

SYNTHESIS REPORT
- FOR PUBLICATION -

Contract n°: BRPR-CT97-0586

Project n°: BE-97-4110

**Title: Development of a Method for Air Transport Safety Improvement through
Quantitative Risk Evaluation**

DESIRE

Project co-ordinator: National Aerospace Laboratory NLR

**Partners: Airbus Industrie
 Joint Research Centre
 SG Services Ltd
 Sextant Avionique
 Airclaims**

Reference period: from 01/01/98 to 31/12/00

Starting date: 01/01/98

Duration: 3 years

Data of issue of this report: 08/09/02

Project funded by the European Community under the Industrial & Materials Technologies Programme (Brite-EuRAM III)

**Industrial & Materials
Technologies**

BRITE-EURAM III  **IMI**



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2 Summary

2.1 Keywords

Air Transport, Safety, Cost/benefit analysis, Risk Assessment, Modelling

2.2 Abstract

A quantitative risk assessment model of air transport safety that allows cost-benefit analysis of safety measures has been developed and evaluated. The model is intended to be used by all actors in the aviation system as a decision support tool to help indicate those areas where the available safety budget can be invested most effectively. The architecture of the model is based on the concept of a single ‘consequence’ resulting from a chain of events (or causal factors) providing the necessary link to connect such events to accident cost.

The model consists of two parts: a causal part and a cost part. The causal part is a set of generic accident scenarios, constructed from elements of the ADREP classification scheme. The cost part lists ‘heads of cost’ of typical accident outcomes.

The most important problems encountered during the development are a lack of available data to properly quantify the causal part of the model, and the difficulty of modelling the cost associated with loss of airline reputation as a result of an accident.

Results of the project are being used as a basis for further development in a 5th framework project.

3 The Consortium

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3.2 Consortium description

3.2.1 National Aerospace Laboratory NLR

The National Aerospace Laboratory NLR is the central institute for aerospace research in the Netherlands. NLR provides scientific support and technical assistance to aerospace industries and organisations, civil and military aircraft operators and government agencies all over the world. NLR is a non-profit organisation, and conducts a basic research and development programme sponsored by the Dutch Government.

NLR employs a staff of about 900 in two establishments, one in Amsterdam and one in the Noordoostpolder. NLR operates several wind tunnels, two laboratory aircraft, two research flight simulators and an ATC research simulator. NLR has available an extensive set of equipment for gathering, recording and processing flight test data. NLR also has facilities for research in the areas of structures and materials, space technology, remote sensing and environmental testing. NLR's extensive computer network includes a NEC SX-5 supercomputer, tools for software development and advanced software for computational fluid dynamics and spacecraft structures.

NLR participates, on an equal base together with the Deutsche Forschungsanstalt für Luft- und Raumfahrt, in the German-Dutch Wind Tunnel, located in the Noordoostpolder. Together with DLR, The Ministry of Defence in the UK and the Office National d'Etudes et de Recherches Aérospatiales of France, NLR also takes part in the European Transonic Wind Tunnel in Cologne.

Within the NLR, the department of Flight Testing and Safety was responsible for the completion of its role in the project. This department has considerable research experience in the field of aviation safety including:

- systematic safety;
- accident investigation;
- analysis of third party risk in the vicinity of airports;
- analysis of factors influencing safety in the approach and landing phase of flight;
- use of flight recorded data for safety improvements;
- human factors in aviation maintenance
- aircraft operations on contaminated runways (in co-operation with Dassault and Saab).

The department of Flight Testing and Safety also maintains a comprehensive air safety database, which contains information on accidents, incidents and all non-accident flights in the EuroControl region.

3.2.2 Airbus Industrie

Airbus Industrie is a partnership of Europe's largest aircraft manufacturers combining the highly advanced technological abilities of the European industry and is one of only three manufacturers in the market for airliners seating more than 100 passengers. It is responsible for co-ordinating design, development, certification and production, and managing the

marketing, sales and support of the Airbus commercial aircraft programmes. Airbus Industrie's headquarters are in France at Toulouse-Blagnac International Airport, close to the final assembly halls of its current products.

Today, the full partners in Airbus Industrie are Aerospatiale of France with a share of 37.9%, Deutsche Aerospace Airbus of Germany with also 37.9%, British Aerospace with 20% and CASA of Spain with 4.2%. Fokker of the Netherlands and Belairbus, a grouping of Belgian interests, are also associate partners.

The total staff at Airbus Industrie headquarters numbers just over 1,500, while the programme involves some 25,000 people in the partners and subcontractors facilities throughout Europe. This figure is expected to grow to around 40,000 as the product line expands. World-wide, over 1,400 companies in 23 countries supply the Airbus production system.

Airbus Industrie has won some 30% of aircraft orders world-wide in recent years, and has been profitable since 1990. Since its formation in 1970, Airbus Industrie has sold more than 1,800 aircraft over 110 customers with almost 1,200 of them delivered and in service with some 120 operators.

In this project, Airbus Industrie was represented by the Training and Flight Operations Support Division. This division is, among others, involved in:

- crew complement validation through crew workload analyses (task analysis, subjective workload modelling) and crew vigilance analysis (crew observation logging, crew performance evaluation, physiological brain wave measurement, crew behaviour);
- man-machine interface analyses through engineering experiments (statistical analyses on the impact of EFIS, FMS, FBW, crew performance measures, aircraft data recording analysis, oculometry, crew error analyses) and simulation models;
- cockpit resource management as a training tool combined with LOFT scenarios and post training CRM debriefings by means of video recording. Airbus Industrie was the first manufacturer to include a module of Aircrew Integrated Management into its training curriculum.
- trainee progress monitoring through the COSYNUS program aimed at tracking trainee difficulties at an early stage to timely formulate remedial strategies and warrant successful progression,
- definition and establishment of a human factors reporting database, the aircrew incident reporting system (AIRS).

3.2.3 Joint Research Center

The Institute for Systems, Informatics and Safety (ISIS) is one of the Institutes of the European Commission's Joint Research Centre (JRC). The staff of the Institute totals 260 persons coming from the 15 member Countries of the European Union. It also hosts visiting scientists, Ph.D. students and undergraduate students from member States and other countries. The Institute has a long and proven experience in research in various domain of technology, such as Nuclear Safety and Safeguards, Industrial Risk Assessment, Data Collection and Analysis, Environmental protection and Accident analysis.

In the area of Transport Aviation, JRC/ISIS is involved in a number of research activities such as:

- the study of complex organisations, with particular reference to Air Traffic Management (ATM),
- the training on human factors of pilots and air traffic controllers,
- the accident/incident analysis and databases,

- the simulation of pilot and operator behaviour during emergency and abnormal conditions,
- the development of methods for prospective and retrospective evaluations of human errors.

