HALON REPLACEMENT FOR AIRPLANE CARGO COMPARTMENTS: THE CHALLENGES

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OBJECTIVE

This paper provides a comprehensive overview of the challenges for installing and certifying a safe, reliable, and economic cargo fire suppression system onto a large commercial airplane.

OVERVIEW

Large Commercial Airplanes currently use Halon 1301 as the cargo fire suppression agent. The aviation industry has been actively seeking a replacement agent and system since production of Halon 1301 ceased in 1994. To date, those efforts have been largely unsuccessful.

There are significant regulatory and technical challenges that an agent and/or system must overcome for it to be approved for airplane installations. These challenges must be clearly understood and comprehensively met prior to a replacement agent being approved for installation.

Airplane fire protection systems are fully integrated airplane systems that must comply with all agency regulations, must be robust enough to survive the airplane environment, must operate within specified parameters when an airplane cargo fire requires their functionality, and must be economical to operate. The requirements are a compilation of performance requirements for the agent, and regulatory and design requirements for the agent and system when installed onto the airplane. A schematic of a typical airplane cargo fire suppression system using Halon 1301 is shown in Figure 1.

Halon 1301 Background

Halon 1301 has been used on all Boeing Class C cargo compartment fire protection systems. Halon use has been prohibited by the Montreal Protocol except for critical use areas. The airplane industry is one of the last remaining industries still with a critical use exemption. Halon 1301 production has been banned in developed countries since 1994.

