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Technical Specification for a Cabin Water Mist System

March 2012

Final Report

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NOTICE

This research was commissioned by Transport Canada by means of the Memorandum of Cooperation regarding Civil Aviation Research and Development between the Civil Aviation Authority of the United Kingdom and the Department of Transport of Canada. This activity has been carried out in cooperation with the Federal Aviation Administration and the UK Civil Aviation Authority under the auspices of the International Cabin Safety Research Technical Group whose goal is to enhance the effectiveness and timeliness of cabin safety research.

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16. Abstract

This Specification has been developed for the purposes of aircraft safety research and must not be used as a basis for influencing the design of any system to be used on an aircraft.

This Technical Specification relates to a Cabin Water Mist (CWM) system, forming part of an Integrated Fire Protection system. However, it is also applicable to a “stand-alone” system. Guidance in the design of a CWM system may be found in NFPA 750: Standard on Water Mist Fire Protection Systems, however, it should be noted that this standard is not aircraft specific and can <u>not</u> be considered as a specification for a CWM system to be installed on an aircraft.

In May 1992, the Joint Aviation Authorities issued a Draft Notice of Proposed Amendment (NPA) for Cabin Water Spray Systems. This document has been taken into account in the formulation of this Technical Specification.

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LIST OF ACRONYMS

AC	Advisory Circular
CAA	United Kingdom Civil Aviation Authority
CAR	Canadian Aviation Regulations
CFR	Code of Federal Regulations
CS	Certification Standards
CWM	Cabin Water Mist
FAA	Federal Aviation Administration
JAA	Joint Aviation Authorities
MEL	Minimum Equipment List
MPS	Minimum Performance Standard
MSG3	Maintenance Steering Group
MTOW	Maximum Take-Off Weight
NFPA	National Fire Protection Association (United States)
NPA	Notice of Proposed Amendment
TC	Transport Canada

EXECUTIVE SUMMARY

In May 1992, the Joint Aviation Authorities issued a Draft Notice of Proposed Amendment for Cabin Water Spray systems. This Specification has been developed, using, in part, that document, for the purpose of aircraft safety research and must not be used as a basis for influencing the design of any system to be used on an aircraft.

This Technical Specification relates to a Cabin Water Mist (CWM) system, forming part of an Integrated Fire Protection system. However, it is also applicable to a "stand-alone" system. Guidance in the design of a CWM system may be found in NFPA 750: Standard on Water Mist Fire Protection Systems. However, it should be noted that this standard is not aircraft-specific and cannot be considered as a specification for a CWM system to be installed on an aircraft.

Areas of consideration in the Specification include system performance and operation, system integrity, firefighting issues, and effects on occupants and evacuation and maintenance.

1. INTRODUCTION AND BACKGROUND.

This Technical Specification has been developed for Transport Canada in fulfillment of Task 2.3.7 of Annex 06-01 to the Memorandum of Co-Operation regarding Civil Aviation Research and Development between the Civil Aviation Authority of the United Kingdom and the Department of Transport of Canada.

This Specification has been developed for the purposes of aircraft safety research and must not be used as a basis for influencing the design of any system to be used on an aircraft.

This Technical Specification relates to a Cabin Water Mist (CWM) system, forming part of an Integrated Fire Protection system (see reference 1). However, it is also applicable to a "stand-alone" system. Guidance in the design of a CWM system may be found in NFPA 750: Standard on Water Mist Fire Protection Systems (reference 2) however, it should be noted that this standard is not aircraft specific and can not be considered as a specification for a CWM system to be installed on an aircraft.

In May 1992, the Joint Aviation Authorities issued a Draft Notice of Proposed Amendment (NPA) for Cabin Water Spray Systems (see reference 3). This document has been taken into account in the formulation of this Technical Specification. A summary of the proposed Specification Requirements is contained in section 5.

2. APPLICABILITY.

The proposed requirements, contained within this specification, are applicable to Large Transport Airplanes certificated with a Maximum Take-Off Weight in excess of 5,700 kilograms. Within this document, reference is made to "Part 25"; this relates to Title 14 Code of Federal Regulations (CFR) 25 (USA), CAR 525 (Canada) or CS-25 (Europe) which are the airworthiness requirements applicable to Large Transport Airplanes.

3. PURPOSE OF THE SYSTEM.

The objective for the CWM system is that it should provide a degree of protection to occupants for both in-flight cabin fires and fire assaults on the cabin in postcrash scenarios.

3.1 GROUND.

The CWM system should be such that it extends the period in which there is a survivable environment in the cabin during a postcrash fire so that occupants have an increased chance of escape.

The system should be designed to withstand the conditions likely to occur following ground impact and a subsequent ground pool fire. The crash conditions appropriate to the CWM System are discussed in subsequent sections of this report.

