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Aircraft Water Spray Systems For Fire Suppression

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1. Introduction

Cabin fire safety is an area in which the CAA is committed to seeking further improvements both with respect to the in-flight as well as the ground fire emergency.

Water spray systems have potential applications as a means of addressing both fire scenarios, but to date, the major effort in developing such systems has been directed toward the ground fire.

The first priority in any ground fire emergency must be to evacuate the aircraft as quickly as possible and requirements governing the number and type of exits, aisles and access to those exits are all directed towards that aim. But as we know from accident statistics, the time available to the escaping passenger can often be very short indeed.

In trying to extend the survival time in such a fire, one needs to delay the fire development within the cabin and, until recently, the major effort has been directed toward fire hardening of the cabin furnishings. These materials have been shown, by full scale fire tests, to play a major role in determining the rate and severity of the developing fire. In recent years therefore, we have seen the introduction of new and much more severe fire test standards for aircraft seating and for wall and ceiling panels.

The obvious advantage of such "passive" fire protection concepts is that they are always there whatever

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the circumstances. There is however a limit to what such materials can reasonably be expected to be capable of doing when considering an extension to the survival time.

"Active" fire protection concepts would appear to offer a further extension to the survival time, but like all "active" concepts, to be of real value, they must be extremely reliable and actually work on the very rare occasion when they are required to function and, of course, not function when they are not required.

In this paper, I will describe some of the work that has been going on in the evaluation, development and optimisation of one such active fire protection system - water sprays.

2. Background

A small UK firm, Safety (Aircraft and Vehicle) Equipment Limited (SAVE), developed a low flow rate cabin water spray system based upon a concept that they had applied to engine compartments of earth moving vehicles used in civil engineering etc. The concept was extremely simple, namely, to fill the cabin and voids above the ceiling with a water mist via an array of spray nozzles located throughout the cabin. Unlike a water sprinkler system often found in buildings, the spray used was much finer but not so fine as to significantly affect visibility. With such an arrangement, they found that they could suppress a fire and maintain temperatures at acceptable levels, with relatively small amounts of water for as long as the spray was applied. A typical system is shown in Figure 1.

To more realistically explore the concept, CAA collaborated in a series of tests early in 1988 to confirm the effectiveness of the system when a fully furnished aircraft is exposed to a large external pool fire.

For these tests we used a Trident II aircraft at the CAA Fire Service Training School at Teesside, UK. Full details of the test conditions and the results obtained are contained in CAA Paper 88014 but presented briefly here are some of the results.

Figure 2 shows the condition of the fuselage from the outside at the end of test No. 3. This was the most severe fire test representing an external fire attacking an already crash-damaged rear fuselage; one in which the water spray system in the real fuselage is assumed to have failed as a result of the crash damage. Figure 3 shows a typical temperature profile within the fuselage measured one metre above the floor and demonstrates, clearly, the rapid fall in temperature once within the sprayed zone. This figure also shows the internal conditions before and after the test.

These proof of concept trials showed that a water spray system has the potential to:

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

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

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

In addition, if the distribution system was capable of being fed with water, carried by the Fire Rescue Services, i.e. a "tender" system, the concept has the potential to:

iv) enable the Rescue Services to extinguish the internal fire whilst passengers are still evacuating the aircraft and to subsequently enter and assist in the evacuation of any remaining passengers.

This is significant because, without such a system, the fire rescue services have limited scope for dealing with the internal fire. Smothering the outside of the fuselage with foam and thus preventing burn through, can exacerbate condition within the occupied areas, i.e. the passenger cabin.

3. <u>International Collaboration</u>

As a result of a shared desire to investigate the potential of a cabin water spray system, the CAA with other European Authorities, FAA and Transport Canada agreed in October 1988 the form of a joint research programme. The primary objective of the programme was to evaluate all the relevant aspects of a water spray system so that the Airworthiness Authorities could decide whether they should require such systems to be installed on passenger aircraft.

