Oxygen Enhanced Fires in LD-3 Cargo Containers

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16. Abstract

Four tests were conducted inside a 169-cubic-foot LD-3 cargo container to demonstrate the hazards associated with the release of gaseous oxygen during suppression of a smoldering fire with Halon 1301. The cargo fires were allowed to burn for a short duration before Halon 1301 was discharged into the container. After the suppressant concentration stabilized to about 3%, the minimum design concentration for inerting, a quantity of oxygen was discharged to simulate the relief of oxygen from an overpressurized cylinder. During the first three tests, 11 cubic feet of oxygen was bled into the container from a remote cylinder. A fourth test was conducted in which 22 cubic feet of oxygen was introduced which produced a severe fire that destroyed the container. Temperature, toxic gases, and halon concentration were measured continuously inside the container and video cameras recorded the tests from three locations external to the container.

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EXECUTIVE SUMMARY

Since the fatal ValuJet in-flight fire accident on May 11, 1996, attributed to the improper shipment of chemical oxygen generators, the shipment of oxidizers and pressurized oxygen has been restricted. In early 1998, at Public Hearings convened by the Research and Special Programs Administration (RSPA), interested parties proposed that the transport of pressurized and medical oxygen cylinders be permitted in cargo compartments protected with fire detection and suppression systems (Class C cargo compartments). During the meeting it became apparent that appropriate test data did not exist regarding the performance of oxygen cylinder overpacks in cargo compartments. Consequently, the FAA committed to performing two different test protocols. One protocol entitled “Oxygen Enhanced Fires in LD-3 Cargo Containers” demonstrated the inadequacy of the LD-3 cargo container in controlling the spread of an oxygen fed fire. The second test protocol entitled “Evaluation of Oxygen Cylinder Overpacks Exposed to Elevated Temperature” evaluated the performance of various cylinder overpacks to determine whether a specially designed overpack would prevent a cylinder from overheating and releasing the oxygen into the cargo bin, thus creating a catastrophic fire.

Two series of tests were undertaken to examine the fire safety aspects of pressurized oxygen cylinders involved in a cargo compartment fire suppressed with Halon 1301. In the first test series, oxygen cylinders were subjected to a furnace temperature of 400°F, which corresponds to the level possible during a suppressed cargo fire. When the surface temperature of the cylinder reached approximately 300°F, which occurred rather quickly, the pressure relief disc failed and discharged the cylinder contents. In the second test series, the oxygen cylinder quantities measured during the initial test series were introduced in a deep-seated cargo fire being suppressed with halon inside an LD-3 cargo container. The results were influenced by such factors as the amount of oxygen discharge, the spacing of the stowed cargo, and the location of the oxygen discharge point relative to the initial fire. In one test involving the release of 22 cubic feet of oxygen, the initial discharge of oxygen caused a violent combustion reaction, which partially separated the front surface of the container and enveloped the periphery of the container in flames. By the end of the test the fire had destroyed the container. The results point to the need for oxygen cylinder shipping containers that are suitably designed for thermal protection against a cargo fire.

BACKGROUND

On May 11, 1996, a fatal in-flight fire occurred onboard a ValuJet DC-9. During this accident, an extremely intense fire fueled by solid oxygen generators erupted in the class D compartment, burned out of control into the passenger cabin, and eventually caused the aircraft to crash, resulting in 110 fatalities. In the wake of this accident, the FAA issued a ban on the shipment of oxidizers in all transport aircraft cargo compartments. Industry, pilot, and user groups have requested an exemption to allow for the shipment of bottled oxygen in class C cargo compartments which have fire detection and suppression systems. In a class C compartment, the fire would be detected and agent discharged to extinguish the fire. In the event of a suppressed but not fully extinguished fire, which would be the case if the origin was a deep-seated fire, the temperatures in the compartment could reach 400°F. A deep-seated fire typically involves class A materials such as paper, cardboard, or clothing that burns deep within the contents where it is difficult for an extinguishing agent to penetrate. In contrast, a surface-burning fire involves the combustion of materials more superficially and is much easier to extinguish. The major concern with the shipment of oxygen cylinders under this scenario is that the elevated temperatures could cause the cylinder pressure to increase, resulting in the opening of the pressure relief mechanism. If this occurs, the contents of oxygen could vent directly into the fire, causing a significant intensification of the fire and possibly overtaxing the suppression system.

Different types of pressure relief devices and cylinders are used for storing breathable oxygen. There are two types of rupturing relief valves, a frangible disc that will fail under excessive pressure (typically 2500 psi) and a thermal disc that will fail when the temperature exceeds 165°F or 225°F, depending on the type. There is also a spring-loaded relief valve that will slowly vent the contents of a pressurized cylinder that is needed to maintain pressure at or below 2000 psi, so that only a percentage of the oxygen would be vented if exposed to elevated temperatures. The rupture disc pressure relief device is the only type used on gaseous oxygen cylinders for crew and passenger breathing systems on commercial transport aircraft, so the research was limited to this type only. Ironically, the rupture disc type pressure relief devices pose a more serious concern in a fire environment because, with these relief devices, it is possible for the entire contents of the oxygen cylinder to be discharged at elevated temperatures.