Tests carried out by the US FAA and UK CAA showed that in a postcrash cabin fire event, water spray[1] is effective in cooling the cabin, wetting the materials, and slowing the progress of fire (reference 4). The system was shown to result in significant delays in the onset of cabin flashover, providing a more survivable cabin atmosphere and additional escape time.

3.2 Flight.

The system should be designed to suppress a cabin fire for sufficient time to allow the cabin crew to access and combat the threat. Testing has not, as yet, been carried out to evaluate the effectiveness of a CWM system to combat in-flight fires. However, sufficient work has been carried out to enable many of the requirements of the system to be defined. CWM systems have also been considered as having a benefit in aviation security, in the event of a terrorist act resulting in fires during flight.

4. OBJECTIVE DESIGN REQUIREMENTS.

Requirements that specifically address a CWM system have not yet been developed. The objective design requirements contained in this section are based on the proposed regulations contained in the JAA document "Draft Notice of Proposed Amendment (NPA) for Cabin Water Spray Systems (see reference 3). However, in certain instances these design requirements have been amended due to:

- The NPA considered Water Spray systems for post impact protection of occupants only and did not address a system also intended for in-flight use.

- Since the time that the NPA was formulated, research and analysis has been conducted that needs to be reflected in any design requirements.

All of the issues raised in the NPA are addressed in this specification, and any suggested deviations from the JAA standard are justified.

No attempt has been made to specify the requirements that might be applied by the airplane manufacturer to all systems, i.e., those relating to vibration, temperature ranges, pressure cycling, etc., since these are likely to be airplane specific. Furthermore, although certain Part 25 requirements are addressed in this Specification no attempt has been made to include all of those that might be applicable to the design of a CWM system since once again these requirements are likely to be airplane specific.

While most of the early research referred to in this specification relates to a "Cabin Water Spray" system, the issues raised and the conclusions reached are considered equally applicable to a "CWM" system. This specification relates to a CWM system, which has been defined as:

[1] Cabin water spray and water mist are generally used interchangeably in this report. CWM is a subset of cabin water spray.

> "A water spray, for which the Dv 0.99[2], for the flow weighted cumulative volumetric distribution of water droplets, is less than 1000 microns at the minimum design operating pressure of the water mist nozzle."

It is considered that systems used on aircraft are most likely to be Water Mist systems.

4.1 SYSTEM PERFORMANCE AND OPERATION.

4.1.1 Minimum Performance Standard.

Specification Requirement 1. The CWM system must perform its intended function for the specific cabin configuration and provide protection to occupants during any in-flight or post crash fire threat.

Currently a Minimum Performance Standard (MPS) has not been produced by the Airworthiness Authorities. The CWM system must meet the ground and in-flight fire threat defined by the Airworthiness Authorities. Testing of the system will be required to ensure that its performance meets the defined threat. Compliance with the criteria defined by the Airworthiness Authorities must be demonstrated for:

- Manual operation in flight
- Either manual or automatic activation on the ground (see section 4.1.2)

Manual operation should be demonstrated taking into account a reasonable crew response time from notification of the fire threat to system functioning.

The required maximum response time of the system for manual and automatic operation is likely to be incorporated in the fire threat defined by the Airworthiness Authorities (see section 4.1.2).

For system operation on the ground, conditions that might affect system operation, e.g., wind, are likely to be specified as needing to be simulated in the required test. Testing carried out by the FAA suggested that the wind conditions at an accident site are likely to be a major factor in some fire threats. Reference 4 states:

> "Finally, in 'high wind' tests the fire was so severe that it overwhelmed the water spray such that it became necessary to terminate the test after only 60 seconds."

The MPS will define the cabin environment acceptance criteria during system operation, e.g., air temperatures, particle concentrations, toxicity levels, etc., and the period of time that it must be maintained for both the in-flight case and the ground case (see section 4.1.5).

The CWM system must meet the MPS acceptance criteria for the cabin configuration of the aircraft to which it is fitted. Changes that are made to the cabin configuration, for example

[2] Dv 0.99, is a drop diameter such that the cumulative volume, from zero diameter to this respective diameter, is the fraction .99, of the corresponding sum of the total distribution.

relocation of galleys, bulkheads, etc., that might significantly affect air flows or water mist distribution, will require an evaluation of the system performance that might result from the change. In certain instances, changes to the cabin configuration, on an in-service aircraft, might result in the need for requalification of the system to the MPS.

4.1.2 System Activation.

Specification Requirement 2. It must be demonstrated that the CWM system will be available in the presence of the specified fire threat to the cabin. Activation of the system must be automatic in circumstances where the flight crew may be incapacitated

System activation for the ground case is addressed in the JAA NPA (see reference 3) Subparagraph (c) (1). The above proposed requirement is modified from that suggested by the JAA to accommodate the intended in-flight use of a CWM system and the levels of integrity required of the system proposed by this Specification.

Manual Operation of the system is likely to be from the flight deck, in order to reduce the risk of inadvertent operation that might result from unruly action by passengers were system activation available in the cabin. This may result in the need for flight deck notification of the fire threat in the cabin.