3.2.4 Marsh (formerly Sedgwick)

Sedgwick is one of the world's leading international risk consulting, insurance and reinsurance broking, employee benefits and financial services groups. It is dedicated to achieving increased value for its clients, shareholders and colleagues, through quality, innovation and profitable investment, and to being a responsible member of the communities in which it operates.

Sedgwick operates from over 270 offices in 68 countries and has correspondents in most major cities throughout the world.

Within the Sedgwick group, Sedgwick UK Risk Services provides risk management consultancy and insurance services to commercial organisations of all types and sizes, including the aviation industry. It works closely with Sedgwick Credit, forming the Sedgwick UK and Credit Group, which employs around 1,000 people. Headquartered in London, Sedgwick UK Risk Services has a network of 18 regional offices throughout the UK, all of which are ISO 9001 accredited, demonstrating the company's commitment to providing a quality service from highly trained personnel.

The Sedgwick UK Risk Services broking operation is a recognised industry leader and is able to access global markets to achieve cost-effective cover commensurate with the quality of risk. Its central claims operation provides fast and efficient support following a loss, assistance to overcome the initial aftermath to the final financial settlement. It provides its services to five market segments: global organisations; major national companies; the middle market, companies with a turnover of £10-100 million; the commercial market, with a turnover of £0.5-10 million; and niche/specialist areas. The company has a number of specialist divisions, dedicated to meeting the needs of a wide range of organisations - from the professions to the utilities, and from financial institutions to local authorities and NHS Trusts. Within Sedgwick UK Risk Services, Sedgwick Risk Consulting will be responsible for the completion of its role in the project.

Sedgwick Risk Consulting provides technical and strategic advice to help organisations control and manage their business risks.

3.2.5 Sextant Avionique

Sextant Avionique (currently part of Thales) was formed in July 1989 through the merger of Thomson-CSF Avionics Division and Aerospatiale subsidiaries.

Sextant Avionique is a world supplier of equipment and avionics systems, involved in most of the flight electronic domains for fixed wing and rotary wing aircraft. It manufactures flight control computers, fully qualified auto-pilots, Flight Management Systems (FMS), probe and sensors (e.g. air data, inertial references, Global Positioning Systems, low range radio altimeter), classical and electronic displays (e.g. instrument indicators, stand-by instruments, head-up and head-down displays). The main customers are Airbus Industrie, Dassault Aviation, Bombardier, Boeing and other aircraft manufacturers or airlines.

As Sextant Avionique is a major designer and manufacturer in the aeronautical sector, the company has a large experience in avionics architecture and safety analysis of airborne systems and equipment. The Commercial Air Transport (APN) unit was in charge of this

project for Sextant. This unit provided expertise in failure analysis and functional hazard assessment. The Sextant objective is to increase design methods and techniques in order to improve equipment and system architectures. This is the way to capture more competitiveness for the nearest future where safety and man-machine interface will have to upgrade their performances due to the expected air traffic growth.

3.2.6 Airclaims Ltd.

Airclaims Ltd., a British company, is a wholly owned subsidiary of Airclaims Group Ltd., which in turn is owned equally by the British Aviation Insurance Company BAIC (British) and La Reunion Aerienne (French). Both of these companies are specialist aviation insurers.

Airclaims is an information and consultancy company specialising in the field of commercial aviation. The company is also an international aviation insurance loss adjuster, investigating and reporting on aircraft accidents world-wide on behalf of insurers.

Airclaims can trace its history back to the 1940s when it was an intelligence and loss adjusting division within the BAIC. This operation was merged into the original Airclaims (formed in 1964 from Air Car Inc.) in about 1970 to create the company in its current form.

Airclaims employees about 100 people in nine-offices world-wide (Montreal, Miami, London, Paris, Moscow, Singapore, Brisbane, Sydney and Wellington)., with 60 of these working at the company's headquarters at London.

Airclaims has developed a unique aviation database, CASE, which tracks the history of more than 60,000 jet and turboprop airliners, commuters and business jets from being ordered, through delivery, changes of owner and operator, changes in specification and configuration etc., until eventual destruction or permanent withdrawal from service. The database also tracks the utilisation (flight hours and flights) of most of these aircraft and includes details of major accidents. Aircraft values and insurance loss amounts are also held on the database.

The Airclaims CASE database has become a standard information source and analytical tool for the aviation industry.

Airclaims also publishes a number of aviation reference books and reports including the World Aircraft Accident Summary (CAP 479) on behalf of the British Civil Aviation Authority. CAP 479 is produced as a total turnkey programme from sourcing and researching the original accident details through publication and marketing.

Airclaims information and data products are widely used and are regularly cited in papers etc. Airclaims consultancy operation is well respected and has acted as expert witnesses in a number of arbitrations and court cases.

4 Technical achievements

4.1.1 Rationale

Since the U.S. domestic airlines were deregulated in 1978, shortly followed by liberalisation in Europe, governments throughout the world have adopted policies to stimulate competition in aviation. Competition has been spurred by the privatisation of national carriers and by economic recession. Above all, these changes have put pressure on costs.

The apparent constant accident rate of the last decade is used in combination with the projected growth in traffic volume as base for concern within industry that there might be an accident every week by the year 2015. This view is however a bit simplistic, as it does not take into account the fact that older generation aircraft, which have a relatively high accident rate, will be replaced by newer generation aircraft. When marketing forecast data for different aircraft generations are combined with the actual fatal accident rate of the different generations, a better prediction of the number of accidents is obtained, see figure 1. Indeed the number of fatal accidents is slowly growing in time, and the forecast suggests close to 16 accidents per year in 2015.

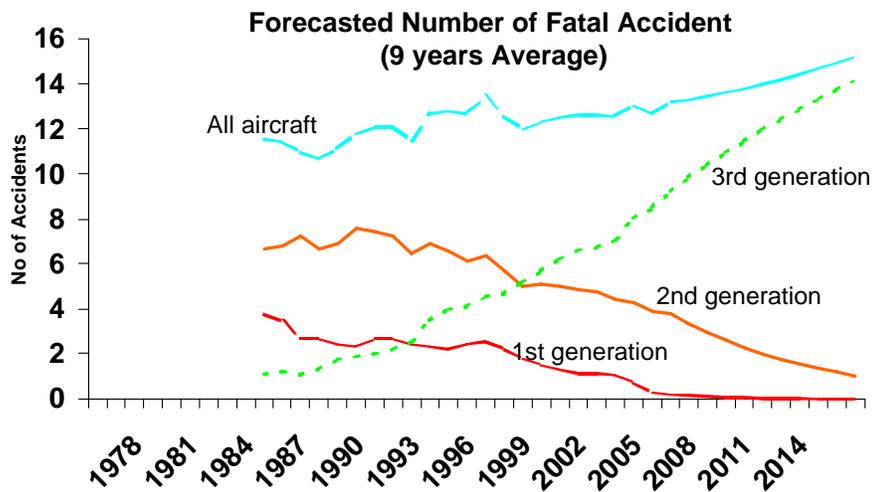


Figure 1: Global fatal accident forecast (large commercial jets)

While this may not seem as dramatic as the “one accident per week” scenario, it must also be expected that public tolerance towards aviation accidents will reduce.

