INCREASING THE SURVIVAL RATE
IN AIRCRAFT ACCIDENTS

impact protection, fire survivability and evacuation

December 1996

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ISBN: 90-801936-8-2

Acknowledgements

This review started under the Chairmanship of the late Roger Green who died in September 1996. His contribution to international air safety will long be remembered, especially by all those associated with the European Transport Safety Council.

ETSC gratefully acknowledges the contributions of members of ETSC's Air Safety Working Party to this review:

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ETSC would like to express its gratitude for preparing the Sections on respectively evacuation, impact protection and fire survivability to:

Prof. Helen Muir
Dr Michel Piers
Mr Frank Taylor

ETSC is also grateful for the financial support provided by DGVII of the European Commission and for the contribution towards the printing and dissemination costs of this review provided by 3M Europe, Ford Europe, BP, KeyMed and KLM Royal Dutch Airlines. The contents of this review are the sole responsibility of ETSC and do not necessarily reflect the view of sponsors nor organisations to which research staff participating in the Working Party belong.

The European Transport Safety Council

The European Transport Safety Council (ETSC) is an international non-governmental organisation which was formed in 1993 in response to the persistent and unacceptably high European road casualty toll and public concern about individual transport tragedies. Cutting across national and sectoral interests, ETSC provides an impartial source of advice on transport safety matters to the European Commission, the European Parliament and, where appropriate, to national governments and organisations concerned with safety throughout Europe.

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Increasing survivability: the scope for benefit

Up until 1970, the fatal air accident rate world-wide had been falling dramatically. While the rate, since then, has decreased slightly, this has not been accompanied by an equivalent reduction in the fatality rate of those onboard aircraft.

Approximately, 90 per cent of aircraft accidents can be categorised as survivable or technically survivable. In round and, of course, fluctuating figures it is estimated that of the 1500 who die each year in air transport accidents some 900 die in non-survivable accidents. The other 600 die in accidents which are technically survivable and crashworthiness, fire and evacuation issues are all important. Of these 600 perhaps 330 die as a direct result of the impact and 270 due to the effects of smoke, toxic fumes, heat and resulting evacuation problems.

Public demand for air travel has increased steadily over the last two decades and further substantial growth can be expected. Forecasts for the doubling of air traffic over the next decade have led airframe manufacturers to start to consider designs for airframes carrying as many as 800 or 1000 passengers. For this reason not only the issues concerned with the prevention of the occurrence of accidents, but also issues related to improving the survival rate in the event of an accident will have major importance in the years to come. Failure to take steps now to deal with the increasing exposure to the risk of accident and injury in air travel can only lead to the lowering of current public confidence in air safety.

Improving survivability will necessitate comprehensive review of all promising options available to regulators and industry. In some cases, actions will involve incorporating new features to aircraft at design stage, where costs can be more easily assimilated. In others, where structural considerations are less important, introduction at 'refit' stage may be appropriate. Some measures will be of the type to allow more or less immediate application, others will require research.

Ideally, the identification of effective cabin safety enhancement measures for implementation should take into account a number of different factors. These include the ranking of potential safety measures in terms of the expected number of lives saved, consideration of how difficult the implementation of the measure will be, the cost of each measure, whether a measure can be implemented as a retrofit to existing fleets or is only applicable to new aircraft, whether a measure will be effective once implemented or will only be effective in combination with passenger behaviour modification.

A fundamental limitation to this process, however, is the lack of adequate accident information from a sufficient number of accidents to allow full cost benefit analyses to be performed. The absence in many accident investigations of detailed information on injury mechanisms and cause of death makes the precise estimation of the potential benefits of any one measure very difficult.

The Cherry study (1995), one of few studies which have performed a detailed trade-off concerning the full range of possible survivability measures, provides insight into available options. However, the small number of accidents available for investigation in such studies means that the basis for determining priorities still relies heavily upon best expert judgement rather than a numerically specific approach.

The current review aims to provide an overview of the various issues in the field of secondary safety or crash protection in commercial aviation, and to suggest steps on the basis discussed previously, which might be taken by the European Union in its new air safety strategy, and others which could contribute to improvements in air crash survivability.

Measures to improve the survival rate

Impact protection

No single solution exists which, if introduced in isolation, would lead to a very significant improvement in impact protection. Rather, an approach which makes many small enhancements aimed at a large improvement is needed. This calls for a proper balance in the state of the art of the various aspects of impact safety instead of a very detailed effort in one field and none in another. For this reason, programmes such as the Occupant Crash Protection Program as defined by the JAA Research Committee, which was not initiated due to lack of funding, the FAA-JAA-TCA Cabin Safety Research Program and the developing EU programme in this area need support.

Many proposed safety measures require further research before their benefit to cabin safety and the optimal design can be firmly established. In most cases, the availability of accurate, validated analytical models is indispensable. Further development of such models, not forgetting further biomechanical data input, and support for the full scale tests required for their validation are essential for work aimed at improving impact protection.

Based on the Cherry study and other information referred to in this report and considering the other aspects mentioned above, three impact protection measures are recommended for priority attention:

- Improvement of seat-floor strength;

- Three-point safety harness occupant restraint;

- Improvement to strength of overhead stowage.

Fire survivability

Statistical trends clearly show that fire substantially decreases the chance of surviving an aircraft accident. In the event of more passengers surviving the impact through improved crash protection, then even more will be at risk from fire. Following research programmes carried out in the last decade, a number of measures show promise in increasing the survivability rate in fire accidents and can be implemented without insurmountable problems and with no or relatively little additional research effort. Looking at these, the following is recommended:

- Fitment of an external camera/cockpit monitor, following study of procedures required to guarantee safe operation;

- Introduction of smoke hoods in all commercial aircraft, following ergonomic study of stowage and accessibility, and suitability to an acceptable proportion of passengers;

- Fitment of watermist systems in new types of commercial aircraft;

- Implementation of proposed regulations for improvements in fireworthiness standards of cabin materials, including toxic emission prevention standards;

- Provision of additional equipment and training for Fire Services operating close to airports.

It should be emphasised that these measures are not mutually exclusive. In addition, there is a case to be made for introducing them all at some reasonable, attainable standard rather than seeking perfection in just one area.

Other measures, though potentially useful, do need more substantial research. One of these is the use of Anti Misting Kerosene (AMK) fuels. Although the potential benefit of using AMK has been widely accepted, it still has to be demonstrated that it could be used safely on a routine basis.

Evacuation

Fast and effective evacuation can save many lives in case of a technically survivable aircraft accident. In the last decade major research programmes have been undertaken which have provided important new information on how evacuations proceed and which factors influence their effectiveness.

People's responses to emergency situations vary from relatively calm and effective responses to competitive and agressive behaviour or in other cases to total inaction. In situations which are perceived as directly life-threatening, many people lose their motivation to collaborate in order to save others, but instead will try to save themselves first.

Of course, it may be difficult if not impossible to change people's immediate response and make them all respond calmly and rationally in these types of situations. However, there are a number of other factors that can be changed and that will improve the overall evacuation speed despite the wide range of responses and behaviours of the passengers. The most important factors are:

- The cabin environment, in particular the presence of fire, smoke and / or toxic fumes in the cabin;

- The configuration of the cabin, in particular the seating configuration near the emergency exits and ease of operating the exit hatch and the bulkhead aperture;

- The behaviour and crowd control skills of cabin crew during emergency evacuations; and

- Passengers' knowledge of safety procedures and their motivation to get acquainted with them.

There are a number of measures which are known to contribute to increase evacuation speed and efficiency and which can be introduced easily. These include:

- Increasing the aperture between bulkheads to 30 inches (76.2 cm);

- Training cabin crew members in crowd management skills and to act assertively in case of emergency evacuations.

Other measures do, indeed, need more study and research to determine the potential benefits and / or the optimal technical specifications. For example:

- Establishing the optimal cabin configuration for evacuation from wide bodied airframes;

- Consideration of an alternative to evacuation slides for escape from Very Large Aircraft;

- Finding ways to reduce the interference of the noise of water spray systems with cabin crew members' oral commands;

- Determining optimal technical specifications for additional tactile cues in the cabin to assist passengers evacuating when visibility is poor;

- Evaluation of new technologies for the presentation of safety information to passengers, such as airport training mock-ups.

It is recommended that research in these areas should be carried out at the earliest opportunity, to ensure that effective measures to increase the evacuation rate and hence increase the survival rate in aircraft accidents can be implemented as soon as possible.

Regulating and implementing measures

As the foregoing recommendations suggest, a package of measures is necessary to improve air accident survivability. This comprises:

- Training of crew and cabin staff to share critical information;
- Improving the energy absorbing qualities in the event of an impact;
- Reducing the chance of fire, in particular in the cabin;
- Avoiding the development of toxic fumes;
- Maximising the opportunities for an orderly and quick evacuation.

ETSC firmly believes that, for EU registered aircraft, a strong, single EU air safety authority has a crucial role to play in promoting and realising such a package of measures. This single EU air safety authority would be able to set binding safety standards which reflect best knowledge and which are in line with EU Treaty obligations.

1. Introduction

Public demand for air travel has increased steadily over the last two decades and, assisted by EU liberalisation policies, industry can expect further substantial growth into the next century. Forecasts for the doubling of air traffic over the next decade have led airframe manufacturers to start to consider designs for airframes carrying as many as 800 or 1000 passengers. While passenger safety in air travel has always been a high priority within the industry these developments demand that new attention is given to the safety of air travel.

Up until 1970, the fatal air accident rate world-wide had been falling dramatically. While the rate, since then, has decreased slightly, this has not been accompanied by an equivalent reduction in the fatality rate of those onboard aircraft. For this reason not only the issues concerned with the prevention of the occurrence of accidents, but also issues related to improving the survival rate in the event of an accident, will have major importance in the years to come.