It will need to be demonstrated, for manual and automatic activation, that the specified threats can be detected in sufficient time to meet the MPS criteria. Account should be taken of the likely response time of the flight crew following a fire threat warning.

A zoning system might be used that divides the cabin into a series of spray zones, each operating independently of the others. This allows the CWM system to operate only in areas of the cabin that are under a fire threat. Tests conducted by FAA have shown that, when compared to a total-flood system, a zoning system would reduce the amount of water required for a “cabin water spray” system without a reduction in effectiveness (see reference 4).

Zoned activation of the system might be achieved by the use of temperature sensors such that the system is initiated, when the ambient cabin ceiling temperature in that zone, is at a specified level. It has been suggested that the sensors should operate at temperatures of approximately 150^{o}C (302^{o}F), or greater for the ground case. However, the required temperature setting will be determined from the MPS acceptance criteria defined by the Airworthiness Authorities. In order to minimise the risk of inadvertent operation the sensors used in the system should be set at temperatures sufficiently above those likely to be encountered in the cabin during normal aircraft operation.

4.1.2.1 System Activation—Ground.

Two cases need to be considered for ground activation of the system:

1. The High-Impact ground case that which could result in crew incapacitation and hence Automatic activation is required and

2. The Low-Impact ground case when crew incapacitation is unlikely and Manual Operation of the system is possible.

4.1.2.1.1 High-Impact Ground Case.

One method of automatic activation of the system could be by "g" sensors. Once again, if used, they should be set at levels significantly above those likely to be encountered during normal aircraft operation in order to minimise the risk of inadvertent operation but at a sufficiently low level to ensure that they will operate under any impact conditions that could result in crew incapacitation or fuselage rupture.

To accommodate for post-impact fuselage breaks "g" sensors, used for activating the system, would need to be located in the same zones of the aircraft, bounded by the breaks, together with the power source discussed in section 4.2.3 and the discrete water supplies discussed in sections 4.1.6.1 and 4.2.2.1.

4.1.2.1.2 Low-Impact Ground Case.

Devices such as "g" sensors would not operate in low impact accident conditions. To accommodate this case manual activation of the system by the crew would be required.

However, the system design must be such that it meets the requirements relating to inadvertent operation specified in section 4.2.4. This is likely to result in the need for redundancy in the system design such that single failures do not result in the system operating. It is likely that two dissimilar means would be needed to activate the system in the presence of a fire threat for example:

- Temperature sensors and "g" sensors for the automatic mode (High-Impact case)
- Temperature sensors and crew activation for the manual mode (Low-Impact case)

4.1.2.2 System Activation – Flight.

Specification Requirement 3. Operation of the CWM system in flight must not present a hazard to continued safe flight and landing.

The proposed design philosophy, relating to the low impact ground case, contained in section 4.1.2.1, would also accommodate the CWM system activation requirements for the flight case.

Operation of the system must not constitute a hazard to other airplane systems. Concern has been expressed, in the past, as to the effects of water on critical systems of the aircraft due to both inadvertent and genuine operation of the system. The primary areas of concern are electrical and electronic equipment that may be affected by water draining or being carried by the air flow, to areas in which they are located. It is therefore necessary that the design of aircraft systems must be such that they do not malfunction due to the presence of water. The Cabin Water Spray Disbenefits study carried out by Boeing Commercial Airplane Group in 1993 for a system intended for ground use only (reference 5) states:

> "Once the system configuration is known, testing must be performed to determine where the water is likely to collect and the total amounts of water involved. This will allow for a more detailed look at how parts could fail, and those that are more likely to fail. From these tests, design practices can be modified to prevent ice build up or water collecting near sensitive equipment in such a way as to avoid negative effects on other aspects of systems design."

Since the purpose of providing in-flight protection from a CWM system is to allow sufficient time to allow the cabin crew to access and combat the threat, co-ordination between the cabin and flight crews would form part of the approved drills for in-flight firefighting. Guidance on fighting in-flight fires may be found in the FAA Advisory Circular (AC) 120-80 (see reference 6).

4.1.3 System Deactivation.

Specification Requirement 4. If manual deactivation of the system is required to meet Specification Requirement 4 or Specification Requirement 15, this means must be installed at each required flight attendant station.

The proposed requirement regarding deactivation, contained in the JAA NPA (see Reference 3) Subparagraph (c) (2), is as follows:

> "Controls for manual deactivation of the system must be at each required flight attendant station."

However, the need for a manual deactivation means is to prevent occupants from being adversely affected by the system operating when not required. Hence, if inadvertent operation can be shown to meet the requirements of section 4.2.4, without a means for deactivation, then this means may not be required. If a means for deactivation is required, then consideration would need to be given to the crew response time from inadvertent system operation to fault recognition and subsequent deactivation. The Cabin Water Spray Disbenefits study carried out by Boeing Commercial Airplane Group in 1993 for a system intended for ground use only (reference 5) states:

> "For inadvertent or uncommanded operation, consideration was given to artificially limiting the spray duration, to 30-seconds or so, as it was thought that a manual shutoff could be performed within that time period. Service experience

> has shown that 30-seconds to be very optimistic, as several past lavatory spills have taken considerably longer to effect a shutoff. It has to be further assumed that whatever caused the system to discharge inadvertently might also prevent its early shutoff."

