14.00-15.00	30.00	96.77	15.20	126.67	13.40	70.53	28.60	92.26	15.80	131.67	12.80	67.37	28.60	92.26	13.00	108.33	14.00	73.68	27.00	87.10
15.00-16.00	30.00	107.14	11.00	78.57	18.80	134.29	29.80	106.43	11.00	78.57	19.60	140.00	30.60	109.29	11.00	78.57	19.00	135.71	30.00	107.14
16.00-17.00	22.60	98.26	12.00	109.09	11.60	96.67	23.60	102.61	12.00	109.09	11.60	96.67	23.60	102.61	12.00	109.09	11.67	97.25	23.67	102.91
17.00-18.00	34.00	94.44	18.20	91.00	15.40	96.25	33.60	93.33	18.00	90.00	15.60	97.50	33.60	93.33	20.00	100.00	13.83	86.44	33.83	93.97
18.00-19.00	33.80	91.35	20.80	122.35	14.20	71.00	35.00	94.59	21.00	123.53	12.40	62.00	33.40	90.27	19.00	111.76	17.83	89.15	36.83	99.54
19.00-20.00	37.00	119.35	16.00	84.21	20.00	166.67	36.00	116.13	16.00	84.21	21.20	176.67	37.20	120.00	18.00	94.74	18.17	151.42	36.17	116.68
20.00-21.00	27.40	101.48	19.00	100.00	7.60	95.00	26.60	98.52	19.00	100.00	7.60	95.00	26.60	98.52	17.00	89.47	7.67	95.88	24.67	91.37
21.00-22.00	20.60	108.42	13.00	108.33	7.80	111.43	20.80	109.47	13.00	108.33	7.80	111.43	20.80	109.47	13.00	108.33	7.33	104.71	20.33	107.00
22.00-23.00	19.00	105.56	11.00	100.00	8.00	114.29	19.00	105.56	11.00	100.00	8.00	114.29	19.00	105.56	11.00	100.00	8.00	114.29	19.00	105.56
23.00-24.00	7.20	72.00	1.00	50.00	6.20	77.50	7.20	72.00	1.00	50.00	6.20	77.50	7.20	72.00	1.00	50.00	6.00	75.00	7.00	70.00
24.00-25.00	1.80	0.00	0.00	0.00	1.80	0.00	1.80	0.00	0.00	0.00	1.80	0.00	1.80	0.00	0.00	0.00	2.00	0.00	2.00	0.00
TOTALS	541.00	**93.98**	267.00	**91.67**	274.00	**89.27**	541.00	**93.93**	0.00	**91.92**	0.00	**89.63**	541.00	**93.97**	267.00	**91.93**	274.00	**89.06**	541.00	**93.96**
Peak Period Totals	155.8		65		92		157		65		92.4		157.4		65		90.16		155.16	

Appendix 7.1

Manchester Hourly Movement Rate Arrivals and Departures Table 1

Time	Case Nine						Case Ten a						Case Ten b					
	Arr	% of plan	Dep	% of plan	Total	% of plan	Arr	% of plan	Dep	% of plan	Total	% of plan	Arr	% of plan	Dep	% of plan	Total	% of plan
0.00-1.00	2.00	100.00	3.00	100.00	5.00	100.00	2.00	100.00	3.00	100.00	5.00	100.00	2.00	100.00	3.00	100.00	5.00	100.00
1.00-2.00	4.00	100.00	1.00	100.00	5.00	100.00	4.00	100.00	1.00	100.00	5.00	100.00	4.00	100.00	1.00	100.00	5.00	100.00
2.00-3.00	1.00	100.00	2.00	200.00	3.00	150.00	1.00	100.00	2.00	200.00	3.00	150.00	1.00	100.00	2.00	200.00	3.00	150.00
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	4.00	100.00	0.00	0.00	4.00	100.00	4.00	100.00	0.00	0.00	4.00	100.00	4.00	100.00	0.00	0.00	4.00	100.00
5.00-6.00	8.00	100.00	0.40	0.00	8.40	105.00	8.00	100.00	0.40	0.00	8.40	105.00	8.00	100.00	0.40	0.00	8.40	105.00
6.00-7.00	7.00	100.00	8.00	72.73	15.00	83.33	7.00	100.00	8.20	74.55	15.20	84.44	7.00	100.00	8.20	74.55	15.20	84.44
7.00-8.00	14.00	140.00	21.20	66.25	35.20	83.81	15.00	150.00	25.80	80.63	40.80	97.14	16.00	160.00	24.80	77.50	40.80	97.14
8.00-9.00	23.00	88.46	17.00	80.95	40.00	85.11	22.00	84.62	24.00	114.29	46.00	97.87	21.00	80.77	25.00	119.05	46.00	97.87
9.00-10.00	17.00	100.00	23.80	119.00	40.80	110.27	17.00	100.00	23.40	117.00	40.40	109.19	17.00	100.00	23.80	119.00	40.80	110.27
10.00-11.00	11.00	91.67	26.00	113.04	37.00	105.71	11.00	91.67	23.00	100.00	34.00	97.14	11.00	91.67	22.60	98.26	33.60	96.00
11.00-12.00	10.00	111.11	23.00	164.29	33.00	143.48	10.00	111.11	16.20	115.71	26.20	113.91	10.00	111.11	16.20	115.71	26.20	113.91
12.00-13.00	14.00	116.67	12.60	114.55	26.60	115.65	14.00	116.67	10.80	98.18	24.80	107.83	14.00	116.67	10.80	98.18	24.80	107.83
13.00-14.00	17.00	94.44	10.40	80.00	27.40	88.39	17.00	94.44	12.00	92.31	29.00	93.55	17.00	94.44	11.80	90.77	28.80	92.90
14.00-15.00	13.00	108.33	14.20	74.74	27.20	87.74	13.00	108.33	12.80	67.37	25.80	83.23	13.00	108.33	13.00	68.42	26.00	83.87
15.00-16.00	11.00	78.57	19.00	135.71	30.00	107.14	11.00	78.57	19.00	135.71	30.00	107.14	11.00	78.57	19.00	135.71	30.00	107.14
16.00-17.00	12.00	109.09	11.60	96.67	23.60	102.61	12.00	109.09	12.20	101.67	24.20	105.22	12.00	109.09	12.20	101.67	24.20	105.22
17.00-18.00	20.00	100.00	14.60	91.25	34.60	96.11	20.00	100.00	15.40	96.25	35.40	98.33	20.00	100.00	15.40	96.25	35.40	98.33
18.00-19.00	19.00	111.76	16.80	84.00	35.80	96.76	19.00	111.76	15.80	79.00	34.80	94.05	19.00	111.76	15.80	79.00	34.80	94.05
19.00-20.00	18.00	94.74	18.40	153.33	36.40	117.42	18.00	94.74	18.00	150.00	36.00	116.13	18.00	94.74	18.00	150.00	36.00	116.13
20.00-21.00	17.00	89.47	7.60	95.00	24.60	91.11	17.00	89.47	7.80	97.50	24.80	91.85	17.00	89.47	7.80	97.50	24.80	91.85
21.00-22.00	13.00	108.33	7.60	108.57	20.60	108.42	13.00	108.33	7.20	102.86	20.20	106.32	13.00	108.33	7.20	102.86	20.20	106.32
22.00-23.00	11.00	100.00	7.80	111.43	18.80	104.44	11.00	100.00	8.00	114.29	19.00	105.56	11.00	100.00	8.00	114.29	19.00	105.56
23.00-24.00	1.00	50.00	6.20	77.50	7.20	72.00	1.00	50.00	6.00	75.00	7.00	70.00	1.00	50.00	6.00	75.00	7.00	70.00
24.00-25.00	0.00	0.00	1.80	0.00	1.80	0.00	0.00	0.00	2.00	0.00	2.00	0.00	0.00	0.00	2.00	0.00	2.00	0.00
TOTALS	267.00	**91.71**	274.00	**89.56**	541.00	**94.18**	267.00	**91.96**	274.00	**88.49**	541.00	**93.36**	267.00	**92.20**	274.00	**88.56**	541.00	**93.35**
Peak Period Totals	65		88		153		65		96.2		161.2		65		96.2		161.2	

Appendix 7.1

Manchester Delay Figures per Hour for SIMMOD Cases

Time	Planned Movements			Base Case Delays					
	Arr	Dep	Total	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	2.00	3.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	4.00	1.00	5.00	1.90	0.49	0.00	0.23	1.90	0.36
2.00-3.00	1.00	1.00	2.00	0.00	0.00	0.00	0.17	0.00	0.09
3.00-4.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	4.00	0.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	8.00	0.00	8.00	1.60	0.20	0.00	0.00	1.60	0.10
6.00-7.00	7.00	11.00	18.00	7.10	1.01	27.20	3.34	34.30	2.18
7.00-8.00	10.00	32.00	42.00	15.20	1.52	438.00	18.51	453.20	10.02
8.00-9.00	26.00	21.00	47.00	246.70	11.84	451.40	22.20	698.10	17.02
9.00-10.00	17.00	20.00	37.00	221.60	11.66	368.90	17.18	590.50	14.41
10.00-11.00	12.00	23.00	35.00	61.70	4.07	487.40	21.19	549.10	12.63
11.00-12.00	9.00	14.00	23.00	2.90	0.29	360.90	16.28	363.80	8.29
12.00-13.00	12.00	11.00	23.00	7.40	0.67	48.70	3.95	56.10	2.31
13.00-14.00	18.00	13.00	31.00	15.40	0.91	26.90	2.57	42.30	1.74
14.00-15.00	12.00	19.00	31.00	22.00	1.57	61.30	4.13	83.30	2.85
15.00-16.00	14.00	14.00	28.00	26.30	2.02	39.60	2.31	65.90	2.17
16.00-17.00	11.00	12.00	23.00	1.30	0.13	28.40	2.28	29.70	1.21
17.00-18.00	20.00	16.00	36.00	51.20	2.85	70.90	4.57	122.10	3.71
18.00-19.00	17.00	20.00	37.00	208.10	9.91	29.70	2.47	237.80	6.19
19.00-20.00	19.00	12.00	31.00	18.90	1.13	331.20	15.17	350.10	8.15
20.00-21.00	19.00	8.00	27.00	56.30	2.79	20.50	2.56	76.80	2.68
21.00-22.00	12.00	7.00	19.00	6.80	0.52	18.30	2.24	25.10	1.38
22.00-23.00	11.00	7.00	18.00	4.40	0.40	16.50	2.10	20.90	1.25
23.00-24.00	2.00	8.00	10.00	0.00	0.00	2.20	0.35	2.20	0.18
24.00-25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	267.00	274.00	541.00	976.80	**Average**	2828.00	**Average**	3804.80	**Average**
Peak Period Delays					**7.27**		**19.77**		**13.52**
					2.25		5.99		4.12

Time	Case Two Delays						Case Three			
	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	1.90	0.49	0.00	0.23	1.90	0.36	2.30	0.56	0.00	0.22
2.00-3.00	0.00	0.00	0.00	0.17	0.00	0.09	0.00	0.00	0.00	0.20
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	1.60	0.20	0.00	0.00	1.60	0.10	1.90	0.23	0.00	0.00
6.00-7.00	7.00	1.00	29.70	3.50	36.70	2.25	7.10	1.02	21.20	2.72
7.00-8.00	15.00	1.50	434.60	18.36	449.60	9.93	13.30	1.33	390.70	15.14
8.00-9.00	246.50	11.74	427.90	21.22	674.40	16.48	234.90	11.19	341.50	16.11
9.00-10.00	205.40	10.81	370.50	16.47	575.90	13.64	229.50	12.08	212.80	9.33
10.00-11.00	55.80	3.72	419.80	18.12	475.60	10.92	65.10	4.34	248.90	10.73
11.00-12.00	2.80	0.28	262.80	11.68	265.60	5.98	2.70	0.27	92.40	4.67
12.00-13.00	7.20	0.65	20.80	1.92	28.00	1.29	6.70	0.61	18.50	1.71
13.00-14.00	14.20	0.84	24.90	2.30	39.10	1.57	12.50	0.73	22.60	2.05
14.00-15.00	21.00	1.50	45.10	3.14	66.10	2.32	19.50	1.39	35.80	2.56
15.00-16.00	26.40	2.03	38.10	2.18	64.50	2.11	27.70	2.13	41.10	2.31
16.00-17.00	1.30	0.13	30.30	2.49	31.60	1.31	1.00	0.10	19.10	1.57
17.00-18.00	51.10	2.81	72.60	4.74	123.70	3.78	57.20	3.11	41.30	2.58
18.00-19.00	196.80	9.44	21.70	1.61	218.50	5.53	191.60	9.30	22.50	1.79
19.00-20.00	18.30	1.08	253.80	12.18	272.10	6.63	15.70	0.92	211.10	10.15
20.00-21.00	45.70	2.28	9.20	1.20	54.90	1.74	43.80	2.19	13.00	1.67
21.00-22.00	6.60	0.51	15.10	1.89	21.70	1.20	6.60	0.51	20.10	2.45
22.00-23.00	4.40	0.40	16.60	2.07	21.00	1.24	4.10	0.38	20.00	2.57
23.00-24.00	0.00	0.00	2.60	0.42	2.60	0.21	0.00	0.00	2.60	0.41
24.00-25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	929.00	**Average**	2496.10	**Average**	3425.10	**Average**	943.20	**Average**	1775.20	**Average**
Peak Period Delays		**6.94**		**18.54**		**12.74**		**7.24**		**12.83**
		2.14		5.25		3.69		2.18		3.79

