Aircraft Cabin Water Spray System

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The U.S. Federal Aviation Administration (FAA) and British Civil Aviation (CAA) have been engaged in a joint program since 1989 to determine the effectiveness and practicability of an onboard aircraft cabin water spray system for improving survival during a postcrash fire. Aviation authorities from Canada and other European countries also participated in the program.

Fire Scenarios. A postcrash aircraft fire is almost always initiated by spilled aviation fuel outside the airplane. Survival of cabin occupants is dependent on how fast the fire spreads in the cabin and the time to flashover. Accident conditions which impact the rapidity of cabin fire involvement include fuselage integrity, whether there are openings (doors, ruptures) adjacent to the fuel fire, and the resultant cabin drafts created by wind and door openings. The fire resistance of cabin materials is also an important factor. FAA full-scale fire tests focused on a fire scenario consisting of an external fuel fire adjacent to fuselage opening. An exhaust fan in the test article was adjusted to vary the degree of flame penetration through the opening, creating a cabin flashover condition that could be varied anywhere from about one to five minutes (zero wind). Additional scenarios included burnthrough (intact fuselage), sprayed fuel (fireball) and, in one test series, enhanced fire caused by metered oxygen (simulating rupture of an emergency oxygen storage tank).

System Design. The baseline water spray system was developed in the United Kingdom (U.K.) by SAVE Incorporated. The SAVE system consisted of a large array of small nozzles, mounted throughout the cabin ceiling, which discharged a fire water spray for a period of three minutes. The characteristics of the agricultural type nozzles are as follows: hollow cone, 100 micron mean droplet diameter, and 0.7 1pm at 40-45 psi. In the FAA narrow body (B-707) test article, the SAVE system consisted of 120 nozzles and 72 gallons of water and 195 gallons of water was required.

System Effectiveness. FAA completed full-scale fire tests in both narrow body and wide body test articles to determine the effectiveness of the SAVE system under various postcrash fire scenarios. CAA also sponsored narrow body tests in the U.K. Test results indicated that the SAVE system effectively suppressed (it is not an extinguishing system) postcrash fires in both aircraft sizes. In particular, the fine water mist caused large reductions in air temperature and water soluble gas concentrations. The concentration of "dry" toxic gases such as carbon monoxide was also lowered. By delaying flashover, survival time improvements of 2-3 minutes were achieved. This improvement is very significant in the context of aircraft fire safety; in this environment, improvements of only 5-10 seconds could conceivably save many lives (see Figures 1 and 2).

A somewhat negative feature of the SAVE system was that the water spray tends to lower the ceiling smoke layer. Compared to an unsuppressed fire, visibility is reduced during the early

stages of a fire. However, as the water spray suppressed the fire, the visibility improved as compared to the unsuppressed fire.

System Optimization. Because of payload, the weight penalty of the SAVE system is excessive by aircraft standards. Tests were first conducted to determine what mechanisms made the SAVE system effective. The results showed that the system's best attributes were reducing the burning rate of materials and lowering cabin air temperatures. This finding led to the development and evaluation of a zoned waterspray system. An optimized zone system was showed to be even more effective than the SAVE system while using only about 10% of the water. Moreover, because water discharge is confined to fire areas, smoke lowering was eliminated in those portions of the cabin where evacuation would be taking place, restoring and even improving visibility (see figures 3-6).

Physiological Hazards and other Human Factors. A number of potential problems were identified and examined. Based on water spray test measurements and pertinent scientific literature, it was concluded that water spray of the type tested would not increase the water content of inhaled air nor carry absorbed toxicants into the lungs. The effect of water spray on emergency evacuation was studied by conducting full-scale tests with human subjects. There was no difference in evacuation time from the sprayed and unsprayed cabin environment. In addition to overcoming the loss in visibility caused by lowering of the smoke layer, a zoned system would also minimize the number of passengers likely to be wetted and, thereby, the risk of hypothermia following evacuation.

