Biography of Speaker

Dr. Robin Pitblado - Robin Pitblado is Director of London Operations for DNV. This is a group of 100 safety and environmental professionals working in several disciplines, and covering both technical and management systems. Robin has worked actively in the area of risk assessment and latterly on safety cases since the early 1980's. He has co-authored four books on risk assessment and published widely. He has been involved in the development of the risk modelling approach for separation standards, taking particular interest in the Hazard Identification phase and ensuring convergence with similar approaches elsewhere. He was project leader for the EU benchmark project risk assessment, developed systems for quantitative assessment of management systems, and more recently has developed a training course for implementation of safety cases. For relaxation, Robin is a trainee pilot.

LOSS OF SEPARATION - RISK ASSESSMENT
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Executive Summary

Europe has a very good record in preventing mid-air collisions of commercial aircraft. The last collision of a jet airliner was in 1976 near Zagreb when a Trident collided with a DC9-32 at FL330 due to an ATC clearance error. Since then there have been over 100 million flight hours in Europe with no further collisions of jet airliners. However, this low level of risk can not be taken for granted. Significant changes are occurring or are planned in Europe which will have a significant impact on Air Traffic Management.

Mathematical modelling of mid-air collisions has been carried out for over 30 years. These risk assessments have played a vital role in improving airspace utilisation in a safe manner. The tools to carry out such risk assessments are continually being developed. In two recent projects for EUROCONTROL, DNV has used hazard analysis as the starting point for assessments of the risk of losing lateral separation on P-RNAV routes and vertical separation above FL 290.

The method involved:

- Hazard identification - aviation data bases and structured hazard identification sessions were used to carry out a comprehensive identification of the causes of deviations and losses of separation.

- Frequency estimation - historical data and fault tree analysis allowed the likelihood of initiating events to be estimated.

- Consequence analysis - the process of ATC intervention was modelled using field data and simulations and these produced inputs to an event tree structure. This allowed the various outcomes of deviations and losses of separation to be evaluated.

- Risk calculation - the Reich model was adapted to allow inputs from the hazard analysis stages above.

- Risk assessment - calculated risks were compared to a Target Level of Safety to determine safe separation standards.

However, risk is not just a function of route/level separation distance. It depends on a vast range of parameters. The approach above has allowed a range of safety systems and risk reducing measures to be evaluated. Importantly it helps to identify the main risk drivers and hence the areas where safety management can produce the most effect. This approach has not been confined to investigating separation standards. It has been used to evaluate new developments in Communications, Navigation and Surveillance (CNS), and has been applied widely at airports. Further

developments in risk assessment techniques and the collection of high quality data will help to maintain Europe's good safety record.

LOSS OF SEPARATION - RISK ASSESSMENT

Introduction

Europe has a very good record in preventing mid-air collisions of commercial aircraft. The last collision of a jet airliner was in 1976 near Zagreb when a Trident collided with a DC9-32 at FL330 due to an ATC clearance error. Since then there have been over 100 million flight hours in Europe with no further collisions of jet airliners. However, this low level of risk can not be taken for granted.

Significant changes are occurring or are planned in Europe which will have a significant impact on Air Traffic Management. These include:

- Introduction of Basic Area Navigation (B-RNAV) routes, with proposals for future Precision Area Navigation (P-RNAV) routes.
- Reduced Vertical Separation Minima with a target date for European RVSM implementation of November 2001.
- Installation of Airborne Collision Avoidance Systems (ACAS) and proposals for ACAS II to take advantage of TCAS version 7.
- Proposals for introduction of datalink.

These changes and proposals are against a background of increasing traffic and improved navigational capability. All these factors will have an influence on the risk of collisions, and hence considerable effort is going in to the study of the current levels of risk and how these will change in the future.

In 1993 EUROCONTROL commissioned DNV to conduct a feasibility study into the use of Hazard Analysis for investigating the effect of separation standards on the safety of P-RNAV routes. This article describes the study and the wider applicability of Hazard Analysis techniques.