It is recognised that the flight attendants are best placed to determine if an inadvertent operation of the system has occurred and therefore that they should be responsible for carrying out deactivation of the system if it is required. However, safeguards must be in place to ensure that a required operation of the system is not mistakenly deactivated. Such safeguards might include rendering the deactivation system inoperative when the flight crew have selected the system to operate as proposed in sections 4.1.2.1 and 4.1.2.2. The system should also have a means for the flight crew reinstating the system after it has been deactivated.

4.1.4 System Indication.

Specification Requirement 5. Means to indicate the status of the CWM system to the flight crew and flight attendants must be provided.

The above proposed requirement is contained in the JAA NPA (see reference 3) Subparagraph (e). The indication provided to the flight crew and flight attendants should include:

- System Armed/Disarmed – (if appropriate)
- System Operating
- System Deactivated

Consideration may also need to be given to providing some warning means to the flight crew to indicate:

- That the water has not become frozen due to prolonged ground soak in cold ambient temperatures

- Low water content

Other flight deck indication may be required in order to meet the levels of integrity defined in section 4.2.3 and 4.2.4 by minimising latent (dormant) failures.

4.1.5 System Operating Time.

4.1.5.1 Ground.

Specification Requirement 6. The operating time required of the system should be such that it maintains a survivable environment for 5 minutes during a postcrash Ground Pool Fire.

Studies of past accidents provide an indication of the likely system operating time that would be required to afford an adequate level of protection for occupants.

An analysis carried out for the UK CAA related to Fuselage Hardening for Fire Suppression (see reference 7) suggested that protection against pool fires provided little benefit after 4 to 8 minutes.

A study of past accidents carried out by the FAA, Transport Canada and the UK CAA in 1993 (see reference 8) found that:

> "…...180 seconds of additional protection could enable all mobile occupants to evacuate. It is therefore appropriate to consider that 180 seconds of additional protection be a design goal for a water spray system. It should be recognised however that the spray can be overwhelmed in certain severe fire threat scenarios. The protection time can therefore only be specified for a given fire threat."

A further study of 24 ground pool-fire accidents carried out for the FAA (see reference 9), used information contained in accident reports to determine the time taken to complete an evacuation. The highest evacuation time recorded in the accident reports for these accidents was 360 seconds (6 minutes). However, this was just one accident out of the 24 studied, for the remaining 23 accidents the evacuation time was 300 seconds (5 minutes) or less.

Based on these studies, it is suggested that operating times in the order of 5 minutes might be assumed in determining the likely water requirement for a CWM system used to protect occupants against post-impact pool-fires.

<u>4.1.5.2 Flight</u>.

Specification Requirement 7. The operating time required of the system should be sufficient to allow the cabin crew to access and combat the threat.

Once again, pending the availability of a MPS, firm requirements can not be established for the required operating time of the system in flight. Since the objective of a CWM system for in-flight use is simply to allow cabin crew sufficient time to access and combat the threat, it is suggested that the quantities of water required for the ground case would be sufficient to meet the needs of the in-flight system. If the CWM is to be a zoned system, it is likely that the water quantity requirements for the ground case would be based on all zones operating. For the flight case, it is difficult to envisage more than a third of the zones being needed to combat the threat. On this basis, a CWM system designed to operate for 5 minutes on the ground would provide protection for around 15 minutes in flight.

<u>4.1.6 Water Supply, Quality, and Protection</u>.

<u>4.1.6.1 Water Supplies</u>.

Consideration has been given in the past to using the onboard potable water system to reduce system weight by utilising existing resources in the aircraft, including the water heating system. While this can not be precluded as either a primary or supplementary water source, it is difficult to envisage how such a system could meet the crashworthiness standards specified in section

4.2.2 relating to post-impact fuselage breaks. Furthermore, since fire protection should always be available, the use of potable water would mean that a proportion of it would need to be retained for the Water Mist system. This would amount to a dedicated supply.

A dedicated supply has advantages over water being supplied from the potable water system. One such advantage is that it allows better control over the water quality such that contamination becomes less of an issue and additives may be used as discussed in section 4.1.6.2.

A "modular" system is one that is configured such that all or part of the system would remain operable following breaks in the fuselage. To achieve this dedicated water tanks would be required in those areas of the aircraft that are likely to be bounded by fuselage breaks in a post-impact crash scenario (see section 4.2.2.1).

4.1.6.2 Water Quality.

Specification Requirement 8. The water quality should be such that it does not result in any degradation of the system performance.