The significant growth of the air traffic volume that is forecasted, combined with new technologies and new operations, placed in the context of today’s society will lead to new pressures on aviation safety. The sector must prepare to meet the demands of a growing industry in a time of decreasing budgets and declining financial resources.

A characteristic of the real world is that available resources are limited. The actors in the aviation system are in need of safety and cost-benefit analysis techniques as evaluation tools to help to decide at an early stage where available resources will have the most impact. These should allow operational managers to communicate in terminology and with argumentation

that is normally used in general and financial management, thus enhancing the decision making process in safety related matters.

4.1.2 Words of caution

The aviation system is incredibly complex and interdependent. As a consequence, it is sometimes stated that it will be impossible to develop a proper risk assessment model. In addition, some believe that a risk assessment model for aviation will not work in practice, since the subjective qualitative judgements of those working within the aviation system have such an important part to play in relation to safety.

A cost benefit analysis can not and should not be used to readily provide answers to the question on what investment is appropriate to protect life and health. A potential danger of cost-benefit analysis can be that it overemphasises readily quantifiable variables and disregards variables that are less readily subject to quantitative valuation. In a cost benefit analysis, it is inescapably necessary to compare costs or benefits that can be quantified with relative certainty to costs or benefits that can not. This requires expert judgement on certain matters and consequently includes subjective elements, rather than being rock solid science. But a thoughtful cost benefit analysis, including explanations of the critical assumptions behind the analysis of scientific evidence, will improve the information relied on in the decision making process. A proper cost benefit analysis is a useful tool for getting an understanding of the gain and loss associated with safety investments.

4.2 Model architecture

The development of a risk assessment model that allows cost benefit analysis requires two elements:

- A causal structure that enables the assessment of the effect of particular measures on risk;
- A cost structure that translates changes of risk into monetary terms.

In both cases, risk is described as a combination of accident probability and accident severity. It is the risk that provides the connection between the causal structure and the cost structure. In order to express and quantify risk, we have introduced the concept of “consequences”.

A ‘consequence’ is defined as the event in the accident sequence that results in the most damage and/or deaths and injuries. This assumes that the event considered as the consequence also gives rise to the most monetary cost. This may not necessarily be so but we believe this holds true in most cases and therefore provides a good initial approach. A consequence provides the necessary link to connect causal factors to accident cost, because it is the governing event of the accident chain of events that gives rise to the cost and determines, all else being equal, the level of cost, rather than what caused it. If an aircraft flies into the side of a mountain this almost always results in the total destruction of the aircraft and the death of all on board, whatever the actual cause of disaster.

An attempt has been made to quantify the occurrence of different consequences and to analyse the relationship between consequences and events in the accident chain, and to explore the relationship between consequences and the cost of the accident. In order to carry out this analysis a sample of more than 1,000 accidents was drawn from the Airclaims CASE database.

The sample was limited to operational accidents involving western-built jet airliners being operated during the period 1970 to 200 and excluded events caused by acts of violence such as sabotage and shoot down. A small number of accidents involving these aircraft in operation with non-airline operators were excluded. Western built jets were chosen because of the

extensive and consistent data set available for both accidents, costs and operational exposure for this class and because these aircraft make up the most important part of the airline fleet. The sample was further limited to accidents where the cost of repairs were equal to or exceeded \$1.0 million or were equal to or exceeded 10% of the aircraft's insurance value, whichever is the lowest.

A total number of 34 consequences were identified, the 10 most frequent being the following:

- Loss of control in flight (not recovered)
- Collision with high ground
- Collision with another aircraft on the ground
- Doors or windows failures
- Uncontained engine failure
- Hard landing (on runway)
- Undershoot
- Overruns (take-off or landing)
- Wheels up landing
- Gear retracted, collapsed or substantially damaged.

The analysis of the accidents showed that in many cases typical accident scenarios could be identified for each of the consequences. For instance, runway overrun accidents are associated with:

- Landing long and fast
- Landing at normal touchdown point on a wet or contaminated runway
- Aborted take-off
- Brake failure.

In other words, accidents are not random combinations of causal factors, but there are patterns visible in the chain of events leading to accidents. By identifying and describing these patterns, we are able to provide the necessary structure that enables the assessment of the effect of a particular measure on risk.

Figure 2 presents the basic architecture of the DESIRE model. The left hand side contains the 'causal' part, with combinations of causal factors eventually resulting in a consequence. As a result of the consequence there will be costs, displayed in the right hand side of the model, the 'cost' part. The next steps in the development of the model are identifying and modelling the causal factors leading to the consequence, and identifying and modelling the cost factors resulting from the consequence.

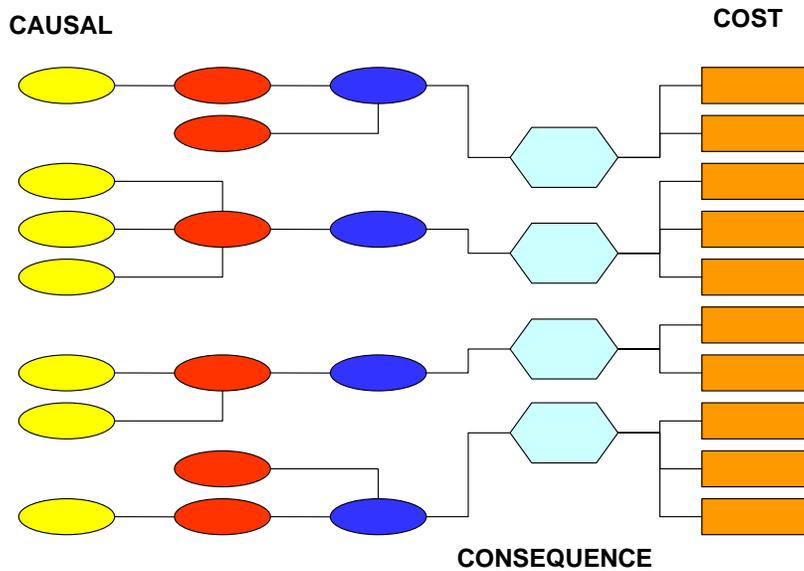


Figure 2: DESIRE model architecture

4.3 Causal factors of accidents

4.3.1 Classification scheme

To describe the chain of events that leads to a particular consequence, the DESIRE model uses a taxonomy of causal factors that is based upon the International Civil Aviation Organisation (ICAO) Accident/Incident Data Report (ADREP) standard. The ADREP system allows tracing back an accident or an incident chronologically by listing all the events that led to this occurrence together with causal factors that triggered these events. Causal factors can be both technical (Descriptive factors) and non-technical (Explanatory factors). We used the proposed ADREP 2000 classification scheme rather than the current ADREP 87 because it provides a more extensive set of categories for coding human performance. These categories are based on the SHELL model (Software, Hardware, Environment, Liveware, see Figure 3) underlying the cause-effect relation with particular emphasis on human factor issues.