INITIAL FURNACE TESTING

The primary focus of the tests was to determine the hazards associated with the release of oxygen from cylinders involved in an aircraft cargo fire. Since there are inherent dangers associated with the heating of pressurized oxygen cylinders, it was determined that all fire tests would be conducted using a remotely placed oxygen cylinder. Gaseous oxygen could be safely piped into the test container to provide the same result as an actual cylinder placed directly in the fire. In order to determine the appropriate time and rate of oxygen release during the fire, a series of tests were first run in a furnace to measure the response of several different sized cylinders. For safety purposes, the cylinders were emptied of all gaseous oxygen and repressurized with gaseous nitrogen at a pressure of 1800 psi.

A large, industrial-type high temperature electric box furnace was used for testing. The furnace was heated by means of coiled electric resistance-type alloy elements that are supported in hard ceramic element holders. The furnace insulation consists of a primary layer of lightweight refractory insulating firebrick which is backed up with 2 inches of high temperature mineral fiber board. The temperature control system includes two separate zones of heating elements that are controlled independently with manual rheostat/bimetal percentage-type input controls. In addition, the overall furnace temperature is set by means of an automatic temperature control, which allowed ramping to 400°F in approximately 6 minutes. The internal dimensions of the furnace measured 37.5 by 26 by 25 inches (figure 1).

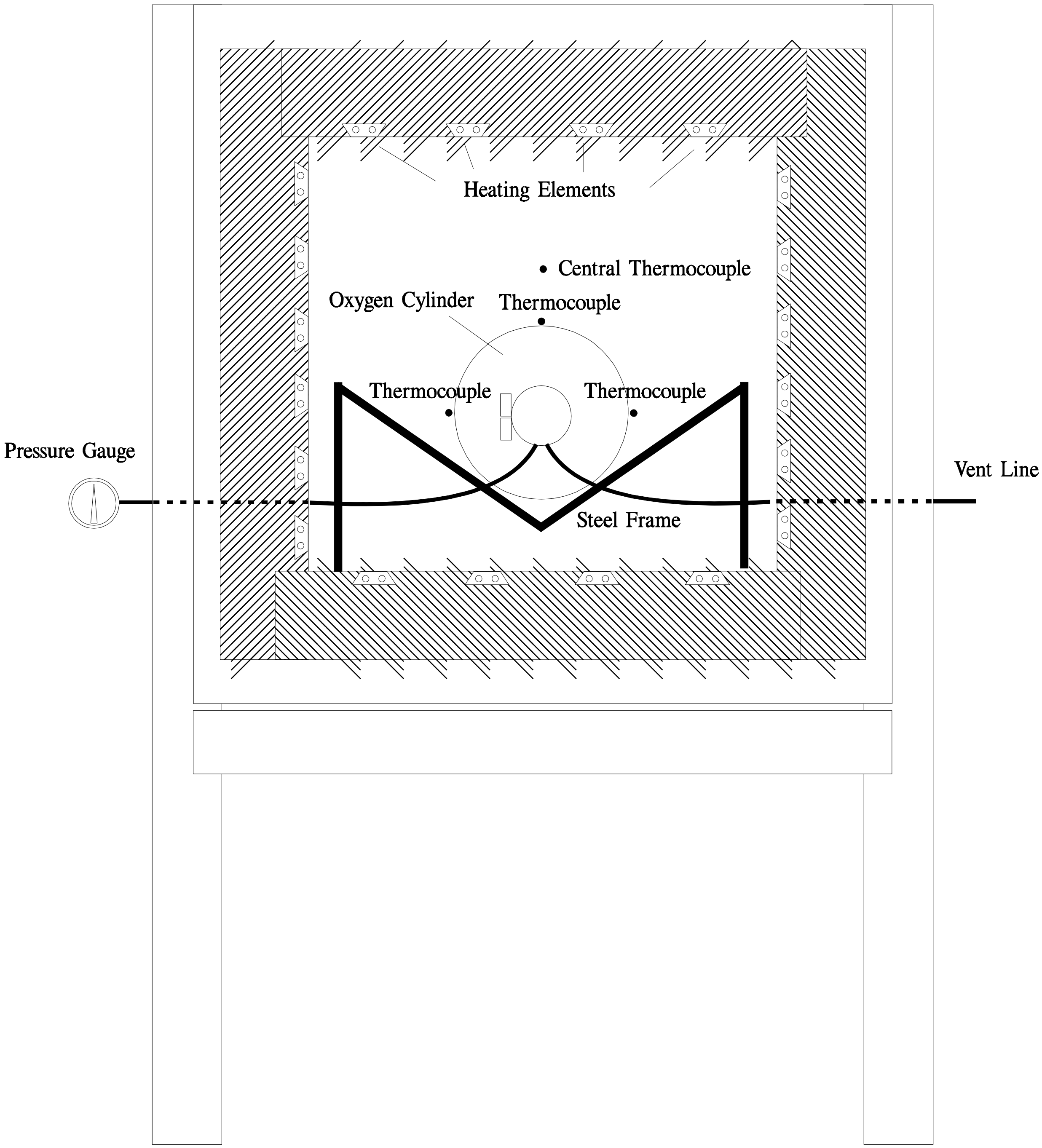

FIGURE 1. TEST FURNACE

During the tests, the cylinders were attached to a steel frame that fit snugly into the test furnace to prevent cylinder movement and subsequent damage to the heating elements. The cylinder surface temperature was continuously monitored using three thermocouples attached directly to the cylinders. The furnace temperature was measured with a thermocouple located in the geometric center. A copper tube from the cylinder valve head was connected to a pressure gauge, allowing the internal pressure of the cylinder to be measured continuously during the heating process.