Special consideration needs to be given to the quality of water used in the water mist system. The use of distilled water has the advantage that it is more likely to be readily available at airports. Furthermore, the electrical conductivity of the water, and hence its potential affects on the aircraft electrical systems, is likely to be reduced by the use of distilled water (see section 4.1.2.2).

However, additives can be used for many purposes such as enhanced fire performance, microbiological growth inhibitors, corrosion inhibitors, freeze protection, etc. Any additives used in the system should be reviewed with the manufacturer for consideration of health or environmental issues since some can cause serious personnel hazards. If multiple additives are to be used the manufacturers should be consulted regarding the additives' compatibility and their combined effects. The water quality should not result in any degradation of the system components due to chemical reaction.

The use of additives is likely to result in the need for a specification defining their composition and the quality standards required for the water.

4.1.6.3 Water Temperature.

Specification Requirement 9. Exposure of the system to temperature conditions, likely to be encountered during normal operation of the aircraft, should not degrade system performance or cause damage to the system.

In order to prevent the water in the system freezing during normal operation, a heating system or low-freeze additives may be required. However, due to their potential effects on occupants some low-freeze additives may not be feasible for use in a CWM system. Water heaters commonly used in the potable water system may be required.

It will be necessary to provide a means for prevention of freezing of the water causing damage to the system when the aircraft is parked in freezing conditions for extended periods. This may necessitate the provision of a drainage system or the system design being such that the water containers may be removed from the aircraft.

Consideration will need to be given to the effects on the system of exposure to elevated temperatures that may be encountered in ground soak conditions in high ambient temperature conditions. Air temperatures in some zones of the aircraft have been known to exceed 100° C.

4.2 SYSTEM INTEGRITY.

4.2.1 Fireworthiness.

Specification Requirement 10. The CWM system must be designed and installed so that the likely exposure of any system components to the effects of fire will not adversely affect the duration and safe operation of the system.

The above requirement is contained in the JAA NPA (see reference 3) as the proposed fireworthiness standard for the components of a CWM system. The NPA further suggests that the system components should be capable of withstanding the application of heat by a flame for a period of five minutes.

The time suggested for the application of heat is consistent with that suggested for system operation in section 4.1.5.1. However, some components may be subjected to intense heat from a ground pool fire. Subparagraph (j) of the Cabin Water Spray Systems – Framework for Advisory Material (see reference 10) suggested that a Zonal Safety Analysis should be carried out in order that a determination could be made of the effects on system components, likely to be exposed to the effects of fire, such that the resultant fire protection needed could be determined.

The Zonal Safety Analysis could result in certain system components needing to be qualified to a fireproof[3] standard or being protected to ensure safe operation in the presence of a pool fire.

Consideration should be given to the degradation in system performance resulting from its exposure to the intense heat generated in a ground pool-fire accident. Additionally the application of heat should not affect the safe operation of the system, e.g. by the water boiling in pipes, or present a hazard to the occupants due to the temperature of the water being sprayed. It is generally accepted that water temperatures above 50°C represent a risk of scalding. However, temperatures below this level should be considered as a maximum in the design of the CWM system. The UK Health and Safety Executive recommend that water temperatures in showers

[3] Fireproof: With respect to materials, components and equipment, means the capability to withstand the application of heat by a flame, for a period of 15 minutes without any failure that would create a hazard to the aircraft. The flame will have the following characteristics:
Temperature 1100ºC ±80ºC
Heat Flux Density 116 KW/m^2 ±10 KW/m^2
NOTE: For materials this is considered to be equivalent to the capability of withstanding a fire at least as well as steel or titanium in dimensions appropriate for the purposes for which they are used.(JAR 1 Definition)

are limited to a maximum of 44°C. The affects of a water mist system are likely to be different from a water spray system in terms of temperature affects on humans. Hence, an evaluation of this aspect will be required in order to determine that under the fire threat conditions likely to be encountered in a ground pool-fire accident, the CWM system does not have any unacceptable adverse physical or behavioural affects on occupants.

It is expected that a ground pool fire will subject the system to a more severe fire threat than is likely to be encountered in any in-flight fire. Hence, a system that meets a satisfactory standard of fireworthiness for the ground case is likely to be acceptable for the in-flight fire case.

4.2.2 Crashworthiness.

4.2.2.1 Separation of the Fuselage (Fuselage Breaks).

Specification Requirement 11. The CWM system must be designed and installed so that it will not be rendered inoperative after the most likely transverse vertical separations of the fuselage during crash landing.

4.2.2.1.1 Number of Breaks.

The above proposed requirement is similar to that contained in the JAA NPA (see reference 3) Subparagraph (h) which is as follows:

> "The Cabin Water Spray system must be designed and installed so that it will not be rendered inoperative after the most likely double transverse vertical separation of the fuselage during crash landing."