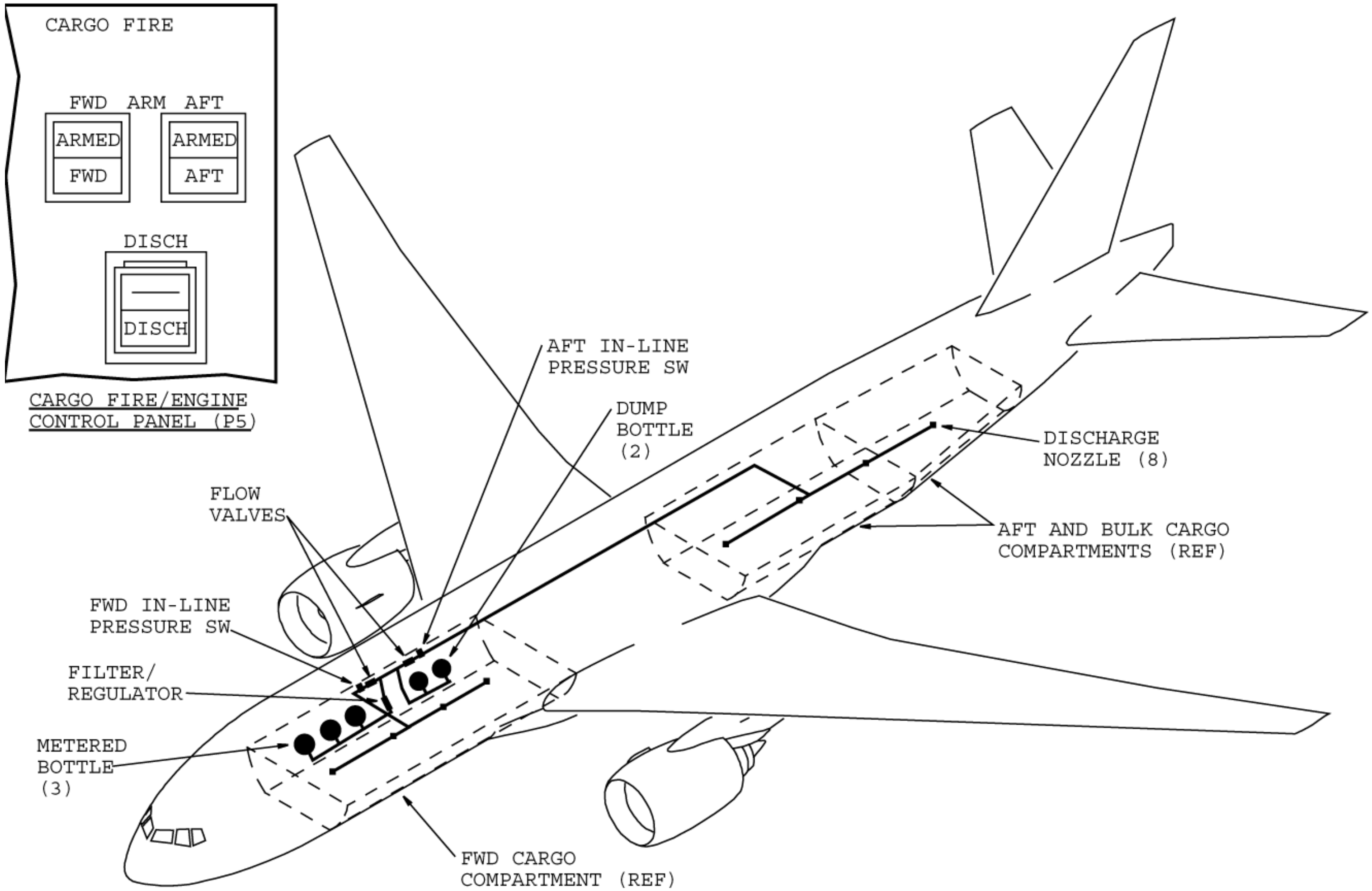

Figure 1. Typical Airplane Cargo Fire Suppression System Schematic.

REPLACEMENT STRATEGY

The first strategy was for fire suppression agent manufacturers to develop a “drop-in” replacement agent – an agent that had the same performance and physical characteristics as Halon 1301. While considerable effort has been expended in the development of potential replacement agents, a suitable “drop-in” agent has not been identified.
When it became apparent that an appropriate “drop-in” replacement agent would not be forthcoming, a phased process was implemented to work with fire suppression agent and system manufacturers on the development of viable replacement agent and/or systems. See Figure 2 for an overview of Boeing’s approach to this phased strategy. That strategy also did not result in a suitable replacement agent. See Table 1 for a summary of agents investigated.

The industry is currently developing new strategies to find a suitable replacement agent.

