4/CC FSS 000944 R

THE FEASIBILITY OF IMPROVED FIRE PROTECTION FOR AIRCRAFT OCCUPANTS

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1. Introduction

In aviation accidents, involving fire, there is evidence that many of the fatalities arise as a result of people being overcome by smoke and toxic fumes rather than by the direct fire threat. Incapacitation disorientation has prevented them from evacuating the aircraft before conditions become unsurvivable.

In respect of the post crash fire scenario, the fire generally originates as an external fuel fire which propagates into the passenger cabin, quickly involving the cabin furnishings. These materials produce smoke and toxic emissions when thermally decomposed and consequently regulatory action has been taken in recent years to enhance their resistance to fire. By delaying the progress of the fire, research has shown that more time is available for safe evacuation and, because rapid evacuation is essential in major cabin fire related accidents, relatively small improvements in enhanced resistance to fire can result in a major contribution to passenger survivability.

Recent regulatory changes in the UK involve the introduction of enhanced flammability tests for passenger seats and major cabin interior materials. These were achieved by retrospective Airworthiness Notices based upon the equivalent FAA Part 121 amendments and applicable to currently operated large public transport aircraft. Unfortunately, neither of these changes had been incorporated into the Boeing 737 aircraft which suffered a major engine non containment and consequential cabin fire at Manchester in August 1985 with tragic loss of life: 55 failed to escape from the burning cabin and, of those, more than 40 were found to have been incapacitated by the inhalation of toxic gases.

The Manchester accident gave rise to renewed interest in the possibility of the mandatory provision of smoke hoods for passengers. However, taking a realistic view of their likely useage in the many and varied accident scenarios, analysis has shown that the saving of life is likely to be modest (reference 1). There also remains a real fear that in some circumstances the task of donning this unfamiliar and unnatural equipment in a real accident might introduce delays to evacuation which would cost, rather than save, lives. Therefore, even though the CAA has prepared and issued a performance specification for smoke hoods, it has reserved its position on this matter until other alternatives have been evaluated.

One such alternative currently under review is a low flow rate internal water spray system developed by Safety (Aircraft and Vehicles) Equipment Limited (SAVE) in the UK. The system concept involves an array of spray nozzles, installed in the cabin ceiling which fill the cabin and the "attic" space above the ceiling with a heavy water mist. Because of the low flow rate requirement of the system a significant level of protection can be provided by water

Two concepts have been considered, an "on-board" system and a "tender" system. The "on-board" system distributes water carried on the aircraft and would have sufficient capacity to be self-sufficient for the first minutes of a ground fire emergency. The "tender" system uses water provided by the fire rescue services and consists simply of suitable ground connections to the distribution system.

From the work described in reference 3, and summarised later in this Paper, an "on-board" system appears to have the potential to:

- fire harden the fuselage structure to an extent that penetration of an external fire, through the skin of an aircraft into the cabin, can be delayed;

- limit fire propagation within the cabin by the absorption of radiant and convective heat from either an internal or external fire and, as a result, prevent the occurrence of a "flash" fire;

- reduce the threat to life in an evacuation by the "washing" of the cabin atmosphere thus limiting the build up of toxic gases and solid particulate from the fire that could have an adverse effect upon both sight and breathing.

A "tender" system used at a later stage has the potential to:

- Enable the fire rescue services to extinguish an internal cabin fire before entering the cabin and assisting in the evacuation of any remaining passengers.

Considering these objectives in more detail, the benefit of fire hardening could be substantial. Provided there is no structural break-up, a fuselage which resists fire penetration will also prevent the ingress of smoke and toxic fumes from an external fire. To achieve this, water would need to be sprayed onto all internal surfaces of the fuselage skin to maintain skin temperatures below their melting point. This would not appear to be very practicable or worthwhile in those areas where cabin insulation is installed. In any case, above floor level the thermal and acoustic insulation will tend to act as a secondary fire barrier once the skin is penetrated. The most likely areas where water could be effectively applied tends to be in the below floor and keel areas and, fortuitously, these are probably the areas at greatest risk to an initial external fire threat. Whether or not it would be worthwhile to provide sprays in such areas or whether reliance could be placed upon the draining of water from an above floor system would need to be established.