Aircraft accidents may be classified according to a number of criteria, the most critical of which being whether the accident was survivable. Using this classification system, it is possible to assign accidents to one of three groups:

(a) those which are FATAL or NON-SURVIVABLE. Accidents in which none of the passengers or crew survive (for example: the Air India 747 in 1985 and the Pan Am 747 in 1988, in which the crash forces were of such severity that all onboard were killed instantly);

(b) the NON-FATAL or SURVIVABLE, in which all the passengers and crew survive (for example: the TriStar which overran the runway in 1985 at Leeds-Bradford Airport);

(c) the TECHNICALLY SURVIVABLE, a grouping which includes the accident at Manchester Airport in 1985, and the accident at Los Angeles Airport in February 1991. Accidents in which some of the passengers or crew survive.

Approximately, 90 per cent of aircraft accidents are categorised as survivable or technically survivable. In round and, of course, fluctuating figures it is estimated that of the 1500 who die each year world-wide in air transport accidents some 900 die in non-survivable accidents. The other 600 die in technically survivable accidents, where crashworthiness, fire and evacuation issues are all important. Of these 600 it is estimated that around 330 die as a direct result of the impact and 270 due to the effects of smoke, toxic fumes, heat and resulting evacuation problems. Due to the expected increase in the amount of air travel and the density of air traffic, the annual number of deaths may rise further.

It must be emphasised that these figures are at best estimates, since insufficient detailed accident information is available. They do, however, point to the need to give increasing attention and effort to improving survivability in aircraft accidents.

Improving survivability will necessitate comprehensive review of all promising options available to regulators and industry. In some cases, actions will involve incorporating new features to aircraft at design stage, where costs can be more easily assimilated. In others, where structural considerations are less important, introduction at 'refit' stage may be appropriate. Some measures are of the type to allow more or less immediate application, others will require further research.

Ideally, the identification of effective cabin safety enhancement measures for implementation should take into account a number of different factors. These include the ranking of potential safety measures in terms of the expected number of lives saved, consideration of how difficult the implementation of the measure will be, the cost of each measure, whether a measure can be implemented as a retrofit to existing fleets or is only applicable to new aircraft, whether a measure will be effective once implemented or will only be effective in combination with a passenger behaviour modification.

A fundamental limitation to this process, however, is the lack of adequate accident information for a sufficient number of accidents to allow full cost benefit analyses to be performed. The absence in many accident investigations of detailed information on injury mechanisms and cause of death makes the precise estimation of the potential benefits of any one measure very difficult.

The Cherry study (1995)[*], one of few studies which have performed a detailed trade-off concerning the full range of possible survivability measures, provides insight into available options. However, the small number of accidents available for investigation in such studies means that the basis for determining priorities still relies heavily upon best expert judgement rather than a truly numerically-specific approach.

As aircraft passengers and crew benefit from the continuous application of new technologies to deliver improvements in mobility and comfort, so continuously updating safety designs can be in line with current knowledge. Failure to take such steps which take account of increasing exposure to the risk of accident and injury in air travel can only lead to the lowering of current public confidence in air safety.

The EL AL Boeing 747 crash on the Amsterdam Bijlmermeer some years ago and a number of recent accidents with crashes in or near populated areas resulted not only in victims amongst passengers and crew but also on the ground. These accidents show that survivability issues also apply to 'third parties' and that third party risk should play a key role in design and location of airport runways, in flight procedures and in the development of emergency plans and services. Whereas third party risk does involve aspects of survivability, which may be a topic for future study, it falls outside the scope of the current review.

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[*] CHERRY, R.G.W. and Associates Ltd (1995) *Analysis of factors influencing the survivability of passengers in aircraft accidents Vol. I-III.* Report presented to the ECE, Transport Directorate.

The current review aims to provide an overview of the various issues in the field of survivability of passengers and crew in aircraft accidents, and to put forward recommendations for future developments. The following issues are discussed: impact protection (Section 2), fire survivability (Section 3), and evacuation (Section 4). In the final Section some regulatory and implementation issues are briefly discussed.

2. Impact Protection

As previously mentioned, of all accidents in which fatalities occur, about 60 per cent are considered as not survivable. In the remaining - technically survivable - accidents, around 55 per cent of the fatalities occur as a result of impact. Measures to improve impact protection will, therefore, have considerable life-saving potential.

The advantage of impact-related safety measures is that they bring about largely "cabin-wide" effects since in any one crash, occupants are exposed to similar impact conditions. Fire protection or evacuation measures, on the other hand, often involve a time element which usually means that in a particular crash only some passengers will benefit from the improvement. Secondly, impact protection does not have to rely on changing human behaviour for its effectiveness. It should be noted, however, that someone who survives the impact due to a particular measure, may still become a victim of the post crash fire.

2.2. Impact protection improvement measures and associated research

2.2.1 Seat and restraint systems

Seat and occupant restraint systems are the main interface between the occupant and the crash environment. In an accident the restraint prevents the occupant from being thrown around in the cabin and contacting different structures. The deformation of the seat structure and cushion helps to absorb some of the crash loads. A number of possible occupant safety improvement measures related to seats and restraint systems are discussed below.

Side-facing seats

New airworthiness requirements require that aircraft seat and restraint systems are dynamically tested in accordance with test standards specifying emergency landing conditions. However, these standards were developed for regular forward facing seats and they are not adapted to side-facing seats which are common in business jets. Research is now needed to identify biomechanical limits to be used in testing of side-facing seats so that these too can be subject to dynamic test requirements. In addition, the existing models used in dynamic seat testing need to represent more realistically the dynamic properties of the seat pan and the seat cushions.

Child restraint devices

Though a minor casualty problem, given the relatively few numbers of children travelling by air, the current protection offered to child occupants in the event of an aircraft accident is inadequate. Research has shown that restraint in the arms of an adult occupant or restraint by a supplementary belt provide inadequate protection. Serious doubts also exist regarding the protection offered by Child Restraint Devices (CRDs) currently in use which are not purpose-designed child safety systems for use on aircraft. Automotive CRDs may, for example, not be fully compatible with the aircraft seat (e.g. break-forward seat backs, no tether strap attachment). Although specific types of automotive CRD's have been approved for use in aircraft in the UK, these restraints are only of the forward facing variety and are not suitable for occupants under 8 months of age which are obviously the most vulnerable to risk of injury. Since aircraft certified CRD's are not available, regulatory authorities are unable to mandate the use of child restraint systems. Research in progress, therefore, aims to develop and test a prototype CRD which meets the requirements of both regulators and industry. This research would be expected to result in recommendations for a standard for the development of aircraft child restraint systems.

Cabin crew seats

The seating allocated for cabin crew is often of a fold-away construction designed to take up the minimum amount of space. These seats are often attached to bulkheads, are sometimes rearward facing and have a full harness - all conditions that should maximise safety. However, the attachment of the seat to a bulkhead means that the seat occupant is exposed to the same acceleration forces as the airframe of the aircraft. Research is required to derive minimum cushioning requirements and determine whether improved safety could be provided by mounting the seats on an energy absorbing mechanism. The protection of the cabin crew is of particular importance in view of their important role in evacuation.

Rearward facing seats

During impact, passengers who are restrained by a lap belt and who do not take up a brace position prior to impact, are likely to suffer serious injuries due to the flailing motion of the upper body. The adoption of rearward facing seats would prevent this situation. Since standard aircraft seats are not designed for the loads which will be applied to rearward facing seats, research is needed to determine the strength requirements for the seat and seat support, and ways to attenuate the loading of the cabin floor through energy absorbing mechanisms in the support structure. In addition to the engineering aspects of rearward facing seats, the willingness of passengers to travel backwards should also be considered.

Brace positions

Taking up a brace position before impact is a highly effective way of attenuating the biomechanical loads on the occupant's body. Considerable research has been carried out into the optimal brace positions. However, the recommendations of this research have not been sufficiently accepted internationally and hence a lack of harmony in the positions of the various authorities persists which hampers their application. A further increase in cabin safety in this regard could be achieved through improving the effectiveness of "short notice" commands (which direct passengers to assume the brace position) and through improvements in the brace position for cabin crew. Research is required into both areas.

Three-point lap and shoulder harnesses

As mentioned above, passengers who are restrained by a lap belt only and who do not take up a brace position prior to impact, are likely to suffer serious injuries due to the flailing motion of the upper body. As with rearward facing seats, the provision of three-point shoulder harness restraint systems would prevent this situation. If all passenger assumed the brace position prior to impact, the additional benefits of a three-point shoulder harness would be small. In reality, however, for a variety of reasons, occupants generally do not assume a proper brace position, so a three-point lap and shoulder harness would be likely improve occupant protection substantially.

While there is currently some difference of opinion about the effects of three-point shoulder harness systems on seat and floor design, the substantial improvement in passenger safety offered by these devices is undisputed. Further research is necessary to resolve these differences before three-point shoulder harness systems can be applied which should also address issues concerning dynamic testing and public acceptance.

Airbags

Airbags have often been discussed as a possible air passenger safety improvement in lieu of a three-point shoulder harness restraint system. The widespread automotive application of airbags would, no doubt, facilitate the introduction of this technology in aircraft. Experience with some fifty million airbags installed in cars shows that the protective capabilities of airbags in reducing severe injury are clear and highly reliable. Not surprisingly, development programmes are in place with production and installation in aircraft planned for 1997.

Current developments focus on providing head strike protection for occupants in front row seat positions behind cabin interior structures such as bulkheads, since it has proven to be very difficult to meet the current head strike protection criteria of the airworthiness requirements. The safety benefits should, however, not be restricted to front row passengers, the application of airbags throughout must be considered as well. Before widespread application of airbags in aircraft cabins can be commenced, a number of design and regulation issues must be resolved. Research will be necessary into the consequences for airbag design of the flammability requirements (automotive airbags are made out of polymers which are not allowed in aircraft cabins), into the consequences for design of differences between car crash dynamics and the more complex aircraft crash dynamics, into specific aircraft aspects such as the possible problems associated with the large combined volume of all airbags deploying in a pressurised cabin, and into the development of appropriate test procedures, specifications and requirements.