Delay Summary Table

Simulation Case	Arrival			Departure			Combined			Max. Mov. Peak Hour
	Total T.T.	Total Delay	Avg. Delay	Total T.T.	Total Delay	Avg. Delay	Total T.T.	Total Delay	Avg. Delay	
Base Case	7723.80	976.80	2.34	4710.30	2828.00	6.64	12434.10	3804.80	4.68	41.16
Case Two	7722.90	929.00	2.22	4630.60	2496.10	5.68	12353.50	3425.10	4.14	41.50
Case Three	7711.70	943.20	2.27	4582.60	1775.20	4.05	12294.30	2718.40	3.23	42.20
Case Four	7710.70	943.10	2.27	4571.90	1772.40	4.06	12282.60	2715.50	3.23	42.20
Case Five	7710.70	944.60	2.28	4616.80	1752.30	4.01	12327.50	2696.90	3.20	42.20
Case Six	6715.40	1273.60	2.93	4614.00	2355.80	5.30	11329.40	3629.40	4.33	43.00
Case Seven	6640.20	1230.50	2.82	4617.80	2213.80	4.90	11258.00	3444.30	4.06	42.40
Case Seven 'B'	6647.60	1300.10	4.87	4616.00	2186.60	7.98	11263.60	3486.70	6.43	44.00
Case Eight	6771.80	308.9	1.99	4610.70	3323.10	12.13	11382.50	3632.00	7.06	41.30
Case Nine	6782.80	321	1.20	4571.40	3987.40	14.55	11354.20	4308.40	7.88	40.80
Case Ten a	6795.00	241.2	0.90	4569.30	1298.40	4.74	11364.30	1539.60	2.82	46.00
Case Ten b	6797.00	234.90	0.88	4568.80	1310.20	4.78	11365.80	1545.10	2.83	46.00

Difference from Base Case

Simulation Case	Arrival			Departure			Combined			Total Chg. T.T.+Dly
	Chg. T.T.	Chg. Delay	Chg. Avg. Dly.	Chg. T.T.	Chg. Delay	Chg. Avg. Dly.	Chg. T.T.	Chg. Delay	Chg. Avg. Dly.	
Base Case	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Case Two	-0.90	-47.80	-0.12	-79.70	-331.90	-0.96	-80.60	-379.70	-0.54	-460.30
Case Three	-12.10	-33.60	-0.07	-127.70	-1052.80	-2.59	-139.80	-1086.40	-1.45	-1226.20
Case Four	-13.10	-33.70	-0.07	-138.40	-1055.60	-2.58	-151.50	-1089.30	-1.45	-1240.80
Case Five	-13.10	-32.20	-0.06	-93.50	-1075.70	-2.63	-106.60	-1107.90	-1.48	-1214.50
Case Six	-1008.40	296.80	0.59	-96.30	-472.20	-1.34	-1104.70	-175.40	-0.35	-1280.10
Case Seven	-1083.60	253.70	0.48	-92.50	-614.20	-1.74	-1176.10	-360.50	-0.62	-1536.60
Case Seven 'B'	-1076.20	323.30	2.53	-94.30	-641.40	1.34	-1170.50	-318.10	1.75	-1488.60
Case Eight	-952.00	-667.90	-0.35	-99.60	495.10	5.49	-1051.60	-172.80	2.38	-1224.40
Case Nine	-941.00	-655.80	-1.14	-138.90	1159.40	7.91	-1079.90	503.60	3.20	-576.30
Case Ten a	-928.80	-735.60	-1.44	-141.00	-1529.60	-1.90	-1069.80	-2265.20	-1.86	-3335.00
Case Ten b	-926.80	-741.90	-1.46	-141.50	-1517.80	-1.86	-1068.30	-2259.70	-1.85	-3328.00

Appendix 7.1

Manchester Delay Figures per Hour for SIMMOD Cases

Time	Case Three		Case Four					
	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	2.30	0.39	2.30	0.56	0.00	0.22	2.30	0.39
2.00-3.00	0.00	0.10	0.00	0.00	0.00	0.20	0.00	0.10
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	1.90	0.12	1.90	0.23	0.00	0.00	1.90	0.12
6.00-7.00	28.30	1.87	7.10	1.02	21.20	2.72	28.30	1.87
7.00-8.00	404.00	8.24	13.30	1.33	390.70	15.14	404.00	8.24
8.00-9.00	576.40	13.65	234.90	11.19	341.50	16.11	576.40	13.65
9.00-10.00	442.30	10.71	229.00	12.05	211.60	9.28	440.60	10.67
10.00-11.00	314.00	7.54	64.20	4.28	239.20	10.22	303.40	7.25
11.00-12.00	95.10	2.47	2.70	0.27	92.10	4.70	94.80	2.49
12.00-13.00	25.20	1.16	6.70	0.61	19.00	1.76	25.70	1.19
13.00-14.00	35.10	1.39	12.50	0.73	22.40	2.04	34.90	1.39
14.00-15.00	55.30	1.98	19.40	1.39	33.70	2.44	53.10	1.92
15.00-16.00	68.80	2.22	28.20	2.17	45.70	2.54	73.90	2.36
16.00-17.00	20.10	0.84	1.00	0.10	20.20	1.66	21.20	0.88
17.00-18.00	98.50	2.85	57.20	3.11	40.40	2.52	97.60	2.82
18.00-19.00	214.10	5.55	191.60	9.30	22.50	1.79	214.10	5.55
19.00-20.00	226.80	5.54	16.00	0.94	216.40	10.40	232.40	5.67
20.00-21.00	56.80	1.93	44.40	2.22	12.80	1.64	57.20	1.93
21.00-22.00	26.70	1.48	6.60	0.51	20.10	2.46	26.70	1.49
22.00-23.00	24.10	1.48	4.10	0.38	20.30	2.61	24.40	1.50
23.00-24.00	2.60	0.21	0.00	0.00	2.60	0.41	2.60	0.21
24.00-25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	2718.40	Average	943.10	Average	1772.40	Average	2715.50	Average
Peak Period Delays		10.03		7.21		12.69		9.95
		2.99		2.18		3.79		2.98

Time	Case Five					
	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	2.30	0.56	0.00	0.22	2.30	0.39
2.00-3.00	0.00	0.00	0.00	0.20	0.00	0.10
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	1.90	0.23	0.00	0.00	1.90	0.12
6.00-7.00	7.10	1.02	21.20	2.72	28.30	1.87
7.00-8.00	13.30	1.33	390.20	15.13	403.50	8.23
8.00-9.00	234.90	11.19	341.10	16.09	576.00	13.64
9.00-10.00	229.50	12.08	212.90	9.34	442.40	10.71
10.00-11.00	65.10	4.34	229.70	9.73	294.80	7.04
11.00-12.00	2.80	0.28	81.80	4.22	84.60	2.25
12.00-13.00	6.70	0.61	18.90	1.75	25.60	1.18
13.00-14.00	12.50	0.73	22.40	2.04	34.90	1.39
14.00-15.00	19.40	1.39	33.80	2.45	53.20	1.92
15.00-16.00	28.20	2.17	45.50	2.53	73.70	2.35
16.00-17.00	1.00	0.10	19.90	1.63	20.90	0.87
17.00-18.00	57.20	3.11	40.60	2.54	97.80	2.83
18.00-19.00	191.60	9.30	22.60	1.79	214.20	5.55
19.00-20.00	16.00	0.94	215.90	10.38	231.90	5.66
20.00-21.00	44.40	2.22	12.80	1.64	57.20	1.93
21.00-22.00	6.60	0.51	20.10	2.46	26.70	1.49
22.00-23.00	4.10	0.38	20.30	2.61	24.40	1.50
23.00-24.00	0.00	0.00	2.60	0.41	2.60	0.21
24.00-25.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	944.60	Average	1752.30	Average	2696.90	Average
Peak Period Delays		7.24		12.57		9.90
		2.19		3.75		2.97

Time	Case Six						Case Seven 'a'		
	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	2.50	0.62	0.00	0.23	2.50	0.43	2.50	0.62	0.00
2.00-3.00	0.00	0.00	0.00	0.12	0.00	0.06	0.00	0.00	0.00
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	2.00	0.24	0.00	0.00	2.00	0.12	2.00	0.24	0.00
6.00-7.00	8.10	1.15	21.60	2.77	29.70	1.96	8.10	1.15	21.60
7.00-8.00	28.50	2.59	409.60	16.52	438.10	9.56	26.10	2.37	409.80
8.00-9.00	427.50	20.36	432.20	20.58	859.70	20.47	424.80	20.23	438.10
9.00-10.00	238.70	11.36	376.70	17.12	615.40	14.24	286.50	13.74	355.30
10.00-11.00	14.50	1.21	386.80	16.82	401.30	9.02	16.00	1.33	378.10
11.00-12.00	3.50	0.39	251.10	11.63	254.60	6.01	2.60	0.29	179.40
12.00-13.00	14.60	0.98	24.30	2.21	38.90	1.60	14.40	0.96	24.50
13.00-14.00	26.00	1.83	17.60	1.63	43.60	1.73	31.40	2.12	15.80
14.00-15.00	40.50	2.56	51.70	3.64	92.20	3.10	37.00	2.44	32.50
15.00-16.00	27.20	2.47	59.90	3.15	87.10	2.81	16.90	1.53	64.50
16.00-17.00	3.50	0.32	22.50	1.94	26.00	1.13	3.30	0.27	24.20
17.00-18.00	56.30	3.03	30.20	1.96	86.50	2.50	27.50	1.51	25.40
18.00-19.00	261.40	12.21	21.10	1.70	282.50	6.96	217.80	10.47	25.90
19.00-20.00	49.50	3.13	213.90	10.09	263.40	6.61	45.60	2.85	180.50
20.00-21.00	53.30	2.77	9.20	1.12	62.50	1.95	49.70	2.62	9.20
21.00-22.00	6.90	0.53	13.20	1.74	20.10	1.14	7.20	0.55	15.40
22.00-23.00	9.10	0.83	11.50	1.43	20.60	1.13	9.10	0.83	11.10
23.00-24.00	0.00	0.00	2.70	0.43	2.70	0.22	0.00	0.00	2.50
24.00-25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	1273.60	Average	2355.80	Average	3629.40	Average	1230.50	Average	2213.80
Peak Period Delays		8.88		17.76		13.32		9.42	
		2.86		4.87		3.86		2.76	

Appendix 7.1

Manchester Delay Figures per Hour for SIMMOD Cases Table 2

Time	Case Seven 'a'			Case Seven 'B'					
	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	0.23	2.50	0.43	2.50	0.62	0.00	0.23	2.50	0.43
2.00-3.00	0.12	0.00	0.06	0.00	0.00	0.00	0.12	0.00	0.06
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	0.00	2.00	0.12	2.00	0.24	0.00	0.00	2.00	0.12
6.00-7.00	2.77	29.70	1.96	8.10	1.15	21.60	2.77	29.70	1.96
7.00-8.00	16.52	435.90	9.45	27.80	2.51	394.00	16.69	421.80	9.60
8.00-9.00	20.67	862.90	20.45	381.60	19.08	474.70	22.18	856.30	20.63
9.00-10.00	16.60	643.80	15.17	355.00	16.90	310.10	13.48	665.10	15.19
10.00-11.00	15.37	394.10	8.35	21.30	1.64	370.20	15.17	391.50	8.41
11.00-12.00	8.79	182.00	4.54	4.80	0.53	150.00	7.35	154.80	3.94
12.00-13.00	2.23	38.90	1.60	15.50	1.03	17.90	1.75	33.40	1.39
13.00-14.00	1.36	47.20	1.74	29.40	2.07	16.10	1.32	45.50	1.70
14.00-15.00	2.42	69.50	2.43	36.40	2.30	33.00	2.58	69.40	2.44
15.00-16.00	3.43	81.40	2.48	20.70	1.88	73.30	3.74	94.00	2.81
16.00-17.00	2.09	27.50	1.18	3.40	0.28	28.60	2.46	32.00	1.37
17.00-18.00	1.65	52.90	1.58	25.80	1.43	24.00	1.54	49.80	1.49
18.00-19.00	1.82	243.70	6.15	251.00	11.95	22.80	1.84	273.80	6.90
19.00-20.00	9.03	226.10	5.94	48.60	3.03	209.60	9.88	258.20	6.46
20.00-21.00	1.21	58.90	1.92	50.10	2.64	10.60	1.39	60.70	2.02
21.00-22.00	1.98	22.60	1.27	7.10	0.54	16.90	2.17	24.00	1.36
22.00-23.00	1.39	20.20	1.11	9.40	0.86	10.60	1.32	20.00	1.09
23.00-24.00	0.40	2.50	0.20	0.00	0.00	2.10	0.34	2.10	0.17
24.00-25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	Average	3444.30	Average	1300.30	Average	2186.10	Average	3486.40	Average
Peak Period Delays	17.29		13.35		10.03		16.88		13.46
	4.59		3.67		2.95		4.51		3.73

