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Cabin Water Spray System Promises Better Crash Survivability

A self-contained quenching system could increase the time available for safe evacuation in the event of a post-crash fire.

by
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The excellent overall safety record of commercial air transportation is due in large part to rigorous quality and safety standards. However, when accidents do occur, fire is a significant cause of fatalities. A crash during landing or takeoff may result in fuel spillage and an external fire. Heat, smoke and toxic fumes represent an immediate hazard to escaping occupants and, if fire spreads into the cabin and ignites the furnishings, the threat to occupants increases.

Delaying the ingress of the fire, blocking the heat, reducing the toxic gas concentration and improving the visibility within the aircraft cabin would provide more time for occupants to escape from an aircraft in a post-crash situation. One means of countering the threats posed by fire, smoke and toxic gases is an internal aircraft cabin water spray system (ACWAS), using an array of spray nozzles installed in the passenger cabin.

Spray System Delays Effects of Fire

The spray system is designed to increase the time available for safe evacuation of an aircraft in the event of a post-crash fire. The system uses water as the quenching medium to delay fire penetration and limit the development of a fire in the aircraft cabin. Water droplet size and velocity distribution are selected to optimize the cooling, gas absorption, particulate elimination and quenching characteristics of the spray, while minimizing system weight. The nozzle is designed to minimize the quantity of water used by producing a spray which has these carefully controlled characteristics. Water flow rate can be further reduced by automatic adjustment of nozzle configuration to match specific fires.

When the system is activated, water is pressurized by a pyrotechnic device and sprayed into the cabin, lavatories, galleys, the pressure bulkhead and other areas to delay fire penetration. For at least the first three minutes after the system is activated, the aircraft's on board water supply is used.

A typical system for a single-aisle aircraft consists of up to four pipes running the length of the aircraft. Two pipes may be located at the center of the cabin ceiling and two others behind the cabin walls immediately below the overhead luggage bins. The longitudinal pipes are cross-connected, and the fuselage is zoned to create independently operable systems, to provide enhanced system integrity in the event of fuselage break-up. Further protection of system water contents is provided through hydraulic fuses which sense and prevent water loss in case of pipe fracture. Each pipe feeds a number of spray nozzles, and in a typical 100-seat narrow-bodied aircraft, approximately 180 nozzles would be installed.

The system can also be supplied from an external fire tender through a hydrant connector having a common feed to the zoned system. This offers extended protection time over the nominal three minutes attained by the on board water supply.

Water Spray Benefits Demonstrated

The benefits of the cabin water spray concept have been shown in full-scale trials by the U.S. Federal Aviation Administration (FAA), the U.K. Civil Aviation Authority (CAA) and industry. These benefits include the delaying of external fire ingress into the fuselage and retarding the spread of heat and flames within the fuselage. The overall effect can be a dramatic increase in escape time for the occupants.

The benefits of the water spray system derive from two groups of mechanisms. The first includes the cooling effect on the passengers; wetting the furnishings and other flammable materials to impede their ignition and combustion; and, cooling the fuselage skin to delay burn-through by the fire. These effects might be expected to be controlled largely by the water flow rate.

The second group of mechanisms consists of absorption of toxic and irritant gases; abstraction of convected heat; screening of thermal radiation; and washing out of smoke. This latter group, too, will be dependent on the water flow rate; but additionally, at a given flow rate, those benefits will be enhanced as the size of the water droplets is reduced — either because a greater surface area is produced or because the total number of drops increases. However, the droplets cannot safely be made too small, because they will then be lofted by the plume of hot gases from the fire and fail to penetrate the fire or to reach the furnishings.

Operational Control Prevents Inflight Operation

The manner in which the system is actuated must be designed to minimize the possibility of unwanted operation while ensuring that protection is provided whenever required. There is continuing discussion about whether the system should be available in flight as a “last ditch” measure against an inflight cabin fire, but current thinking is that it should probably be operable only for ground fires. It is therefore planned to provide interlocks so that the system is enabled only at or below a pre-determined radio altitude, for instance. These and other suitable parameters can be met by existing sensors.

Thereafter, two possibilities are considered. In one scenario, the system would be armed by the flight crew if an emergency threatened, then each zone would be activated if and when required by the cabin crew. In the second scenario, the cabin crew would have sole control. Automatic backup is proposed in case the crew is disabled, probably a crash switch to arm the system and a heat or smoke detector to actuate it.