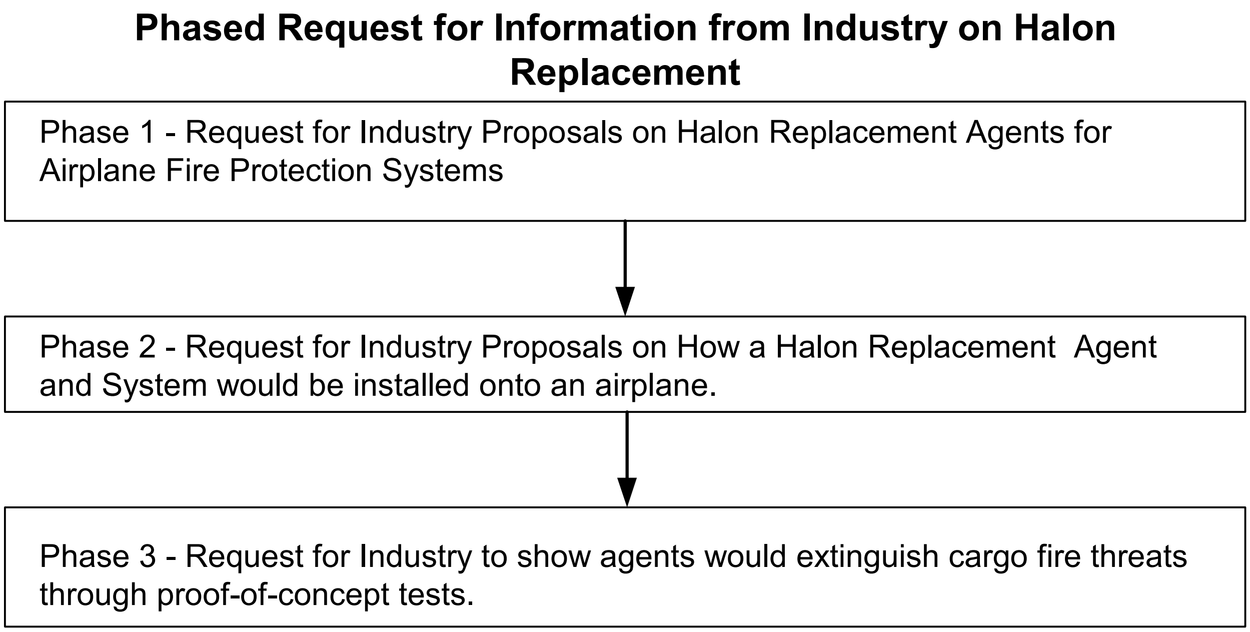

Figure 2. Phase Request for Cargo Fire Suppression Information.

Table 1. Cargo Fire Suppression - Halon Alternatives.

Agent	Type	MPS Status	Technical Issues
Halon 1301	Gas	Baseline	High Ozone Depletion Potential (ODP). Production Ceased.
Agent A	Solid Aerosol	Not tested	Failed corrosion testing. High temperature discharge onto cargo. Light residue requiring clean-up. Less weight than Halon.
Agent B	Solid Aerosol	Not tested	Failed corrosion testing. Less weight than Halon. Light residue requiring clean-up.
Agent/System C	Water mist/ nitrogen	Passed MPS	Complex temperature feedback system. MPS used long version of aerosol can test – Boeing designs to the short version of test. Development of new delivery system. Approximately 3 times weight of Halon system with temp feedback system, approximately 4+ times weight of Halon system with programmed discharge. Low temperature discharge issues.
Agent/System D	Water mist/ nitrogen	Not tested	
Agent E	Gas	Not tested	Tests demonstrate significant weight penalty (2x wt had no effect on fire). 4 times weight of Halon system.
Agent F	Gas (liquid at room temp – but vaporizes quickly)	Failed Preliminary MPS Tests	Failed Aerosol Can Explosion Test. Approx. 1.75 times the weight of a Halon 1301 system.
Agent G	Foam	Not Tested	Clean-up required. Low Temp Discharge not demonstrated. More than 10 times the weight of Halon.
HFC-125	Gas	MPS Tests Suspended	Lots of HF gas generated during fire suppression. At lower concentrations, acted as fuel for fire. High GWP. Approximately 4 times weight of Halon 1301.
CF3I	Gas	Not Tested	Minor corrosion concerns as gas. ODP at altitude. Cold temperature not as effective. Toxic after combustion at 2 ppm.

AGENT REQUIREMENTS

The intent of the design and regulatory requirements is to ensure the cargo fire suppression system performs its intended function under any foreseeable operating condition. Airplane Cargo Fire Suppression Systems using Halon 1301 as a suppression agent are required to provide 5 % minimum initial agent concentration, and 3 % minimum sustained agent concentration throughout the compartment until the airplane can land safely at the nearest suitable airport. See Figure 3 for a typical analysis showing that minimum concentrations are met. For each airplane, there must be sufficient fire suppression agent to provide continuous protection until the plane can land. On some airplanes, the nearest suitable airport may be three hours or more away. Any replacement agent and/or system must demonstrate a comparable level of protection.