However, a study carried out for Transport Canada based on past accidents (see reference 11) concluded that:

> "……………the CWM system for aircraft, with a maximum certificated number of passenger seats of 19, up to around 30-40 only need to cater for one [fuselage] break. Above this size, and up to around 370-390, the system would need to cater for two fuselage breaks. Above this size, consideration would need to be given as to whether a CWM system might need to cater for three fuselage breaks."

Based on this study the required number of discrete areas of the cabin that are bounded by fuselage breaks would be as shown in table 1.

Table 1. Number of Discrete Areas of the Cabin Bounded by Fuselage Breaks for Aircraft of Varying Size

Aircraft Type Certificated Maximum Number of Seats	Number of Discrete Areas of the Cabin Bounded by Fuselage Breaks
19 to 30/40	2
30/40 to 370/390	3
370/390 and above	4

4.2.2.1.2 Location of Breaks.

The location of the breaks is dependent on the structural characteristics of the aircraft and the nature of the ground impact. As such, a determination would need to be made of their location by the airplane manufacturer.

However, a study of past accidents carried out by the FAA, Transport Canada and the UK CAA (see reference 8) concluded:

> "From a study of the break-up of aircraft in accidents it is concluded that a cabin water spray system of a 'crashworthy' design would be required. The system should cater for the most likely accident scenarios involving the fuselage breaking in front of and behind the wing."

Another study, of aircraft ground pool-fire accidents, carried out for the FAA (see reference 12) concluded:

> "Although no firm conclusions can be made, it is considered likely that approximately half of the Fuselage Breaks occur at a point of structural discontinuity."

4.2.2.1.3 Modular System.

Compliance with Specification Requirement 11 is likely to result in the CWM system being configured as a modular system (see section 4.1.6.1). A further conclusion from reference 11 was:

> "The results of this analysis imply that it is likely that a "modular system" would be required. A modular system would be configured such that all or part of the system would remain operable following breaks in the fuselage that might otherwise render a singular system inoperative. Such a system would have discrete supplies of water intended to enable continued operation following disruption of elements of the system."

Discrete supplies of water, power supplies (e.g., standalone power packs) and system activation devices (e.g., 'g' sensors) would need to be located such that the likelihood of their being available to supply their designated area of the cabin following fuselage rupture is optimised. The requirements of CS-25 state:

> "CS 25.1362 Electrical supplies for emergency conditions
>
> A suitable supply must be provided to those services, which are required, in order that emergency procedures may be carried out, after an emergency landing or ditching ……………………"

Specification Requirement 11 is also likely to result in the system being equipped with components such as frangible couplings or hydraulic fuses such that the occurrence of fuselage breaks does not completely disrupt the water supply to nozzles. Localised deformation and crushing of the fuselage may also need to be considered in terms of the potential effects on the CWM system. The distribution system should be sufficiently flexible to reduce the effects of flexing, compression and tension loads induced in the system as a result of the impact conditions.

4.2.2.2 Inertia Forces.

Specification Requirement 12. The CWM system must be capable of operation after having been subjected to the inertia forces specified in §§ 25.561 and 25.562

The JAA NPA (see reference 3) suggests:

Subparagraph (g)

> "The cabin water spray system must be capable of operation after having been subjected to the inertia forces listed in JAR 25.561(b)."

However, since the CWM system is intended for use in postcrash conditions, it may be that more stringent crashworthiness requirements need to be considered. It may be more appropriate that the system meets the crashworthiness standards reflected in 25.562 for the dynamic testing of occupant seats (other than flight crew [EASA requirement only]). This will ensure that the CWM system will operate satisfactorily under impact conditions that are deemed survivable to occupants. The CWM system will also need to meet the requirements of 25.789[4].

Consideration will also need to be given to any adverse effects on the performance of the Water Mist due to derangement of the cabin interior. Guidance on the Crashworthiness Standards appropriate to Cabin Interiors may be found in AC 25-17 Transport Airplane Cabin Interiors Crashworthiness Handbook (see reference 13). Any degradation in system performance and the loss of water mist coverage or duration, under post-impact crash conditions, should be agreed with the Airworthiness Authorities.

[4] Requirement 789 of 14 CFR Part 25, CAR 525 or CS-25

4.2.2.3 Engine Noncontainment.

The requirements of Part 25 state:

> "25.903 (d) Turbine engine installations. For turbine engine installations--
>
> (1) Design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure or of a fire originating within the engine which burns through the engine case."

Ideally, the CWM system equipment and components would be located outside of the specified engine debris zone for the aircraft. However, this may not be feasible for some aircraft. If this were the case, consideration would need to be given to any hazards resulting from their being struck by debris released from the engine e.g. the effects on other aircraft systems and equipment by the release of water.

4.2.2.4 Fuselage Orientation.

Specification Requirement 13. The CWM system must perform its intended function and provide protection to occupants taking into account the fuselage orientation likely to be encountered post-impact, when the aircraft is on a gradient and after the collapse of any one or more landing gear legs.

