Minimum Performance Standard for Aircraft Cargo Compartment Halon Replacement Fire Suppression Systems

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16. Abstract

This technical note presents the updated version of the minimum performance standards (MPS) that a Halon 1301 replacement or alternate system for aircraft cargo compartment must meet as part of the aircraft certification procedures. This standard considers gaseous and nongaseous fire suppression systems for full-scale fire testing. The Federal Aviation Administration developed this MPS in conjunction with the International Aircraft Fire Protection Systems Working Group (formerly know as the International Halon Replacement Working Group).

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Page v, last paragraph: **CHANGE:** For the bulk load fire scenario, the average of the 5 tests peak temperatures shall not exceed 720°F (382°C) starting 2 minutes after the suppression system is initially activated until the end of the test (28 minutes later or diversion time, whichever is longer). In addition, the average of the 5 tests peak areas under the time-temperature curve shall not exceed 9,940°F-min (5,504°C-min). The area should be computed from 2 minutes (t_3) after the time of initial suppression system activation (t_2) to 28 minutes after t_3.

Page vi, second paragraph: **CHANGE:** For the containerized-load fire scenario, the average of the 5 tests peak temperatures shall not exceed 650°F (343°C), starting 2 minutes after the suppression system is initially activated until the end of the test (28 minutes later or diversion time, whichever is longer). The average of the 5 tests peak areas under the time-temperature curve shall not exceed 14,040°F-min (7,782°C-min). The area should be computed from 2 minutes (t_3) after the time of initial suppression system activation (t_2) to 28 minutes after t_3.

Page vi, third paragraph: **CHANGE:** For the surface-burning fire scenario, the average of the 5 tests peak temperatures shall not exceed 570°F (299°C) starting 2 minutes (t_3) after the suppression system is initially activated until the end of the test, 3 minutes after t_3. In addition, the average of the 5 tests peak areas under the time-temperature curve shall not exceed 1230°F-min (665°C-min) for the same period mentioned in the previous sentence.

Page 10, fifth paragraph: **CHANGE:** The acceptance criteria for the bulk load fire scenario is that the average of the 5 tests peak temperatures shall not exceed 720°F (382°C), starting 2 minutes after the suppression system is initially activated until the end of the test. In addition, the average of the 5 tests peak areas under the time-temperature curve of the compartment thermocouples shall not exceed 9,940°F-min (5,504°C-min). The area is computed from 2 minutes after the time of initial suppression system activation until the end of the test (30 minutes after the agent was discharged).

Page 10, sixth paragraph: **CHANGE:** The criteria for the containerized-load fire scenario is that the average of the 5 tests peak temperatures shall not exceed 650°F (343°C), starting 2 minutes after the suppression system is initially activated until the end of the test. The average of the 5 tests peak areas under the time-temperature curve shall not exceed 14,040°F-min (7,782°C- min). The area is computed from 2 minutes after the time of initial suppression system activation until the end of the test (30 minutes after the agent was discharged).

Page 10, seventh paragraph: **CHANGE:** The acceptance criteria for the surface-burning fire scenario is that the average of the 5 tests peak temperatures shall not exceed 570°F (299°C) starting 2 minutes after the suppression system is initially activated until the end of the test (5 minutes after the agent was discharged). In addition, the average of the 5 tests peak areas under the time-temperature curve shall not exceed 1230°F-min (665°C-min) over the 5-minute interval following agent discharge.

Page 11, second paragraph: **CHANGE:** For systems tested using the diversion time (instead of the 30 minutes), the average peak temperature is determined by using the collected data that is between 2 minutes after discharging the agent and the diversion time. The average of the 5 tests peak temperatures shall not exceed the values presented in table 1. For the peak area under the time-temperature curve, the 2- to 28-minute boundaries and criteria apply.

Page 11, third paragraph: **CHANGE:** Five tests must be conducted for each scenario. The peak temperature and area under the time-temperature curve must be determined for each test, the 5 tests peaks shall be averaged and compared to the acceptance criteria values (pass/fail); to pass the MPS tests, the average of the new agent performance values shall not exceed the acceptance criteria values provided in table 1. Table 1 summarizes the acceptance criteria for the four fire tests.

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EXECUTIVE SUMMARY

This technical note establishes the minimum performance standard (MPS) that a Halon 1301 replacement aircraft cargo compartment fire suppression system must meet. It describes the tests that shall be performed to demonstrate that the performance of the replacement agent and system provides the same level of safety as the currently used Halon 1301 system. The results of these tests will be used to determine the required concentration levels to adequately protect an aircraft cargo compartment against fire and hydrocarbon explosions. The Supplemental Type Certificate (STC) applicant shall provide the minimum agent protection concentration, density, etc., to the Federal Aviation Administration (FAA) Aircraft Certification office with an objective way of measuring it. Currently, the FAA Transport Airplane Directorate, in conjunction with the Joint Aviation Authority, is developing an advisory circular to address the certification of aircraft cargo compartment fire extinguishing or suppression system.

This MPS was developed in conjunction with the International Aircraft Fire Protection Systems Working Group (IAFPSWG), formerly known as the International Halon Replacement Working Group. Consensus amongst the IAFPSWG members was reached on three out of the four tests protocols presented in this document; some members objected to the long version of the aerosol can simulator explosion test. Appendix A explains the objections to the long version of the fourth protocol. The two versions, both long and short, of the explosion test are published in this document. While the FAA will accept either version of the aerosol can simulator explosion test as an acceptable means to test a new agent or system, other entities in the IHRWG will not. The STC applicant is encouraged to consult with his or her customer to determine which version they prefer. The MPS discussed in this technical note replaces the standard reported in FAA Technical Report DOT/FAA/AR-00/28, Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Fire Suppression Systems.

The four different MPS fire test scenarios that new cargo compartment fire suppression systems must meet are bulk-load fire, containerized fire, flammable liquid fire (surface burning), and an aerosol can explosion. The bulk-load and containerized-load fires, which are deep-seated fire scenarios, use shredded paper loosely packed in cardboard boxes to simulate the combustible fire load. The difference between these two tests is that in the containerized fire load the boxes are stacked inside an LD-3 container, while in the bulk-load fire scenario the boxes are loaded directly into the cargo compartment. The surface-burning test (Class B fire) uses 0.5 U.S gallon (1.89 liters) of Jet A as fuel. The aerosol explosion tests are executed by using an aerosol can simulator containing a flammable and explosive mixture of propane, alcohol, and water. This mixture ignites or explodes when it is exposed to an arc from sparking electrodes. At least five tests per MPS scenario must be conducted. These tests shall be performed in a 2000 ft^3 simulated aircraft cargo compartment.

The suppression performance of a new agent, once the data is collected and analyzed, is then compared with the standard acceptance criteria to determine if it passes or fails the fire tests. None of the peak temperatures and areas under the time-temperature curves may exceed the values specified in the acceptance criteria table. The acceptance criteria are as follows:

- For the bulk-load fire scenario, none of the ceiling or sidewall thermocouples shall exceed 720°F (382°C), starting 2 minutes after the suppression system is initially

activated until the end of the test (28 minutes later or diversion time, whichever is longer). In addition, the area under the time-temperature curve, for each compartment ceiling thermocouple, shall not exceed 9,940°F-min (5,504°C-min). The area should be computed from 2 minutes (t_3) after the time of initial suppression system activation (t_2) to 28 minutes after t_3.

- For the containerized-load fire scenario, none of the ceiling or sidewall thermocouples shall exceed 650°F (343°C), starting 2 minutes after the suppression system is initially activated until the end of the test (28 minutes later or diversion time, whichever is longer). The area under the time-temperature curve shall not exceed 14,040°F-min (7,782°C-min). The area should be computed from 2 minutes (t_3) after the time of initial suppression system activation (t_2) to 28 minutes after t_3.

- For the surface-burning fire scenario, none of the ceiling or sidewall temperatures shall exceed 570°F (299°C), starting 2 minutes (t_3) after the suppression system is initially activated until the end of the test, 3 minutes after t_3. In addition, the area under the time-temperature curve shall not exceed 1230°F-min (665°C-min) for the same period mentioned in the previous sentence.

- For the aerosol can scenario, no evidence of an explosion shall be present in the compartment at the time the simulator is activated, such as no overpressure (0.0 psig) or deflagrations.

Appendix B presents a table showing how the acceptance criteria values were determined based on the Halon 1301 test data. Appendix C illustrates the aerosol can simulator drawings.

1. INTRODUCTION.

Federal Aviation Regulations (FARs) and Joint Airworthiness Requirements (JARs) require fire suppression systems for some classifications of cargo compartments. In the past, the aircraft industry selected Halon 1301 total flood fire suppression systems as the most effective means for complying with the regulations. Because of the ban on production of Halon 1301 (effective January 1994, as mandated by the Montreal Protocol), new fire suppression systems will need to be certified when Halon 1301 is no longer available. The tests described in this standard are one part of the total Federal Aviation Administration (FAA) and the Joint Aviation Authority (JAA) certification process for cargo compartment fire suppression systems. Compliance with other applicable regulations, some of which are listed below, is also required. Applicants attempting to certify replacement systems are encouraged to discuss the required process with regulatory agencies prior to conducting testing. Currently, the FAA Transport Airplane Directorate, in conjunction with the JAA, is developing an advisory circular to address the certification of aircraft cargo compartment fire extinguishing or suppression system employing halon replacement agents.

The following existing FARs/JARs pertain to cargo compartment fire suppression systems: 14 CFR Part 25.851 [Doc. No.5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-54, 45 FR 60173, Sep. 11, 1980; Amdt. 25-72, 55 FR 29783, Jut. 20, 1990; Amdt. 25-74, 56 FR 15456, Apr. 16, 1991] "(b) Built-in fire extinguishers. If a built-in fire extinguisher is provided-

(1) Each built-in fire extinguishing system must be installed so that-

(i) No extinguishing agent is likely to enter personnel compartments will be hazardous to the occupants; and

(ii) No discharge of the extinguisher can cause structural damage.