To satisfy this objective, it was agreed that the Authorities would examine the following:

a) To more fully evaluate the effectiveness of the system in maintaining a survivable cabin atmosphere under the most likely post crash fire scenarios;

b) To evaluate increase in evacuation time afforded by such a system;

c) To evaluate the effect upon an aircraft (its systems and structure) of an intentional or unintentional activation of a water spray system in flight;

d) To carry out a Net Safety Benefit Study;

e) To optimise the water spray system as it is currently arranged and to examine any other similar concepts and, from this work, prepare a design and performance specification.

The programme, as scheduled, has a very tight timescale and most of the items are to be completed by the end of 1990 with sufficient data being available by then for the Joint Airworthiness Authorities to be able to decide whether regulatory action is appropriate.

4. Current Research Programme

a) FAA Test Programmes

The first series of full-scale tests being conducted at the FAA's Technical Centre, Atlantic City use a narrow bodied aircraft (B-707) fitted out with a CAA supplied SAVE system of spray nozzles in a very similar manner to that used in the Trident II tests at Teesside. However, unlike the earlier Teesside tests, these tests are being conducted indoors under controlled ambient conditions in order to minimise the variability that is almost always associated with open air tests. As a series of "base line" tests, a variety of fire scenarios are being represented and the conditions assessed within the passenger cabin with the interior both furnished and unfurnished. The tests are then being repeated with the water system functioning so that the effectiveness of the system can be more scientifically compared. The various fire scenarios include an external pool fire at two locations, one adjacent to a floor level exit and the other beneath the fuselage. In addition, the effect of various wind conditions and the effects of both immediate and delayed system activation are being evaluated to determine their influence on the fire development.

Compared to the earlier Trident II trials, far more parameters are being monitored so that a more accurate assessment of the systems ability to control the spread of fire in a typical aircraft cabin and maintain a survivable atmosphere can be made. Of particular interest is the system's ability to remove water soluble toxic and irritant gases, the ability to wash out solid particulate and thereby improve visibility and the extent to which Carbon Monoxide (CO) remains a major combustion product. The levels of Hydrogen and Hydrogen Cyanide will also be carefully monitored.

Once these narrow bodied tests are completed early in 1990, the FAA plan to conduct a similar series of tests using a wide bodied fuselage test specimen based on the DC10 aircraft.

Progress on this work has been somewhat slower than originally planned but recent test results from the B707 show that the spray system is able, under zero wind conditions, to significantly limit the spread of fire through a furnished cabin. In doing so, the spray system appears to substantially limit the evolution of life threatening fire gases such as HCN and CO and maintains cabin temperatures at survivable levels. Such results are very similar to those reported by SAVE in the VC10 fuselage specimen at Catterick in 1987. It is evident, however, from these tests, that, as with all fire protection concepts, the system has its limitations. For example, the system operation can adversely affect visibility at lower levels. This occurs because spray cools the hot fire gases at ceiling level reducing their buoyancy, allowing them to mix with clearer air nearer the floor. The water spray also has limited capability when an external fire is drawn through the cabin at relatively high velocity due to the effects of high wind. At present, however, there is insufficient data to determine how limiting such conditions may be, and more work in this area is needed.

The CAA remains optimistic that, overall, the spray system still shows considerable potential for saving lives.

b) CAA Test Programme

Complementary to the FAA's programme, the CAA has commissioned the Fire Research Station (FRS), Borehamwood (North London) to carry out detailed research to further understand the physical and chemical interactions of the water spray to determine the critical droplet size, and velocity and thereby optimise nozzle design and cabin location in interacting with a fire environment.

The FRS programme is divided into the following four stages:

1) Preliminary Studies - To provide a comprehensive understanding of available scientific, technical and commercial information relevant to the programme (literature search),

2) Fundamental Spray Studies - To investigate the basic principles involved in the interaction of the water sprays and the fire environment (radiant and convective heat, fire gases absorption and the washing out of solid particulate),

3) Full Scale Environmental Studies - With a stylized mock-up of a cabin section, determine the optimum physical and chemical characteristics of a cabin water spray installation.

