HUMAN FACTORS OF AIRCRAFT CABIN SAFETY

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Abstract

A Practical Programme for Research into Human Factors and Cabin Safety in UK

A programme of research into the human factors aspects of cabin safety has been undertaken in the UK. The initiative was based on the belief that if we had a better understanding of the behaviour which can occur in circumstances which can potentially be life threatening, additional steps could be taken by the regulatory authorities to improve the probability of survival in an aircraft accident.

A large experimental programme has been completed in which the influence of passenger evacuation of rates of changes to the cabin configurations adjacent to the exits, the presence of smoke in the cabin, a range of weights of the type III hatch and the presence of an injured and immobile passenger seated adjacent to an exit, have been investigated. Other studies have included the influence of changing the format and content of the information included in the preflight briefing and the influence of practice on the ability of volunteers from the public to operate a type III hatch.

These investigations together with the implications of the results will be discussed in the paper.

1. Introduction

The first priority in the quest for aviation safety is to achieve PRIMARY safety - to avoid accidents happening. However, this goal will always be elusive in the real world and thus it is necessary to devote considerable efforts to ensuring that passengers can survive accidents as far as possible. Many accidents, worldwide, have focused the attention of airlines and regulatory authorities alike. Some of these accidents have been survivable in terms of human tolerance to the crash forces experienced but the design of the aircraft interior has led to death and injuries. However the most urgent hazard is the risk of fire. It is acknowledged that the best strategy is to evacuate the passengers from the threat as rapidly as possible. An understanding of the physical and psychological constraints is essential in order to devise the best tactics to achieve this strategic aim.

In this paper the British work which has been directed towards gaining knowledge and understanding of the passenger survival issue is described. Relevant technical improvements are considered, but the primary concern is with the behaviour of the passenger in an emergency situation - the human factor. Suggestions for further work will be proposed as a challenge to the aeronautical community, worldwide.

2. The Cranfield Programme - Practical Research into the Human Factors of Cabin Safety

2.1 Behaviour in Accidents

The evidence available from aircraft accidents and other situations in which people are in a confined space and life is under severe threat, suggests that people are (a) very frightened and (b) will compete to escape in order to survive, a scenario which is particularly relevant to accidents which involve smoke and fire within the cabin, such as the British Airtours 737 accident in 1985. In such situations, the orderly evacuation which is seen in the 90 second aircraft certification demonstration breaks down. Rather than working in collaboration to get everyone out of the aircraft as quickly as possible, the threat to life is perceived to be so intense that each individual's behaviour is directed towards survival. In some instances this objective may extend to include the survival of members of their family. Experience shows that the resultant egress is disorganised. Some passengers will pass open exits, while those not surviving a crash will often block aisles and exits.

2.2 Aircraft Evacuations

In 1987 the United Kingdom Civil Aviation Authority, commissioned Cranfield Institute of Technology to conduct an experimental programme of research into passenger behaviour in aircraft emergencies. The research was to differ from previous evacuation tests in that it included an attempt to simulate the behaviour which can occur in accidents involving smoke and fire. In order to reproduce the rush towards exits and competition to get out as quickly as possible a system of bonus payments was introduced. This simply involved paying US$8 to the first half of the passengers to evacuate through any of the aircraft exits used in the test.

The main objective of the evacuation test programme was to investigate the influence of changes to the cabin configuation adjacent to the emergency exits, on the rate at which passengers could evacuate an aircraft. The configurations evaluated involved a range of apertures through a bulkhead leading to floor level exits, and a range of seating configurations adjacent to a Type III overwing exit. The range of configurations tested were not only evaluated when passengers were motivated by the bonus payments to evacuate the aircraft but also when passengers were evacuating in an orderly manner as occurs in aircraft certification evacuations and in some accidents.

Volunteers were recruited from the public in groups of approximately 60, to perform a series of emergency evacuations. A total of 2,262 volunteers took part in the evacuations from a Trident aircraft parked on the airfield at Cranfield. The evacuations times for the range of configurations tested are shown in tables 1 and 2.

Table 1 Competitive and non-competitive tests. Mean evacuation times for the thirtieth volunteer to exit over the six bulkhead conditions.