(2) The capacity of each required built-in fire extinguishing system must be adequate for any fire likely to occur in the compartment where used, considering the volume of the compartment and the ventilation rate."

14 CFR Part 25.855 [Doc. No.5066, 29 FR 18291. Dec. 24, 1964, as amended by Amdt. 25-15, 32FR 13266, Sep. 20, 1967; Amdt. 25-32, 37 FR 3972, Feb. 24, 1972; Amdt. 25-60, 51 FR 18242, May 16, 1986; Amdt. 25-72, 55 FR 29784, Jut. 20, 1990; Amdt. 25-93, 63 FR 8048, Feb. 17, 1998] "(h) Flight tests must be conducted to show compliance with the provisions of Sec. 25.857 concerning-

(1) Compartment accessibility,

(2) The entries of hazardous quantities of smoke or extinguishing agent into compartments occupied by the crew or passengers, and

(3) The dissipation of the extinguishing agent in Class C compartments.

(i) During the above tests, it must be shown that no inadvertent operation of smoke or fire detectors in any compartment would occur as a result of fire contained in any other compartment, either during or after extinguishment, unless the extinguishing system floods each such compartment simultaneously."

14 CFR Part 25.857 [Doc. No.5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-32, 37FR 3972, Feb. 24, 1972; Amdt. 25-60, 51 FR 18243, May 16, 1986; Amdt. 25-93, 63 FR 8048, Feb. 17, 1998] "(c) Class C. A Class C cargo compartment is one not meeting the requirements for either a Class A or Class B compartment but in which-

(1) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station.

(2) There is an approved built-in fire extinguishing or suppression system controllable from the cockpit;

(3) There are means to exclude hazardous quantities of smoke, flames, or extinguishing agent, from any compartment occupied by the crew or passengers;

(4) There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment."

In addition to these regulations, the FAA issued Airworthiness Directive (AD) 93-07-15 that required, among other things, that after November 2, 1996, the Class B cargo compartments on Boeing Models 707, 727, 737, 747, and 757 and McDonnell Douglas Models DC-8, DC-9, and DC-10 series airplanes have improved fire protection features. One of three options available to comply with this AD is to modify Class B cargo compartments on these airplanes to comply with the requirements for Class C compartments. This option would require the installation of a fire suppression system.

One other area of rulemaking activity relating to cargo compartment suppression system requirements is the "Revised Standards for Cargo or Baggage Compartments in Transport Category Airplanes, Final Rule," amendments 25-07, and amendments 121-269 effective March 19, 1998. This rule eliminates Class D cargo compartments on newly certified aircraft under 14 CFR Part 25 and requires existing Class D compartments on 14 CFR Part 121 certified passenger aircraft to comply with the detection and suppression/extinguishing system aspects of Class C cargo compartment requirements by March 19, 2001. This rule was issued by the FAA and at this time applies only to aircraft operated by U.S.-based airlines.

2. SCOPE.

This document establishes the minimum performance standard (MPS) that a cargo compartment halon replacement fire suppression system must meet. It describes the tests that shall be performed to demonstrate that the performance of the replacement agent and systems equals the performance of the currently approved Halon 1301 systems.

3. AGENT SELECTION GUIDANCE.

3.1 ENVIRONMENTAL.

The replacement agent must be approved under the U.S. Environmental Protection Agency (EPA), Clean Air Act, Significant New Alternatives Policy (SNAP) program, or other international governmental approving programs. The primary environmental characteristics to be considered in assessing a new agent are Ozone Depletion Potential (ODP), Global Warming Potential (GWP), and Atmospheric Lifetime. The agent selected should have environmental characteristics in harmony with international laws and agreements, as well as applicable local laws. This MPS sets out the means of assessing the technical performance of potential alternatives. In selecting a new agent, it should be noted that an agent which does not have a zero or near-zero ODP, and the lowest practical GWP and Atmospheric Lifetime may have problems in terms of international availability and commercial longevity.

3.2 TOXICOLOGY.

The toxicological acceptability of an agent is dependent on how it is used. As a general rule, the agent must not pose an unacceptable health hazard for workers during installation and maintenance of the suppression system. At no time should the concentration present an unacceptable health hazard in areas where passengers or workers are present or where leakage could cause an agent to enter an occupied area. Following the release of the agent during fire suppression, the cumulative effect of the agent, its pyrolytic breakdown products, and the by-products of combustion must not pose an unacceptable health hazard.

14 CFR Parts 25.851, 25.855, and 25.857 all address the issue of hazardous quantities of smoke, gas, or extinguishing agent in occupied compartments. The fire tests described in this MPS do not address these issues.

4. TEST REQUIREMENTS.

4.1 TEST CELL (CARGO COMPARTMENT).

The fire tests are conducted inside a simulated, below-floor cargo compartment of a wide-body aircraft. The volume of the compartment is 2000 ±100 cubic feet (56.6 ±2.8 m^3), see figure 1. The leakage rate from the compartment is 50 ±5 cubic feet per minute (1.4 ±0.14 cubic meter per minute). The leakage from the compartment is configured to simulate the U shape of the cargo door seals that would exist on an actual aircraft. This can be done by installing perforated ducts inside the compartment in the shape of the perimeter of a cargo door and then venting those ducts outside the test article. A variable speed fan installed in the exit of the duct draws air out of the compartment. One-inch-diameter holes spaced at 5-inch (12.7-cm) intervals in a round, 4-inch-diameter steel duct has been shown to be effective. The perforated ducts are installed on the side of the cargo compartment opposite the ignition box for the bulk-load and containerized-load fire scenarios. The return air that goes back into the compartment should be evenly distributed and not from anyone location.

4.2 INSTRUMENTATION.

Temperature measurements are taken throughout the cargo compartment. Type K chromel/alumel 22-gauge thermocouples have been found to be effective at measuring temperatures in the range these fire scenarios produce. Ceiling thermocouples are evenly spaced along the compartment ceiling at 5-foot intervals. One of the ceiling thermocouples is installed directly above the initial ignition location for all fire scenarios. The beads of the ceiling thermocouples are 1 inch (2.5 cm) below the compartment ceiling. At least one thermocouple is placed on the compartment sidewall 1 foot below ceiling level and centered on the fire ignition location. The sidewall thermocouple is installed on the compartment wall nearest to the ignition location. At least two additional thermocouples are placed in and above the box containing the igniter for the bulk and containerized fire scenarios. The purpose of these two thermocouples is to monitor and verify the ignition of the boxes. The readings are not part of the acceptance criteria. Care should be taken to prevent these thermocouples from contacting the energized coil of the nichrome wire.

A continuous gas analyzer with a real-time display of the gas (extinguishing agent) volumetric concentration is required for the aerosol can scenario when the suppression system is a gaseous total flood system (short-test version). A continuous gas analyzer may also be required, depending on the suppression system design, for the bulk-load and containerized-load fire scenarios. The accuracy of the analyzer shall be ±5% of the reading. The gas analyzer is used to measure the concentration of the gaseous suppression agent. The data-sampling rate for all the temperature measurements and the gas concentrations should be at least one data point every 5 seconds.

A pressure transducer is also required for the aerosol can fire scenario. The maximum transducer pressure range is 0-50 psig. The minimum frequency response of the transducer is 3000 Hz. Omega® manufactures several transducers suitable for this application. The transducer is mounted on the ceiling in the geometric center of the compartment. The data-sampling rate for the pressure transducer is at least 3000 data points per second.

4.3 FIRE SCENARIOS.

The aircraft cargo compartment fire suppression system must successfully control the following four fire scenarios. Five replicate tests are required for each fire test scenario.

4.3.1 Bulk-Load Fire.

The fire load for this scenario consists of single-wall corrugated cardboard boxes, with nominal dimensions of 18 x 18 x 18 inches (45.7 x 45.7 x 45.7 cm). The weight per unit area of the cardboard is 0.11 lbs/ft^2 (0.5417 kg/m^2). The boxes are filled with 2.5 pounds (1.1 kg) of shredded office paper, loosely packed without compacting. The standard weight office paper is shredded into strips, not confetti. The weight of a filled box is 4.5 ±0.4 lbs. (2.0 ±0.2 kg). The boxes are conditioned to room standard conditions. The flaps of the boxes are tucked under each other without using staples or tape. The boxes are stacked in two layers in the cargo compartment in a quantity representing 30% of the cargo compartment empty volume. For a 2000-cubic-foot (56.6 m^3) compartment, this requires 178 boxes. The boxes touch each other to prevent any significant air gaps between boxes. The fire inside the ignition box is started by applying 115 Vac to a 7-foot (2.1-m) length of nichrome wire. The wire is wrapped around four folded (in half) paper towels. The resistance of the nichrome igniter coil is approximately 7 ohms. The igniter is placed into the center of a box on the bottom outside row of the stacked boxes. Several ventilation holes are placed in the side of the box to ensure that the fire does not self-extinguish. Ten 1.0-inch (2.5-cm) -diameter holes have been shown to be effective (see figures 2 and 3).

4.3.2 Containerized-Load Fire.

The same type of paper-filled cardboard boxes and the same type of igniter as used in the bulk-load fire scenario is used in this scenario. The boxes are stacked inside an LD-3 container as shown in figure 4. The boxes touch each other to prevent any significant air gaps between them. The container is constructed of an aluminum top and inboard side, a Lexan (polycarbonate) front, and the remainder of steel. Two rectangular slots for ventilation are cut into the container in the center of the Lexan front and in the center of the sloping sidewall. The slots are 12 by 3 ±1/4 inches (30.5 x 7.6 ±0.6 cm) (see figure 5). The igniter is placed in a box on the bottom row, in the center column next to the sloping side of the container. Ventilation holes are placed on the front face of the box facing the ventilation hole. Ten 1.0-inch (2.5-cm) -diameter holes have been shown to be effective. Two additional empty LD-3 containers are placed adjacent to the first container (see figure 6).