2.2.2. Cabin furnishings

Structural integrity of overhead luggage bins and bin attachment fittings

In many accidents, whole or parts of luggage bins break loose either because the bin itself fails structurally or the fittings which attach the bins to the fuselage structure fail. The bins then become potentially lethal projectiles in a crash environment and may end up as obstacles hampering the evacuation of passengers. In crashes, overhead bins can be exposed to crash environment dynamic loadings well in excess of the maximum static loadings addressed by the airworthiness requirements. Several full scale tests have therefore been carried out in order to establish dynamic fracture loads on bin attachment fittings and modes of fracture of these fittings. A revision of the requirements is necessary such that the overhead luggage bins will be able to meet the same dynamic loading requirements which must be met by passenger seats.

Overhead luggage bin loadings

Any increase in the stowage capability of overhead luggage bins seems to be met by at least an equal increase in the amount of carry-on luggage being taken aboard by the average passenger. Although airlines impose limitations on the amount of carry-on luggage, enforcement of these limitations seems limited in view of the operational consequences and, perhaps more importantly, a wariness of losing commercial advantage due to reduced passenger appeal. Consequently, the amount of luggage stowed in overhead luggage bins may be such that either the bin is incapable of retaining the contents or the bin attachment fittings fail when exposed to the crash forces present in a survivable accident. To enable both the design of adequate luggage bins and the establishment of appropriate airworthiness requirements, new data is required on the loadings of overhead bins as achieved by the travelling public. It is noted that in the UK, the CAA intends to carry out a passenger survey to this end.

Overhead luggage bin containment capability

Airworthiness standards require stowage compartments to remain closed and retain their content under emergency landing loads. There is evidence that this is not always achieved in real accidents. Research must address the bin design considerations as well as the influence on the retention capability of in-service wear and deterioration of latches and hinges, inappropriate latch engagement, closure misalignment and excessive bin loading of passengers. Research in this field is planned by Transport Canada.

Cabin delethalisation and inflight entertainment equipment

The kinematics of body action associated with aircraft crash impacts are quite violent, even in accidents of moderate severity. The occupant's immediate environment should be designed so that when body parts flail and contact rigid or semi-rigid structures, injury risk is minimised. Relocating hazardous structure out of the occupant's reach is not always an option, in particular if the structure is provided for use by the passenger while seated. Alternatives might be to mount the offending structure on frangible or energy absorbing supports or by applying padding to distribute the contact force over a larger part of the body. This concern is of particular relevance to the personal inflight entertainment equipment increasingly being provided by airlines. This involves each passenger having their own TV screen, perhaps mounted in the back of the forward seat. It seems unlikely that aircraft being refurbished to have such devices would be required to demonstrate through dynamic seat testing that the devices would not compromise passenger safety. Research is required to support subjective judgements by the regulator.

2.2.3. Cabin structural integrity

Floor strength

The structural properties of the cabin floor play an important role in impact survivability. Not only does a strong floor improve the capability of the cabin to maintain habitable space during a crash, it does in addition influence the ability of the seats and safety belts to remain attached and provide their passenger restraint function, and the attenuation of the shock load applied to the aircraft structure at impact. Following some accidents where the seats had remained intact, but the floor had failed, it was suggested that cabin floors should be designed to a tougher and more realistic standard. At least, the strength of the floor should be such that the maximum load capability of the seats and restraints is available in accident environments.

Composite aircraft

Although the use of composite components in aircraft structures keeps increasing with newer designs, entire aircraft cabins built out of composite materials are not yet very widely utilised in large transport category aircraft. New smaller passenger carrying aircraft are currently already built of composite components. The concern about composite structures regards the consequences of such structures for impact survivability. Composite structures often have very rigid mechanical properties which fail in a rather unfavourable way. In accidents such structures have limited structural deformation and energy absorption capability which means that the crash loads to which the aircraft structure is exposed are hardly attenuated. Consequently, occupants may be exposed to very high unattenuated crash loads. Research is required into ways of improving the impact protection provided by composite structures.

Very Large Aircraft

Transport aircraft carrying perhaps as many as 800 passengers are currently on the drawing boards. Such designs usually involve double passenger decks along the full length of the fuselage. New crashworthiness issues will undoubtedly arise. One obvious issue, in view of the importance of the cabin floor in impact survivability, are the floor concepts proposed for these aircraft. A survey of anticipated crashworthiness issues for very large aircraft needs to be carried out to ensure that state of the art crash protection is taken up in design.

2.2.4. Effectiveness of potential impact safety improvement measures

Just over 50 per cent of all fatalities in survivable or technically survivable accidents are due to impact. While too few accidents have received sufficient study as regards injury causation and cause of death to offer more than those most tentative numerically specific conclusions to be drawn, there have been attempts to identify the potential effectiveness of different impact safety measures from accident analysis.

The 1995 Cherry study found that about one third of the fatalities in the 39 accidents studied were unavoidable in the sense that no cabin safety measures could be identified which could have prevented their occurrence. The purpose of this analysis was to determine for each accident what reduction in the number of fatally injured cabin occupants could be expected from different cabin safety measures. The expected reduction in the number of fatalities on each accident was estimated by experts based on the data available in the accident investigation reports of these accidents. Thirty-two different cabin safety enhancement measures were analysed in the study. Table 1 below shows for the most effective impact-related safety measures, what the expected percentage reduction[*] in the number of fatalities would be, if a particular cabin safety measure had been implemented.

Obviously, since the life of a cabin occupant can only be saved once in a particular accident, the reductions in fatalities anticipated for different safety measures cannot simply be added up to arrive at the expected reduction if all safety measures were taken. Furthermore, an occupant saved from fatal impact injuries by a particular safety measure may subsequently be killed by post crash fire. This effect has been accounted for in the estimates of expected survivability improvements.

The Table shows that increasing the strength of cabin floor and seat configurations is the most effective impact-related safety measure. Of all avoidable impact-related fatalities in survivable accidents, the study estimates that some 31 per cent could be saved by the introduction of stronger floor and seat configurations. In another study, however, simulations of accidents with three different floor concepts found no significant differences in occupant injury patterns between the concepts tested. Additional study is required.

Table 1: Expected percentage reduction in avoidable impact fatalities and overall fatalities from various measures (derived from Cherry, 1995)

Safety measure	% reduction in avoidable impact fatalities	% reduction in overall fatalities
seat-floor strength	31	8.3
rearward facing seats	19	5.0
occupant restraint	18	4.7
strength of overhead stowage	13	3.3
head strike adequacy	10	2.7
structural strength of cabins	10	2.7
infant seats	1	< 1

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[*] These particular figures are not quoted in the study, but have been calculated from the data provided in the study report.

2.3. Human impact tolerance

General

The relevance to impact safety research of biomechanical knowledge is often underestimated. The identification of effective measures to reduce injury is dependent on knowledge about human tolerance to static and dynamic loading and mechanism of injury. Since effective modelling and simulation have to be based on increasingly realistic biomechanical inputs, greater attention needs to be given to this area in aviation to bring levels of knowledge up to those achieved in the automotive world.

Impact injuries to lower body

Injuries to the legs and the pelvis are not necessarily fatal, but they are of serious concern when they immobilise passengers and prevent their escape from a post crash fire. Adequate measurement technology for the pelvis and legs of passengers and the ability to relate these measurements to injury risk do, however, not yet exist. Research must therefore be carried out in order to determine the impact load tolerance of the lower body. Particular attention must be given to leg fracture loads. FAA CAMI and NHTSA have proposed to set up a data collection initiative on human impact tolerance of the lower body.

Head injury assessment

The present head injury assessment is through the Head Injury Criteria index which is relevant when injury is due to head contact. Another frequent source of head injury is the high angular acceleration of the head which results from forward deceleration of the aircraft when the occupant is wearing a lap belt only. This type of head and neck injuries of such a case must be identified.

2.4. Simulation

The need for simulation

The factors which govern occupant survival can be described by the sequence of response mechanisms in an aircraft accident. At impact, and depending on the aircraft altitude, velocity, type of terrain, etc., deceleration and deformation occur in the aircraft structure. These decelerations are transferred through the structure to the structure which supports the occupant's seat and restraint system. Through the seat and restraint system and possibly the surrounding structure, the crash loads are eventually transmitted to the body. The body will show a dynamic response to the applied loads. The forces exerted on the occupant and the loads introduced by the dynamic response of the body result in loads in different parts of the body. These loads may or may not exceed human tolerance and hence may or may not (fatally) injure the occupant.

In order to perform a proper analysis of how cabin safety can be improved through impact-related safety measures, an adequate understanding of each of the mechanisms involved in the sequence of events described above is required. Not surprisingly, research in each of these is ongoing or intended.

Practical obstacles are present with regard to improving understanding of these mechanisms. Obviously, it is not feasible to expose real humans to crash loads in order to study body response dynamics and human tolerance to crash loads. Therefore, anthropomorphic test dummies are used to simulate humans. Although sled tests with anthropomorphic dummies are certainly less expensive than full scale crash tests, here too the costs associated with sled tests for many different combinations of seat configuration, impact parameters and restraint devices as usually required in research would prove prohibitive. Therefore, accurate theoretical models of the human body allowing the calculation of loads to different parts of the body and the dynamic body response are required.

Obviously, it is also not practically feasible to carry out full scale crash tests every time a new impact safety measure has been devised and must be evaluated. Similarly, when making trade-offs between various structural design options, full scale tests of the alternatives are usually not feasible. It is, therefore, essential to have highly accurate theoretical models for calculating impact decelerations, deformations and structural responses of aircraft hull designs and cabin structural features.

Progress in cabin safety is therefore critically dependent on the availability of accurate simulation models which allow 'low cost' investigations of potential safety improvements and design optimisation.

