Safety Regulation Group

Civil Aviation Authority

CAA PAPER 2004/08

Delivering Safety in the Context of Environmental Restrictions

Aviation Expert and Research Review

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Aviation Expert and Research Review

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Executive Summary

1 The aim of this Paper is to answer the question: "Are there any instances where the desire to promote environmental benefits raises real problems about the safety assurance being provided operationally?" It must be stressed that Department for Transport Guidance to the Civil Aviation Authority is in no way equivocal about the priority of safety in decision-making; it certainly never suggests that the achievement of safety could ever be 'traded off' against other goals. This Paper reviews information gathered from aviation experts' (pilots, safety researchers, airline operations managers, regulators, etc.) response to the open letter plus literature searches through the web, Cranfield University library databases, etc.

2 Seven current types of environmental constraint at an airport are examined:

a) Continuous Descent Approach (CDA);

b) Low Power Low Drag (LPLD);

c) Use of 'non-precision' runways;

d) Crosswind component;

e) Tailwind component;

f) Noise abatement take-off procedure;

g) Noise Preferential Routeing (NPR).

3 Based on the aviation expert inputs and the review of the research literature, several of the present environmental constraints do not appear to pose a significant problem in terms of the risks of an accident. There appear to be three problem areas where there are reasoned concerns:

a) The evidence is that the use of non-precision approaches solely for environmental reasons is unwise. This is a policy conclusion not a requirement for any further work.

b) It is important to demonstrate that NPRs can be flown safely, i.e. they are within normal operational conditions and fully under the pilot's control, immaterial of the type of aircraft using the NPR.

c) The acceptability of workload under CDAs needs to be demonstrated.

4 The missing ingredient as regards existing policies and regulations appears to be the system safety case. Environmental changes tend to have been introduced decades ago, before the safety case philosophy was developed, so there is a need for the problem 'owners' to meet the safety case requirements. The tasks would be:

a) **NPR Design**: A methodology needs to be developed that will establish criteria for the required flyability of NPRs, i.e. ensure that safety levels defined by JAA guidelines are achieved.

b) **CDA**: The safety regulator must be able to judge that the safety 'defences' have not been weakened to levels below JAA guidelines.

Glossary

Abbreviation	Meaning given
ALARP	As Low As Reasonably Practicable
AMSL	Above Mean Sea Level
AOB	Angle of Bank
ARIBA	ATM system safety criticality Raises Issues in Balancing Actors responsibility
ATC	Air Traffic Control
ATM	Air Traffic Mtanagement
BEAA	Aviation Accident Investigation Bureau [Switzerland]
CDA	Continuous Descent Approach
CFIT	Controlled Flight Into Terrain
CHIRP	Confidential Human Factors Incident Reporting Programme
DAP	Directorate of Airspace Policy
DER	Departure End of Runway
DfT	Department for Transport
DGVII	Directorate General VII [European Commission]
DME	Distance Measuring Equipment
FMS	Flight Management System
FSF	Flight Safety Foundation
GPWS	Ground Proximity Warning Scheme
ILS	Instrument Landing System
JAA	Joint Aviation Authorities
LPLD	Low Power Low Drag
MORS	Mandatory Occurrence Reporting Scheme
NLR	National Aerospace Laboratory [Netherlands]
NPR	Noise Preferential Routeing
PDG	Procedure Design Gradient
RNAV	Area Navigation
RVTV	Transport Safety Board [Netherlands]
SEL	Sound Exposure Level
SID	Standard Instrument Departure
SOP	Standard Operating Procedures
STAR	Standard Arrival Route
TAWS	Terrain Awareness Warning System

TMA	Terminal Control Area
TSB	Transportation Safety Board [Canada]
VOR	Very High Frequency Omnidirectional Range

Delivering Safety in the Context of Environmental Restrictions

1 Introduction

1.1 Aviation has to take full account of its environmental consequences. Where the aircraft noise impact on people can safely be reduced, then this should be done. But nobody would want to discover that an accident had happened as even a partial consequence of environmental constraints. There should be no 'trade-offs' between necessary safety and anything else: no environmental gain could in any way compensate for the loss of a life. But European airports, airline operators and air traffic control have to respond to considerable pressures – this is illustrated in Offerman and Bakker (1998). [The Netherlands' policies on flight paths have been significantly affected by the 1992 El Al cargo Boeing 747 crash into a block of flats in an Amsterdam suburb, which killed 43 people.]

1.2 The background to this study, 'Delivering Safety in the Context of Environmental Restrictions', is most easily explained by referring to the 'Open Letter to Aviation Experts' – ~ 100 Experts in all (pilots, safety/environmental researchers, airline operations managers, regulators, etc.). The Open Letter text is displayed on the next page. The aim is to answer the question: "*Are there any instances where the desire to promote environmental benefits raises real problems about the safety assurance being provided operationally?*". This Paper reviews the information gathered from aviation experts' response to the Open Letter plus literature and database analyses.

1.3 As noted in the Open Letter, airport noise related issues are the major area of investigation. The common feature is that the aircraft's operation has to be *significantly* different from what it would have been in the absence of the environmental constraints. This is driven by the nature of aircraft noise, generated by the aircraft's passage and then attenuated through the atmosphere. Thus, there are not many different ways of reducing noise from departing and landing aircraft that affect a sensitive populated area: either the aircraft makes less noise and/or it is further away.

1.4 Section 2 of this Paper sets out a systematic breakdown of these types of constraints. Section 3 then examines the evidence and opinions about safety gathered. Not all the sources for the text in Section 3 are publicly available: some are CAA or equivalent official sources; others are 'non-attributable'. All inputs from the Open Letter are referred to as Expert(s) and noted anonymously: unless noted otherwise, their text is either verbatim or is edited for clarity (many respondents used email notes). Some inputs are certainly 'anecdotal' – but are still serious comments by seasoned professionals. Airports, operators and ATC bodies not explicitly mentioned in accident reports are dis-identified. Section 4 includes some general comments. Section 5 contains some conclusions and recommendations for future work.

1.5 The author wishes to thank all the Aviation Experts who responded for their inputs and insights, both in writing and in discussions, and to express gratitude to Hans Offerman and his colleagues of the Netherlands National Aerospace Laboratory (NLR) for reviewing this document.

OPEN LETTER TO AVIATION EXPERTS FROM PETER BROOKER

The Civil Aviation Authority's Safety Regulation Group (SRG) works within a declared policy on environmental issues:

- Safety is paramount.
- Safety can never be downgraded because of environmental concerns, no matter how significant.
- The necessary safety can sometimes be delivered in different ways - perhaps variations in the costs to operators and (e.g.) the noise nuisance caused. Where such choices exist, there is an onus to take proper account of externalities and the potential for appropriate mitigation of their effects.

Safety requires constant vigilance. There is thus a need to verify that safety is indeed being assured in aviation operations where environmental restrictions are in place. SRG has asked me to carry out such a study. This open letter requests assistance from aviation experts likely to have relevant information.

Examples of environmental restrictions would arise from airport noise related issues. This is not to say that noise issues exhaust all possibilities, merely that noise in the environs of airports generates significant environmental concerns and hence the potential for 'safety choices'. The common feature of such choices is that the aircraft's operation would have to be **significantly** different from what it would have been in the absence of the environmental constraints.

By 'significant' would be meant that the aircraft is flying in a fashion that is possibly much nearer to the edge of its performance envelope. This could mean that there was a restricted amount of testing before such environmental procedures were introduced. Workload implications might not have been explored fully in earlier eras, when human factors aspects did not receive the attention that they do today. Past decisions would have been made cautiously on the evidence available, but it is not always possible to predict fully aircraft performance and operational practices.

The first step in this study consists of gathering information, data collection and literature review. A key element is consultation with relevant experts - people with real practical/technical experience in this area. The aim is to indicate the size and nature of potential problems. Subsequent work will depend very heavily on what the expert inputs, data collections and literature searches reveal. If the situation appears to be completely containable in safety terms, then the project ends. If aspects of safety significance are apparent, then they will be investigated in detail.

I would therefore be very pleased if I could have any information that you have about recorded incidents or 'symptoms', personal/company operational or training experience, pilot reports to airline safety management systems, technical studies and data sources relevant to this project. I would ask you to restrict your inputs to operations at European airports by aircraft types that are currently in operation, and to focus wherever possible on documented evidence. I will of course respect any confidential inputs - but if you think it best to dis-identify the operator or airport involved, please do so.