Bulkhead Aperture	Competitive Trials Mean	Competitive Trials SD	Non-Competitive Trials Mean	Non-Competitive Trials SD
20"	26.3	2.9	25.1	2.0
24"	24.5	5.8	21.8	1.4
27"	23.2	7.1	23.7	2.7
30"	18.4	1.9	23.4	0.0
36"	17.2	3.1	21.4	3.4
PGR	14.7	1.4	17.6	0.5

PGR = Port galley removed

In the competitive evacuations statistical treatment of the data indicated that as the aperture between the bulkheads was increased, the evacuation rate increased, leading to a reduction in the time for the first thirty individuals to evacuate the aircraft ($F511 = 10.5$ $p<0.001$). The individual comparisons of means indicated that there was a significant difference between the mean times when the aperture in the bulkhead was 27" or less, and the mean times when this aperture was 30" or greater.

In the non-competitive evacuations the means suggested that increasing the width of the aperture through the bulkheads leads to a small reduction in the evacuation times. Statistically there was no significant difference between the mean evacuation times for the first thirty to evacuate the aircraft ($F5,11 = 3.2NS$) through the six configurations, however this result may have been due to the fact that only two evacuations were conducted through each configuration.

The mean times also show that in the tests of the 20" and 24" bulkhead apertures the times for thirty people to exit were a little faster on the non-competitive trials. For the remaining widths, the times were faster in the competitive trials. The total of 12 non-competitive evacuations as opposed to 56 competitive evacuations meant that no significant difference was found between the means for the competitive and non-competitive evacuations ($F5,1 = 0.2NS$). Overall the results suggested that the blockages known to occur in some emergency evacuations, can be significantly reduced when the width of the passageway through a bulkhead is greater than 30 inches.

Table 2 Competitive and non-competitive tests. Mean evacuation times for the thirtieth volunteer to exit over the six overwing conditions.

Vertical Projection Between Seat Rows	Competitive Trials Mean	Competitive Trials SD	Non-Competitive Trials Mean	Non-Competitive Trials SD
3"	71.4	15.0	53.2	1.8
6"(OBR)	53.2	10.0	39.6	2.5
13"	55.9	10.3	39.9	3.3
18"	53.7	8.2	37.2	0.2
25"	54.9	11.5	40.8	2.7
34"	62.3	8.1	35.3	0.6

OBR = Outboard seat removed

The data from the competitive evacuations indicated that the seating configuration had a significant effect on the mean evacuation times ($F6,1 = 7.0$ $p<0.001$). Individual comparison of means indicated that the time for the first thirty volunteers to egress through the configuration involving a 3" vertical projection was significantly longer than the evacuation times for all of the other configurations.

In the non-competitive evacuations the data indicated a significant difference between the mean evacuation rates for the various configurations ($F5,11 = 16.84$ $p<0.01$). Individual comparisons of means indicated that the seating configuration involving a 3" vertical projection gave rise to significantly increased evacuation times when compared to any of the other configurations.

As can be seen from the means, the times to evacuate thirty passengers were slower in the competitive trials for all of the configurations tested ($F5,1 = 37.99$ $p<0.001$). The removal of the outboard seat meant that rather than there being a single aisle with a 6" vertical projection adjacent to the exit which would be comparable to the other conditions, there were two aisles with 6" vertical projections leading to the exit.

The minimum seating configurations specified by the UK Civil Aviation Authority in Airworthiness Notice No 79 in 1986 (six inch and thirteen inch vertical projection between the seat rows) were shown to have significantly increased the rate at which passengers can evacuate through a Type III overwing exit in an emergency. Blockages were found to occur in evacuations involving a three inch vertical projection between the seats (pre AN79). The six inch vertical projection with the outboard seat removed (an AN79 alternative) led to a rapid evacuation flow rate but had a tendency to give rise to blockages and the opening and disposing of the exit was found to be more difficult in this configuration. The results suggested that the optimum distance between the seat rows either side of the exit would involve a vertical seat projection of between 13" and 25". A CAA report[1] is available in which a full description of the methodology and results obtained from the programme of competitive and non-competitive evacuations is included.

2.3 Evacuations in Smoke

In 1989, the CAA extended the programme of evacuation research at Cranfield to include a preliminary investigation of the influence of the presence of non-toxic smoke in the cabin. The results from the experimental programme (see Tables 3 and 4) indicated that in a non-competitive evacuation the presence of non-toxic smoke in the cabin, significantly reduced the rate at which volunteers were able to evacuate the aircraft. The initial results also appeared to indicate that in the presence of non-toxic smoke, changing the configuration of the cabin adjacent to the exits may influence the rate at which passengers are able to evacuate an aircraft in an emergency(2).