Historic Background to Collision Modelling

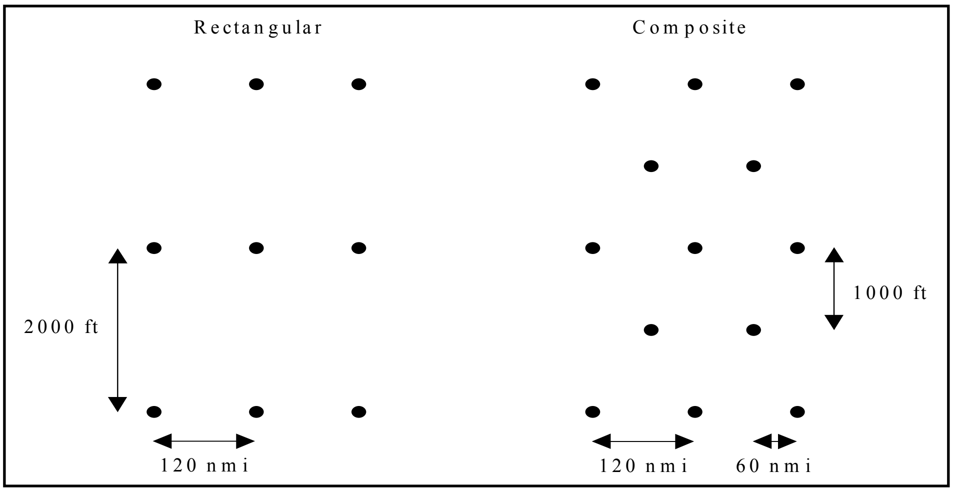
Mathematical modelling of mid-air collisions has been carried out for over 30 years (Machol, 1995). B. L. Marks of the Royal Aircraft Establishment developed the principles on which a collision risk model could be developed in the early 1960s. Marks' work was modified and enhanced by P. Reich and that model, later called the Reich model, has been the basis for many of the important developments in this field.

The model was soon put to use in resolving a dispute about lateral separation standards over the North Atlantic. In 1964, North Atlantic vertical and longitudinal separation standards were 2,000 feet and 20 minutes respectively. Lateral separation had been established at 120 nautical miles. The airlines wished to reduce this separation to 90 nautical miles. The pilots represented by the International Federation of Airline Pilots Associations considered that this would be unsafe. After considerable data collection and analysis using the Reich model it was concluded that a reduction to 90 miles separation standard would indeed be unsafe.

Alternative separation standards were considered and in 1971 the first reduction of separation based on a collision model was agreed; a 120/ 60 mile composite separation standard was judged safe for the North Atlantic (Figure 1). During the late

1970s, more than 100,000 additional flights were observed to determine if 60-mile non-composite separation could be safely implemented. Minimum Navigational Performance Standards (MNPS) were specified based on the collision risk model and by 1981 these standards had been achieved. An important result of the data collection exercise was that critical operational errors were identified; follow up with airlines enabled the causes of these errors to be addressed and remedial actions to be taken.

Figure 1 Composite Route Structure

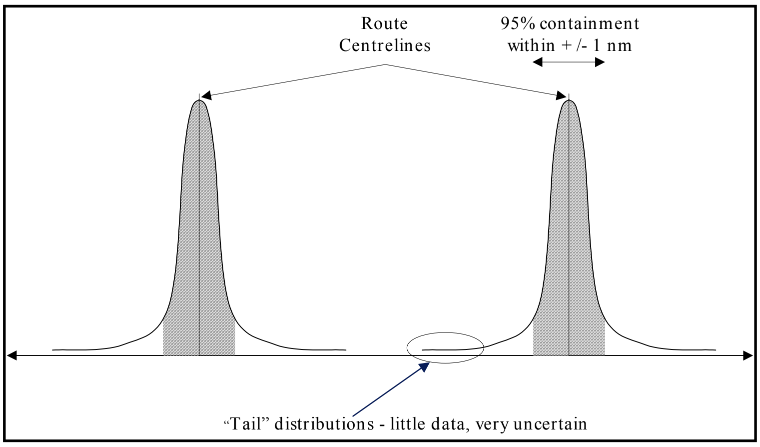


Since then the model has been used in decisions to reduce longitudinal and vertical separation in the North Atlantic, setting up track structures across the Pacific, and assessing closely spaced parallel runways. The developing sequence of models has resulted in separation standards being safely reduced, with increased airspace capacity and consequent economic benefits. Importantly the models have provided a common framework for the various interest groups to discuss issues of safety.