4) Aircraft Trials - Using a B707 test fuselage at the FRS Cardington facility, demonstrate the efficiency of an optimised design of water spray system under fire scenarios similar to those undertaken by the FAA.

5) System Specification. Based upon data obtained from 1 to 4 (incl.) above, provide the CAA with guidance data for the development of a performance specification.

The FRS programme has already characterised the SAVE nozzle water droplets using a system based upon high speed cinematography synchronised with a pulsed laser. This permits water droplet images to be captured and analysed on a frame by frame basis and enables the droplet size distributions, trajectory and velocity to be determined at selected locations. This work has shown that at a pressure of 3 bar and a flow rate of 0.8L/min the nozzle generates droplet sizes in the order of 100µm Sauter mean diameter.

FRS has also studied the water spray's radiant heat absorption characteristics. The test apparatus is shown in Figure 4 and these tests have shown that one line of sprays can absorb some 15% of the radiant heat. Although this seems somewhat lower than suggested by subjective experience, the test method does not account for the effect of water droplets settling on exposed surfaces (eg, skin). The evaporative cooling effect of additional surface cooling, combined with the radiant heat absorption of the spray has not been scientifically quantified but it should be remembered that, during SAVE tests, occupants were able to sit in a sprayed cabin about 5 feet from a major exterior kerosene tray fire without any discomfort.

The current FRS work is centred on the mock-up section of a passenger cabin and is exploring the optimum water spray pattern to maximise heat and gas absorption, smoke particulate wash-out and visibility. Details of this rig are shown in Figure 5. Tests use both kerosene tray fires and fires involving typical cabin furnishing materials. The results from these tests have not yet revealed anything that was not expected. These tests should be completed by April when the programme will concentrate on full-scale tests using an optimised system installed in the B707 fuselage at Cardington.

A number of separate studies are also being carried out under FRS supervision. The possible use of additives to enhance the removal of toxic components (eg CO) by water sprays are under study and any solutions proposed will need physical testing to demonstrate their effectiveness. Also, the hazard to cabin occupants of inhaling water droplets containing scrubbed toxic products is being assessed.

5. Disbenefit Study

Regardless of the precautions taken to minimise the risk, it is inevitable that at some point in the future, should water sprays have been required to be fitted, that such systems, even if intended for ground use only, would be activated in the air, either intentionally or inadvertently. To address this and other potential hazards, the Joint Authorities are sponsoring two major manufacturers to carry out a detailed assessment of the disbenefits of water sprays.

Airbus Industrie are carrying out some of this work under a shared EEC, DGAC and CAA funded contract and will be looking at the effects on electrical systems and components, including the risk of shock, effects on structure and flying control through freezing and the effects upon evacuation through wet surfaces in aisles, vestibules and escape slides. Once these effects have been systematically identified and evaluated, some indication of the scale of the hazards or problems and the difficulty of solving or eliminating them will be made. The study includes an assessment of both current in-service aircraft and advanced technology aircraft likely to enter service in the next 10 years or so.

A parallel programme with another manufacturer is planned which will explore the problems with current aircraft designs and also in-service older technology aircraft.

Again these tasks are expected to be completed by the end of 1990.

6. Overall Programme Timescale

It can be seen from Figure 6 that the research programme is scheduled for completion by the end of 1990. In parallel to this work, CAA issued a Discussion Paper No. S851 in November 1988 to elicit views from interested parties on technical and regulatory issues and has more recently issued a Comment Document No. S851/1 in November 1989 which summarises the comments and views received by the CAA. It is proposed to convene an open Meeting in the UK of all interested parties towards the end of 1990 to discuss the findings of the research work and the future strategy.

