A Review of Fire Related Accidents, 1985 - 1995

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1. ABSTRACT
In the 1975 and 1989 AGARD Symposia statistics were presented concerning the survival aspects of transport aircraft accidents. Although much relevant data was still missing it was concluded that not much had changed in the intervening years. Following the Manchester B737 fire accident in 1985 many important recommendations were made and much research has been completed. The current study reviews relevant accidents 'post Manchester' and tries to assess to what extent the changes that have been made have improved our chances of escaping safely from an aircraft that is on fire or has been damaged sufficiently for fuel to have been spilt

As far as possible criteria identical to those used previously will be employed in order to make the comparisons valid, however it must be appreciated that international aviation is changing and any effects of these changes that can be quantified will also be discussed..

2. INTRODUCTION
It is not unusual for the Abstract of a paper to be written well before the paper itself and for intervening events to require some alteration to the route originally anticipated. The above Abstract, written in June 1994 for the following paper, written two years later is no exception thus, before discussing post-Manchester accidents, a variety of points of a more general nature will be made.

Previous papers (references 1 and 2) have suggested that in order to proceed along the route towards ever safer air transport we need to consider not only single significant accidents but also such general trends and pointers as may be gleaned from a study of accident statistics The implication was that such consideration would lead to sensible and effective action But has it? - that is the important question and if this has not always been the case, as will emerge, how should we organise matters in the future to ensure the progress that the ever increasing numbers of flights per year makes essential?

In an ideal world the investigation and reporting of incidents would quickly and effectively prevent accidents but we are still some way short of this ideal What may happen after an accident is that the investigator discovers that there has been at least one previous similar accident and any number of related incidents The former had been treated as a 'one off' and the incidents as being of no real significance since they had not led to an accident!

Reference 3 pointed out that, to paraphrase the immortal Lady Bracknell in Oscar Wilde's 'The Importance of Being Earnest', it may be said that *'to lose one aircraft may be regarded as a misfortune, to lose two looks like carelessness'*. Thus the dedicated and, it is sometimes said, idealistic work of the accident investigators may be dismissed since a single accident, being merely a misfortune, does not seem to merit any extensive and perhaps expensive action Now of course if we have a second, something must be done immediately!

At the beginning of the jet era this approach paid valuable dividends; no country, airline or manufacturer had to wait very long for a second or even a third accident so, whether due to carelessness or something else, the cause was not only found but acknowledged and action taken. As a result the accident rate fell dramatically However a system is still needed to ensure that we not only learn lessons from the past but continue to act upon them.

One difficulty that we appear to be facing is the increasingly litigious nature of the aftermath of an accident, in which lawyers claim that making a change is an admission that matters were not right before and is therefore an admission of liability. This does not encourage change. To balance this may be the fear that a further accident will occur before a change has been made, when circumstances clearly, at least to the lawyer with 20/20 hindsight, show an early change to be necessary

This question of balance is central to all such discussions since, in some cases, there are valid reasons for not making a change; the facts always have to be weighed up very carefully.

3. LEARNING LESSONS FROM PAST ACCIDENTS
The following example illustrates the consequences of not making changes in time. In October 1971 a Vickers Vanguard crashed in Belgium, killing all 63 on board, due to a failure of the rear pressure bulkhead allowing cabin air into the tail cone and hence into the horizontal stabiliser. The stabiliser could not withstand the pressure, 'blew up' and detached (reference 4) This accident has been amongst those presented by the author (reference 5) each year, from 1978 onwards, to airworthiness and design engineers from Europe and beyond, as an example of how the catastrophic secondary consequences of a serious but non-catastrophic primary failure could be overlooked or ignored by design and certification teams alike.

The August 1985 accident to a B747 in Japan, for very similar reasons and with the loss of 520 of the 524 on board, therefore came as a very nasty shock and a reminder that discussing an accident, without checking that proper action has been taken, does not prevent the next. This point was made in subsequent lecture notes. What was even more alarming was that even then no action was taken and it appears to have been only after a similar but fortuitously non-fatal accident to a Tristar over Manchester in December 1990 that regulations were eventually amended

This is where it has been suggested that accident statistics can help. Is an accident a one-off or is it one with many similarities to previous accidents? The inference is obvious and has been spelled out many times before (references 1 and 2) nevertheless a question remains as to whose job it is to point out the similarities

In the UK the Air Accidents Investigation Branch (AAIB) of the Department of Transport investigates accidents and is meticulous in determining the facts, analysing them, drawing conclusions and making recommendations that are usually of a general, not too specific nature. The Civil Aviation Authority (CAA) then considers the recommendations, decides whether or not to act on them and publishes its decision with explanations. Thus the investigators, having pin-pointed safety deficiencies, pass them to the regulators, the regulators decide how to implement them. What is not clear to the outside observer who studies the records is which body is responsible for putting the recommendations into the wider context of past accidents and incidents. Since the CAA is, in effect, now part of the JAA, the Joint Airworthiness Authorities of Europe, this matter has become even more complex and it is important that an effective system is developed.

