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# Fire Extinguishing Agents for Oxygen–Enriched Atmospheres

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Fire-suppression agent requirements for extinguishing fires in oxygen-enriched atmospheres were determined employing small-, medium-, large-, and full-scale test apparatuses. The small- and medium-scale tests showed that a doubling of the oxygen concentration required five times more HALON for extinguishment. For fires of similar size and intensity, the effect of oxygen enrichment of the diluent volume in the HC-131A was not as great as in the smaller compartments of the B-52 which presented a higher damage scenario. The full-scale tests showed that damage to the airframe was as important a factor in extinguishment as oxygen enrichment.

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# PREFACE

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This report summarizes work done between April 1982 and November 1985. Mr. Joseph L. Walker was the HQ AFESC/RDCF Program Manager.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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# SECTION I
## INTRODUCTION

### OBJECTIVE

The requirement for oxygen to be carried onboard military aircraft causes a significant increase in the potential fire hazard when these aircraft are involved in accidents. All flammable materials burn more readily in an oxygen-enriched atmosphere (OEA) than in air. The inadvertent release of oxygen in several recent military aircraft incidents involving fire significantly increased the complexity of fire management and extinguishment of these fires. The present method of mass application of Aqueous Film-Forming Foam (AFFF) has failed to control these types of fires. The lack of data concerning the performance of materials and agents in an OEA is such that choosing the most satisfactory agent for firefighting is not possible.

The objective of this effort was to conduct analytical and experimental tasks to define the optimum fire suppressant to extinguish fires in an OEA inside a crashed airframe. In addition, guidelines to be used in fighting fires with or without oxygen enrichment were to be developed for firefighters, based on the information gathered.

### SCOPE

An initial attempt was made to determine extinguishing agent requirements based on analytical methods and experimentally determined combustion properties of materials. Following an extensive literature review and initial tests, this approach was abandoned in favor of an empirical approach which more faithfully considered the complex interactions which might be expected in a crashed aircraft fire.

A program was established to quantitatively measure the agent requirements for suppression and inertion of various fuels in atmospheres ranging from less than 20 percent oxygen to 100 percent oxygen using small-scale laboratory experiments. This was followed by verification and extension of the obtained results in medium-scale experiments. Large- and full-scale experiments, using aircraft sections and complete aircraft, were performed to demonstrate the validity of the smaller-scale test results. Only those agents identified as effective in the smaller-scale tests were used in the large- and full-scale tests.

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# SECTION II
## LITERATURE REVIEW AND THEORETICAL CONSIDERATIONS

### LITERATURE SUMMARY

The literature search included a review of previous research in the areas of ignition and fire propagation, burning materials, extinguishing agents and systems, and the fire hazards presented in an OEA. The citations came primarily from the aerospace agencies and industries with a few from the aircraft firefighting and nuclear communities. Appendix A contains an annotated bibliography of citations pertinent to this effort.

Several articles reviewed the nature of the combustion process in an OEA, including ignition temperatures, flame temperatures, and flame propagation rates for various materials. These citations were used in the attempt to develop an analytical solution to the agent requirement in an OEA. The significant citations are discussed in detail in this section under the heading, Empirical Approach.

Two reports were used extensively to set up and conduct the small-scale empirical test program. Reference 1 describes the standard apparatus and technique for measuring Halon concentration requirements adopted by the NFPA. Data for Halon 1211, 1301, and 2402 in air for a variety of fuels and Halon 1211 at elevated oxygen concentrations are presented. This provided an excellent base from which to verify the procedures and expand the scope of the experiment for the test program. Reference 2 reviews the use of Halon 1301 as a fire suppressant in a spacecraft environment. Test procedures and apparatus for measuring the ignitability of materials in various atmospheres are also presented. This procedure appears to provide a more realistic and more difficult fire suppression problem than does the apparatus described in Reference 1. Again, the published data provided a comparable basis upon which to expand.

EMPIRICAL APPROACH

A test program to empirically determine the agent requirements and application methods in an OEA was developed. This test program consisted of a series of experiments beginning with small-scale laboratory tests and progressively increasing to full-scale wide-body airframe fires. This program structure allowed precise quantitative data obtained in a controlled laboratory environment to be applied to progressively larger, more complex, and less controllable fire environments. Four test scales--small, medium, large, and full were used.

Small-scale laboratory experiments allowed for the study of the effects of atmosphere composition, temperature, pressure, and fuel type on agent requirements for fire suppression and ignition prevention. In these tests, the OEA environment was precisely measured and controlled, providing a parametric study of its effect on agent requirements. Because of the small scale, a large number of tests were economically performed. Two types of apparatus were used and are shown in detail in Section III. The classical cup burner apparatus described in Reference 1 provided an accepted means of measuring agent concentration requirements for flame extinguishment. However, these experiments did not faithfully represent some of the characteristics expected in aircraft fires, such as deep-seated fires and persistent heat sources. There was also some question concerning the effects of flame stability in a flowing atmosphere on agent requirements, particularly in an OEA. A photograph of the cup burner apparatus used by NMERI is shown in Figure 1. The static chamber apparatus similar to that described in Reference 2 provided an alternative means of measuring agent requirements in an OEA. Front and rear views of the NMERI static chamber are shown in Figure 2. The electric ignitor coil used in these tests simulates the presence of a deep-seated fire, hot metal, or other persistent heat source and the test results more realistically indicate agent requirements to suppress the fire, prevent its spread, and prevent reignition. The small-scale experiments were limited to the Halons and other gaseous agents for two reasons. First, the Halons are the most efficient agents available and agent efficiency is an important factor when responding to a remote location such as an aircraft crash site. Second, other agents such as water, AFFF, and dry chemicals could be more realistically tested in larger-scale experiments.

Figure 1. Cup Burner Apparatus Used in Small-Scale Testing at NMERI.

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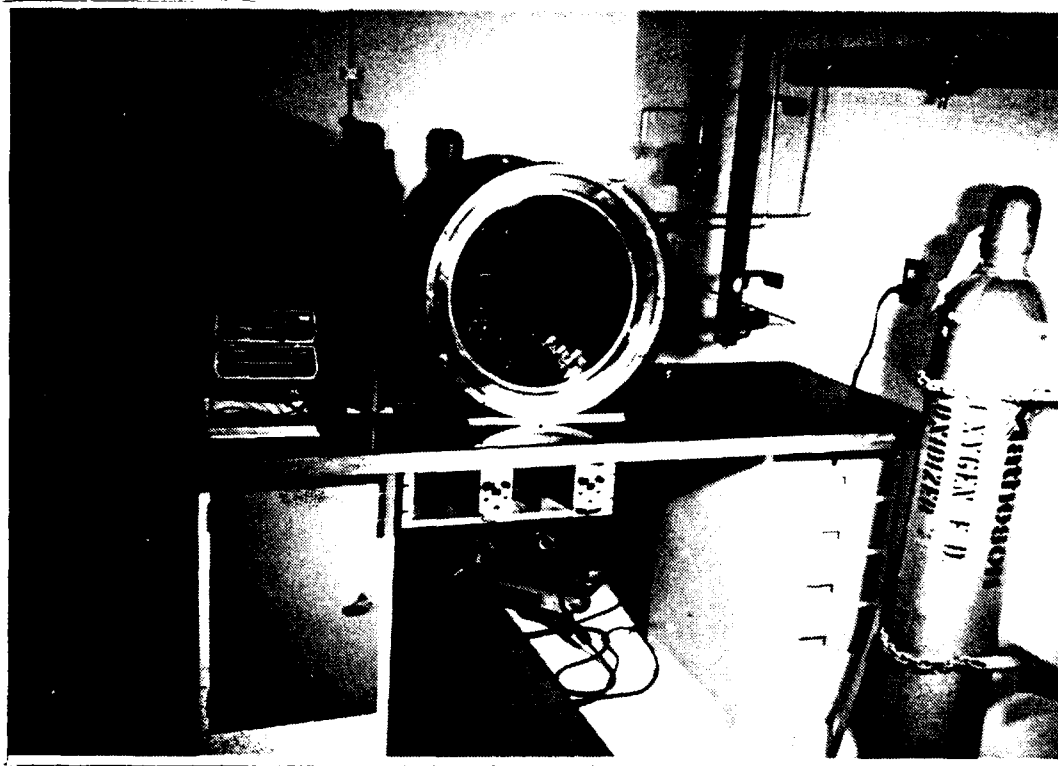
Front View
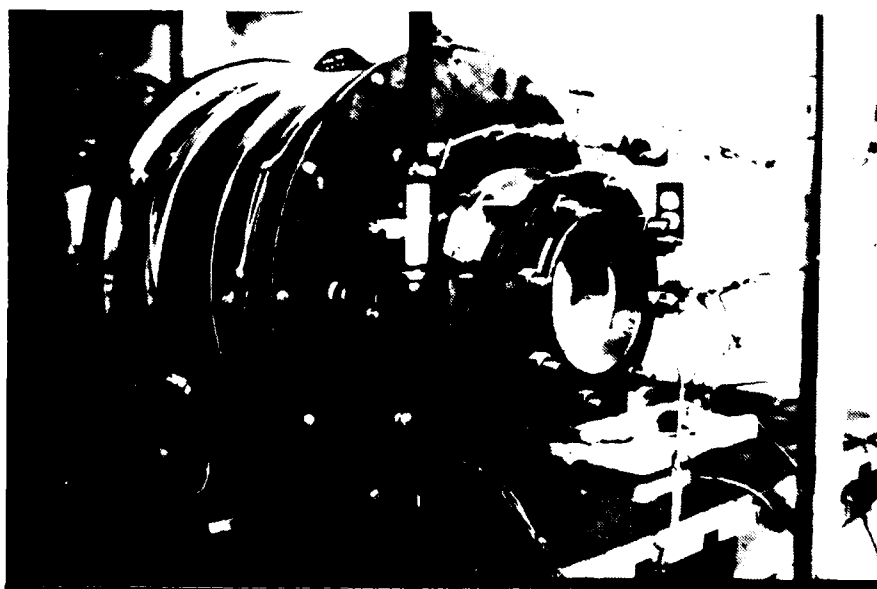


Rear View

Figure 2.  Static Chamber Used in Small-Scale Testing at NMERI.

The medium-scale experiments were designed to maintain control over atmosphere composition while increasing the scale of the test fires. The purpose of these tests was to verify the agent requirements predicted by the small-scale tests and develop scaling criteria for increased fire size. The apparatus consisted of a horizontal culvert (Figure 3) closed at one end where the atmosphere and agents were introduced. Fires were located near the closed end of the culvert. In many ways, the medium-scale apparatus was similar to the cup burner apparatus used in the small-scale tests. Again due to scale and apparatus design, multiple tests were possible.

The large-scale experiments were conducted in the forward section of a B-52 fuselage (Figure 4). The experiment was designed to test agents in realistic small-compartment aircraft fires and to evaluate additional agents and application techniques. Oxygen release simulated the rupture of an oxygen supply line at maximum pressure. The fires generated were also realistic, involving a multitude of internal aircraft components and materials. Because of the resulting damage, only a limited number of large-scale tests were possible per compartment. These tests accurately represented full-scale fires in many aircraft fire situations.

Full-scale tests were performed in the passenger/cargo compartment of a C-131A aircraft (Figure 5). The experiment was intended to verify the agent requirements and application techniques determined by previous testing for large fires in an enclosed OEA of large volume. Only a limited number of these tests were required.

End View



Side View

Figure 3. Medium-Scale Test Apparatus in Operation.

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Front View
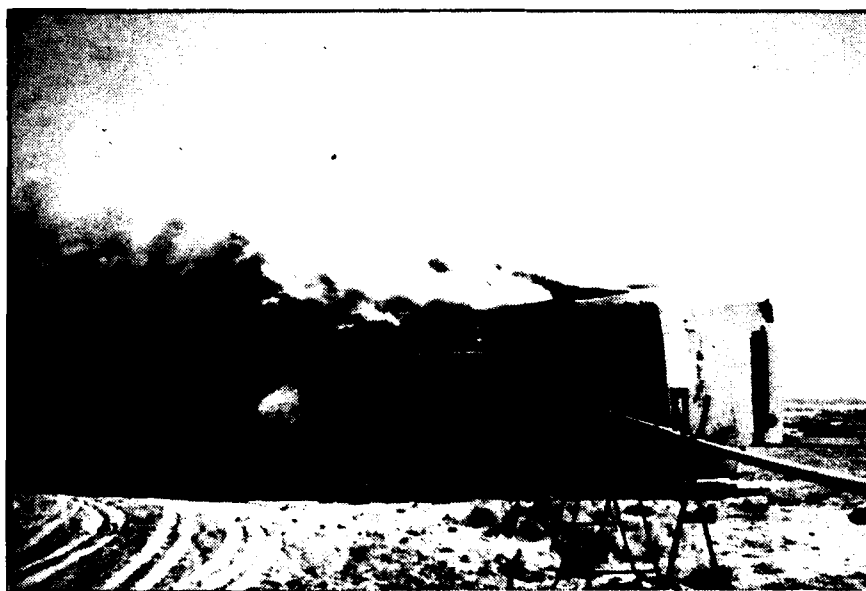


Side View

Figure 4.  Large-Scale Test in B-52 Fuselage Section.