2 Types of Constraint

2.1 Baseline and Constraint Breakdown

2.1.1 To categorise current types of environmental constraints, it is first necessary to have some kind of baseline aircraft operation at a current commercial airport. This baseline is chosen as a simplified 'traditional' operation at a major airport of some 30 or 40 years ago. Figure 1 is intended to show an observer's perspective from several thousand feet up, and south of a westerly operating airport runway. The lines with arrows show a landing and a take-off. The 'O' symbols represent reporting points. (NB: For expansion of common aviation abbreviations please see Glossary.)

2.1.2 The aircraft flightpaths' main determinants are aerodynamics, pilot workload, and air traffic control (ATC) – not by considerations of noise impact on the ground. Thus, the take-off simply gets the aircraft airborne and then it is turned to fly along a Standard Instrument Departure (SID), generally with a level segment at 3000 or 4000 feet to the reporting point, where it would then be vectored towards the required airway. The landing starts from the reporting point (probably a holding area), the aircraft is next vectored and descended by ATC to fly at 3000 feet along the extended runway line; and the pilot then intercepts an ILS 3 degree glideslope and lands the aircraft. Noise effects under airborne holding areas are not considered here.

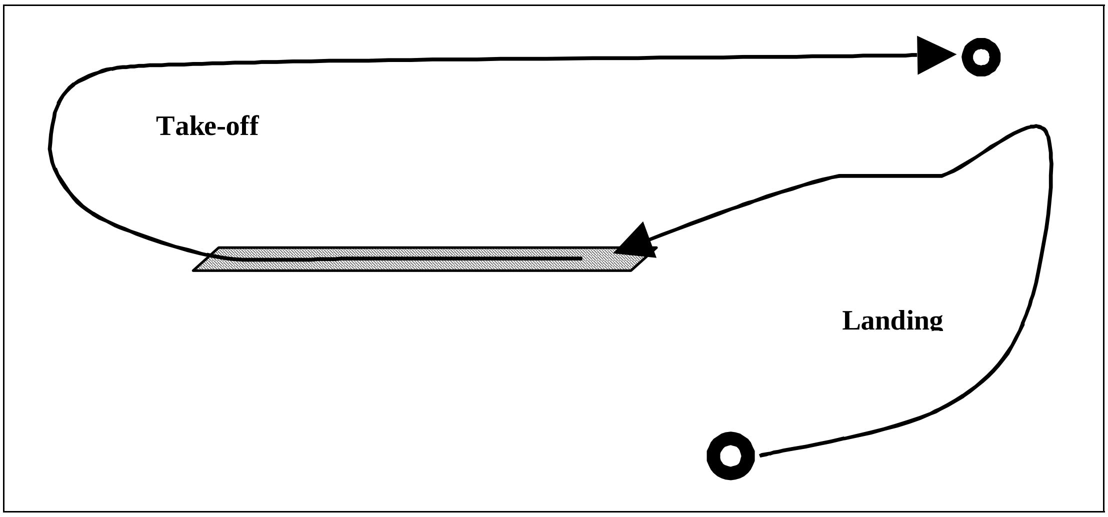

Figure 1 Baseline aircraft operation at an airport – perspective view

2.1.3 The increasing focus on the level and effects of aircraft noise on communities near airports has resulted in considerable efforts by aircraft and airport operators, ATC service providers, and governments to find ways of reducing the noise impact on the ground. There are some excellent general references on the topic available to commercial and business aviation, e.g. the NBAA's 'Airports and the Environment' webpage (2003).

2.1.4 Leaving aside the possibility of individuals' relocation, there are only limited possibilities for reducing noise impact on nearby residents:

a) move the aircraft's ground track away;

b) use that ground track less frequently ;

c) increase the height of the aircraft ;

d) reduce the power setting or alter the aircraft's aerodynamic configuration.

The most important reductions have been achieved – and continue to be sought – through engine design, particularly the introduction of high-by-pass ratio engines, i.e. by reductions in source noise. Airframe noise is now seen as being as important as engine noise, especially during landing. Figure 2, which is a plan view of Figure 1, identifies notional locations (shown as letters) for the various current types of environmental rule, constraint or procedure – all are regarded as 'constraints' in the following.

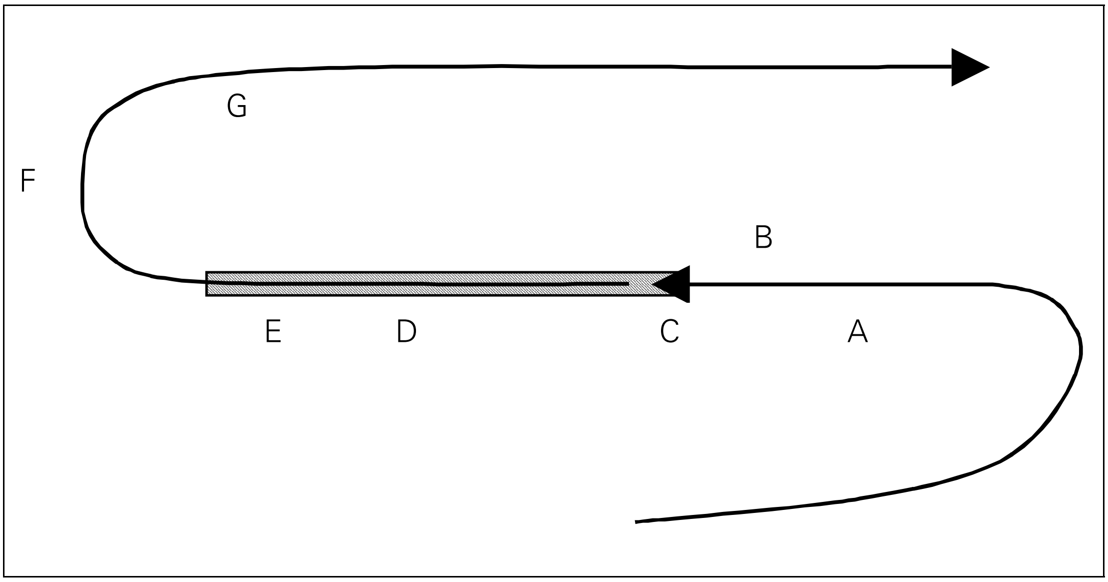

Figure 2 Location of Constraints – plan view of landing and take-off

2.1.5 The letters in Figure 2 stand for:

A – Continuous Descent Approach (CDA)

B – Low Power Low Drag (LPLD)

C – Use of 'non-precision' runways

D – Crosswind component

E – Tailwind component

F – Noise abatement take-off procedure

G – Noise Preferential Routeing (NPR)

This list could of course be supplemented – for example, reverse thrust might be included, as might the 'knock on' implications of rushed procedures in time-critical ground environments – but it does pick up what are generally seen as the major constraints. The following paragraphs describe existing versions of each of these briefly – with considerable simplification – and indicate their noise benefits. Some comments are also made in Section 4 about research and development into noise constraints and procedures.

2.1.6 One possibly important omission might be runway incursions, i.e. where environmental constraints could be a contributory factor in the rate and nature of runway incursions. Several Experts suggested this as a possibility, although precise mechanisms for such events were not identified (but see paragraph 2.1.12). This topic is omitted partly because it is an indirect 'second order' effect, but more properly because runway incursions are already a subject of considerable safety and research interest in both Europe and the USA.

2.1.7 It must be stressed that this breakdown does not cover these 'indirect effects'. One Expert gives another example of these, in ground operations:

> "Ground running of engines by engineers to rectify faults are now strictly limited to 'daytime' hours at several UK airports. Although within itself this may seem a very neighbourly thing to do, it puts a lot of pressure onto the engineer to complete the power runs before the curfew commences. There is also the commercial pressure (real or apparent) on the engineer to complete the check otherwise the aircraft could be out of service until the following day."

Could these pressures affect the correct completion of checks?

2.1.8 There are also concerns expressed about related ATC practices. An example is the speeds within the London TMA. To quote two inputs to CHIRP:

> "I have noticed that the speeds requested by ATC have been creeping up and to positions closer in: '160 to four miles', and now '180 to four miles'. The majority of these speeds/positions are not compatible with establishing a stabilised approach by 1,000 feet above touchdown. High-speed approaches are yet another subtle erosion of safety."