In the USA the National Transportation Safety Board (NTSB) is charged not only with investigating individual accidents but with carrying out special studies often involving the consideration of many accidents. Thus some US safety recommendations made to the Federal Aviation Administration (FAA) quite clearly emanate from accident statistics rather than from a single accident. In the UK the AAIB may refer, as it did following the Tristar bulkhead failure over Manchester, to previous accidents and/or incidents in the main report but this may not always be obvious in the recommendations As a result we sometimes have the desired result of the recommendation being expanded to cover a wide range of aircraft types and thus implementing it most effectively, while on the other hand the wider implications of a recommendation may sometimes be missed because a specific 'fix' is appropriate to the one specific aircraft type of the accident investigation and report

The problem we are facing is perhaps one created by our own success. The accident rate has for the last few years been at a level that ensures that accidents occur so infrequently, particularly to a given aircraft type or to a given airline or even in most countries, that designers, operators and airworthiness authorities cannot easily carry a clear idea in their minds of what is really important Yet unless we assess very carefully indeed the results of all our accident reviews, we may waste lives as well as money

So why is the information that is available on past accidents and from safety research not always used? It is easy to answer *'lack of money'* but that is not the real answer; if all manufacturers and all airlines are called upon to make internationally agreed changes, no one suffers. The passenger will have to pay a little more but will have the benefit of safer flights, after all a few million pounds a year may sound a great deal of money, but shared between a few million passengers it represents only a very small increase in the cost of each ticket Without understanding why agreement cannot now be reached in a reasonable time, when authorities in Europe are coming closer and closer together, and closer to the FAA in the USA, it is not possible to offer a solution to this international problem.

As another example of where it seems that lessons have not been learnt we need look no further than the accident on Manchester airport in the UK on 22 August 1985 in which 55 people died in a B737 (reference 6). This accident is extremely well documented, a great deal of valuable research followed, yet many of the conclusions have still not been implemented. Even, as in the instance below, where the CAA has been whole-hearted in its endorsement of a finding and recommendation we are still awaiting implementation, over eleven years after the accident! This is apparently because the CAA is unable to act alone and some of the other European authorities in the JAA do not agree or do not understand the importance of the proposed changes

It must be accepted that some safety systems do have balancing dangers that have to be overcome before implementation so as to ensure that there will indeed be a net benefit. However there can be no such danger in making the minimum width of passageways through cabin bulkheads 30 inches (0.76m), so why are we still waiting? The Manchester report was absolutely clear in its findings that a 22 inch (0.56m) wide passageway through the bulkhead at the front of the passenger cabin was not wide enough This narrow gap produced a bottleneck that prevented the two forward main exits beyond the bulkhead from being used effectively, yet regulations still allow this gap to be even narrower at 20 inches (0.51m) CAA sponsored research (reference 7) clearly indicated that 30 inches was the minimum acceptable width of such a passageway and a study of relevant emergency evacuations (reference 8) confirmed that evacuation through the front half of the exits and hence through such a passageway was common A comparison with escape paths and doorway widths in buildings (reference 9) suggested that a minimum width of 0.80m (31 5 inches) would be appropriate, thus there is long established evidence supporting a change.

Although bulkhead widths have not yet increased, other features that could reduce the number of passengers being overcome by fire have been introduced, though not necessarily world-wide A careful study of the accident record is required to see if the introduction of these features has made any difference to survivability.

4. THE PAST TEN YEARS

Unfortunately the promised review of jet and turboprop aircraft accidents since Manchester has not been able to go into as much detail as previous such reviews, for reasons that will be explained later Furthermore due to the changes in, for example, aircraft types and sizes, it has not been practicable to make exact comparisons Note that in earlier papers where there was no direct indication that there had been a fire or spilt fuel the probability of there being sufficient damage to provide a real risk of fire was often a matter of judgement The criterion for inclusion is now based, if there is no other relevant information, on the quoted 'loss percentage'. If this is 100% the accident is included (this figure may be revised downwards when the criteria used in assessing this figure are better understood)

Notwithstanding the shortage of detailed information it can be shown that the proportion of those killed in survivable accidents as opposed to those killed in non-survivable accidents has remained essentially unchanged. For the earliest period considered, 1955 to 1974 some 45% of all fatalities occurred in survivable accidents (reference 10). This decreased to 36% for 1967 to 1986 (reference 11) or to 39% for the pre-Manchester period 1976 to 1985 (reference 2).