Improved anthropomorphic test dummies

The type of anthropomorphic test dummies (ATD) to be used in crashworthiness testing is specified in the airworthiness requirements. The ATD currently specified in the regulations, the so-called hybrid II ATD is an outdated ATD technology. Newer designs (Hybrid III) as used in automotive applications are not necessarily suitable for use in aircraft situations. Issues to be addressed in this regard are among other things the use of ATD for evaluating side-facing seats, measurement capabilities and child-size ATD. Although FAA CAMI plans to work on the issue, research is not yet ongoing.

Analytical modelling development

Computer simulation models are indispensable tools in impact safety research and development. As new impact safety enhancement measures are devised, the capabilities of the analytical models must be expanded in order to be able to model the effects of safety measures on the airframe response characteristics in relation to the impact condition and the resultant occupant response and injury risk. Areas for improvement and/or expansion concern the response prediction for different types of terrain, composite airframe dynamics, different lower lobe setting configurations, and high-fidelity modelling of the critical details of the seat-restraint-occupant interaction and occupant response models through finite element modelling of energy absorbing seat designs, seat cushion performance, infant restraint systems and Head Impact

Criterion. Any significant extension of the analytical model capabilities must of course be validated through comparison with test data.

2.5. Testing

The need for full scale testing

In order to ensure that the analytical models utilised in design provide an adequate representation of actual crash behaviour, full scale tests are required. The results of these tests are used to validate the models. In addition, the tests provide an opportunity to observe the sequence of events during the crash in great detail due to the availability of extensive instrumentation and a controlled environment. Real accidents obviously provide limited opportunities in this regard because the exact sequence of events can only be deduced from the resulting wreckage after the accident. The efficiency of this source of data is limited because much of the tell-tale evidence may altered by secondary crash effects or consumed by fire, and also because the accident investigation is primarily aimed at finding the causes of the accident. The investigators are usually not crashworthiness experts and the experts are not often part of an investigation team. Finally, many accidents do not get investigated in any great detail and reports are often not widely available.

Types of testing and test facilities

Full scale impact testing may range from drop tests and sled tests of seat and restraint components involving the use of dummies, through drop testing of fuselage sections and drop/swing testing of entire airframes to impacts of remotely piloted flying aircraft. Many impact safety improvements concern seat and restraint issues which can be tested in drop tests of sled tests of the components involved. Many organisations have facilities for these types of tests because these facilities are often used for automotive applications as well. Larger scale tests involving fuselage sections and entire airframes require dedicated aircraft crash test facilities not only for dropping the test article in a controlled manner, but also in view of the specific instrumentation requirements. A few such facilities are available world-wide. Controlled impact test from flight require even more extensive facilities, only one such experiment has been carried out today in a combined NASA-FAA effort. The facilities involved are, however, not of a permanent nature intended for regular use. In Europe, one swing-drop crash test facility for airframes is available in France and a rather sophisticated crash test facility for airframes is under development in Italy.

The French facility is sponsored by DGAC and has been used for the test of a Falcon 10 fuselage section occupied by instrumented dummies. The test was aimed at verification of the available computational models for small FAR/JAR-25 aircraft. As is the case with many airworthiness requirements, regulations are developed with large transport aircraft in mind. These regulations are not always adequate for smaller aircraft. Therefore, one of the objectives of this test was to examine whether the regulations relating to landing dynamic testing conditions are appropriate and if necessary, to propose rule making changes and compliance demonstration means for business aircraft.

The Italian LISA facility under development at Centro Italiano Ricerche Aerospaziali (CIRA) is expected to be capable to impact test large structures under precisely controlled impact conditions onto different types of terrain and water. The intended set-up of the facility is such that a wide range of crash tests of complete aircraft structures can be carried out in a manner which avoids many of the disadvantages of traditional drop / swing test facilities.

Full scale crash test research remains necessary now and in the future. Crash test are rather costly due to the fact that facility investments are high, utilisation is limited and the test article can only be used once. Therefore, progress in crash test research which is a condition of validated analytical model improvements and improved understanding of the phenomena involved, will necessitate continued support.

2.6. Conclusions and recommendations

No single solution exists which, if introduced in isolation, would lead to a very significant improvement in impact protection. Rather, a package approach which makes several enhancements aimed at a large improvement will be necessary. This calls for a proper balance in the state of the art of the various aspects of impact safety instead of a very detailed effort in one field and none in another. For this reason, programmes such as the Occupant Crash Protection Program as defined by the JAA Research Committee, which was not initiated due to lack of funding, and the FAA-JAA-TCA Cabin Safety Research Program, which take a broad perspective, should be supported.

Many proposed safety measures require further research before their optimal design can be firmly established. In most cases, the availability of accurate, validated analytical models is indispensable in this regard. Further development of such models and support to the full scale tests required for their validation are essential elements in the improvement of the survival rate due to impact factors.

Based on Cherry and other information referenced in this report and considering the other aspects mentioned above, three impact safety enhancement measures are considered to be priority areas candidates for impact safety improvement:

- Improvement of seat-floor strength;

- Three-point safety harness occupant restraint;

- Improvement to strength of overhead stowage.

The appropriate development work towards international standards should be carried out as soon as possible.

3. Fire survivability

3.1. Introduction

Statistical trends indicate that fire is an important factor in aircraft accident survivability. Taylor (1989) analysed 262 accidents between 1975 and 1989 involving fire and/or sufficient damage to cause fuel spillage and thus a real risk of fire. He concluded that many accidents during this period were replicas of those occurring during the first 25 years of turbine operations and that it was unlikely that recent and future trends would differ greatly from the past. It is, therefore, timely to consider the current state of the art concerning actions to reduce the severity of aircraft fires and/or to minimise the effects of a fire on the aircraft occupants.

There have been several accidents in Europe involving fatalities by fire, for example the A320 at Habsheim in 1988 and, it is assumed from photographs of the wreckage, the recent C-130 accident at Eindhoven. A particularly well documented and, in many ways, typical example of a survivable accident with spilled fuel and fire is the B737 accident at Manchester in 1985. The Manchester accident will be used to illustrate the various aspects of 'fire survivability' that need to be addressed.

3.2. The Manchester B737 accident

On 22 August 1985 a British Airtours Boeing 737 with 131 passengers had been prepared for a flight from Manchester to Corfu.

'At 0612 hrs GMT the aircraft commenced its take off on runway 24 with the co-pilot handling and the wind reported at 250^o at 7 knots. At an airspeed of approximately 125 knots (well below the take off decision speed V1) and 32 seconds from the commencement of the take off run, the crew heard a loud bang. The commander immediately ordered 'STOP' and closed the throttles, selected reverse thrust on both engines and checked that the spoilers had extended' (from UK AAIB Special Bulletin, 1985).

The aircraft was brought to a halt just on the entrance to a taxiway but despite the fire service arriving promptly, 2 stewardesses and 53 passengers died as a result of the fire that had penetrated the cabin, probably even before the aircraft had come to rest.

The Manchester accident sequence as set out by the UK Air Accidents Investigation Branch (AAIB) shortly after the accident will be used as a framework for the various points for discussion rather than any attempt being made at an order of priority. It is suggested that fire protection must be tackled on a broad front rather than concentrating on any one priority issue.

3.3. External camera/cockpit monitor

Although a loud bang was heard 32 seconds after the commencement of the take off run and eyewitnesses reported (and photographed) massive fuel spillage, fire and smoke trailing from around the port engine, the crew did not know they might have an engine fire until some 9 seconds later.

In fact, this accident was one of many where the flight deck crew members were unaware of the problem they had. They and, indeed, the cabin crew at the front of the cabin did not know about the engine until the aircraft was nearly at rest. Had they known the position and extent of the fire while still on the runway, from a small monitor on the flight deck, they could have stopped straight along the runway or even turned to the left so that the wind blew the fire away from the fuselage (instead of onto it as tragically happened). Other accidents have occurred such as the B707 at Heathrow and the DC10 at Chicago where the crew were unaware that an engine had become detached from the wing in flight.

The UK AAIB made recommendations concerning external viewing following the Manchester accident and again following the 1989 accident to B737 near Kegworth. The original proposal for the evaluation of this idea suggested that the most important issue was the incorporation of the use of such a system into the normal operational procedures on the flight deck. It was suggested that this could be studied in a flight simulator and that procedures could be developed that would not introduce any significant additional hazard, such as distraction from primary tasks or misleading or confusing information.

Despite extensive trials, however, we are little nearer to having an external viewing system in operation. The objective should now be to explore further operational needs which could to a large extent be accomplished in a non-moving flight simulator and therefore at reasonable cost.

3.4. Extinguishing the cabin fire

The AAIB Special Bulletin on the Manchester accident states that *'there is evidence that the aerodrome fire service was in attendance and generating foam within approximately 30 seconds of the aircraft coming to rest. The airport fire service initial presence comprised two Rapid Intervention Vehicles (RIVs) and two foam tenders which were quickly joined by a third foam tender. Local authority fire appliances and ambulances attended shortly afterwards'*.

There is no doubt that the fire service quickly dealt with the external fuel fire, but it has long been recognised that the airport fire service, so well equipped for dealing with fuel and other external fires around a crashed aircraft, is virtually powerless to deal with an internal cabin fire. For many years ideas have occasionally been put forward for introducing water mist into the cabin but it was only in the 1980s that these ideas were given serious attention. In 1987 at least two proposals were working, both offering an opportunity to improve the chance of surviving cabin fires, and there were many calls for them to be developed as a matter of priority.

One system is a form of sprinkler system capable of first using the water present on board to at least slow down the influx of fire, and second, via a plug-in system, allowing the fire service to deluge the flames, rapidly settling the smoke and toxic gases and extinguishing the fire. Although the water supply was thought to form a problem, the system appeared to require much less water than originally thought. The second system introduces the water mist in a supply of air and requires even less water than the sprinkler system.