Time	Case Eight						Case Nine					
	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	1.90	0.48	0.00	0.19	1.90	0.34	1.90	0.47	0.00	0.23	1.90	0.35
2.00-3.00	0.00	0.00	0.60	0.28	0.60	0.14	0.00	0.00	0.70	0.33	0.70	0.17
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	1.80	0.22	0.00	0.00	1.80	0.11	1.80	0.22	0.00	0.00	1.80	0.11
6.00-7.00	5.10	0.73	25.20	3.14	30.30	1.94	5.10	0.73	24.20	3.02	29.30	1.88
7.00-8.00	31.10	2.08	362.50	16.86	393.60	9.47	22.60	1.61	366.60	17.28	389.20	9.45
8.00-9.00	71.80	3.26	66.30	35.06	138.10	19.16	86.90	3.78	695.10	40.89	782.00	22.34
9.00-10.00	33.40	1.97	775.10	31.85	808.50	16.81	32.30	1.90	896.20	37.66	928.50	19.78
10.00-11.00	6.30	0.57	691.40	27.11	697.70	13.84	6.30	0.58	908.60	34.95	914.90	17.77
11.00-12.00	3.20	0.32	287.70	12.98	290.90	6.65	2.80	0.28	457.10	19.87	459.90	10.08
12.00-13.00	8.80	0.62	19.20	1.72	28.00	1.17	8.40	0.60	54.90	4.36	63.30	2.48
13.00-14.00	17.50	1.03	16.60	1.58	34.10	1.31	17.60	1.04	14.40	1.39	32.00	1.22
14.00-15.00	6.10	0.47	46.80	3.34	52.90	1.91	6.40	0.49	47.00	3.31	53.40	1.90
15.00-16.00	14.50	1.31	79.70	4.20	94.20	2.76	14.50	1.31	67.20	3.54	81.70	2.43
16.00-17.00	2.50	0.21	27.20	2.33	29.70	1.27	2.40	0.20	26.40	2.27	28.80	1.24
17.00-18.00	11.10	0.56	27.60	2.00	38.70	1.28	11.90	0.59	30.00	2.06	41.90	1.33
18.00-19.00	50.20	2.64	109.90	6.16	160.10	4.40	56.80	2.99	215.90	12.85	272.70	7.92
19.00-20.00	12.90	0.72	168.20	9.26	181.10	4.99	13.10	0.73	159.40	8.66	172.50	4.70
20.00-21.00	21.30	1.25	9.40	1.23	30.70	1.24	21.20	1.25	8.20	1.07	29.40	1.16
21.00-22.00	4.60	0.36	8.90	1.21	13.50	0.79	4.50	0.35	10.10	1.33	14.60	0.84
22.00-23.00	4.70	0.43	5.80	0.73	10.50	0.58	4.60	0.41	3.80	0.49	8.40	0.45
23.00-24.00	0.00	0.00	1.10	0.19	1.10	0.10	0.00	0.00	1.10	0.18	1.10	0.09
24.00-25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	308.80	Average	2729.20	Average	3038.00	Average	321.10	Average	3986.90	Average	4308.00	Average
Peak Period Delays		1.97		27.72		14.85		1.97		32.70		17.33
		0.80		6.73		3.76		0.81		8.16		4.49

Appendix 7.1

Manchester Delay Figures per Hour for SIMMOD Cases

Time	Case Ten a						Case Ten b					
	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	1.90	0.47	0.00	0.23	1.90	0.35	1.90	0.47	0.00	0.23	1.90	0.35
2.00-3.00	0.00	0.00	0.70	0.33	0.70	0.17	0.00	0.00	0.70	0.33	0.70	0.17
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	1.80	0.22	0.00	0.00	1.80	0.11	1.80	0.22	0.00	0.00	1.80	0.11
6.00-7.00	5.20	0.74	26.40	3.22	31.60	1.98	5.20	0.74	26.40	3.22	31.60	1.98
7.00-8.00	27.60	1.84	400.10	15.51	427.70	8.68	30.40	1.90	385.20	15.53	415.60	8.72
8.00-9.00	53.40	2.43	289.70	12.07	343.10	7.25	44.90	2.14	325.70	13.03	370.60	7.59
9.00-10.00	31.50	1.85	156.80	6.70	188.30	4.28	31.20	1.84	156.00	6.56	187.20	4.20
10.00-11.00	6.20	0.57	73.50	3.19	79.70	1.88	6.20	0.57	63.90	2.83	70.10	1.70
11.00-12.00	3.20	0.32	39.10	2.42	42.30	1.37	3.30	0.33	37.70	2.33	41.00	1.33
12.00-13.00	4.10	0.29	13.80	1.28	17.90	0.79	4.10	0.29	14.00	1.30	18.10	0.80
13.00-14.00	7.20	0.42	14.00	1.17	21.20	0.80	7.20	0.42	15.00	1.27	22.20	0.85
14.00-15.00	4.40	0.34	21.90	1.71	26.30	1.03	4.40	0.34	23.30	1.79	27.70	1.07
15.00-16.00	10.90	0.99	51.40	2.71	62.30	1.85	10.90	0.99	51.70	2.72	62.60	1.86
16.00-17.00	0.80	0.06	18.40	1.51	19.20	0.79	0.80	0.06	18.50	1.51	19.30	0.79
17.00-18.00	11.70	0.58	21.30	1.38	33.00	0.98	11.70	0.58	21.30	1.38	33.00	0.98
18.00-19.00	35.40	1.86	21.10	1.34	56.50	1.60	35.10	1.85	21.10	1.33	56.20	1.59
19.00-20.00	10.80	0.60	131.60	7.31	142.40	3.96	10.70	0.60	131.30	7.29	142.00	3.95
20.00-21.00	15.90	0.93	5.90	0.75	21.80	0.84	15.90	0.93	5.80	0.74	21.70	0.84
21.00-22.00	4.00	0.31	8.60	1.19	12.60	0.75	4.00	0.31	8.60	1.19	12.60	0.75
22.00-23.00	5.30	0.48	2.70	0.34	8.00	0.41	5.30	0.48	2.70	0.34	8.00	0.41
23.00-24.00	0.00	0.00	1.20	0.21	1.20	0.11	0.00	0.00	1.20	0.21	1.20	0.11
24.00-25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	241.30	**Average**	1298.20	**Average**	1539.50	**Average**	235.00	**Average**	1310.10	**Average**	1545.10	**Average**
		1.67		**9.37**		**5.52**		**1.61**		**9.49**		**5.55**
Peak Period Delays		0.64		2.69		1.66		0.63		2.71		1.67

Appendix 7.2

Cost Benefit Analysis Case Study Results

Manchester Airport

Case Two - Intersection Departures -
Total Delay Saving = 6.33 Hrs from the Base Case

Costs	Value	Benefits	Value
Planning and Lobbying time (1 Month)	£30,150 **(a)**	Reduction in Delay for Business Pax.	£170 **(a)**
Test the procedure (1 Day)	£21,384 **(b)**	Reduction in Delay for Leisure Pax.	£38 **(b)**
TOTAL	**£51,534**	Reduction in Operating costs for Regional Aircraft	£2743 **(c)**
		Reduction in Operating costs for Jet Aircraft	£22,076 **(d)**
		TOTAL	**£25,027**
		Potential Multiplier Effect	£10,261 **(e)**

Notes:

Costs

(a) To calculate the cost given, the number of hours accumulated during the month whilst planning and lobbying for the procedures needed deriving. To do this the author has guestimated to a certain extent. It was assumed that three people would be involved with this issue for 150 hrs each over the month, (37.5 hrs a week). This figure was then multiplied by £67, the value given for business time.

(b) There were two values to calculate in this figure. Firstly the aircraft cost involved to test the procedure was made assuming 12hrs of testing were required at a cost of £1313/hr for regional aircraft. The second part related to the cost of peoples time involved in the testing, again for 12 hours, involving 7 people; 2 flight crew, 2 ATCO's, 2 airport representatives and 1 unbiased observer. These two costs were £15,756 and £5,628 respectively.

Benefits

(a) To calculate the benefit associated with a reduction in delay for business passengers, the number of business passengers travelling during the period of the simulation needed to be defined. Three pieces of information were required, the average aircraft seat size for regional and jet aircraft, the total number of business and lesiure flights and the average load factor for business and lesiure flights. For simplicity in this example, it was assumed that all regional flights were business flights, as were all scheduled flights. These were totalled and subtracted from the charter/leisure flights taken from the arrival and departure schedules given in appendix 6.2 The total passengers figures were then calculated and the percentage of business versus leisure passengers deduced. Using this information the total delay saving made during the simulation was split proportionally between business and leisure, according to the percentages derived from the passenger figures. The resultant delay saving was then multiplied by the value of passenger time per hour.

The figures used to calculate the figures above are given below:

Manchester Traffic Figures Calculated from Airport Schedule in Appendix 6.2

Regional Aircraft	- 180	= 33% of total flights
Jet Aircraft	- 334	= 62% of total flights(Of which 191 are charter flights)

Average Regional Aircraft Seat Capacity	= 60
Average Jet Aircraft Seat Capacity	= 160
Regional Aircraft Passengers	= 7020 (Assuming 65% load factor)
Charter Passengers	= 27,504 (Assuming 90% load factor)
Business Passengers	= 11,440 (Assuming 50% load factor)
TOTAL PASSENGERS	**= 45,964 (40% Business/60% Leisure)**

(b) The monetary saving for leisure passengers was calculated in exactly the same format as (a).

(c) Savings for regional aircraft operating costs were made by proportionally splitting the total delay saving to account for the percent of total traffic the regional aircraft represented and multiplying the resultant by £1313/hr.

(d) The saving for jet aircraft was calculated in the same manner as regional aircraft, except the operating value per hour was changed to £5625/hr.

(e) The multiplier figure represents 41% of the total benefits, which represent the direct investments. It is not included in the total figure given as it may take longer time for the multiplier effect to take place due to its very nature. The result would be a slower accumulation of benefit within the system, so making exact definition of its value at any one time rather difficult.

Case Three - Early Turns After Take Off -
Total Delay Saving = 18.1hrs from the base case

Costs	Value	Benefits	Value
Planning and Lobbying Time (One Month)	£30,150	Reduction in Delay for Business Pax.	£487
Testing of Procedure (1 Day)	£21,384	Reduction in Delay for Leisure Pax.	£108
Obtaining Permission to run procedure (1 Week)	£7537 (a)	Reduction in Operating costs for Regional Aircraft	£7843
IncreasedATC Workload (10hrs/day)	£670	Reduction in Operating costs for Jet Aircraft	£63,124
Cost to train crews	£98,924 (b)	**TOTAL**	**£71,562**
TOTAL	**£158,665**	IncreasePeak Period movement rate by one.	£50,000 (a)
		Potential Multiplier Effect	£29,340

Notes:

Costs

(a) This cost is based on the assumption that it takes three people from each of the organisations concerned, airport, airline and ATC, 37.5 hrs each to obtain permission to operate this procedure. Cost per hour for each person is £67.

(b) This cost uses the information taken from Crossair given in chapter six. Crews have one hour of briefing and two hours simulator training for early turns. This costs £911 per person. With two crew per aircraft and 89 regional aircraft in the schedule the total cost is derived.

Benefits

(a) This figure for an additional slot at Manchester is purely a guess by the author. It is not included in the total figure given as the slot improvement may not be used immediately due to inertia in the system.

Case Four - Early Turns After Take Off (Stage 2) -
Total Delay Saving = 18.15hrs from the Base Case

Costs	Value	Benefits	Value
TOTAL (From Case 3)	**£158,665**	Reduction in Delay for Business Pax.	£486
		Reduction in Delay for Leisure Pax.	£109
		Reduction in Operating costs for Regional Aircraft	£7864
		Reduction in Operating costs for Jet Aircraft	£63,298
		TOTAL	**£71,757**
		Increase Peak Period movement rate by one.	£50,000
		Potential Multiplier Effect	£29,420

Case Five - Early Turns After Take Off (Stage 3) -
Total Delay Saving = 18.49hrs from the Base Case

Costs	Value	Benefits	Value
TOTAL (From Case 3)	**£158,665**	Reduction in Delay for Business Pax.	£496
		Reduction in Delay for Leisure Pax.	£111
		Reduction in Operating costs for Regional Aircraft	£8,012
		Reduction in Operating costs for Jet Aircraft	£64,484
		TOTAL	**£73,103**
		Increase Peak Period movement rate by one.	£50,000
		Potential Multiplier Effect	£29,972

Case Six - Discrete Arrival from the North -
Total Delay Saving = 2.9hrs from the Base Case

Costs	Value	Benefits	Value
Planning and Lobbying Time (1 Month)	£30,150	Reduction in Delay for Business Pax.	£78
Test the Procedure (1Day)	£21,384	Reduction in Delay for Leisure Pax.	£17
Obtain Permission to operate procedure (1 Week)	£7,538	Reduction in Operating costs for Regional Aircraft	£1,261
Retrain flight crews to fly procedure	£47,704 **(a)**	Reduction in Operating costs for Jet Aircraft	£10,148
Retrain ATC to operate procedure	£6,030 **(b)**	**TOTAL**	**£11,504**
IncreasedATC Workload (20hrs/Day)	£1,340	Increase Peak Period movement rate by one.	£50,000
TOTAL	**£114,146**	Potential Multiplier Effect	£4,717
OPTIONS			
Addition of DGPS	£93,750		
Addition of RNAV	£56,250		

Notes:

Costs

(a) It was assumed that each pilot would need 4 hours of retraining at £67/hr. With two pilots per crew and 89 relevant aircraft the total cost was derived.