A further advantageous feature of the ACWAS system is the use of a pyrotechnic gas generator as the power source, rather than stored high pressure. One benefit of this approach is that it does not require regulators to provide the constant pressure operation necessary to maintain the spray at its optimum efficiency; and that the container need not withstand pressures in excess of the operating level. These features combine to minimize weight. Another advantage is that there is no danger of leakage because the system is not pressurized until it is operated. The pyrotechnic pressurization system is as easy to operate mechanically in the event that electrical power is lost as is a conventional system.

System Must Survive the Crash

Another essential consideration is that the system must have the maximum probability of remaining fully functional after a crash — even one severe enough to cause the fuselage to break. This problem is addressed by dividing the system into independently operable zones covering the nose, wingbox and tail sections of the aircraft, corresponding to the typical pattern of damage observed when fuselage integrity is lost. Interconnections between the zones will be retained, so that an external water supply, such as from a fire tender, can be linked in at any one of a number of points to provide continuing protection beyond the endurance of the on board system. It is planned to fit hydraulic fuses both within and between the zones, so that broken pipework will not result in catastrophic loss of water and system pressure.

There are other measures that will enhance survivability in a heavy landing. These include using lightweight, dry piping to minimize the loads on attachments and connections (because pipework does not contain water when the system is in standby); attaching equipment to the airframe rather than to interior furnishings which could break away; locating ceiling nozzles so that their spray pattern is minimally affected in the case that luggage bin doors are jarred open; and, avoiding sole reliance on the on board sources of actuation and operating power.

Fire Tests Validate the System

To establish the effectiveness of the ACWAS installation, a mock-up of a section of aircraft interior was constructed. This was approximately 26 feet (eight meters) long, 10 feet (three meters) across and semi-circular in cross section with "luggage bins" fitted — approximately the dimensions of a Boeing 737 cabin interior. Jet fuel fires 18 inches (450mm) square could be ignited inside the simulated cabin, or a propane burner of comparable calorific output (about 250 kilowatts) could be substituted to isolate the effects of smoke. In other tests, a very large, four-foot square (1.2-meter square) jet fuel fire was located at the mouth of the mock-up. Temperature was measured at 28 locations; concentrations of oxygen, carbon monoxide and carbon dioxide were continuously monitored; and radiation screening and visibility obscuration measurements were made.

System performance was assessed as a function of nozzle type (a small number of variants selected on the basis of the earlier work), pressure and spacing. There were additional investigations using water curtains, use of surfactants (detergents) and mixed arrays of nozzles.

These tests indicated that the level of benefits achieved by previous trials could be attained using a much reduced flow rate. A mixed array of nozzles — the ACWAS system — was optimized for final, full-scale testing.

Full-scale Trials Begin

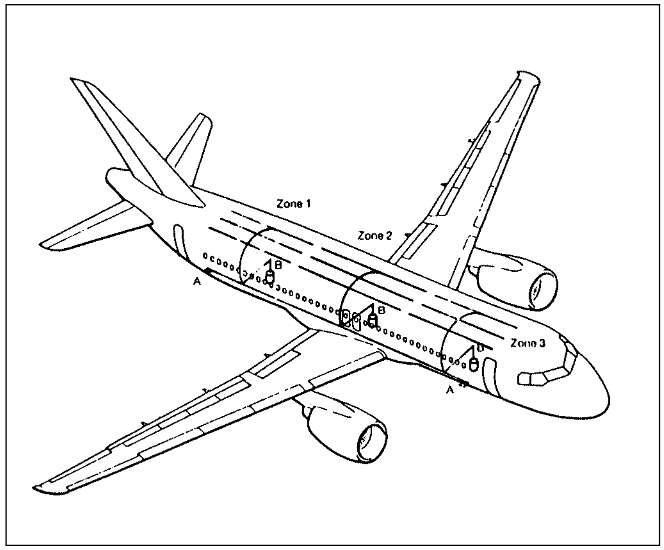
Trials are now in progress at the Fire Research Station (FRS), Cardington (United Kingdom) on a Boeing 707 fuselage belonging to the CAA. The external test fire, using 52 gallons (200 liters) of jet fuel in an 8-foot (240 cm) by 10-foot (300 cm) pan, is combined with a simulated crosswind that provides an airflow through the fuselage at 1.6 feet (0.5 meters) per second. The ACWAS spray system configuration is the mixed array optimized in preceding tests and is active along a 20-foot (6-meter) section spanning the fire opening and covering approximately one quarter of the total fuselage length.