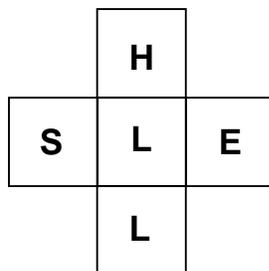


Figure 3: The SHELL model

In correspondence to the SHELL model, in the DESIRE classification scheme the headings and structure of explanatory factors are as follows:

- **Human** covers all of the aspects associated with the individual and his performance, including physical characteristics, physiological issues and psychological issues;

- **Human-Environment** Interface covers aspect associated with the environment, including the physical environment, the task environment (including the workload level imposed upon the individual), and social and company / management issues which may affect the work.
- **Human-System** Interface refers, in this case, to the system as the aircraft or ATC operations room and its equipment and software, and any supporting materials which the human may use to carry out his job.
- **Human-System Support** Interface is considered separately from the Human-System interface in that indirect or non-tangible issues are covered under this heading (training, procedures).
- **Human-Human** Interface covers communications, supervision and checks.

The use of the ADREP system for the classification of causal factors of accidents and incidents has several drawbacks. It is a rather complicated system, requiring experience in using it. The most important limitation comes from the fact that the system is developed for the coding of past occurrences. This renders the classification scheme less suitable for the purpose of modelling accident scenarios in a risk assessment model.

The reasons for adopting this scheme despite these drawbacks are standardisation and data. ADREP has been and will be the accident classification standard for ICAO. In addition, the European states have adopted this standard for the European mandatory incident reporting system ECCAIRS. The ECCAIRS reporting system is maintained, supported and made available to EU civil aviation authorities to collect and exchange aviation incident information from EU member states. The Airclaims CASE database also uses the ADREP classification to record details of accident cost where the aircraft was damaged.

In order to be able to perform any quantified analysis, the risk assessment model must be fed with data specifying the frequency of occurrence of causal factors, alone and in combination with other factors. Adopting the ADREP standard allows us to make full use of the ICAO ADREP, ECCAIRS and Airclaims databases.

4.3.2 Development of accident scenarios

Accident consequence scenarios for each of the identified ‘consequences’ have been developed, using the elements of the classification scheme as ‘building blocks’. The objective was to develop generic scenarios, i.e. typical patterns that are visible for certain types of accidents. For this reason we used higher level elements of the classification scheme, and not the most detailed level. The scenarios were initially established by the analysis of accident and incident reports, i.e. retrospective analysis. Such an approach requires extensive analysis before obtaining an acceptably exhaustive model for each accident consequence category. In addition, there is a risk of possible loopholes in the model with respect to hazards that have not yet materialised and potential hazards in future aviation. It is therefore required to combine retrospective analysis with prospective analysis.

Two different types of prospective analysis were used during the development of the model:

- Extrapolation of existing accident circumstances in order to determine whether variations in the accident sequence would result in differences with respect to fatalities and damage.
- Systematic analysis in order to find original combinations.

It should be remembered that, although it is possible to create ‘generic’ accident scenarios for the purpose of risk analysis, in reality, generic accidents do not exist and individual accidents

may not fit in this scheme. Because of the paradox between model completeness and model uncertainty we decided not to develop the scenarios into more detail. However, we believe that the generic accident scenarios that were developed are suitable to conduct a risk analysis, and are a proper match with the current cost part of the model.

4.3.3 Quantification of causal factors

Data from aircraft operators, manufacturers and incident databases (from both mandatory and voluntary incident reporting system) were analysed to estimate the probability of occurrence of events and descriptive and explanatory factors. For this purpose we not only need accident and incident data, but also data on normal operations (exposure data). Exposure data is required to determine whether particular factors or combinations of factors occur more frequently in incidents than in normal operations. The probability of occurrence follows from dividing the number of occurrences by the corresponding exposure.

The following data sources were used:

- Operator data
- FAA incident data system
- NLR air safety database and denominator database
- Aviation Incident Reporting System (ASRS)
- Manufacturer data (aircraft and systems manufacturers)

Analysis shows that airline operational data and data from the manufacturer are reliable sources of information. A problem with these sources is that the information is often regarded as confidential and hence not accessible. We were only able to establish frequencies of occurrence for a limited number of causal factors. The other sources of information had to be used to quantify the frequency of occurrence of the remaining factors. A problem with these sources is that not every occurrence will be stored in the databases. Only occurrences that are considered to be 'severe' enough will be captured by incident reporting systems. As an example, the airline operator will know exactly how many autopilot problems have occurred, but not every autopilot problem will be (nor has to be) reported to a (mandatory) incident reporting system. In order to estimate how many occurrences take place for every reportable occurrence, we compared airline operational data with data from incident reporting systems for similar causal factors.

From the analysis it followed that on average 1 in every 350 occurrences is reported in mandatory incident reporting systems, while 1 in every 15 occurrences is reported in a confidential incident reporting system. These figures are approximately the same for all factors that could be analysed. This means that not only one in every 15 autopilot problems is reported in a confidential incident reporting system, but also 1 in every 15 flap control system problems, etc. We acknowledge that these are very rough estimates, but in the absence of better alternatives we will continue using them.

These results were subsequently used to estimate probabilities of occurrence for those factors where operator or manufacturer data was not available. Despite a significant research effort and the innovative way of using incident data to estimate frequencies of occurrence in nominal operations, we were not able to determine probabilities of occurrence for all elements of the taxonomy of events, descriptive factors and explanatory factors. In cases where we could not determine the probability of occurrence for a given item, we used the probability of items that belong to the same group or tackle similar technical or human concerns as estimates.

The quality and quantity of data varies from one database to the next. There are many different databases maintained by different actors within the aviation system with different contents, levels of detail, volume, accessibility, etc. This holds for Europe in particular and is an obstacle to getting full benefits of the good data that do exist in different bodies within aviation. There is a particular need for a European confidential incident reporting system. Confidential incident reporting systems are indispensable because they can provide information on events and causal factors which are not measurable in any other way. Development of a complete, fully operational European confidential incident reporting system is of paramount importance. A proper legal framework that would protect individual reporters and reporting parties should accompany this.

4.4 Accident cost factors

The most significant determinants of cost arising from accidents and incidents are aircraft damage, deaths and injuries suffered by occupants, and loss of airline reputation. However, costs may arise from an accident in a number of ways, both directly and immediate and indirectly, perhaps over a longer term. The DESIRE model uses heads of cost that includes both direct and indirect factors.