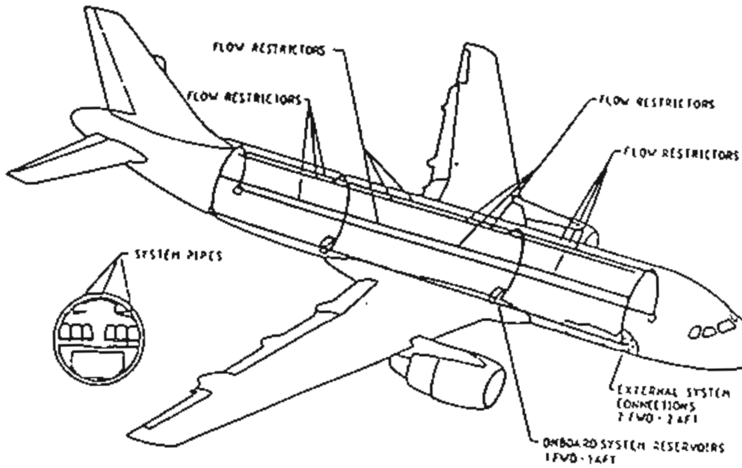
Conclusions

To summarise, we have embarked upon a programme which is targeted to be completed by the end of 1990. It is a flexible programme which may well be altered or adapted as we proceed.

We are currently about one third of the way into our research programme and still have some way to go. We do not expect to have answers to all the questions by the end of 1990, but it is likely that, by then, we will be in a position to decide whether or not regulatory action is appropriate.

There is no doubt that water spray systems have potential to improve fire survivability at this time, but I am not prepared to speculate on the future use of such systems. All I can guarantee is that 1990 promises to be a year in which we in the Aviation Community will learn a lot more about water sprays and what they can and cannot do.

TYPICAL SYSTEM FOR 150 SEAT NARROW BODY AIRCRAFT

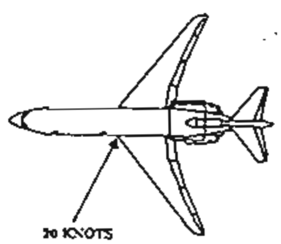


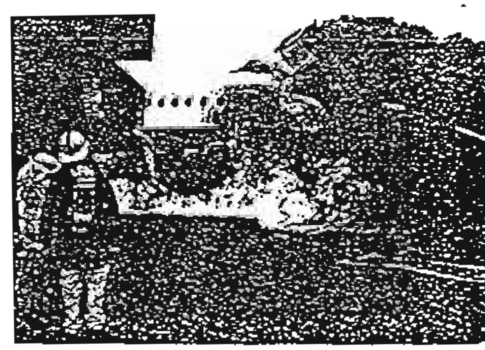
- 'ON-BOARD' SYSTEM PROVIDES 3 MINUTES PROTECTION WITH WATER FLOW RATE OF 70 L/M
- 'TENDER' SYSTEM USES EXTERNAL WATER SUPPLY WITH 700 L/M FLOW
- SYSTEM WEIGHT ≈ 700 LBS

FIGURE 1

AIRCRAFT CABIN WATER SPRAY SYSTEMS

SAVE DEMONSTRATION
TEESSIDE UK MAY 1988





FUEL LOAD
900L KEROSENE + 20L PETROL
IN 19M SQUARE TRAY
SYSTEM CONFIGURATION
SYSTEM COMPLETE IN CABIN UP
TO LAST 4 ROWS OF PASSENGER
SEATS

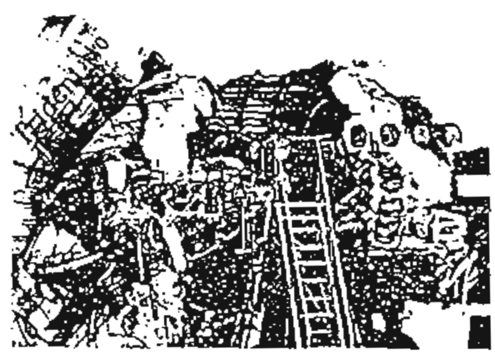
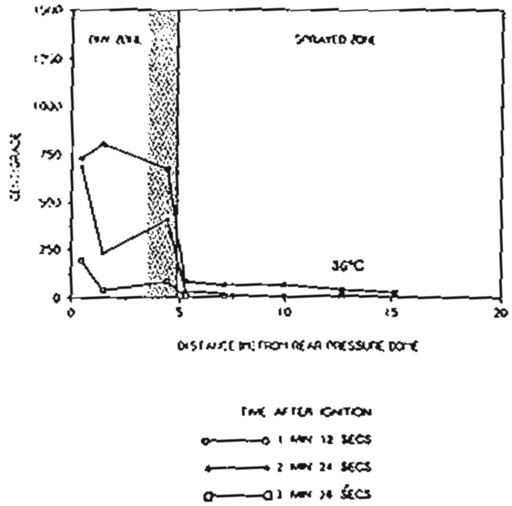