4.3.3 Surface-Burning Fire.

One-half U.S. gallon (1.9 liters) of Jet A fuel in a square pan is used for this scenario. The pan is constructed of 1/8-inch (0.3-cm) steel and measures 2′ by 2′ by 4″ high (60.9 x 60.9 x 10.2 cm). Approximately 13 fluid ounces (385 ml.) of gasoline should be added to the pan to make ignition easier. Two and one-half gallons (9.5 liters) of water placed in the pan has been found to be useful in keeping the pan cool and minimize warping. This quantity of fuel and pan size is sufficient to burn vigorously for approximately 4 minutes if not suppressed. The pan should be positioned in the cargo compartment in the most difficult location for the particular suppression system being tested. The pan is located 12 inches below the cargo compartment ceiling if the suppression system uses a gaseous agent with a density greater than air at standard pressure and temperature (14.7 psia (101.3 kPa), 59.0°F (15°C)). The pan is 12 inches (30.5 cm) above the floor of the compartment if the suppression system uses a gaseous agent with a density less than air at standard pressure and temperature. The pan is placed in the compartment at mid height when the suppression agent has a density equal to that of air. The pan is located at the maximum horizontal distance from any discharge nozzles for all tests, regardless of the suppression agent used (see figure 7).

4.3.4 Aerosol Can Explosion.

This scenario addresses the hazards of an exploding aerosol can during an aircraft cargo compartment fire. This test protocol uses a modified version of the bulk-load fire test scenario to determine the activation time of the aerosol can simulator. Based on experiments with aerosol cans subjected to fires, the FAA William J. Hughes Technical Center developed an aerosol can simulator (figures 8 and C-1) that releases a mixture of propane and alcohol through a large-area valve and across sparking electrodes [1]. This specific test protocol may be substituted with the shorter protocol version specified in section 4.3.5. For example, the short-test protocol version may be used with gaseous fire suppression agents or if the system does not have unique capabilities, such as thermodynamic cooling that would need to be demonstrated during a fire test.

The cargo compartment is loaded with corrugated cardboard boxes, galvanized steel pipes, and the aerosol can simulator. Each box is a single-wall corrugated cardboard box, with nominal dimensions of 18 x 18 x 18 inches (45.7 x 45.7 x 45.7 cm). The weight per unit area of the cardboard is 0.11 lbs/ft^2 (0.5417 kg/m^2). The boxes are filled with 2.5 pounds (1.1 kg) of shredded office paper, loosely packed without compacting. The standard weight office paper is shredded into strips, not confetti. The weight of a filled box is 4.5 ±0.4 lbs. (2.0 ±0.2 kg). The flaps of the boxes are tucked under each other without using staples or tape. The boxes are stacked in two layers in the cargo compartment in a quantity representing about 10% of the cargo compartment empty volume. For a 2000-cubic-foot (56.6-m^3) compartment, this requires 58 boxes. The boxes touch each other to prevent any significant air gaps between boxes. The boxes are arranged as shown in figure 9. Three galvanized steel pipes, with a thermocouple attached to the outer surface (centered) of each pipe, is inserted (one per box) in the boxes adjacent to the box above the ignition box. The schedule 80 pipes are 8.25" (20.96 cm) long and have an outer diameter of 1.75″ (4.45 cm). The main function of the three galvanized steel pipes is to hold the thermocouples in place rather than simulating the heating of an aerosol can. The fire in the box is initiated by applying 115 Vac to a 7 foot (2.1 m) length of nichrome wire. The wire is wrapped around four folded (in half) paper towels. The resistance of the nichrome igniter coil is approximately 7 ohms. The igniter is placed into the center of a box on the bottom outside row of the stacked boxes. Several ventilation holes are placed in the side of the box to ensure that the fire does not self-extinguish. Ten 1.0-inch (2.5-cm) -diameter holes have been shown to be effective (see figure 3).

The aerosol can explosion simulator is placed near the centerline of the cargo compartment (as long as there is no agent impingement on the simulator or electrodes), at least 5 feet (1.52 m) forward from the boxes, aft of the boxes containing the igniter and pipes. The unit could also be mounted outside the compartment, with the discharge port inside the compartment, to prevent heat damage; but, the location of the igniter, with relation to the simulator discharge port, must be maintained. The simulator's sparking electrodes are located 3 feet in front of the simulator discharge port and 2 feet above the floor. The simulator has a cylindrical pressure vessel for storing the base product hydrocarbon propellant. The pressure vessel is capable of withstanding a minimum pressure of 300 psi (2068.5 kPa). The pressure vessel has a ball valve to rapidly discharge the propellant, capable of withstanding a minimum pressure of 300 psi (2068.5 kPa). The port diameter of the ball must be 1.5 inches (3.8 cm) (note: a ball valve is typically classified according to the diameter of the pipe that it connects to, but this is not necessarily the size of the ball port). The ball valve is capable of rotating from the fully closed position to the fully open position in less than 0.1 second in order to form a vapor cloud. Longer opening durations will significantly affect the size of the vapor cloud formed and, hence, the explosive force. The ball valve can be activated by any suitable means, including pneumatic or hydraulic actuators or manually via the appropriate linkage. The pressure vessel is mounted vertically above the ball valve to allow for complete expulsion of the liquid contents. A discharge elbow located vertically under the ball valve directs the contents horizontally (see figures 8 and C-1).

The following list describes the major components of the aerosol can simulator.

- Pressure Vessel. A steel 2-inch (5.1-cm) -diameter, 11-inch (27.9-cm) -long schedule 80 pipe welded or capped at one end.

- Ball Valve. The 2-inch (5.1-cm) valve is constructed of a material capable of withstanding interaction with ethanol and propane. A DynaQuip stainless steel valve has been found suitable for this application.

- Ball-Valve Actuator. A pneumatic rotary actuator is suitable for quickly and reliably rotating the ball valve from closed to fully open. A Speedaire 90-degree actuator with a 2-inch (5.1-cm) bore performs well.

- Propellant Heater. A system for heating the pressurized propellant mix after transfer to the pressure vessel is provided. This could include a hot-air gun directed toward the pressure vessel, a hot-wire wrap, or other suitable means.

- Pressure Gauge. A suitable device for measuring the pressure of the contents is installed on the simulator pressure vessel, capable of measuring the pressure to within ±5 psi (34.5 kPa).

- Propellant Mix. The base product/propellant mix is 20% liquid propane (3.2 ounces [0.09 kg]), 60% ethanol (denatured alcohol, 9.6 ounces [0.27 kg]), and 20% water (3.2 ounces [0.09 kg]). The total weight of the base product/propellant mix is 16 ounces.

- Spark Igniters. A set of direct current (DC) spark igniters is used to ignite the propellant/base product mix discharged from the pressure vessel. An ignition transformer capable of providing a 10,000-volt output has been found to be suitable for powering the igniters, which should be placed 36 inches (91.4 cm) from the point of discharge. The spark igniter gap is set at 0.25 inch (0.64 cm). The igniter should be protected from the rapidly discharged simulator contents by shielding it. A bent piece of sheet metal, like a ramp, provides adequate protection.

The procedure for setting up the aerosol simulator is as follows.

Weigh the empty simulator device on a suitable scale and zero the scale. Place 9.6 ounces (0.27 kg) of ethanol (denatured alcohol) and 3.2 ounces (0.09 kg) of water into the pressure vessel. Transfer 3.2 ounces (0.09 kg) of liquid propane into the pressure vessel. Remove all transfer lines and check final mass. Mount the simulator device in the forward compartment bulkhead in a manner that directs the discharge across the spark igniters. The simulator discharge port and the spark igniter are 2 feet (60.9 cm) above the compartment floor, and the spark igniter is 3 feet away from the discharge port. The simulator discharge port is located on the centerline of the aircraft, 5 feet forward of the first rows of cardboard boxes spanning the width of the compartment. Again, the simulator may be placed outside the cargo compartment with the discharge port installed on the compartment bulkhead. Heat the pressure vessel to raise the pressure of the contents to 240 ±5 psi (1655 ±34.4 kPa). Activate the suppression agent/system and aerosol can simulator as described in section 4.5.

4.3.5 Aerosol Can Explosion (Short Version).

As previously explained, the shorter version of the aerosol can explosion test protocol may be used for gaseous agents in lieu of the version specified in section 4.3.4.

In the short version, the aerosol can simulator is placed inside the empty standard compartment (see figure 10). The simulator is prepared as specified in section 4.3.4.1. This test starts when the fire suppression agent is discharged. The aerosol can simulator is activated at least 2 minutes after agent discharge. The activation time is dictated by the measured volumetric concentration, within ±0.1% of the minimum protection concentration. The minimum concentration is measured 2 feet (60.9 cm) above the floor, near the sparking electrodes. The agent concentration must be measured during the test, and calculation of agent concentration based on the leakage rate is not permitted. The gas-sampling probe is 36 inches (91.4 cm) from the exit of the aerosol simulator and 18 inches (45.7 cm) to the side of the spark igniters (starboard or port side). The applicant must demonstrate that the system is capable of providing sufficient agent, at least to maintain the minimum inert concentration. The exploding aerosol can test scenario shall be conducted for at least 180 minutes or until the simulator is activated, whichever is shorter.

4.4 SUPPRESSION SYSTEM DESIGN.

Some aspects of the fire suppression system to be installed in an aircraft cargo compartment shall be based on the results of the MPS fire tests. For example, these tests results will provide the required concentration levels to adequately suppress standardized cargo fires and a hydrocarbon explosion, based on quantitative measurements, and not extrapolated from the bay volume concentration. Extrapolation of data to account for the required duration and analysis for cargo load configurations may be acceptable provided there is sufficient test data to support the analyses. The agent concentrations for the required duration of a diversion, accounting for leakage rates in an empty cargo compartment, must be demonstrated to be equal to or greater than that established in the MPS tests. It should also be noted that the initial concentrations to knock down the initial fire flames and the concentration to control the fire shall be determined, which could be different values. The method of measuring the concentration of agent in the required flight test shall not use the arithmetic average of the probes.

The selected agent is required to be compatible with the aircraft material to prevent problems like corrosion.

The following table provides a synopsis of the required airplane design minimum fire protection when associated with the four MPS test scenarios.