Safety Benefit Analysis. FAA, CAA and Transport Canada analyzed world-wide transport accidents over the past 20 years to calculate the number of fire fatalities that could have been prevented had a water spray system been onboard. The analysis factored into consideration fire safety improvements (e.g., seat fire blocking layers, floor proximity, lighting) mandated after the time of the accident. It was estimated that a maximum of 14 lives a year world-wide, or 4 lives per year in the U.S., can be saved by the use of an onboard water spray system. Although the "average" savings in lives is relatively low, it is also recognized that a water spray system could save a large number of people in a major aircraft fire accident.

Manufacturers Disbenefits Study. Boeing and Airbus completed separate studies to evaluate the adverse effects of water spray discharge in an airplane. Particularly, the consequences of an inadvertent discharge while the airplane is flying of great concern. The installation of a water spray system is feasible, but certain protective measures would have to be taken to enable an airplane to tolerate an inadvertent discharge. Since the analysis was based on the SAVE system (continuous water discharge throughout cabin for 3 minutes), additional considerations such as system zoning and arming would reduce the level of protection required.

Airworthiness Design Requirements. Design requirements for an aircraft water spray system were developed by the airworthiness authorities participating in the program with industry input. The requirements provided a realistic basis for a cost assessment.

Cost Analysis. A cost study commissioned by CAA was conducted to cover a range of water spray system configurations and airplane types. The fleet costs to retrofit systems would

currently indicate a $22-32 M cost per life saved.

Future Studies. It is clear that the safety potential of an aircraft water spray system is very great; conversely, the cost/benefit is high and the concerns with installing in an airplane persist. Therefore, future studies should address cost issues and further evaluate operational feasibility.