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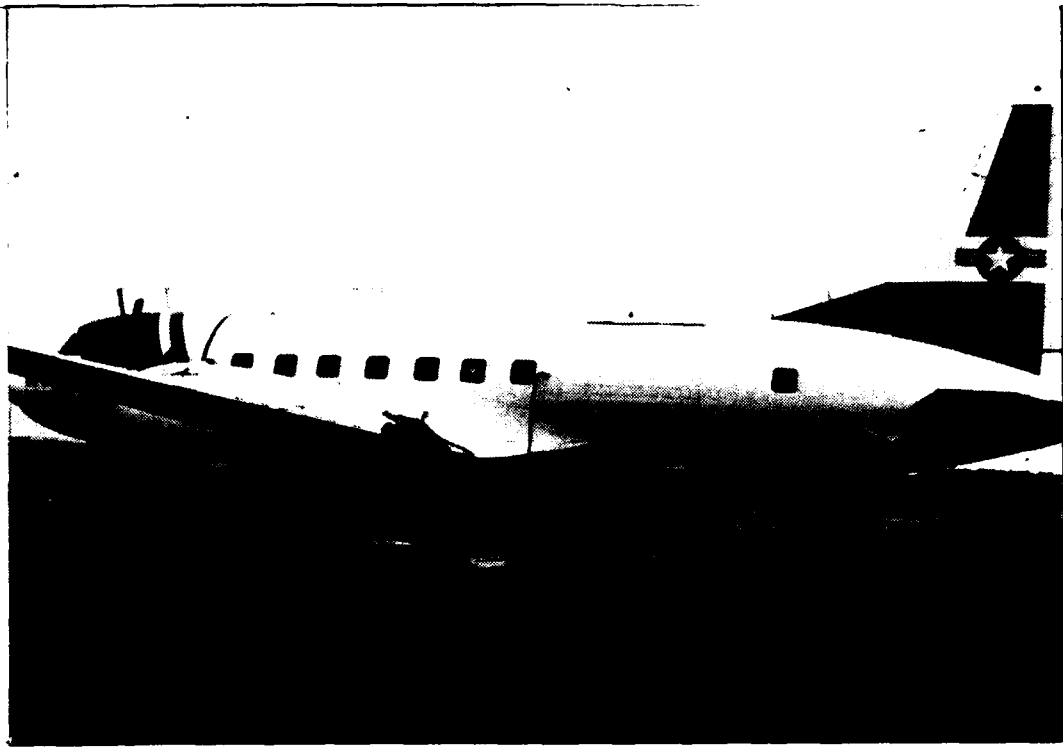
Figure 5. C-131 Aircraft During Full-Scale Tests.

# SECTION III
## SMALL-SCALE TESTS

### PURPOSE

The purpose of the small-scale OEA experiments was to quantitatively measure the agent requirements versus the atmospheric oxygen concentration. The experiments were conducted in strictly controlled environments which were comparable to previously published tests. These small-scale experiments also provided the background necessary to develop larger-scale experiments. Although these tests were not truly representative of real-world fires, the results were expected to provide a proportionality between the amount of agent required for a fire in an air atmosphere and one in an OEA. These tests were limited to the Halon extinguishing agents due to their demonstrated high efficiency in air and their ability to fill indirectly accessible volumes often present in aircraft fires. The parameters studied included percent Halon versus percent oxygen, type of Halon, total atmospheric pressure, and type of fuel.

### EXPERIMENTAL METHOD

Two types of test apparatus were used. The classical cup burner apparatus (Reference 1) was used to measure agent concentration required to extinguish a flame in a flowing atmosphere. A static premixed atmosphere chamber was used to measure agent concentrations required to prevent ignition (Reference 2) of a fuel. This represented agent requirements to prevent the spread of a fire from an ignition source to adjacent fuel. Both types of experiments expanded on previously published test results.

The cup burner apparatus (Figure 6) consisted of a glass chimney surrounding a fuel cup, supported by a long stem which also supplied fuel to the cup. An atmosphere of oxygen, nitrogen, and Halon was fed to the bottom of the chimney where it passed through a mixing bed of glass beads before flowing up the chimney past the fuel cup. The flow rate of each atmospheric component was measured, using a rotometer prior to mixing. Heating elements and insulation on the atmosphere supply lines were used to heat the incoming atmosphere for elevated temperature tests.

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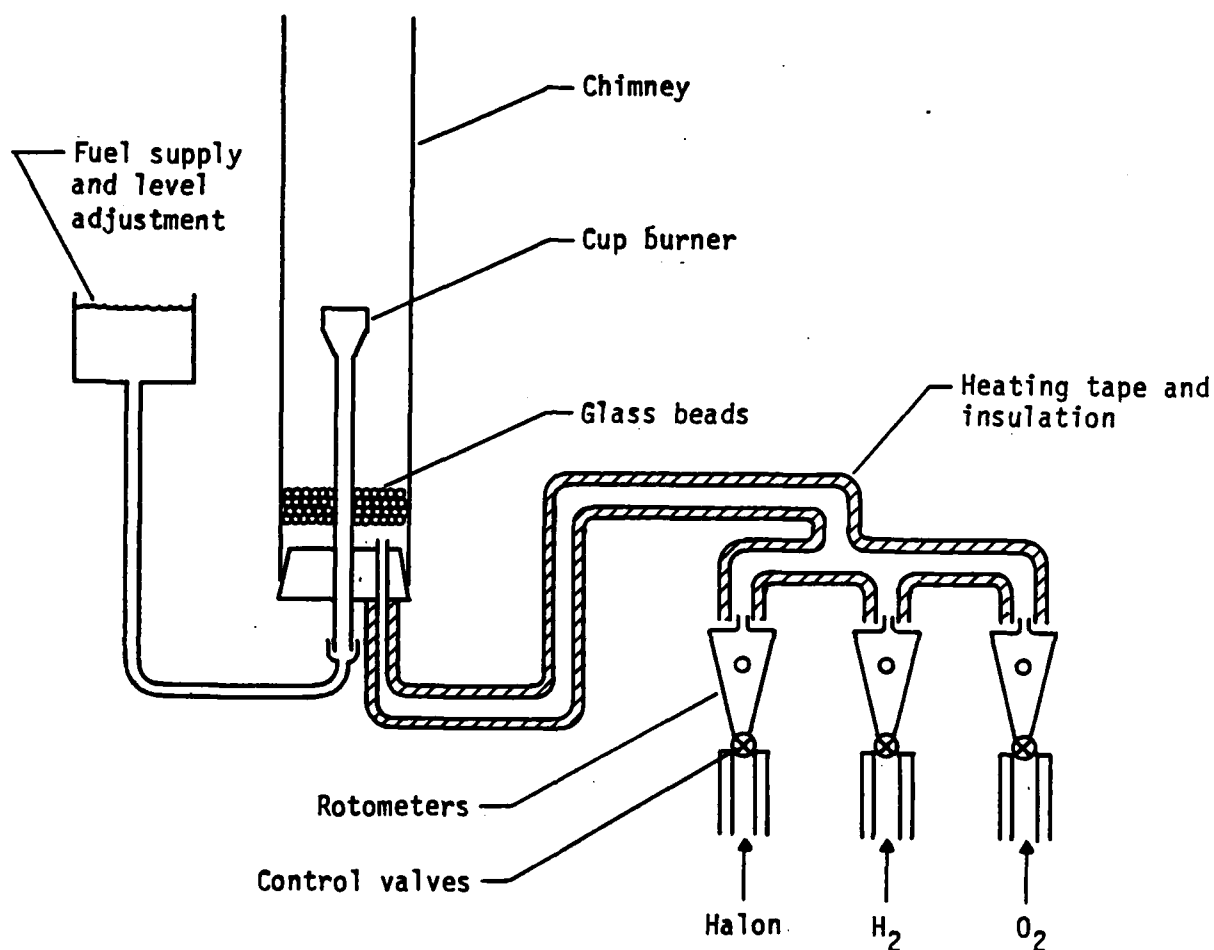
Note:
For all small-scale testing only high-purity gases were
used. These gases were purchased from Matheson with
the following specifications:

Oxygen, ultra-high purity, 99.99 percent minimum
Nitrogen, ultra-high purity, 99.999 percent minimum
Air, dry
Mixtures, primary standard of oxygen x percent
    balance in nitrogen, are ±0.02 percent absolute
    of the components used.

Figure 6.  Components of Cup Burner Apparatus.

The following describes the procedure for using the cup burner apparatus. A flowing atmosphere of nitrogen and oxygen was established in the chimney and the nitrogen and oxygen flow rates were recorded. The Halon flow rate was slowly increased until the flame was extinguished. The Halon flow rate at extinguishment was recorded. It has been shown that linear atmosphere velocities above 12 cm/s (4.7 in/s) in the chimney produce a stable flame on the cup burner and that variations in velocity above this value have no effect on the agent concentration required for extinguishment (Reference 1). The measured flow rates were corrected for pressure, temperature, and fluid density using Equation (1) and the volume percentage of each atmosphere component was determined.

$$Q_A = Q_M \ (\rho_0/\rho_a) \ \frac{P}{760} \ \left[\frac{530}{T}\right]^{1/2} \tag{1}$$

where

$Q_A$ = actual flow rate

$Q_M$ = measured flow rate

$\rho_0$ = gas density

$\rho_a$ = air density

$P$ = pressure (mm/Hg)

$T$ = temperature (°R)

Published results of extinguishing concentrations for Halons 1211, 1301, and 2402 in air and Halon 1211 in atmospheres of up to 35 percent oxygen are shown in Table 1. The fuel used was n-Heptane. It was expected that the extinguishing concentrations for Halons 1301 and 2402 would increase with increasing oxygen concentration in a similar manner to Halon 1211. It was also expected that the relationship between the extinguishing concentrations required for the three Halons would not change, i.e., more Halon 1211 would be required than Halon 1301 and more Halon 1301 would be required than Halon 2402 at a given oxygen concentration. The experiments repeated by NMERI were expected to produce slightly lower results than those listed due to the lower atmospheric pressure at Kirtland AFB [1676 meters (5500 feet)]. The fuels tested at NMERI included n-Heptane, JP-4, hydraulic fluid, and cotton duct.

TABLE 1. PREVIOUS FLAME EXTINGUISHING HALON
CONCENTRATION RESULTS (REFERENCE 1)

| Oxygen,[a] % | Halon,[b] % | | | Fuel |
|---|---|---|---|---|
| | 1211 | 1301 | 2402 | |
| 21 (AIR) | 3.8 | 3.5 | 2.1 | n-Heptane |
| | 4.4 | 4.3 | | n-Heptane (Hot) |
| 25 | 7.2 | | | n-Heptane |
| 30 | 11.8 | | | n-Heptane |
| 35 | 16.0 | | | n-Heptane |

[a]Percent oxygen of oxygen/nitrogen atmosphere before adding Halon.

[b]Percent Halon of oxygen/nitrogen/Halon atmosphere at flame extinguishment.

The apparatus for the static chamber experiments consisted of a horizontal cylinder with a Plexiglas® window at one end and a steel plate covering the other, as shown in Figure 7. Atmosphere supply lines, pressure lines, electrical lines, a fuel line, vents, and a pressure relief disc were connected to the steel plate. A fuel holder, electric ignitor coil, and a fan were located inside the cylinder. Insulation and heating elements were wrapped around the cylinder to maintain the Halon 2402 in the vapor phase during tests.

The procedure used in conducting static chamber experiments began with an evacuation of the chamber to within 20 mm Hg of absolute vacuum. The chamber was then partially filled with the extinguishing agent to be used in the test and reevacuated. This step reduces the contribution of the unknown atmosphere in the chamber prior to the test to an insignificant portion of the final test atmosphere. The chamber was then filled with the desired fractions of Halon, nitrogen, and oxygen based on partial pressures. When the desired total test pressure was achieved, the internal fan was used to mix the atmosphere. The fan was then turned off and the electric igniter was started. Ignition or

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Shutoff Valves

Rupture
Disk

Pressure
Tap

DC
Power

Vacuum
Pump

Regulators

O₂

H₂

Halon

Vent
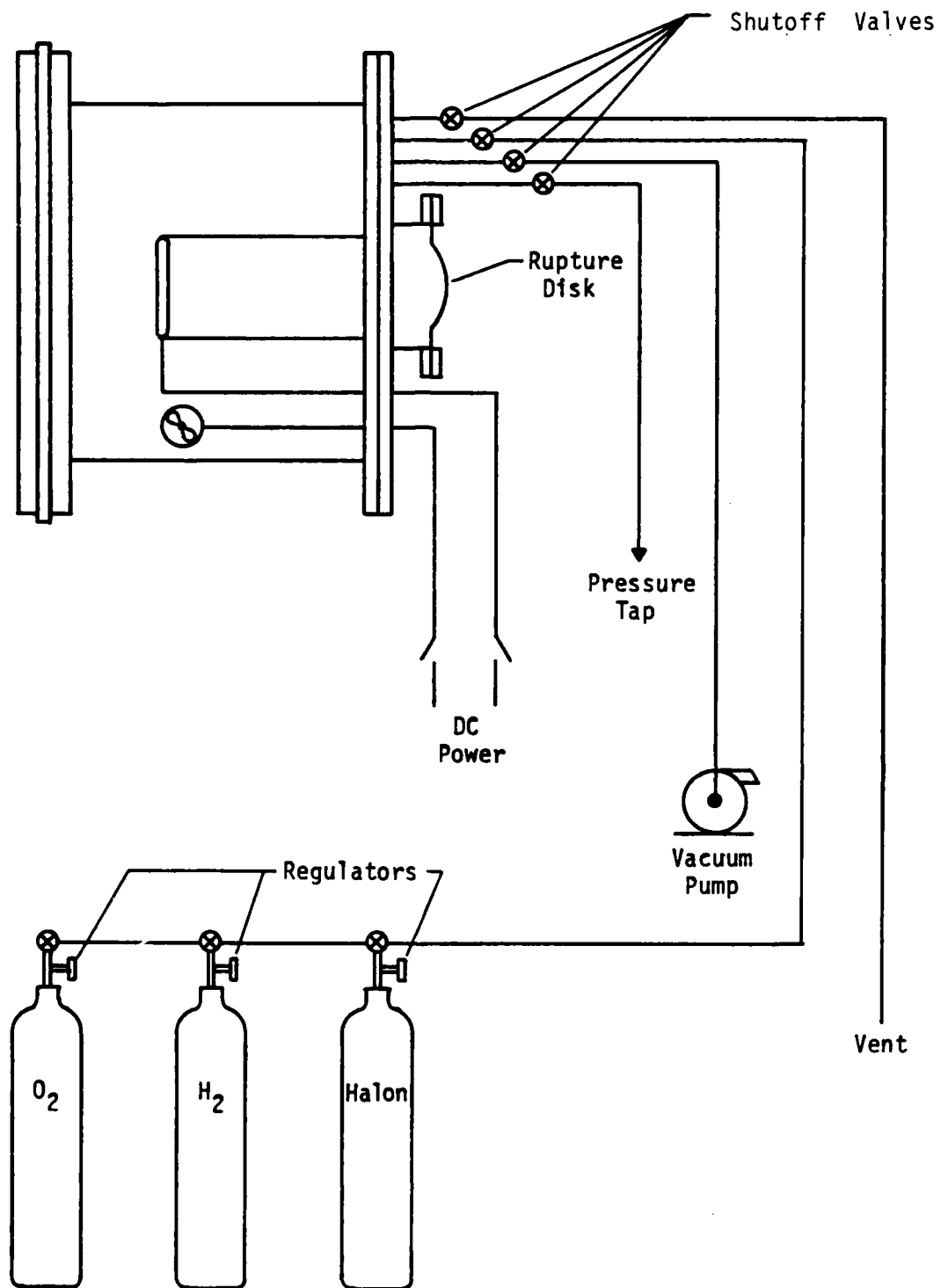
Figure 7. Static Chamber Ignition Suppression Apparatus.