FURNACE TEST RESULTS

During the first furnace test, a 3HT-type, 76.5-cubic-foot cylinder was placed in the test frame holder. The cylinder measured 7.25 inches in diameter by 29.75 inches in length, excluding valve assembly. After the start of the test, the rupture disc activated at 9 minutes 53 seconds and required 33 seconds for the cylinder to fully evacuate. The temperature of the cylinder was 285°F, and the temperature inside the furnace was approximately 380°F at the time of release (figure 2). The cylinder internal pressure was approximately 2650 psi at the time of rupture disc activation. A second test was run under nearly identical conditions using a larger 115-cubic-foot cylinder that measured 9.00 inches by 29.56 inches. During this test, the rupture disc activated at 15 minutes 23 seconds and required 1 minute 12 seconds to fully empty. At the time of disc failure, the internal pressure was 2600 psi, and the cylinder surface temperature ranged between 300 and 320°F (figure 3). A final test was run using a small, 11-cubic-foot "walkaround" bottle that is typically used by flight attendants in the event of cabin depressurization. The cylinder was a type 3AA and measured 3.25 by 18.75 inches. A malfunction with the furnace temperature control resulted in a lengthy heating period; however, the rupture disc activated during temperature ramp-up at 17 minutes 12 seconds. The furnace temperature had reached between 350 and 370°F during release, at which point the cylinder surface temperature was between 300 and 325°F. The cylinder required only 5 seconds to fully discharge, and the pressure was observed to be approximately 2500 psi (figure 4). The average rate of release of nitrogen from the three cylinders was calculated to be approximately 2 ft^3/sec.