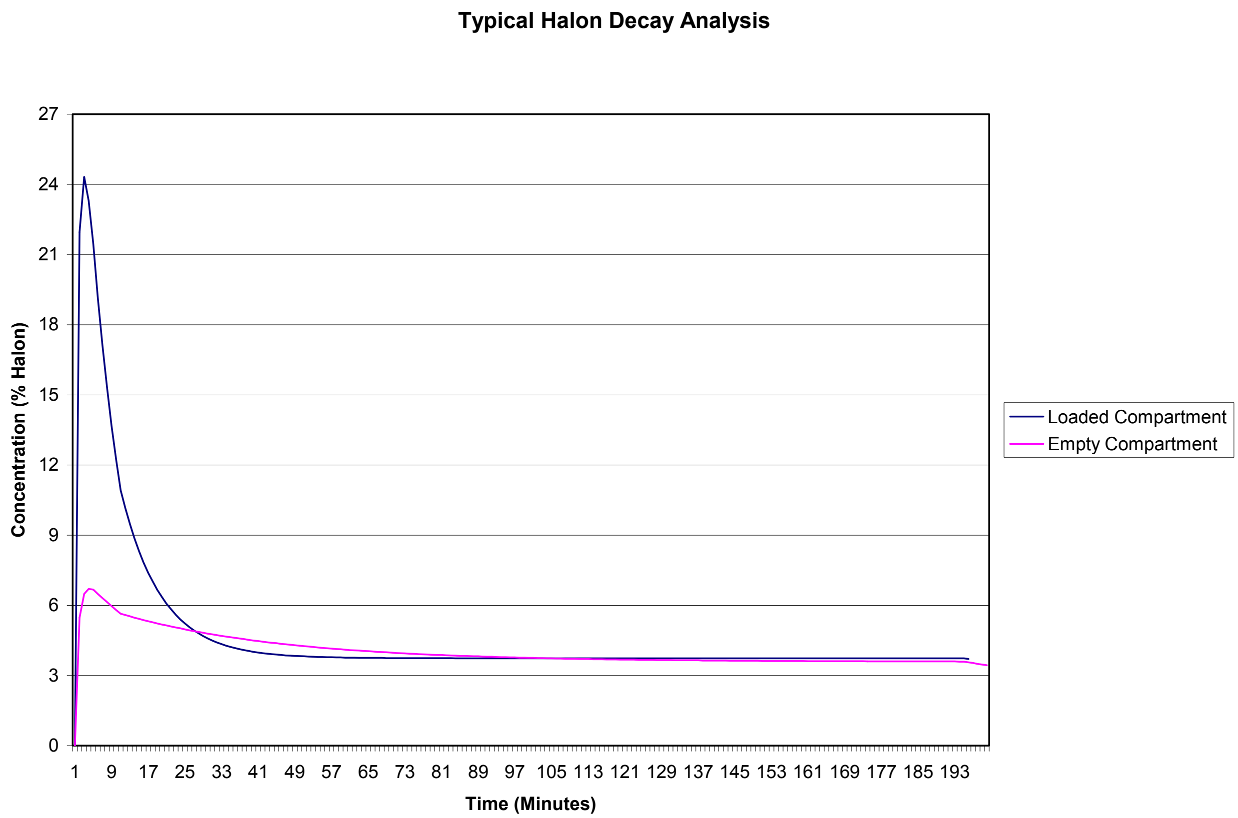

Figure 3. Typical analysis of a Cargo Suppression System Using Halon 1301.

Minimum Performance Standard

The Federal Aviation Administration's (FAA) Technical Center and the International Aircraft Systems Fire Protection Working Group have developed four fire types as representative of the cargo fires that an airplane cargo fire suppression system must provide continued safe flight and landing protection for (Ref. 1). Any replacement agent and/or system must perform to an equivalent level of suppression capability as Halon 1301 for each of these fire types. These four fire types are a Bulk Load Fire, a Containerized Fire, a Surface Burning (Jet A) Fuel Fire, and an Aerosol Can Explosion. These are representative of airplane cargo fires for which any replacement agent must be effective. They are not all inclusive of the fires that could occur.

SNAP Approval

Any replacement agent for use in airplane fire suppression systems must be SNAP (Significant New Alternatives Policy program) approved by the Environmental Protection Agency (EPA). The SNAP program is intended to ensure that any replacement agent represents an overall improvement in environmental performance.

Corrosion Requirements

Any replacement agent must not be corrosive to the airplane environment in which it is discharged. A discharged agent will not be completely contained within the cargo compartment and likely will find its way to electronic bays, typically adjacent to cargo compartments, and other areas where equipment sensitive to corrosive materials may be located. A gaseous agent is generally preferred because a gas will quickly dissipate, minimizing any corrosive effects of the agent. A liquid or solid agent may adhere to surfaces and is more difficult to remove resulting in long-term corrosion concerns.