Hazard Analysis Approach

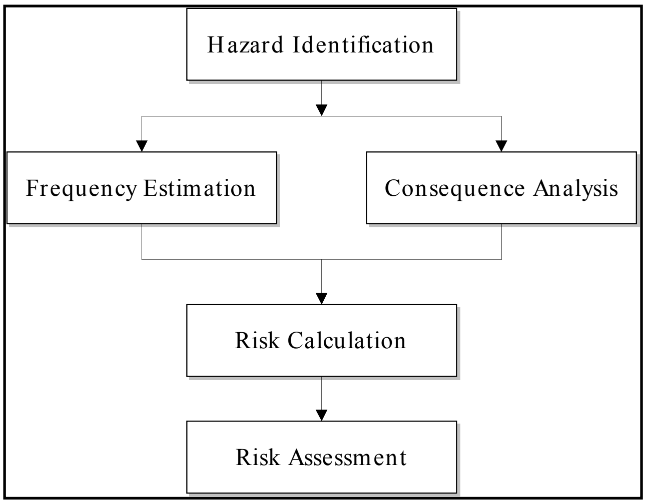
In the recent work for EUROCONTROL on lateral separation of parallel P-RNAV routes, the traditional approach to collision risk modelling has been adapted. Although an extensive data collection exercise was conducted in the 1980s of P-RNAV equipped aircraft (EUROCONTROL, 1988), the "tail" of the distribution of lateral distance from route centre-lines was still very poorly defined (Figure 2).

Figure 2   Lateral Distributions about P-RNAV Route Centrelines



Hence it was necessary to use more theoretical techniques to estimate the frequency of lateral deviations into a parallel route. In addition, the study needed to take account of ATC intervention in terms of detecting lateral deviations and resolving any resulting conflicts. The overall approach is illustrated in Figure 3. Each of these stages is described below.

Figure 3   Hazard Analysis Approach



Hazard Identification

To ensure a comprehensive identification of the causes of lateral deviations a large number of databases were reviewed including:

- Mandatory Occurrence Reports from the UK CAA's Safety Data Unit
- AIRPROX reports published by the UK CAA
- NASA's Aviation Safety Reporting System
- British Airway's BASIS reports

- EUROCONTROL's studies of deviations from RNAV routes.

This enabled a large number of causes to be identified. It also formed the basis for a comprehensive checklist that was taken forward to structured hazard identification sessions (HAZIDs). Two sessions were run with multi-disciplinary groups incorporating pilots, air traffic controllers, navigation equipment manufacturers and risk analysts. Care was taken to involve persons with experience of the full range of operational environments in Europe; thus, for example, pilots were invited from major airlines such as BA and KLM as well as operators of executive jets.

Pilot and ATC tasks were analysed in a systematic manner with "What-if" questions prompting discussion for each task. The group identified causes of problems, together with the possible consequences, the safeguards currently in place and any relevant comments or recommendations. A sample HAZID sheet is shown in Figure 4.

Figure 4 Sample HAZID Record Sheet

Task Description: 1 Pilot Tasks - Preflight Briefing				
What-If Questions	Cause	Consequences	Safeguards	Comments
1.1 Collect Flight Plan What if an up-to-date, accurate flight plan is not collected?	Rerouting not put into flight plan Flight plans held by ATC do not match company plans (summer and winter plans might not correspond) Time of week/day confusion (different routes are used as different airspace becomes available)	Deviation from ATC expectations. Increase in ATC workload dealing with deviating aircraft Enter danger area	ATC and pilot checks of routing Readback by pilots confirming flight route intentions - not always given due to workload and RT blockage	Datalink in future will enable ATC and a/c plan to be compared

The combination of historical data searches together with HAZIDs generated a large list of hazards. Key ones included:

- Flight planning error - a discrepancy between the intentions of the pilots and the flight plan held by the relevant ATC centre.
- Mis-entry of plan - flight plan details incorrectly entered into the aircraft’s RNAV equipment.
- Confusion over navigational modes - aircraft wrongly assumed to be in lateral navigation (LNAV) mode.