For the period 1986 to 1995 the figure has remained at about 36%, however, although for 1989 to 1995 it is 38% and for the three year period 1993 to 1995 it is up to 43%, the variations from year to year do not allow us to be sure that the proportion is in fact increasing, nor of course to claim that it is decreasing! The safest thing to say is that overall it seems to have stayed at around 40%, which is to say that in a year where 1000 are killed in all accidents some 400 will have died in survivable accidents and 600 in non-survivable accidents. It therefore appears that despite the incorporation of some new safety features in some aircraft no improvement is yet apparent. This is disappointing since many people had hoped that changes in cabin materials, better seating arrangements, floor level lighting etc would have reduced the number of fire deaths, and higher strength seating etc would both have reduced the number of impact deaths and also, by reducing the number of incapacitating injuries, have reduced the number of fire deaths as well.

The figure of 1000 fatalities per year has been a convenient yet reasonably accurate round number to use for a remarkably long period, a fact that demonstrates how fatal accident rates have steadily decreased. What is now apparent is that this round figure should increased to 1400, the average over the past four years and with little variation from year to year. Thus the actual numbers killed in survivable accidents, in round figures, now appears to be about 600 per year with the other 800 being killed in non-survivable accidents.

What is clear is that we do still need to make further improvements in order to enhance the chances of surviving an accident as well of course as needing to reduce the probability of having an accident in the first place.

References 10 and, later, 2 attempted to establish how many of the (then) 400 were as a result of the impact and how many were as a result of a fire or, in a few cases, other causes such as drowning. The conclusions were that some 220 died as a result of the impact and 180 as a result of fire, other causes were not discussed but should not be considered negligible. Consequently an objective of the present paper had been to see if these figures had changed as a result of the recommendations and research that followed Manchester. Unfortunately, while some manufactures have been helpful, others, for example Fokker, have been unable to find the time to help as they have in the past, and other available records, including the ICAO data base, provided information on too few accidents for any conclusions to be made concerning cause of death. This last fact would appear to be because many accident investigation agencies still fail to make a complete return to ICAO. In some such cases, but probably not all, this is because the national culture does not permit the time to make an autopsy when a large number of fatalities is involved.

This makes it expedient to take a wider look at the accident statistics and at the route that we might follow to achieve improved cabin safety, though first of all it must be stated that no improvement had been expected since the few safety features that have been introduced in some aircraft have not yet been introduced world-wide. So where do we go from here?

5. A WAY FORWARD?

If we accept, as has the International Society of Air Safety Investigators (ISASI), that the AAIB's report (reference 6) on the B737 accident at Manchester in 1985 was a milestone in the investigation of accidents involving cabin fire, then we must also accept that in the past eleven years we have not travelled far beyond this milestone. As with an actual accident investigation it is all too easy to try to allocate blame, in this case for lack of progress, when we should be looking for the way forward. Perhaps, to conclude the analogy, we have been stuck at cross-roads and need urgently to turn off the road that seems to have made progress virtually impossible.

The underlying spirit behind the Manchester report's recommendations seems to be that there was no single answer but, rather a need to tackle a wide range of problem areas; these were listed and discussed at Sintra in 1989 (reference 2 and others). Many, including the present author, agreed with this wider approach and have emphasised the point that we should tackle fire protection on a broad front rather than concentrate on any one priority issue.

However although research has been conducted into a number of the issues since 1985, there does not appear to have been a unified approach to the problem; some single issues have been almost totally rejected, others have been encouraged for several years only to be dropped later as being not cost effective. It must now be hoped that the recently announced (reference 12) joint US, Canadian and European Aviation Authorities Cabin Safety Research Program, *'described as a totally integrated plan that allows three separate aviation-safety authorities to get the most from their cabin-safety research budgets'* will be able to achieve not just agreement on research programmes but *action* based on the results of this research and on that which has gone before it.

Until now one significant reason for our lack of progress could well be that with the very low accident rate that the industry has achieved over the past few decades, *no* single safety feature is likely to appear to be cost effective. If one looks at the money needed to be spent each year, usually amounting to many millions of pounds, to save only a few lives, then the argument that it would be better to spent the money elsewhere may seem reasonable. On the other hand if one looks at the additional cost on every ticket required to recover this money, probably only a few pounds on a ticket costing perhaps anywhere between £100 and £500, depending upon how and when purchased, then it may seem *unreasonable not* to proceed. But if so, how should we proceed?