A large sample of some 1,000 accidents was reviewed in order to produce a profile of the aircraft physical damage and the percentage of occupants killed in each 'consequence'. Aircraft physical damage is expressed as a percentage of repair costs (or estimated repair cost for insurance purposes) relative to the theoretical new price of the aircraft in the year of the accident. As an example, the profile of aircraft physical damage for the consequence 'hard landing' is presented in Figure 4.

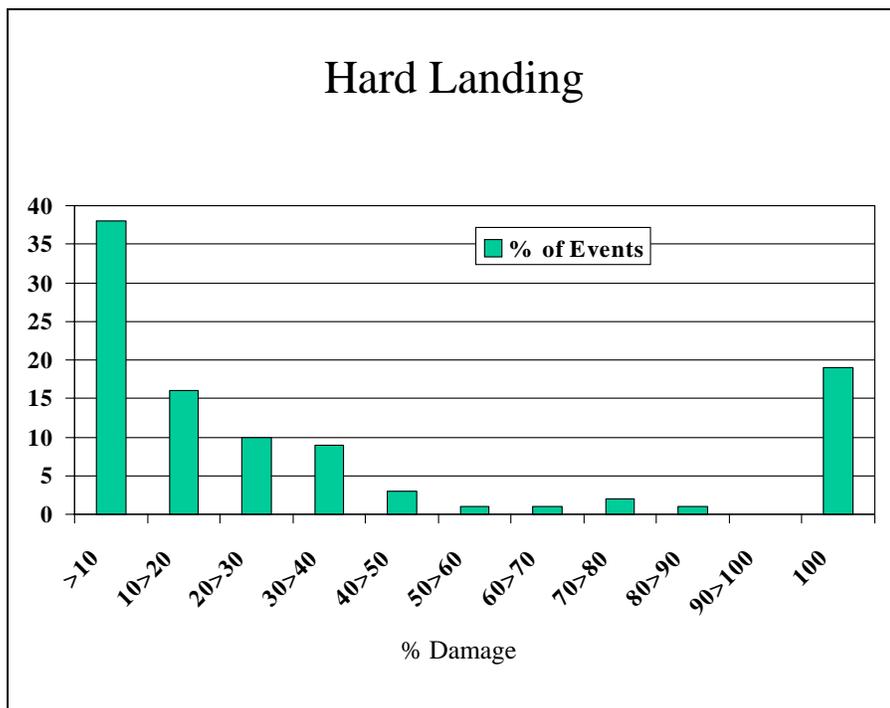


Figure 4: Profile of aircraft physical damage for hard landings

The analysis not only shows a direct link between aircraft damage and the number of occupants killed, but it also suggests that for the majority of the other heads of cost the level of cost is largely dependent upon the accident severity. To model the effect of accident severity on the level of cost, 'consequences' were classified according to the accident severity scheme presented in Table 1.

Table 1: Accident severity classification scheme

Level	Damage	Death
Catastrophic	100%	80%
Disaster	100%	30%
Major	80%	0%
Moderate	50%	0%
Minor	20%	0%

For each ‘consequence’, a typical severity level was established. The correlation between some consequences and their ‘typical’ severity level was found to be very strong, e.g. 98% of ‘collision with high ground’ accidents matched the definition of catastrophic. However, others showed considerably less strong correlations. Where no typical severity level could be established (more than 50% of the accidents in the sample meeting the level definition), the average damage level was used. For the 10 most frequent consequences, this provided the following results:

Table 2: Classification of the 10 most frequent consequences.

Consequence	Class
Loss of control in flight (not recovered)	Catastrophic
Collision with high ground	Catastrophic
Collision with another aircraft on the ground	Disaster
Doors or windows failures	Minor
Uncontained engine failure	Major
Hard landing (on runway)	Moderate
Undershoot	Catastrophic
Overruns (take-off or landing)	Moderate
Wheels up landing	Moderate
Gear retracted, collapsed or substantially damaged	Moderate

In combination with the average damage and deaths for each class (Table 1), this information is used to calculate typical aircraft damage and fatalities according to the scheme presented in Figure 5.

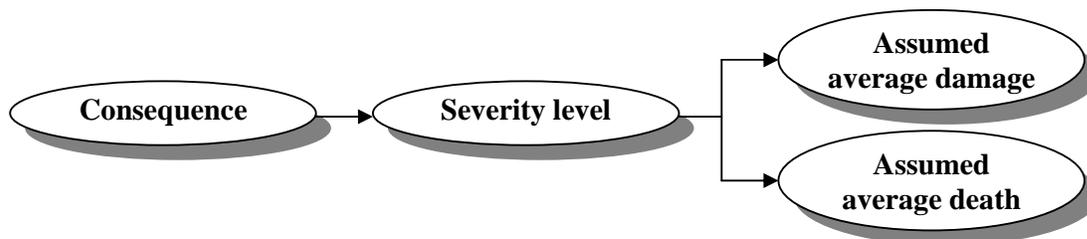


Figure 5: Sizing the main cost headings

Detailed specific costs of more than 1000 accidents were used to build a database of actual costs for each of the ‘heads of cost’ together with their associated accident ‘consequence’. For those heads of cost where individual figures for specific accidents are not available, estimates

have been made of the costs which might arise from certain defined 'typical' accidents by people with extensive and direct involvement in the area under consideration.

The following heads of cost are covered in the DESIRE model:

- Aircraft damage
- Passenger/crew deaths
- Site contamination and clearance
- Loss of aircraft resale value
- Loss of aircraft use
- Airport disruption
- Loss of staff investment
- Loss of cargo, mail, passenger baggage
- Search and rescue
- Airline response
- Accident investigation.

The most important cost factors of accidents, aircraft physical damage, passenger and crew deaths and injuries, and loss of airline reputation, are discussed in the following sections.

4.4.1 Aircraft damage

Under the cost model, aircraft physical damage is one of the key determinants in categorising accidents. However, the actual costs arising from similar physical damage suffered by different aircraft can vary by perhaps as much as two orders of magnitude – consider an old Boeing 707 with a value of \$1 to \$2 million and a brand new Boeing 747 valued in excess of \$150 million. The destruction of these aircraft will produce very different resulting costs for aircraft physical damage. Costs will also vary with time as inflation causes new prices and costs for repair to gradually rise.

Therefore, rather than using actual cost figures for individual aircraft, these figures are normalised so that an 'index' for relative degree of damage is obtained. The index is expressed as a percentage of the aircraft damaged. It is not thought practical to determine the percentage of damage suffered by an aircraft by reviewing the description of the parts/components damaged in the accident. Instead the percentage damage is determined by comparing the actual costs of repairs to the theoretical new price of the aircraft in the year of the accident. Aircraft which were destroyed are self-evident and are counted as 100 % damage. For less severe accidents, where the aircraft is never repaired (Constructive Total Losses) an estimate of the likely repair costs is made and this is used instead of the actual insurance claim.