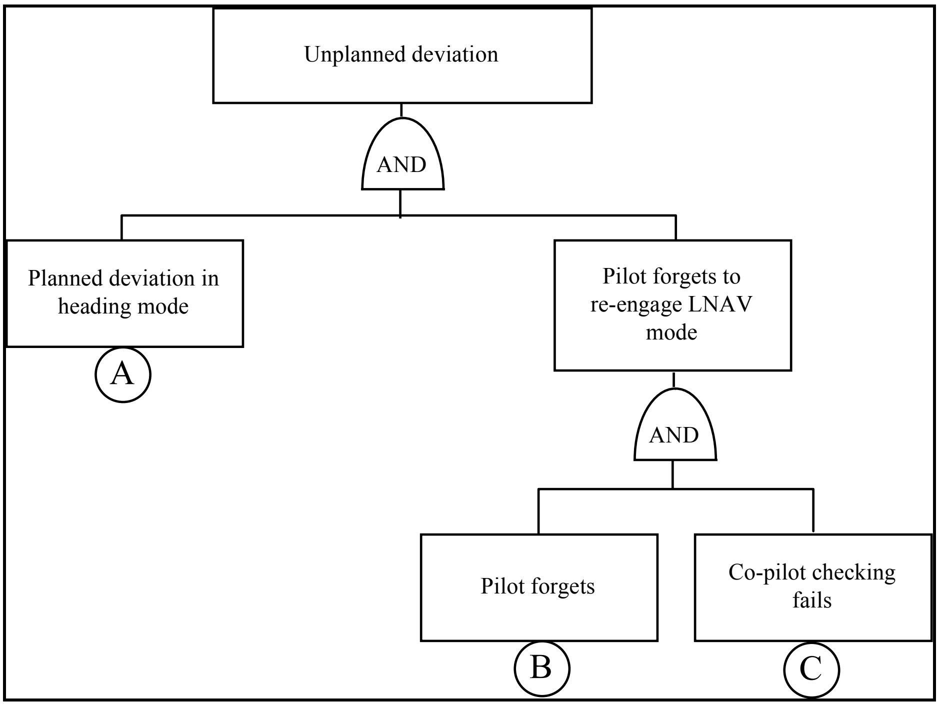
- Callsign confusion - leading to the wrong aircraft turning off a route.
- RNAV equipment fault - occurring in the hardware or operational software.
- Navigational database error.
- Navaid faults.

These hazards were fed through to the frequency estimation stage.

Frequency Estimation

A combination of historical data and Fault Tree Analysis (FTA) were used to generate estimates of the frequency of lateral deviations. FTA breaks down an incident into its component causes, including human error. It uses a logical representation of the many events and component failures which can combine to cause a critical "top event". An example fault tree is shown in Figure 5 for an error in the use of the lateral navigation (LNAV) mode. The top event is an unplanned lateral deviation. The immediate causes of this are the execution of a planned deviation in "heading" mode (Basic Event A) combined with failure to re-engage LNAV mode once the planned deviation is completed. The latter error requires both pilot (Basic Event B) and co-pilot (Basic Event C) to forget to re-engage LNAV mode. Expert judgements from pilots flying in a range of different environments across Europe were used to estimate the relevant frequencies and probabilities.

Figure 5 Fault Tree for LNAV Mode Error



Given the low frequency of such events there is clearly a significant degree of uncertainty attached to the estimates. Credible ranges were generated for the frequency of each hazard and this was reflected in full uncertainty testing of the final results.

The results of this stage illustrated the important contribution that human factors are likely to play in deviations from P-RNAV routes. With increasing reliability of equipment hardware and the extra controls being put into place for operational software and navigational databases, much of the residual risk is likely to arise from human errors in flight planning, use of navigational modes, and pilot-ATC communication.

Consequence Analysis

The ability of ATC to intervene to recover lateral deviations and potential conflicts, should be a major factor in reducing collision risk on European RNAV routes. The general process of ATC intervention is represented in Figure 6. A deviating aircraft is shown heading towards another aircraft on a parallel P-RNAV route. ATC intervention is influenced by a large number of factors. As a result, the modelling of the process could be made highly complex. Given the limited data that is currently available to support the modelling, a simplified structure has been used for the present analysis.