In the final phase of the evacuation research non-toxic smoke was present in the cabin and passengers again competed with one another for bonus payments in an attempt to simulate an emergency situation. It was found that as the width of the aperture between the bulkheads was increased the rate of egress tended to increase, although the differences did not reach statistical significance (see Table 3). However, a significant difference in egress rates was found when four alternative vertical projections between seats adjacent to a Type III exit were tested (see Table 4).

Table 3 Competitive and non-competitive evacuations in smoke. Mean evacuation times for the thirtieth volunteer to exit over the four bulkhead conditions.

Bulkhead Aperture	Competitive Trials Mean	Competitive Trials SD	Non-Competitive Trials Mean	Non-Competitive Trials SD
24"	32.0	6.1	40.1	2.9
30"	28.3	3.1	38.0	4.4
36"	30.1	5.1	32.6	7.0
PGR(72")	26.8	3.1	55.9	2.0

PGR = Port galley removed
SD = Standard deviation
N = Number of cases

Table 4 Competitive and non-competitive evacuations in smoke. Mean evacution times for the thirtieth volunteer to exit over the four overwing conditions.

Vertical Projection	Competitive Trials Mean	Competitive Trials SD	Non-Competitive Trials Mean	Non-Competitive Trials SD
6"(OBSR)	70.7	16.2	59.7	9.9
13"	55.3	9.2	51.7	14.9
18"	57.2	6.7	49.5	7.0
34"	51.5	6.2	57.9	3.2

OBSR = Outboard seat removed
SD = Standard deviation
N = Number of cases

The results from this programme of evacuations were compared with those from the non-competitive evacuations previously performed in non-toxic smoke. The presence of a competitive element was found to have had a significant effect upon egress rates for the evacuations through the bulkhead. However, the competition did not affect the evacuation rate through the Type III exit. In the latter case, the four vertical projections between seats were found to explain the differences in escape times. From information derived from the questionnaires administered to participants after the evacuations it was found that they mainly relied upon the sense of touch to assist in their evacuation from the aircraft when smoke was present in the cabin.

It can be concluded from this experimental programme that the use of incentive payments to produce a competitive evacuation has been shown to have the potential to provide both the behavioural and statistical data required for the assessment of design options or safety procedures for use in emergency evacuations which maximise the degree of realism. Nevertheless, the technique should be used sparingly since it can be potentially hazardous for volunteers.

2.4 Acoustic Exit Location Signals

A recommendation of the UK Air Accident Investigation Branch in their report on the accident at Manchester Airport in 1985 was that an assessment should be made into the viability of 'audio attraction' towards viable exits. A prototype system for producing acoustic signals at exits was developed by the Medical Research Council Applied Psychology Unit at Cambridge and the Institute of Sound and Vibration at Southampton University. In 1990, The Civil Aviation Authority commissioned the Applied Psychology Unit in the College of Aeronautics at Cranfield to conduct a series of evacuations from a stationary aircraft in order that a preliminary assessment of the influence of these signals on the rate of evacuation of people from an aircraft could be made. The objective of this research was to determine the influence of acoustic signals at exits on the rate at which "passengers" evacuate an aircraft in the presence of non-toxic smoke. The tests were carried out without competition but with smoke in the cabin. The cabin staff did not assist with the evacuation.

The mean evacuation times are shown in Tables 5 and 6.

Table 5 Mean evacuation time for the thirtieth volunteer to evacuate through the bulkhead aperture.

Bulkhead Aperture	Mean	SD
Acoustic Signal	68.64	14.23
No Acoustic Signal	75.30	14.43

Table 6 Mean evacuation time for the thirtieth volunteer to evacuate through the overwing exit.

Overwing Exit	Mean	SD
Acoustic Signal	65.49	8.30
No Acoustic Signal	73.46	12.64

For the evacuations through the aperture between the bulkheads, the results demonstrated that the presence of an acoustic signal had no significant effect upon egress rates, although from a point at which over 10 volunteers had evacuated, the evacuations with the acoustic location signal were faster. In addition, although the egress rates through the Type III exit were consistently faster when the location signal was in operation, the differences were not found to be significant. It was therefore concluded that the use of acoustic exit location signals does not have a significant effect upon egress rates. However, when the possible influence of practice effects were investigated, it was discovered that egress rates for evacuations in which the volunteers escaped via the Type I exit were significantly faster when this was performed after the equivalent evacuation without an acoustic signal, than when the order was reversed. It was concluded that acoustic signals may aid egress rates when participants have previously had direct experience of using the Type I exit(3).