Health and Safety

Fire protection equipment shall be designed to adequately protect from personnel injury due to moving parts, electrical shock, burns, high energy levels, and toxic and radiation emitting substances. Requirements include, but are not limited to, maximum surface temperature limits, flammability and toxicity requirements to an established standard acceptable to Boeing, and the safe containment of toxic substances during both normal and non-normal operating conditions. Toxicity must be considered for both the agent itself, and its by-products. Although the cargo compartment is not considered a normally occupied area, it is in close proximity to passengers. Cargo Handlers are present during cargo loading and unloading, and would evacuate the compartment for any accidental discharge via a cargo door or exit that is normally open anytime the compartment is occupied. However, their brief exposure to an initial discharge must be considered.

REGULATORY REQUIREMENTS

In addition to meeting the FAA's Minimum Performance Standards (MPS) to demonstrate its effectiveness, a replacement agent and system must meet applicable Federal Aviation Regulations (FAR's), Joint Aviation Regulations (JAR's) that are evolving into European Aviation Safety Authority (EASA) Certification Specification (CS) regulations, and other applicable aviation agency regulations. These regulations have been developed through years of experience and judgment, with safety paramount, to ensure continued safe flight and landing of the airplane. The primary regulations that address cargo fire suppression specifically are FARs (or CS) 25.851(b), 25.855 and 25.857(c).

Specific Regulations

FAR 25.851 requires that no agent likely to enter personnel compartments be hazardous to occupants; no discharge of agent can cause structural damage; and that any agent must be adequate for any fire likely to occur in the compartment where used considering the volume and ventilation rates. EASA requires that minimum concentration be met anywhere within the compartment.

FAR 25.855(h) requires flight test demonstrations of the system to show no hazardous quantities of agent enter occupied areas and to demonstrate the dissipation rates of any extinguishing agent. FAR 25.857(c) requires an approved cargo fire suppression system controllable from the flight deck.

There are other regulations that deal with airplane system design and integration for systems, such as FARs 25.869, 25.1301 and 25.1309 that specify other design safety and performance requirements.

Advisory Material

Associated with the regulations are Advisory Circulars (AC's) to provide regulatory guidance in the manufacture of the airplane and its systems, such as fire protection systems. The guidance material is intended to provide procedures and methods, but not the sole means, for the manufacturer to comply with the regulations. AC's that impact the design of airplane cargo fire suppression systems include AC 25.1309-1A and AC 120-42A.

AC 25.1309-1A, Systems Design and Analysis, describes various acceptable means for showing compliance with the requirements of FAR 25.1309(b), (c), and (d). These means are intended to provide guidance for the experienced engineering and operational judgment that must form the basis for compliance findings. They are not mandatory, though are typically used to show compliance. Other means may be used if they show compliance with this section of the FAR. This AC provides guidance on such items as the "Fail-Safe Design Concept," analysis of failure conditions, qualitative and quantitative assessments, and functional hazard assessments (FHAs).

AC 120-42A, Extended Range Operation with Two-Engine Airplanes (ETOPS), states an acceptable means, but not the only means, for obtaining approval under FAR Section 121.161 for airplanes to operate over a route that contains a point farther than 1-hr flying time at the normal one-engine inoperative cruise speed (in still air) from an adequate airport. Specific criteria are included for deviation of 75 min, 120 min, or 180 min from an adequate airport. This AC limits airplane range on two-engine airplanes to diversion time plus a 15-min holding and an approach and landing. There is a Notice of Proposed Rulemaking (NPRM DOT-FAA Docket No. 2002-6717, Notice No. 03-11) that will supersede AC 120-42A and codify the requirements into FAR 25.1535 for Production Certificates. Fire suppression systems are required to provide sufficient coverage for the diversion time of the airplane plus 15 minutes.

Airplane manufacturers design to meet these regulations and advisory material, as well as additional design requirements based on years of service experience and best design practices.