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nonignition of the fuel sample was then observed. The ratio of Halon to oxygen and nitrogen was adjusted up or down until both a nonignition and an ignition test were obtained for each ratio of oxygen to nitrogen.

Results for similar tests using Halon 1301 and a variety of solid fuels are published in Reference 2. The published Halon concentrations for various oxygen/helium atmospheres and cotton fuel are listed in Table 2. It was expected that the results for Halon 1301 in oxygen/nitrogen atmospheres would be close to those listed. Halon 1211 was expected to require slightly higher concentrations,while Halon 2402 would require slightly lower concentrations. Limiting the total atmosphere pressure to 0.10 MPa (15 $lb/in^2a$) was expected to reduce the Halon required to prevent ignition,particularly at the higher oxygen concentrations.

The first series of tests performed at elevated oxygen levels demonstrated that the evaluation of ignition was not as clear cut as expected. Short-lived, self-sustaining and non-self-sustaining flames were generated over a broad range of Halon concentrations. A liberal definition of ignition was adopted for the majority of the tests. By this definition,any flames produced, even those sustained by the ignitor coil, were considered to be ignition. A number of tests were repeated at the end of the experiment, using a more conservative definition of ignition. In these tests, the flame was required to be self-sustaining for ignition to occur. Tests using the more restrictive ignition criterion were expected to produce results close to those

TABLE 2. PREVIOUS IGNITION PREVENTION HALON
CONCENTRATION RESULTS (REFERENCE 2)

| Oxygen, % | Halon 1301, % | | Fuel |
|---|---|---|---|
| | $P_{TOT} = 15 + P_{Halon}$ | $P_{TOT} = 5 + P_{Halon}$ | |
| 21 (Air) | 3 | 2 | Cotton |
| 40 | 25 | 3 | Cotton |
| 60 | 45 | 27 | Cotton |
| 80 | 54 | 45 | Cotton |
| 100 | 57 | 49 | Cotton |

observed in the flow experiments. The fuels tested included JP-4, hydraulic fluid, and cotton duct.

TEST RESULTS

Table 3 lists the results of the cup burner flow tests and Figures 8-10 show plots of Halon concentration versus oxygen concentration for the three Halons and various fuels. These tests were limited to a maximum oxygen composition of 40 percent due to the extreme heat and violent nature of the flame produced at higher oxygen levels.

A comparison of the values listed in Tables 1 and 3 shows, as was expected, that the results obtained by NMERI for flame-extinguishing Halon concentrations were slightly lower than those published in Reference 1. The Halon 1211 and 1301 concentrations measured in air by NMERI were 84 and 83 percent of the values published in Reference 1. At 28.6 percent oxygen, the NMERI data were 71 percent of the value for Halon 1211 obtained by interpolating between the 25- and 30-percent oxygen levels in Reference 1. The interpolated value for 35 percent oxygen obtained by NMERI for Halon 1211 were 79 percent of the Reference 1 value. Table 4 provides a comparison of the effectiveness of the three Halons where the Halon 1211 and 2402 requirements

TABLE 3. MEASURED FLAME EXTINGUISHING HALON CONCENTRATION

| Oxygen, % | Halon, % | | | Fuel |
|-----------|------|------|------|------|
|           | 1211 | 1301 | 2402 |      |
| 17.6      | 0.6  | 0.7  |      | n-Heptane |
| 21 (AIR)  | 3.2  | 2.9  |      | n-Heptane |
|           |      | 2.4  | 1.7  | Hydraulic fluid |
|           | 2.2  | 2.1  | 1.4  | JP-4 |
|           | 2.0  | 1.9  |      | Cotton |
| 28.6      | 7.5  | 7.3  |      | n-Heptane |
| 40.0      | 16.5 | 16.5 |      | n-Heptane |
|           | 11.6 | 12.2 | 8.8  | Hydraulic fluid |
|           | 11.2 | 10.9 | 8.0  | JP-4 |
|           | 12.3 | 10.0 | 8.4  | Cotton |

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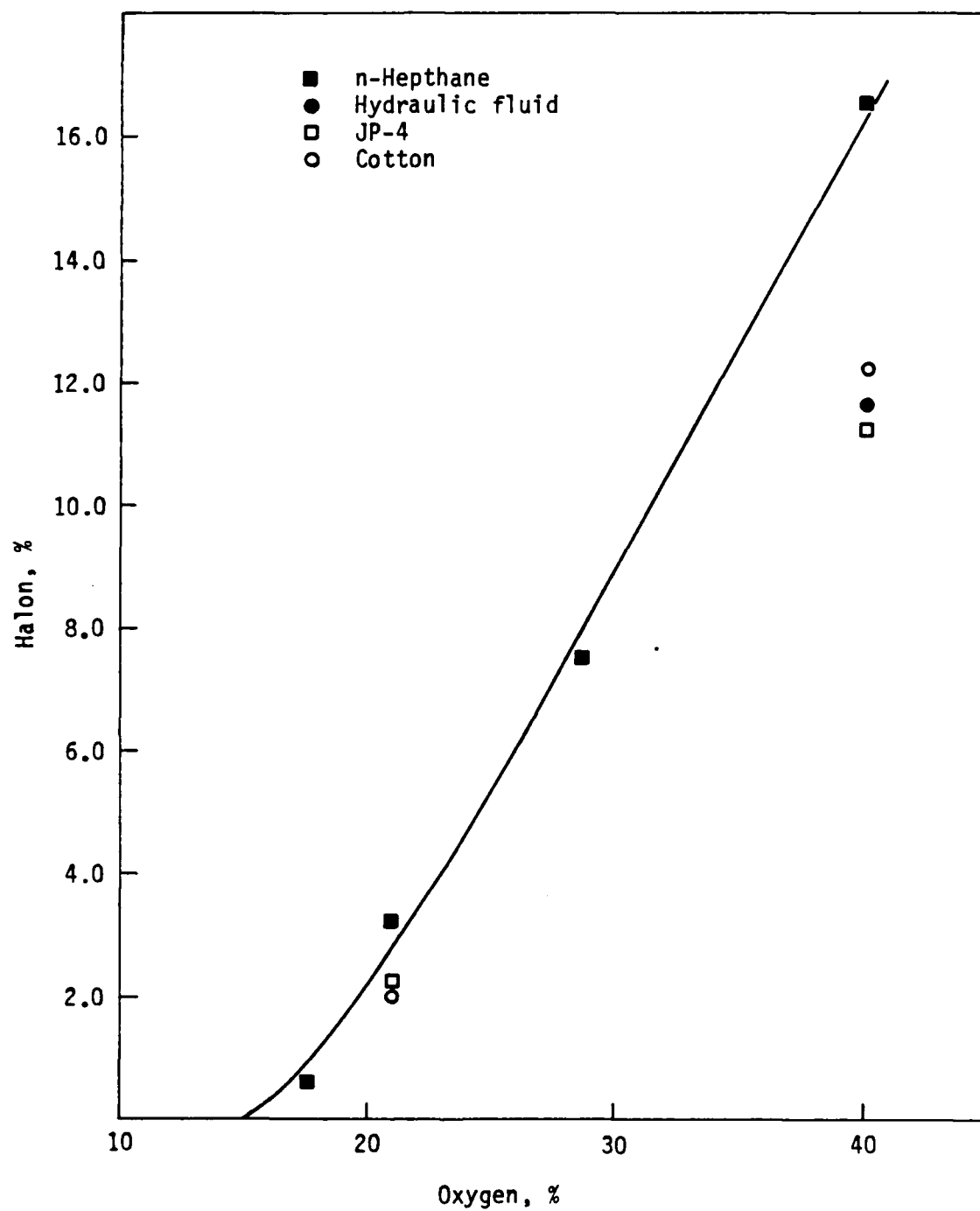
Figure 8. Halon 1211 Flame-Extinguishing Concentrations.
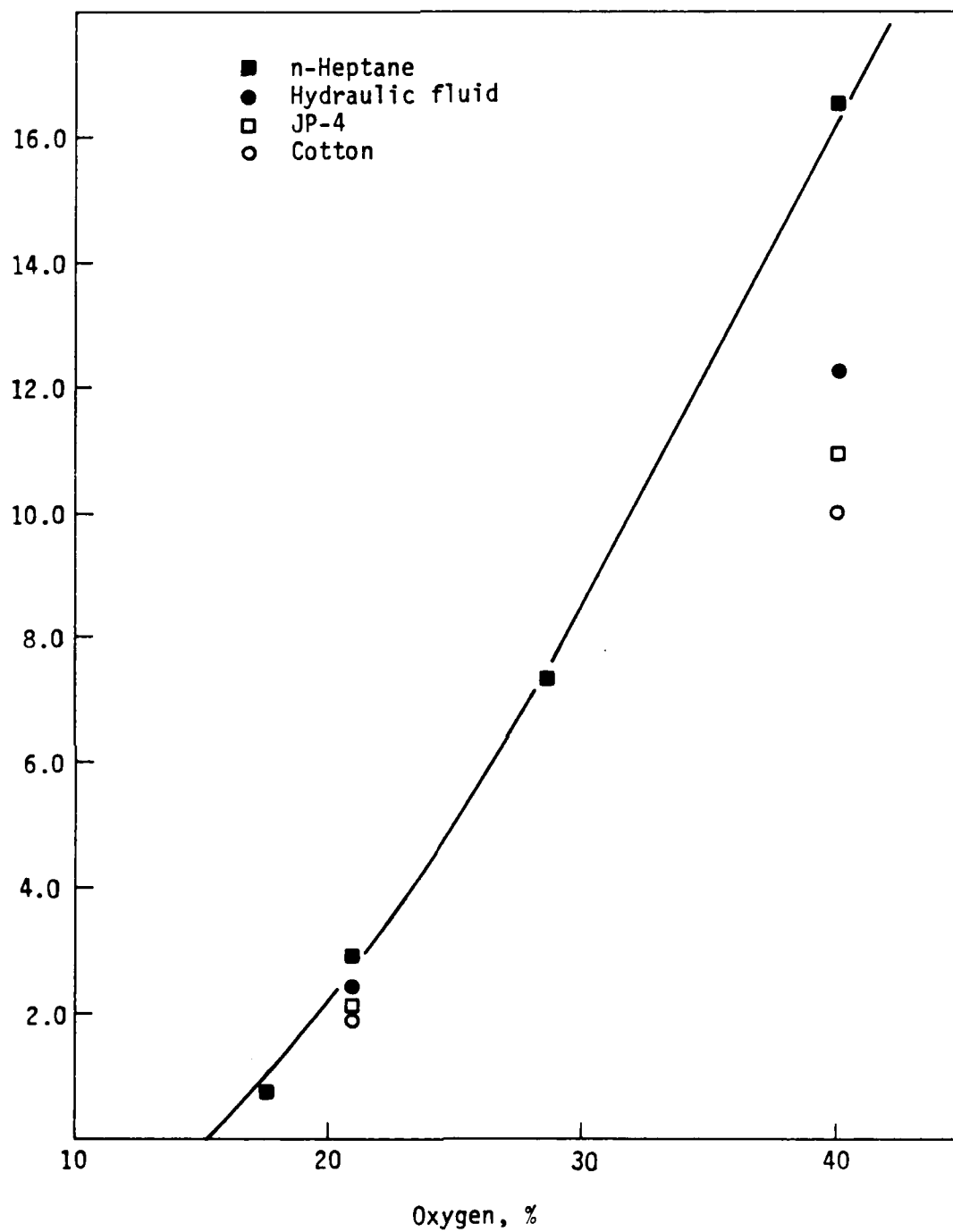
Figure 9.  Halon 1301 Flame-Extinguishing Concentrations.
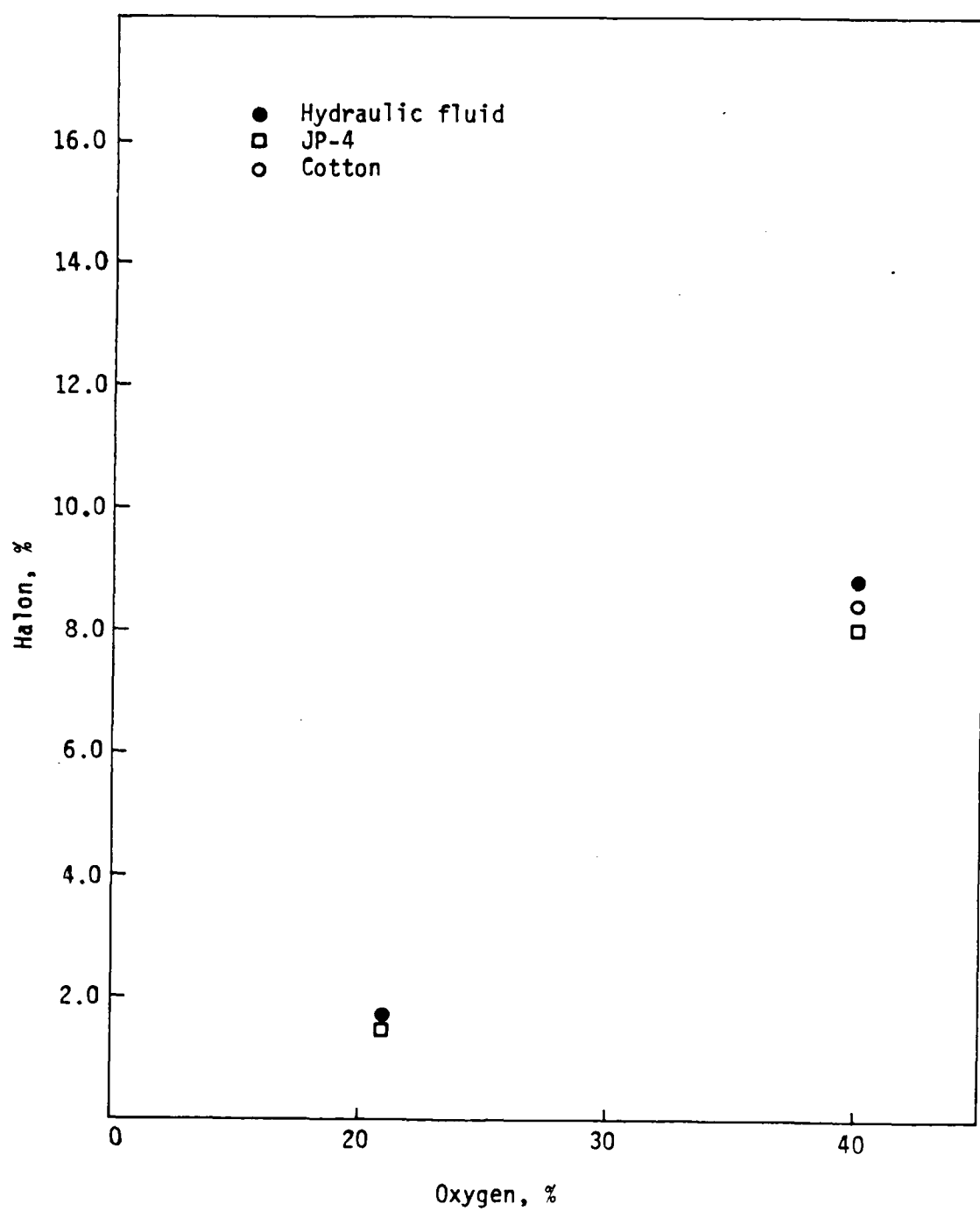
Figure 10. Halon 2402 Flame-Extinguishing Concentrations.