> "…my own experience, and current evidence from active colleagues and friends, causes me increasing concern over the continuing practice of ATCC H cancelling speed control immediately or shortly after take off. This is routinely done regardless of time of day or night, weather conditions, or aircraft type. The most obvious effect is a considerable and unnecessary extension of the noise footprint, which has a negative effect for the industry. My concern, however, is that this practice is seriously reducing safety margins." [NB: the CHIRP input does not explain this point; presumably he or she is concerned that manoeuvres are taking place with the aircraft operating at markedly higher speeds.]

2.2 Continuous Descent Approach (CDA)

CDA requires an aircraft to descend from (say) 6000 feet altitude to intercept the ILS glideslope without using level flight. Descriptions of CDA procedures and noise benefits are given in Kershaw et al (2000) and Bolz and Reuss (2001). The noise benefit, from 6000 feet to ILS intercept, arises from reduced thrust and higher altitude of the aircraft and is substantial – typically 5 dBA (SEL).

2.3 Low Power Low Drag (LPLD)

In LPLD, the aircraft is flown at the highest safe speeds, with aircraft configuration as 'clean' as possible – see Kershaw et al (2000) and Bolz and Reuss (2001). The pilot delays the extension of wing flaps and undercarriage until the final stage of the approach. Benefits are typically 1 dBA (SEL).

2.4 Use of 'non-precision' runway

For certain time periods and conditions, e.g. at night, aircraft might not be permitted to use the usual ILS-equipped runways, but rather to carry out a 'non-precision' approach – e.g. using VOR/DME on a different runway. This removes noise from populated communities at sensitive times.

2.5 Crosswind component

Heathrow airport was originally intended to have 9 runways. One reason was that aircraft in the 1950s had difficulty operating in significant crosswinds. As aircraft design and flight control systems have developed, aircraft can now operate on runways with crosswinds of (say) 25 knots. This may be environmentally beneficial. To quote Offerman and Bakker (1998) re Schiphol: "…runway usage is dictated by avoiding as much as possible these populated communities depending on the meteorological conditions." [NB: Schiphol's multiple runway arrangements appear to have some significant indirect problems – one Expert noted the increased likelihood of runway incursions as a major potential hazard.]

2.6 Tailwind component

It is generally preferable to take-off and land into the wind, but this can result in aircraft flying over some communities for a high proportion of the time. For example, at Heathrow the wind is from the west about 75% of the time and from the east about 25%, i.e., other things being equal, people living to the west get more noise than those in the east of the airport. Governments may decide to change the operating rules ("preferences") so in some periods operations can take place in tailwinds of up to (say) 5 knots, e.g. see DfT (2000).

2.7 Noise abatement take-off procedure

Several types of noise abatement take-off procedures have been adopted to reduce the impact on sensitive areas near the airport runway. They generally involve a thrust reduction after a first segment at take-off power/thrust. The simplest procedure involves a cutback to climb setting power/thrust at 1500 feet above the aerodrome surface level (e.g. see Swatton, 2000). ICAO (2001) Volume 1, Flight Procedures, Part V, Noise Abatement Procedures, Chapter 3 paragraph 3.2.3 (a) states "Noise abatement procedures [for Departure Climb] shall not be executed below a height of 240 m (800 ft) above aerodrome elevation". The procedure is by no means the main factor, as noise impact on the ground varies considerably between types, but it can certainly be very significant.

2.8 Noise Preferential Routeing (NPR)

Historically, SID development was based upon the ground infrastructure of navigation aids. The location of these aids – VORs and DMEs – depended on suitable sites and the need to avoid flying, as far as possible, over populated communities. Governments and ATC bodies therefore produced what were once known as Minimum Noise Routes – now termed Noise Preferential Routes (NPR). These are specific ground tracks, which map on to the SID structure – the NPR is essentially the first part of the SID. By careful choice of NPR/SID, aircraft tracks can be moved up to several miles away from a sensitive community – producing very large reductions in noise impact.

3 Constraints and Safety

3.1 This section examines the evidence and opinions about safety for the constraints sketched in the last section, in the light of the Expert input arising from the Open Letter and from literature/database searches. To stress again, not all the sources for the text in Section 3 are publicly available: some are CAA or equivalent official sources; others are 'non-attributable'. A general observation is made, in italics at the end of each sub-section, on the situation with each constraint. Some conventions need to be stated:

a) A 'concern' is a negative comment made by an Expert.

b) A 'reasoned concern' is such a view plus some comment about the reasons for this concern.

c) The adjective 'several' means 'three or four'. If there were markedly more than three or four Experts involved then the number is noted.

It should also be noted that all the Experts contacted were CAA staff, or individuals suggested by the CAA's staff, or people whose names arose subsequently by Expert recommendation (e.g. the Netherlands ATC body recommended Experts from NLR). All the Experts contacted were in the employment of established aviation or related technical organisations. All the Experts gave every sign of taking this exercise very seriously. No person in the list of contacted Experts is known by the author to be in any way discredited professionally. Environmental lobby groups and airport-resident associations were not contacted.

3.2 A variety of statistical reviews, sources and databases have been consulted, albeit not all to the maximum depth theoretically possible. These include:

a) MORS (Mandatory Occurrence Reporting Scheme);

b) CHIRP (Confidential Human factors Incident Reporting Programme);

c) Eurocontrol Safety Regulation Commission Doc 2 (2002) - Aircraft Accidents/ Incidents and ATM Contribution: Review and Analysis of Historical Data;

d) Flight Safety Foundation reports (some specific documents are listed in the References);

e) Flight Data Monitoring information.

3.3 Continuous Descent Approach (CDA)

3.3.1 Bolz and Reuss (2001) comment that:

> "The CDA procedure … requires planning and analysis on the part of the crew to determine the proper descent initiation point. Since this activity occurs prior to the beginning of final descent, workload level during critical flight phases is not affected. However, given wind deviations from forecast, or errors in selecting the descent initiation point, an overshoot of the glide slope course can occur, causing a period of high workload during that critical phase of flight."

They note that it can be difficult for pilots continually to change speed and aircraft configuration, and that ATC may have to do extra work to ensure that the approach separations are capacity-efficient. One Expert almost verbatim repeated this same message.

3.3.2 One Expert commented that:

> "…the tools required by ATC to give accurate information (track miles etc.) have still not been delivered, and therefore over-emphasis on this requirement by the DfT may lead to an increase in rushed or unstable approaches by pilots and errors by ATC."

3.3.3 Some initial research has been carried out by Heilingers et al (2003) into modelling pilot workload when flying routes and procedures modified because of noise considerations. In this context, one Expert commented:

> "The spare capacity of crew could be eroded through being absorbed by the demands (e.g. of a complex approach, items that have to be remembered) without being detectable by any current recorded means. The eroded situation does not 'cause' a problem and is not in itself unsafe. This is a 'latent' situation that continues dormant until something else happens that the crew should normally be able to cope with – but it demands the use of the spare capacity (e.g. an engine failure). The crew would be assumed to have had that spare capacity available, but now they do not have it due to the erosion from small but additional – perhaps multiple – demands. In such a case, the crew may not react correctly or in sufficient time, and this will be referred to as a crew error –

instrumental in 85% of fatal aviation accidents. (It is like not carrying spare fuel – there is no consequence until a diversion is required.) The presence of such erosion is not evident from CAA data, and in a similar way, such data would not tell the analyst if a design feature were so distracting that, while attending to it, the crew failed in their primary task. This might be regarded as an issue of the way about the collection and recording of data rather than a statement that, despite much anecdotal support, there is 'no evidence'."

3.3.4 *CDA safety issues appear to be focused on workload considerations on the aircraft crew and ATC.*

3.4 Low Power Low Drag (LPLD)

3.4.1 In 1994, a Canadian-operated B757 suffered a tailstrike on landing following a LPLD approach (TSB, 1994). One safety action was the enhancement of procedures to ensure clear guidance for pilots on the technique and the need for a go-around if the aircraft is not stabilised by the minimum altitude specified in the standard operating procedures (SOP). However, LPLD does not appear to be a leading causal factor in the accident: the immediate cause was that the flight crew had not retracted the speed brakes prior to landing – the crew had deviated from SOP and the aircraft flight manual; there was inadequate crew resource management and incomplete checklist procedures.