In 1993 the UK Civil Aviation Authority (CAA) issued a summary of the extensive work done on water mist systems and concluded that they were likely to be effective and presented no insurmountable problem areas. It was estimated that water spray would save an average of 14 lives annually world-wide or 6 lives in the US, Canada and European countries of the JAA, giving a cost per life saved of $22m to $32m. It is believed that these figures underestimate the number of lives that could be saved, and with costs minimised if features are introduced at design stage, future aircraft should be equipped accordingly.

3.5. Less flammable fuels

'An explosive rupture of the Combustion Chamber Outer Casing (CCOC) of No. 1 engine ...., following rupture the dome of No. 9 combustion can, and a small piece of the fan case struck a fuel tank access panel immediately outboard of the No, 1 engine. A roughly circular hole of about 8 inches diameter was made in the panel allowing fuel to pour out of the left wing tank... Fuel was released in large quantities and immediately ignited. An extremely large fire developed which trailed aft from the region beneath the tank puncture, extending well beyond the tail of the aircraft. The external fire very rapidly penetrated the left side of the fuselage. Shortly after, the fuselage in this area became weakened by heat and the tail section sank to the ground'.

Of all the fuels used by civil aircraft kerosene or JetA/JetA1 sets a reasonable standard and is demonstrably less dangerous (it is put that way around advisedly) than gasoline or widecut gasoline, Jet B. Less dangerous still due to its lower volatility and higher viscosity is the naval fuel AVCAT or JP5, high flash point kerosene. Whenever safety versus cost is discussed this well proven fuel should be considered. Nevertheless, in the past, it tends to have been overlooked with the emphasis being placed on modified fuels such as gels, emulsions and more recently (i.e. for some 30 years now) anti misting kerosene, AMK.

The advantages of AMK are proven and accepted. Yet, without sufficient operational experience the possible hazards (e.g. the wrong 'mix' going undetected and causing flame out of all engines) cannot be properly evaluated and hence reduced to an acceptable level. Thus, AMK remains, and is likely to remain for some time yet, something of a dream solution. However enough is known of AMK's operational properties to at least get it onboard regular military transport flights, for example in one tank, feeding one engine, if confidence is not yet high enough for full use. Its properties could also benefit strike aircraft so again the military services could provide a valuable proving ground. So far as is known work on AMK has practically, or perhaps totally ceased.

In 1990, the Transport Committee of the UK House of Commons recommended ‘that a thorough technical and financial study be commissioned into the future use of high flash point kerosene, such as AVCAT or JP5, as the principal commercial aviation fuel’. Although it is known that the CAA did some work in this area, a report of its findings does not yet seem to be available. It is accepted that JP5 is more expensive at present, but it is not known how much this is due to the very much smaller production quantities of JP5 and how much to more expensive production processes that would remain even if a version of JP5 became the principal fuel. It is recommended that the current and future price differential (if any) between JP5 and JetA1 should be established on the basis of a suitable high flash point JP5 type fuel becoming the principal fuel used by air transport aircraft.

3.6. Cabin materials

'The internal fire in the rear fuselage subsequently developed into a more general fire in the cabin which destroyed much of the cabin furnishings, large areas of the fuselage crown and the cabin floor above the rear freight hold'.

Current and proposed regulations call for significant improvements in the fireworthiness standards of cabin materials and further improvements should be sought. However there is a limit to what can be achieved so long as passengers can bring on, or are supplied with, plastic bags, newspapers, magazines and clothing, all of which of course fall well short of the standards appropriate for cabin furnishings and fittings.

Better and more realistic regulations and testing methods have been introduced since Manchester (some were already in the pipeline). However, as long as fuel can burn around the fuselage and, together with the baggage etc., can still give off black, choking, irritant and toxic smoke, the benefits are limited and the need for passenger protection remains.

3.7. Smoke hoods

Survivors from the Manchester accident spoke of *'lungs feeling as though they had solidified after one breath of smoke'* and after two breaths of feeling *'like falling asleep'*. Others spoke of a film forming over their eyes preventing them from seeing and of removing lumps of material *'like crumpled Oxo cubes'* from their mouths. Of those who did not survive only 9 were reported as having died as a direct result of the flames. Smoke and toxic fumes, hydrogen cyanide and carbon monoxide, overpowered the other 46.

Fairly soon after the accident it was suggested that if each passenger had had a smoke hood available then many lives could have been saved. Since then smoke hoods (or Passenger Protective Breathing Equipment, PPBE) have come in for considerable attention, much valuable research and development has taken place and an international EUROCAE Specification has been agreed. There is, however, no regulatory requirement for their mandatory provision.

Opinions have been strongly divided on the provision of smoke hoods with those against stating that there could be some genuine disbenefits relating to smoke hoods, and in particular that it would lead to an increase in evacuation time and consequently to more deaths.

Although it is not known how passengers would actually react in a Manchester or similar cabin fire if smoke hoods had been available to them, it seems reasonable to say that smoke hoods might lead to some delay in starting the evacuation. However, this does not have necessarily any detrimental effect. As the House of Commons Transport Committee in its report on 'Aircraft Cabin Safety' concluded: 'it is no use passengers being able theoretically to evacuate an aircraft in 60 seconds if, in toxic smoke and without a smoke hood, they collapse unconscious in half that time. The possibility that it may take 10 seconds longer to evacuate with a smoke hood on is of little consequence if indeed passengers can actually evacuate in 70 seconds from a cabin full of toxic smoke and live to tell the tale'.

The probable reasoning behind the assumption that any delay in the evacuation may lead to more deaths may arise from a genuine misunderstanding of the nature of real cabin fires. The results of the valuable cabin fire trials at the FAA Test Center at Atlantic City may have been used to arrive at a conclusion that is not valid for the majority of real cabin fires. The fuselage used for cabin fire trials at Atlantic City is fire hardened in such a way as to ensure that it can be used many times over without the roof burning through. Thus in most, if not all trials, conditions are reached after a few minutes where flashover (the almost explosive ignition of unburned gases along the length of the cabin ceiling) is almost certain to occur. It is generally recognised that the chances of surviving after flashover, even with a smoke hood, are practically zero.

It, therefore, follows that if flashover does occur then any delay in evacuation could well cost lives. The trap that it is easy to fall into is to assume that flashover always or nearly always occurs in actual cabin fires. In the Manchester report, the AAIB concluded that 'there are powerful reasons to question whether flashover occurs at all often in real aircraft fires, as opposed to test fires'. Other research (e.g. Taylor, 1989) supports the view that flashover is comparatively rare. Many accidents with fire deaths result in a broken fuselage allowing fumes to vent out and several, like Manchester, which start with an intact fuselage, burn through or collapse locally to produce an outlet before flashover has occurred. There is no doubt that in some accidents flashover has occurred and it will no doubt occur again, but it is incorrect to assume that it will always occur.

Furthermore, it is important to remember that people collapsing from the effects of toxic smoke may cause delays to those having to get past or over them, and this actually occurred at Manchester. It is also important to remember the long term effects of inhaling smoke and toxic matter on those who do escape from the aircraft, and which may lead to permanent and disabling lung damage of those who survive the accident.

In summary, it seems that the delay in evacuation time due to the use of smoke hoods may only have detrimental effects in the relatively rare event of flashover, whereas in other cabin fires, the initial delay may be outweighed by the subsequent increase in evacuation speed and the number of people who can be successfully evacuated. Although there are a few practical problems to be resolved, such as stowage, accessibility and suitability to all (or at least an acceptable proportion of) passengers, there do not seem to be any major, justified arguments against the introduction of smoke hoods in all commercial aircraft.

Regarding stowage and acceptability, experience with life jackets confirms that in a normal, cluttered, closely packed cabin environment putting items under the seats renders them almost totally inaccessible. Smoke hoods need to be in view and easy to remove and don whether from one's seat or when moving through the cabin to get out. Of all the positions suggested, arm rest, seat pocket etc., the best position appears to be in the bottom (or outer face) of the seat back tray with the hood and instructions on how to use it clearly visible at all times.

3.8. Passenger smoking

In principal, a general smoking ban on aircraft could certainly reduce the risk of a cabin fire. In practice, however, such a ban could produce an increase in the number of people who attempt to smoke in the toilet or who crouch low in their seats in an attempt to conceal their cigarette from view. This could easily produce an increased risk of a cigarette dropping onto newspapers, into plastic bags or otherwise increase the risk of fire. As many airlines have already introduced a ban on smoking, albeit more for social than for safety reasons, the opportunity should be taken to evaluate their experience before making a further decision on safety grounds.

3.9. Other aircraft-related topics

The above list of issues relevant to fire survivability is not by any means exhaustive. Other accidents have shown other deficiencies, which pointed at additional measures. These included improving fuel tank integrity following a minor crash, but with the undercarriage collapsing; the protection of fuel and hydraulic lines within the fuselage; compartmentalisation within the fuselage; and onboard extinguishing systems in equipment bays.

3.10. Associated rescue and fire fighting operations

Increasing the survival rate in aircraft accidents does not only involve aircraft design and safety management but also involves the efficacy of ground based rescue and fire fighting facilities. As some 75 per cent of accidents occur during the take-off or approach and landing phases of the flight, the majority of accidents will be on or close to an airport.

The Airport Fire Service is equipped and trained to deal with aircraft fires but still cannot readily extinguish an internal cabin fire. Nevertheless, there is a role for this service in fighting cabin fires as well. As discussed in Section 3.4, the original idea behind water mist systems was that the Fire Service, having gained access to the aircraft, could plug in a hose (or hoses) to connect the water supply to a cabin spray system and thus rapidly extinguish the cabin fire. This system should not be forgotten.

Experience has shown, for example with the City hopper accident at Schiphol Amsterdam that the Airport Fire Service cannot always, for many reasons, be used outside the airport boundary. Consideration should be given either to extending the range of the Airport Fire Service outside the boundary or to providing additional equipment and training for Fire Services operating close to airports.