One suggestion is that we reconsider the reasons behind our lack of progress, maybe the apparently small benefits to be derived from any one safety feature, the way many research programmes have concentrated on proving and/or improving benefits rather than on minimising the disbenefits of a particular feature, and so on. We should also consider the consequent dangers of suddenly calling for the immediate provision of one or more of the safety features under review before we can be absolutely sure that the benefits *do* outweigh the disbenefits.

Perhaps we should seek a new philosophy in which we aim at having a collection of safety features waiting on the shelf until their need is agreed by all concerned. To achieve this we must concentrate R&D on minimising, to an acceptable level, the disbenefits of any feature. Only when this has been achieved should further improvements or further proof of particular benefits be sought.

Examples from safety features already in use are stick pushers and fuel jettison systems. In these the most important issue is to ensure that the chances of inadvertent (and potentially catastrophic) operation are minimised to an acceptable level. That the systems should usually work on the very rare occasions that they are needed is of course highly desirable but several orders of magnitude less important. Similarly it is absolutely essential that doors do not come open in flight, yet they must open readily on the very rare occasions that they are needed for an emergency evacuation following an accident that may well have caused fuselage damage and distortion.

Of those other features relevant to cabin safety several have parallels; Anti-Misting Kerosine, AMK should never cause all engines to stop at the same time; external video systems should never distract the crew and contribute towards causing an accident; water mist systems should not operate inadvertently (or, if they do, they should not jeopardise the aircraft even if they do dampen the passengers); use of smokehoods, whether as instructed or otherwise, should not reduce the number of passengers successfully evacuating an aircraft (note that this is ***not*** the same as saying that they should not increase the time to evacuate); and so on.

Such an approach would, it is suggested, represent a major change in philosophy but it is a fail-safe one in that should a major accident clearly reinforce the need for one or more of these features then there would be no misgivings about too rapid or unconsidered introduction, as may be feared at present.

6. SURVIVABLE ACCIDENTS

6.1 Accidents with deaths by fire

Although accidents, both non-fatal and fatal but where no-one died as a result of the fire, are of major importance to any complete study, it is interesting to look at those where the cause of death is known. Table 1 lists these 24 'fire death' accidents and shows how many died by impact and by fire. In addition the two 'percentage' columns show the percentage of those on board who died as a result of the impact, and the percentage of those who survived the impact who subsequently died as a result of the fire. These figures have been derived from a variety of sources and are believed to be correct, however alternative figures with the necessary justification would be welcomed.

It is also important to consider, in all survivable accidents, the number of serious injuries. Not only do injuries affect the progress of an evacuation but many, whether due to the impact or to a fire, may result in permanent disabilities.

Date	Aircraft	S of O	Dead	S Inj	M/N	Total	Imp	%I	Fire	%F
850121	L-188	USA	70	1	0	71	43	61	27	96
850415	B-737-200	Thailand	11	0	0	11	2	18	9	100
850802	L-1011-385	USA	134	15	14	163	114	70	20	41
850822	B-737-236	UK	55	15	67	137	0	0	55	40
851212	DC 8-63CF	Canada	256	0	0	256	205	80	51	100
861020	TU-134A	USSR	70	22	2	94	12	13	58	71
870619	YAK-40	USSR	8	12	9	29	5	17	3	13
880227	TU-134	USSR	20	30	1	51	1	2	19	38
880626	A-320	Germany	3	30	97	130	0	0	3	2
880831	B-727-200	USA	14	26	68	108	0	0	14	21
880915	B-737-200	Ethiopia	35	27	42	104	29	28	6	8
890310	F-28-1000	Canada	24	10	35	69	9	13	15	25
890617	IL-62	Germany	21	29	63	113	10	9	11	11
890719	DC 10 10	USA	111	185	0	296	76	26	35	16
900214	A-320	India	92	22	32	146	7	5	85	61
900511	B-737-300	Philippines	8	30	87	125	1	1	7	6
901104	DC-9-32	Switzerland	44	0	0	44	31	70	13	100
901203	DC 9 14	USA	8	10	26	44	0	0	8	18
910201	B-737	USA	22	10	45	77	1	1	21	27
920120	A-320	France	87	5	4	96	85	89	2	18
920910	F-27 500	Peru	1	24	11	36	0	0	1	3
921221	DC-10-30F	Portugal	56	106	180	342	10	3	46	14
930914	A-320-200	Poland	2	9	59	70	1	1	1	1
940702	DC-9-31	USA	37	16	4	57	32	56	5	20

Table 1 Accidents with known deaths by fire, 1985 - 1995

It will be noted that several 'Eastern' built aircraft are included and it may be argued that their cabin materials may be to a different standard (not necessarily lower - look at the record) to those found in 'Western' aircraft. As this aspect has not been investigated the possibility that this could make a difference has to be accepted, however it should also be noted that the aircraft fuel and the baggage, in both the cargo hold and cabin, are likely to dominate the fire and the production of toxic smoke. Thus even the use of totally non-flammable, non-smoke producing cabin materials will not prevent people from dying as a result of a post impact fire. Nevertheless in at least one accident, that to the B727 on 31 August 1988 (reference 13) the investigators were able to conclude that *'a number of lives were saved because the seat cushions were covered with fire blocking material'* but that *'due to a number of variables .... an exact number of persons who were saved .. cannot be determined'*.