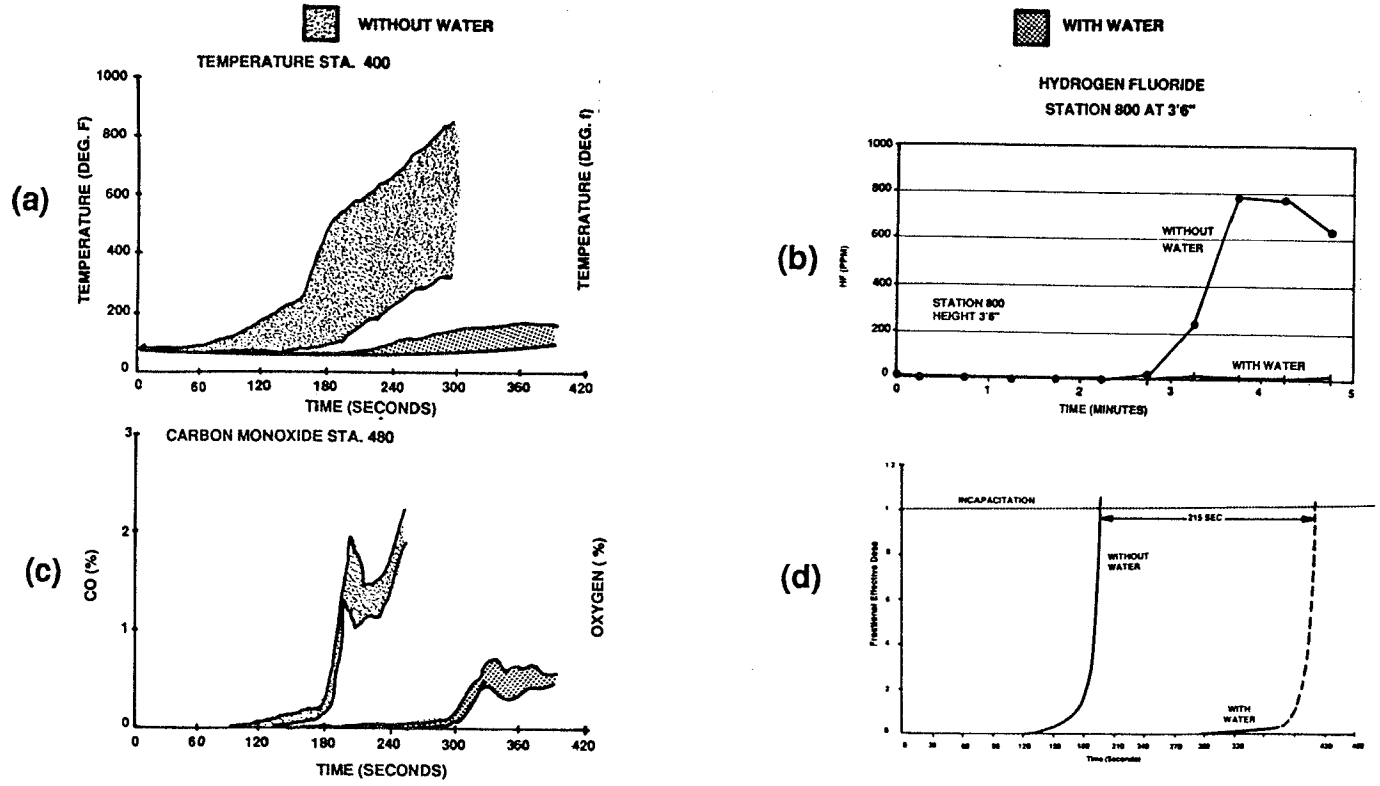

FIGURE 3. 1
NARROW BODY RESULTS/ SAVE SYSTEM/MODERATE WIND/FUSELAGE OPENING

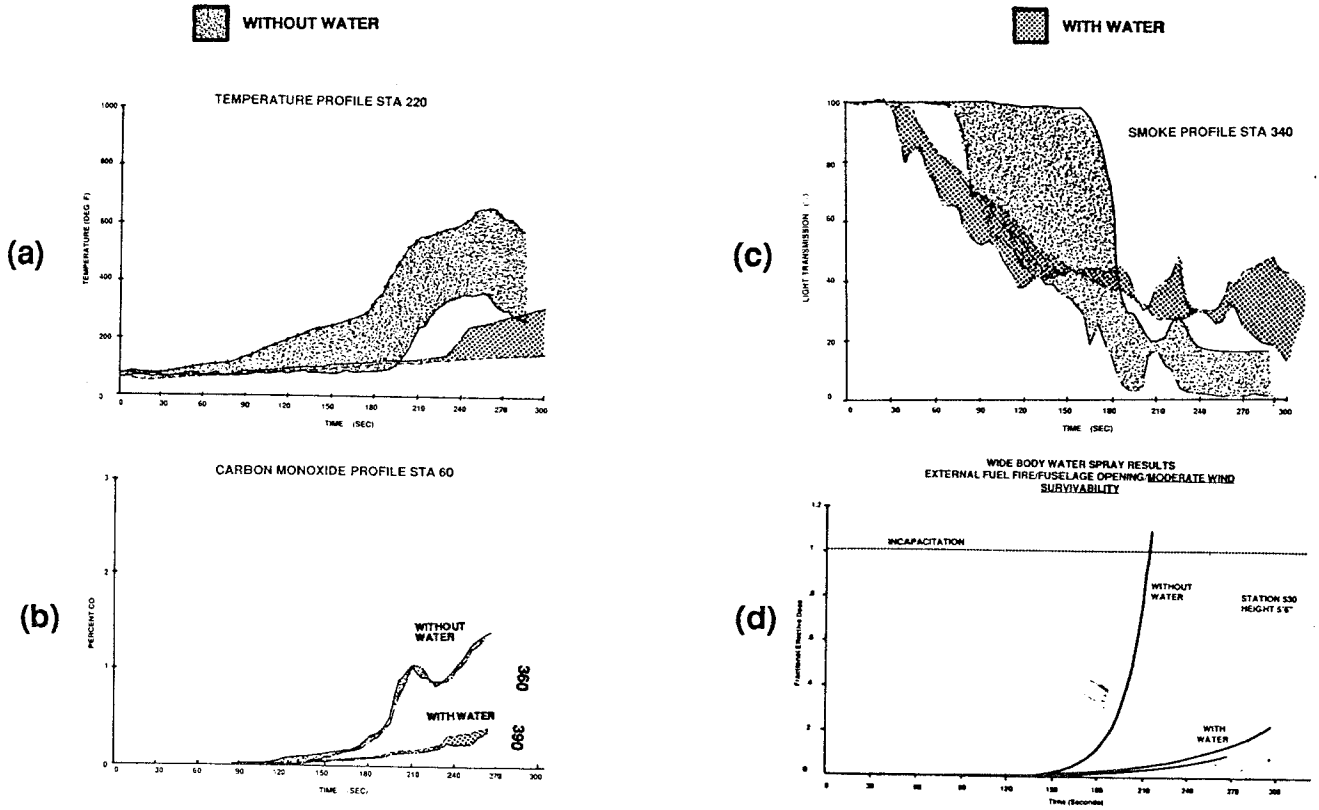

FIGURE 4. 2
WIDE BODY RESULTS/ SAVE SYSTEM/MODERATE WIND/FUSELAGE OPENING

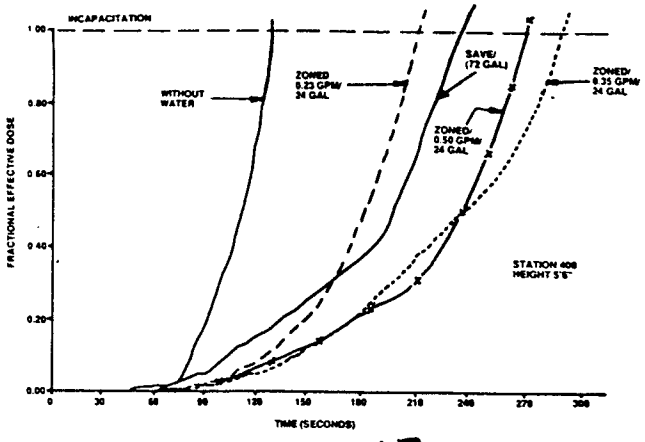

FIGURE 7. 3.
ZONED SYSTEM SURVIVAL TIME
IMPROVEMENT 24 GALLONS

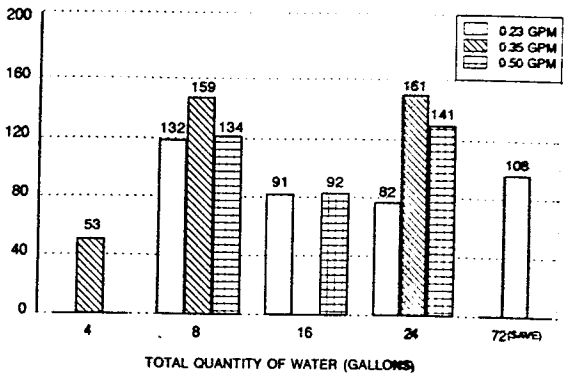

FIGURE 8. 4
ZONED SYSTEM AVAILABLE
ESCAPE TIME

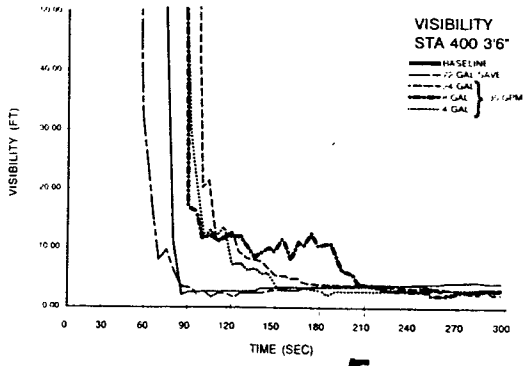

FIGURE 7. 5
ZONED SYSTEM
VISIBILITY IMPROVEMENT

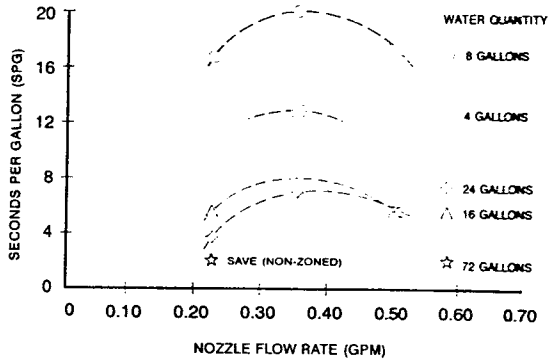

FIGURE 8. 6
ZONED SYSTEM
OPTIMIZATION

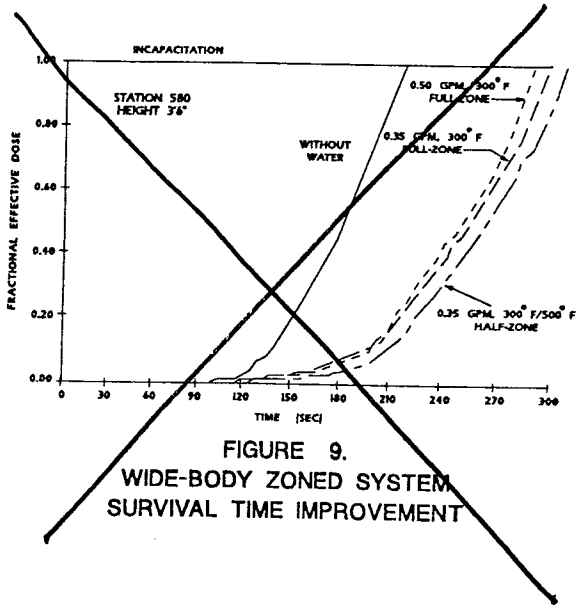

FIGURE 9.
WIDE-BODY ZONED SYSTEM
SURVIVAL TIME IMPROVEMENT

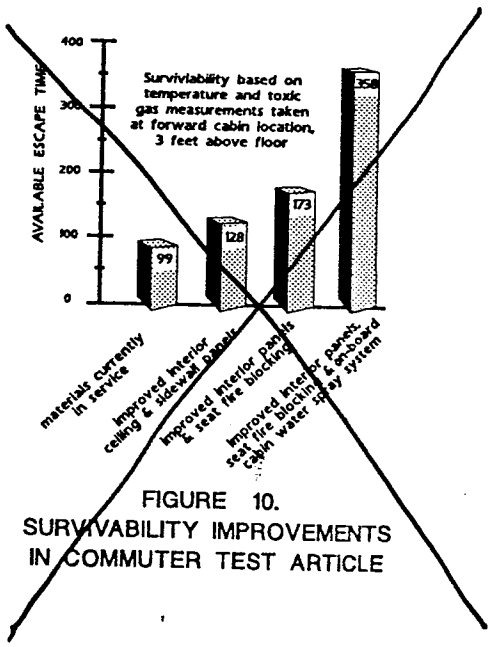

FIGURE 10.
SURVIVABILITY IMPROVEMENTS