3.4.2 One Expert commented:

> "Low drag, minimum power approaches have been in place for many years and in our experience do not seem to be a problem."

3.4.3 No Experts mentioned current LPLD approaches as a safety issue.

3.5 Use of 'non-precision' runways

3.5.1 The literature contains some strong statements about the use of 'non-precision' runways. To quote from Eurocontrol SRC (2002):

> "Two accident studies published by the Flight Safety Foundation shows how frequent is the absence of approach aids or adapted procedure in CFIT or landing accidents. The absence of approach radar and precision approach increases the accident risk by a factor of 3 to 5."

An Expert commented that:

> "A non-precision approach is actually 8.5 times more risky than a precision approach and the absence of approach radar increases the risk by a factor of 4. The factors 5 and 3 stated in this report, which are taken from the tables presented in the FSF study, are in fact misleading as they refer to the total risk and don't correctly indicate the true risk increase."

An important problem is the loss of situational awareness by pilots, in some instances exacerbated by high workload.

3.5.2 Quoting again from Eurocontrol SRC (2002) [derived from Enders et al, 1996]:

> "The comparative risks of flying precision approaches vs. non-precision approaches should be conveyed to all operators and airport authorities. Although many other factors influence approach and landing risk, precision approaches provide an extra margin of safety, and providing suitable guidance equipment for accomplishing precision approaches should be a high priority."

3.5.3 One Expert highlighted approach procedures at airport W [minor edits]:

> "Pilots have been complaining for years about W. It involves a dog-leg out to sea and a visual approach avoiding a high-income residential area. [NB: The weather minima for that approach are quite high – an ILS approach is made if the minima are not met, so there is some safety mitigation.]"

3.5.4 Several Experts mentioned the fatal crash involving a Crossair aircraft at Zurich. The following information is drawn from the BEAA [Swiss Aviation Accident Investigation Bureau] press notices (2001 and 2002).

3.5.4.1 At about 22:00 on November 23, 2001, the Crossair Flight 3597 crew were carrying out an approach briefing for a runway 14 ILS approach at Zurich, but were then told to make a runway 28 VOR/DME approach – that runway does not have ILS equipment. The aircraft was descended to 4000ft, then turned right for the final approach to runway 28; the captain reported reaching the minimum descent altitude and said that he could see the ground. Soon afterwards, the radio altimeter reported 500ft agl, followed by a "minimum" warning. The captain then ordered a go around, but this was too late. The aircraft struck treetops (at 1784ft AMSL) and crashed. Weather around the time of the crash included snow. [NB: An Expert says that runway 28 is to be equipped with an ILS in the future, but that, due to the mountainous terrain, it will have a 3.5 degree glide slope, so CAT III (autoland) approaches will not be possible.]

3.5.4.2 The context to this accident is important. An agreement between Switzerland and Germany, made just prior to the accident for noise abatement reasons, prevents the use of German airspace at certain times of the day. When unable to use German airspace for approaches to Zurich runway 28, the approach has to be conducted entirely in Swiss airspace. As an ILS (precision) approach to that runway would be in German airspace, aircraft are therefore required to use the VOR/DME (non precision) approach, which is entirely in Swiss airspace. Thus, after 22:00, incoming aircraft had to approach Zurich from the east to land on runway 28.

3.5.4.3 Unfortunately, the causes of the Crossair accident have not yet been identified. There was no apparent evidence of any misunderstanding at any time between ATC and the two pilots or between the pilots. The most recent press notice (BEAA, 2002) reported continuing investigations. It noted that some causes could be ruled out, e.g. the engine systems were functioning properly at the time of the accident. Eight recommendations were made by the BEAA, but these appear to be of a general nature.

3.5.5 One Expert, whose point was amplified by a CAA Expert (in square brackets below) stressed the need for clarity in this debate:

> "The use of non-precision approaches is *not* inherently unsafe if these procedures are designed and operated to ICAO Doc 8168 standards. [Nevertheless, it is recognised that pilot workload during a non-precision approach is much higher than that required of a precision approach.] The key point is that the highest possible category of runway and approach available should be used regardless of environmental constraints. The USA has a problem with CFIT from non-precision approaches mainly because of the use of a "dive and drive" principle rather than opt for a stabilised approach. Therefore, this aspect is not necessarily appropriate to read across into the European scenario."

3.5.6 *The message from studies of accidents is clear: it is difficult to see how the use of non-precision approaches when precision approaches are available can be justified purely for environmental reasons.*

3.6 Crosswind component

3.6.1 ICAO PANS-OPS Volume 1 Part 5 Chapter 2 paragraph 2.1.3 inter alia lays down that "noise abatement should not be the determining factor in runway nomination … if the runway is not clear and dry … when the crosswind component including gusts exceeds 28 km/hr (15 kt)". High crosswinds produce difficult control conditions in which the aircraft has to be flown in 'drift' or 'wing down' techniques. The aircraft is subject to yawing and rolling moments, and can suffer stability problems. The danger may be worst just after touchdown – gusts may require pilots to input large, rapid and positive steering inputs with the rudder pedals.

3.6.2 There has been considerable interest in recent years in safety aspects of aircraft operations in crosswind, particularly at Schiphol. Indeed, several Experts mentioned that the 'preferential runway is not always the preferred option for the pilots, i.e. crosswind and turbulence'. One of the main reasons for these concerns was an accident at Schiphol in 1997 involving a Transavia B757-200, non-fatal but with minor passenger injuries and a collapse of the nosegear. One Expert asserted that the runway choice for the Transavia flight had been influenced by the 'number of permissible noisy landings having been exceeded'.

3.6.3 The Netherlands investigation (RVTV, 1999 and 2000) identified a number of causal factors and conclusions, including:

- Runway allocation system at Schiphol Airport resulted in strong crosswind conditions for the landing runway in use.
- …omission to state clear and definite crosswind condition limitations in the Operations Manual…
- Non-calculation and/or discussion of crosswind component.

3.6.4 Conclusions 3.16 to 3.18 (in RVTV Report numbering) are worth quoting verbatim:

"3.16 There is a reasonable probability that an actually encountered wind during landing deviates from the reported wind. This uncertainty warrants substantial margins to theoretical wind limitations when operating in crosswind. Note: NLR calculated that the crosswind component at the time of landing was more than 10 kt higher than could have been derived from the latest wind information received from the tower.

3.17 The accident risk increases exponentially when operating in crosswind conditions exceeding 20 kt, including gusts.

3.18 The crosswind criteria of 25 kt and the freedom to exceed this value, as laid down in the preferential runway allocation system used at Schiphol airport, are in potential an invitation to unsafe operations."

3.6.5 The Schiphol accident took place in extremely turbulent conditions. Control tower wind data indicated a crosswind of 35 kt, but subsequently, as part of the work for the accident report, NLR estimated it as up to 45 kt (but see below).

3.6.6 This accident was analysed in an NLR Report (van Es et al, 1998 and 1999) into safety aspects of crosswind [NB: The NLR study had commenced before the accident.] A substantial part of the report consists of criticisms of Boeing practices and FAA certification and regulatory policy. A Boeing response to these points was tabled at a JAA Flight Study Group meeting in 1999 (Boeing, 1999).

3.6.7 Subsequently (RVTV, 2000), NLR detected some irregularities in their calculations of wind speeds during the Schiphol accident. The RVTV Addendum notes that the crosswind in the final phase of the approach was 'in excess of 50 *[sic]* kt'.

3.6.8 Some of the NLR and Boeing documents are concerned with flight-testing and certification in crosswinds, in which pilots have to indicate whether the crosswind conditions are control limiting. Other aspects debated include the best technique for defining and measuring winds and gusts, and the problems posed by wet and/or contaminated runways. To quote Boeing's main points (1999):

"1) The flight test demonstrated crosswind values should not necessarily be considered limiting, since these winds frequently do not reflect the maximum capability of the airplane. Whether the demonstrated crosswinds are considered limiting should be based on engineering analysis and the judgement of the evaluation pilots.

2) Operators should be advised of crosswind guidelines derived from simulation studies, provided the simulation model used adequately represents the airplane. It is necessary to use analytical methods to derive the airplane crosswind capability, since it is impractical to find flight test conditions that will define the airplane crosswind capability on all runway surfaces, i.e. dry, wet and contaminated. …

3) It is appropriate to use calculated winds rather than the tower-reported winds to establish the airplane demonstrated crosswind capability. The calculated values are the preferred wind measurement since they represent the actual winds acting on the airplane."