In order to establish in which kind of accident the majority of fire deaths occur reference 1 provided a histogram showing the number of fire deaths in turbine powered aircraft up to the year 1978 plotted against the percentage of those onboard who were killed by the impact. At that time just over 300 had been killed where no-one had died in the impact and another 450 where up to 20% of those onboard died in the impact. In the remaining survivable accidents, more severe in terms of the impact, another 150 died as a result of the fire.

The accidents listed in Table 1 are plotted individually in Figure 1 and Figure 2, by the percentage and by the actual number killed by the impact respectively. It can be seen that, as in the earlier period considered above, over half of these accidents, like the Manchester B737, involve no impact deaths or only a few impact deaths but also that it would be unwise to ignore the others.

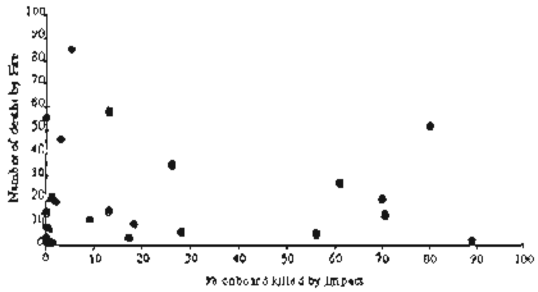

Figure 1 Fire deaths v percentage killed by the Impact

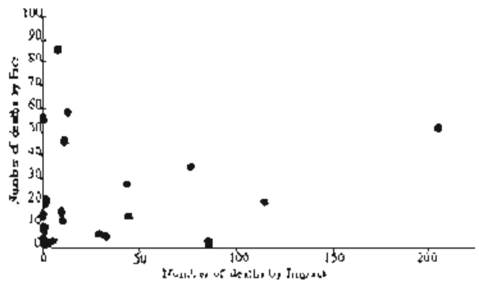

Figure 2 Fire deaths v number killed by the Impact

In addition to these 23 accidents there are some 117 where the cause of death is as yet unknown and as the details from these will obviously affect the results of any analysis this will be pursued no further.

6.2 Categorising survivable accidents

The finding that the majority of fire deaths occur when few if any have died as a result of impact forces can lead to the categorisation of accidents in terms of impact severity but care must be taken when using such data. The airworthiness authorities have the unenviable task of explaining to the media why it is not always possible to produce the 'instant fix' called for, it must be very difficult to get across to the media why we have to be so careful before we introduce changes. Perhaps because of this a rather defensive attitude may have been adopted. In general of course we must heed Murphy, in that *'every solution breeds new problems'*, but as with the bulkhead gap these new problems are sometimes difficult to substantiate.

In reference 11 the scope of cabin safety improvements was sensibly considered under three headings, one non-survivable, involving some 64% of all fatalities and two survivable, involving some 22% and 14% respectively. The difference between the latter two was whether cabin safety improvements *'would be unlikely to make a significant improvement to survival'*, or *'may improve survival'*.

An accident that typified an accident where *'it would be unrealistic to expect that more than a very marginal increase in survival would have resulted from improved fire precautions, evacuation provisions or seating'* was stated to be the DC-10 accident at Sioux City on 19 July 1989. While no-one would disagree that this was a very severe accident, the appropriate details appear in Table 1 and in the above figures, it may be considered that such a categorisation is inappropriately defeatist and consequently counterproductive to our search for improved cabin safety.

There were 296 people on board of whom 111 died, the accident report (reference 14) states that *'35 **passengers died of asphyxia due to smoke inhalation, including 24 without traumatic blunt force injuries**. The other fatally injured occupants died of multiple injuries from blunt force impact. Of the remaining 185 persons onboard, 47 sustained serious injuries, 125 minor injuries, and 13 were not injured.'* (author's emphasis).