MPS Test	Airplane Design Minimum Knockdown Concentration is MPS Test-Demonstrated Maximum Concentration for Knockdown of:	Airplane Design Minimum Sustained Concentration is MPS Test-Demonstrated Maximum Concentration to:
Bulk-Load Test	Flames	Maintain Continued Fire Suppression
Containerized-Load Test	Flames	Maintain Continued Fire Suppression
Surface-Burning Test	Flames	Prevent Re-Ignition of Class-B Fire
Aerosol Can Explosion	Flames (Long Version)	Prevent Hydrocarbon Explosion

The minimum agent concentration or system configuration (in the case of nongaseous systems) shall be dictated by the fire protection system performance during the MPS tests. The basic (knockdown and sustained) suppression concentration requirements will be established during the MPS testing. As mentioned before, the volumetric concentration is based on an empty 2000-ft^3 cargo compartment. The minimum selected value or configuration shall be the one(s) that was (were) capable of suppressing/inerting all four MPS fire scenarios. The aircraft cargo compartment shall always be protected against any the MPS-specified fire threats. Variable metrics of not only duration but also compartment size and leakage rate should be accounted for by maintaining objective measurement of minimum concentration of agent in the cargo compartment. To measure the concentration levels that will dictate the minimum concentration requirements that will be demonstrated on an aircraft, the suppression agents shall be measured in a nonfire test in a discharge that is identical to the agent discharge in an actual fire test. This will eliminate any possible effect from the by-products of combustion and fire on the gas/agent analyzer readings.

4.5 SUPPRESSION SYSTEM ACTIVATION.

For the bulk-load, containerized-load, and surface-burning fire scenarios, the suppression system is activated 60 seconds after any one of the ceiling-mounted thermocouples equals or exceeds 200°F (93.3°C).

For the aerosol can scenario (long version) the suppression system is activated 60 seconds after any ceiling thermocouple equals or exceeds 200°F (93.3°C) after the start of the fire. The aerosol can simulator is activated 5 minutes after any thermocouple, attached to the galvanized steel pipes inside the cardboard boxes reaches 212°F (100°C). In the event that the thermocouples attached to the pipes do not reach 212°F (l00°C) or the fire is completely extinguished, activation of the simulator is not required. The suppression system must not directly impinge upon or affect the normal operation of the simulator and electrodes.

For the aerosol can scenario (short version), refer to section 4.3.5 for details.

4.6 TEST DURATION.

The duration of the bulk-load and containerized-load fire scenario tests is 30 minutes after the activation of the suppression system. The fifth test of the bulk-load and containerized-load fire scenarios must be conducted for at least 180 minutes and must ensure that the temperatures at the end of the test are stable or decreasing. If the system tested is a hybrid system (dual agent), the bulk-load and containerized-load fire scenarios must be run for a minimum of 180 minutes.

The surface-burning fire test is conducted for 5 minutes from the time the suppression system is activated. (Note: the surface-burning fire test self-extinguishes in less than 10 minutes due to the consumption of the Jet A fuel.)

The exploding aerosol can test scenario shall be conducted for at least 180 minutes or until the simulator is activated, whichever is shorter.

5. ACCEPTANCE CRITERIA.

The acceptance criteria determine whether a suppression system passes or fails the MPS tests. The criteria depend on three factors: peak temperature, the area under the time-temperature curve, and evidence of explosion. The MPS bulk-load test, containerized-load test, and surface-burning test use the peak temperature and area criteria, while the aerosol explosion test depends on the evidence of explosion. The time-temperature area is calculated by multiplying the temperature at a specific time by the time increment and then adding up all the areas calculated or integrating the temperature vs. time curve. Table 1 provides the values of the pass/fail criteria. Figure 11 shows the critical times during a test for computing the acceptance criteria for the bulk-load and containerized-load fire scenarios.

The acceptance criteria for the bulk-load fire scenario is that none of the ceiling or sidewall thermocouples exceed 720°F (382°C), starting 2 minutes after the suppression system is initially activated until the end of the test. In addition, the area under the time-temperature curve of each thermocouple in the compartment shall not exceed 9940°F-min (5504°C-min). The area is computed from 2 minutes after the time of initial suppression system activation until the end of the test (30 minutes after the agent was discharged).

The criteria for the containerized-load fire scenario is that none of the ceiling or sidewall thermocouples exceed 650°F (343°C), starting 2 minutes after the suppression system is initially activated until the end of the test. The area under the time-temperature curve shall not exceed 14,040°F-min (7,782°C-min). The area is computed from 2 minutes after the time of initial suppression system activation until the end of the test (30 minutes after the agent was discharged).

The acceptance criteria for the surface-burning fire scenario is that none of the ceiling or sidewall temperatures exceed 570°F (299°C), starting 2 minutes after the suppression system is initially activated until the end of the test (5 minutes after the agent was discharged). In addition, the area under the time-temperature curve cannot exceed 1230°F-min (665°C-min) over the 5-minute interval following agent discharge.

These criteria values for the bulk-load, containerized-load, and surface-burning fire tests were based on the Halon 1301 test data and computed using the analysis presented in appendix B.

The criterion for the aerosol can scenario is that there is no evidence of an explosion or reaction. Evidence of an explosion or reaction includes deflagrations, flashes, and overpressures, etc. There shall be no overpressures (zero pressure rise).

For systems tested using the diversion time (instead of the 30 minutes), the peak temperatures is determined using the collected data that is between 2 minutes after discharging the agent and the diversion time. The peak temperature shall not exceed the values presented in table 1. For the area under the time-temperature curve, the 2- to 28-minute boundaries and criteria apply.

Five tests must be conducted for each scenario. The peak temperature and area under the time-temperature curve must be determined for each test and compared to the acceptance criteria values (pass/fail); to pass the MPS tests, none of the new agent performance values on any of the tests may exceed the values provided in table 1.