When attempting to estimate the actual costs of accidents, the potential effect of the insurance value (agreed value) should be remembered. The actual insurance value for aircraft ranges between 1.2 and 1.4 times the 'new value'. In the model, we have arbitrarily used a multiple of 1.3.

To calculate the effect of loss of value with age, we use the curve presented in Figure 6 which is based on actual observations across all western-built jet airliner types for all years of manufacture and all market conditions.

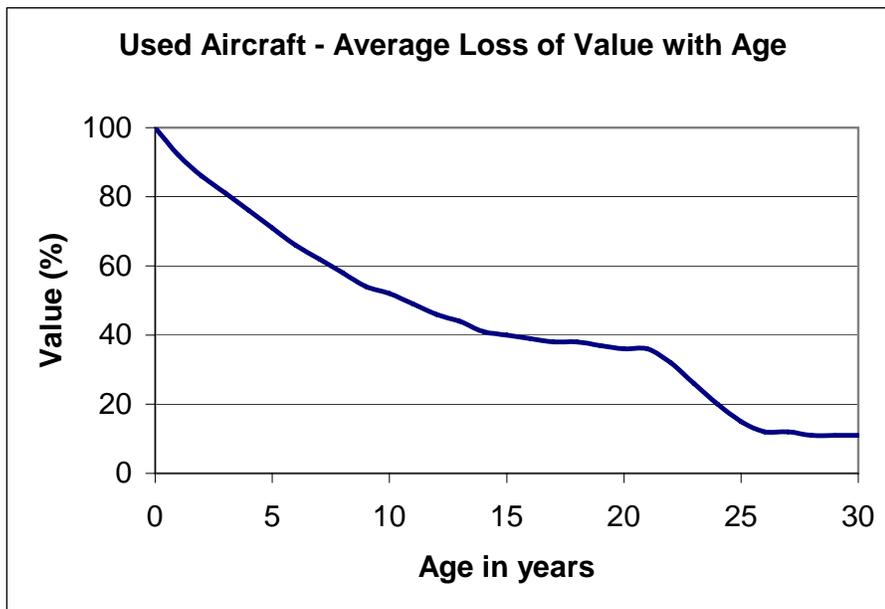


Figure 6: Average loss of aircraft value with age

The model provides new value prices both for aircraft currently in production and estimated new price values for those aircraft that are no longer being produced, but users of the model may of course also use their own figures.

4.4.2 Passenger and crew deaths

Human life is precious and beyond price and it is, therefore, not possible, nor indeed desirable, to attempt to put a price on it. Nevertheless, attempts are made to indemnify for the purely material losses arising from deaths and serious injuries.

Currently the FAA uses a figure of \$2.7 million as the ‘cost of a life’ in its modelling and the aviation insurance community uses an assumed \$3.0 million as the average insurance cost incurred as a result of the death of a US citizen in an air crash. It is assumed that both these amounts are loosely based on the ‘human capital method’ of valuing life.

Cost benefit models increasingly use a Value of Statistical Life in their calculations where this ‘value’ generally includes an element of indemnity together with society’s ‘Willingness to Pay’ to avoid a statistical fatality.

It is felt that no one ‘cost of life’ should be recommended for use in the model but that, rather, it should be left to the user to decide what approach should be adopted and what monetary value should be used.

To assist in calculating the costs related to deaths and injuries, the model provides guidelines for calculating the average number of occupants for a given fleet of aircraft. These guidelines are based on operational data regarding the average number of seats and average load factors for different types of aircraft. Of course, users of the model may also use their own specific data.

4.4.3 Airline reputation

A major accident may change the way the general public and, directly and indirectly, how business views the airline or the aircraft manufacturer which may be associated with the crash. This can have both short term and longer term implications for the company.. The loss

of business after a crash can be considerable. Figure 7 shows the operational history of an airline that suffered a fatal accident in May 1996.

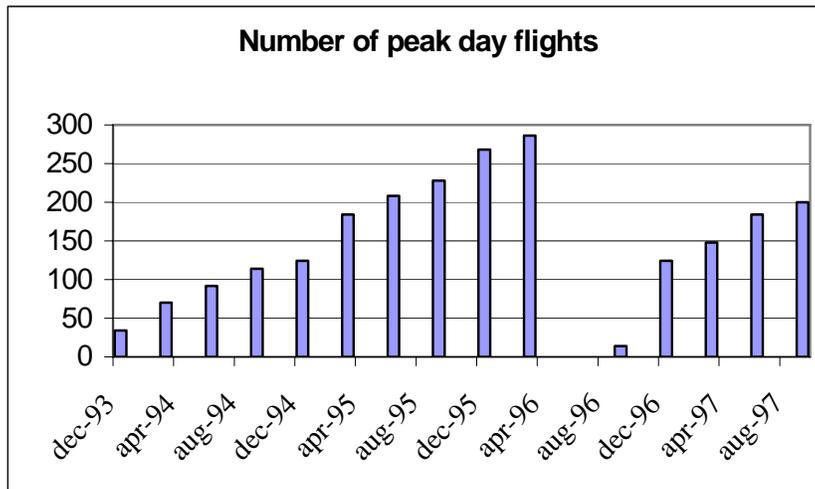


Figure 7: Example of the impact of fatal accident on airline operations

Aircraft reputation can be affected in a similar fashion. For an airline, these costs of lost business are particularly important, as these cost are not covered by insurance. The impact of accidents on aircraft and airline reputation is a direct outcome of the way media is covering the aftermath of an accident and especially who is blamed for the mishap. Factors that play a role in media coverage are the following:

Factors non controllable by an airline

- Speculation
- Fatality dimension of the accident
- Accident site
- Accident images

Factors controllable by the airline

- Safety reputation of the airline
- Financial health of the airline
- Age and size of the fleet
- Crisis/management/initial response

The accident ‘consequence’ type (i.e. loss of control or hard landing, etc.), which is used by the DESIRE model as the starting point for the cost calculations, only has a remote effect on media coverage. Therefore the model is not very well suited to calculate these ‘loss of business’ costs.