Although parts of the cabin may have been totally non-survivable it is difficult to accept that only a marginal reduction in the number killed would have resulted from some of the structural and restraint system improvements under consideration. But what of the 24 without injuries who died of asphyxia due to smoke inhalation? Surely some of the measures discussed before and, more extensively after Manchester could have helped these passengers to survive. Unfortunately such judgements have seriously affected the estimates of the number of lives that might be saved and hence the stated benefits and, consequently, the opinion of many others. Categorising other similar accidents in the same way seriously diminishes the case for making cabin safety improvements.

6.3 The potential for saving lives

With the breakdown suggested above the maximum number of lives that might be saved, by the whole range of cabin safety features, is only 14% of those killed each year, say 140 out of the nominal 1000. Reference 11 went on to suggest that in practice not all of even this small number could be saved. However on the basis that lives could be saved in accidents 'typified' by the Sioux City DC-10, while it is still unreasonable to claim that all, for this period, 360 could be saved, something much closer to this should be within our grasp. If, instead of 360, we use the average number killed in survivable accidents over the three year period 1993 to 1995, approximately 600, then the potential for saving lives is even greater and therefore worth exploring further.

If, in the absence of any better data, we assume that of these 600 fatalities 330 were as a result of the impact and the remaining 270 died as a result of the fire then we may estimate how many in each category might be saved.

The second category is easier in that if we could prevent a fire from occurring then all fire deaths would be eliminated, however even with a usable AMK, anti-misting kerosine, we might not quite achieve this. Smokehoods would not save all since some passengers might not be conscious or in a fit state to don them and some might not choose to. A water mist system could not be guaranteed to work on all occasions, particularly with extremely severe fuselage break up (it has been suggested that such a system should have three independent sections but not cope with greater break-up). Faster evacuations would certainly benefit some but not all. Nevertheless in the long run we might strive to save, by a variety of means, perhaps 90% or say 240 of these fatalities.

Improvements to passenger restraint systems, seats, floors, seat to floor attachments, overhead bins and other equipment would save a considerable number of lives but we must accept that some parts of the cabin will continue to be totally non-survivable. Although no estimate has been made of this figure we might reasonably aim at saving 60% of impact fatalities or say 200. Thus as a first guess we might be able to save 440 of our 600 fatalities. Unfortunately there is a further complication (reference 15). reducing the number of impact fatalities increases the number at risk should there also be a fire. Since many of those previously fatally injured may still be seriously injured we might save only 80% of them (all where there is no fire and some lower percentage where there is). Thus of the 200 saved from death by impact forces 40 may succumb to the fire, reducing our overall benefit to 400 lives saved each year. It must be appreciated that this is only an estimate but it is one that can be improved upon as more data becomes available to justify a fuller analysis.

Since categorising survivable accidents can certainly be useful then a better example of an accident where cabin safety improvements would have been unlikely to have helped might have been the JAL B747 accident on 12 August 1985 referred to earlier and where just four of the 524 onboard survived. However even here it is conceivable that many more did survive the impact and that had the fire not spread then they too would have survived the accident as a whole, but without autopsies or useful statements from the survivors we will never know for sure. For such severe impacts perhaps only AMK might have helped but this is pure speculation.

It has already been mentioned that a study of the data available on survivable accidents will show that many accident investigation agencies continue to ignore the recommendations of ICAO (reference 16) concerning the various reasons for determining and recording the cause of death of each person onboard. This has meant that the cause of death has not been established in a considerable number of possibly important accidents involving both a significant impact and a post impact fire. Of the 117 such fatal but survivable accidents the 21 with at least 50 fatalities are listed in Table 2.

Date	Aircraft	S.of O.	Dead	S.Inj	M/N	Total
850222	An-24	Mali	50	1	0	51
850812	B-747	Japan	520	4	0	524
861212	TU-134	Germany	69	12	0	81
861225	B 737 200	Saudi Arabia	63	31	12	106
870103	B-707-320C	Ivory Coast	50	1	0	51
881019	B-737-200	India	124	5	0	129
890607	DC-8-62	Surinam	177	8	2	187
890727	DC-10-30	Libyan AJ	82	0	117	199
890905	IL-62	Cuba	125	1	0	126
901002	B-737-247	China	82	20	0	102
920731	Yak-42B	China	106	0	20	126
930305	Fokker 100	Macedonia	81	15	1	97
930426	B-737-200	India	55	16	47	118
930723	BAe 146-300	China	55	10	48	113
931120	Yak-42D	Macedonia	115	1	0	116
940426	A-300-622R	Japan	264	7	0	271
940701	F-28-6000	Mauritania	80	9	4	93
941229	B-737-400	Turkey	57	19	0	76
950111	DC-9-10	Colombia	51	1	0	52
951203	B-737-200C	Cameroon	72	6	0	78
951218	L-188 Electra	Angola	141	3	0	144

Table 2 Severe accidents where cause of death is unknown

Any relevant information received pertaining to these accidents would be particularly appreciated.