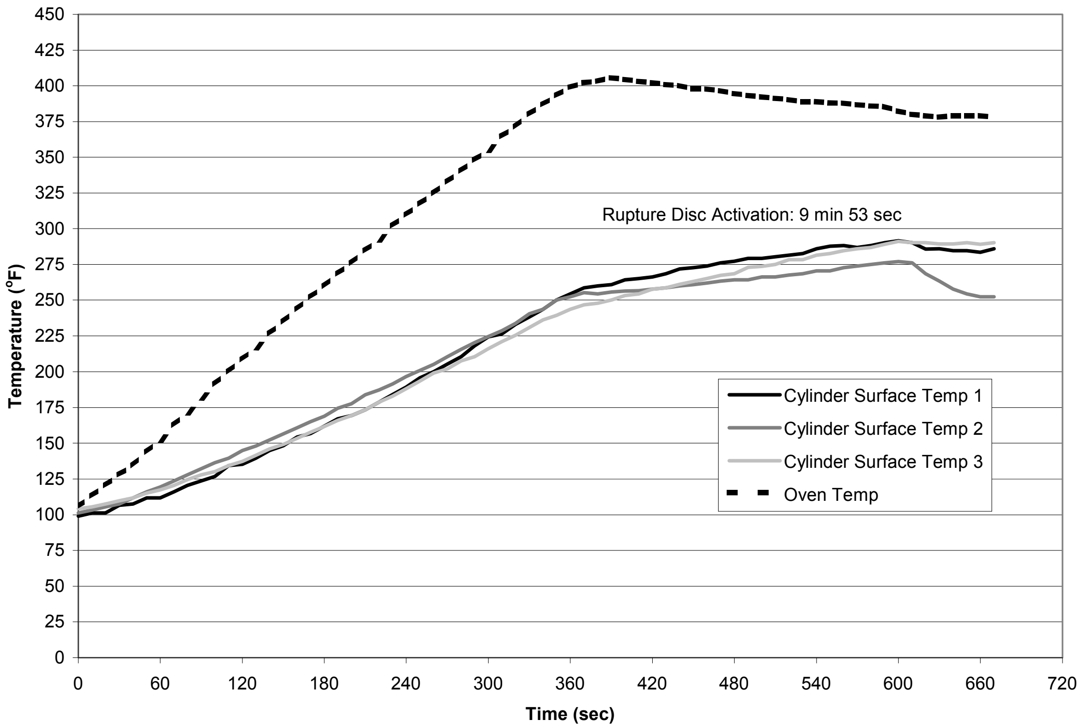

FIGURE 2. FURNACE TEST RESULTS USING A 76.5-CUBIC-FOOT CYLINDER

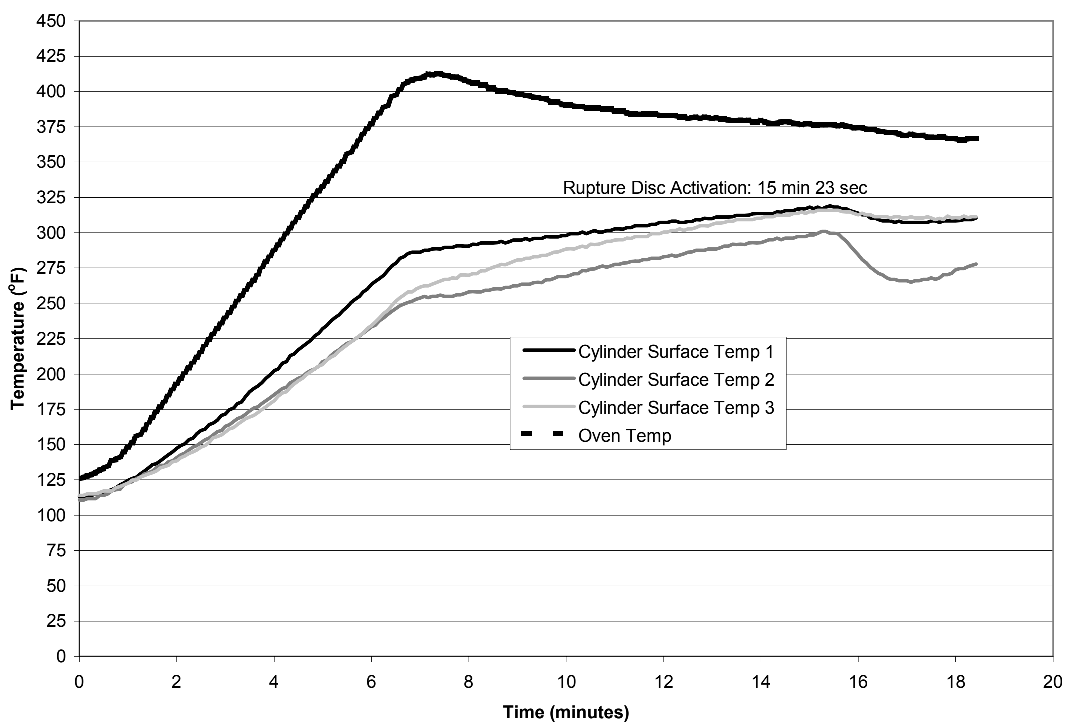

FIGURE 3. FURNACE TEST RESULTS USING A 115-CUBIC-FOOT CYLINDER

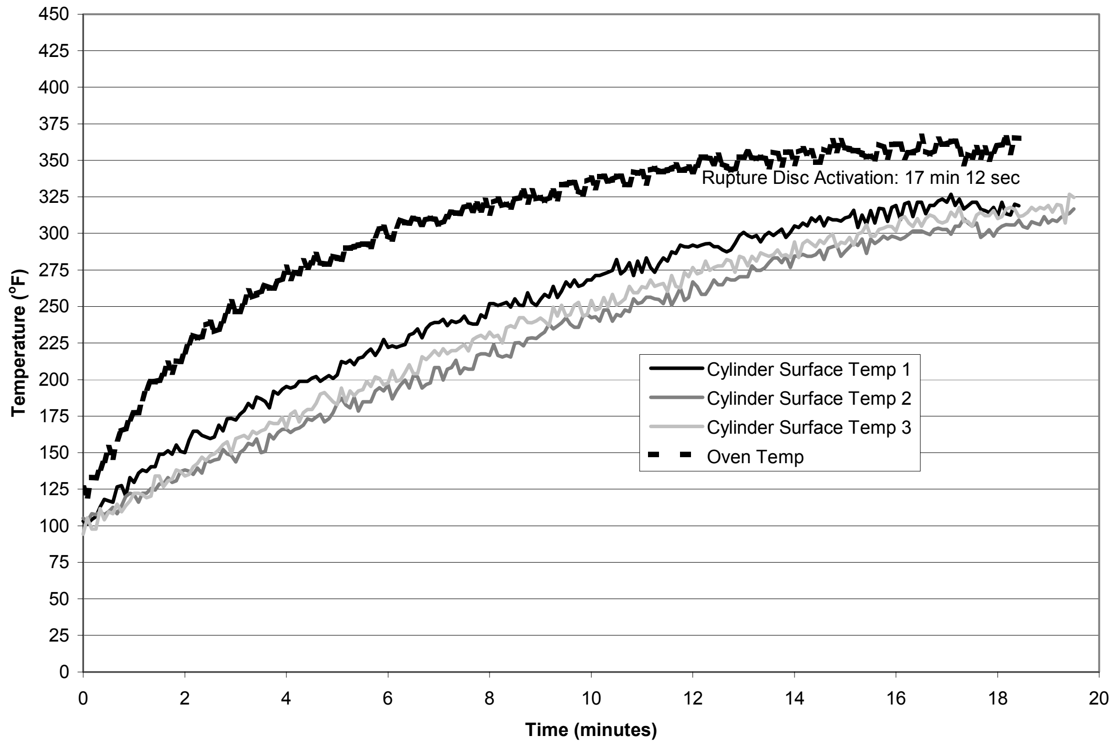

FIGURE 4. FURNACE TEST RESULTS USING AN 11-CUBIC-FOOT CYLINDER

LD-3 TEST ARRANGEMENT

In order to determine the impact of oxygen release during a fire, a steel-framed receptacle was constructed in the shape of an LD-3 container, which is typically used in the lower lobe of wide-bodied aircraft (DC-10, B-747, B-767, and L-1011). The test container had an internal volume of 169 cubic feet and could be rebuilt in the event of sidewall or ceiling damage. Sheet steel was used on most of the surfaces except for the top and front side, which was aluminum (0.63 inch thick). The fire load consisted of shredded paper-filled cardboard boxes measuring 18 by 18 by 18 inches. The boxes were loaded into the container in two tiers, each containing 9 boxes. An additional 2 boxes were loaded into the container for a total of 20. Thermocouples were placed on the four sides and ceiling of the test container. A gas sampling station contained intake ports at heights of 21, 37, and 54 inches from the floor. These lines passed through a series of filters prior to entering the gas analyzers, which continuously monitored the concentration of carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and Halon 1301. A large, 1000-lb. Halon 1301 tank was available for fire suppression. A 0.375-inch diameter transfer line from the tank discharged halon from the center of the test container ceiling (figure 5).

TEST EXECUTION

During all of the LD-3 tests, the basic configuration and execution remained the same. A nichrome wire igniter was energized in the bottom center "fire box", and a fire was allowed to