SYSTEM DESIGN REQUIREMENTS

A system installed within an airplane must meet specific performance requirements. Boeing cargo fire suppression system performance requirements include, but are not limited to

a. A specific extinguishing agent quantity discharge for initial discharge capability.
b. A specified rate of extinguishing agent discharge for a specified duration for continued suppression capability.
c. Performance within parameters when exposed to life cycle and fatigue testing.
d. Distribution of agent within a cargo compartment
e. Particle size distribution of a non-gaseous agent

System Certification

Prior to installation and delivery of an airplane fire protection system, the system must be certified as compliant to all pertinent regulatory requirements. The process for certifying a new system is typically developed in parallel with the design and component qualification processes.

A certification plan is presented and agreed to with the appropriate regulatory agencies. The certification plan defines the certification requirements for a system and should provide sufficient overall system detail and description so that all certification requirements can be adequately assessed and agreed to. The certification plan includes, but is not limited to, a detailed system description and operation, a functional hazard assessment (FHA), identification and means of compliance to each applicable regulatory requirement, minimum dispatch configuration, certification documentation, and a schedule.

Compliance to the regulations will typically require qualification of all equipment and components installed in the system and associated formal documentation, possibly system test demonstrations, Failure Modes and Effects Analyses (FMEAs), numerical safety analyses (NSA), and flight test demonstrations. Qualification and flight tests typically require conformity inspections to ensure the test and configuration are installed per drawing and the tests are properly conducted.

The design and certification of Halon 1301 airplane cargo fire extinguishing systems have a history from which the system design requirements have evolved and are in fair agreement between the industry and the regulatory agencies on most specifics. Any alternate agent to Halon 1301 has not been used on large commercial airplane cargo compartments, and its effectiveness for controlling a cargo fire would have to be validated prior to ultimate definition of performance and certification requirements. These performance and certification requirements would need to be validated at each step in the certification process.

The cargo fire suppression FARs require an airplane flight test be conducted to demonstrate extinguishing agent dissipation in Class C compartments and that minimum concentrations to ensure fire suppression are maintained for the required duration in the event of an actual cargo fire. The system is tested to ensure proper operation and to validate system performance parameters. The airplane is configured in a conservative configuration for retaining Halon within the compartment, the test is conducted, and the airplane cargo fire fighting procedure is followed. Analysis is performed, based on flight test results, to demonstrate minimum Halon concentrations are also met for all cargo loading configurations.

Minimum agent concentration requirements are based on test results conducted by industry and the FAA and the other regulatory agencies. There is no FAR or advisory material specifying what minimum Halon concentrations are required, except in one option in AD 93-07-15, Amendment 39-8547, which defines minimum Halon 1301 concentrations for one of the design options for a main deck Class B cargo compartment. The 5% knockdown and 3% sustained Halon 1301 concentrations have been the accepted standard for airplane cargo fire suppression systems.

COMPONENT DESIGN REQUIREMENTS

Airplane cargo Fire Protection Systems are comprised of components integrated into a system. All components installed in the airplane, including components installed in the fire protection systems, are subjected to rigorous, controlled qualification test procedures to demonstrate the equipment's airworthiness. These tests ensure that each component is sufficiently robust to withstand the airplane operating environment in which it is installed and is able to perform within specified parameters when needed. Any new equipment must undergo formal qualification tests that demonstrate compliance to regulations and additional engineering tests to ensure any non-regulatory design requirements are met.

Environmental Requirements

Equipment installed in Boeing airplanes must survive and operate in a broad range of environments. The airplane may fly into and be stored in desert or in arctic conditions. It may be cold-soaked or heat-soaked. The airplane may not be at ambient, normally comfortable conditions prior to its required operation. Boeing therefore imposes strict tests representative of the environmental conditions the airplane is exposed to both for storage and for operating conditions. For fire protection equipment inside the pressurized areas of the airplane include, the environmental requirements include but are not limited to, temperature extremes (Table 2), altitude extremes (Table 3), continuous humidity, exposure to fluids, salt spray, and fungus. Equipment may be exposed to such fluids as hydraulic fluid, lubrication oil, cleaning solvents, de-icing fluid, fire extinguishing agent, insecticides, and sullage (waterborne dirt).

Table 2. Operational and Non-operational Environmental Temperature Limits.