FIGURE 2

TRIDENT 2. FIRE TEST 3.

CABIN TEMPERATURE AT SHOULDER HEIGHT (1M) AXIAL/TIME PLOT



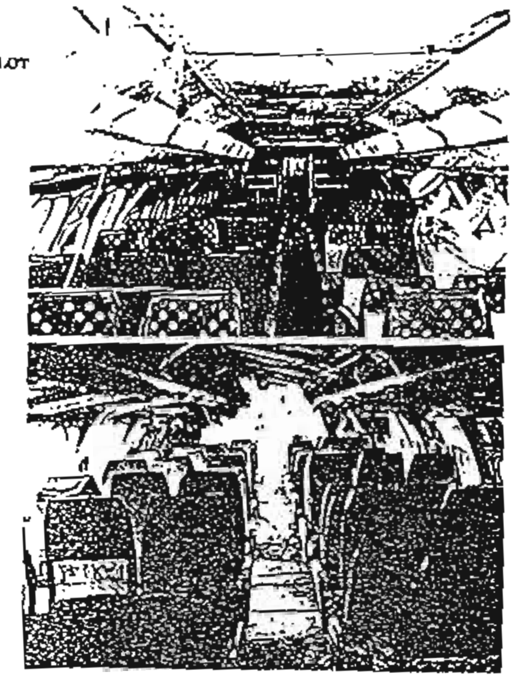


FIGURE 3

AIRCRAFT CABIN WATER SPRAY SYSTEMS

FRS - RADIANT HEAT ABSORPTION TEST

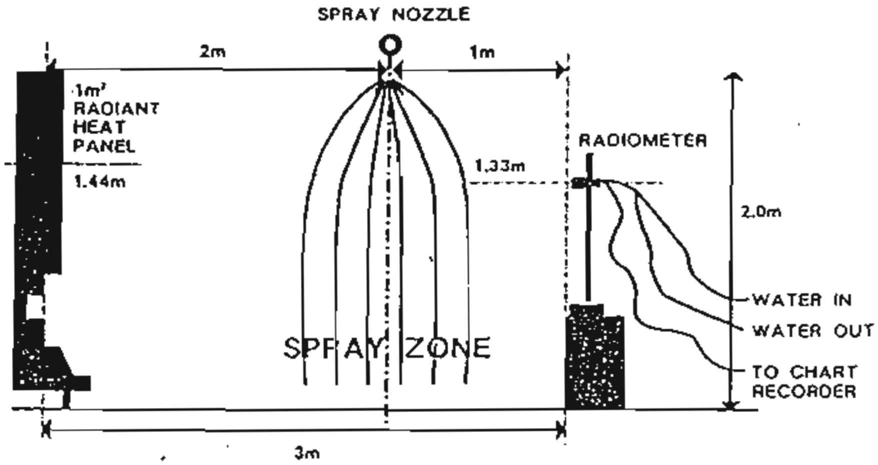
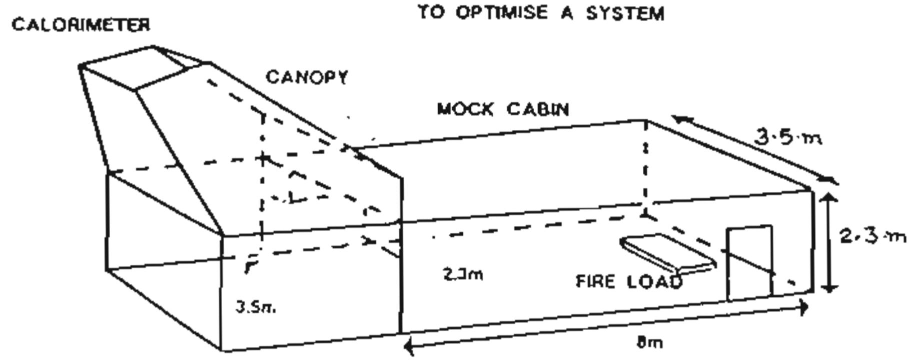