3.11. Conclusions and recommendations

A number of measures which have proven to be effective in increasing the survivability rate in fire accidents can be implemented without insurmountable problems and with no or relatively little additional research effort. Looking at these, the following are recommended:

- Fitment of an external camera/cockpit monitor, following study of procedures required to guarantee safe operation;

- Fitment of watermist systems in new types of commercial aircraft;

- Introduction of smoke hoods in all commercial aircraft, following ergonomic study of stowage and accessibility matters and suitability to acceptable proportion of passengers;

- Implementation of proposed regulations for improvements in fireworthiness standards of cabin materials, including toxic emission prevention standards;

- Provision of additional equipment and training for Fire Services operating close to airports.

It should be emphasised that these measures are not mutually exclusive. In addition, there is a case to be made for introducing them all at some reasonable, attainable standard rather than seeking perfection in just one area.

Other measures, though potentially useful, do need more substantial research. One of these is the use of AMK fuels. Although the potential benefit of using AMK has been proved, it still must be demonstrated that it could be used safely on a routine basis.

4. Aircraft evacuation

4.1. Introduction

Since the large majority of air crashes are survivable or technically survivable, quick, efficient and effective evacuation is of vital importance for those who survive the initial crash. Current international regulations require that an aircraft must be evacuated within 90 seconds with half of the exits operational and this is tested during aircraft certification.

However, in real life crashes evacuations often do not run as smoothly as necessary and require more time. There are many factors which influence evacuation time and survivability in aircraft accidents. These factors can be broadly classified into four groups (Snow, Carrole and Allgood, 1970).

(a) *Configurational:* These are the standard features of the aircraft cabin which may influence access to exits and hence evacuation flow rates, e.g. seating, number and location of exits.

(b) *Environmental:* These are the features of the cabin and external conditions which influence the survivability and evacuation time, e.g. heat and toxic smoke in the cabin, light and weather conditions externally.

(c) *Procedural:* This includes the experience and training of the crew and other rescue personnel, e.g. fire crew, which can influence the evacuation procedures.

(d) *Behavioural:* These include the psychological, biological and cultural attributes of individual passengers which influence their behaviour as individuals and as members of a group, e.g. sex, age, prior knowledge and experience, fitness, physical and mental health, etc.

In this Section these four categories will be discussed and possible improvements and aspects for future consideration will be highlighted. It will start, however, with some information about the behaviour of people in aircraft emergency situations.

4.2. Passenger behaviour in aircraft emergencies

With comprehensive understanding of behaviour in highly stressful and disorienting conditions steps can be taken to improve the probability of a successful evacuation from an aircraft. Unfortunately, as yet, limited research effort has centred on the impact of passenger behaviour on aircraft emergencies and evacuation. However, information from other disaster situations, such as building fires and earthquakes, along with reports from survivors of recent aircraft accidents, has been used to build up a representation of the behaviours which passengers adopt and the impact of such behaviours within the cabin, particularly in those emergencies which involve smoke and fire.

It is well known that in some aircraft accidents everyone files out of the plane in a rapid although orderly manner - for example, in the evacuation of a British Airways 747 at Los Angeles in 1987 as a result of a bomb scare. In other accidents however, the orderly process breaks down and confusion in the cabin can lead to blockages in the aisles and at exits, with a consequent loss of life.

One of the primary reasons for the differences in behaviour between the orderly and disorderly situations must rest with the *individual motivation of the passengers.* In some accidents, all of the passengers assume that the objective is to get everyone out of the aircraft as quickly as possible, and they therefore all work collaboratively. In other emergencies, however, where an immediate threat to life is perceived, the main objective will be survival for themselves, and in some instances, members of their family instead of all passengers being motivated to help each other, . In this situation when the primary survival instinct takes over, people do not work collaboratively. The evacuation can become very disorganised, with some individuals competing to get through the exits.

Information obtained from accident experience suggests that fire and smoke are the most serious environmental factors to affect the efficiency of the evacuation and the behaviour displayed by passengers. If smoke and fire are *outside* the aircraft when an evacuation is initiated the number of exits which can be used is often limited. A limited number of exits obviously increases the demand on available escape routes. Accounts from survivors of the British Airtours Boeing 737 at Manchester in August 1985 and the 737 at Los Angeles in 1991 indicated that passengers egressed over seat backs and forcibly pushed themselves towards available exits. Consequently, human blockages occurred adjacent to the overwing exit and at the vestibule area of the galley, which dramatically decreased the efficiency of the evacuation. If there is smoke and fire *inside* the cabin this can lead to the impairment of breathing and vision, and the toxic fumes which emulate from cabin fires may affect the behaviour of individuals in an emergency evacuation.

There are many different ways in which individual passengers respond to an aircraft emergency situation. Responses may include fear, anxiety, disorientation, depersonalisation, panic, behavioural inaction and affiliative behaviour.

- *Fear*: Fear is a primary response when survival is threatened. The two reactions to fear are "fighting" and "flight". Either of these reactions can occur in an aircraft accident. The most frequently reported reaction is that of "flight", for instance by rapidly evacuating the aircraft. However, in response to a situation such as an inflight cabin fire the "fight" response may be induced, for example resulting in highly compatitive behaviour.

- *Anxiety*: Anxiety is experienced by the majority of passengers in an emergency situation, because the situation is frequently perceived as potentially life-threatening. Anxiety makes that even very simple tasks, such as unfastening the lap belt, become difficult for passengers. Since in an emergency situation passengers are required to make a series of novel and difficult responses, it is hardly surprising that the optimum egress does not occur.

- *Disorientation*: Disorientation can be experienced as a result of factors such as the reduction in visibility caused by dense black smoke or the fact that the airframe may have come to rest on its side or at some strange angle. The disorientation will not only increase levels of anxiety among passengers, but may also cause them to enter areas of the aircraft from which there is no escape.

- *Depersonalisation*: For some people, detaching themselves from the actual situation, and acting as an "observer", means that they feel better and are able to think and respond effectively. Such depersonalisation may account for the reactions of passengers during three premeditated evacuations (Robson, 1973). Of the 268 individuals, cabin staff classified 35 per cent as calm, 47 per cent as mildly agitated, 2 per cent as very agitated, with less than 1 per cent exhibiting signs of panic.

- *Panic*: Panic may be defined as uncontrollable and irrational behaviour. In practice it is believed that true instances of panic among passengers involved in aircraft accidents are relatively rare. The behaviour of passengers in emergencies can usually be interpreted as a series of rational responses. In fact, Robson (1973) indicated that less than 1 per cent of passengers displayed responses akin to uncontrollable panic, a result which is also reported from the analysis of other disaster situations.

- *Behavioural inaction*: The evidence from aircraft accidents seems to indicate that there are many more instances of behavioural inaction than of panic. The analysis of four disasters, led Allerton (1964) to conclude that between 10 and 25 per cent of people did little or nothing to escape from danger. For example, a number of fatalities on an Air Canada DC-9 accident in 1983 were located in seats which had been allocated to them before take-off. Equally, a number of passengers onboard the taxiing Boeing 747 at Tenerife in 1977 were judged by their fellow passengers to make little attempt to escape from the burning aircraft.

- *Affiliative behaviour*: Affilitative behaviour involves movement towards the familiar and has frequently been observed in aircraft accidents. An example is passengers' attachment to their hand luggage, with many passengers insisting on taking their personal belongings with them when undertaking an emergency evacuation. It seems that the perceived value of the contents outweighs the risk they believe they will encounter if they take it with them.

In order to simulate the evacuation of large numbers of individuals from an enclosure and to predict the behaviour of passengers in various conditions, a number of computer-based egress models are being developed and applied in an aviation context. The model developed by Galea et al (1993) appears to be the first which has used behavioural data from simulated aircraft emergencies in order to determine the accuracy of the predictions from the model. The model tracks the trajectory of each individual as they make their way out of the aircraft, or are overcome by fire hazards.

A long term objective within the aviation industry will be to use egress models to slowly replace the need for human testing for the evaluation of the emergency facilities on new aircraft. However, it is clear that to develop a valid computer model, many full-scale human tests are required.

4.3. Cabin configuration and evacuation

4.3.1. Seating configuration near Type III exits

In the accident which occurred at Manchester Airport in the UK in 1985 the evacuation of passengers was impeded by blockages at the Type III exit and at the aperture between the bulkheads at the front of the cabin. Blockages also occurred during the evacuation through the Type III exit in the accident which happened in Los Angeles in 1991.

Following the accident at Manchester the UK Civil Aviation Authority (CAA) sponsored a major programme of research to determine whether making changes to the seating configuration within the cabin adjacent to the Type III exit would reduce the likelihood of blockages. A major test programme was undertaken involving members of the public taking part in simulated emergency evacuations from a Trident aircraft.

The results from the tests (Muir et al., 1989) indicated that when the distances between the seat rows (involving three seats per row) adjacent to the Type III exits is increased from a 3 inch (7.6 cm) vertical projection to between 13 inches (33 cm) and 25 inches (63.5 cm) vertical projection, and with the hatch thrown out of the cabin, there will be an increase in the evacuation rate and a reduction in the probability of blockages. A configuration was also tested involving the outboard seat removed and a 10 (25.4 cm) inch vertical projection between the seat rows. This also gave rise to an improvement in the evacuation rate. The results clearly demonstrate that the changes made by the CAA have been a significant improvement. Similar tests have also been conducted by the Civil Aeromedical Institute at Oklahoma City in USA for the FAA (McLean et al., 1995a, 1995b).

Recently, the Association of European Aircraft Manufacturers (AECMA) have sponsored a series of extensions to this programme which has involved additional seating configurations. The tests have included 6 inch (15.2 cm) and 10 inch (25.4 cm) vertical projections when three seats are positioned in the rows adjacent to the exit, and a 6 inch (15.2 cm) and 10 inch (25.4 cm) vertical projection when two seats are positioned in the row adjacent to the exit.