TABLE 4. HALON COMPARISON FOR FLAME EXTINGUISHMENT

| Oxygen, % | Halon, % (normalized to 1301) | | | Fuel |
|---|---|---|---|---|
| | 1211 | 1301 | 2402 | |
| 17.6 | 0.86 | 1.00 | | n-Heptane |
| 21.0 | 1.10 | 1.00 | | n-Heptane |
| | | 1.00 | 0.71 | Hydraulic fluid |
| | 1.05 | 1.00 | 0.67 | JP-4 |
| | 1.05 | 1.00 | | Cotton |
| 28.6 | 1.03 | 1.00 | | n-Heptane |
| 40.0 | 1.00 | 1.00 | | n-Heptane |
| | 0.95 | 1.00 | 0.72 | Hydraulic fluid |
| | 1.03 | 1.00 | 0.73 | JP-4 |
| | 1.23 | 1.00 | 0.84 | Cotton |

are normalized to the Halon 1301 requirements for each fuel and oxygen concentration. The Halon 1211 requirements ranged from 85 to 123 percent of the Halon 1301 required, while 67 to 84 percent of the Halon 1301 concentration was required to extinguish the flame using Halon 2402. Table 5 shows, for all fuels and all Halons, that the Halon concentration required to extinguish a flame increases more than 500 percent when the oxygen concentration was increased from 21 percent (air) to 40 percent.

The results of the static chamber tests are listed in Table 6. Figures 11-13 show plots of the same data. It was expected that the Halon 1301 concentrations measured at NMERI would fall between the values published in Reference 2 for high and low atmosphere pressures. Comparing Tables 2 and 6, show that all of the NMERI values for Halon 1301 and cotton duct at increased oxygen concentrations were well above the values from Reference 2. This is probably due to the liberal ignition criterion used in the NMERI tests. Comparing the more conservative ignition criteria values for Halon 1211 and cotton duct from Table 6 with Table 2 shows close agreement. The results showed no discernable difference between the concentration requirements of Halon 1301 and 2402. The results also show that the concentration of Halon 1211 required was the same as or higher than the other Halons. Comparison also shows that the increment in Halon concentration between ignition and

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TABLE 5.  FLAME-EXTINGUISHING HALON CONCENTRATION
INCREASE FOR 40 PERCENT OXYGEN ATMOSPHERE

| Halon Increase, % | | | Fuel |
|---|---|---|---|
| 1211 | 1301 | 2402 | |
| 516 | 569 | | n-Heptane |
| | 508 | 518 | Hydraulic fluid |
| 509 | 519 | 571 | JP-4 |
| 615 | 526 | | Cotton |
| 547 | 531 | 545 | Average |

TABLE 6.  IGNITION PREVENTION HALON CONCENTRATIONS

| Oxygen, % | Halon (Ignition-Nonignition), % | | | Fuel |
|---|---|---|---|---|
| | 1211 | 1301 | 2402 | |
| 21 | 0-3 | 3-3.8 | 0-3 | Cotton |
| | 11-13 | 8-13 | 8-13 | JP-4 |
| 40 | 30-40 | 30-35 | 30-40 | Cotton |
| | 10-20 | | | Low ignition |
| | 30-40 | | | Low ignition and high pressure |
| | 50--- | | | High pressure |
| | 50-60 | 40-50 | 40-50 | JP-4 |
| | 10-20 | | | Low ignition |
| | 20-30 | | | Low ignition and high pressure |
| | 50--- | | | High pressure |
| 60 | 60-70 | 50-55 | 50-60 | Cotton |
| 100 | 70-80 | 60-65 | 60--- | Cotton |
| | 70-80 | 70-80 | 70-80 | JP-4 |
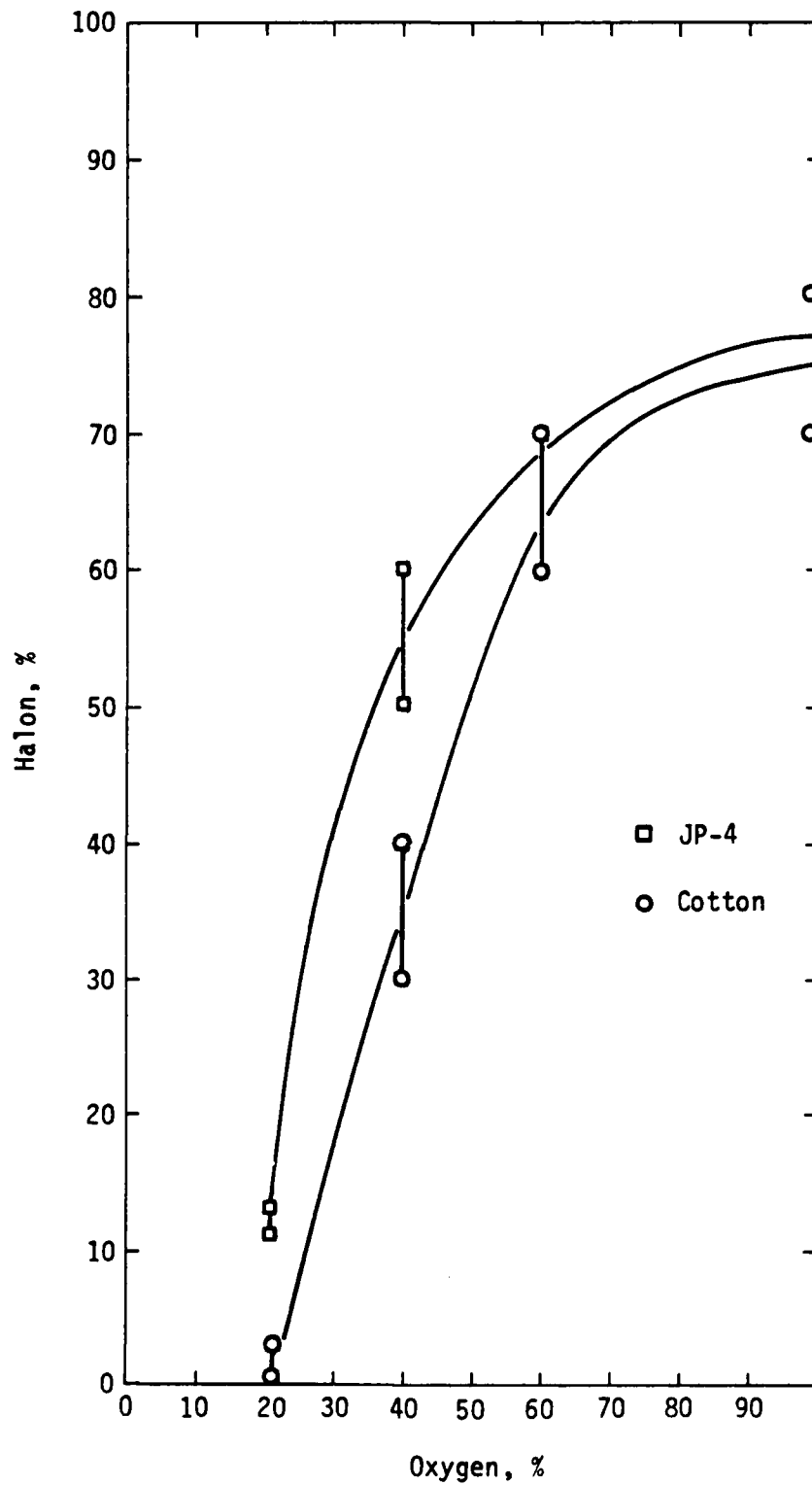
Figure 11.   Halon 1211 Ignition-Prevention Concentrations
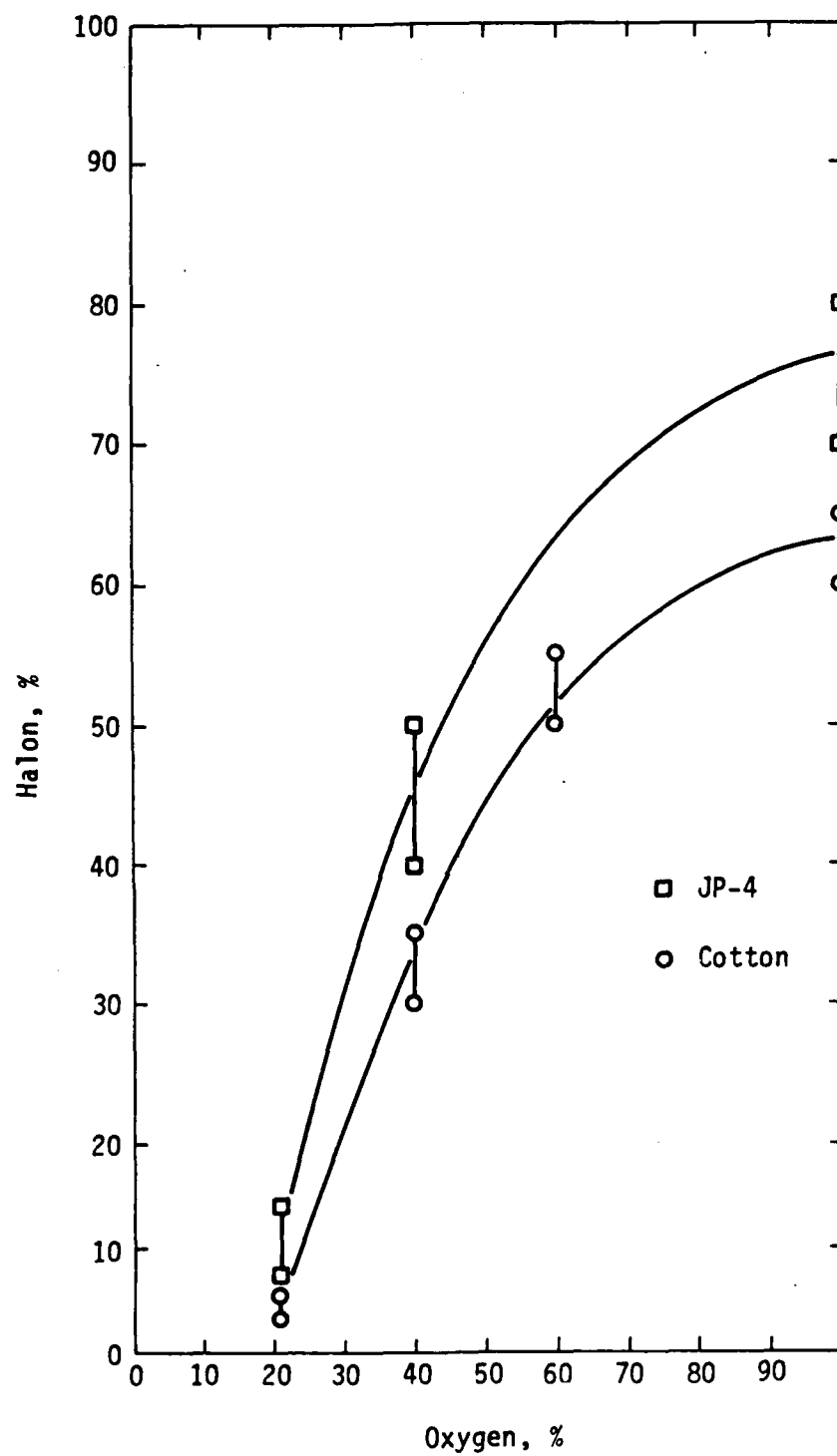
Figure 12.   Halon 1301 Ignition-Prevention Concentrations.
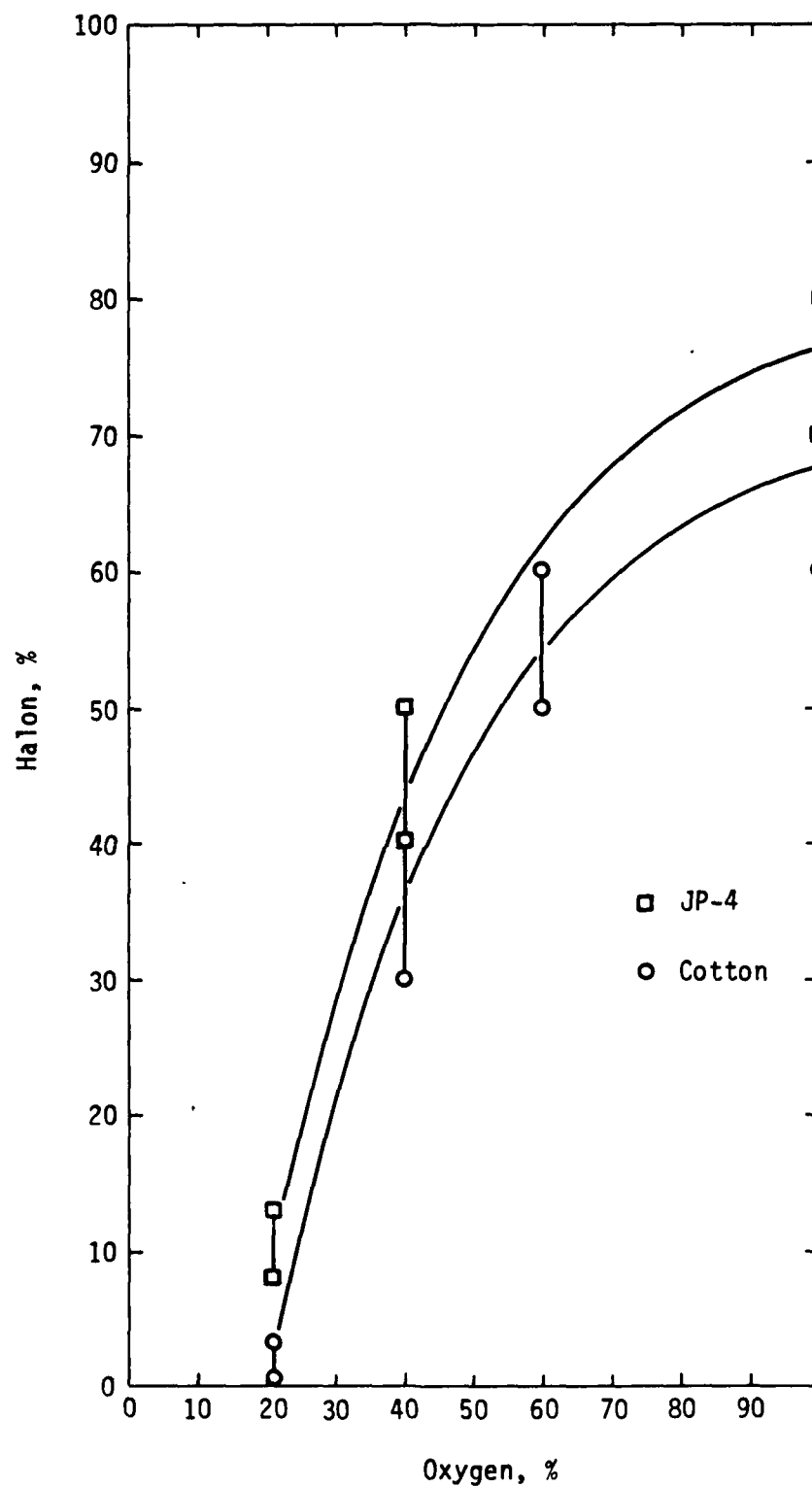
Figure 13. Halon 2402 Ignition-Prevention Concentrations.