The above text is based on that contained in the JAA NPA (see reference 3). Extreme attitudes in pitch and roll may be encountered by sections of the fuselage in post-impact crash conditions. An inspection of the Cabin Safety Research Technical Group Accident Database (see reference 14) suggests that there are little data currently available on post-impact fuselage orientation. It is evident that in certain post-impact conditions sections of the fuselage could become inverted or inclined at extreme conditions. This is supported by the limited data contained in reference 14. However, the following recommendations are made regarding CWM operation in unusual fuselage orientations:

- The system meets the specified standard for a CWM system following the collapse of any one or more landing gear legs.

- It is recommended that a determination be made as to the likely system performance under varying pitch and roll angles beyond those achieved from the collapse of any one or more landing gear legs.

4.2.3 Failure to Operate When Required.

Specification Requirement 14. The probability of the CWM system becoming inoperable should be no worse than 10^{-3} per flight.

The above requirement is similar to that proposed in the JAA NPA (see reference 3) except that the probability target is expressed on a per flight basis rather than a per hour basis. This is because if the required target reliability were expressed on a per hour basis the probability of the CWM system being available in an accident would tend to be less for long range aircraft than for short range aircraft. This would seem inappropriate since it is considered that the availability of the system should be the same irrespective of flight duration.

A justification of the required probability target of 10^{-3} per flight, based on studies of past accidents carried out for Transport Canada as part of the Integrated Fire Protection system project, is contained in reference 11. This target reliability level should take into consideration flight operations with equipment inoperative (i.e. operating in accord with the Minimum Equipment List).

It was shown from a study of past accidents carried out for Transport Canada (see reference 15) that fuselage breaks occur in 50% of accidents that involve ground pool fires. Probabilistic assessments of the risk of fuselage breaks resulting in failure of the CWM system to operate are not considered appropriate due to the difficulty in characterising structural failure for the varying impact conditions that might be encountered in an accident. Section 4.2.2.1 addresses the required integrity of the CWM system to accommodate fuselage breaks and other structural failures. On this basis, it is considered that the 10^{-3} per flight target probability should exclude failure of the CWM system due to structural failure (e.g. breaks, deformation, crushing, etc).

Reference 11 suggests that:

> "Since the probability of an in-flight fire is significantly less than the rate of occurrence of survivable Ground Pool Fire accidents, 1.2 x 10^{-7} per aircraft landing, then the target probability of 10^{-3} [per flight] will provide adequate integrity for the in flight use of the system."

The reliability of the power supply and any other potentially dormant (latent) failures in the system should be taken into consideration during the safety analysis to determine compliance with the 10^{-3} per flight probability target.

4.2.4 Inadvertent Operation.

Specification Requirement 15. Inadvertent operation of the CWM system must be shown to be Extremely Remote[5].

The Extremely Remote[5] classification is normally appropriate to failure conditions that are classified as Hazardous[5] in accord with the Advisory Material to 25.1309. Although inadvertent operation of the system in the absence of a threat will not constitute a hazard to the aircraft per specification 3, the primary concern is the inconvenience caused to passengers and aircraft operators by nuisance operation. In order to ensure that inadvertent operation of the system occurs at an acceptably low frequency it should be designed and manufactured to a level of reliability commensurate with the Extremely Remote[5] classification—equivalent to a numerical target of 10^{-7} per aircraft hour or less.

[5] As defined in the Advisory Material to 25.1309

4.3 FIREFIGHTING ISSUES.

The JAA NPA (see reference 3) proposed the following Airworthiness Requirement:

> "Means must be provided to allow an external supply of water to be connected to the cabin water spray system. Access to these means should not be prevented by collapse of any one or more landing gear legs."

However, the ability of the firefighters to connect into a Water Mist system is considered unnecessary. As suggested in section 4.1.6.1 a Modular system is required with dedicated water supplies to cater for disruption of the system that might be caused by fuselage breaks. The modular system will continue to provide water to the majority of the nozzles, following disruption of the fuselage, for approximately 5 minutes, beyond which time it is unlikely that the evacuation of occupants will still be taking place. The addition of an external supply facility may also compromise the design of the CWM system since it is likely that it will be optimised in terms of working pressures and water quality to achieve the most effective protection for occupants.

For systems that would not be compromised in the manner suggested above, the provision of a means for allowing an external supply of water to be connected to the CWM system might be considered as proposed by the JAA requirement.

4.4 EFFECTS ON OCCUPANTS AND EVACUATION.

4.4.1 Occupants.

Specification Requirement 16. Operation of the CWM system must not present a hazard to occupants.

A number of potential physiological hazards were identified and examined by the International Cabin Water Spray Research Management Group (reference 16), as follows:

- Inhalation of Hot Moist Air—"Measurements taken during the wide body optimisation tests showed that the increase in water vapour content with time was similar for sprayed and unsprayed tests and was well below saturation at the higher temperatures. There is, consequently, no increase in hazard from this source."