7. ACCIDENT STATISTICS

7.1 Problems with the statistics of survivable accidents

There are also some peculiar difficulties in actually dealing with accident statistics even when the basic figures are agreed. For example if the recent emphasis in reducing the likelihood of CFIT accidents, virtually all of which are non-survivable, is successful then the result will be that a larger proportion will be killed in survivable accidents. This section therefore goes back over old ground in an attempt to clarify matters.

Any examination of the accident record over the last twenty or thirty years will show that the accident rate to civil transport aircraft has fallen dramatically but a closer look has shown that the fatality rate in those accidents that have still occurred has remained much the same. We have it seems succeeded in considerably reducing the chances of having an accident but not the chances of dying should we be unlucky enough to be involved in an accident. This is a critical reason behind the need to increase our understanding of the crashworthiness and survival aspects of accidents.

So far, so good; one can divide the accidents as suggested, the only difficulty being to agree a definition of a 'survivable accident'. Although several definitions exist the one that seems most useful is 'an accident in which at least one person survives the impact'. In a few accidents where all on board have died, some have survived the impact only to die as a result of the post-impact fire. Such accidents are survivable by the definition but can only be so attributed if the cause of death is known, three accidents of this nature appear in Table 1. It is therefore unfortunate that the researcher sometimes still has difficulty in tracking down the information necessary to establish this extremely important point and that sometimes the information has not been recorded.

There have inevitably been a few accidents where one or more persons have survived the impact apparently quite miraculously and there is the reasonable temptation to make a judgement that such accidents should be classified as non-survivable. This has been resisted by the author, or rather the temptation has been rejected partly to keep matters simple and partly on the basis that it would be surprising if there were not also a few accidents where all died but where more detailed information would indicate that some did in fact survive the impact. Luckily such borderline accidents seem to be very rare and thus do not affect the overall numbers to any great extent.

The real difficulties start when we try to read significance into the numbers. The shortcomings of looking only at fatal accidents are important. In short many clearly significant differences are totally obscured, the most obvious being the presence or not of a post impact fire (reference 10). Considering fatal accidents alone and out of context can lead to some quite ridiculous conclusions. The finding that roughly the same percentage of those on board died in accidents with a post-impact fire as when impact was the only killer possible should alert one to the problem. Bringing into the equation appropriate non fatal accidents produces sensible results which can lead to sensible conclusions and useful recommendations.

7.2 When Is an Improvement not an Improvement?

A further problem is that a genuine improvement in survivability can make the record appear worse and of course, vice versa. If this is not already clear then the reader is invited to consider two consecutive years each with 10 identical fatal but survivable accidents. If, for example, we save one in every ten killed in each of the 10 accidents then the overall fatality rate is reduced by 10%. If on the other hand the same number of lives is saved but this time all from one accident, making this one non-fatal, then we have only 9 fatal accidents with which to divide the fatalities and the apparent overall fatality rate will have remained unchanged.

If we consider an extreme case then it is hoped that the argument becomes totally obvious. Take two accidents each with 100 on board. In one accident only one dies, in the other 99, and the average fatality rate is 50%. If we save that one person in the first accident then the fatality rate, now based solely on the one remaining fatal accident, increases to 99%. If we fail to save the one survivor in the other accident then this becomes non-survivable and we are left with a fatality rate in the survivable accidents of 1%. These are clearly major distortions of the figures and illustrate the dangers of looking at fatal, survivable accidents alone and out of context.

Another distortion can arise if we do not treat with care any combination of accidents involving greatly differing numbers of people. Again considering an extreme example should make the point. Suppose our two accidents, to the same aircraft type, are such that in one 10 people are killed out of 20 on board, while in the other 190 are killed out of 380 on board. Each kills 50% of those on board. Does a safety measure that saves all 10 in one accident count for more or less than one that saves 15 of the 190 in the other? The numbers say one thing but the real relative merits must depend on whether it is likely that, had the first aircraft had 380 onboard, all or most of these would have been saved. It is by no means easy to make such a judgement even when an accident has been investigated thoroughly!

7.3 New safety features

Another difficult problem (reference 2) that we have to deal with when trying to use past accidents as a guide to the potential benefits of some new safety feature is that other improvements may have been incorporated since some of these past accidents occurred. It then becomes necessary that we try to assess how many lives might have been saved had these other improvements been installed earlier, before trying to assess how many more lives might have been saved by the new feature. In one accident we can only save a life once! For such calculations to be convincing it must first be shown that there has been a genuine reduction in the fatality rate in relevant survivable accidents and then that this reduction may reasonably be attributed to some particular previous safety feature or features. This technique is still in its infancy and, largely because some relevant accidents were not investigated in sufficient detail, the results of early attempts to state 'what would have happened if .....' have been unavoidably controversial.