nonignition was, in most oxygen-rich cases, 10 percent. Thus, the differences between the concentration of the different Halons required to prevent ignition within each 10-percent increment were not distinguishable. The data again show the rapid increase in Halon concentrations required to prevent ignition with increasing oxygen concentration.

CONCLUSIONS

Two distinct types of small-scale experiments were performed to measure Halon requirements for combatting fires in oxygen-enriched atmospheres. The first series of cup burner tests measured the Halon required to extinguish a flame in atmospheres ranging from 17.6 to 40 percent oxygen. During testing with air and n-Heptane fires, $CO_2$ and $N_2$ were tested as extinguishing agents. The percentages needed for extinguishment were 19.59 percent $CO_2$ and 85.6 percent total $N_2$ concentration. The results of these tests agreed closely with data published previously in Reference 1 and extended the published data to Halons and additional fuels.

These cup burner tests showed a requirement for an increase of more than 500 percent in Halon concentration to extinguish a flame when the oxygen fraction of the atmosphere was increased from 21 percent to 40 percent regardless of the fuel and Halon used. The oxygen concentration was limited to 40 percent in these experiments because the flame produced at higher oxygen concentrations was too violent for the apparatus to handle.

The second series of tests measured the Halon required to prevent ignition of a fuel in oxygen-enriched atmospheres ranging from 21 to 100 percent oxygen. It was believed that these tests would more realistically represent the requirements for extinguishing deep-seated fires and preventing the spread of the fire due to persistent heat sources expected in aircraft fires. The results obtained in these tests were significantly higher than the data listed in Reference 2. It is believed that the discrepancy was due to the liberal definition of ignition utilized during testing. A number of tests were performed using more conservative ignition criteria which agreed closely with the data in Reference 2. The previous data were extended to Halon 1211 and Halon 2402 and to JP-4 fuel during this experiment. Halon requirements in air

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increased by 400 percent to more than 1000 percent at 40 percent oxygen and by 500 percent to more than 2000 percent at 100 percent oxygen depending on fuel type.

Both of these experiments demonstrated the drastic increase in Halon required to combat fires in an OEA regardless of fuel or Halon type used. These results indicate the undesirability of attempting to combat local fires in an OEA using a full-flood Halon technique and, conversely, the advantage, and possibly the essential requirement, of applying the Halons directly to the fire at the point of highest oxygen concentration. The small-scale experiments indicated that between 5 to 20 times as much Halon is required to fight a fire in an OEA as that required to fight the same fire in air.

# SECTION IV
## MEDIUM-SCALE TESTS

### PURPOSE

The purpose of the medium-scale experiment was to extend the results of the small-scale tests to larger fires and to develop scaling techniques if necessary. Control of the atmosphere composition and fire configuration were maintained during these tests allowing the results to be verified through repetition. The hypotheses generated at the end of the small-scale experiments were tested during the medium-scale experiments. The medium-scale tests also provided the opportunity to develop the supply and control systems and the safe operating procedures that would be required in performing the large- and full-scale experiments.

### EXPERIMENTAL METHOD

Medium-scale tests were conducted in a horizontal cylinder that was closed at one end. Oxygen, nitrogen, and Halon supply lines entered the cylinder at the closed end as shown in Figure 14. Remotely actuated valves for atmosphere and extinguishing agent control were located as close to the outside of the test cylinder as possible. A window and a video camera were located at the closed end of the test cylinder. A spray bar supported above the test cylinder provided cooling water to the outside of the cylinder. Basically, the medium-scale apparatus represented a larger version of the small-scale flame-extinguishing apparatus oriented in a horizontal direction.

Oxygen and nitrogen were supplied to injector tubes from high-pressure gas cylinders. The supply pressure was regulated at the outlet of the gas cylinders and flow was controlled by solenoid valves located immediately outside the test cylinder. Flow rate was controlled by regulating the supply pressure. Each system was calibrated by determining gas flow rate at selected regulator pressures using the weight-loss method. The weight-loss method consisted of weighing the supply cylinder, allowing the gas to flow through the delivery system at a constant supply pressure for a measured amount of time, and then weighing the supply cylinder again. The weight difference divided by the duration of the flow determined the flow rate of the system for
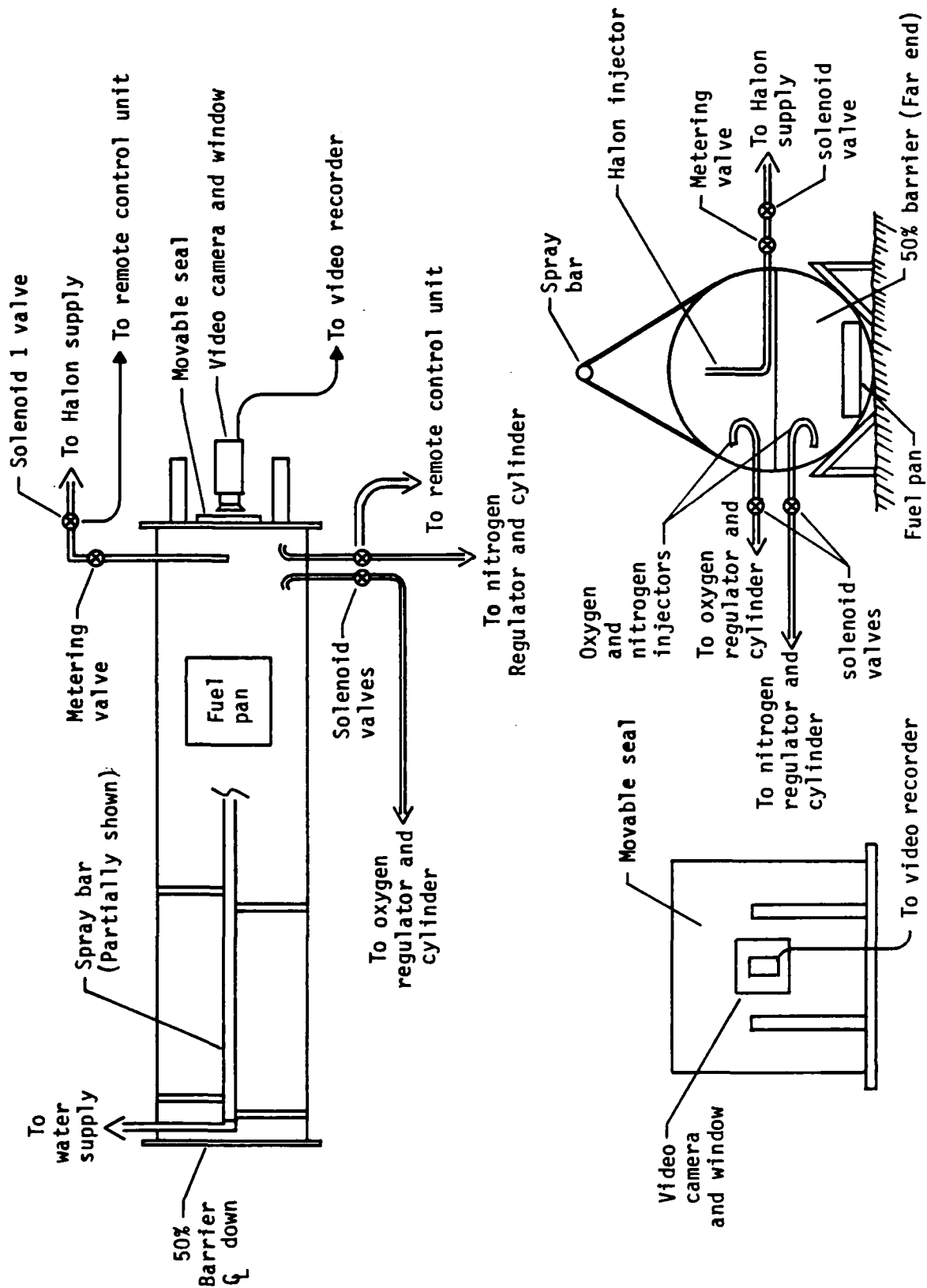
Figure 14. Medium-Scale Apparatus.

the selected supply pressure. Using this information, only the gas supply pressure needed to be recorded during fire tests to establish the flow rate of each atmosphere component.

The Halons were supplied to an injector from pressurized cylinders. A metering valve and a solenoid valve located as close to the injector as possible were used to control agent flow. The metering valve setting determined the flow rate and the solenoid valve was used to start and stop flow. The system was calibrated for each agent at a range of metering valve settings and supply pressures using the weight-loss method. Calibration of the Halon systems was conducted after the tests were completed so the supply pressures and metering valve settings of interest were known. Supply pressure and metering valve settings were recorded during tests.