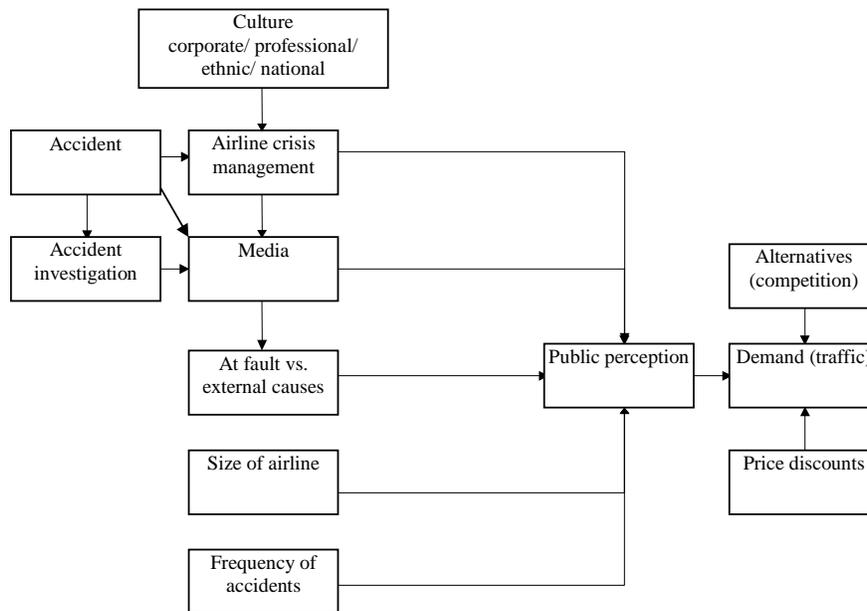


Figure 8: Scheme of the influence of an accident on airline reputation.

4.4.4 Concluding remarks

Two important elements have been conceived to achieve the objective of determining the cost related to an accident:

- Cost protocol
- Cost classification and database.

The cost protocol lists the heads of cost identified in the DESIRE project and provides guidance as to the impact on each cost of each accident severity level.

The cost database provides guidelines to the expected level of cost under each head of costs and relevant figures for the determination of the costs.

Cost profiles were created by a combination of normalising part of the expected outcome and identifying as far as possible those costs which could, in broad terms, be considered as constants. In those cases where no information was available, we have attempted to at least determine the approximate level of these costs based on informed opinion.

4.5 Cost of safety measures

Due to the wide variety of possible safety measures (variation in types of measure, scope, scale of introduction, etc) it is deemed impossible to develop a simple model for the calculation of these costs. Therefore a pragmatic approach to the development of a taxonomy for the cost of safety measures has been adopted. It has been concluded that developing a new cost taxonomy that attempts to categorise the safety costs according to the type of safety measure would be too complex a task as there are thousands of potential safety measures and as mentioned numerous aviation stakeholders to consider. Also, the addition of new classes of safety measures that may be developed in the future could further complicate the taxonomy.

An alternative and more pragmatic approach would be to treat the cost of safety measures in exactly the same way that the aviation industry and any other commercial company accounts for safety in their financial reports. For example introducing a new safety device would have costs that relate to the purchase of the device, its installation, the ongoing maintenance,

specialist-training etc. Equally if a new procedure were introduced cost may include specific training and recruitment of additional personnel.

When the cost of safety is viewed in this manner generally accepted accounting principles can be applied. It is therefore proposed to use cost categories commonly used in the balance sheet and profit and loss statements.

We assume that the user that would want to apply the model for one or more specific cases will be able to make an estimation of the costs involved in implementing the measure. The 'cost of safety measures' taxonomy that was developed can be used as a guideline for determining these costs. It is expected that the user of the model will enter the safety costs under the appropriate cost description. The following heads of cost are suggested:

- Delivery costs,
- Equipment –IT capitalised costs,
- Equipment running costs,
- Installation costs,
- Insurance premium spend,
- Legal costs,
- Machinery and equipment costs,
- Maintenance costs,
- Research and development capitalised costs,
- Salaries and wages,
- Training costs,
- User defined costs.

4.6 Application of the model

Figure 9 gives an overview of the steps involved in the application of the DESIRE model.

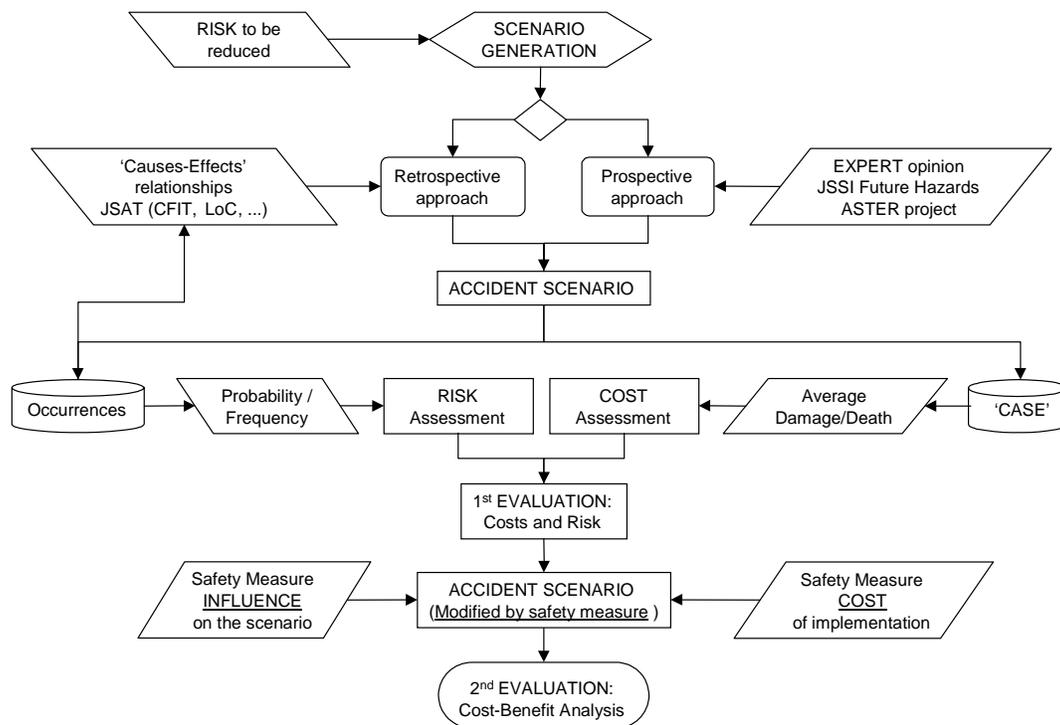


Figure 9: DESIRE schematic

Starting from the intention to reduce a particular risk, accident scenarios are developed using a combination of retrospective and prospective analysis. The model provides generic accident scenarios for the most frequent consequences, but users of the model have the freedom to develop their own specific scenarios. Accident scenarios are described as a sequence of events, each with descriptive and explanatory factors, ending in the final ‘consequence’ event. The accident scenario is subsequently used to calculate the probability of occurrence and the expected cost of such an occurrence. This is the 1st evaluation in Figure 9.

Next, the effect of particular safety measures on the scenario is determined. The features of each safety measure are described by qualitative and quantitative changes of items of the DESIRE taxonomy. Changes can be either positive or negative. In combination with the accident scenario, this information is used to determine the overall effect on the probability of occurrence of the consequence.

The cost side of the model is subsequently used to calculate, again for the specific circumstances of then user, what the cost implications are of the changed probability of accidents. The cost model provides step-by-step guidelines and data to account for specific fleet characteristics such as aircraft age and type of aircraft.