2.5 Operation of a Type III Overwing Hatch

In all the evacuation tests which were conducted by Cranfield a member of the research team was responsible for the operation of the overwing type III hatch. This was done to ensure that the hatch was always opened in a constant time and manner and thus remove the possibility of an interaction between the times taken to operate the hatch and the evacuation times for the range of configurations being tested. In an actual emergency members of the public seated adjacent to the hatch would be responsible for its operation. Since a typical hatch on a 737 will weigh 20 kg and may be even heavier on some aircraft, the Civil Aviation Authority initiated a series of investigations to determine the influence of changes to the weight of the hatch on the time taken by members of the public to open this exit and evacuate onto the aircraft wing. In these investigations the influence of the presence of an incapacitated dummy passenger seated adjacent to the exit and the sex of the volunteer on the operation and disposal of the hatch was also assessed. Since concern had been expressed that members of the public who were less than the average height and weight might experience particular difficulty operating the hatch, only volunteers who were representative of the 0-50th percentile population range were recruited (taken from American norms). Ninety-six volunteers, 48 males and 48 females, participated in individual tests aboard a Boeing 737 cabin mock-up. An emergency situation was simulated in which each volunteer was required to open and dispose of the Type III hatch and to evacuate through the exit onto the wing.

Table 7 Mean times (in seconds) taken by the volunteers in each experimental condition.

Hatch Weight	Males Without Dummy	Females Without Dummy	Males With Dummy*	Females With Dummy*
12.5kg	11.36	17.08	20.49	65.29
15.0kg	13.87	26.55	15.05	87.57
25.0kg	15.92	80.65	25.59	76.25

* times do not include time taken by volunteers in moving the dummy prior to, and during, operation of the hatch.

The results suggested that increasing the weight of the hatch, and the presence of a dummy beside the exit significantly increased the time taken to open the hatch and evacuate onto the wing. Males were found to be able to open the hatch and evacuate onto the wing, significantly more quickly that females. The weight of the hatch was found to significantly influence the time taken by the female volunteers but was not found to significantly influence the time taken by the male volunteers. Although both males and females were significantly slower in the condition with the dummy beside the exit, females were slowed down to a significantly greater extent than the males in this condition.

The findings from the test programme indicate that it may be beneficial to ensure that the seat immediately adjacent to the Type III hatch is occupied by a fit and healthy male. The findings from the initial programme suggested that the space between the seat row adjacent to the Type III hatch could influence the operation of the hatch in an emergency. Further research has recently commenced in order to assess the influence of seating configuration adjacent to the exit and hatch weight on the operation of the Type III hatch. The potential benefits of practice, the design of the hatch handle and improvements to the diagrammatic instructions are also being investigated.

2.6 Safety Information

Another area of concern which has been included as part of the CAA research programme conducted at Cranfield has been that of the information passengers successfully obtain from the pre-flight briefing and the knowledge of the safety procedures.

In 1989 an investigation to determine the most effective ways in which passengers could be encouraged to pay more attention to safety procedures was conducted. One hundred and sixty-six passengers responded to a questionnaire survey which investigated the influence of passenger attitudes towards the safety briefing, their perceptions of the role of the cabin attendants and their perceptions of the severity of aircraft emergencies on their motivation to attend to safety procedures. 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 their knowing how to carry out safety procedures, would be more likely to encourage attention to the safety briefing and the safety card. The cabin attendants were 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% 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 banning of smoking, alcohol and duty free goods, making safety briefings more interesting or varied and the promotion of safety education.

A second programme was conducted in order to investigate passenger comprehension of airline safety information. Two experimental studies were conducted in order to investigate:-

(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 visual demonstration was shown to significantly increase the likelihood that volunteers would know the correct method of operation of the oxygen mask and the correct method of donning the lifejacket and that they could adopt an effective brace position. 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 volunteers' knowing how to operate items of safety equipment in briefings would not discourage the majority of passengers from flying and would be likely to increase attention to safety briefings.

A number of human factors problems were identified as affecting volunteers' 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 indicate 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 alternate aircraft emergency situations. In order to improve the accuracy of passengers' perceptions of aircraft accident survivability a more realistic image of aircraft safety is required. The public need to be made aware through the media that the majority of aircraft accidents are survivable and the information contained in safety briefings and on safety cards may save their lives.

2.7 Cabin Water Spray Systems

The Civil Aviation Authority have recently extended the programme of evacuation research at Cranfield. An initial evaluation of the effect of the operation of a cabin water spray system on passenger behaviour and egress rates will be conducted.