3.6.9 In the UK, a Boeing 747 landing at Heathrow Runway 27R (AAIB, 2002) came off the runway and finished up on grass between taxiways: there was no damage or injuries. It had landed on a wet runway "on the margins of permitted crosswind limits" and a gust had then caused an aircraft yaw rate that could not be contained. The crosswind guidelines for the aircraft were 32 kt on a wet runway, based on simulator trials and steady wind conditions (NB: 28 kt had been demonstrated on initial certification on a dry runway). After the incident, the operator revised the crosswind limits down to 25 kt on a wet runway. For the wind conditions at that time, there was turbulence from buildings upwind of the final approach path. A recommendation to make changes in the nomination of runways so as to minimise the use of Runway 27R during periods of strong south-westerly winds was accepted by Heathrow ATC and the airport company. An Expert noted that this kind of recommendation has been put in place at many other airports.

3.6.10 A considerable amount of work has been done on crosswind components. There are differences of view between some in the USA and Europe about certification and wind measurement aspects.

3.7 Tailwind component

3.7.1 ICAO PANS-OPS Volume 1 Part 5 Chapter 2 paragraph 2.1.3 *inter alia* lays down that "noise abatement should not be the determining factor in runway nomination … if the runway is not clear and dry … when the tailwind component including gusts exceeds 9 km/hr (5 kt)". JAR-OPS and JAR 25.105(d)(1) require that the tailwind component used in take-off and landing calculations is increased by 50% (Swatton, 2000).

3.7.2 Again, the Netherlands NLR has carried out studies into this area. Van Es and Karwal (2001) based their work on analyses of criteria for safe operation and scrutiny of tailwind-related overrun events. Their findings and comments [with slight edits and one note] include:

> "There should be increased flight crew awareness of the high risk of an overrun when operating with a tail wind on a wet runway or a runway contaminated with standing water, snow, slush or ice.

Aircraft flying at low approach speeds are relatively more sensitive to variations in tailwind with respect to landing distance than aircraft flying at high approach speeds. The braking action of the runway also is important. On a runway with medium to poor braking action, an aircraft is more sensitive to variations in tail wind with respect to landing distance than on a dry runway. Especially aircraft with good aerodynamics (high lift-over-drag ratio) can experience problems when approaching under high-tail-wind conditions. Due to the high lift-over-drag ratio of such aircraft, the engine thrust levels have to be low. With a constant approach speed, the engine thrust must decrease with increasing tail wind to maintain glideslope. In high-tail-wind conditions, the engine thrust may [decrease] as low as flight idle. [Also, anti-icing requirements may mean that it is not possible to select a flight-idle thrust setting.] Flight-idle thrust during the approach is undesirable because engine response to throttle input is slow in this condition. Quick response of the engines is necessary when conducting a go-around. With engines at or near flight idle and the aircraft on a constant glideslope, it will become difficult to reduce [speed] to final approach speed and to configure the aircraft in the landing configuration without exceeding flap-placard speeds. An unstabilized or rushed approach can be the result.

The increased aircraft groundspeed during tail wind operations also increases the required runway lengths for take-off and landing, reduces the time available to conduct an approach, increases pilot workload, and can require a relatively high rate of descent that, at a low altitude, may trigger sink rate warnings by a ground-proximity warning system (GPWS)/terrain awareness and warning system (TAWS) and/or require a go-around for safety.

Landing is the most critical flight phase regarding overrun risk in a tail wind condition.

The FMS-computed tail wind is of little value to the pilot [in] his/her decision to land at the top of descent, during descent and upon initiation of the final approach.

In many of the analysed accidents, the actual tail wind exceeded the approved limit."

3.7.3 The UK arrangements for night time use of runways (DfT, 2000) explicitly note that the landing with up to 5kt tailwind is only permissible in dry conditions. There are still some UK concerns about operational performance, e.g. from two Experts:

"Whether tailwind landings can be consistently achieved is dependent on a range of issues. For example, are safety cases revised when a new type of aircraft starts operating from the runway?"

"I recall an example of airport procedures being approved with permissible tailwind component that were followed by new certification of aircraft that cannot tolerate tailwind component."

3.7.4 *Tailwind constraints do cause concerns if runways are contaminated, but much less so when dry.*

3.8 Noise abatement take-off procedure

3.8.1 Few Experts commented on safety aspects of noise abatement take-off procedures, and there is comparatively little about them in the recent literature and accident reports. The only relevant comment in Eurocontrol SRC (2002) Conclusions is:

"Regulators should not allow noise abatement procedures that reduce the level of safety that existed prior to their implementation."

One Expert noted that "the major problem is not noise abatement on take-off …as the extreme power reductions of Trident days are largely past."

3.8.2 Another Expert comment was that the requirement to be above 1000 feet by 6.5 km from the start of take-off poses problems for some aircraft types. In particular:

> "The A340 has been designed around the need to operate it in the most economic fashion with scant, if any regard, to the needs of the ATM system. The government's position will be to off-load some pax/freight/fuel – almost anything – to achieve the environmental requirements."

3.8.3 *Noise abatement take-off procedures have been in place for the last quarter century. There do not appear to widespread safety issues per se – but note some of the comments in the next sub-section re NPRs.*

3.9 Noise Preferential Routeing (NPR)

3.9.1 Eight Experts noted problems with NPRs. Some commented on institutional issues, e.g:

> "No design criteria for NPRs currently exist and therefore it is difficult to regulate their design with any consistency. Indeed, they are not offered to the CAA for comment prior to publication. There appears to be no methodology for validating the flyability of NPRs. ICAO Doc 8168 PANS-OPS criteria are for evaluating/achieving obstacle clearance only. The same also applies to SIDs. The UK has put a design document for SIDs together, but publication of this essential document has been stopped."

3.9.2 The problems are not confined to Europe, see Aviation Week (2003).

3.9.3 To quote one Expert [a safety specialist – the text has been edited down]:

> "In quite a few investigations concerning loss of separation I found that the basic 'system weakness' was awkward design of SIDs (and STARs) due to environmental restrictions…There appear to be no rigorous discussions concerning flight safety versus environmental requirements between providers of air traffic control and environmental regulators.
>
> Another problem I see is from the controller point of view. They are allowed to deviate from the restrictions 'if flight safety so requires', but they are very unsure of how this should be interpreted. Therefore, they 'play it safe' concerning environmental restrictions, but take flight safety risks instead – not an appropriate trade-off.
>
> A couple of examples:
>
>> At X they use a weird SID taking the aircraft in a 180 degree left turn immediately after take-off. It is difficult to navigate this, turning and climbing. If aircraft 1 starts its turn rather late, and has a low climb rate, and the next aircraft 2 turns early and has a good climb rate, then you may get serious trouble at around 5000 feet. We have had a loss of separation incident. Furthermore, the controller work tasks were not very well designed, since he/she had to monitor 'hot spots' situated in the opposite corner of the sector.
>>
>> The departure controller at Y has a complicated traffic situation. A starting aircraft following the rather weird SID (because of environmental restrictions) would conflict with an inbound to Y, and one to the neighbouring airport Z. It ended with a loss of separation incident. The easy solution would have been to give the starting aircraft a runway heading, but she was not sure whether this was allowed. And she had fresh in her memory that the

tower controller had phoned and (wrongly) criticized her because of a noise complaint."

3.9.4 The majority of existing UK SIDs pre-date the 1980s ICAO procedure design guidance material. At that time, it was known from judgements made from practical experience that the SIDs were 'flyable' by that generation of aircraft. However, one Expert (not a CAA staff member) comments that in the past there has been correspondence from MoD to the CAA from safety researchers about the safety of large jets on London area SIDs. An Expert noted:

> "Many UK airfields have noise abatement procedures that cannot be flown automatically by modern aircraft … These procedures were designed in the 1960s when aircraft were slower and had a tighter radius of turn. To comply with these procedures, modern aircraft have to be de-automated to various degrees thus increasing pilot workload at a very undesirable time. Many noise abatement tracks meander between villages setting an unrealistic expectation with the public, UK airports P and Q being classic examples. The simplest way to reduce noise is to climb straight ahead after take-off to the get to the greatest height in the minimum possible time and distance."