4.3.2. Ease of operation of Type III exit hatches

It is clear that the ease of operation of the hatch, when opened by passengers, may affect the evacuation rate. Therefore, in a series of further tests, members of the public were involved to explore the influence of changes to the weight of a Type III exit hatch involving a 3 inch (7.6 cm) and 13 inch (33 cm) seating configuration adjacent to the exit. The results showed that reducing the hatch weight from 25 to 12 kilos led to a significant improvement in the rate at which passengers can operate the hatch and evacuate onto the wing of the aircraft (Muir and Fennell, 1993).

Recently the UK CAA have sponsored the development and performance evaluation of a new Type III exit hatch concept. The design has involved the development of an "up and over door" at the exit with no modification to aperture. In addition to improving the ease of operation, the new design removes the problem of exit disposal during the evacuation. The report from this project will be available in 1997.

4.3.3. Bulkhead aperture

In the 1985 Manchester accident, serious blockages had occurred at the aperture leading to floor level Type I exits. A number of tests explored the influence of changes to the aperture between the bulkheads on evacuation rate. The results indicated (Muir et al., 1989) that increasing the minimum distance between these units from 20 inches (50.8 cm) to 30 inches (76.2cm) would lead to a significant improvement in the evacuation rate and a reduction in the likelihood of blockages. The configuration involving no bulkhead on one side of the airframe impeded the ability of the cabin crew to operate the exits and on several occasions led to the crew being pushed out of the aircraft by the initial rush of passengers. This configuration was therefore not recommended although it does exist on some aircraft with Type I exits.

4.3.4. Evacuations from the rear of the cabin

A further series of tests were conducted involving members of the public, evacuating from the front or the rear of a 737 simulator. The results indicated that although the overall evacuation rates tended to be a little slower when passengers were evacuating through the rear of the aircraft, the differences between the times were not significant (Muir and Cobbett, 1995).

4.3.5. Future considerations

Combined ease of operation and evacuation tests

An important next stage in the programme of evacuation research should be combined tests involving ease of operation and evacuation. In other words tests in which members of the public operate the hatch and evacuate onto the wing to ensure that the seating configurations which are included in the regulations will lead to a rapid evacuation when members of the public operate the hatch. All of the previous tests have involved the use of only one Type III exit. Since many airframes now fly with two pairs of Type III exits located near the centre of the cabin, this factor should also be included in the consideration of the design of future tests.

Aisle joggle
Transport Canada have also sponsored some initial tests to explore the influence of a "joggle" or slight bend in the main aisle on the evacuation rate. These tests are to be continued with emergency lighting in the cabin and darkness outside the cabin. The report from this project will be published in 1996.

Wide bodied airframe tests
The evacuation tests which have been conducted in the UK and by FAA (CAMI) in the USA have exclusively involved narrow bodied airframes. Research should be undertaken involving wide bodied airframes to ensure that the dimensions which have been recommended for narrow bodied airframes, e.g. 30 inch (76.2 cm) aperture between bulkheads, would be appropriate for wide bodied airframes. Such testing could look at other configurations such as cross-aisles and access to Type I exits.

Evacuation slides
The slides continue to give rise to injuries both in accidents and in certification tests and test programmes. Indeed it has been the occurrence of injuries during aircraft certification that has led to the demand for changes to the full scale evacuation demonstration test conducted for aircraft certification. There are no published reports of research in this area.

Very Large Aircraft
With the development of Very Large Aircraft capable of carrying up to 1000 passengers it will be important to determine whether the airworthiness and evacuation requirements specified for current airframes will be adequate for Very Large Aircraft, e.g. for aisle widths, seating density and mechanism for transporting passengers from the exit to the ground in the event of an emergency evacuation. There are also operational considerations such as in-flight turbulence which may be affected by new commercial concepts,. e.g. concepts such as casinos, fitness centres, duty free shops, business centres which would encourage passengers to leave their seats and put them at greater risk if turbulence or decompression is encountered.

4.4. Cabin environment and evacuation

4.4.1. Non-toxic smoke in the cabin

In the majority of accidents in which there is loss of life a fire will have occurred. In the event of a fire there is usually a period of approximately two minutes between the onset of the fire and the conditions in the cabin becoming non-survivable due to the presence of smoke and toxic fumes. Since the accident which occurred at Manchester in 1985 the regulatory authorities have introduced a number of regulations specifically addressing the problems of smoke and fire entering the cabin. These measures have included fire blocking of seats, fire hardening of interiors e.g. panels, floor proximity lighting and smoke detectors in the toilets and cargo holds. As indicated previously, accident investigators' recommendation for the provision of smokehoods, watermist systems mad external cameras have not yet been taken up.

The UK CAA sponsored a programme of evacuation tests involving the presence of dense non-toxic smoke in the cabin. The results (Muir et al., 1989) indicated that the main effect of the smoke was to lead to a significant increase in the time taken to evacuate the aircraft and that the configurations which had been shown to be optimum in clear air did not give rise to any greater increase in evacuation time than the other configurations tested. Another important finding was the value which participants placed on information gained from tactile cues during the evacuations.

4.4.2. Cabin water spray systems

In the UK AAIB report following the accident which occurred at Manchester Airport one of the recommendations was that consideration should be given to the introduction of cabin water spray to be used in the event of a major fire. As a number of systems had been developed and been shown to be highly effective in preventing the spread of the fire through the cabin (see Section 4.4), a test programme was undertaken to determine whether the operation of a cabin water spray system would create problems for passengers and slow down the evacuation rate. The results from the programme indicated that there was no significant difference between the evacuation rates with and without the cabin water spray operating (Muir et al., 1993). One of the other findings from the test programme was the fact that participants subjectively reported good visibility within water spray, although those wearing spectacles were found to have more visibility problems than those wearing contact lenses or no eye wear. No potential problems with the floor surface or cabin fittings becoming wet were identified. Participants reported that the evacuation commands given by the cabin crew were significantly less audible when the spray was operating.

4.4.3. Darkness

Transport Canada have sponsored some initial tests to explore the influence of reduced lighting on the ability of passengers to evacuate the airframe. This work has to date only involved Type I exits, but additional tests involving passengers evacuating through Type III exits would lead to a better understanding of what steps can be taken to assist the passengers to reorientate and to reduce the probability of passengers falling from the wing in darkness. It is expected that testing programmes will continued in the near future.

4.4.4. Future considerations

Tactile cues

Consideration must be given to the introduction of additional tactile cues to assist passengers evacuating from a smoke filled cabin and ensuring that there is sufficient information for them to understand their location in the cabin when their vision is impaired.

External environment

The external environment into which passengers evacuate has not historically been given consideration apart from the ditching scenario or over run into water, in which case, life jackets and rafts are available. No provision is given for passenger protection following an evacuation into a hostile environment e.g. extremes of temperature. This might be of even greater relevance if water spray systems are introduced since once the passengers clothing had become wet by the spray, they would be severely disadvantaged in a cold environment.

Water spray systems

If cabin water spray systems are to be introduced, tests will be required to determine the maximum level of noise emanating from the nozzles which ensures that this does not impede the ability of the passengers to hear the commands from members of the cabin crew.

4.5. Evacuation procedures

4.5.1. Assertive cabin crew

In 1994 a programme of research into cabin crew behaviour during emergency evacuations was jointly sponsored by the CAA and FAA. The tests involved passengers evacuating from a sixty seater 737 simulator with a range of conditions. Some groups of passengers experienced assistance from two assertive members of the cabin crew, others experienced assistance from one assertive cabin crew member, others from two non-assertive cabin crew members, and for others no cabin crew was present to assist the evacuations. Assertive behaviour included calling volunteers to exits and actively pushing them through exits as rapidly as possible in a highly active but non-aggressive manner. Non-assertive behaviour involved asking volunteers to come to exits and only giving physical assistance when someone was in danger of falling in the vestibule area. The results clearly indicated that assertive cabin crew significantly increased the speed at which passengers were able to evacuate the aircraft when compared to non-assertive or no cabin crew present (Muir and Cobbett, 1995).

As the test programme developed, it was confirmed that in addition to the operation of the exits, the management of passengers and crowd control skills with appropriate commands are important functions to be performed by cabin crew.

4.5.2. Acoustic attraction signals

One of the recommendations in the UK AAIB report following the accident at Manchester was that consideration should be given to the introduction of acoustic signals which in the event of a fire could be used to attract passengers to operational exits. Acoustic signals were developed, fitted in the Trident Aircraft and a series of evacuations tests with non-toxic smoke present in the cabin were conducted. The results indicated that the presence of the acoustic signals did not significantly increase the rate at which passengers were able to evacuate the aircraft (Muir and Bottomley, 1992).

4.5.3. Future considerations

Initial and recurrent training of cabin crew

The results from the evacuations involving assertive cabin crew clearly indicated their important role in emergency evacuations. The demonstration of an ability to perform assertively in a simulated emergency should, therefore, be a requirement for all students during initial training before they go onto the line. Any student who cannot achieve the standard will be placing themselves and members of the public at increased risk in the event of an accident. Ultimately this may have implications for the selection criteria used for cabin crew. The requirement to demonstrate assertive behaviour during evacuations should also be introduced into recurrent training. Indeed consideration could be given to future work to develop performance standards to be used for both initial and recurrent training.

CRM for cabin crew

Crew resource management (CRM) training involving cabin crew and members of the flight deck is being introduced by some companies. The objectives, syllabus, methods of training and evaluation require continuous consideration. Research should be undertaken to determine the effectiveness of a sample of the current programmes and to develop performance standards. The possibility of Line-Oriented Flight Training (LOFT) for cabin crew could also be considered. JAR OPS will require cabin crew to carry out CRM training. Additionally, on promotion to senior status, cabin crew will be required to complete safety promotion training which will include an additional CRM element.