Our studies thus far have shown that for a water spray system to absorb effectively radiant and convective heat, the water spray needs to be fine and evenly distributed. It must not, however, be so fine that it cannot penetrate powerful convective gas flows generated within a fire, nor must it be so fine as to adversely affect vision. Furthermore, to "wash-out" solid particulate generated by the fire, the water droplets must be small in diameter and large in number so as to bombard the smoke, carrying the solid particulate to the floor. The same is true for the absorption of the water-soluble toxic gases. The effectiveness of this "wash-out" is also dependant upon a homogeneous water spray distribution throughout the cabin. There must be no regions within the cabin or above the cabin ceiling through which hot smoke and toxic gases can migrate forward or aft.

that measured on the C133 test facility confirming that the 10 ft x 8 ft. tray fire was broadly equivalent to 80% of an infinite pool fire as determined by the FAA during an earlier test programme using a DC7 fuselage specimen. Here again results showed that, while the on-board system was in use, little or no fire development occurred within the fuselage and that fire damage was limited to the exposed outboard edges of the seat armrest, the seat cushion and the seat back upholstery. Throughout such tests the cabin environment remained survivable without any form of respiratory protection. The Catterick facility also provided the opportunity to refine the nozzle design, and to develop guide-lines to optimise their location. Having reviewed the results of these tests, it was decided that a programme of tests on a fully furnished aircraft was then needed using a fire scenario similar to that which existed in the tragic accident to the B737 aircraft at Manchester.

Proof of Concept : Trident at Teesside

The CAA collaborated with SAVE in a series of tests to confirm the effectiveness of the system in the case of a pooled fuel fire and a fully furnished aircraft. Use was made of a Trident 2 aircraft at the CAA's fire Service Training School at Teesside. Three tests were carried out with, in each case, a substantial fire under the rear of the aircraft aft of the wing (comparable in position and intensity to the fire at Manchester). The fire was allowed to burn for approximately three minutes before external fire fighting commenced. In all cases the internal spray system was switched on when smoke entered the cabin, (for a production installation this water would be carried on board).

The sequence of events and the outcome of each test were as follows:

1. In the first test, the aircraft was intact at the start with the rear baggage hold full of baggage. The fuselage skin below cabin floor level (baggage hold) was substantially destroyed, and there was considerable damage to the structure behind the rear pressure bulkhead. The fire did not penetrate the cabin, and temperatures throughout remained survivable.

2. In the second test, with crudely repaired skin the baggage hold was again filled but the fire rapidly destroyed the repairs so that the protection provided by the baggage was quickly lost. As a result the cabin floor above the baggage hold was severely damaged with only the upper skin of the "sandwich" construction floor remaining intact. Again, there was no fire penetration of the cabin, and temperatures remained survivable. Fire damage aft of the rear pressure bulkhead was such that the tailcone and empennage fell to the ground.

3. In the third test, the spray system was removed from the toilets and the area of the last four rows of seats. The fire thus gained entry to this part of the cabin very rapidly indeed, and it was totally destroyed. The water spray kept the fire at bay such that the sprayed part of the cabin suffered no fire damage whatever and the temperature remained survivable.

In summary, not only did the spray system keep the cabin temperatures survivable in the face of a fully developed fire in the cabin, but it also provided a degree of protection against fire penetration through aircraft structure which was wetted on the inside.

3 minute minimum design duration would be appropriate for the on-board water spray system. This also corresponds to the internationally agreed maximum time for the fire rescue services to reach an accident on the airfield.

ii Flowrate

The system development tests conducted by SAVE in the VC10 test fuselage in 1987 suggest that, for a narrow bodied aircraft, a flowrate of about 0.2 gallons of water per foot-run of cabin per minute is needed. For an aircraft the size of a Boeing 737 aircraft this equates to approximately 15 gallons/minute (45 gallons for a three minute system).