Figure 6 Intervention Process

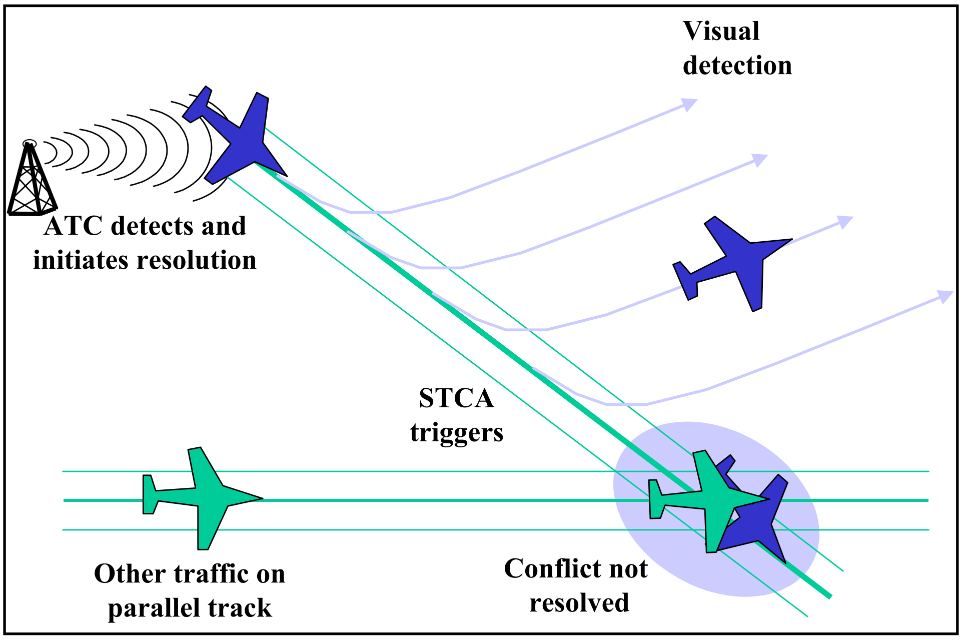
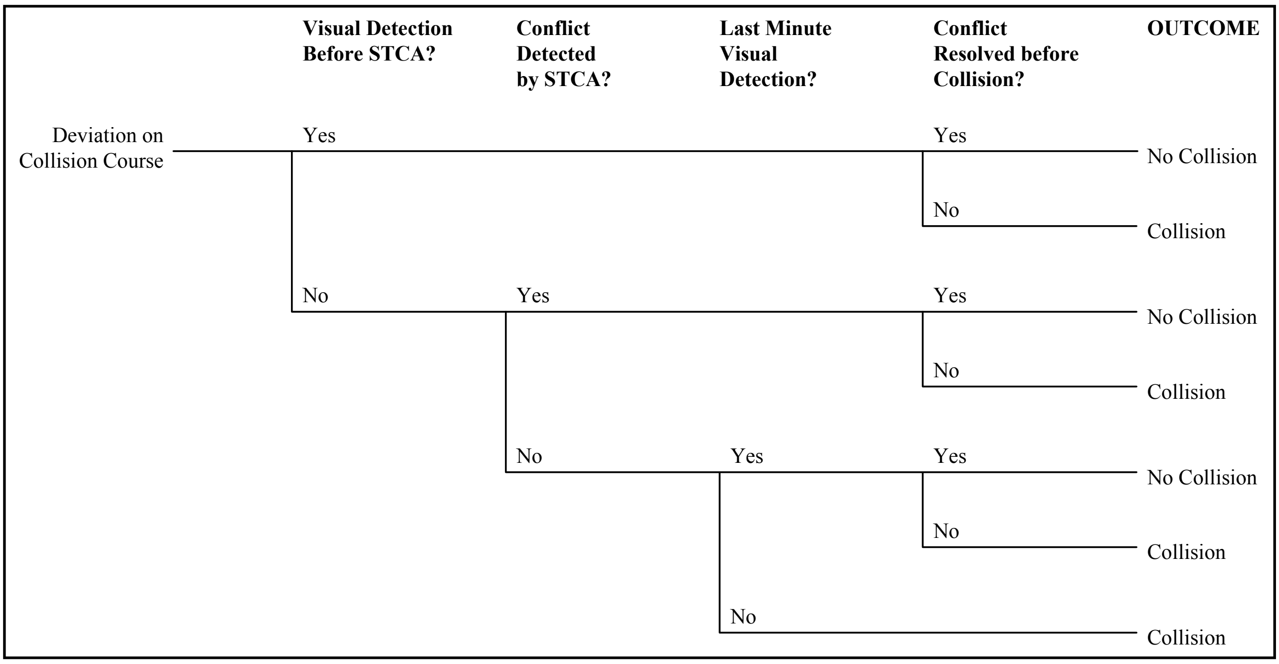