6. REFERENCES.

1. T. Marker, "Initial Development of an Exploding Aerosol Can Simulator," DOT/FAA/AR-TN97/103, April 1998.

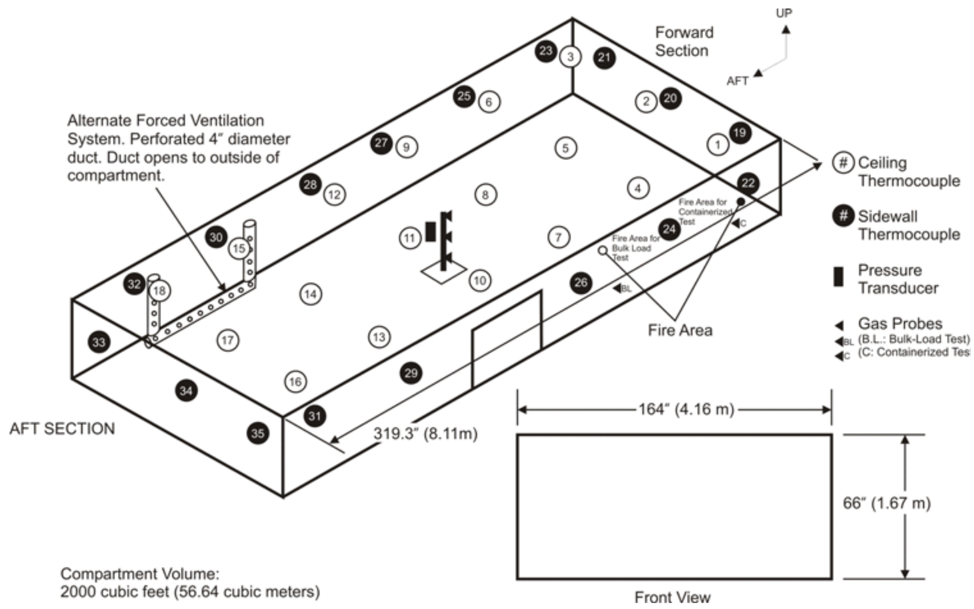

FIGURE 1. CARGO COMPARTMENT LAYOUT AND INSTRUMENTATION LOCATIONS

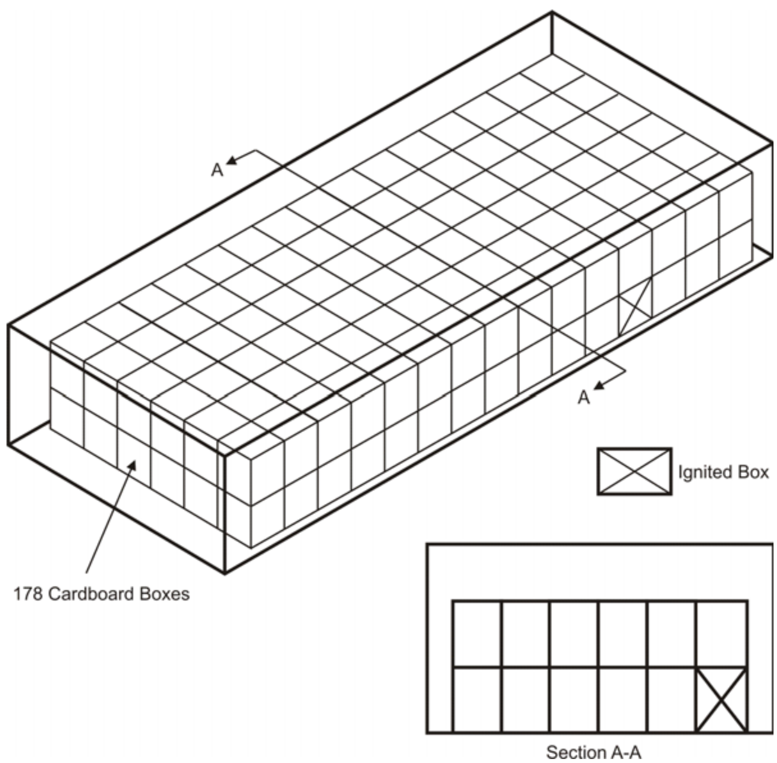

FIGURE 2. BULK-LOAD FIRE TEST SETUP

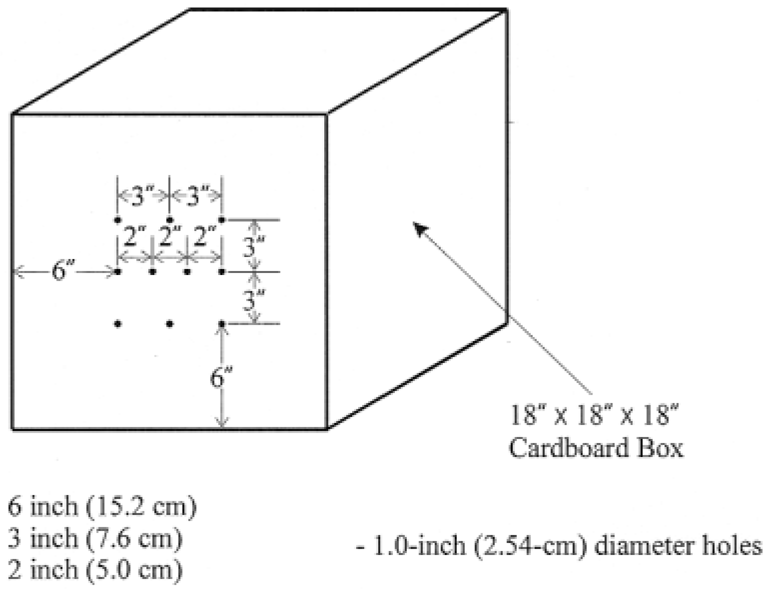

FIGURE 3. IGNITER BOX

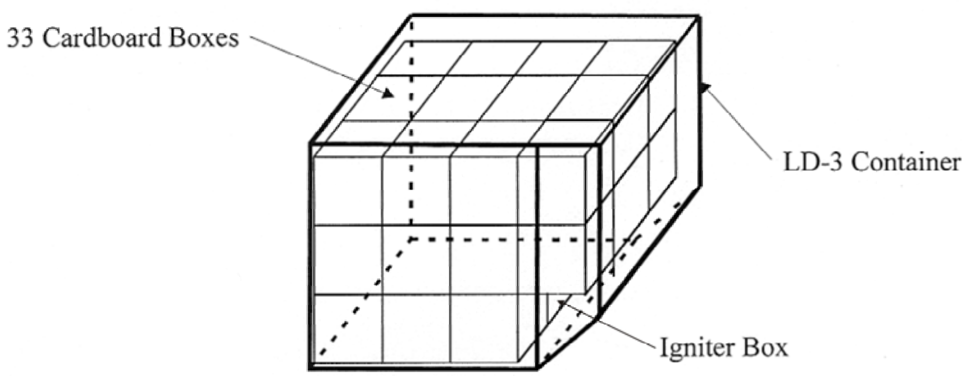

FIGURE 4. CONTAINERIZED FIRE TEST SETUP

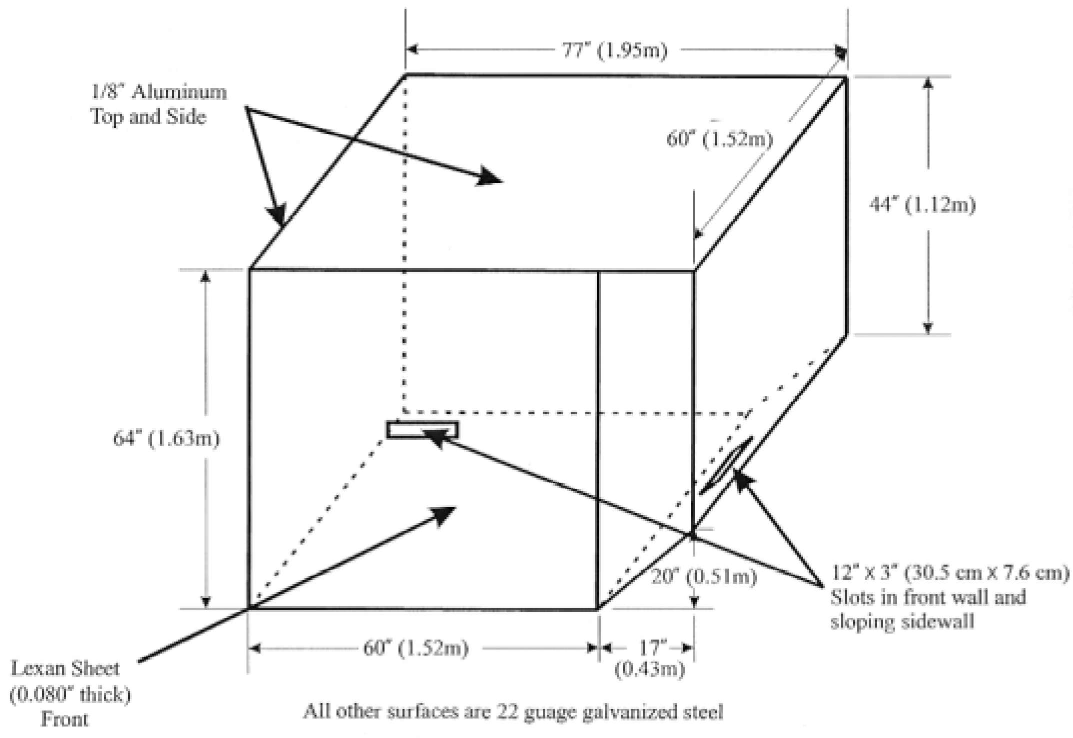

FIGURE 5. LD-3 CONTAINER

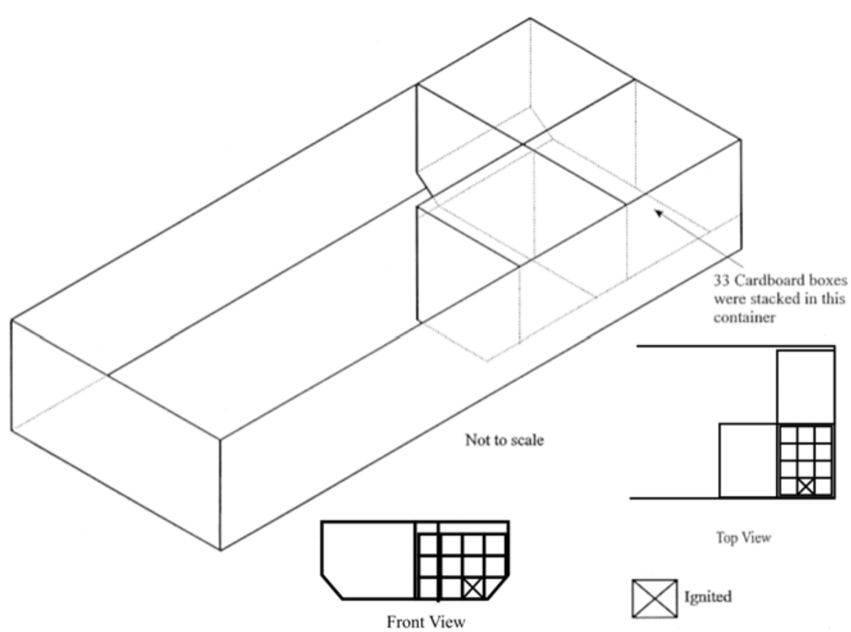

FIGURE 6. LD-3 CONTAINER ARRANGEMENT

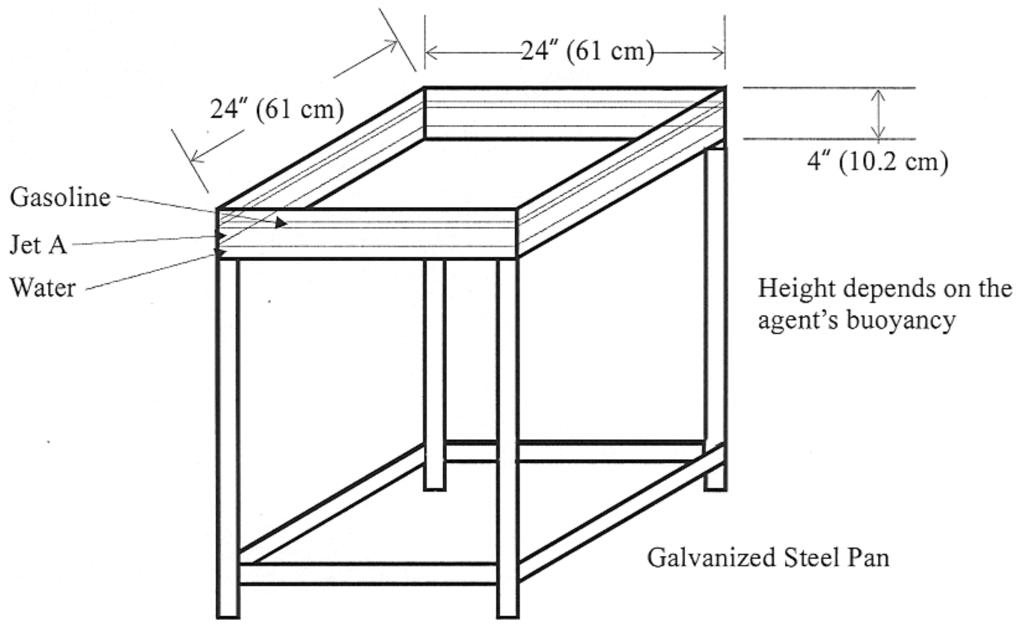

FIGURE 7. SURFACE-BURNING FIRE PAN

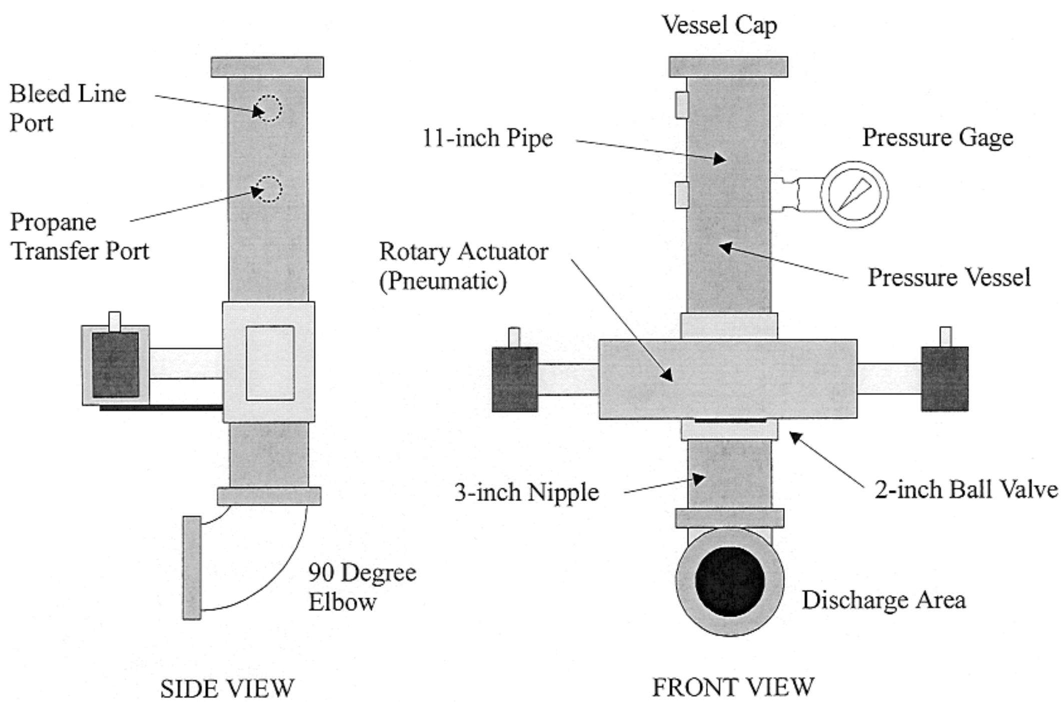

FIGURE 8. SCHEMATIC OF AEROSOL EXPLOSION SIMULATOR

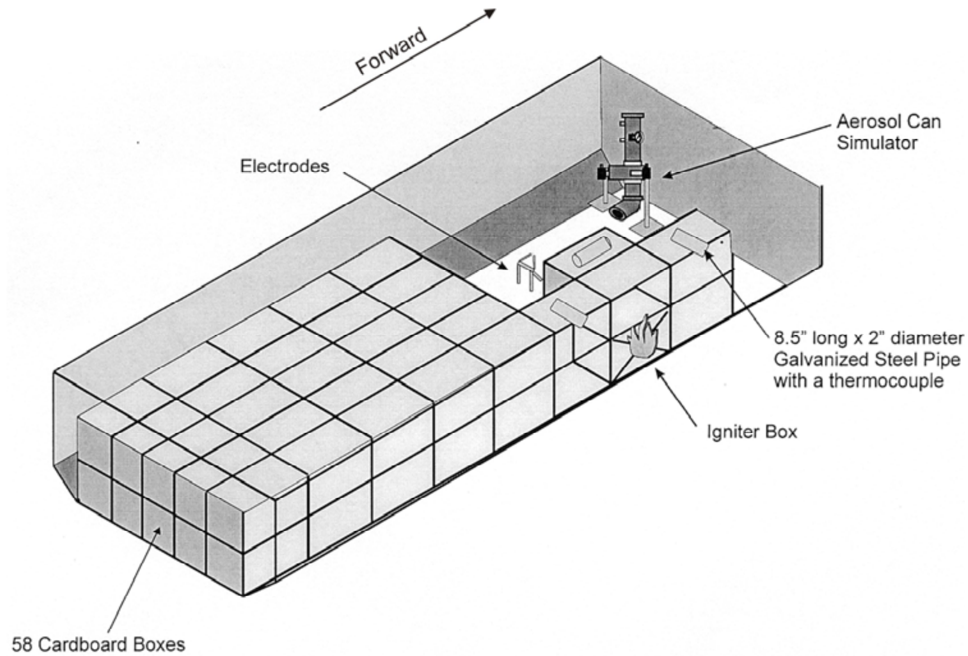

FIGURE 9. AEROSOL CAN SIMULATOR EXPLOSION TEST SETUP

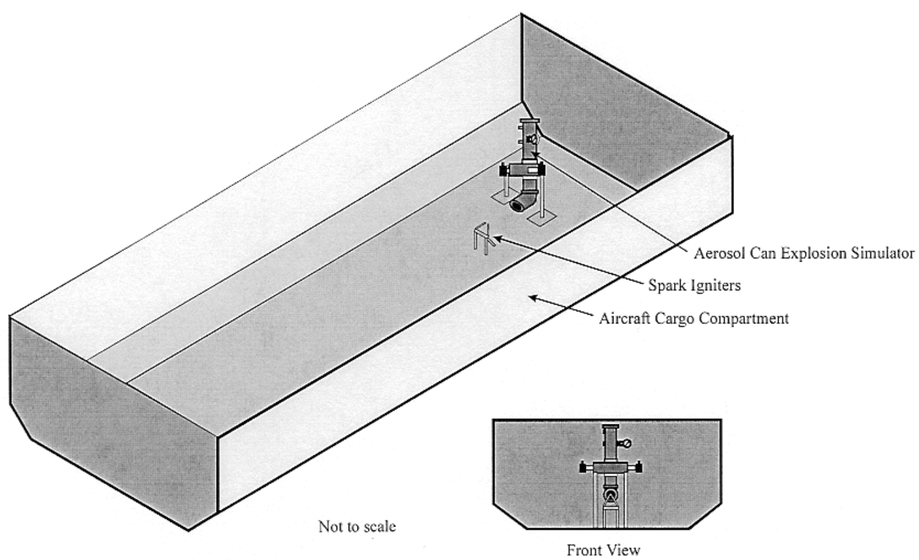

FIGURE 10. AEROSOL CAN SIMULATOR EXPLOSION TEST SETUP
(SHORT VERSION)

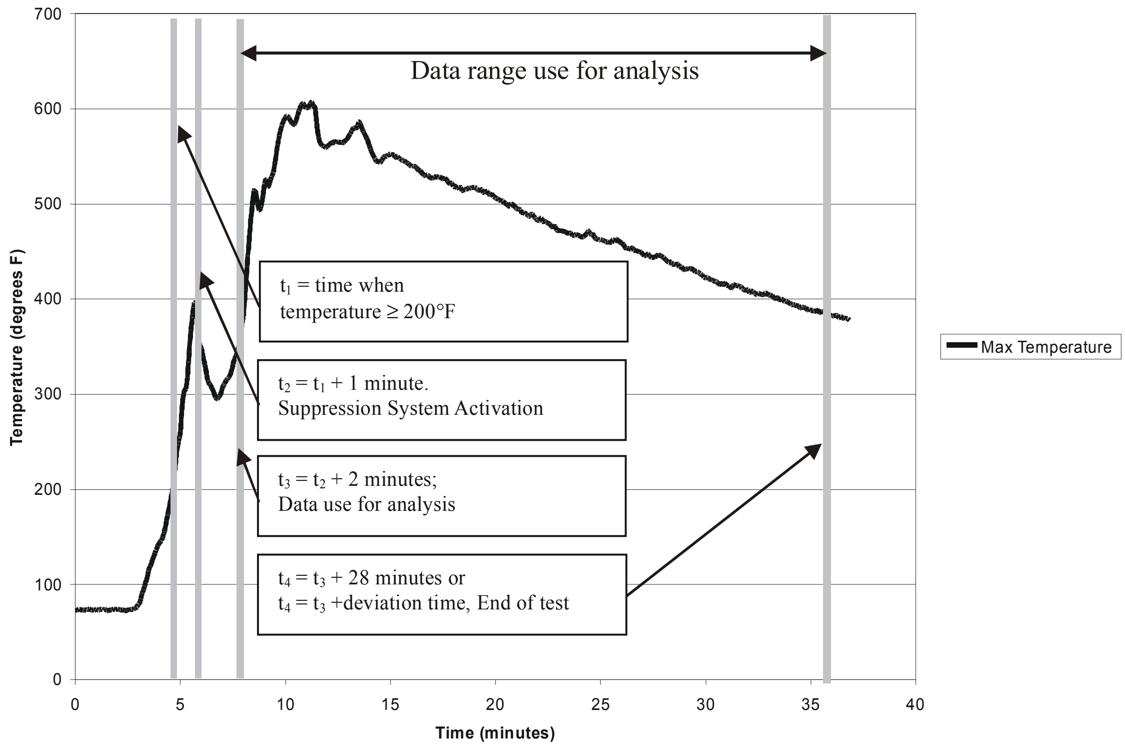

FIGURE 11. ACCEPTANCE CRITERIA BOUNDARIES

TABLE 1. ACCEPTANCE CRITERIA

Fire Scenario	Maximum Temp. °F (°C)	Maximum Pressure psi (kPa)	Maximum Temp-Time Area °F-min. (°C-min.)	Comments
Bulk Load	720 (382)	Not Applicable	9940 (5504)	Use the data that is between 2 and 28 minutes after suppression system activation. See figure 11.
Containerized Load	650 (343)	Not Applicable	14,040 (7,782)	Use the data that is between 2 and 28 minutes after suppression system activation. See figure 11.