(b) Retraining ATC was assumed to take three hours per person and involving 30 people at £67/hr.

Case Seven 'a' - Discrete Arrival from the North and South -
Total Delay Saving = 6 hrs from the Base Case

Costs	Value	Benefits	Value
TOTAL (As Case 6)	**£114,146**	Reduction in Delay for Business Pax.	£161
OPTIONS		Reduction in Delay for Leisure Pax.	£36
Addition of DGPS	£93,750	Reduction in Operating costs for Regional Aircraft	£2,600
Addition of RNAV	£56,250	Reduction in Operating costs for Jet Aircraft	£20,925
		TOTAL	**£23,722**
		Increase Peak Period movement rate by one.	£50,000
		Potential Multiplier Effect	£9,726

Case Seven 'b' - Discrete Arrival from the North and South -
Total Delay Saving = 5.3 hrs from the Base Case

Costs	Value	Benefits	Value
TOTAL (As Case 6)	£114,146	Reduction in Delay for Business Pax.	£142
Additional 20hrs/day ATC Workload	£1,340	Reduction in Delay for Leisure Pax.	£32
TOTAL	**£115,486**	Reduction in Operating costs for Regional Aircraft	£2,296
OPTIONS		Reduction in Operating costs for Jet Aircraft	£17,888
Addition of DGPS	£93,750	**TOTAL**	**£20,358**
Addition of RNAV	£56,250	Increase Peak Period movement rate by one.	£50,000
		Potential Multiplier Effect	£8,347

Case Eight - Discrete Arrival and Steep Approach -
Total Delay Saving = 2.9 hrs from the Base Case

Costs	Value	Benefits	Value
Planning and Lobby time (2 Months)	£60,300	Reduction in Delay for Business Pax.	£77
Test the Procedure (1 Week)	£78,780	Reduction in Delay for Leisure Pax.	£17
Add Steep Approach Mod.to aircraft	£338,200 (a)	Reduction in Operating costs for Regional Aircraft	£1,257
Retrain Flight Crews to carry out steep approach	£173,995 (b)	Reduction in Operating costs for Jet Aircraft	£10,114
Retrain ATC to operate procedure	£60,300 (c)	**TOTAL**	**£11,465**
IncreasedATC workload (30 hrs/day)	£2,010	Potential Multiplier Effect (including Steep Approach investment)	£143,363
TOTAL	**£713,585**		

Notes:

Costs

(a) Crossair figures show that to retrofit a 146 aircraft with steep approach modification costs £3,800. This figure represents £3,800 x 89 aircraft in schedule.

(b) Again Crossair figures were used. Flight crew training requires four hours of simulator training per pilot at £67/hr. Simulator costs per four hour period are £1419. Figure is for 89 aircraft crew costs.

(c) Figure assumes 30 ATC personnel trained for three hours each at £67/hr.

Case Nine - Discrete Arrival, Steep Approach and Special Holds -
Total Delay Saving = -8.4 hrs from the Base Case

Costs	Value	Benefits	Value
TOTAL (as Case 8)	£713,585	Reduction in Delay for Business Pax.	-£225
Extra ATC Workload (Another 40hrs/day)	£2680	Reduction in Delay for Leisure Pax.	-£50
TOTAL	**£716,265**	Reduction in Operating costs for Regional Aircraft	-£3,640
		Reduction in Operating costs for Jet Aircraft	-£29,295
		TOTAL	**-£33,210**
		Potential Multiplier Effect (including Steep Approach investment)	£125,046

Case Ten 'a' - STOL Runway for Regional Arrivals -
Total Delay Saving = 37.8 hrs from the Base Case

Costs	Value	Benefits	Value
Design, Planning and Lobbying Time (1 Year)	£1,535,138 (a)	Reduction in Delay for Business Pax.	£1,013
Test New Runway (1 Week)	£78,780	Reduction in Delay for Leisure Pax.	£227
Build New Runway (1500m STOL strip)	£6,090,000 (b)	Reduction in Operating costs for Regional Aircraft	£16,378
Retrain Flight Crews	£173,995 (c)	Reduction in Operating costs for Jet Aircraft	£131,828
Add Steep approach Mod. to aircraft	£338,200	Increase of Peak Period Slots by 5.5	£2,750,000
Retrain ATC to operate new runway	£120,600 (d)	**TOTAL**	**£149,446**
Increased ATC Workload	£13,400 (e)	Potential Multiplier Effect (including Steep Approach investment and Runway Construction)	£2,696,835
TOTAL	**£8,350,113**		
OPTIONS			
Fit RNAV to Aircraft	£56,250		
Fit DGPS to Aircraft	£93,750		

Notes:

Costs

(a) The planning time is calculated assuming the involvement of five airport, two ATC and six airline staff over a year. Each person works a 37.5 hr per week for 47 weeks a year. Cost per hour is £67.

(b) Dimensions of the new runway are assumed to be 1500m x 50m, with 240m x 50m of taxiways. This makes 87,000 sq. m., which at £70/ sq. m. gives the cost.

(c) Costs to retrain flight crews as taken from case eight.

(d) Costs to retrain ATC are based on 60 hours of retraining per person, for 30 people, at £67/hr.

(e) ATC Workload is expected to increase by 200hrs a day. This figure attempts to take into account the need for additional ATC controllers.

Case Ten 'b' - STOL Runway for Regional Arrivals and Holding
Total Delay Saving = 37.7 hrs from the Base Case

Costs	Value	Benefits	Value
TOTAL (As Case 10 'a')	**£8,350,113**	Reduction in Delay for Business Pax.	£1,010
OPTIONS		Reduction in Delay for Leisure Pax.	£226
Fit RNAV to Aircraft	£56,250	Reduction in Operating costs for Regional Aircraft	£16,335
Fit DGPS to Aircraft	£93,750	Reduction in Operating costs for Jet Aircraft	£131,479
		Increase of Peak Period Slots by 5.5	£2,750,000
		TOTAL	**£149,050**
		Potential Multiplier Effect (including Steep Approach investment and Runway Construction)	£2,696,673

Appendix 7.3

Zurich Hourly Movement Rate Arrivals and Departures - Table 1

Time	Planned			Base Case						Case Two						Case Three		
	Arr	Dep	Total	Arr	% of Plan	Dep	% of Plan	Total	% of Plan	Arr	% of Plan	Dep	% of Plan	Total	% of Plan	Arr	% of Plan	Dep
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00-3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00
6.00-7.00	24.00	9.00	33.00	24.00	100.00	10.00	111.11	34.00	103.03	24.00	100.00	10.80	120.00	34.80	105.45	24.00	100.00	10.80
7.00-8.00	8.00	32.00	40.00	8.00	100.00	26.40	82.50	34.40	86.00	8.00	100.00	26.20	81.88	34.20	85.50	8.00	100.00	29.20
8.00-9.00	18.00	18.00	36.00	16.00	88.89	23.00	127.78	39.00	108.33	16.00	88.89	22.60	125.56	38.60	107.22	16.00	88.89	19.60
9.00-10.00	31.00	17.00	48.00	31.00	100.00	17.60	103.53	48.60	101.25	31.00	100.00	17.40	102.35	48.40	100.83	31.00	100.00	17.40
10.00-11.00	29.00	28.00	57.00	29.00	100.00	26.40	94.29	55.40	97.19	29.00	100.00	26.60	95.00	55.60	97.54	29.00	100.00	26.60
11.00-12.00	29.00	27.00	56.00	31.00	106.90	27.60	102.22	58.60	104.64	31.00	106.90	27.40	101.48	58.40	104.29	31.00	106.90	27.40
12.00-13.00	21.00	35.00	56.00	21.00	100.00	36.20	103.43	57.20	102.14	21.00	100.00	37.00	105.71	58.00	103.57	21.00	100.00	38.00
13.00-14.00	19.00	27.00	46.00	18.00	94.74	28.20	104.44	46.20	100.43	18.00	94.74	27.00	100.00	45.00	97.83	18.00	94.74	26.20
14.00-15.00	17.00	23.00	40.00	16.00	94.12	20.40	88.70	36.40	91.00	16.00	94.12	21.00	91.30	37.00	92.50	16.00	94.12	21.80
15.00-16.00	15.00	18.00	33.00	16.00	106.67	17.60	97.78	33.60	101.82	16.00	106.67	17.40	96.67	33.40	101.21	16.00	106.67	17.00
16.00-17.00	14.00	14.00	28.00	15.00	107.14	17.00	121.43	32.00	114.29	15.00	107.14	17.00	121.43	32.00	114.29	15.00	107.14	16.60
17.00-18.00	28.00	13.00	41.00	24.00	85.71	10.40	80.00	34.40	83.90	24.00	85.71	10.80	83.08	34.80	84.88	24.00	85.71	10.40
18.00-19.00	29.00	13.00	42.00	31.00	106.90	12.20	93.85	43.20	102.86	31.00	106.90	11.80	90.77	42.80	101.90	31.00	106.90	12.20
19.00-20.00	24.00	26.00	50.00	12.00	50.00	24.60	94.62	36.60	73.20	12.00	50.00	24.20	93.08	36.20	72.40	12.00	50.00	24.20
20.00-21.00	0.00	0.00	0.00	0.00	0.00	10.40	0.00	10.40	0.00	0.00	0.00	10.80	0.00	10.80	0.00	0.00	0.00	10.60
TOTALS	306.00	300.00	606.00	293.00	**89.40**	308.00	**93.71**	601.00	**91.34**	293.00	**89.40**	308.00	**93.89**	601.00	**91.29**	293.00	**89.40**	308.00
Peak Period Totals	129.00	134.00	263.00	130.00		136.00		266.00		130.00		135.40		265.40		130.00		135.60

Movement Summary Table

Case	Max. Mov	Avg. % Mov.	Avg % Mov. Peak hr.	Diff Max Mov/hr
Base Case	59.00	91.34	101.13	0.00
Case Two	58.40	91.29	100.81	-0.60
Case Three	59.00	91.20	100.98	0.00
Case Four	59.20	91.41	100.18	0.20
Case Five	59.00	91.26	99.10	0.00
Case Six	58.20	91.20	99.76	-0.80

Appendix 7.3

Zurich Hourly Movement Rate Arrivals and Departures Table 1

Time	Case Three			Case Four						Case Five						Case Six					
	% of Plan	Total	% of Plan	Arr	% of Plan	Dep	% of Plan	Total	% of Plan	Arr	% of Plan	Dep	% of Plan	Total	% of Plan	Arr	% of Plan	Dep	% of Plan	Total	% of Plan
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00-3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00
6.00-7.00	120.00	34.80	105.45	24.00	100.00	10.20	113.33	34.20	103.64	24.00	100.00	8.60	95.56	32.60	98.79	24.00	100.00	8.80	97.78	32.80	99.39
7.00-8.00	91.25	37.20	93.00	8.00	100.00	29.40	91.88	37.40	93.50	8.00	100.00	27.40	85.63	35.40	88.50	8.00	100.00	30.60	95.63	38.60	96.50
8.00-9.00	108.89	35.60	98.89	16.00	88.89	20.20	112.22	36.20	100.56	16.00	88.89	23.00	127.78	39.00	108.33	16.00	88.89	20.60	114.44	36.60	101.67
9.00-10.00	102.35	48.40	100.83	30.00	96.77	16.80	98.82	46.80	97.50	30.00	96.77	16.40	96.47	46.40	96.67	30.00	96.77	15.40	90.59	45.40	94.58
10.00-11.00	95.00	55.60	97.54	29.00	100.00	26.20	93.57	55.20	96.84	29.00	100.00	25.00	89.29	54.00	94.74	29.00	100.00	26.00	92.86	55.00	96.49
11.00-12.00	101.48	58.40	104.29	30.00	103.45	27.20	100.74	57.20	102.14	30.00	103.45	29.00	107.41	59.00	105.36	30.00	103.45	28.20	104.44	58.20	103.93
12.00-13.00	108.57	59.00	105.36	22.00	104.76	37.20	106.29	59.20	105.71	22.00	104.76	29.40	84.00	51.40	91.79	22.00	104.76	33.20	94.86	55.20	98.57
13.00-14.00	97.04	44.20	96.09	17.00	89.47	28.40	105.19	45.40	98.70	17.00	89.47	32.20	119.26	49.20	106.96	17.00	89.47	31.40	116.30	48.40	105.22
14.00-15.00	94.78	37.80	94.50	19.00	111.76	20.40	88.70	39.40	98.50	19.00	111.76	24.00	104.35	43.00	107.50	19.00	111.76	21.20	92.17	40.20	100.50
15.00-16.00	94.44	33.00	100.00	16.00	106.67	18.60	103.33	34.60	104.85	16.00	106.67	18.20	101.11	34.20	103.64	16.00	106.67	17.40	96.67	33.40	101.21
16.00-17.00	118.57	31.60	112.86	14.00	100.00	17.00	121.43	31.00	110.71	14.00	100.00	16.40	117.14	30.40	108.57	14.00	100.00	16.60	118.57	30.60	109.29
17.00-18.00	80.00	34.40	83.90	23.00	82.14	9.20	70.77	32.20	78.54	23.00	82.14	10.40	80.00	33.40	81.46	23.00	82.14	10.40	80.00	33.40	81.46
18.00-19.00	93.85	43.20	102.86	30.00	103.45	14.20	109.23	44.20	105.24	30.00	103.45	13.40	103.08	43.40	103.33	30.00	103.45	14.20	109.23	44.20	105.24
19.00-20.00	93.08	36.20	72.40	14.00	58.33	23.40	90.00	37.40	74.80	14.00	58.33	22.60	86.92	36.60	73.20	14.00	58.33	23.00	88.46	37.00	74.00
20.00-21.00	0.00	10.60	0.00	0.00	0.00	9.60	0.00	9.60	0.00	0.00	0.00	12.00	0.00	12.00	0.00	0.00	0.00	11.00	0.00	11.00	0.00
TOTALS	**93.29**	601.00	**91.20**	293.00	**89.71**	308.00	**93.70**	601.00	**91.41**	293.00	**89.71**	308.00	**93.20**	601.00	**91.26**	293.00	**89.71**	308.00	**92.80**	601.00	**91.20**
Peak Period Totals		265.60		128.00		135.80		263.80		128.00		132.00		260.00		128.00		134.20		262.20	