Low temperature: survival (non-operating)	-55 ^{o}C
Low temperature: short-term operation	-40 ^{o}C
Low temperature: continuous operation	-15 ^{o}C
High temperature: survival (non-operating)	85 ^{o}C
High temperature: continuous operation	70 ^{o}C

Table 3. Operational Pressure Altitude Limits.

Normal operation	-2,000 to 10,000 ft
Design limit for functioning properly	25,000 ft continuous, 43,000 ft transient (rapid decompression)

Structural Requirements

An airplane may experience routine shock and vibration exposure. Equipment, such as fire protection systems, must be able to withstand continuous exposure to the shock of handling and dynamic loads. These handling and dynamic loads include, but are not limited to, mechanical shock, bench handling drop, shipping container handling drop, vibration, acceleration, and airplane operating attitude. The vibration test is typically a sinusoidal scan and five hour random vibration in a specified spectrum in each of three perpendicular axes. The vibration tests are several times the normal airplane vibration in order to provide assurance during the test of adequate component integrity when exposed to normal vibration levels over the life of the airplane. The vibration spectrum varies based on location in the airplane.

Electrical Requirements

For fire protection systems, Boeing electrical requirements include, but are not limited to, ac and dc power characteristics, normal and abnormal steady-state and transient characteristics, voltage transients and spikes, electrostatic discharge susceptibility, radio frequency susceptibility, lightning induced transients, power quality, electromagnetic induction, and grounding.

BIT Requirements

Current state-of-the-art airplane systems require continuous built-in test (BIT) monitoring to provide operational integrity status of electrical equipment.

Software

If equipment contains software, that software must be qualified independently of the hardware with its own qualification plan and documentation.

Component Reliability

The overall cargo fire protection system, to demonstrate compliance to FAR 25.1309(b), must provide a numerical analysis that an uncontrolled fire (an undetected and/or unsuppressed in-flight fire) is extremely improbable (less than 10^{-9} probability of an event per flight hour). An airplane integrated cargo fire extinguishing system (high rate discharge and metering systems and associated wiring and control) must reliably provide adequate fire suppression at minimum concentration levels. To support that requirement, a failure modes and effects analysis (FMEA) must be developed to demonstrate the replacement agent's system itself functions reliably. A comprehensive numerical analysis must be provided to substantiate component and system reliability.

GENERAL MAINTENANCE REQUIREMENTS

Cargo fire extinguishing systems are located inside pressurized areas of the airplane. General Boeing maintenance requirements for these systems include, but are not limited to

a. No predetermined (scheduled) maintenance intervals on components, only airplane maintenance schedules apply.
b. No piece parts or assemblies with definite life limits less than airplane life expectancy.
c. No on-airplane adjustments.
d. No more than one mechanic for on-airplane maintenance and servicing.
e. Only "common" tools for on-airplane maintenance.

SUMMARY

Finding a viable alternative to Halon 1301 is an extremely difficult task. A drop in replacement has not been identified. The alternate agents investigated need further development to meet all requirements and be airplane compatible.

Minimum agent concentrations for any replacement agent, both for the initial high rate discharge and the follow-on sustained concentrations, are determined from the MPS test results. Any new cargo fire suppression system, using a replacement agent, will have rigorous development and qualification tests, then demonstrate minimum performance standards via flight test to be successful.

Any alternate agent must successfully pass the MPS, the airplane certification requirements, and the airplane manufacturer's requirements. It will take a concerted effort by the regulatory agencies, the agent suppliers, the systems suppliers, and the airplane manufacturers to find a successful replacement agent.

ACKNOWLEDGEMENTS

On behalf of the Boeing Company, I would like to extend our gratitude to the organizers and sponsors of the Halon Options Technical Working Conference for providing a forum for the technical exchange of Halon replacement developments; to the FAA for taking a leadership role and their time and resources, in finding a replacement agent to Halon 1301; to the fire protection agent and system suppliers working earnestly to find a replacement agent; and, finally, to my colleagues within the Boeing Company for their support in finding a viable replacement agent.

REFERENCE

1) FAA Report DOT/FAA/AR-00/28, Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Fire Suppression Systems.