Surface Fire	570 (299)	Not Applicable	1230 (665)	Use the data that is between 2 and 5 minutes after suppression system activation.
Aerosol Can	Not Applicable	0.0	Not Applicable	There shall be no evidence of an explosion.

APPENDIX A—UNRESOLVED DEBATE

The International Aircraft Fire Protection Systems Working Group Task Group IV was responsible for the development of the minimum performance standard (MPS) for aircraft cargo compartment halon replacement fire suppression systems. In September 2000, the task group published its first report, DOT/FAA/AR-00/28, Development of a Minimum Performance Standard for Aircraft Cargo Compartment Gaseous Fire Suppression Systems. As indicated by the title of the report, the MPS was mainly targeted to gaseous agents, which was a consequence of the aerosol can explosion test protocol. To evaluate systems that were not gas based, like water mist systems and aerosols, the aerosol can protocol requires modification. The task group discussed and debated different test protocols for several years. Two final protocols were on the table by the end of the last task group meeting in London, England, in June 2002. The two protocols in discussion were the long and short version of the aerosol can explosion test. The long version of the explosion test is a modification of the accepted MPS bulk-load fire test combined with the aerosol can simulator. The shorter version uses the aerosol can simulator in an empty cargo compartment with no fire, which was originally developed for gaseous agents.