The oxygen and nitrogen injectors were arranged so that the gases were directed against the walls of the test cylinder to break up the jet and cause turbulence that helped mix the atmosphere before it reached the fire. The Halon injector also directed the extinguishing agent against the test cylinder wall for the same reason.

The procedure used in conducting the medium-scale tests consisted of the following steps. The oxygen/nitrogen ratio for the test was established by setting the regulated supply pressures for each gas with the solenoid valves open. The solenoid valves were then closed. An initial Halon-metering valve setting was selected. The fuel pan was then ignited and the end of the test cylinder was sealed. The oxygen and nitrogen flows were initiated using the remotely controlled solenoid valves and the fire was allowed to burn for a fixed preburn interval. Halon application was initiated and maintained for a fixed-time interval of 10 seconds using the remotely controlled solenoid valve. Following Halon application, an interval of 20 seconds was allowed to let the fire become reestablished, if it was not extinguished. During this time period, the Halon metering valve was adjusted to the next highest setting. If the fire was not extinguished, the steps beginning with Halon application were repeated. This process continued until the fire was extinguished. The Halon supply pressure and metering valve setting were recorded before and after each application. The final metering valve setting and supply pressure determined the Halon flow rate necessary to extinguish the

fire at the preset oxygen/nitrogen ratio and flow rates. The oxygen concentration was determined by comparing the oxygen flow rate to the combined oxygen and nitrogen flow rate. The Halon concentration was determined by comparing the Halon flow rate to the combined oxygen, nitrogen, and Halon flow rates. Each test, i.e., oxygen concentration and Halon type, was repeated three times to verify the results. Halon type and oxygen concentration were the only parameters studied during these tests.

TEST RESULTS

The results of the medium-scale testing are listed in Table 7. Two data points were obtained during these tests, one for Halon 1211 at 40-percent oxygen and one for Halon 2402 at 40-percent oxygen. Both values were obtained through repeated testing providing a high degree of confidence in the results. Considerable experience with oxygen supply systems, OEA characteristics in larger volumes and fires, the operation of support systems monitoring these fires, and the development of safe operating procedures for testing in this environment proved invaluable during large- and full-scale tests. Halon 1301 was excluded from these tests because it was not considered realistic for use in a flightline environment and it did not provide a significant performance advantage over the other two Halons used during small-scale tests.

TABLE 7. MEDIUM-SCALE TEST RESULTS

| | Halon 1211 | Halon 2402 |
|---|---|---|
| $O_2$ flow rate, units | 9.2 liters/sec | |
| $N_2$ flow rate, units | 12.1 liters/sec | |
| Oxygen concentration, % as $[O_2/(O_2+N_2)]$ | 43.2% | |
| Halon flow rate, units | 4.25 liters/sec | 2.94 liters/sec |
| Halon concentration, % as $[Halon/(Halon+ O_2+N_2)]$ | 16.6% | 12.13% |

CONCLUSIONS

Comparing the medium-scale results with the 40-percent oxygen small-scale results shows close correlation. The medium-scale results were consistently slightly less than those obtained in the small-scale tests. It is believed

that the lower Halon requirements observed in medium-scale tests were due to the lower flame stability on the fuel pan in the turbulent crossflow atmosphere present in the medium-scale apparatus. The small discrepancy between the two test scales indicated there was no need to develop further scaling techniques.

Observation of the fire during the medium-scale tests revealed that there was an intense jet of flame where the swirl of the advancing OEA first crossed the fuel pan. However, the flame rapidly decreased to what appeared to be a normal non-oxygen-rich flame towards the trailing edge of the fuel pan. This effect indicates that oxygen enrichment of the atmosphere decreases rapidly in the vicinity of a fire. The intense jet of flame observed in the medium-scale tests, where the atmosphere is premixed to a uniform oxygen concentration before reaching the fire, should be accentuated in a situation where fire is exposed to a jet of pure oxygen from a ruptured oxygen line in an aircraft fire. An intense flame would be expected where the oxygen jet first intersects the fire. However, this area of intensity would be limited since the fire would consume the oxygen rapidly. This situation reinforces the observation made at the conclusion of the small-scale testing that suggested direct application of Halon to the fire at the location of highest oxygen concentration may be essential to successfully extinguish the fire.

# SECTION V
## LARGE-SCALE TESTS

## PURPOSE

The purpose of the large-scale test program was to test agents in
realistic oxygen-enriched atmosphere aircraft fires. Fires were established
in the forward section of a B-52 fuselage. The fire configuration, oxygen
supply and agent application were all representative of actual aircraft fire
situations. In addition to JP-4 fuel, aircraft interior materials were also
tested in the fires. The agents AFFF and PKP were also tested during these
experiments. Fires were limited to relatively small compartments, providing
an intermediate step before testing in the wide-body aircraft during full-
scale tests. The test specifics were a fuel fire on an airplane which had
suffered frame damage and was no longer airtight. Because of the considerable
skin damage to the plane before testing started there was no way to seal the
airplane. This was an advantage because it provided useful results concerning
oxygen-enriched fires in damaged compartments.

In addition to testing the extinguishing agents, a new agent applicator
was tested in the large-scale tests. A skin-penetrator tool recently devel-
oped by the Air Force for delivering agents to the interior of an aircraft
appeared to be ideal for applying agents directly on fires at the point of
highest oxygen concentration.

## EXPERIMENTAL METHOD

The large-scale tests were conducted in the forward section of a B-52
fuselage. The configuration of the apparatus is shown in Figure 15. A 1016-
by 1524-millimeter (40- by 60-inch) fuel pan was located on the floor of the
cockpit area immediately behind the pilot and copilot seats. Oxygen was
supplied from a liquid oxygen Dewar flask after passing through a vapor gene-
rator. The oxygen delivery system including the Dewar flask, supply lines,
and control valves were designed to simulate the oxygen flow rate that would
be produced by a ruptured 7.9-millimeter (5/16-inch) oxygen line at a pressure
of 2.76 MPa (400 lb/in$^2$). The oxygen supply lines entered the rear of the
cockpit through an access hatch. Two injectors located at the rear of the

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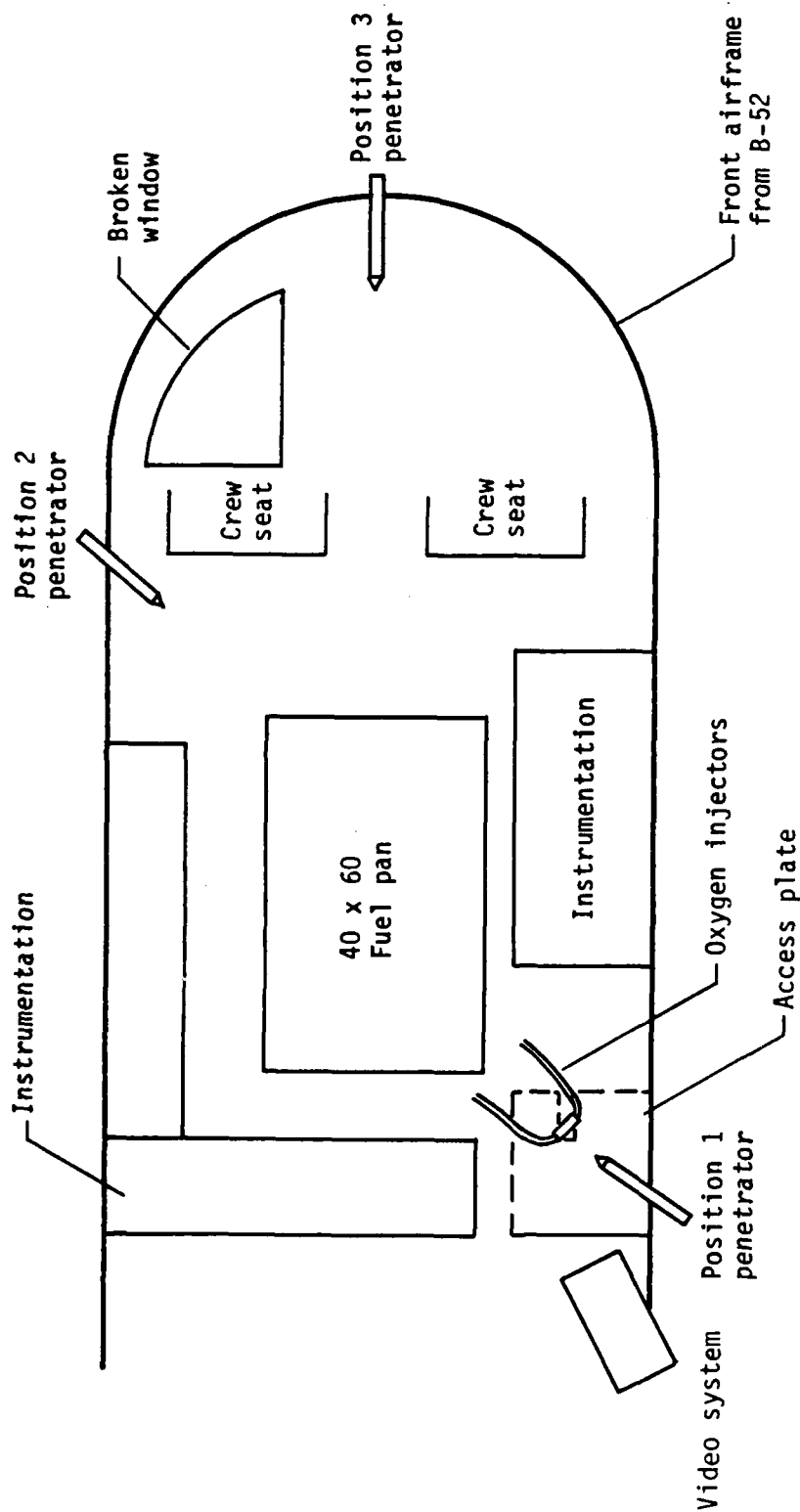
Figure 15. Large-Scale Test Setup.

Note: All dimensions in inches
unless otherwise specified.

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cockpit directed the oxygen flow across the fuel pan towards the front of the cockpit and through a missing window. Small-scale results showed an increased concentration of Halon was needed to suppress an oxygen-enriched fire. This effect was confirmed by tests on the B-52. To fight oxygen-enriched fires effectively, a penetrator tool was used. The penetrator tool designed by the Air Force allows Halon to be applied to the inside of an airplane close to the source of the fire. A hole is drilled through the outer skin layers, using a hardened steel bit driven by an air drill. Once inside the aircraft, Halon is injected through a series of orifices located behind the drill bit. This allows a firefighter to apply Halon close to the fire source without risking himself or adding air to the fire, e.g., opening a door. The penetrator can then be used to apply a high concentration of directed Halon in a small area. Simulated penetrator tool nozzles injected extinguishing agents from three positions. Position 1 was located behind the oxygen injectors, Position 2 was located below the missing window, and Position 3 injected agents through a small window at the front of the aircraft. Halons 1211 and 2402 were applied from the first and second positions at different pressures.

The agents were injected either with or counter to the flow of oxygen. Another penetrator nozzle was located directly over the fuel pan to provide a backup extinguishing capability. This backup was necessary if the test agent failed to extinguish the fire. Halon 1211 was used as the backup extinguishing agent. Oxygen and Halon flows were controlled by remotely actuated solenoid valves. The AFFF and PKP flows were manually controlled at the supply tanks. Modified 37.9-liter (10-gallon) CB extinguisher tanks were used as agent supply tanks in all but the AFFF tests. AFFF was supplied from a skid-mounted 1136-liter (300-gallon) pressurized tank on an XP-13 fire truck. The oxygen flow rate was determined by using the weight-loss method described in Section IV. The quantity of agent applied during a test was determined by weighing the agent supply tank before and after each test for all agents except AFFF. A flow rate for AFFF was determined by measuring the weight of the agent discharged during a measured time interval. The quantity of AFFF used during a test was then determined by measuring the time interval the agent was applied and multiplying that by the predetermined flow rate $(M = Q \Delta T)$.

The test procedure consisted of igniting the fuel pan, allowing a 20-second preburn, initiating oxygen flow, allowing an additional 10-second preburn and then applying the agent. The agents were applied for fixed-time intervals depending on the test. An oxygen flow rate of 0.129 lb/s was used for all tests. In the course of testing, considerable damage was done to the front compartment. As a result, corrugated metal panels were constructed to reinforce the roof of the aircraft. Halon 1211, Halon 2402, AFFF and PKP were tested. Halon 1301 was not tested because it was not considered a realistic agent for open-air use.

During testing, Halons injected through the penetrators at positions one and two worked effectively with or counter to the oxygen flow. In the counterflow orientation suppression was difficult to obtain. At reduced charging pressures with Halon 1211 suppression did not occur. Though suppression occured in most of the fires, actual extinguishment of the fire was difficult because reignition kept occuring. In all cases, Halon 2402 was more effective in suppressing the fire than Halon 1211. This was especially dramatized in the counterflow condition. During Test 5, Halon 1211 did not suppress the fire. However, under the same conditions (Test 8), using Halon 2402, suppression was obtained. In suppressing the fire in a counterflow condition, liquid Halon 2402 penetrated the fire more effectively and final extinguishment was easier to obtain. Some of this may be due to the heat absorption by Halon 2402 as it changes from a liquid to a gas.

TEST RESULTS

The results of the large-scale test program are shown in Table 8. A description of each test follows.

Test 1-3

In tests 1-3 the system was checked out.

Test 4

In Test 4, the penetrator was positioned to inject the agent with the flow of oxygen. The storage cylinder was charged to 0.7 MPa (100 lb/in$^2$) at the start of the test. During the test, Halon 1211 was injected into the fuselage for 5 seconds. Suppression was accomplished. Halon usage was lost in an attempt to extinguish the fire.