Appendix 7.3

Zurich Delay Figures per Hour for SIMMOD Cases Table 2

Time	Planned Movements			Base Case Delays						Case Two Delays						Case Three	
	Arr	Dep	Total	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00-3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.00-7.00	24.00	9.00	33.00	133.80	5.58	19.90	1.99	153.70	3.78	133.30	5.56	14.40	1.33	147.70	3.45	133.00	5.54
7.00-8.00	8.00	32.00	40.00	1.60	0.20	137.30	5.20	138.90	2.70	1.50	0.19	125.20	4.78	126.70	2.49	1.60	0.20
8.00-9.00	18.00	18.00	36.00	11.60	0.72	201.40	8.76	213.00	4.74	11.10	0.69	168.50	7.46	179.60	4.08	11.00	0.69
9.00-10.00	31.00	17.00	48.00	95.10	3.07	5.40	0.31	100.50	1.69	94.90	3.06	5.00	0.29	99.90	1.68	94.50	3.05
10.00-11.00	29.00	28.00	57.00	85.10	2.93	27.00	1.02	112.10	1.98	86.60	2.98	23.90	0.90	110.50	1.94	85.10	2.94
11.00-12.00	29.00	27.00	56.00	86.80	2.80	38.90	1.41	125.70	2.11	77.30	2.49	31.80	1.16	109.10	1.83	80.00	2.58
12.00-13.00	21.00	35.00	56.00	20.50	0.97	113.70	3.14	134.20	2.06	20.20	0.96	109.40	2.96	129.60	1.96	18.90	0.90
13.00-14.00	19.00	27.00	46.00	21.20	1.18	65.70	2.33	86.90	1.76	21.70	1.21	48.10	1.78	69.80	1.50	24.40	1.36
14.00-15.00	17.00	23.00	40.00	17.30	1.08	73.50	3.60	90.80	2.34	15.00	0.94	63.00	3.00	78.00	1.97	17.00	1.06
15.00-16.00	15.00	18.00	33.00	13.00	0.81	22.10	1.26	35.10	1.04	13.40	0.84	23.10	1.33	36.50	1.09	10.30	0.65
16.00-17.00	14.00	14.00	28.00	18.50	1.23	20.90	1.23	39.40	1.23	18.00	1.20	21.90	1.29	39.90	1.25	24.40	1.63
17.00-18.00	28.00	13.00	41.00	44.30	1.84	6.10	0.59	50.40	1.22	41.60	1.73	7.30	0.68	48.90	1.21	41.90	1.74
18.00-19.00	29.00	13.00	42.00	122.60	3.96	10.60	0.87	133.20	2.42	122.20	3.94	8.50	0.72	130.70	2.33	122.40	3.95
19.00-20.00	24.00	26.00	50.00	76.20	6.35	46.40	1.89	122.60	4.12	79.50	6.62	50.20	2.08	129.70	4.35	79.30	6.60
20.00-21.00	0.00	0.00	0.00	0.00	0.00	9.10	0.87	9.10	0.44	0.00	0.00	9.20	0.85	9.20	0.43	0.00	0.00
TOTALS	306.00	300.00	606.00	747.60	**Average**	798.00	**Average**	1545.60	**Average**	736.30	**Average**	709.50	**Average**	1445.80	**Average**	743.80	**Average**
Peak Period Delays					**2.19**		**1.64**		**1.92**		**2.14**		**1.42**		**1.78**		**2.17**
					1.56		1.64		1.60		1.54		1.46		1.50		1.57

Delay Summary Table

Simulation Case	Arrival			Departure			Combined			Peak Hour Delay per Movement	
	Total T.T	Total Delay	Avg. Delay	Total T.T	Total Delay	Avg. Delay	Total T.T	Total Delay	Avg. Delay	Arrival	Departure
Base Case	9772.00	747.50	2.55	9374.80	798.00	2.59	19146.80	1545.50	2.57	6.35	8.76
Case Two	9774.40	736.47	2.51	9264.50	709.60	2.30	19038.90	1446.07	2.41	6.62	7.46
Case Three	9770.70	743.90	2.54	9201.80	338.60	1.10	18972.50	1082.50	1.82	6.6	2.76
Case Four	9908.50	1047.30	3.57	9199.10	504.50	1.64	19107.60	1551.80	2.61	7.87	2.85
Case Five	9907.40	1029.50	3.51	10361.30	1062.90	3.45	20268.70	2092.40	3.48	7.8	14.41
Case Six	9907.60	1050.50	3.59	9995.20	510.10	1.66	19902.80	1560.60	2.63	8.02	5.62

Delay Difference from Base Case

Simulation Case	Arrival			Departure			Combined			Total Chg T.T. +Dly
	Chg T.T	Chg Delay	Chg Avg. Dly.	Chg T.T	Chg Delay	Chg Avg. Dly.	Chg T.T	Chg Delay	Chg Avg. Dly.	
Base Case	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Case Two	2.40	-11.03	-0.04	-110.30	-89.00	-0.29	-107.90	-100.03	-0.17	-207.93
Case Three	-1.30	-3.60	-0.01	-173.00	-459.40	-1.49	-174.30	-463.00	-0.75	-637.30
Case Four	136.50	299.80	1.02	-175.70	-293.50	-0.95	-39.20	6.30	0.04	-32.90
Case Five	135.40	282.00	0.96	986.50	264.90	0.86	1121.90	546.90	0.91	1668.80
Case Six	135.60	303.00	1.04	620.40	-287.90	-0.93	756.00	15.10	0.06	771.10

Appendix 7.3

Zurich Delay Figures per Hour for SIMMOD Cases Table 2

Time	Case Three				Case Four					
	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00-3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.00-7.00	5.70	0.53	138.70	3.04	167.70	6.99	22.80	2.24	190.50	4.62
7.00-8.00	80.70	2.76	82.30	1.48	2.60	0.32	83.70	2.85	86.30	1.59
8.00-9.00	32.40	1.65	43.40	1.17	6.90	0.43	49.60	2.46	56.50	1.45
9.00-10.00	3.80	0.22	98.30	1.64	172.80	5.76	6.10	0.36	178.90	3.06
10.00-11.00	17.00	0.64	102.10	1.79	97.60	3.37	41.50	1.59	139.10	2.48
11.00-12.00	18.70	0.72	99.70	1.65	236.10	7.87	33.40	1.23	269.50	4.55
12.00-13.00	52.50	1.38	71.40	1.14	37.40	1.70	92.70	2.49	130.10	2.10
13.00-14.00	24.90	0.95	49.30	1.16	20.10	1.18	32.70	1.15	52.80	1.17
14.00-15.00	35.40	1.63	52.40	1.35	11.20	0.59	28.60	1.40	39.80	1.00
15.00-16.00	8.60	0.50	18.90	0.58	9.50	0.59	27.90	1.50	37.40	1.05
16.00-17.00	15.50	0.94	39.90	1.29	10.60	0.75	16.40	0.96	27.00	0.86
17.00-18.00	2.80	0.27	44.70	1.01	62.70	2.73	4.40	0.47	67.10	1.60
18.00-19.00	8.30	0.68	130.70	2.32	131.60	4.39	20.60	1.45	152.20	2.92
19.00-20.00	25.00	1.03	104.30	3.82	80.70	5.76	40.90	1.75	121.60	3.76
20.00-21.00	6.10	0.57	6.10	0.29	0.00	0.00	3.20	0.33	3.20	0.17
TOTALS	338.40	**Average**	1082.20	**Average**	1047.50	**Average**	504.50	**Average**	1552.00	**Average**
Peak Period Delays		**0.78**		**1.47**		**3.98**		**1.36**		**2.67**
		0.69		1.13		2.02		1.06		1.54

Time	Case Five						Case Six					
	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00-2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00-3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.00-4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.00-7.00	166.80	6.95	6.60	0.76	173.40	3.86	167.50	6.98	6.60	0.75	174.10	3.87
7.00-8.00	2.10	0.26	85.40	3.12	87.50	1.69	2.10	0.27	50.50	1.65	52.60	0.96
8.00-9.00	5.70	0.35	77.00	3.35	82.70	1.85	5.60	0.35	28.10	1.36	33.70	0.86
9.00-10.00	169.70	5.66	6.50	0.40	176.20	3.03	170.10	5.67	3.60	0.23	173.70	2.95
10.00-11.00	91.10	3.14	32.80	1.31	123.90	2.23	97.50	3.36	28.20	1.08	125.70	2.22
11.00-12.00	234.10	7.80	81.10	2.80	315.20	5.30	240.70	8.02	34.40	1.22	275.10	4.62
12.00-13.00	41.00	1.86	176.60	6.01	217.60	3.94	37.90	1.72	109.00	3.28	146.90	2.50
13.00-14.00	18.00	1.06	464.00	14.41	482.00	7.74	18.20	1.07	176.50	5.62	194.70	3.35
14.00-15.00	10.00	0.53	64.50	2.69	74.50	1.61	10.50	0.55	14.10	0.67	24.60	0.61
15.00-16.00	8.60	0.54	17.40	0.96	26.00	0.75	6.00	0.37	7.70	0.44	13.70	0.41
16.00-17.00	10.00	0.72	13.50	0.82	23.50	0.77	16.10	1.15	11.40	0.69	27.50	0.92
17.00-18.00	61.90	2.69	6.90	0.66	68.80	1.68	62.20	2.70	5.10	0.49	67.30	1.60
18.00-19.00	130.10	4.34	7.90	0.59	138.00	2.47	135.80	4.53	10.60	0.75	146.40	2.64
19.00-20.00	80.40	5.74	17.70	0.78	98.10	3.26	80.40	5.74	21.30	0.93	101.70	3.34
20.00-21.00	0.00	0.00	5.10	0.43	5.10	0.22	0.00	0.00	3.00	0.28	3.00	0.14
TOTALS	1029.50	**Average**	1063.00	**Average**	2092.50	**Average**	1050.60	**Average**	510.10	**Average**	1560.70	**Average**
Peak Period Delays		**3.90**		**4.99**		**4.45**		**3.97**		**2.29**		**3.13**
		1.98		1.86		1.92		2.02		0.93		1.47

<u>*Appendix 7.4*</u>

Cost Benefit Analysis Case Study Results

Zurich

Case Two - Intersection Departures -
Total Delay Saving = 1.7 Hrs from the Base Case

Costs	Value	Benefits	Value
Planning and Lobbying time (1 Month)	£30,150	Reduction in Delay for Business Pax.	£81
Test the procedure (1 Day)	£21,384	Reduction in Delay for Leisure Pax.	£4.5
Add new taxiway to Runway 28.	£105,000 **(a)**	Reduction in Operating costs for Regional Aircraft	£414
Increased ATC Controller Workload (10hrs/day)	£670	Reduction in Operating costs for Jet Aircraft	£7,563
TOTAL	**£157,204**	**TOTAL**	**£8,063**
		Potential Multiplier Effect (including Taxiway construction)	£46,356

Notes:

Costs

(a) Cost figure relates to construction of additional intersection departure taxiway at the 28 threshold end of the runway. Dimensions 50m x 30m = 1500 sq. m. @ £70/sq. m.