FIGURE 4

AIRCRAFT CABIN WATER SPRAY SYSTEMS

FRS - MOCK CABIN TRIALS

MOCK CABIN IS DESIGNED TO QUICKLY VARY THE NOZZLES AND THE NOZZLE ARRANGEMENTS SO AS TO OPTIMISE A SYSTEM



CALORIMETER MEASUREMENTS
- TEMPERATURE, TOTAL HEAT RELEASE
- OPTICAL
- AIR FLOW

CABIN MEASUREMENTS
- CO, CO_x, O_2
- TEMPERATURE PROFILES
- OPTICAL DENSITY

AIRCRAFT CABIN WATER SPRAY SYSTEMS

JOINT RESEARCH PROGRAMME - TIMESCALE

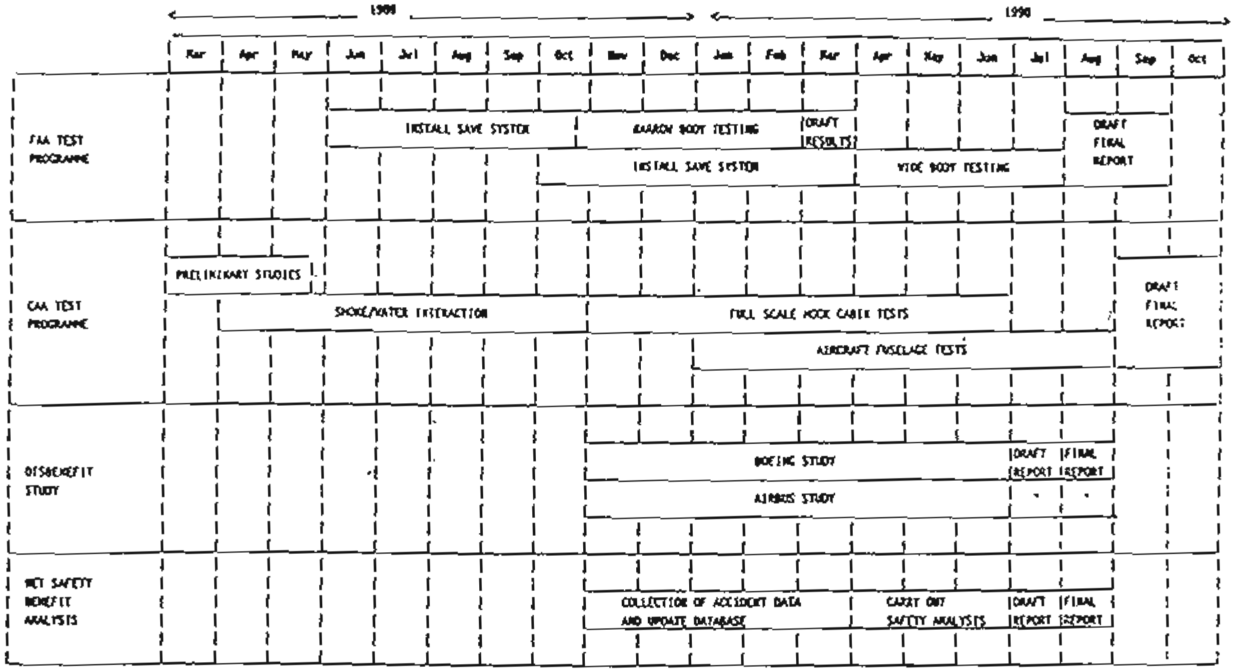


FIGURE 6