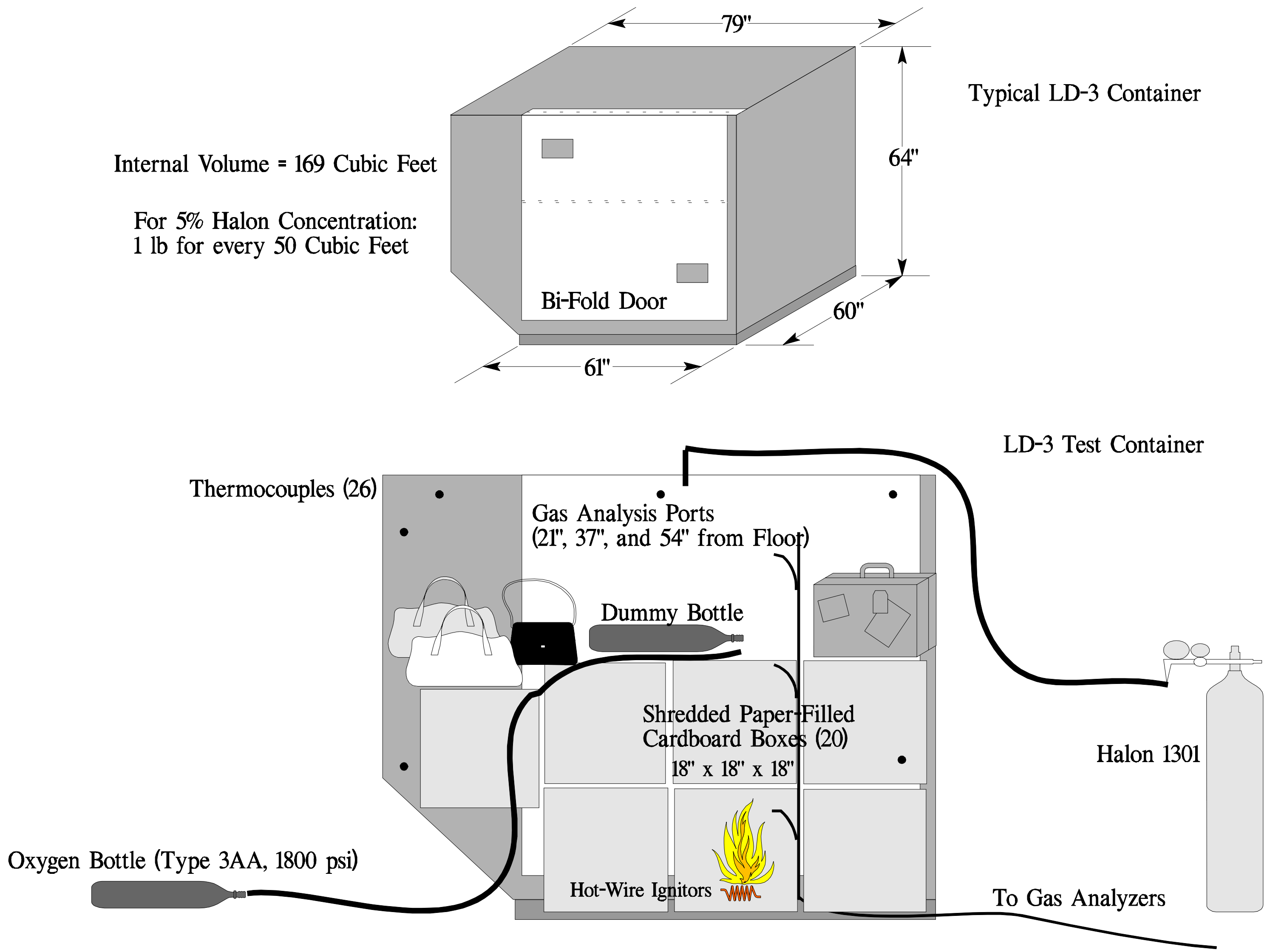

FIGURE 5. TEST 1 ARRANGEMENT IN AN LD-3 CARGO CONTAINER

progress until a significant amount of smoke was produced and the in-box thermocouples indicated the presence of fire. Once this occurred, the Halon 1301 was slowly bled into the test container until at least 3% concentration was achieved. Since the first fire test employed an 11-cubic-foot oxygen release, the temperature results obtained during the furnace test were set as the initial test conditions. A "dummy" cylinder identical to the 11-cubic-foot walkaround cylinder was placed in the fire load and outfitted with thermocouples. When the temperatures of the dummy cylinder reached the temperatures at which the disc ruptured during the furnace test, oxygen was released into the container. The oxygen was supplied by a remote 11-cubic-foot cylinder and transferred through a 0.375-inch-diameter copper line approximately 15 feet in length. At the end of the discharge line, a fitting was installed to deflect the oxygen flow in a 360-degree pattern to prevent whipping of the line.

LD-3 TEST RESULTS

During the first test several small rag-filled duffel bags and a large suitcase were also placed on top of the shredded paper-filled boxes (figure 5). The dummy cylinder was placed amongst this luggage which was also the area where the gaseous oxygen was discharged.

After ignition of the paper-filled fire box, the fire was allowed to develop for approximately 18 minutes, at which point the temperature in the fire box had reached 600°F, and a large amount of smoke was emanating from the edges of the container. Halon 1301 was then discharged into the LD-3 container, initially reaching a concentration of 8% at the top station (54 inches from the floor). The Halon 1301 concentration was allowed to decay until 30 minutes into the test where it had decreased to between 3.5% and 4.0%. At this point, the 11-cubic-foot oxygen cylinder was opened, but a problem with the valve prevented a rapid discharge. Instead of emptying in 5 seconds, as evidenced during the furnace test, the bottle required approximately 2 minutes to fully discharge. A review of the test data indicated the oxygen concentration inside the container rose from approximately 7% to 16% during the discharge. Slight increases in temperature were observed, but the oxygen release had little overall impact on the fire. The aluminum container ceiling did not allow flames to burn through at any time. At 60 minutes, the container was opened and the remaining fire was extinguished. Much of the original fire load was intact, as only 6 of the 20 boxes were burned, and there was no evidence of fire in and around the area of oxygen release.

Because the pressurized oxygen was not released into the fire at the appropriate rate, an identical test was run during which several adjustments to the test setup and execution were incorporated. First, it was determined that by switching to an alternate valve port the contents of the oxygen cylinder could be released in a much shorter duration (5 seconds). Second, the oxygen was released closer to the fire box in order to increase the chance of direct interaction with flaming combustion (figure 6). Third, the LD-3 container was modified to allow for more ventilation which would provide quicker fire development.

During the second test, the fire developed more rapidly, and Halon 1301 was deployed 3 minutes into the test. The concentration of halon reached 10% then slowly tapered off, but the fire was nearly extinguished by the high halon concentration. In order to continue with the test, a second ignition source was activated inside the box at approximately 14 minutes. The temperatures