Although it would be attractive from weight considerations to make as much use as possible of drinkable/potable water already carried on the aircraft, this could create practical difficulties. Firstly, there is a risk of the contamination of the drinking water and secondly there would be the need to ensure that there is always a minimum reserve retained for the water spray system.

On current aircraft, potable water is often depleted by the time the aircraft arrives at its destination and would therefore be unavailable in a post landing accident. It would therefore seem to be essential to have a dedicated water supply to provide a specified minimum period. Means for interconnecting this to the potable supply could, for accidents at take-off, provide extended duration.

The number of storage tanks required for a specific aircraft would need to take into account the system redundancy philosophy. The likelihood of a major fuselage break suggests that at least two storage tanks would be necessary, one located towards each end of the fuselage.

Material used in the construction of the tank would need to take into account considerations such as impact resistance, affects of fire and the range of working pressures.

(b) PUMPING SYSTEMS

Whatever means is used to "atomise" the water into a suitable spray, some form of pumping/power system would be required. The power for such a system could be derived from a number of sources but the most likely would seem to be either electrical or pneumatic. Whatever the power source, it would have to be independent of the failure of any normal aircraft power sources or supplies, and one of the simpler ways of achieving this independence would appear to be a stored gas pneumatic system that pressurizes the storage cylinder. It could perhaps utilize components currently used to deploy inflatable escape slides, ie a nitrogen system.

(c) DISTRIBUTION SYSTEM

Ensuring that the water spray is fed to all the required regions of the fuselage and at the same time minimizing system water loss in the event of structural damage to the fuselage in a survivable accident, would require check valves, restrictors, frangible self close crew and is capable of being initiated by both the flight crew and cabin crew. The location for the controls for use by cabin attendants should be near to those cabin attendant stations which are adjacent to floor level exits.

(f) ENVIRONMENTAL FACTORS

To date, all tests have been conducted using water without any additives such as "antifreeze". Glycols and similar agents can depress the freezing temperature to a level where it would be unnecessary to drain the system during cold overnight soak conditions. However, such agents can produce toxic thermal break-down products which could represent an unacceptable hazard. Facilities for draining the system overnight are therefore, likely to be required.

As with potable water systems the water tanks and controls may need thermal protection in flight, particularly on long-haul flights with extended periods at high altitude.

Tender System

A viable tender system presupposes that a suitable water supply is readily transportable to the aircraft by the fire rescue services, and dedicated specifically to this particular purpose. The airframe part of a "tender system" would need to be able to handle the high flow rates needed to extinquish an established fire and could be expected to consist of:

- ground vehicle connections accessible in likely fire scenarios,
- a distribution and spray nozzle system

(a) GROUND CONNECTIONS

The number and location of the tender connections for such a system would vary from aircraft to aircraft. They would need to be readily accessible to the fire service vehicles used in this role and should be located where at least one would be clear of any likely ground fire and remain clear throughout the emergency. Accessibility should not be adversely affected with any or all of the landing gears collapsed. With these constraints in mind the most likely locations would be at each end of the fuselage, on each side and just below the cabin floor. Wing tip connections could be considered but, with the length of pipework feeding from the wing tip to the fuselage, this would be vulnerable to damage and would represent a substantial weight penalty. Wing tips on large aircraft can also be a long way above the ground. The type of connection used would need to be standardised and would have to cope with flowrates of up to say 200 gallons per minute. To be realistic, standardisation would have to be internationally agreed as would the provisioning of appropriate and adequate water supplies at each airport.

(b) DISTRIBUTION AND SPRAY SYSTEM

The distribution system, its redundancy and crash integrity would be very similar to the on-board system discussed above. The spray nozzles would need to be able to cope with the higher water flow rates. Where both on-board and tender systems were installed much of the distribution system could be common to both systems, particularly

Especially if the capability of the fire rescue services were enhanced by the provision on the aircraft of the couplings for the tender system, it is likely that all sprayed zones of the aircraft could be saved, with only some external damage due to fire impingement. Depending on the fire scenarios, therefore, use of the system may also reduce the likelihood of a total hull loss.