TABLE 8. LARGE-SCALE TEST RESULTS

| Test no. | Flow type | Agent | Weight change kg | (lb) | Charging Pressure, MPa | (lb/in²) | Test Results | Comments |
|---|---|---|---|---|---|---|---|---|
| 1-3 | --- | --- | --- | --- | --- | --- | --- | System check out |
| 4 | With flow | 1211 | N/A | | 0.7 | (100) | Suppression | |
| 5 | Counterflow | 1211 | N/A | | 0.7 | (100) | No suppresion | Stuck valve |
| 6 | With flow | 1211 | 3.7 | (8.25) | 0.7 | (100) | No suppression | |
| 7 | Counterflow | 1211 | 10.8 | (23.9) | 1.0 | (150) | Suppression | |
| 8 | Counterflow | 2402 | 12.4 | (27.4) | 0.7 | (100) | Suppression | |
| 9 | With flow | 2402 | 8.7 | (19.2) | 0.7 | (100) | Suppression | |
| 10 | With flow | 2402 | 7.6 | (16.8) | 0.7 | (100) | No suppression | Three-second burst |
| 11 | With flow | 2402 | 9.4 | (20.7) | 0.7 | (100) | Suppression | |
| 12 | Counterflow | 2402 | 14 | (31) | 0.34 | (50) | Suppression | |
| 13 to 15 | --- | --- | --- | --- | --- | --- | --- | Test of Halon 1301 stopped because of safety considerations |
| 16 to 19 | Both | AFFF | N/A | | 1.0 | (150) | No effect on fire | |
| 20 | Neither | PKP | 30.8 | (156) | 1.0 | (150) | Suppression | Flow rate of 3.5 kg/s (7.8 lb/s) |
| 21 | Neither | AFFF | 9.7<br>19.3 | (21.3)<br>(42.6) | 1.0<br>1.0 | (150)<br>(150) | No suppression<br>Suppression | Flow rate of 1.93 kg/s (4.25 lb/s)v |

## Test 5

In Test 5, the penetrator was positioned to inject the agent counter to the flow of oxygen. The storage cylinder was charged to 0.7 MPa (100 lb/in²) at the start of the test. During the test, Halon 1211 was injected into the fuselage for 5 seconds. Suppression was not obtained, Halon usage was lost in an attempt to extinguish the fire. After the test a backup system was installed so Halon usage could be recorded.

## Test 6

In Test 6, the penetrator was positioned to inject the agent with the flow of oxygen. The storage cylinder was charged to 0.7 MPa (100 lb/in²) at the start of the test. During the test, Halon 1211 was injected into the fuselage for 5 seconds. Suppression was not obtained. The initial weight of the Halon was 106 kilograms (234.5 pounds). The final weight was 103 kilograms (226 pounds). As shown by the small weight loss, the Halon valve did not completely open. This is why suppression did not occur.

### Oxygen Flow Rate

During a weight-loss test, a mass flow rate of 0.6 kg/s (0.13 lb/s) was obtained. By reducing this, a volume rate of 0.04 m³/s (1.46 ft³/s) was obtained.

$$\frac{0.13 \text{ lb}}{s} \times \frac{\ell}{1.43 \text{ g}} \times \frac{454 \text{ g}}{\text{lb}} \frac{\text{ft}^3}{28.32} = 1.46 \text{ ft}^3/s$$

### Test 7

In Test 7, the penetrator was positioned to inject the agent counter to the flow of oxygen. The storage cylinder was charged to 1.0 MPa (150 lb/in²) at the start of the test. During the test, Halon 1211 was injected into the fuselage for 5 seconds. Suppression was accomplished. The initial weight of the Halon was 102.5 kilograms (225.9 pounds). The final weight was 92 kilograms (202.0 pounds).

### Test 8

In Test 8, the penetrator was positioned to inject the agent counter to the flow of oxygen. The storage cylinder was charged to 0.7 MPa (100 lb/in$^2$) at the start of the test. During the test, Halon 2402 was injected into the fuselage for 5 seconds. Suppression was accomplished. The initial weight of the Halon was 116 kilograms (255.4 pounds). The final weight was 127 kilograms (228.0 pounds).

### Test 9

In Test 9, the penetration was positioned to inject the agent with the flow of oxygen. The storage cylinder was charged to 0.7 MPa (100 lb/in$^2$) at the start of the test. During the test, Halon 2402 was injected into the fuselage for 5 seconds. Suppression was accomplished. The initial weight of the Halon was 96 kilograms (212.2 pounds). The final weight was 88 kilograms (193 pounds).

### Test 10

In Test 10, the penetrator was in a position to inject the agent with the flow of oxygen. The storage cylinder was charged to 0.7 MPa (100 lb/in$^2$) at the start of the test. During the test, Halon 2402 was injected into the fuselage for 3 seconds. Suppression did not occur. The initial weight of the Halon was 88 kilograms (193 pounds). The final weight was 80 kilograms (176.2 pounds).

### Test 11

In Test 11, the penetrator was positioned to inject the agent counter to the flow of oxygen. The storage cylinder was charged to 0.7 MPa (100 lb/in$^2$) at the start of the test. During the test, Halon 2402 was injected into the fuselage for 5 seconds. Suppression was accomplished. The initial weight was 78 kilograms (172.4 pounds). The final weight was 69 kilograms (51.7 pounds).

### Test 12

In Test 12, the penetrator was positioned to inject the agent counter to the flow of oxygen. The storge cylinder was charged to 1.0 MPa (150 lb/in$^2$) at the start of the test. During the test, Halon 2402 was injected into the fuselage for 5 seconds. Suppression was accomplished. The initial weight of the Halon was 67 kilograms (148.0 pounds). The final weight was 53 kilograms (117 pounds).

### Tests 13-15

In Tests 13-15, attempts were made to apply Halon 1301 to the fire. Mechanical problems with the piping system prevented the application and these tests were discontinued because of safety considerations.

### Tests 16-19

In Tests 16-19, AFFF was tested,using the Air Force Applicator. AFFF had no effect on the fire and suppression did not occur during the tests.

### Test 20

In Test 20, a 1/2-inch diameter schedule 40 pipe was located in the front of the aircraft (Position 3). The storage cylinder was charged to 1.0 MPa (150 lb/in$^2$) for the test. During the test, PKP was injected into the fuselage for 20 seconds. The PKP flow rate was 0.35 kg/s (7.8 lb/s). Suppression was accomplished.

### Test 21

In Test 21, the penetrator tip was located at the front of the aircraft. A 1136-liter (300-gallon) foam tank was charged with 1.0 MPa (150 lb/in$^2$) of nitrogen. During the test, AFFF was injected into the airframe at two time intervals, the first for 5 seconds and the second for 10 seconds. The AFFF was applied at the rate of 2 kg/s (4.25 lb/s). Suppression did not occur during the 5-second application. Extinguishment did occur during the 10-second application.

The results of large-scale testing demonstrate *the critical importance of* Halon application techniques in combating oxygen-enriched fires. Halon worked effectively when injected with or counter to the flow of oxygen. However, there was difficulty in extinguishing the fire with Halon when it was used in the counterflow mode. Halon 2402 worked more effectively than Halon 1211 in the counterflow mode because as a liquid it could be thrown against the atmospheric draft better than the more gaseous Halon 1211.

Tests indicated that PKP and AFFF work well against pool fires in oxygen-rich atmospheres. Quantitative data for equivalencies between Halon and the other agents were not generated because of the differences in character of the agents; i.e., the 1-D character of AFFF should not be compared to the flooding performance of Halon. However, rapid knockdown was achieved with Halons whereas the security against flashback was achieved with the cooling/blanketing affects of AFFF.

As shown in Table 8, the use of the penetrator suppressed most of the fires; however, this does not mean that the fires were always extinguished. During some fires, the aircraft heated above the point of spontaneous combustion and, after suppression, the fire would reignite. This indicated a need for cooling the aircraft. If water or AFFF was sprayed inside the aircraft immediately following suppression, the temperature would drop and the fire was extinguished. Halon has approximately one-twentieth the heat absorption of water. Consequently, cooling the aircraft with Halon was not considered practical. Tests of the penetrator showed that it was able to successfully apply AFFF. AFFF exited the nozzles in a large semihollow cone with only a small amount of aeration (small voids) present. When spraying AFFF the throw range is about 6 to 8 meters (20 to 25 feet). This was considered a drawback for a pool fire but an advantage when spraying inside an airplane.

In the first tests, AFFF was injected through a standard AFFF nozzle. The throw range was 15 to 18 meters (50 to 60 feet) and the AFFF was well-aerated. Testing this nozzle from multiple positions showed little to no effect on the fire. The penetrator was then used from Position 3 at the front of the aircraft. During this test, with the oxygen flowing, a 5-second burst of AFFF was injected. This temporarily reduced the intensity of the fire but did not suppress it. The fire was allowed to rebuild and a 10-second burst

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was injected. During the 10 seconds, suppression was attained, and, even with the oxygen flowing, the fire did not reignite.

PKP was also tested. During Test, 20 PKP was blown through a 1/2-inch diameter schedule 40 pipe at the rate of 3.5 kg/s (7.8 lb/s). A 20-second burst was used with the fire directly accessible and suppression was obtained. During an after-test inspection it was found that all exposed surfaces were covered with powder. This shows there may be only limited results obtained on an indirectly accessible fire.

During mass flow calculations, the oxygen flow rate was found to be 0.04 m$^3$/s (1.45 ft$^3$/s). This flow rate is small as compared to the volume flow inside an aircraft and should have little effect on the fire. Although the oxygen had a small flow rate, it had a high velocity as it left the oxygen line. This velocity drafted a large amount of air into the fire. The resulting turbulence mixed the fuel vapors and caused a large aggressive fire. When oxygen is mixing with air the overall oxygen concentration is lowered. With a lower oxygen concentration, the fire is easier to extinguish. Because of the aggressive flame, the fire was much more destructive and harder to suppress than an undisturbed fire. Other testing done with an oxyacetylene torch where fuel is premixed with 100 percent oxygen showed that even a large amount of Halon could not extinguish this fire. This shows the fires generated during testing had a greater concentration of oxygen than air, but much less than 100 percent.

During testing, a relationship between time and temperature was found and is shown in Figure 16. The plot shows the atmospheric temperature of the aircraft and time. Curves A and B are time-temperature profiles,with and without oxygen enrichment. From full-scale results it was found that the relationships shown were not in complete agreement with the profiles produced in a sealed airframe. With an oxygen-enriched fire, the temperature rose to a higher level in a shorter time than a non-oxygen-enriched fire.

With both types of fires a temperature level was reached where the fires could spontaneously start if only temporarily suppressed. This is the point of spontaneous combustion. Whenever the atmospheric temperature is above the point of spontaneous combustion and the fire is put out, only suppression has occurred. Extinguishment can only be obtained when there is no fire and the
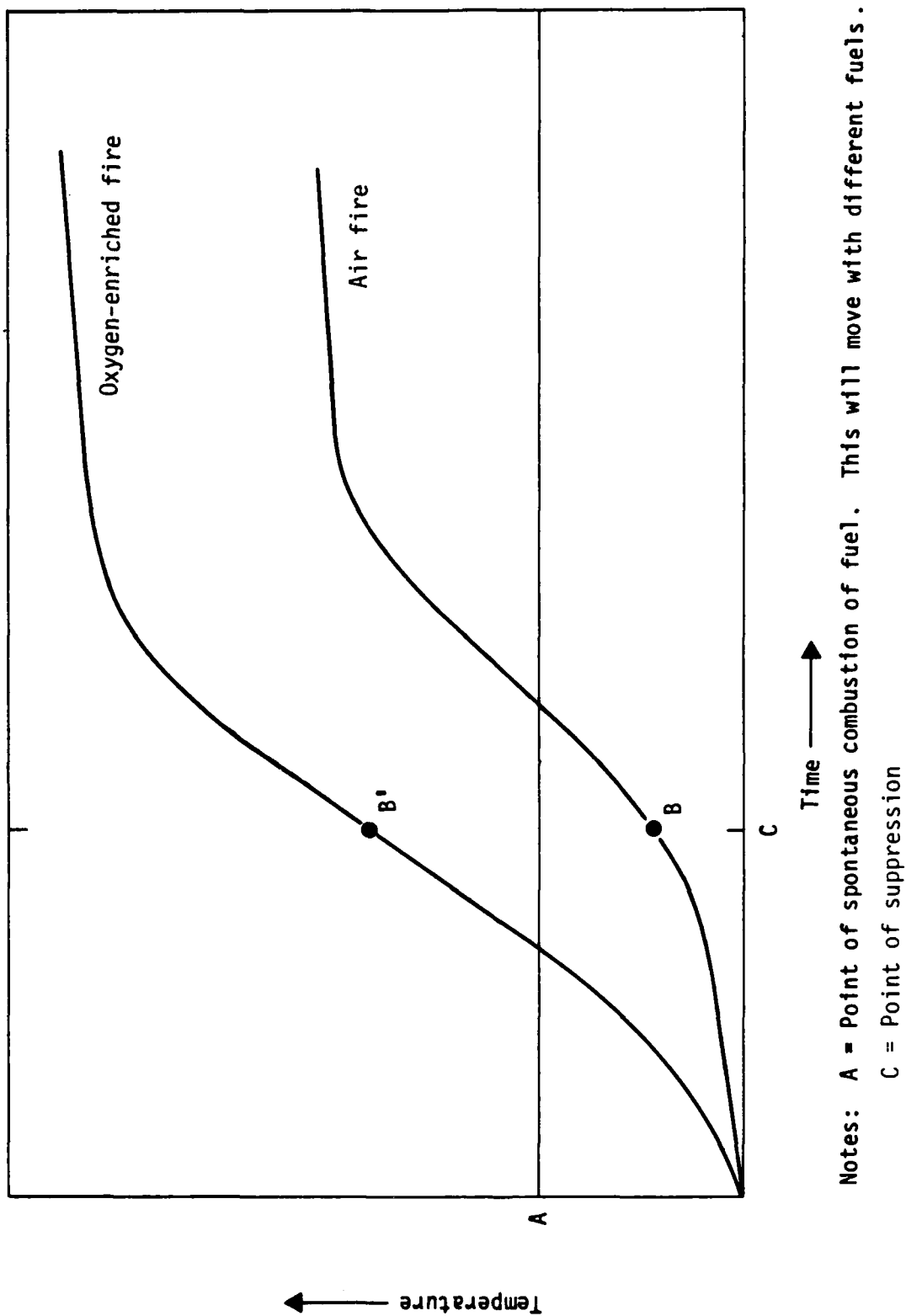
Figure 16. Time-Temperature Relationship for Large-Scale Tests.