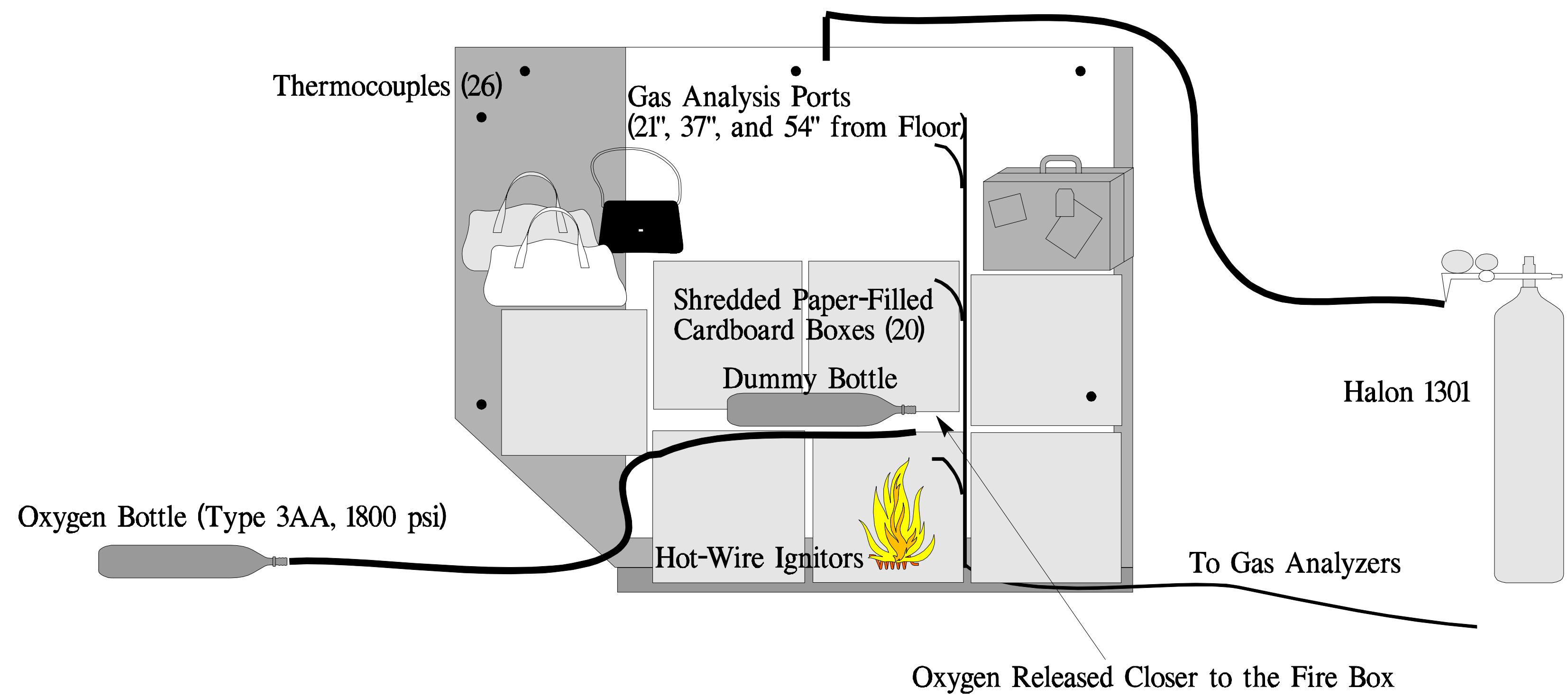

FIGURE 6. TESTS 2 AND 3 ARRANGEMENT IN AN LD-3 CARGO CONTAINER

began to increase, and the oxygen was released at 17 minutes (the halon concentration was approximately 3.8% at the time of oxygen release). Upon release, the smoldering fire erupted violently, as observed via video monitors. Visible flames appeared at one edge of the LD-3 container. Although violent, the eruption was short in duration, and the fire was contained. The fire did not burn through the aluminum ceiling of the container. When the oxygen was released, the concentration was initially 15%, but quickly reached 24%. The test was allowed to progress an additional 23 minutes (40-minute total) without interruption. At this point, the test was terminated, and the container was opened for extinguishment of any remaining fire. Approximately 50%-60% of the fire load (cardboard boxes) was undamaged. Although the test was executed as planned, there was concern over the amount of oxygen released into the fire, as a pre-existing leak in the cylinder valve was discovered just prior to the test. For this reason, the test was repeated in an identical manner.

During the repeat test (test 3), the fire was initiated in an identical fashion, but the Halon 1301 was bled into the container more slowly, to simulate a more realistic condition with the container inside a totally flooded compartment at 3% halon concentration. After 31 minutes, the temperature inside the fire box was approximately 800°F, and the oxygen concentration inside the container was about 8%. At this point, the oxygen was discharged. The release of oxygen again caused a violent reaction inside the container that produced enough pressure to force open taped seams on the container at several locations. Although the event produced elevated temperatures inside the fire box (1300°F), it was again very short in duration much like the previous test. After about 30 seconds, the temperatures inside the box appeared to be even lower than the prerelease conditions. Apparently, the oxygen release had resulted in an intense combustion period, leaving reduced levels of oxygen and temperature. Halon was continually bled into the container during the test to maintain a 3% concentration, and the test progressed from this point on for another 18 minutes (50-minute total) without incident.

Although the 11-cubic-foot oxygen release produced a severe condition inside the container, because of the short duration, it did not overcome the suppression capabilities of the Halon 1301. Since the planned test effort was to continue introducing greater but realistic oxygen quantities into the container in order to examine fire suppression capabilities of halon, twice the amount of oxygen was used in the fourth test. In an effort to expedite testing, a large welding torch oxygen cylinder was acquired and fitted with a manual on-off 90-degree valve. This allowed subsequent tests to be conducted at various discharge quantities, alleviating the need to purchase expensive cylinders of various sizes. It was predetermined that 22 cu ft of oxygen weighed 1.8 lb., so the cylinder was placed on a digital scale and the time required to release this amount from the cylinder was measured. This was observed to be 5 seconds. The execution of the test remained identical to the previous three, except for a minor deviation in the loading of the cardboard boxes, which were placed more randomly to allow for greater air circulation and better fire development (figure 7).