3. Future Research - A Challenge to the Aeronautical Community

In this paper the British programme has been described. We are aware that much valuable work has been done elsewhere in the World. We feel that much more is yet to be done and we conclude this paper with suggestions for further work as a challenge to the worldwide aeronautical community, exemplified by ICAS, to co-operate in an international programme.

We address these points under three headings.

i) Design, Testing and Certification of Aircraft and Equipment

ii) Cabin Staff

iii) Passenger Behaviour

3.1 Design, Testing and Certification of Aircraft and Equipment

(i) Certification Tests

The current emergency evacuation certification trial - the "90 second test" - combines rapid progress of passengers through a darkened cabin, exit through a 'restriction' (door or hatch) and 'escape' down a slide. The last element, possible from a height as high as 7.8 metres, at a steep angle (up to 36°) can be hazardous in itself. There have been some serious injuries in such trials - notably the MD-11 in October 1991. This poses an ethical problem. Research is needed to look at the possible division between the testing of the use of slides and the progress of passengers to and through the exits.

(ii) Modelling

Computer modelling is widely used in the aeronautical industry. The development and validation of modelling techniques to predict passenger evacuation in a range of scenarios would be of great value. The sensitivity of cabin layouts to a range of parameters (e.g. layout, load factor, visibility) could be explored quickly and cheaply. We recommend an international effort to pool information and direct efforts to develop such modelling techniques.

(iii) Ergonomics

We have indicated that studies in Britain have been initiated to investigate the effect of weight and handle design on passenger ability to open emergency exits (e.g. Type III, overwing). We do not claim to have studied all the parameters, such as the effects of seat spacing and crowding. Markings and the need for pre-flight briefing should be studied. The results of such work could be incorporated into guideline documents for designers. Accident and incident reports have shown that emergency oxygen masks are often not used correctly - the ergonomics of all passenger use items need consideration.

(iv) Minimum Size of Exit

Blockages have been known to occur in Type III hatches in two recent accidents (Manchester 1985 and Los Angeles 1991). The minimum size of this exit is 20" x 36". Although changes to the seating configuration adjacent to the exit can reduce the likelihood of blockages occurring, research is required to determine the minimum size of an overwing hatch which will not lead to blockages in an emergency.

(v) Safety of "Safety" Equipment

Items of equipment for individual use by passengers must not have hidden dangers - this is acknowledged in airworthiness codes. However, it would seem wise to review all such equipment (lifejackets, oxygen masks, smokehoods, etc) to identify possible hazards - again a guideline document for designers would be the result.

3.2 Cabin Staff

(i) Selection and Training

It is easy to forget that the primary function of cabin staff is to assist passengers in emergency. Indeed a cabin staff member may, typically, never experience an emergency. But if these skills are needed they will be VITAL. Thus it is important that cabin staff are SELECTED to have appropriate physical and psychological attributes - we suggest that information about selection criteria worldwide should be gathered and analysed. If necessary research might be conducted to further develop such criteria.

(ii) Training

Training of cabin staff is of equal importance. Most are well trained already - however, regular reviews of the training syllabus are desirable to ensure that the latest research findings are incorporated. International comparison of training programmes should be encouraged.

(iii) Handling of Emergencies

Accident and incident reports, and research "trials", have shown that the presence of well trained cabin staff can make all the difference between successful and disastrous evacuations. Work which will emphasise this point to the world community must be beneficial. The function of the cabin staff is of such importance that we suggest it deserves special study - again, guidelines for the industry would be the result.

3.3 Passenger Behaviour

(i) Safety Briefings

The presentation of safety information is of such fundamental importance that an international study should be started to determine:-

- the best form and length of presentation
- the best medium of presentation
- the vital contents
- the retention capability of passengers
- the role of the cabin staff
- how to encourage passenger appreciation of the value of the briefings

(ii) Ability to Use Equipment

Numerous accident and incident reports have indicated that passengers have considerable difficulty in actually using equipment such as lifejackets and oxygen masks (see 3.1(iii), Ergonomics). A better understanding of the human factors should assist in the design process - this is a field for further research.

(iii) General Education

Since aviation is now the foremost means of travel (at least for longer distances) it seems logical that the education of school age children should include some instructions in the practicalities of such travel - the reason for and use of emergency procedures must be foremost. The aviation and educational communities should combine to research this fundamental point.

SUMMARY

In this paper an insight has been given into the major programme of research into human factors in the field of cabin safety which has recently been conducted in the UK. The authors acknowledge the value of related work carried out by other nations. It is strongly recommended that there should be an international effort to build onto this research for the benefit of the worldwide community.

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