DISBENEFITS

Costs

The costs inevitably fall into two broad categories, initial outlay and the cost of ownership. However, the latter can be further broken down into:

- maintenance,
- cost of carrying the weight, and
- refurbishment of an aircraft following precautionary or accidental discharge of the system.

Until the system is better defined, it is not possible to state weight or cost figures with any degree of precision, but preliminary estimates are discussed in the following:

a. <u>Initial Cost</u>

In reference 2, the installed cost of a water sprinkler system, similar in many respects to the proposed water spray system was estimated to be about £50,000 for a narrow body aircraft and £70,000 for a wide body (costings escalated at 4% per annum since the estimates were prepared in 1981).

The spray systems would have about three times as many nozzles as the sprinkler proposal and so an increased cost can be expected, perhaps by one third. "Installed cost" (parts plus installation but not excluding development and testing) would therefore be:

	Narrow Body	Wide Body
Installed Cost	£65,000	£90,000

Preliminary discussions with industry and airlines suggest that these figures are realistic, provided that the modifications could be carried out during scheduled maintenance. Unscheduled "down time" would be an additional cost.

These figures do not include design, development and test of prototype systems, nor do they include the design cost for the particular fleet. The magnitude of this cost depends to some extent on the nature of the regulation. If it took the form of an engineering specification requiring limited small scale development testing but no long-term research, the figures given in Reference 2 may again be appropriate, i.e. approximately £1.3 million for a narrow body and £1.5 million for a wide body. It is clear that for any reasonable implementation programme, the cost for aircraft of this work should not exceed £10,000 - 15,000.

	Narrow Body	Wide Body
Development and Testing	£10,000	£15,000

7. REMAINING CONCERNS

7.1 Effectiveness in Wide Bodied Aircraft

All testing so far has been conducted in a narrow bodied VC10 and a Trident II aircraft. There has been no assessment in a wide bodied aircraft.

Whilst no major problems are foreseen, it may be necessary to increase the number of spray distribution manifolds to ensure complete coverage of the cabin interior including loft spaces and particularly where multiple overhead stowages could result in potential dead spaces. Ceiling height may also influence spray penetration. A slight increase in droplet diameter may be necessary to ensure good droplet penetration down to floor level.

Further practical fire tests in a wide bodied fuselage are necessary to determine optimum droplet size and distribution.

7.2 Carbon Monoxide

Whilst water in the form of a spray has the potential to absorb much of the water soluble products of combustion such as the highly irritant HF and HCL gases, its ability to absorb carbon monoxide (CO) is minimal. In fact it has been suggested that the addition of moisture to the combustion process may potentiate the production of CO and hydrogen (H_2) through the reaction between the water and the hot carbonaceous products of combustion.

Additives could be introduced into the water spray which may well reduce the total CO yield but they, in turn, may create other hazardous thermal breakdown products.

Further tests are necessary to determine whether such additives would be worth while.

7.3 Effects on Egress

In the tests so far performed, the reduction in visibility has been slight and is therefore, unlikely to affect aircraft egress rates. However, wet floor surfaces and escape routes may have an effect which needs to be evaluated. Further trials may be necessary to quantify such effects, including that of drenching of the cabin occupants.

7.4 Definition of the Water Spray System

Much is known about the definition of the typical sprinkler systems used in buildings, their installation going back to about 1860. The empirical data developed over the years however, relates to relatively coarse spray patterns where fairly large droplets are employed. To optimise the airborne use of such concepts and thereby minimise the amount of water required has necessitated the development of systems which produces a much finer and more evenly distributed water droplets within the spray pattern. Testing to date, may not necessarily have fully optimised the relationship between the system performance and water consumption. From a regulatory viewpoint it may be possible to define a system in terms of its fire fighting capability, but practicable long term approval this may not present a process in that it may require multiple full scale fire tests.

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