During the fourth test, one of the three dummy cylinder thermocouples had reached a temperature in excess of 300°F at approximately 6 minutes. Since one of the other two dummy cylinder thermocouples appeared to be malfunctioning, a determination was made to allow the test to progress a little further, since the remaining thermocouple was still well below 300°F. At

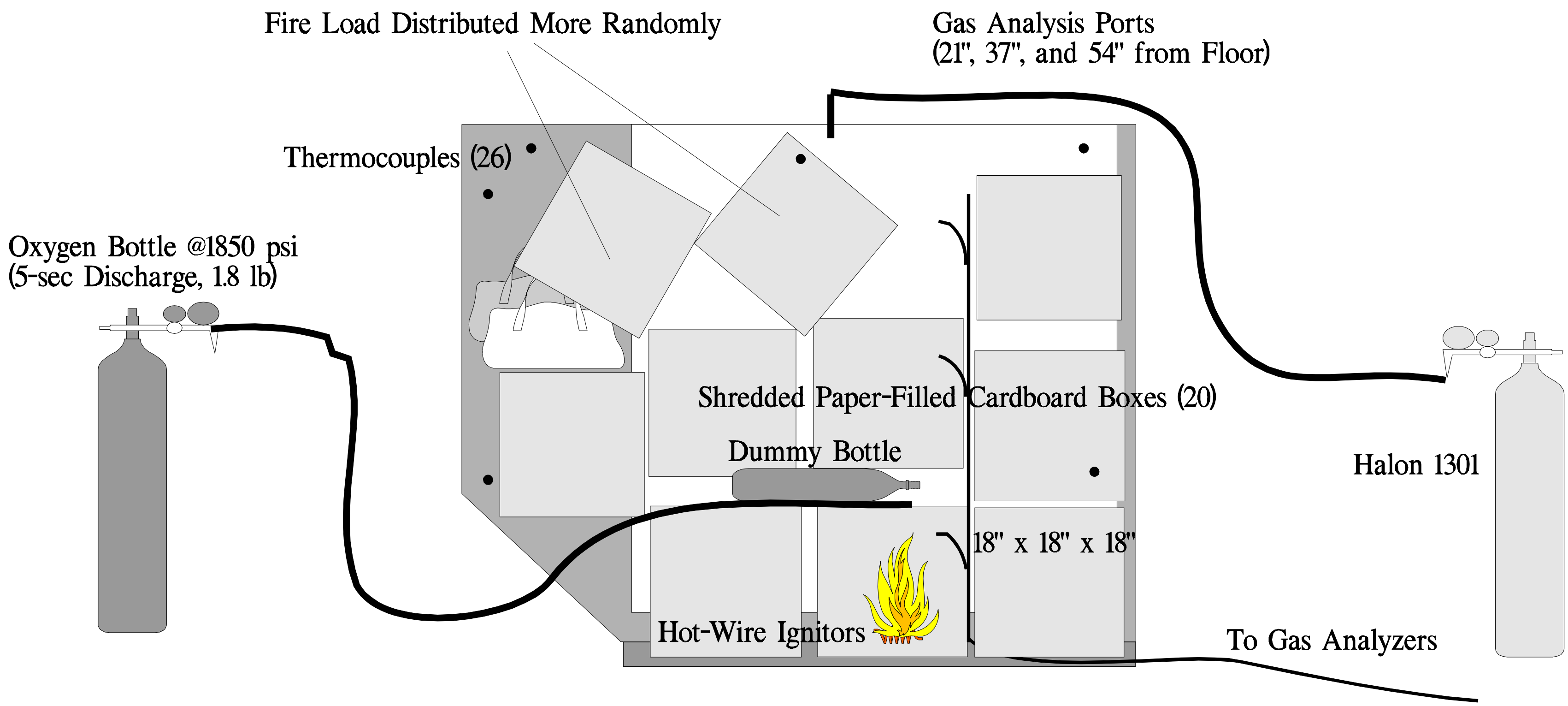

FIGURE 7. TEST 4 ARRANGEMENT IN AN LD-3 CARGO CONTAINER

12 minutes 30 seconds into the test, the conditions were right for oxygen release, as the halon concentration was between 3% and 3.2%. Upon release, the front surface of the container was partially blown off, and flames shot out around the periphery in a violent fashion. An attempt was made to maintain the halon concentration at 3% to simulate a container inside a flooded compartment, but all of the gas analysis intake ports were clogged, so there was no way of tracking the concentration. As the test progressed, flames began to burn through the aluminum ceiling. After 21 minutes, the flames were extinguished but not before burning completely through the ceiling and part of the front side of the container, totally destroying it. A review of the thermocouple data indicated dramatic increases in temperature in the container four walls and ceiling immediately following the oxygen release.

CONCLUSIONS

Although the 11-cubic-foot oxygen release into the test container produced a severe event during tests 2 and 3, it was short enough in duration to be contained. The fire load of cardboard boxes may have been too tight to allow for fire development, as actual baggage is typically loaded more randomly, allowing greater air circulation. The results of test 4 more clearly indicate the potential severity of an oxygen-enriched fire. During this test, the front surface of the container was partially forced open from the heat generated during the release of 22 cubic feet of oxygen. Larger amounts of oxygen could create even more violent results. It is possible that the resultant forces from the expanding hot gases generated during oxygen introduction could dislodge the cargo liner, allowing the fire suppression agent to escape, causing a loss in fire fighting capability.

The oxygen quantities used in these four tests are relatively small in comparison to the amounts available in commonly used cylinders. As shown in the initial furnace tests, relatively low surface temperatures (300°F) can cause the cylinder rupture disc to activate, initiating a full discharge of oxygen in a short duration. Oxygen cylinder shipping containers designed for thermal protection could prevent the overheating of cylinders during a suppressed cargo fire and the potential increase in fire hazards associated with the release of oxygen.