The following comments were compiled and included in this section to illustrate the philosophy behind the members' response that were in favor or opposed to the long version of the aerosol can explosion test. As mentioned before, a consensus could not be reached after months of discussions.

In Favor.

"The idea behind the long version, of the explosion test protocol, is to provide a test for all types of systems, not only gaseous ones. This test protocol allows the new suppression systems to interact with the fire and extinguish or suppress it as intended by the system designer. It allows for other fire fighting techniques, such as fire control by thermodynamic cooling to be used in order to prevent a hydrocarbon explosion, not just chemical reaction inerting techniques.

It is a known fact that there are times that not even a Halon 1301 system is capable of preventing an explosion from happening. The current Halon 1301 fire protection system installed onboard an aircraft needs a fire in order to be activated by the pilot. The current protection system is not capable of detecting explosive mixtures coming from leaky containers (nor it was intended to), such as aerosol hairsprays or other hydrocarbons; and, if combined with an electrical arc or short the results are detrimental. Historically, Boeing and other aviation manufacturers have used the average method to demonstrate the fire suppression agent volumetric concentration in the cargo compartment. This practice, by definition, does allow lower than required percent concentrations in the cargo bay. Halon 1301 tends to stratify; if it is allowed to drop below its minimum inert concentration, like near the ceiling area, and explosive gases are accumulated on the ceiling, the risk of an explosion is also present. In the case of an aerosol hairspray can, containing propane and/or isobutene and exposed to a fire, the can may rupture, may become a projectile, and may release its explosive hydrocarbon mixture. FAA tests have shown that the compartment, during the fire suppression with Halon 1301, may reach temperatures between 400 and 600°F. At these temperatures, additional FAA tests have shown that an aerosol container may rupture in about 4 minutes and may become a projectile that could rupture the cargo liner.

If the cargo liner is breached, the Halon 1301 may become ineffective due to an increase in oxygen concentrations and agent leak. Therefore, the protection of an aircraft cargo compartment shouldn't just be narrowed to gaseous chemical reacting agents, but on all of the fire fighting technologies that may be available today and in the future, that are either single or hybrid systems, in order to prevent a hydrocarbon explosion. For example, the FAA Technical Center tested, using the long version protocol, a hybrid system (water mist combined with nitrogen) that was capable of preventing an aerosol can BLEVE by means of fire control and oxygen dilution (inert environment). The fire control technique used reduced significantly the spread of the fire along the compartment due to the excellent heat absorption capacity of the water mist; this in turn allowed enough time for the nitrogen generator to create a hypoxic condition which created an inert cargo compartment. And, the compartment remained inert and relatively cool (under 200°F) for the duration of the test. This combination of fire fighting resources and techniques reduced significantly the damage to the boxes inside the cargo compartment when compared to the damage caused when Halon 1301 is used, 4% vs. 30% damage. These attained benefits could not have been observed if the short version was used. The FAA will accept the results of both test protocol versions. The FAA believes that there is a place for both of these protocols. For example, the long version may be used if the STC applicant has a system that offers significant fire fighting benefits that can not be appreciated by the short version and still prevents the hydrocarbon explosion; while the short version may be used if the applicant has a gaseous fire suppression agent and would like to reduce the amount of effort and expense by not running the longer version." (FAA Fire Safety Section, 08 August 2002)

2. "The aerosol can test should follow a fire of adequate intensity capable of bringing about an aerosol explosion. The detection complementing the suppression would pick the ensued fire way before the actual explosion takes place and system activation will take place before the explosion. Whether the agent concentration would be adequate in that time to either suppress the fire and prevent explosion or to suppress the explosion having failed to suppress the preceding fire, is subject of further work. Perhaps additional pressure transducer detection may also improve system responsiveness." (E-Mail sent by P G Papavergos, Kidde Deugra (Germany), 14 August 2002)

<u>Opposed</u>.

1. "Boeing's objection to this test is that it does not demonstrate an equivalent level of safety as that accorded by Halon 1301. Halon 1301 provides continuous, active suppression capability at all times from the time of initial discharge to prevent a fire from an exploding aerosol can. Airplane certification tests for Halon 1301 require continuous suppression capability after initial knockdown. This test allows for a system that would not be capable of suppressing a fire, the type of fire represented by the exploding aerosol can, at all times after initial knockdown.

Boeing recommends the short or original version aerosol can test be conducted for all systems and agents, at the minimum sustained design concentration.

Boeing's rationale for the long version aerosol can test not affording an equivalent level of safety is that the MPS fire threats are representative fire threats, not the only fire threats. A system may be particularly effective on one type of fire threat, the bulk-load fire test, but not effective at all against another type of fire threat, represented by the aerosol can. Combustible gases accumulate during a suppressed fire and volatile fuels may be present from the cargo (propane bottle rupturing in an August, 1971 fire on a 707). With an ignition source, and the presence of fuel, a fire can re-ignite if there is not continuous suppression capability.

Ignition sources are not only possible but likely after the initial knockdown in a cargo fire event. First, there is the ignition source of the original fire, that may or may not still be present. There is also the suppressed, but not necessarily extinguished fire (e.g., a cargo fire on-board a 747 in October, 1978 was suppressed but not extinguished). While one can't state with certainty, a review of airplane cargo fire data (typically Class D compartments which did not have an extinguishing system) provides multiple instances where an ignition source may not be effectively removed upon discharge of a knockdown system. There are numerous ignition sources such as chemical spills (MD80 in February, 1988, 727 in July, 1986, 737 in January 1983), batteries (727 in June, 1981), drain line heaters (747 in May, 1989, 767 in May 2002), and plastic contacting heater pipes (747 in June, 1985) for which it is not clear that a knockdown agent would remove the ignition source. Combine these demonstrated ignition sources with possible fuel loads within a cargo compartment, and we believe continuous suppression capability against each of the MPS fire threats is required." (E-Mail sent by Mr. Dan Lewinski, Boeing, 06 August 2002)

2. "The aerosol can explosion test and "short" aerosol can explosion test do not measure the same protection capability. The current Halon systems provide uninterrupted protection for the required duration and would pass both types of aerosol can explosion test. An alternate agent system that applies agent intermittently may be able to pass the aerosol can explosion test but will probably not pass the short aerosol can explosion test. Therefore, this agent will not provide the same level of protection as Halon 1301. Recommend using the short aerosol can explosion test protocol only." (E-Mail sent by Mr. Terry Simpson, Kidde Aerospace, 06 August 2002)

APPENDIX B—DETERMINATION OF ACCEPTANCE CRITERIA VALUES

The following table contains the results of the MPS tests conducted with Halon 1301 as the fire suppression agent. The presented peak temperatures and peak areas were determined by using the data that falls between 2 and 28 minutes after the agent was discharged in the cargo compartment. The acceptance criteria values were determine by adding the maximum value attained during the five tests with the standard deviation of the data set and then rounded off.

		Bulk Load Test			Containerized Test			Surface Burn Test	
Test	Test ID	Max Temp (ºF)	Max Area (ºF-min)	Test ID	Max Temp (ºF)	Max Area (ºF-min)	Test ID	Max Temp (ºF)	Max Area (ºF-min)
1	081198T1	511	8002	082898T1	586	12845	111899T3	548	1184
2	081298T1	431	8906	083198T1	577	13029	111899T4	539	1195
3	081398T2	450	9097	090198T1	606	13136	111999T1	549	1203
4	081498T1	382	8938	090298T1	520	11967	111999T2	514	1147
5	081998T1	632	9453	090498T1	498	10996	111999T3	517	1153
6	082198T3	461	8733						
Standard Deviation		86.4	483.4		46.1	907.5		16.8	25.1
Maximum Value		632	9453		606	13136		549	1203
Sum of Std. Dev. + Max		718.4	9936.4		652.1	14043.5		565.8	1228.1
ACCEPTANCE CRITERIA (ºF)		**720**	**9940**		**650**	**14040**		**570**	**1230**
ACCEPTANCE CRITERIA (ºC)		382	5504		343	7782		299	665