- Inhalation of Particulate and Water Droplets—"The use of water spray was found to decrease greatly the amount of solid particles and liquid droplets capable of penetrating into the lungs, and also the irritants attached to them, thereby reducing the risk of lung damage. "Although a small amount of larger, non-respirable droplets in the smoke may have been due to the water spray, these had a low dissolved acid gas content and were considered unlikely to present any additional hazard."

- Hypothermia in Evacuees—"… medical advice is that the water spray will not increase the risk of hypothermia unless the victim is wet through to the skin, and the likelihood of this is considerably reduced in the case of a zoned system…"

The Eurofeu Position Paper on Water Mist for Firefighting Application (reference 17) states the following:

> "Human safety relating to the deployment of water mist in manned areas has been addressed by the US Environmental Protection Agency (E.P.A). A Medical Health Panel evaluated the water mist under the Significant New Alternatives Policy (SNAP) and the results were published in August 1995.
>
> The overall conclusion was that water mist using potable water is benign to nature and does not present a toxicological or physiological hazard to human beings and is thus safe for use in occupied areas."

However, as an integral part of the design process it is recommended that a risk assessment be carried out to verify that during normal and abnormal operation of the CWM system there are no hazards to personnel.

4.4.2 Evacuation.

Specification Requirement 17. Operation of the CWM system must not adversely affect the emergency evacuation capability of the airplane.

The above proposed requirement is contained in the JAA NPA (see reference 3) Subparagraph (i). Characteristics of a CWM system that may have the potential to affect adversely the emergency evacuation include the following:

- Visibility within the cabin
- Noise levels interfering with Cabin Attendant commands
- Escape Routes becoming wet
- Particulates from the fire mixing with water and obscuring escape path markings

Evacuation Trials carried out by Cranfield University on behalf of the UK CAA (see reference 18) addressed each of these factors. The conclusions from the trials include the following statement:

> "The results from the test programme suggest that, for the specific scenario investigated, the use of cabin water spray systems would not be likely to cause any significant adverse consequences for emergency evacuation of the aircraft."

However, the design of a CWM system should take all of these factors into account to ensure that it does not have significantly different characteristics from the system used in the Cranfield University trials.

4.5 MAINTENANCE.

Specification Requirement 18. A Maintenance Program must be developed such that the required levels of integrity and performance of the CWM system are ensured throughout the life of the aircraft.

The Maintenance Program for the CWM system is likely to be developed in accordance with ATA MSG-3 Operator/Manufacturer Scheduled Maintenance Development (see reference 19). The maintenance checks required will be dependent on the system design, but the MSG3 process and compliance with Part 25 requirements is likely to result in the following tasks:

- Checks for dormant failures—Operational Checks: In any design, it is likely that there will be failures that are not evident to the flight crew and maintenance checks will be required in order that they are identified and the appropriate rectification action is taken. The frequency of these checks must be such that the specified system reliability levels are maintained.

- Functional Checks: Checks of the CWM system will be required to ensure that it performs within the specified limits. The maintenance burden on the Operator will be reduced by ensuring that there is a suitable margin between the limits specified for satisfactory in-service performance and those limits used in the design and manufacture of the system.

Some guidance on the maintenance that may be required on the CWM system may be obtained from "NFPA 750—Standard on Water Mist Protection Systems" (see reference 2), however, it should be noted that this standard is not aircraft specific.

5. SUMMARY OF SPECIFICATION REQUIREMENTS.

6. REFERENCES.

1. Summary of the Feasibility Study for an Aircraft Integrated Fire Protection System, Prepared for Transport Canada, 0938/R/000388/KK, RGW Cherry & Associates Limited, March 2007.

2. NFPA 750: Standard on Water Mist Fire Protection Systems, US National Fire Protection Association, 2006.

3. Draft Notice of Proposed Amendment (NPA) to JAR 25 Cabin Water Spray Systems, Issue 2, May 1992, WP Ref: DSC/DRAFTNPA, Joint Aviation Authorities.

4. International Cabin Water Spray Research Management Group – Conclusions of Research Programme, CAA Paper 93012, United Kingdom: Civil Aviation Authority, June 1993.

5. Aircraft Cabin Water Spray Disbenefit Study, DOT/FAA/CT-92/6, United States Federal Aviation Administration, October 1993.

6. FAA Advisory Circular AC No: 120-80 In-Flight Fires, August 2004.

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14. The Cabin Safety Research Technical Group Accident Database, Version 27, Prepared for Transport Canada, the Federal Aviation Administration and the UK Civil Aviation Authority, RGW Cherry & Associates Limited, February 2006.

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18. Aircraft Evacuations: The Effect of a Cabin Water Spray System upon Evacuation Rates and Behaviour, CAA Paper 93012 United Kingdom: Civil Aviation Authority, March 1993.

19. ATA MSG-3 Operator/Manufacturer Scheduled Maintenance Development, Air Transport Association of America.