IN COMMUTER TEST ARTICLE

Aircraft Cabin Water Spray System
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Ames, S.A., Purser, D.A., Fardell, P.J., Ellwood, J., Murrell, J. and Andrews, S.

Cabin Water Sprays for Fire Suppression: An Experimental Evaluation Fire
Research Station of the Building Research Establishment (study sponsored by Civil Aviation Authority).
CAA Paper 93009, March 1993, 135 pages.
This report describes a series of experiments to investigate the effectiveness of low volume water sprays in reducing the risk to passengers in an aircraft cabin exposed to a severe external fire. It was shown that water sprays significantly reduce the temperature and level of toxic and irritant fire products within the cabin. A major conclusion was that the principle action of water sprays is to reduce fire penetration into the cabin and to inhibit fire growth in the cabin contents.

Bottomley, D.M., Muir, H.C. and Lower, M.C.

Aircraft Evacuations: The Effect of a Cabin Water Spray System upon Evacuation Rates and Behavior.
Cranfield Institute of Technology (study sponsored by Civil Aviation Authority)
CAA Paper 93008, March 1993, 72 pages.
This paper describes eight full-scale aircraft evacuations using a 707 airframe. Each evacuation involved a group of around 45 adults. Four groups evacuated in dry conditions the remaining four evacuated in the waterspray. The results revealed the evacuation for the two conditions were virtually identical, suggesting that the presence of water spray did not affect evacuation rates.