Figure 7 is an Event Tree representing the general intervention process shown in Figure 6. An Event Tree is a graphical representation of a logic model which identifies and quantities possible outcomes following an initiating event. The input to this tree is a lateral deviation which would lead to a collision. The Event Tree represents detection by ATC as occurring:

- Visually (from the radar screen), before Short Term Conflict Alert (STCA) activates
- When the STCA activates
- At the "last minute", if STCA fails or is initially ignored.

If detection occurs before the predicted collision point, the last node of the tree determines whether resolution is achieved. This will be time-dependent; the longer it takes to detect the deviation, the less time will be available to resolve the conflict. If detection does not take place even at the "last minute", then the conflict will not be resolved.

Figure 7 Event Tree - ATC Intervention



Aviation-specific data were used to quantify the Event Tree branches. These were drawn from simulation studies, and field data (e.g. from AIRPROX reports). This information was supplemented and interpreted using ATC expert judgement.

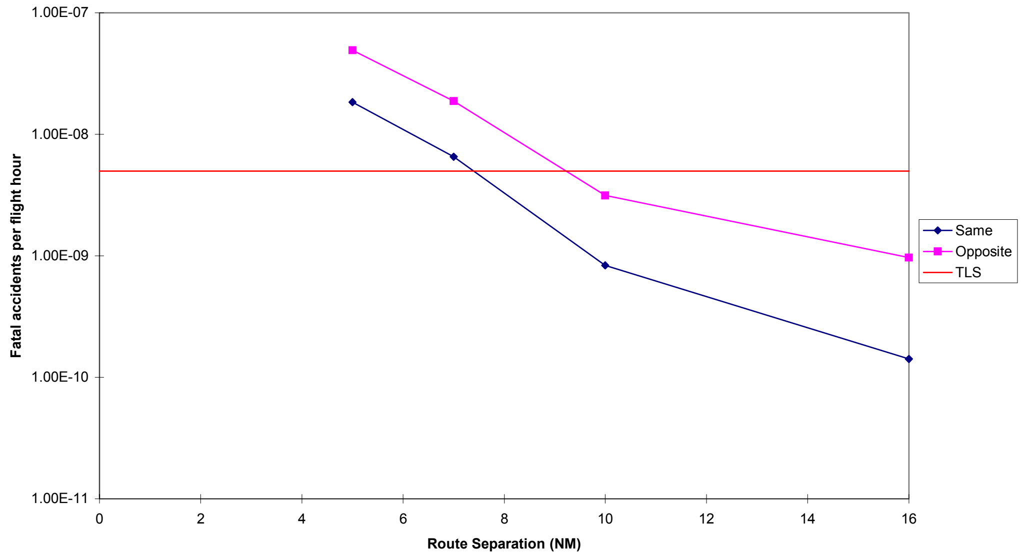
The outputs from this stage of the analysis were estimates of ATC successfully resolving conflicts arising from lateral deviations, and how this would be influenced by separation standards of the parallel routes.

Risk Calculation and Assessment

The Reich model uses information relating to the probabilistic distributions of aircraft's lateral and vertical position, traffic flows on the routes, aircraft's relative velocities and aircraft dimensions to generate estimates of collision risk. The probability of ATC successfully intervening in the event of an impending collision was also integrated into the risk calculation.

The results were presented in the form of fatal accidents per flight hour against separation standard. Figure 8 shows a sample output for same and opposite direction traffic on parallel routes. A range of input parameters was fed into the risk model to reflect the uncertainty associated with deviation frequencies, ATC intervention probabilities, traffic flows, etc. Figure 9 shows the uncertainty bands associated with same direction traffic on parallel P-RNAV routes.