Benefits

(a) The passenger and aircraft figures used to calculate the benefits above are given below:

<u>**Zurich Traffic Figures Calculated from Airport Schedule in Appendix 6.4**</u>

Regional Aircraft = 114 = 19% of total flights
Jet Aircraft = 492 = 81% of total flights (Of which 100 are charter flights)

Average Regional Aircraft Seat Capacity = 60
Average Jet Aircraft Seat Capacity = 200
Regional Aircraft Passengers = 4,446 (Assuming 65% load factor)
Charter Passengers = 19,000 (Assuming 95% load factor)
Business Passengers = 47,040 (Assuming 60% load factor)
TOTAL PASSENGERS = 70,486 (73% Business/27% Leisure)*

*Total Passenger figure breakdown between leisure and business is calculated by summing the regional and jet business passengers to obtain the total business passengers and taking the charter passengers to represent the leisure passengers.

Case Three - Early Turns after Take Off -
Total Delay Saving = 7.72 Hrs from the Base Case

Costs	Value	Benefits	Value
Total from Case 2	£157,204	Reduction in Delay for Business Pax.	£378
Additional 20hrs/day ATC workload	£1,340	Reduction in Delay for Leisure Pax.	£21
TOTAL	**£158,544**	Reduction in Operating costs for Regional Aircraft	£1,926
		Reduction in Operating costs for Jet Aircraft	£35,174
		TOTAL	**£37,499**
		Potential Multiplier Effect (including Taxiway construction)	£58,425

Other Zurich Cases

As none of the other cases produced a delay reduction compared to the base case, no positive benefits were generated, negating the need to provide a cost benefit analysis for them.

Appendix 7.5

London Gatwick Hourly Movement Rate Arrivals and Departures Table 1

Time	Planned			Base Case						Case Two			
	Arr	Dep	Total	Arr	% of Plan	Dep	% of Plan	Total	% of Plan	Arr	% of Plan	Dep	% of Plan
0.00-1.00	1	5	6	0.00	0.00	5.00	100.00	5.00	83.33	0.00	0.00	5.00	100.00
1.00-2.00	2	3	5	3.00	150.00	3.00	100.00	6.00	120.00	3.00	150.00	3.00	100.00
2.00-3.00	1	0	1	1.00	100.00	0.00	0.00	1.00	100.00	1.00	100.00	0.00	0.00
3.00-4.00	2	0	2	2.00	100.00	0.00	0.00	2.00	100.00	2.00	100.00	0.00	0.00
4.00-5.00	3	1	4	3.00	100.00	1.00	100.00	4.00	100.00	3.00	100.00	1.00	100.00
5.00-6.00	8	2	10	8.00	100.00	4.00	200.00	12.00	120.00	8.00	100.00	4.00	200.00
6.00-7.00	15	12	27	15.00	100.00	9.67	80.58	24.67	91.37	15.00	100.00	9.60	80.00
7.00-8.00	26	20	46	18.83	72.42	17.33	86.65	36.16	78.61	19.00	73.08	17.00	85.00
8.00-9.00	26	25	51	21.17	81.42	20.17	80.68	41.34	81.06	21.20	81.54	20.00	80.00
9.00-10.00	17	30	47	22.67	133.35	19.00	63.33	41.67	88.66	22.40	131.76	20.80	69.33
10.00-11.00	18	17	35	21.83	121.28	21.17	124.53	43.00	122.86	22.00	122.22	21.40	125.88
11.00-12.00	12	29	41	14.50	120.83	20.50	70.69	35.00	85.37	14.40	120.00	20.80	71.72
12.00-13.00	21	15	36	21.00	100.00	17.83	118.87	38.83	107.86	21.00	100.00	18.80	125.33
13.00-14.00	11	18	29	13.00	118.18	20.67	114.83	33.67	116.10	13.00	118.18	22.60	125.56
14.00-15.00	15	21	36	14.00	93.33	19.00	90.48	33.00	91.67	14.00	93.33	19.80	94.29
15.00-16.00	16	11	27	15.00	93.75	19.33	175.73	34.33	127.15	15.00	93.75	20.80	189.09
16.00-17.00	18	14	32	18.33	101.83	18.00	128.57	36.33	113.53	19.00	105.56	15.40	110.00
17.00-18.00	20	15	35	15.33	76.65	18.00	120.00	33.33	95.23	15.00	75.00	16.00	106.67
18.00-19.00	19	21	40	20.17	106.16	18.50	88.10	38.67	96.68	20.60	108.42	18.40	87.62
19.00-20.00	14	26	40	18.17	129.79	17.33	66.65	35.50	88.75	17.40	124.29	18.80	72.31
20.00-21.00	14	10	24	14.00	100.00	20.00	200.00	34.00	141.67	14.00	100.00	20.80	208.00
21.00-22.00	12	7	19	12.00	100.00	7.83	111.86	19.83	104.37	12.00	100.00	5.20	74.29
22.00-23.00	11	15	26	10.00	90.91	16.17	107.80	26.17	100.65	10.00	90.91	16.40	109.33
23.00-24.00	3	8	11	3.00	100.00	8.50	106.25	11.50	104.55	3.00	100.00	8.40	105.00
24.00-25.00	0	0	0	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00
TOTALS	305	325	630	305.00	**95.60**	325.00	**97.42**	630.00	**98.38**	305.00	**95.52**	325.00	**96.78**
Peak Period Totals	120	136	256	120		116		236		120		118.8	

Summary Table

Case	Max Mov/hr	Avg. % Mov.	Avg. % Mov. Peak hr.	Diff max mov/hr
Base Case	43.00	98.38	94.07	0.00
Case Two	43.40	98.39	95.23	0.40
Case Three 'a'	43.20	98.19	95.48	0.20
Case Three 'b'	43.80	98.23	95.43	0.80
Case Three 'c'	43.80	98.23	95.43	0.80

Appendix 7.5

London Gatwick Hourly Movement Rate Arrivals and Departures Table 1

Time	Case Two		Case Three 'a'						Case Three 'b'					
	Total	% of Plan	Arr	% of Plan	Dep	% of Plan	Total	% of Plan	Arr	% of Plan	Dep	% of Plan	Total	% of Plan
0.00-1.00	5.00	83.33	0.00	0.00	5.00	100.00	5.00	83.33	0.00	0.00	5.00	100.00	5.00	83.33
1.00-2.00	6.00	120.00	3.00	150.00	3.00	100.00	6.00	120.00	3.00	150.00	3.00	100.00	6.00	120.00
2.00-3.00	1.00	100.00	1.00	100.00	0.00	0.00	1.00	100.00	1.00	100.00	0.00	0.00	1.00	100.00
3.00-4.00	2.00	100.00	2.00	100.00	0.00	0.00	2.00	100.00	2.00	100.00	0.00	0.00	2.00	100.00
4.00-5.00	4.00	100.00	3.00	100.00	1.00	100.00	4.00	100.00	3.00	100.00	1.00	100.00	4.00	100.00
5.00-6.00	12.00	120.00	8.00	100.00	4.00	200.00	12.00	120.00	8.00	100.00	4.00	200.00	12.00	120.00
6.00-7.00	24.60	91.11	15.00	100.00	9.60	80.00	24.60	91.11	15.00	100.00	9.60	80.00	24.60	91.11
7.00-8.00	36.00	78.26	19.00	73.08	17.20	86.00	36.20	78.70	19.00	73.08	17.20	86.00	36.20	78.70
8.00-9.00	41.20	80.78	21.20	81.54	20.40	81.60	41.60	81.57	21.20	81.54	20.40	81.60	41.60	81.57
9.00-10.00	43.20	91.91	22.40	131.76	20.60	68.67	43.00	91.49	22.40	131.76	20.40	68.00	42.80	91.06
10.00-11.00	43.40	124.00	22.00	122.22	21.20	124.71	43.20	123.43	22.00	122.22	21.80	128.24	43.80	125.14
11.00-12.00	35.20	85.85	14.40	120.00	20.40	70.34	34.80	84.88	14.40	120.00	20.00	68.97	34.40	83.90
12.00-13.00	39.80	110.56	21.00	100.00	19.60	130.67	40.60	112.78	21.00	100.00	19.40	129.33	40.40	112.22
13.00-14.00	35.60	122.76	13.00	118.18	22.80	126.67	35.80	123.45	13.00	118.18	23.20	128.89	36.20	124.83
14.00-15.00	33.80	93.89	14.00	93.33	21.00	100.00	35.00	97.22	14.00	93.33	21.00	100.00	35.00	97.22
15.00-16.00	35.80	132.59	15.00	93.75	21.20	192.73	36.20	134.07	15.20	95.00	21.00	190.91	36.20	134.07
16.00-17.00	34.40	107.50	19.00	105.56	13.00	92.86	32.00	100.00	18.80	104.44	13.20	94.29	32.00	100.00
17.00-18.00	31.00	88.57	15.00	75.00	16.00	106.67	31.00	88.57	15.00	75.00	16.00	106.67	31.00	88.57
18.00-19.00	39.00	97.50	20.80	109.47	18.60	88.57	39.40	98.50	20.40	107.37	18.40	87.62	38.80	97.00
19.00-20.00	36.20	90.50	17.20	122.86	20.40	78.46	37.60	94.00	17.60	125.71	20.20	77.69	37.80	94.50
20.00-21.00	34.80	145.00	14.40	102.86	19.00	190.00	33.40	139.17	14.20	101.43	19.20	192.00	33.40	139.17
21.00-22.00	17.20	90.53	11.60	96.67	5.20	74.29	16.80	88.42	11.80	98.33	5.00	71.43	16.80	88.42
22.00-23.00	26.40	101.54	10.00	90.91	16.60	110.67	26.60	102.31	10.00	90.91	16.80	112.00	26.80	103.08
23.00-24.00	11.40	103.64	3.00	100.00	8.20	102.50	11.20	101.82	3.00	100.00	8.20	102.50	11.20	101.82
24.00-25.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00
TOTALS	630.00	**98.39**	305.00	**95.49**	325.00	**96.22**	630.00	**98.19**	305.00	**95.53**	325.00	**96.24**	630.00	**98.23**
Peak Period Totals	238.8		120		119.4		239.4		120		119.2		239.2	

Appendix 7.5

London Gatwick Hourly Movement Rate Arrivals and Departures Table 1

Time	Case Three 'c'					
	Arr	% of Plan	Dep	% of Plan	Total	% of Plan
0.00-1.00	0.00	0.00	5.00	100.00	5.00	83.33
1.00-2.00	3.00	150.00	3.00	100.00	6.00	120.00
2.00-3.00	1.00	100.00	0.00	0.00	1.00	100.00
3.00-4.00	2.00	100.00	0.00	0.00	2.00	100.00
4.00-5.00	3.00	100.00	1.00	100.00	4.00	100.00
5.00-6.00	8.00	100.00	4.00	200.00	12.00	120.00
6.00-7.00	15.00	100.00	9.60	80.00	24.60	91.11
7.00-8.00	19.00	73.08	17.20	86.00	36.20	78.70
8.00-9.00	21.20	81.54	20.40	81.60	41.60	81.57
9.00-10.00	22.40	131.76	20.40	68.00	42.80	91.06
10.00-11.00	22.00	122.22	21.80	128.24	43.80	125.14
11.00-12.00	14.40	120.00	20.00	68.97	34.40	83.90
12.00-13.00	21.00	100.00	19.40	129.33	40.40	112.22
13.00-14.00	13.00	118.18	23.20	128.89	36.20	124.83
14.00-15.00	14.00	93.33	21.00	100.00	35.00	97.22
15.00-16.00	15.20	95.00	21.00	190.91	36.20	134.07
16.00-17.00	18.80	104.44	13.20	94.29	32.00	100.00
17.00-18.00	15.00	75.00	16.00	106.67	31.00	88.57
18.00-19.00	20.40	107.37	18.40	87.62	38.80	97.00
19.00-20.00	17.60	125.71	20.20	77.69	37.80	94.50
20.00-21.00	14.20	101.43	19.20	192.00	33.40	139.17
21.00-22.00	11.80	98.33	5.00	71.43	16.80	88.42
22.00-23.00	10.00	90.91	16.80	112.00	26.80	103.08
23.00-24.00	3.00	100.00	8.20	102.50	11.20	101.82
24.00-25.00	0.00	0.00	1.00	0.00	1.00	0.00
TOTALS	305.00	**95.53**	325.00	**96.24**	630.00	**98.23**
Peak Period Totals	120		119.2		239.2	