The fuselage is fitted with comprehensive instrumentation. Temperature is measured at 50 locations. Oxygen, carbon monoxide and carbon dioxide are monitored continuously, while spot samples are taken for laboratory analysis of other toxic and irritant gases. Smoke obscuration is determined at three heights and two locations; and there are four internal and one external radiometers. These measurements are supplemented by video recordings from the front and rear of the cabin and by still photography. Pressure and flow rate in the spray system is also monitored.

Temperature measurements are taken at the height of a person's head along the axis of the cabin 60, 120, 180, 240 and 300 seconds into the test. Results were compared for a test with the water spray system in operation and for a test without the water spray.

At 60 seconds, there is little difference between the sprayed and unsprayed tests, but by 120 seconds the temperature close to the fire is rising significantly without the spray. At 180 seconds, the difference is major — in the absence of the spray, conditions are unsurvivable throughout the fuselage, with very high temperatures near the fire; in tests with the spray operating, survivable conditions were maintained. At 240 seconds, the unsprayed peak temperature is extreme, approaching 1,830 degrees F (1,000 degrees C); with the spray, conditions are becoming dangerous, but only in the fire area. At 300 seconds this region is no longer survivable, and although temperatures are much reduced throughout the cabin, they are now becoming dangerously high.

Temperature is only one of the many hazardous conditions which together represent the threat to the passengers. Models have been developed which seek to combine the effects of



Cabin water spray system — typical 3 zone configuration
A = External tender coupling; B = Underfloor water containers for each zone.

heat, oxygen deprivation and toxic and irritant gases to derive a fractional effective dose (FED). An FED of one indicates that lethal conditions have been reached.

The results indicate that conditions become unsurvivable at about two minutes in the absence of spray, and at about four minutes with the earlier high-flow spray systems. With the ACWAS system, despite its reduced flow, survivability is maintained for about six minutes.

Further evidence of the effectiveness of the ACWAS system is provided by the condition of the cabin furnishings after a test during which the external fire was allowed to burn for six minutes. There was smoke blackening of the wall panels and luggage bins, and the seat adjacent to the door was destroyed. The furnishings were otherwise substantially intact.

The results of the experimental program, which is approaching completion, have produced an extensive database on nozzle performance, a detailed understanding of the sprays and their interaction with fires and fire gases, and information on the effects of varying system parameters such as pressure and nozzle spacing. This knowledge base is valuable in allowing precise tailoring of the system to new or changed applications. Discussion continues, however, as to the dominant mechanisms by which the sprays are effective.

In addition, the overall aim of achieving the benefits of a water spray system while using a substantially reduced rate of flow has been met. The current test program at Cardington confirms that the optimized ACWAS approach is effective at full scale and, on its completion, will confirm the extent to which flow can safely be reduced.

A continuing consideration in this research and development program has been the generation of data which can be used as a basis for modelling the operation and effectiveness of the system. As a final link in this process, computer-aided design tools are being developed to assess the performance of the sprays in sweeping the volume and covering the surfaces of an aircraft interior. The aim is to complete the construction of a model which, once validated, can be used to minimize the time and effort required to design installations for new aircraft or to modify them for particular variants.

System Confirmation is the Next Step

A conference was held in May 1991 at London's Gatwick Airport to discuss cabin water spray systems for aircraft. It was hosted by the CAA and was attended by nearly 150 delegates representing a variety of worldwide organizations, including airlines, government agencies and airframe manufacturers. The delegates were presented with results from full-scale trials and the status of industry development. According to CAA, 371 lives could have been saved since 1966 had water spray systems been installed in transport aircraft.

Both the FAA and the CAA are continuing their evaluation of water spray costs vs. benefits. A decision on proposed rulemaking could be made during early 1992.

Kidde-Graviner Ltd., developer of the ACWAS, has now reached the stage of having proved the effectiveness of the reduced water flow ACWAS system and is in the process of confirming this in full-scale fire trials on a CAA Boeing 707. System concepts which minimize the possible problems of a water spray system and maximize its crash survivability are being evolved. Development is in progress, both of components and of efficient installation design methods, to make the equipment commercially available. ♦

About the Author

David J. Wyatt has been the business development manager for Kidde-Graviner Ltd. since 1988, and he has since undertaken several key management tasks for aircraft fire protection systems. Previously, he worked for Lear Siegler Inc. as a customer support engineer, providing technical and operational support for the company's product range of aircraft systems.

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