3.9.5 Another Expert referred to a recent ICAO working paper (OCP, 2002). To quote:

> "It is the opinion of many international pilots that many noise/SIDs cannot be successfully flown either automatically or manually.
>
> There are more examples of operational problems caused with the interface between the many operational factors involved in flying the standard/noise departure."

3.9.6 Recent UK activity on safety aspects of NPRs has been under the auspices of the CAA SIDs and STARs Working Group, chaired by DAP and with DfT participation. The Group has met on numerous occasions from 1997 onwards. It has produced more than 60 pages of meeting notes and 19 working papers. One of its main drivers has been the introduction of RNAV-defined routes. The PANS-OPS RNAV criteria are based upon conventional SID design, which requires:

a) first turn is no earlier than 1.9 nm from departure end of runway (DER) which allows the aircraft to achieve a minimum height of 394 feet (120m) on a procedure design gradient (PDG) of 3.3%;

b) there is an assumed aircraft height of 16 feet (5 m) at the DER;

c) aircraft do not exceed an average bank angle (AOB) of 15° during turns;

d) turns must not exceed 120° or be less than 5°;

e) there is a period of stabilisation between turns which would be determined by aircraft speed and bank angle.

3.9.7 Unfortunately, not all UK SIDs match these criteria. For example, there are 16 runways with turns less than 1nm from DER; and 75 turns of 120° or greater in SID procedures – out of a total of 208 UK SID procedures.

3.9.8 The Working Group has tackled these issues in a variety of ways. For example, modern aircraft's climb performance exceeds the current ICAO PDG – 5.75% is feasible – and the assumed DER height (which is applied to assure obstacle clearance) 150ft is feasible. This would allow an increase in the assumed DER height and an earlier turn point. The Working Group judged that bank angles of 20° up to 2000 feet and 25° at 2000 feet and above were operationally acceptable and did not impinge on the safety margins of aircraft operation close to the ground.

3.9.9 Some subtle issues were identified by the Working Group. Rate of turn is controlled by speed – if that is too low *[sic]* (note the speed restriction in UK TMAs), then no amount of bank angle would give the rate of turn required. Moreover, some displays in cockpits were limited to 30° AOB and the proposal to use 25° AOB in procedure design would put the aircraft handling in the upper regions of this equipment. It was noted that agreed criteria must not put an aircraft too near the extremities of its flight envelope, i.e. if an emergency develops, they must not increase the difficulties for aircrew attempting to recover the situation.

3.9.10 Several Experts suggested the need for examination of Flight Data Recorder data and radar track analysis. One Expert commented:

> "How often are aircraft operations eroding the 'margin' between what they actually do and the limits of the safe flight envelope? If turns in reality come within (say) 5% of the limit, whereas normally they would have been expected to come only within 20%, then is there significantly less room for error, for variation, or indeed for dealing with some abnormal event? Moreover, flying closer to the limits may require more attention from the crew, thus also tending to erode their spare workload capacity."

3.9.11 *Experts noted potential problems with the 'safe flyability' of some NPRs. The need to deal with RNAV aspects led to the setting-up of the CAA Working Group, which has managed after considerable hard work to produce what seem to be sensible UK design procedures. Nevertheless, some doubts remain. The Working Group did not – nor was it intended to – examine the safety of the current system. There are several Expert comments from the industry that AOB exceeding 30× are 'not uncommon' at the major airports, particularly for foreign operators.*

4 General Comments

4.1 Potential Changes

4.1.1 The first general comment that needs to be made is to reiterate that the constraints described here are simplified versions of current rules, constraints and procedures. Bolz and Reuss (2001, Section 3, page 15 et seq) give a very structured account (with pros and cons) of the possible range of procedures, covering technology and operational implementation issues, particularly for landings. Many of these procedures were in fact the subject of research and development in the 1970s, but it is only now, with wider implementation of highly automated avionics systems, the availability of highly accurate satellite-based navigation system, and the roll-out of computer assistance to controllers, that such procedures are 'practical propositions'. Obviously, any new noise procedure will have to pass safety decision 'hurdles' and *inter alia* will need to demonstrate 'acceptable workload' for pilots and controllers.

4.1.2 Several Experts voiced their concerns about potential changes of this kind. Indeed, some of the language used shows the concerns: one particular two-segment approach variant, i.e. with a high gradient initial segment, was referred to by one Expert – presumably not an enthusiast – as the 'Stuka dive'. To quote one Expert on the topic of 'steeper approaches':

> "An area of concern … is the mooted increase in approach angle from the traditional 3 degrees. Industry worldwide flies 3 degree approaches and to increase that figure would give severe operational problems for airlines and pilots and would be a major flight safety problem due to potential hard landings and overruns. Operators into the few limited airports like London City have to have specially certified aircraft and crews to enable a safe operation."

4.1.3 There is certainly a strong desire by the Experts that new types of procedure are exposed to the most rigorous data collection, modelling and safety assessments.

4.2 What are the Underlying Questions?

4.2.1 Returning to the main subject here, the safety of existing environmental constraints, what are really the underlying questions that need to be answered by regulators and safety managers? A scan through reports of accident investigation indicates the kinds of messages that matter in practice. The underlying need is that people have done their job properly. They must have acted reasonably and rationally; they must demonstrate that the necessary professional skills have been employed; they must have been active rather than passive.

4.2.2 The third of these clauses – active rather than passive – is very important. At the birth of commercial aviation, significant safety improvements tended to be subsequent to crashes, but, with the current safety culture, regulators and safety managers have to be far more active. They have to monitor safety-related incidents, try to identify the precursors of accidents, sponsor research into potential problem areas, listen and think about pilots' and controllers' expressed safety concerns, etc: they have to 'look for trouble'. Moreover, continued analysis by itself is not enough: the public and the aircraft passenger expect appropriate action, taken at an appropriate time, to ensure continued safety.

4.2.3 One useful metaphor is 'threads of safety'. Threads secure a button on a coat: the more threads then the less likely that the button will be pulled off. The safety threads for aircraft operations at airports are the crew's competence, standard procedures, aircraft controllability and performance within the certificated limits, warning devices such as GPWS, reliability of engines, avionics and navigational aids, etc. If one or more of these threads breaks then the risks of an accident are greater – because the 'defences' have been weakened. In some instances, the defences are valuable because they prevent the crew from being 'boxed in', e.g. an automatic alarm system tells the pilot that the present course of action is a hazardous one, and some different option must be adopted if the pilot is not to be 'boxed in' to a dangerous situation.

4.3 Is there JAA Guidance that can help?

4.3.1 Could JAA Guidance be helpful in this analysis? What kinds of 'safety cases' would be appropriate in examining such constraints?

4.3.2 One way of tackling these kinds of question is to recognise that environment constraints and restrictions are all, in essence, aspects of the 'control of air traffic'. They *restrain* the performance, spatial and time parameters of aircraft – the pilot might otherwise be doing something rather different. So these are actually questions about ATC safety regulation.

4.3.3 ATC safety regulation does not easily match into traditional safety regulation of aircraft systems. ATC safety traditionally focuses on Target Levels of Safety for operation, using various collision and system failure models. However, there has been some work to try to integrate together JAA and ATC safety philosophy – indeed to fit it in with Health and Safety Executive Guidelines (in particular, 'ALARP' – The concept of risk reduction to 'As Low As Reasonably Practicable'). Appendix A provides a very short summary of JAA guidance as it might be adapted for air traffic operations, based on work carried out under the ARIBA (1999) project. [Awareness of the ARIBA work is at present patchy in the aviation safety community. However, there is little doubt that ATM safety experts, both regulators and safety managers, recognise its usefulness, and the implementation of the ARIBA principles is becoming increasingly common.]

4.3.4 The ARIBA work raises very large issues beyond this Paper's remit. But one important issue is the need for an agreed and clear stated safety methodology to be employed when assessing environmental constraints. The present CAA general policies on this topic are set out in "CAA Board 'Sustainable Development and Environmental Policy'" (Doc. 2000/53). Some relevant extracts are:

> "…Thus, where there are 'equivalent options' that meet statutory duties, the best environmental/sustainable one should be chosen.
>
> To ensure that changed environmental requirements do not significantly increase the risk of causing or contributing to an aircraft accident.
>
> Safety must remain paramount in everything that the CAA does.
>
> …safety could not be downgraded because of environmental concerns, no matter how significant."