Appendix 7.5

London Gatwick Delay Figures per Hour for SIMMOD Cases Table 2

Time	Planned Movements			Base Case Delays						Case Two Delays					
	Arr	Dep	Total	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	1.00	5.00	6.00	0.00	0.00	1.80	0.37	1.80	0.19	0.00	0.00	1.70	0.34	1.70	0.17
1.00-2.00	2.00	3.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00-3.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.00-4.00	2.00	0.00	2.00	2.00	1.01	0.00	0.00	2.00	0.51	2.00	1.01	0.00	0.00	2.00	0.51
4.00-5.00	3.00	1.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	8.00	2.00	10.00	1.70	0.21	1.20	0.29	2.90	0.25	1.70	0.21	1.10	0.28	2.80	0.25
6.00-7.00	15.00	12.00	27.00	21.30	1.42	23.30	2.41	44.60	1.92	21.90	1.46	23.10	2.40	45.00	1.93
7.00-8.00	26.00	20.00	46.00	55.50	2.95	58.10	3.35	113.60	3.15	58.50	3.08	62.70	3.69	121.20	3.39
8.00-9.00	26.00	25.00	51.00	509.00	24.05	241.00	11.95	750.00	18.00	514.50	24.27	257.40	12.87	771.90	18.57
9.00-10.00	17.00	30.00	47.00	793.80	35.02	240.30	12.65	1034.10	23.84	785.70	35.07	252.70	12.15	1038.40	23.61
10.00-11.00	18.00	17.00	35.00	388.70	17.80	652.50	30.83	1041.20	24.32	394.40	17.93	622.00	29.07	1016.40	23.50
11.00-12.00	12.00	29.00	41.00	86.50	5.97	824.50	40.22	911.00	23.10	86.80	6.03	715.80	34.41	802.60	20.22
12.00-13.00	21.00	15.00	36.00	189.70	9.03	1064.00	59.67	1253.70	34.35	189.80	9.04	1064.00	56.60	1253.80	32.82
13.00-14.00	11.00	18.00	29.00	28.00	2.15	1338.10	64.75	1366.10	33.45	27.90	2.15	1158.20	51.25	1186.10	26.70
14.00-15.00	15.00	21.00	36.00	30.90	2.21	1028.80	54.15	1059.70	28.18	31.00	2.21	754.80	38.12	785.80	20.17
15.00-16.00	16.00	11.00	27.00	45.60	3.04	1058.30	54.74	1103.90	28.89	45.60	3.04	809.50	38.92	855.10	20.98
16.00-17.00	18.00	14.00	32.00	63.50	3.47	746.00	41.45	809.50	22.46	59.70	3.14	149.80	9.72	209.50	6.43
17.00-18.00	20.00	15.00	35.00	45.00	2.94	311.40	17.30	356.40	10.12	43.60	2.90	87.20	5.45	130.80	4.18
18.00-19.00	19.00	21.00	40.00	192.60	9.55	188.70	10.20	381.30	9.88	170.10	8.26	102.40	5.56	272.50	6.91
19.00-20.00	14.00	26.00	40.00	84.60	4.65	379.50	21.89	464.10	13.27	64.40	3.70	318.50	16.94	382.90	10.32
20.00-21.00	14.00	10.00	24.00	41.60	2.97	570.20	28.51	611.80	15.74	41.10	2.93	421.40	20.26	462.50	11.60
21.00-22.00	12.00	7.00	19.00	23.80	1.99	93.00	11.87	116.80	6.93	22.50	1.87	7.80	1.49	30.30	1.68
22.00-23.00	11.00	15.00	26.00	7.20	0.72	103.60	6.41	110.80	3.57	7.10	0.71	100.40	6.12	107.50	3.42
23.00-24.00	3.00	8.00	11.00	0.00	0.00	25.30	2.98	25.30	1.49	0.00	0.00	22.50	2.68	22.50	1.34
24.00-25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	305.00	325.00	630.00	2611.00	**Average**	8949.60	**Average**	11560.60	**Average**	2568.30	**Average**	6933.00	**Average**	9501.30	**Average**
Peak Period Delays					**15.80**		**26.45**		**21.12**		**15.90**		**24.80**		**20.35**
					5.46		19.83		12.65		5.38		14.51		9.94

Delay Summary Table

Simulation Case	Arrival			Departure			Combined			Peak Hour Delay per Movement	
	Total T.T.	Total Delay	Avg. Delay	Total T.T.	Total Delay	Avg. Delay	Total T.T.	Total Delay	Avg. Delay	Arrival	Departure
Base Case	11250.00	2611.00	8.56	7088.50	8949.60	27.71	18338.50	11560.60	18.14	35.02	64.75
Case Two	11249.80	2568.20	8.42	7094.70	6932.70	21.33	18344.50	9500.90	14.88	35.07	56.60
Case Three 'a'	11251.00	2546.60	8.35	7075.10	6364.80	19.58	18326.10	8911.40	13.97	34.81	55.66
Case Three 'b'	11251.70	2556.40	8.38	7072.00	6344.50	19.52	18323.70	8900.90	13.95	34.91	56.18
Case Three 'c'	11251.00	2555.90	8.38	7064.60	6330.00	19.48	18315.60	8885.90	13.93	34.91	56.18

Delay Difference from Base Case

Simulation Case	Arrival			Departure			Combined			Total Chg T.T.+Dly
	Chg. T.T.	Chg Delay	Chg Avg Dly	Chg. T.T.	Chg Delay	Chg Avg Dly	Chg. T.T.	Chg Delay	Chg Avg Dly	
Base Case	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Case Two	-0.20	-42.80	-0.14	6.20	-2016.90	-6.38	6.00	-2059.70	-3.26	-2053.70
Case Three 'a'	1.00	-64.40	-0.21	-13.40	-2584.80	-8.13	-12.40	-2649.20	-4.17	-2661.60
Case Three 'b'	1.70	-54.60	-0.18	-16.50	-2605.10	-8.19	-14.80	-2659.70	-4.19	-2674.50
Case Three 'c'	1.00	-55.10	-0.18	-23.90	-2619.60	-8.23	-22.90	-2674.70	-4.21	-2697.60

Appendix 7.5

London Gatwick Delay Figures per Hour for SIMMOD Cases Table 2

Time	Case Three 'a'						Case Three 'b'						Case Three 'c'					
	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov	Arr	Delay/mov	Dep	Delay/mov	Total	Delay/mov
0.00-1.00	0.00	0.00	1.50	0.31	1.50	0.16	0.00	0.00	1.50	0.31	1.50	0.16	0.00	0.00	1.50	0.31	1.50	0.16
1.00-2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00-3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.00-4.00	2.00	1.01	0.00	0.00	2.00	0.51	2.00	1.01	0.00	0.00	2.00	0.51	2.00	1.01	0.00	0.00	2.00	0.51
4.00-5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00-6.00	1.70	0.21	1.10	0.27	2.80	0.24	1.70	0.21	1.10	0.27	2.80	0.24	1.70	0.21	1.10	0.27	2.80	0.24
6.00-7.00	21.90	1.46	22.90	2.38	44.80	1.92	21.90	1.46	22.90	2.38	44.80	1.92	21.90	1.46	22.90	2.38	44.80	1.92
7.00-8.00	56.20	2.96	58.40	3.40	114.60	3.18	56.60	2.98	58.50	3.40	115.10	3.19	56.60	2.98	58.50	3.40	115.10	3.19
8.00-9.00	514.00	24.25	243.20	11.92	757.20	18.09	514.00	24.25	242.90	11.91	756.90	18.08	514.00	24.25	242.90	11.91	756.90	18.08
9.00-10.00	779.70	34.81	230.60	11.19	1010.30	23.00	782.00	34.91	232.10	11.38	1014.10	23.15	782.00	34.91	232.10	11.38	1014.10	23.15
10.00-11.00	389.80	17.72	607.50	28.66	997.30	23.19	392.60	17.85	612.10	28.08	1004.70	22.97	392.60	17.85	612.10	28.08	1004.70	22.97
11.00-12.00	84.30	5.85	691.90	33.92	776.20	19.89	85.00	5.91	662.70	33.14	747.70	19.53	85.00	5.91	662.70	33.14	747.70	19.53
12.00-13.00	199.40	9.50	1090.90	55.66	1290.30	32.58	203.60	9.70	1089.90	56.18	1293.50	32.94	203.60	9.70	1089.90	56.18	1293.50	32.94
13.00-14.00	27.90	2.15	1115.00	48.90	1142.90	25.53	28.00	2.15	1130.10	48.71	1158.10	25.43	28.00	2.15	1130.00	48.71	1158.00	25.43
14.00-15.00	30.90	2.21	704.60	33.55	735.50	17.88	31.00	2.21	691.10	32.91	722.10	17.56	31.00	2.21	691.10	32.91	722.10	17.56
15.00-16.00	45.60	3.04	685.90	32.35	731.50	17.70	46.00	3.03	663.90	31.61	709.90	17.32	46.00	3.03	663.30	31.59	709.30	17.31
16.00-17.00	57.40	3.02	39.80	3.06	97.20	3.04	52.20	2.78	45.40	3.44	97.60	3.11	52.20	2.78	45.40	3.44	97.60	3.11
17.00-18.00	41.60	2.77	67.10	4.19	108.70	3.48	41.40	2.76	67.40	4.21	108.80	3.49	41.40	2.76	67.40	4.21	108.80	3.49
18.00-19.00	168.70	8.11	95.60	5.14	264.30	6.63	167.90	8.23	97.60	5.30	265.50	6.77	167.90	8.23	97.60	5.30	265.50	6.77
19.00-20.00	63.20	3.68	310.80	15.23	374.00	9.46	68.10	3.87	314.90	15.59	383.00	9.73	68.10	3.87	314.60	15.57	382.70	9.72
20.00-21.00	35.70	2.48	275.80	14.51	311.50	8.50	35.50	2.50	285.20	14.85	320.70	8.68	35.20	2.48	272.20	14.18	307.40	8.33
21.00-22.00	19.50	1.68	5.10	0.98	24.60	1.33	19.70	1.67	5.10	1.01	24.80	1.34	19.60	1.66	4.90	0.98	24.50	1.32
22.00-23.00	7.00	0.70	97.40	5.87	104.40	3.29	7.10	0.71	100.60	5.99	107.70	3.35	7.10	0.71	100.20	5.97	107.30	3.34
23.00-24.00	0.00	0.00	19.70	2.40	19.70	1.20	0.00	0.00	19.60	2.39	19.60	1.20	0.00	0.00	19.60	2.40	19.60	1.20
24.00-25.00		0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTALS	2546.50	**Average**	6364.80	**Average**	8911.30	**Average**	2556.30	**Average**	6344.60	**Average**	8900.90	**Average**	2555.90	**Average**	6330.00	**Average**	8885.90	**Average**
Peak Period Delays		**15.85**		**24.13**		**19.99**		**15.93**		**24.02**		**19.97**		**15.93**		**24.02**		**19.97**
		5.32		13.08		9.20		5.34		13.04		9.19		5.34		13.01		9.18

Appendix 7.6

Cost Benefit Analysis Case Study Results

London Gatwick

Case Two - Intersection Departures -
Total Delay Saving = 34.3 Hrs from the Base Case

Costs	Value	Benefits	Value
Planning and Lobbying time (1 Month)	£30,150	Reduction in Delay for Business Pax.	£1241
Test the procedure (1 Day)	£21,384	Reduction in Delay for Leisure Pax.	£158
Increased ATC Controller Workload (10hrs/day)	£670	Reduction in Operating costs for Regional Aircraft	£9,908
TOTAL	**£52,204**	Reduction in Operating costs for Jet Aircraft	£150,491
		TOTAL	**£161,798**
		Potential Multiplier Effect (including Taxiway construction)	£66,337

Notes:

Benefits

(a) The passenger and aircraft figures used to calculate the benefits above are given below:

London Gatwick Traffic Figures Calculated from Airport Schedule in Appendix 6.6

Regional Aircraft = 141 = 22% of total flights
Jet Aircraft = 489 = 78% of total flights (Of which 100 are charter flights)

Average Regional Aircraft Seat Capacity = 88
Average Jet Aircraft Seat Capacity = 220
Regional Aircraft Passengers = 8,065 (Assuming 65% load factor)
Charter Passengers = 41,173 (Assuming 95% load factor)
Business Passengers = 39,336 (Assuming 60% load factor)
TOTAL PASSENGERS = 88,574 (54% Business/46% Leisure)*

*Total Passenger figure breakdown between leisure and business is calculated by summing the regional and jet business passengers to obtain the total business passengers and taking the charter passengers to represent the leisure passengers.