Technical training

Consideration should be given to the requirement for basic technical training for aircraft operations for cabin crew, since recent accidents clearly illustrated the potential importance of this training (e.g. Mohansky, 1992). JAR OPS will require this aspect to be included in cabin crew training.

Cabin crew and Type III exits

The fact that assertive cabin crew can significantly increase the speed of the evacuation through Type I exits calls for research to determine whether the presence of a cabin crew member at Type III exits will increase the speed at which passengers can evacuate through these exits as well. If this were shown to be the case, on those aircraft with two pairs of Type III overwing exits this could lead to a substantial reduction in the time taken to complete the evacuation.

Crowd control

There is an urgent need for further work to determine the most effective method of controlling passengers rushing towards exits in an emergency and for determining the most appropriate commands which will be understood by passengers of different nationalities.

4.6. Passenger behaviour and evacuation

4.6.1. Presentation of safety information

In 1989 an investigation was sponsored by the UK CAA to determine the most effective ways in which passengers could be encouraged to pay more attention to safety procedures (Muir and Fennell, 1992). Passengers' opinions of the effectiveness of possible alternative introductions to the safety briefing indicated that an approach in which passengers are informed of the importance of knowing how to carry out safety procedures would be more likely to encourage attention to the safety briefing and the safety card. Cabin crew was perceived to be primarily responsible for passenger safety in an emergency, suggesting that the lack of attention to safety information on the part of some passengers may be attributable to a belief that they need not assume responsibility for their own safety.

Almost 80 per cent of passengers involved in the survey thought that the operators should encourage passengers to be more safety conscious. The passengers suggested ways in which this could be achieved and these included tighter control over the stowage and quantity of cabin baggage, the restriction of smoking, alcohol and duty free goods, making safety briefings more interesting or varied and the promotion of safety education.

Two experimental studies were conducted in order to investigate passenger comprehension of airline safety information and to determine:

(a) the effectiveness of safety cards for conveying safety information to passengers, and

(b) the effect of varying the content of information presented in safety briefings on passenger attention.

In both the experimental studies, volunteers boarded a stationary aircraft and were given a safety briefing. An emergency situation was simulated and the volunteers were instructed to put on their lifejackets, and then to brace for an emergency landing.

Volunteers' knowledge of the less complicated safety briefing card information, such as the location of the oxygen masks and when and how to inflate the lifejacket, was generally high. However, volunteers' knowledge of more complex procedures, such as the correct method of donning the lifejacket and of operating the overwing and main exits, was more limited. A comparison of lifejacket donning times indicated that volunteers who donned their lifejacket four hours after having seen a standard safety briefing were not significantly slower than those who donned the jackets 5-10 minutes after the briefing. Volunteers' opinions indicated that emphasis on the importance of passengers knowing how to operate items of safety equipment in briefings would not discourage the majority of them from flying and would be likely to increase attention to safety briefings.

A number of problems were identified as affecting passengers' ability to carry out safety procedures quickly and effectively. For example, the lack of specific information (in all of the briefings investigated) led to problems in locating and retrieving the lifejacket from under the seat. Inadequate instructions led to the loss of valuable time as passengers tried to find out how to open the lifejacket container and identify the inside and outside of the jacket. These problems indicated the need for more specific information to be included in the safety briefing and on the card to ensure that the correct method of operating safety equipment and the appropriate procedures to adopt are obvious to passengers.

Although air travel was considered by passengers to be the safest form of transport, aircraft accidents were perceived to be less survivable than accidents involving other forms of transport. Previous findings that passengers tend to underestimate their chances of survival in aircraft accidents were supported by passengers' relatively low perceptions of their survival chances in eight different aircraft emergency situations.

4.6.2. Passenger Training

In 1994 a project involving members of the public was undertaken to determine whether practising emergency safety procedures in a non-threatening environment improved performance in a simulated emergency. The project also provided information on whether training improved passengers' knowledge of airline safety procedures. The results indicated that a training programme incorporating instruction and practice in the use of certain cabin safety procedures and equipment, enhanced performance of those tasks in a simulated emergency. The improvement was particularly noticeable for procedures which were novel or complex, e.g. locating the lifejacket, adopting the brace position. An increase in safety information following participation in the training was demonstrated by all participants (Parkinson and Muir, 1995).

There are however many potential problems associated with the introduction of passenger training centres. These include different location and operation of lifejackets and oxygen, different international standards for the brace position, different aircraft specific equipment such as door/exit operation, slides etc. Other questions to be solved are: who provides the resources, who pays and who trains?

4.6.3. Future considerations

Aircraft safety information

An evaluation of alternate methods to assist passengers to follow the emergency procedures accurately in an evacuation together with research into the use of new technology and the potential benefits of alternate methods of training is required. The length and content of safety briefings/training should form part of the evaluation.

Cultural and language differences

One of the difficulties to overcome when safety information is required is to ensure that it is understood by passengers from many cultures and tongues. A project is currently being undertaken by the JAA Cabin Safety Working Group to explore the effectiveness of symbols for conveying information to passengers about the location of exits.

Survival perception

The survey of passengers' perceptions of aircraft accident survivability indicated that a more realistic image of aircraft safety is required. The public needs to be made aware that the majority of aircraft accidents are survivable and the information contained in safety briefings and on safety cards may save their lives.

Passengers with mobility problems

So far, the research which has been undertaken has been based on the ability of adults with no physical or mental difficulties to follow the emergency procedures. Consideration should be given to the factors which could influence the survival of other groups of passengers in an emergency.

4.7. Conclusions and recommendations

A fast and effective evacuation procedure can save many lives in case of a technically survivable aircraft accident. In the last decade major research programmes have been undertaken which have provided important new information on how evacuations proceed and which factors influence their effectiveness.

People's responses to emergency situations vary from relatively calm and effective to total panic or in other cases to total inaction. In situations which are perceived as directly life-threatening, many people lose their motivation to collaborate in order to save others, but instead will try to save themselves first.

Of course, it will be difficult if not impossible to change peoples immediate response and make them all respond calmly and rationally in these types of situations. However, there are a number of other factors that can be changed and that will improve the overall evacuation speed despite the wide range of response and behaviour of the passengers.

The most important factors are (i) the cabin environment, in particular the presence of fire, smoke and/or toxic fumes in the cabin; (ii) the configuration of the cabin, in particular the seating configuration near the emergency exits, the ease of operating the exit hatch and the bulkhead aperture; (iii) the behaviour and crowd control skills of the cabin crew during emergency evacuations; and (iv) passengers' knowledge of safety procedures and their motivation to get acquainted with them.

Some of the measures to improve evacuation procedures as discussed in the foregoing sections can be introduced with no or relatively little additional research efforts, knowing that they will contribute to increase evacuation speed and efficiency, for example:

- Increasing the aperture between bulkheads to 30 inches (76.2 cm);
- Training cabin crew in crowd management skills and to act assertively in case of emergency evacuations.

It is recommended that these measures should be introduced as soon as possible.

Other measures do, indeed, need more study and research to determine the potential benefits and/or the optimal technical specifications. For example:

- Establishing the optimal cabin configuration for evacuation from wide bodied airframes;
- Consideration of an alternative to evacuation slides for escape from Very Large Aircraft;
- Finding ways to reduce the interference of the noise of watersprays systems with cabin crew's oral commands;
- Determining optimal technical specifications for additional tactile cues in the cabin to assist passengers evacuating when visibility is poor;
- Evaluation of new technologies for the presentation of safety information to passengers, such as airport training mock-ups.

It is recommended that research in these areas should be carried out at the earliest opportunity, to ensure that effective measures to increase the evacuation rate and hence increase the survival rate in aircraft accidents can be implemented as soon as possible.

5. Regulating and implementing measures

This review has clearly pointed out that many aircraft accidents are survivable, contrary to the belief of the general public that involvement in an air crash will automatically lead to death. In some cases this is indeed true. For example surviving an explosion at 30,000 feet and free falling without parachute and special equipment at minus 50 degrees is unimaginable. However, around 75 per cent of the aircraft accidents occur during the approach and landing or take off phases of the flight and then the situation can develop quite differently.

Survival of certain emergencies is possible, although sometimes not for all passengers. Recent accidents, the latest (24 November 1996) involving a Boeing 767 and another involving a military C-130, provide the necessary illustrative information. The crash of the highjacked 767 aircraft near the Comoren islands after it had run out of fuel shows that a significant number of passengers can, indeed, survive a major break up of the airframe. In this case around one third of the passengers were able to reach the shore after the aircraft crashed near the beach.

Another recent crash with a military C-130 at Eindhoven in the Netherlands demonstrated that survival after impact is possible but in this case escape was impossible because of a deformation of the airframe which blocked the escape hatches. Rescue by ground assistance came too late to prevent fumes and fire to overwhelm the survivors.

These and many other examples clearly show that a systematic approach to increasing survival rates is essential. There is no point in improving the survivability of impact if passengers and crew are then killed by the subsequent fire. The following steps are proposed to form the basis for such a package of measures to increase the survivability rate in aircraft accidents:

- Training of crew and cabin staff to share critical information;
- Improving the energy absorbing qualities in the event of an impact;
- Reducing the chance of fire, in particular in the cabin;
- Avoiding the development of toxic fumes;
- Maximising the opportunities for an orderly and quick evacuation;

In such a highly competitive industry, improvements in aircraft survivability will come primarily from regulatory action. On the national level, some commendable efforts have been initiated which have been noted in this review. However, further and more extensively co-ordinated work is required to realise progress on a wider scale. ETSC firmly believes that, for EU registered aircraft, a strong, single EU air safety authority has a crucial role to play in promoting and realising such a package of measures. This single EU air safety authority would be able to set binding safety standards which reflect best knowledge and which are in line with EU Treaty obligations.

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