4.3.5 These are, unfortunately, not equivalent to a safety methodology on JAA lines. Additional constraints will generally increase risk potential – there are one or more extra factors in any safety assessment. But what degree of risk assessment is necessary? What would be 'tolerable'? How would 'reasonably practicable' be judged?

4.3.6 JAA guideline material (JAA, 2000) does indeed note some important considerations for evaluating the severity of failure conditions, e.g:

> Paragraph 7b(1): re "…reductions in safety margins, degradations in performance, loss of capability to conduct certain flight operations…"
>
> Paragraph 7b(2): re the "Effects on crew members, such as increases above their normal workload that would affect their ability to cope with adverse operational or environmental conditions."

4.3.7 But there are issues to resolve re quantitative guidelines – an Expert comments:

> "The JAA currently defines safety levels in JAR AMJ 25.1309. These levels are for aircraft systems only. Some people have been using these quantitative safety levels for aircraft operations as well. The safety levels (or target levels of safety) were based on the assessment of historical accident data in which aircraft systems were a factor. Furthermore, the levels defined by the JAA are per flight hour and not by flight. Therefore it is questionable whether the quantitative safety levels defined by the JAA can be used for other safety assessments. There are fewer problems with using the qualitative safety levels given in the JAR AMJ 25.1309."

4.4 Is Governmental Policy Guidance clear?

4.4.1 One important question that might be asked is: "Is Governmental Policy Guidance about safety and environmental constraints clear?". Fortunately, the UK Department for Transport (DfT) has recently issued "Guidance to the Civil Aviation Authority on Environmental Objectives relating to the Exercise of its Air Navigation Functions" (2002). Appendix B lists all those paragraphs in this document with instructions or guidance specifically related to 'safety'.

4.4.2 Key quotations from the DfT Guidance are:

> "In exercising its air navigation functions the Civil Aviation Authority (CAA) must give priority to maintaining a high standard of safety in the provision of air traffic services in accordance with section 70(1) of the Transport Act 2000 (the 2000 Act)."

"The third strand is to apply (and to encourage and assist airports and operators of aircraft to apply) noise abatement operational procedures, to the extent possible without affecting safety, in order to control operational noise and to mitigate its worst effects."

"It has therefore been the view of successive Governments that: the balance of social and environmental advantage lies in concentrating aircraft taking off from airports along the least possible number of specified routes, consistent with airspace management considerations and the overriding need for safety."

"Changes to airspace arrangements (which includes procedures for the use of controlled airspace in addition to its design) should: be made after consultation, only where it is clear that an overall environmental benefit will accrue or where airspace management considerations and the overriding need for safety allow for no practical alternative."

"Departure procedures should: be designed to enable aircraft to climb quickly and not be inhibited from climbing by conflicts with other traffic, including holding positions, taking into account the overriding need for safety."

"If safety factors preclude consideration of an option that would have a significantly better environmental impact, those factors should be explained."

4.4.3 The key words and phrases regarding safety are 'priority', 'to the extent possible without affecting safety', and 'overriding need'. The document is in no way equivocal about the priority of safety in decision-making: it certainly never suggests that the achievement of safety can be 'traded off' against other goals.

5 Conclusions and Next Steps

5.1 Conclusions

5.1.1 Based on the Aviation Expert inputs and the review of the research literature, few of the present environmental constraints identified appear to pose a significant problem in terms of the risks of an accident. There are large amounts of data on operational performance; and/or there are research studies; and/or there are no significant reports of incidents related to the constraint. Words such as reasonable, rational, professional skills and active can be employed to describe safety work in these areas. Given aviation's strong safety culture, which *inter alia* emphasizes feedback from operational experience, it would be surprising if there had been a large number of Experts concerned about any specific safety issue in this area. Such an event would have indicated both a serious safety situation and major problems with safety regulation processes: it did not happen.

5.1.2 There appear to be three problem areas where there are reasoned concerns by safety Experts. In order of importance:

a) The evidence is that the use of non-precision approaches solely for environmental reasons is unwise. This is a policy conclusion not a requirement for any further work.

b) It is important to demonstrate that NPRs can be flown safely, i.e. they are within normal operational conditions and fully under the pilot's control, immaterial of the type of aircraft using the NPR.

c) The acceptability of workload under CDAs needs to be demonstrated.

5.1.3 There also appears to be a need to develop an agreed and clearly stated safety methodology to be employed when assessing environmental constraints, consistent with JAA guidelines and suitable for practical use. But, it must be stressed that DfT Guidance is in no way equivocal about the priority of safety in decision-making: it certainly never suggests that the achievement of safety could ever be 'traded off' against other goals.

5.2 Next Steps

5.2.1 The missing ingredient as regards existing policies and regulations appears to be the system safety case. Environmental changes tend to have been introduced decades ago, before the safety case philosophy was developed, so there is a need for the problem 'owners' to construct a formal safety case. A system safety case in this context (Profit, 1998) is:

> "A formal document that provides the evidence, arguments and assumptions to support the claim that the system is safe enough for operational use.
>
> This should describe the 'system' and its functions, identify the hazards, assess the risks, identify the measures in place to control the risks, and define the safety management arrangements for the operational system.
>
> This provides an assurance that any risks introduced by the change have been minimised as far as is reasonably practicable."

5.2.2 These statements were made when the author was Group Director Safety Regulation of the CAA, so presumably represent a cogent view about what would be best practice.

5.2.3 In the problem areas above, the problem owners' tasks would be:

a) **NPR Design**: Data needs to be collected, from Flight Data Recording, radar monitoring and other sources, to establish the frequency of extreme events such as a 30° angle of bank. A methodology then needs to be developed that will establish criteria for the required flyability of NPRs, i.e. ensure that safety levels defined by JAA guidelines are achieved. [Note that a poorly designed NPR could affect safe flight on its associated SID.]

b) **CDA**: The target would be to establish that the safety 'defences' have not been weakened to levels below JAA guidelines. In particular, this would need to examine control and pilot workload – and go beyond incident reporting.

Their outputs should be submitted to the safety regulator.

5.2.4 The owners of the two tasks would appear to be the 'operators' – DfT/DAP and the ATC provider respectively. Their initial work would be to identify what could reasonably be done in terms of monitoring and analysis, and to debate this with the regulator. The development of the system safety case would be very much an iterative process.

5.2.5 One caveat: judged in terms of the number and nature of Expert comments – and as indicated by the priority order above – the arguments for the NPR design safety task are markedly stronger than those for the CDA safety case work. The regulator could take the view that a safety case for CDAs might readily be constructed, i.e. that there is known evidence about the necessary oversight of both crew and ATC procedures, and that effective mitigation measures are in place. If such a judgement were to be made, then presumably the decision needs to be 'signed off' in the appropriate safety management controlled document. There would of course still be the requirement to monitor carefully research results on workload measurement in CDAs, the facet noted by Experts.

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The literature search was completed in Summer 2003.

Appendix A JAA Guidelines and ATC – A Sketch

1 To begin with, it is necessary to set out a simplified version of the classification criteria adopted by JAR AMJ 25.1309 for tolerability criteria for any failure condition of a technical system. A 'failure condition' is defined by:

> "**Failure condition**: A failure condition is defined at the level of each system by its effects on the functioning of that system. It is characterised by its effects on other systems and on the whole system. All single failures and combinations of failures…which have the same effects on the system under consideration, are grouped in the same failure condition."

First, each failure condition is classified according to its severity. The JAA qualitative definitions of severity are shown in Table 1.

Table 1 Simplified definitions of severity categories – JAR AMJ 25.1309

Description	Definition
Catastrophic	Failure conditions which would prevent continued safe flight and landing.
Hazardous	Failure conditions which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be…serious injury or fatal injury to a relatively small number of the occupants.
Major	Failure conditions which would reduce the capability of the aeroplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be …discomfort to occupants, possibly including injuries.
Minor	Failure conditions which would not significantly reduce aeroplane safety, and which involve crew actions that are well within their capabilities…May include some inconvenience to occupants.

For each failure condition a classification of its frequency or probability of occurrence is next given. Qualitative definitions of probability according to the JAA standard are given in Table 2, along with 'acceptable' numerical frequency ranges for each flight hour.