Civil Aviation Authority

Cabin Water Spray Systems: Disbenefits Study by Airbus Industries.
CAA Paper 92016, December 1992, 10 pages.
This report presents an executive summary of a study undertaken by Airbus Industries. The study highlighted disbenefits which could result from the installation of a water spray system on current and future Airbus passenger aircraft. Disbenefits are identified as; affecting the safety of the aircraft, hindering orderly evacuation or inducing high return to service costs.

Civil Aviation Authority

International Cabin Water Spray research Management Group: Conclusions of Research Programme
CAA Paper 93012, June 1993, 17 pages.
This paper is a summary of research and analysis conducted with the purpose of determining the feasibility and practicability of an onboard aircraft cabin spray system for extending survival time during a post crash fire. The research

programme was carried out by the FAA and the CAA and managed by a Group which has included representatives of the FAA, Transport Canada, CAA, DGAC, LBA and RLD. This paper was prepared by the Research Management Group and is published in the U.K. by the Civil Aviation Authority.

Civil Aviation Authority

Cabin Water Sprays for Fire Suppression: Design Considerations and Safety Benefit Analysis Based on Past Accidents.
CAA Paper 93010, August 1993, 293 pages.
This report studied 95 accidents, to civil passenger aircraft, reported as potentially survivable, in which fatalities and fire occurred, over a 26 year period. It was concluded that today cabin water sprays would save an average 14 lives per year world-wide. Considering only the airlines of the nations comprising the JAA, the FAA and Transport Canada, this figure reduces to 6 lives per year.

Civil Aviation Authority

Cabin Water Sprays for Fire Suppression: A Cost Analysis
Aim Aviation (study sponsored by Civil Aviation Authority)
CAA Paper 93011
This report derives design, equipment, installation, maintenance and direct operating costs of a theoretical cabin water spray design for three typical sizes of civil aircraft. This data was used to calculate cost benefit figures for different cabin water spray designs.

Hill, R.G., Sarkos, C.P., and Marker, T.R.

Development and Evaluation of a Onboard Aircraft Cabin Water Spray system for Postcrash Fire Protection
Federal Aviation Administration
SAE, Aerospace Technology Conference and Exposition, Long Beach, CA, September 23-26, 1991, SAE Paper 912224, 11 pages.
This paper outlines a program that could ultimately lead to design standards for an on-board aircraft cabin water spray system. Full-scale effectiveness tests showed that a water spray system may provide passengers 2-3 minutes of additional time to escape under certain postcrash fire scenarios.

Hill, R.G., Marker, T.R., and Sarkos, C.P.

Evaluation and Optimization of an On-Board Water Spray Fire Suppression System in Aircraft
Federal Aviation Administration
Water Mist Fire Suppression Workshop, March 1-2, 1993; Proceedings, NIST Report NIST1R 5207, 93-103 pp, June 1993.
This paper summarizes a series of full-scale fire tests to evaluate and develop an on-board aircraft cabin water spray system against postcrash fires. A zoned water spray system was conceptualized, designed and tested under full-scale conditions in an attempt to reduce the weight penalty of water. Test results indicated a zoned system may be designed to provide more protection and improved visibility than a

continuous spray system with approximately 10% of the water.

Marker, T.R.
Onboard Cabin Water Spray System under Various Discharge Configurations
Federal Aviation Administration
Report No. DOT/FAA/CT-TN91/42, October 1991, 25 pages.
This report describes six full-scale fire tests in a modified DC-10 fuselage to investigate the effects of spraying water at different cabin locations or "pre-wetting" the cabin while keeping the fire conditions constant. Spraying in the area of the fire was found to be overall more effective than "pre-wetting" or cleansing" the smoke layer.

Marker, T.R, and Downie, B.
Effectiveness of an Onboard Water Spray System During an Oxygen Enriched Postcrash Cabin Fire
Federal Aviation Administration
Report No. DOT/FAA/CT-TN91/51, December 1991, 30 pages.
This report describes three full-scale fire tests in a modified DC-10 fuselage to determine the effectiveness of an onboard water spray system in reducing the hazards of an oxygen enriched postcrash cabin fire. The results showed the water spray was effective in increasing survival during an oxygen enriched fire by significantly prolonging the period of time that the cabin environment remains habitable.