The current position is that until we can establish the causes of death in a reasonable proportion of the accidents that have occurred during the nineties we cannot assess accurately whether any changes have occurred. Nevertheless such information as we do have suggests that little, if anything has changed and that action on cabin safety matters is still urgently required.

8. CONCLUSIONS

Many accident investigation agencies do not establish and/or report the cause of death in survivable accidents. This seriously curtails research into the means of preventing such fatalities.

Since the Manchester B737 accident in 1985 and the safety recommendations and research that followed, there has been no noticeable improvement to the overall record of survivable accidents.

Some cabin safety improvements that have been introduced are expected to lead to a reduction in fatalities but so far there is insufficient detailed information available to establish if they have had any beneficial effect.

Many other recommendations made following the Manchester accident have not yet been implemented, over eleven years after the accident.

The overall safety record is sufficiently good to make it very unlikely that any particular safety feature will appear to be cost-effective. Consequently, if progress is to be made, a new way is needed of dealing with such safety features.

Emphasis should be placed on minimising the disbenefits of potential safety features in order to optimise the net benefit.

The world's airworthiness authorities are getting together to co-ordinate cabin safety matters. They should be encouraged to act upon relevant research already completed as well as to initiate new research. They should examine past accident statistics with care and develop and use appropriate cross checks in order to avoid distortions. They should seek to establish ways of speeding up all routes leading to the implementation of significant improvements in cabin safety throughout the world.

9. REFERENCES

1. Taylor, A.F. 'Accident statistics', 1986, Royal Aeronautical Society Symposium on Passenger Cabin Safety.

2. Taylor, A.F. 'Aircraft fires - a study of transport accidents from 1975 to the present', 1989, AGARD- CP-467 paper 2.

3. Taylor, A.F. 'Aircraft accident statistics' 1993 Cranfield College of Aeronautics *Aerogram*, Vol 7, No. 3.

4. UK Accidents Investigation Branch (AIB) 'British European Airways Vanguard G-APEC. Report on accident at Aarsele, Belgium on 2 October 1971' 1972, copy of report published by The Kingdom of Belgium, Civil Aircraft Accident Report 15/72.

5. Taylor, A.F. 'Systems design philosophy - a traditional approach' first issued 1978, Cranfield short course on Safety Assessment of Aircraft Systems

6. UK Air Accidents Investigation Branch (AAIB) 'Report on the accident to Boeing 737-236 series 1 G-BGJL at Manchester International Airport on 22 August 1985', 1989, Air Accident Report 8/88.

7. Muir, H. et al 'Aircraft evacuations: the effect of passenger motivation and cabin configuration adjacent to the exit', 1989, CAA Paper 89019

8. Schaeffer, F. 'Passenger emergency exit usage in actual emergencies of jet airliners 1960 - 1989', 1990, CAA European Cabin Safety Conference.

9. Taylor, A.F. 'Fire Protection, aircraft fires and evacuation problems' 1996, European Transport Safety Council International Conference on Passenger Safety in European Public Transport.

10. Taylor, A.F. 'Fire, fuel and survival - a study of transport aircraft accidents, 1955 - 1974', 1975, AGARD- CP-166 paper 26

11. Minutes of evidence by the UK Civil Aviation Authority (CAA) to the House of Commons Transport Committee, 'Aircraft Cabin Safety', 1990, HMSO.

12. Robert L Koenig 'US, Canadian and European Aviation Authorities Coordinate Cabin-safety Research' 1996, Cabin Crew Safety, Vol. 31 No 3, May-June 1996, Flight Safety Foundation

13. National Transportation Safety Board (NTSB) 'Delta Air Lines, Inc. Boeing 727-232, N473DA Dallas-Fort Worth International Airport, Texas August 31,1988' 1989, Aircraft Accident Report NTSB/AAR 89/04.

14. National Transportation Safety Board (NTSB) 'United Airlines Flight 232 McDonnell Douglas DC-10-10 Sioux Gateway Airport Sioux City, Iowa July 19, 1989' 1990, Aircraft Accident Report NTSB/AAR-90/06

15. R.G.W. Cherry & Associates Ltd 'Analysis of factors influencing the survivability of passengers in aircraft accidents' 1996, International Conference on Cabin Safety Research, DOT/FAA/AR-95/120

16. International Civil Aviation Organization (ICAO) 'Manual of Aircraft Accident Investigation, Part III, paragraphs 9.6 and 9.8' Doc 6920-AN/855/4