Table 2 Definitions of frequency levels and 'acceptable' numerical frequency ranges for each flight hour – JAR AMJ 25.1309

Description	Estimate of Frequency	Frequency per aircraft flight hour
Probable	Anticipated to occur one or more times during the entire operational life of each aeroplane.	more than 10^{-5}
Remote	Unlikely to occur to each aeroplane during its total operational life but which may occur several times when considering the total operational life of a number of aeroplanes of the type.	between 10^{-7} and 10^{-5}
Extremely Remote	Unlikely to occur when considering the total operational life of all aeroplanes of the type, but nevertheless, has to be considered as being possible.	between 10^{-9} and 10^{-7}
Extremely Improbable	So unlikely that they are not anticipated to occur during the entire operational life of all aeroplanes of one type.	less than 10^{-9}

2 JAR AMJ 25.1309 (Section 4: Background) is the key reference document explaining the derivation of this target. It starts from the premise that 'historical evidence indicates that the risk of a serious accident due to operational and airframe-related causes is approximately 1 per million hours of flight', i.e. a rate of 10^{-6}. There is then an allocation of 10% of the risk of a 'serious accident due to operational and airframe-related causes'. Next it is assumed that there are 100 possible failure conditions on an aircraft that can prevent continued safe flight and landing. This assumption is somewhat arbitrary. It is similar to assuming that there are 100 safety-critical systems on each aircraft – there are around 70 safety-critical systems on the A320. The allowable probability of an accident, taken by JAA to be '1 in 10 million hours' is then apportioned equally among the 100 failure conditions. This gives a maximum permissible frequency of occurrence of each catastrophic failure condition of one per billion hours of flight, and hence a maximum acceptable probability of catastrophic failure of 10^{-9} per flight hour.

3 The European Commission ARIBA (1999) project has attempted to build an accident risk tolerability matrix for air traffic operations on HSE (UK Health and Safety Executive, 1992, 1999) lines. ARIBA stands for 'ATM system safety criticality Raises Issues in Balancing Actors responsibility'. It is a project carried out on behalf of DGVII of the European Commission in 1998-1999 and addresses certification in ATM services.

4 The key point is that UK industry safety assessments usually use the HSE studies and guidelines about 'tolerable' and 'acceptable risk' – probably the most well developed decision-making frameworks regarding the control of risk in Europe.

5 A checklist of (simplified) HSE definitions is:

ALARP principle The principle that no risk in the tolerability region can be accepted unless reduced 'As Low As Reasonably Practicable'.

broadly acceptable risk A risk which is generally acceptable without further reduction.

intolerable risk A risk which cannot be accepted and must be reduced.

tolerability region A region of risk which is neither high enough to be unacceptable nor low enough to be broadly acceptable. Risks in this region must be reduced ALARP.

The JAR AMJ 25.1309 guidance then allows failure conditions with the combinations of severity and frequency shown in Table 3. It must be stressed that the words 'Intolerable', 'Tolerable' and 'Negligible' are as suggested by ARIBA, **not** the JAA.

Table 3 Failure condition tolerability matrix adapted from JAR 25.1309 (Annex A).

	Severity			
Probability Level (frequency per flight hour)	Minor	Major	Hazardous	Catastrophic
Probable: $> 10^{-5}$	Tolerable	Intolerable	Intolerable	Intolerable
Remote: 10^{-7} - 10^{-5}	Negligible	Tolerable	Intolerable	Intolerable
Extremely remote: 10^{-9} - 10^{-7}	Negligible	Negligible	Tolerable	Intolerable
Extremely improbable: $< 10^{-9}$	Negligible	Negligible	Negligible	Tolerable

6 ARIBA then produced a matrix indicating how the ALARP concept might be integrated into this framework – Table 4 below. The three regions – shown in different grey shades here – indicate the management decision-making and action required. Thus, in the ALARP region, specific safety management measures should be defined (e.g. safety monitoring, safety improvement projects, etc.) as long as such is reasonably practicable.

Table 4 Possible aviation accident risk tolerability matrix – adapted from ARIBA

Severity of accident	**Frequency of accident**				
Expected fatalities	1 a year in civil aviation	> 1 a year in civil aviation	1 a year per large airline	> 1 a year per large airline	1 a year per aircraft
Hundred(s) of fatalities	**ALARP**	**ALARP**	**Intolerable**	**Intolerable**	**Intolerable**
Many fatalities		**ALARP**	**ALARP**	**Intolerable**	**Intolerable**
Single fatality			**ALARP**	**ALARP**	**Intolerable**
Major injury		**'Tolerable' – manage through normal procedures**		**ALARP**	**ALARP**
Minor injury					**ALARP**
No injury					

Appendix B Extracts re Safety

From "Guidance to the Civil Aviation Authority on Environmental Objectives relating to the Exercise of its Air Navigation Functions"

(January 2002, Department for Transport)

All those paragraphs in the Guidance material with instructions or guidance specifically related to 'safety' are set out below, with the key 'safety sentences' noted by an asterisk (not in original text).

1. *In exercising its air navigation functions the Civil Aviation Authority (CAA) must give priority to maintaining a high standard of safety in the provision of air traffic services in accordance with section 70(1) of the Transport Act 2000 (the 2000 Act). Otherwise it exercises these functions in the manner it thinks best calculated to meet the requirements set out in (a) to (g) of section 70(2) of the 2000 Act, in no particular order of importance:

   (a) to secure the most efficient use of airspace consistent with the safe operation of aircraft and the expeditious flow of air traffic;

   (b) to satisfy the requirements of operators and owners of all classes of aircraft;

   (c) to take account of the interests of any person (other than an operator or owner of an aircraft) in relation to the use of any particular airspace or the use of airspace generally;

   (d) to take account of any guidance on environmental objectives given to the CAA by the Secretary of State after the coming into force of this section;

   (e) to facilitate the integrated operation of air traffic services provided by or on behalf of the armed forces of the Crown and other air traffic services;

   (f) to take account of the interests of national security;

   (g) to take account of any international obligations of the United Kingdom notified to the CAA by the Secretary of State (whatever the time or purpose of the notification).

   If there is a conflict inherent in the application of these provisions, the CAA must apply them in the manner it thinks is reasonable having regard to them as a whole.

29. The Government's approach to tackling aircraft noise has four main strands and is consistent with the "balanced approach" to aircraft noise management described in ICAO Resolution 14/1 14. The first is to seek reductions in noise at source by exploiting and encouraging developments in aircraft and engine technology. This is primarily a matter for international negotiation and agreement, implemented by EU and national regulation. The second, through the application of land-use planning and management policies (described in Section B above), is to direct the location of new noise sensitive development away from major sources of noise and to limit the encroachment of incompatible development into noise-sensitive areas. *The third strand is to apply (and to encourage and assist airports and operators of aircraft to apply) noise abatement operational procedures, to the extent possible without affecting safety, in order to control operational noise and to mitigate its worst effects. The fourth and final strand is to provide the necessary legal framework for operating restrictions to be applied on the numbers and types of aircraft that may operate at particular airports or at particular times. The DAP has an important role to play in

supporting the second and third strands. That role is set out in more detail in the following paragraphs.

32.*It has therefore been the view of successive Governments that:

> *the balance of social and environmental advantage lies in concentrating aircraft taking off from airports along the least possible number of specified routes, consistent with airspace management considerations and the overriding need for safety.

36.*Changes to airspace arrangements (which includes procedures for the use of controlled airspace in addition to its design) should:

> *be made after consultation, only where it is clear that an overall environmental benefit will accrue or where airspace management considerations and the overriding need for safety allow for no practical alternative.

Existing boundaries to controlled airspace should not be a constraint if a satisfactory environmental outcome can be achieved only by taking additional airspace into control.

41.*Departure procedures should:

> *be designed to enable aircraft to climb quickly and not be inhibited from climbing by conflicts with other traffic, including holding positions, taking into account the overriding need for safety.

57. A consultation should usually include an examination of more than one option and reasons should be given if one option is strongly favoured over the others. An explanation should be given of the factors that will be taken into account in reaching a decision, but not so that these preclude consideration of relevant information and comments received from respondents. *If safety factors preclude consideration of an option that would have a significantly better environmental impact, those factors should be explained. Where compliance with internationally recognised procedures is a factor in the development of the proposals, it should be made clear whether compliance with them is mandatory, and if not whether United Kingdom practice in the case in question is always to comply with the internationally recommended procedure.