Marker, T.
Narrow-Body Aircraft Water Spray Optimization Study
Federal Aviation Administration
Report No. DOT/FAA/CT-TN93/3, February 1993, 35 p.
This report describes 25 full-scale fire tests in a modified 707 narrow body fuselage as part of an aircraft cabin water spray optimization study. Several spray configurations were tested by varying the amount of water sprayed, the flow rate, and the orientation of nozzles, in an attempt to minimize the quantity of water required. It was shown that the optimal zoned system was more effective than the SAVE system and used only 11% of the water.

Marker, T.R
Widebody Cabin Water Spray Optimization Tests
Federal Aviation Administration
Report No. DOT/FAA/CT-TN93/29, August 1993, 46 pages.
This report describes 9 full-scale fire tests in a modified DC-10 test article as part of an aircraft cabin water spray optimization study. The tests were aimed at validating optimization tests in a narrow body test article. It was shown survival time was extended between 41 and 103 seconds, depending on zone configuration, discharge activation temperature and cabin location.

Marker, T.R.

Impact of Improved Materials and Cabin Water Spray on Commuter Aircraft Postcrash Fire Survivability.
Federal Aviation Administration
Report No. DOT/FAA/CT-TN93/40, November 1993, 35 pages.
This report describes 12 full-scale tests in a modified Metroliner fuselage to study the impact of using improved fire retardant materials and a cabin water spray system on postcrash fire survivability. It was shown that the water spray improved survival by 3 minutes. The effectiveness of improved fire retardant materials was significant but less than water spray; e.g., seat fire blocking layers improved survival by 45 seconds.

Reynolds, T.L., and Porter, K.W.

Aircraft Cabin Water Spray Disbenefits Study
Boeing Commercial Airplane Group (study sponsored by FAA and NASA)
Report No. DOT/FAA/CT-92/6, October 1993, 148 p.
This report describes the potential "disbenefits" of an aircraft cabin water spray system from the perspective of an aircraft manufacturer and an operator. Disbenefits identified in the report include potential evacuation delays, introduction of "common cause failure" in redundant safety in flight systems, physiological problems for passengers, high cost of refurbishment for inadvertent discharge, and potential to negatively affect other safety systems. The report reviews all key functional areas and makes appropriate recommendations for further study.

Sarkos, C.P., Hill, R.G., and Marker, T.R.

Development of an On-Board Water Spray Fire Suppression System for Transport Aircraft
Federal Aviation Administration
AGARD-IIA Aircraft Flight Safety Symposium, Zhukovsky, Russia, August 31 - September 5, 1993, 8 pages.
This paper summarizes a series of full-scale tests to evaluate and optimize an on-board aircraft cabin water spray system for postcrash fire protection. Test results indicated that an optimal zoned system gave more protection and improved visibility than a continuous spray system with approximately 10% of the water. Tests were also conducted in a commuter aircraft to determine the relative effectiveness of water spray and improved fire resistant materials.

Speitel, L.C.

Analytical Method for Water Vapor Collection and Analysis in Aircraft Cabin Fires
Federal Aviation Administration
Report No. DOT/FAA/CT-TN93/33, August 1993, 20 pages.
This report describes a method of collection and analysis to determine the concentrations of water vapor in full-scale aircraft cabin fire tests as a function of time. It was shown that the concentration of water vapor as a function of time

was similar in aircraft full-scale fire tests with and without water spray discharge.

Whitfield, R.T., Whitfield, Q.d'A., and Steel, J.
Aircraft Cabin Fire Suppression by Means of an Interior Water Spray System
Safety (Aircraft and Vehicles) Equipment Limited (study sponsored by Civil Aviation Authority)
CAA Paper 88014, July 1988, 64 pages.
This report describes tests carried out using a fully furnished Trident aircraft to determine the effectiveness of an interior water spray system in preserving a survivable cabin environment in the face of an external fuel fire. In three tests during which the aircraft structure suffered increasing external damage, the water spray prevented fire damage in the cabin and delayed the migration of toxic fumes.