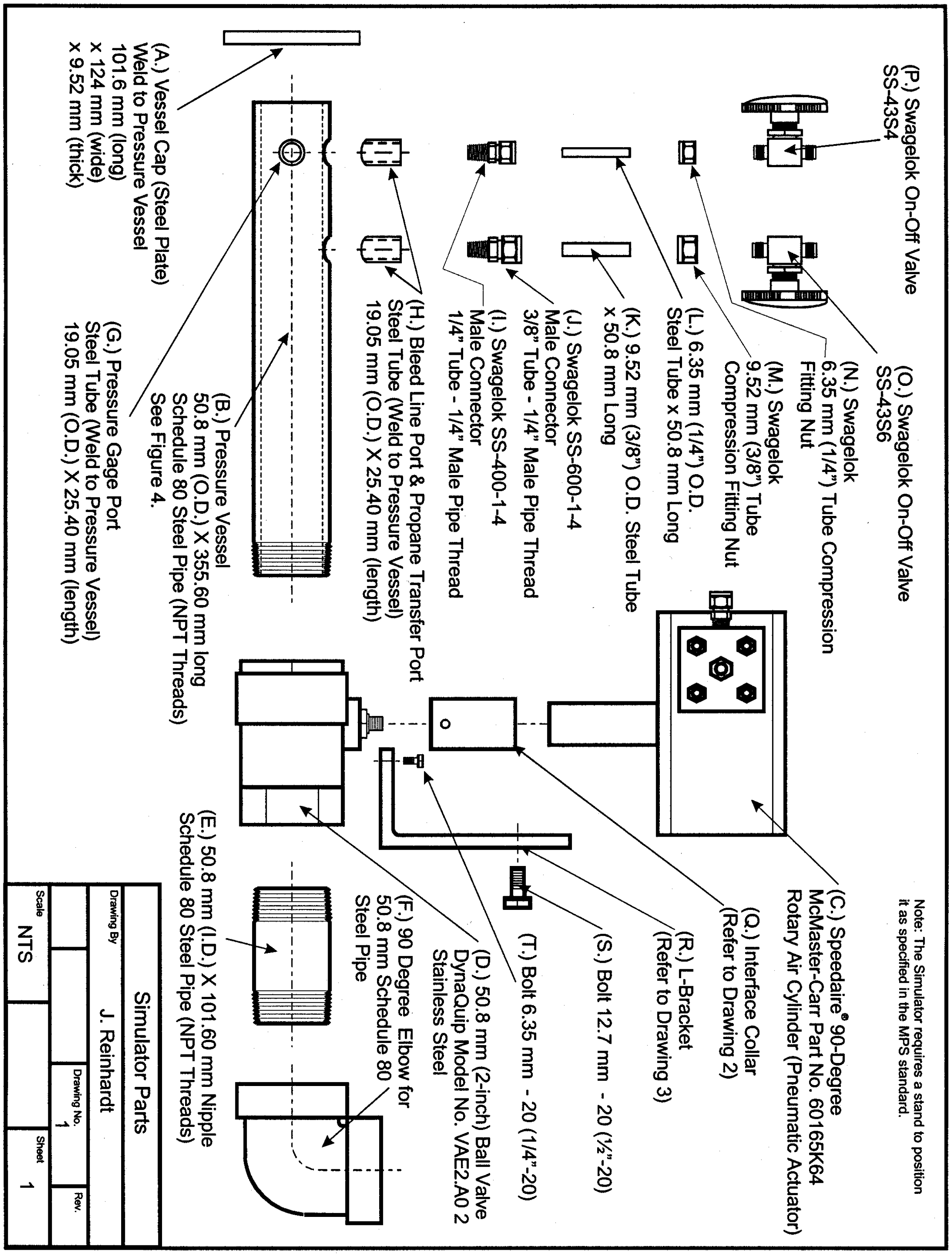

FIGURE C-1. AEROSOL CAN SIMULATOR PARTS

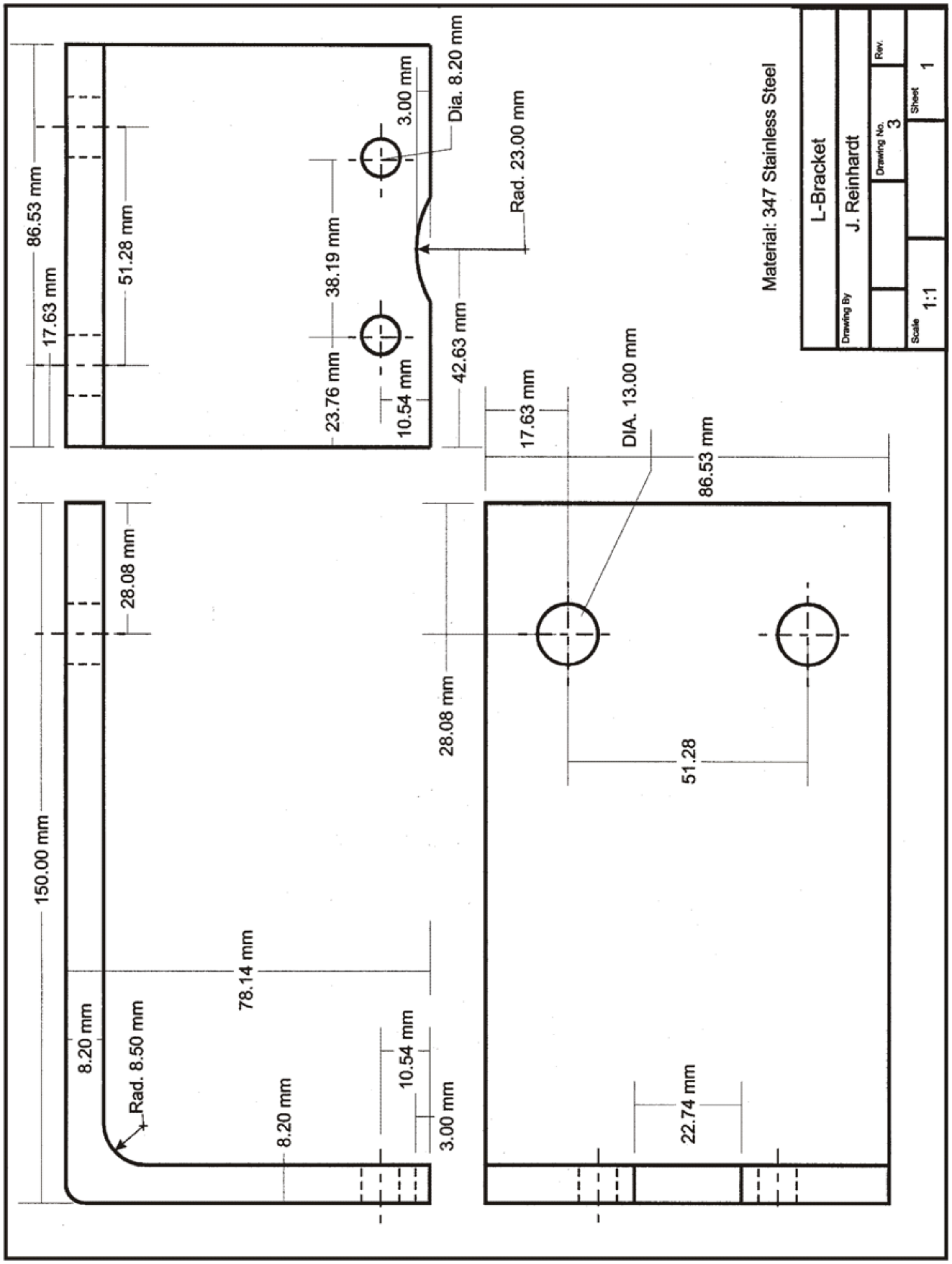

FIGURE C-2. L-BRACKET

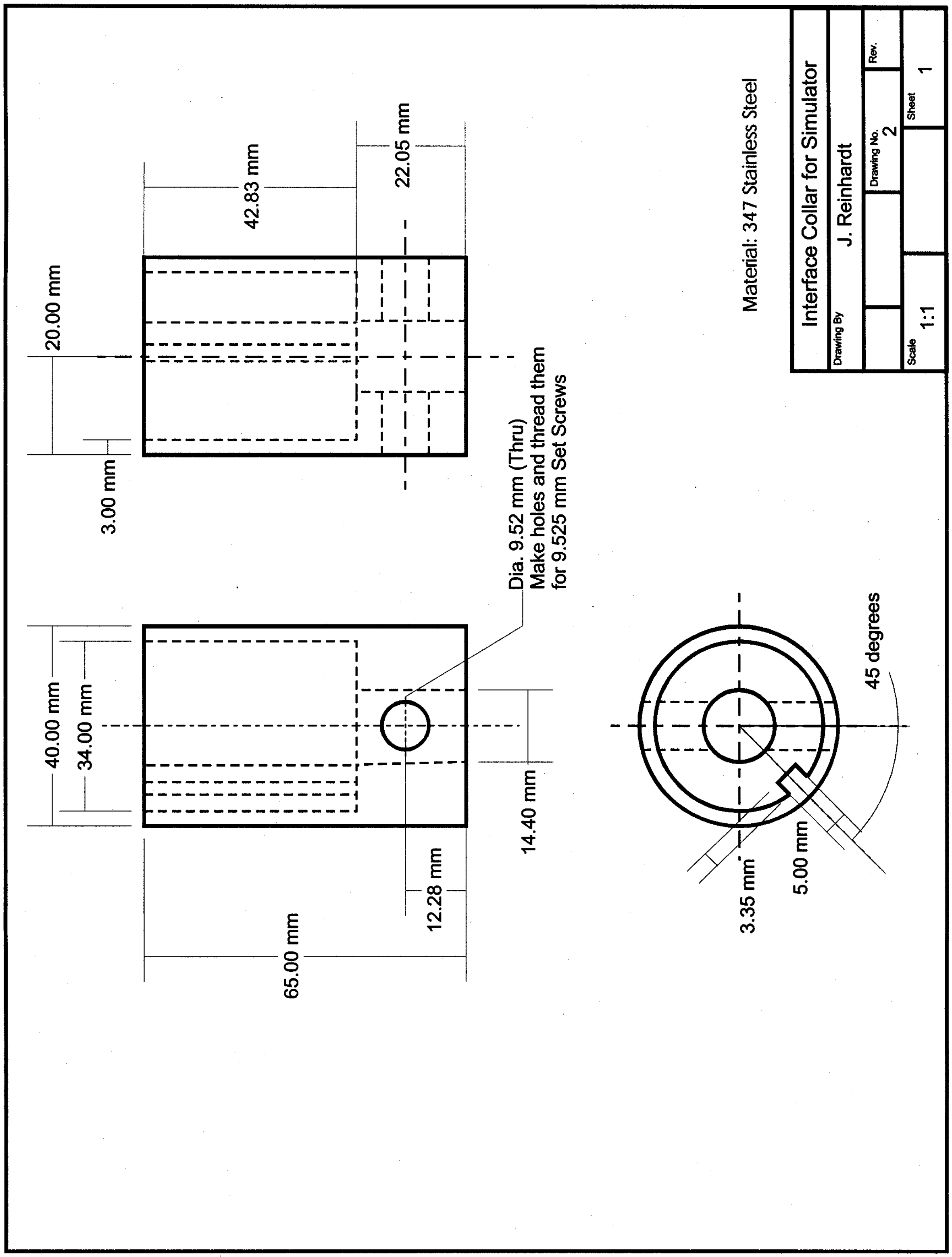

FIGURE C3. INTERFACE COLLAR FOR SIMULATOR