By comparing the cost and safety implications of different safety measures, the user of the model can get an indication of the relative cost effectiveness of each of those measures. This is the 2nd evaluation in Figure 9.

The model should not be used as a tool to justify cuts in the safety budget. It should be used as one of many tools that can help in determining how to spend the safety budget in the most efficient manner. A key feature of the model is the possibility to compare the effect of alternative measures on risk.

The model can help generate support from management for funding related to safety. The tools that have been developed should allow operational managers to communicate in terminology and with argumentation that is normally used in general and financial management.

A typical user of the DESIRE model could be an airline safety manager who wants to introduce two safety-enhancing measures to the company but only has the budget for either one of those.

4.7 Validation of the model

In order to obtain feedback from sector parties, especially with respect to their view on the validity of the approach that has been developed in the DESIRE project, a workshop was held at Airbus Headquarters in Toulouse, France on 13 December 2001. The workshop was attended by representatives of 6 different airlines, an aircraft manufacturer, research organisations, and universities.

One of the prime comments made during the workshop was that, in the case of an accident, the most important cost element is loss of reputation. Most of the other significant costs are covered by insurance. The airline is considered as a *brand*. Public reaction on accidents is vitally important for the airline. The fact that the DESIRE model does not cover this cost element was seen as a deficiency. A lengthy discussion confirmed however that it will be extremely difficult to model this cost element, as there are so many parameters involved.

A second important concern that was raised was the fact that the model will be used *against* safety. Concern was expressed that the model would be used by people to “prove” that certain safety measures are not cost efficient and should thus be abolished. However, it was also stated that the budget for “flight safety” is limited in most airlines, and that for those airlines it would be useful to have a tool that would help to spend that budget in the most efficient way. It was expressed by all parties that extreme caution is necessary in this respect.

When the technical details of the models were explained to the workshop participants, there was much confusion with respect to the ADREP classification scheme of causal factors to accidents, and the way in which these are used to build the ‘generic’ accident scenarios. The structure of ADREP, where an accident is modelled as a sequence of events, with each event having descriptive factors, and where each descriptive factor can have explanatory factors, was not self evident. In addition, the fact that within the classification there are up to four levels of detail created confusion. As an example, the generic accident scenario for ‘loss of control’ accidents that was displayed contained the descriptive factor “wind”, which includes not only various types of atmospheric winds, but wake vortices as well.

Concern was raised by the participants that if the model is so complicated that it can not be explained within say half a day, there is a serious danger that it will not be used by the industry. In order to convince management, the model needs to be “compressed”. In this respect it was also stated that there is no need for a perfect model” and that we must refrain from perfecting the model to the limit.

5 Exploitation plan and follow up activities

5.1 ASTER project

ASTER is a project funded under the Competitive and Sustainable Growth programme (5th Framework Programme). The objective is the development of a methodology enabling safety targets to be set and optimised for each of the participants in the air transport system (airlines, air traffic management, airports, regulatory bodies, etc), to optimise the optimum level of safety for the system as a whole. The ASTER study is performed by a consortium of NLR (co-ordinator), JRC, Eurocontrol, Airclaims, NEI, Meridiana and Israel Aircraft Industries. Three partners (NLR, JRC and Airclaims) were also part of the DESIRE consortium.

The ASTER study builds upon the experience that was gained in DESIRE. The model is constructed in a similar way, with a causal part and a cost part. The causal part consists of a protocol that guides to the creation of typical accident scenarios, similar to the scenarios that we developed in DESIRE. Two improvements are made:

- 1) A better classification system for causal factors is used. The number of elements is drastically reduced and the structure is simplified.
- 2) The identification of causal relationships is supported by a functional model of the air transport system.

The cost part of the model takes the DESIRE cost model as starting point. This is expanded with elaborations on the impact of accidents on reputation, and the role of insurance is described in better detail. The 'heads of cost' are structured in a way that better reflects some basic methodological notions in measuring the cost of unsafety. Because the ASTER model is aimed more at regulators as potential users, the cost of regulation is also addressed.

5.2 Causal modelling of aviation safety

Under the framework of a Memorandum of Cooperation between the United States Federal Aviation Administration and the Netherlands Civil Aviation Authority (MoC-AIAA/CA-52, Annex 8) a contract was awarded to the National Aerospace Laboratory NLR for the development of a causal model of aviation safety. This causal model will be based on the generic accident scenarios that have been developed in DESIRE.

6 References

A presentation was given at the annual meeting of *the International Society of Air Safety Investigators* (ISASI) in Boston, 23rd-26th August 1999, which was attended by more than 300 delegates. The presentation “A new approach to hull loss statistics?” described our approach to normalising aircraft physical damage data and explained how this approach had been developed as a tool for use in DESIRE.

Air Safety Week of January 10, 2000, published an article with the title “A new approach to hull loss statistics” which gives reference to DESIRE.

The spring 2000 issue of “Fly Safely” a publication of the European Airline Association (ERA) included a special report “A new approach to hull loss statistics” which gives reference to the DESIRE project.

The proceedings of the Flight Safety Foundation’s 12th European Aviation Safety Seminar (12 March 2000, Amsterdam), of March 2000, included the paper “A new Approach to Hull loss statistics” which gives reference to DESIRE.

During the GAIN conference in Paris (June 14-15, 2000), Matthias Schmidlin presented data that resulted from (and gave reference to) the DESIRE project.

A.L.C. Roelen, M. Pedrali, P. Hayes, T-L Mariton, The development of an aviation risk assessment model which allows cost benefit analysis of safety measures, in PSAM 5 – Probabilistic Safety Assessment and Management, Proceedings of the 5th International Conference on Probabilistic Safety Assessment and Management, held on November 27-December 1, 2000, Osaka, Japan. Edited by S. Kondo, K. Furuta, Universal Academy Press, Inc. Tokyo, Japan.

A. Roelen gave a presentation: Development of an aviation risk assessment model that allows cost benefit analysis of safety measures, at the Fourth Community Aeronautical Days “Aeronautics Days 2001, preparing for the global challenge, held at Hamburg, Germany, 29-31 January 2001.

A.L.C. Roelen, M. Pedrali and P. Hayes, Development of a decision support tool for safety investments, paper presented at the 13th European Aviation Safety Seminar, Amsterdam, March 2001.

At the “Aviation 2001” virtual conference, held on the WWW on 5-16 March 2001, the paper “The development of an aviation risk assessment model which allows cost benefit analysis of safety measures” was presented by A. Roelen.

At the Human Issue in Aviation Safety (HIAS) conference, September 26-28 2001 at ENAC in Toulouse, France, the following two papers were presented:

- M. Pedrali and A.L.C. Roelen, Causal and Functional models of the air transport system for cost benefit analysis of safety measures in aviation.
- J.J. Speyer and A. Roelen, Cost – benefit considerations relative to human factors: an example in the fatigue domain.