Case Three 'a' - Early Turns after Take Off -
Total Delay Saving = 44.2 Hrs from the Base Case

Costs	Value	Benefits	Value
Total from Case 2	£52,204	Reduction in Delay for Business Pax.	£1,559
Additional 10hrs/day ATC workload	£670	Reduction in Delay for Leisure Pax.	£203
TOTAL	**£52,874**	Reduction in Operating costs for Regional Aircraft	£12,768
		Reduction in Operating costs for Jet Aircraft	£193,928
		TOTAL	**£208,498**
		Potential Multiplier Effect (including Taxiway construction)	£85,484

Case Three 'b' - Early Turns after Take Off -
Total Delay Saving = 44.3 Hrs from the Base Case

Costs	Value	Benefits	Value
TOTAL (As Case 3 'a')	**£52,874**	Reduction in Delay for Business Pax.	£1,603
		Reduction in Delay for Leisure Pax.	£204
		Reduction in Operating costs for Regional Aircraft	£12,796
		Reduction in Operating costs for Jet Aircraft	£194,366
		TOTAL	**£208,969**
		Potential Multiplier Effect (including Taxiway construction)	£85,677

Case Three 'c' - Early Turns after Take Off -
Total Delay Saving = 44.6 Hrs from the Base Case

Costs	Value	Benefits	Value
TOTAL (As Case 3 'a')	**£52,874**	Reduction in Delay for Business Pax.	£1,614
		Reduction in Delay for Leisure Pax.	£205
		Reduction in Operating costs for Regional Aircraft	£12,883
		Reduction in Operating costs for Jet Aircraft	£195,683
		TOTAL	**£210,385**
		Potential Multiplier Effect (including Taxiway construction)	£86,258

Appendix 7.7

Regional Airline Questionnaire Responses

Airport Delay List

Airport	Mentioned	Delay Out	Delay In	Delay Both	Could use Special Procedures
Amsterdam	x2	N	Y	Y	Y
Athens	x1	N	Y	N	N
Berlin Templehof	x1	N	Y	N	N
Brussels	x2	Y	Y	Y	N
Copenhagen	x1	Y	N	N	N
Florence	x2	Y	N	Y	Y
Frankfurt	x1	N	Y	N	N
Helsinki	x1	Y	Y	N	Y
Iraklion	x1	N	Y	N	N
London Gatwick	x2	N	N	Y	Y
London Heathrow	x3	Y	N	Y	Y
Manchester	x2	N	N	Y	Y
Marseille	x1	N	Y	N	N
Milan Linate	x1	N	N	Y	Y
Nice	x1	N	Y	N	Y
Paris CDG	x1	N	Y	N	Y
Rhodes	x1	N	Y	N	Y
Rome Fiumincino	x1	N	N	Y	Y
Stockholm Arlanda	x1	Y	N	N	Y
Thessaloniki	x1	N	Y	N	Y
Zurich	x1	N	N	Y	Y

Use of Special Procedures

Procedure	Present	Past	Future
Intersection Dept.	10	1	1
Early Turn	9	3	3
Steep Approach	3	0	0
STOL/Separate RWY	1	1	0
Separate Arr/Dept. Path	2	0	3
Combination	2	0	1
Other Procedures Mentioned			
Reduced Separation	1		
RNAV Direct Routing	1		
High Speed Approach	1		
DGPS Trial	1		
Early Turn Off (RETS)	1		

Restrictions on Special Procedures
None of the procedures outlined above are certified
3 are restricted to Visual conditions only
2 do not allow the use of either Fokker 50 or 146/Avro RJ aircraft
One early turn procedure is limited to aircraft take off weights less than 5700kgs.

Ability of the Procedures to solve airport congestion	
Short Term	9
Long Term	6

Obstacles to Use of Procedures	
Dominant Major Airlines	2
Airport/Government Restrictions	11
ATC Restrictions	9
Local Pressure Groups	7
Poor Communication	6
Other	1

Appendix 7.8

Regional Airline Questionnaire Results - Part 2

Response	Question Number																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Strongly Disagree	2	8	4				5	1		3	6	4		7				1
Disagree	11	6	9		1	1	7		9	10	7	9	1	6	2	3	3	12
Agree				5	5	8	2	11	5	1		1	9		7	7	9	
Strongly Agree				9	7	5		1					3	1	4	4	1	
Uncertain	1		1		1			1			1		1		1		1	1
TOTALS	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
% Negative Replies	93	100	93	0	7.1	7.1	86	7.1	64	93	93	93	7.1	93	14	21	21	93
% Positive Replies	0	0	0	100	86	93	14	86	36	7.1	0	7.1	86	7.1	79	79	71	0

Response	Question Number																			
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Strongly Disagree		1				3	3		1	4	1			3		1		3		1
Disagree	6	9	4	8	10	7	11	3	2	9	2	2	2	11	4	8		11	2	
Agree	7	3	10	4	4	3		9	10	1	7	9	12		7	2	10		9	5
Strongly Agree				1				2	1			3			2		4		1	6
Uncertain	1	1		1		1					4				1	3			2	2
TOTALS	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
% Negative Replies	43	71	29	57	71	71	100	21	21	93	21	14	14	100	29	64	0	100	14	7.1
% Positive Replies	50	21	71	36	29	21	0	79	79	7.1	50	86	86	0	64	14	100	0	71	79

Airlines Participating

Air UK	Gill Aviation
Avianova	Hamburg Airlines
British Midland	Interot Airways
Brymon European	Loganair
Business Air	Lufthansa Cityline
Crossair	Olympic Aviation
Finnaviation	Regional Airlines

Questionnaire

		Strongly Disagree	Disagree	Agree	Strongly Agree
1.	Managing special procedure routes will create too much work for the air traffic controller.	1	2	3	4
2.	Aircraft size is growing and this problem will go away.	1	2	3	4
3.	Special allowances for turboprops will create further noise pollution problems around airports.	1	2	3	4
4.	Regional aircraft need access to congested hubs to feed the major carriers.	1	2	3	4
5.	Landing charges are unfair to regional carriers.	1	2	3	4
6.	Too little use is made of regional aircraft performance.	1	2	3	4
7.	Aircraft occupying runway space should be charged the same rate irrespective of their size.	1	2	3	4
8.	Microwave landing systems or GPS will greatly enhance the regional aircraft's ability to access congested airspace.	1	2	3	4
9.	Common practice in the aviation world, such as large carriers dominating airports and squeezing regional airlines out, will mean special procedures will have little effect at the end of the day.	1	2	3	4
10.	Environmental issues make special procedures too costly to consider.	1	2	3	4
11.	Regional aircraft should use reliever airports.	1	2	3	4
12.	The infrastructure costs required to develop these special procedures are too high, giving the ideas no chance of success.	1	2	3	4
13.	Regulation authorities are too short sighted to recognise the benefits of special procedures.	1	2	3	4
14.	The safety issues, related to the special procedures, present too high a risk, making the concepts unworkable.	1	2	3	4
15.	The use of area navigation, (RNAV), routes would improve a regional airlines chance to access congested airports.	1	2	3	4
16.	Too little is known of individual regional aircraft performance capabilities by the aviation community with the result that their potential is not realised.	1	2	3	4
17.	Access to congested airports, for regional airlines, is crucial no matter what the cost.	1	2	3	4
18.	Congested terminal airspace around busy airports allows no room to accommodate the new special routes.	1	2	3	4
19.	The routes will only work if they are totally self-sufficient, requiring minimal air traffic control intervention.	1	2	3	4
20.	These special procedures will only be applicable to airports with more than one runway.	1	2	3	4
21.	High levels of navigational accuracy will be required for these special routings to be considered.	1	2	3	4

	Strongly Disagree	Disagree	Agree	Strongly Agree
22. The problem is not airspace or runway congestion but taxiway, apron, and/or terminal congestion.	1	2	3	4
23. Separate STOL ports are better than trying to fit aircraft into emergency or cross runways at existing airports.	1	2	3	4
24. Special Procedures, such as steep 6° approaches, which involve operating at the edge of an aircraft's performance envelope, present safety implications.	1	2	3	4
25. Making special allowances for regional aircraft will detrimentally affect current commercial operations in terms of safety separation standards and possible longer delays on the ground for other aircraft.	1	2	3	4
26. The procedure would only be worthwhile if extra movements into the congested airport are created and air traffic delays reduced.	1	2	3	4
27. These procedures represent a long term solution to the problems of regional aircraft access to congested airports.	1	2	3	4
28. Regional aircraft should make better use of the off-peak slots and lighter night restrictions, than trying to increase capacity in an already saturated time zone.	1	2	3	4
29. If regional aircraft can be put on separate approaches to STOL/emergency runways at congested airports, while the larger jet aircraft remain on the standard arrival routes for the main runways, there will be a double increase in capacity.	1	2	3	4
30. These special procedures will only work with the co-operation of all airlines, airports, air traffic controllers, and aircraft manufacturers, involved.	1	2	3	4
31. A full cost benefit analysis, taking into account both the direct and indirect effects of the routes would be required, if these routes were to be considered at all.	1	2	3	4
32. Overall the idea is a good one but just not feasible due to the high costs associated with training air crew and air traffic controllers, in addition to infrastructure modifications, etc.	1	2	3	4
33. Air traffic controllers are not given the flexibility to cope with special performance procedures for turboprops.	1	2	3	4
34. United States special turboprop procedures will not be feasible in Europe due to differing operating rules.'	1	2	3	4
35. Although some European airports are already doing something towards developing special procedures for regional aircraft, much more could still be done.	1	2	3	4
36. Route operating costs for special procedures will be too high to justify their use.	1	2	3	4
37. Aviation regulators are aware of the problem of commuter access to congested airports but have to take every users interests into account.	1	2	3	4
38. Commuter traffic should not be forced to move to reliever/regional airports, but increase their movements at international hubs to feed the majors'.	1	2	3	4

That completes the questionnaire. Thank you very much for taking the time to fill it in.

Appendix 7.9

European Airport Questionnaire Responses

Respondants	
Amsterdam	Geneva
Barcelona	London Heathrow
Brussels	Manchester
Copenhagen	Munich
Dublin	Stockholm Arlanda
Dusseldorf	Zurich
Frankfurt	

Percentage of Regional Traffic		
Combined Summary to Provide Confidentiality	13.6	4
	10	25
	30	25
	22	41.5
	50	25
	25	8.8

Type of Traffic	Rating	Response
Point to Point	1	1
	2	5
	3	2
	4	4
Hub Feed	5	1

Weight Related Airport Charges	Yes	No
Landing	13	0
Passenger	0	13
Parking	10	2

Rating of Airport in Congestion Terms	Rating	Response
Not Congested	1	2
	2	1
	3	1
	4	4
Very Congested	5	4

Airport Development Plans - Runways and Taxiways	
Amsterdam	New runway planned to allow independant parallel appraoches in all visibility conditions
Brussels	Construction of RET's, new taxiways and apron traffic flow schemes planned
Copenhagen	Plan to increase hourly movement rate from 73 to 91
Frankfurt	Plan to improve operations, increase aircraft stands, decrease approach separation with technical improvements. Increase movement rate from 70 to 80 per hour, and from 370,000 to 430,000 annual movements by 2000. Further expansions also planned
London Heathrow	Taxiway modifications, addition of RET's and DSP's for runway 27L and 27R
Manchester	2nd Runway enquiry under way in addition to apron and DSP extensions.
Stockholm Arlanda	Plans for a third runway to be operational in 1999

Expectations for Regional Traffic	Responses
Reduce	3
No Change	1
Increase	9

Use of Special Procedures	Response
Yes	8
No	4

Type of Special Procedure Used	Response
Early Turn	8
Discrete Arrival	2
Steep Approach	1

Appendix 7.9

European Airport Questionnaire Responses

Does use of Special Procedure Enhance Capacity		
Yes	9	
No	1	Use of the STOL approach on Runway 28 at Zurich increases departure delays

Largest Issue of Concern with use of Procedures	
Environmental	5
Physical	5
Political	0
Other	0

Comments regarding Changes to Issues affecting Procedures

DUS = Early turns may be introduced for regional aircraft
DUB = Environmental restictions will increase
ARL = 3rd runway will remove current problems
MAN = Airport congestion will put pressure on airports to increase non standard departures but environmental restrictions will increasingly opose the use of non standard departures
AMS = Environmental restrictions at the airport will make operations at the airport more difficult esp. Noise zoning, flight track and noise monitoring

If not using Procedures, why not?	Responses
No Demand	3
Environmental Restrictions	2
Physical Restrictions	1
Political Restrictions	1
Other	0

If not using procedures, is there a need to develop them?	
Yes	2
No	5

Are the procedures a short or long term solution	
Short Term	8
Long Term	5

Comments:

BCN = Development will be dictated by the % of regional aircraft movements and demand
XXX = Longer term may see regional traffic relocated to another airfield
FRA = Procedures represent a long term solution because they represent a potential to reduce used airspace
DUS = Regional traffic will be moved to Monchengladbach
MAN = We try to strike a balance and have sold earlty turns as a method of controlling non standard departures by larger nosier jets. Early turns only apply for aircraft upto BAe ATP size. We are currently evaluating the comments of a selection of regional operators as to their operating procedures prior to any decision on the 2nd runway.

Appendix 7.10

Major Airline Questionnaire Responses

Respondants	
British Airways	Lufthansa
Finnair	SAS
Sabena	KLM
TAP Air Portugal	

Franchise Agreements	
Yes	6
No	1

Importance of Feed Traffic		
Not Important	1	0
	2	1
	3	1
	4	3
Very Important	5	1

Restrictions	
Yes	4
No	2

Airports highlighted as causing restrictions = German Airports, DUS, FBU, CPH, ARL

Future Expectations	Respondant						
in Next 5 Years	1	2	3	4	5	6	7
Regional Increase in Aircraft Size	1		5	3	2.5	2	5
Regionals Move to Reliever Airport	3		1	2	1	1	1
Imporved Technology	5	5	3	4	4.5	4	3
Other						5	

Note: 1= Very Unlikely, 5= Very Likely

Longer Term Expectations	
Comments Made:	Use of reliever airports will increase for routes less than 300km Technological developments will improve the current congestion problems Aircraft size will increase High speed trains will replace some regional feed traffic