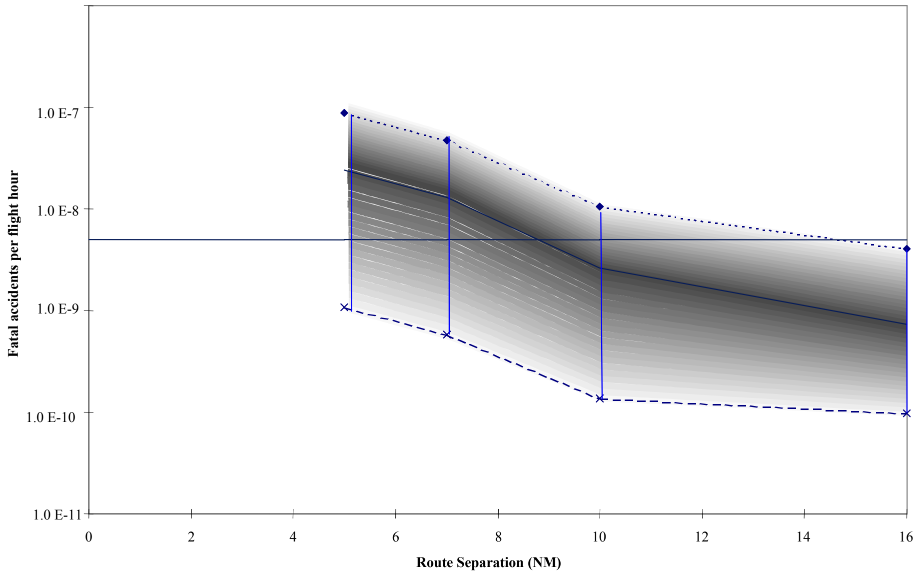
Figure 8 Sample Risk Results - Parallel P-RNAV Routes



The risk results have been compared to a Target Level of Safety (TLS) of 5 fatal aircraft accidents per 1000 million flight hours (5×10^{-9} per flight hour). One collision is assumed in the Reich model to lead to two fatal aircraft accidents. This TLS has been used as a benchmark for the introduction of RVSM in the North Atlantic and is based on an extrapolation of historical accident trends. Its use enables safe separation standards to be derived.

The wide uncertainty band in Figure 9 reflects the difficulty of quantifying the reliability of human actions which can lead to deviations, in the first instance, but then mitigate the consequences of such deviations. Further work will be needed to reduce the uncertainty bands currently associated with the risk estimates.

Figure 9 Uncertainty Bands



Discussion and Wider Applicability

It is important to recognise that quantitative risk assessment (QRA) is not just about generating numbers. The approach outlined above demands a systematic approach which provides valuable insights into how the disparate elements of a complex system (such as ATM) interact. In addition it:

- Highlights the main contributors to overall risks and indicates where risk reduction efforts are best directed.
- Enables the effect of risk reducing measures to be evaluated.
- Encourages collection of data, which aids organisations in ongoing risk management.
- Facilitates communication between groups from different disciplines leading to a more robust assessment of risk.

It is also necessary to recognise the limitations of QRA. The uncertainties associated with low frequency, high fatality events will inevitably be high, particularly when human actions play such a large role in initiating and mitigating such events. It should be recognised that while QRA can be an important input to decision-making, it should not be the only input.

The ability of such a model to assess risk reduction measures is especially valuable. The model developed in this project has already been used to evaluate the potential benefits of ACAS, datalink and cross track deviation alerts. Other changes to Communications, Navigation and Surveillance (CNS) could be evaluated within the model in the future.

EUROCONTROL also commissioned DNV to study risks arising from loss of **vertical** separation due to operational errors. The driver for this study was the proposed introduction of RVSM in Europe. A similar approach to the one described above was adopted building on initial hazard identification. This approach helped to highlight the critical contribution that ATC clearance errors make to loss of vertical separation events above FL290. Prior to RVSM implementation, it will be important to address such errors as well as altitude deviations which have received most attention up until now.

The work to date has highlighted the crucial importance of good sources of data. Databases such as BASIS provide valuable insights into what can go wrong. This improves the quality of risk assessments and the management of the main sources of risk. As the earlier applications of the Reich model have shown, collection of high quality data can act as an important risk control measure. Together with further developments in risk assessment, comprehensive collection of navigation error data would help to maintain Europe's good record in collision prevention.

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