Notes: A = Point of spontaneous combustion of fuel. This will move with different fuels.

C = Point of suppression

temperature is below the point of spontaneous combustion. Therefore, suppression does not always mean extinguishment. After suppression, the Halon concentration is reduced by being drafted away by the buoyancy induced by the heat from the fire and passes through damaged areas in the fuselage skin. When enough Halon has been removed to lower the concentration below the point of ignition, spontaneous combustion and continuous burning of fuel will occur. With oxygen flowing, this problem is aggravated because the oxygen jets blow the Halon out of the airframe and increase the oxygen supply to the fire.

# SECTION VI
## FULL-SCALE TESTS

## PURPOSE

The purpose of the full-scale tests was to extend previous test data and observations to realistic, large-compartment aircraft fires. Additional fuels and geometries were tested. Only a limited number of tests could be run before fire damage to the aircraft presented a hazard.

## EXPERIMENTAL METHOD

The full-scale fire tests were conducted in the main body compartment of a HC-131A aircraft. The fuel pans, Class A and B combustibles, thermocouples, oxygen injectors, agent applicators, and video camera were arranged as shown in Figures 17 and 18. The two 0.4 $m^2$ (4 $ft^2$) fuel pans contained approximately 9.5 liters (2.5 gallons) of JP-4 each. The 0.7 $m^2$ (8 $ft^2$) pan contained 19 liters (5 gallons) of JP-4. The chair consisted of typical aircraft Class A combustibles, such as foam and synthetic fabrics, bound to a metal frame. Oxygen was supplied to the injectors from a liquid oxygen Dewar flask. Flow was controlled by an inline ball valve. The oxygen was injected at the fuel surface level or approximately 0.6 meters (two feet) above the fuel pans depending on the test. Again, the oxygen delivery system was designed to simulate the flow rate expected from a ruptured 7.9-millimeter (5/16-inch) oxygen line. Two simulated penetrator tips were used inside of the aircraft to apply Halon. The test nozzle was connected to a 227-kilogram (500-pound) Halon 1211 tank on an XP-13 firetruck. The second was a backup penetrator connected to a 73-kilogram (160-pound) portable Halon 1211 tank. This penetrator was pointed directly at the fuel pans from above. An AFFF line from the XP-13 firetruck was positioned near the camera box located in the tail section of the aircraft. This line was to be used for cooling the inside of the aircraft if necessary. During most tests, Halon was injected through the simulated penetrator nozzle either in front or behind the fuel pan. In one test, a Halon handline nozzle located near the front stairwell was used to apply Halon. Tests were performed with both the cargo and passenger doors closed and open.
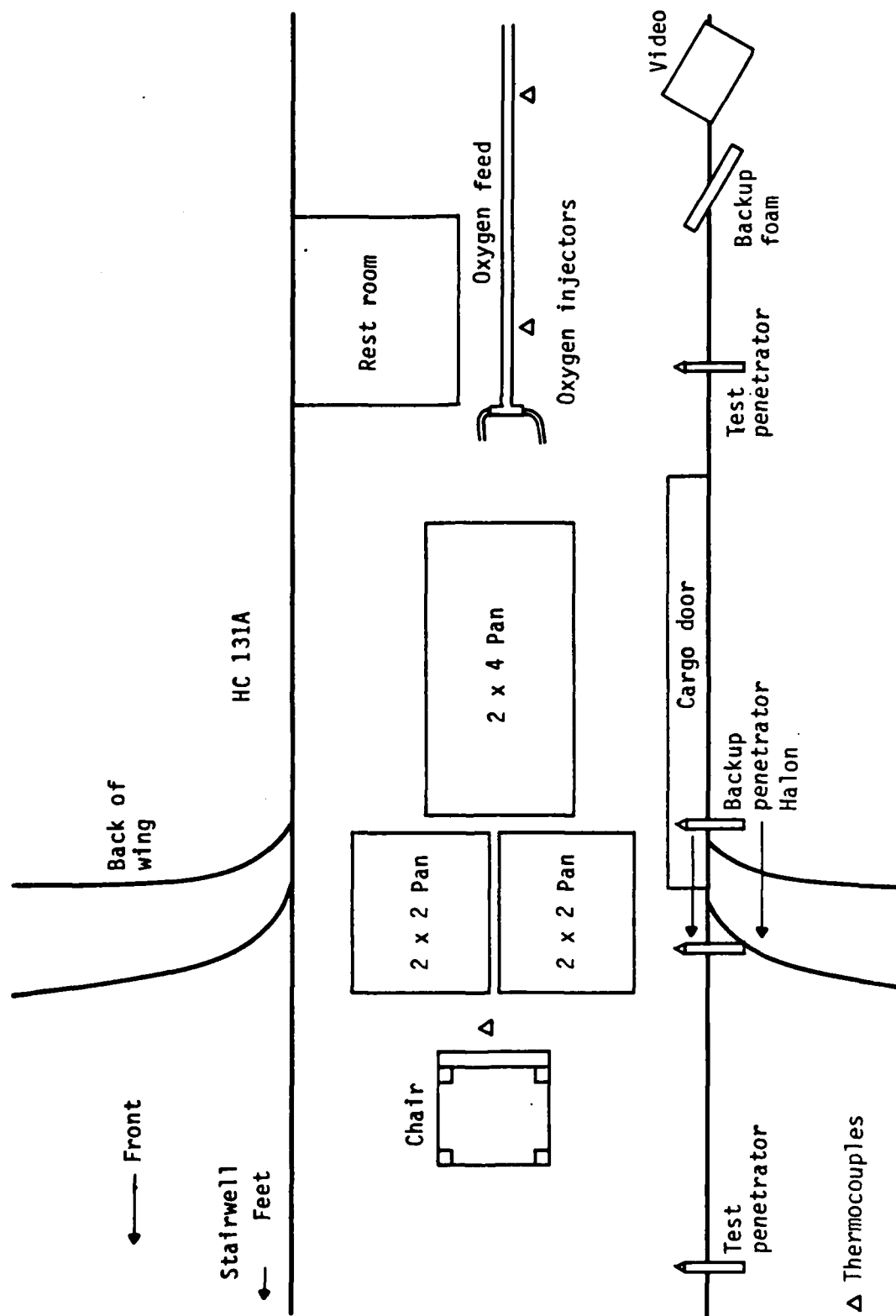
Figure 17. Full-Scale Test Layout in C-131A Aircraft.

45

X

00
X=175
Y= 67

01
X=115
Y= 67

X=124
Y= 10

Penetrator

Oxygen injectors

X=60
Y= 6
Y=22

Fuel pans

Y

02
X=-24
Y= 69

Chair

05
X=-144
Y= 67

03
X=-108
Y= 49

X=108
Y= 18

04
X=-190
Y+ 52

Penetrator

Class A material
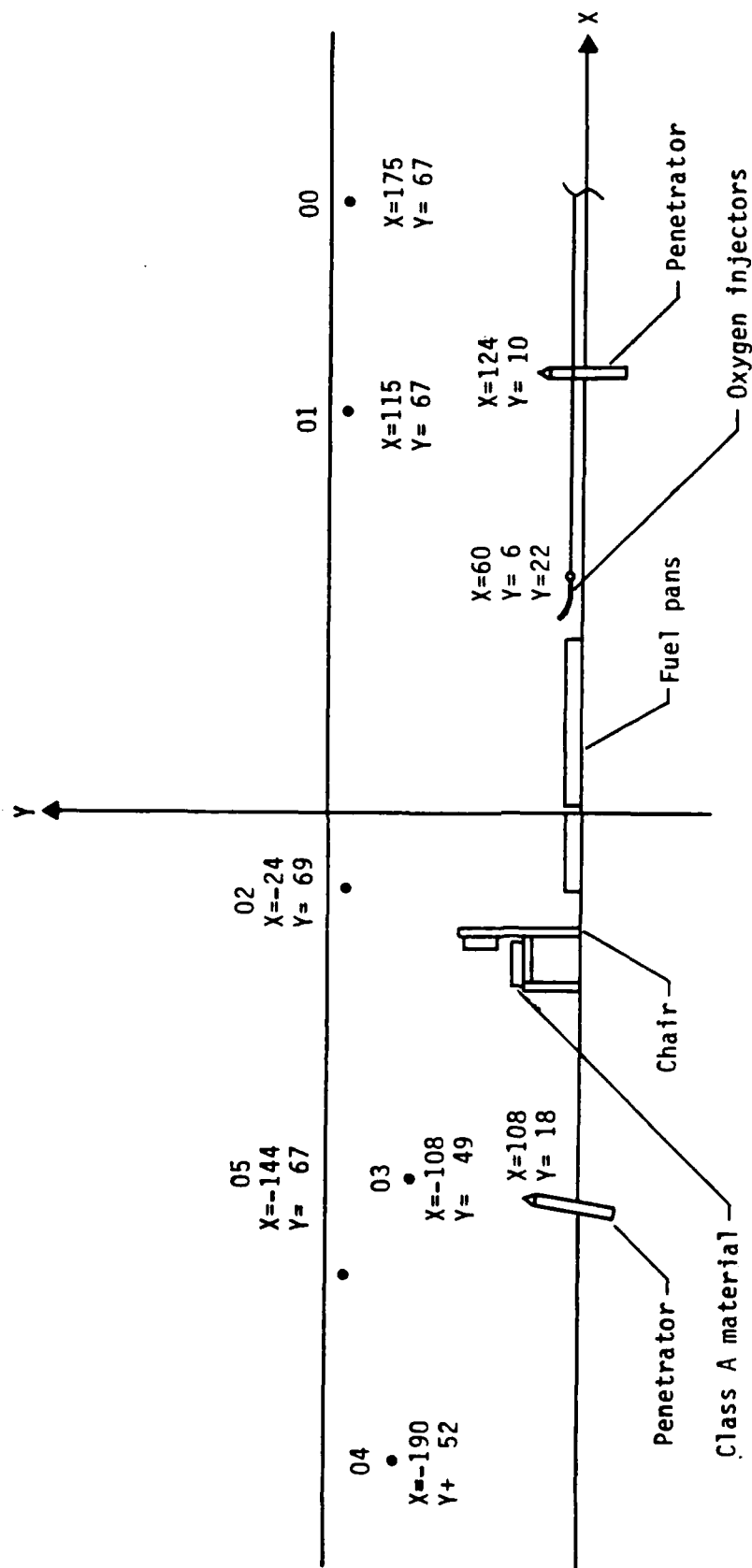
Note: All dimensions in inches unless other-wise specified.

Figure 18. Thermocouple Arrangement on HC 131A Full-scale Tests.

Thermocouples were used because smoke obscured the view of the video camera during tests and the only way to tell if the fire had been suppressed was by watching the thermocouple readings. The thermocouple also gave a time-temperature history inside of the aircraft which may be useful in other areas.

The procedure used during full-scale tests was similar to that used for large-scale tests. The major difference in procedure was that in the full-scale tests the timing of oxygen feed and agent application was determined by thermocouple readings and a fixed-time interval. Oxygen feed was initiated 5 seconds after thermocouple 02 reached 538°C (1000°F) and Halon application began after 15 seconds of oxygen preburn.

TEST RESULTS

The Halon suppression results are shown in Table 9. As shown from the results, all fires were relatively easy to suppress when the aircraft was sealed. This helped to confirm the belief that the additional oxygen had little effect on the fire. The fire was more intense when the oxygen was injected close to the fuel level but was still readily extinguished. Calculations showed there is enough air on the aircraft to burn approximately 14 kilograms (30 pounds) of fuel stoichiometrically. Each test started with approximately 27 kilograms (60 pounds) of fuel. Theoretically there was more fuel onboard than can be consumed by air inside the aircraft. Fourteen kilograms (30 pounds) is a small amount of fuel when compared to the amount of combustibles onboard the airplane. To see how long it would take to burn this much fuel inside the aircraft and to see if more fuel would be consumed, the aircraft was sealed as tightly as possible and a fire was ignited in the fuel pans. During the test (Test 9), the fire burned itself out. By watching the thermocouple readings located inside the aircraft, it was determined that the fire burned for 72 seconds before burnout occurred. After the test, fuel consumption was measured at 12 kilograms (25.6 pounds). This was close to the 14 kilograms (30 pounds) calculated. The Air Force and firefighters use a figure of 60 seconds till burn-through as an average time before a fire will burn through the outer skin of an aircraft. In the case just discussed, the fire would probably have burned through the outer skin and destroyed the aircraft.

TABLE 9. FULL-SCALE TEST RESULTS

| Test no. | Flow type | Halon type | Halon discharge time, s | Test results | Fuel loss, Kg (lb) | Oxygen loss, (lb) | Chair damage | Comments |
|---|---|---|---|---|---|---|---|---|
| 1 & 2 | --- | --- | --- | --- | --- | --- | --- | System check out |
| 3 | Counterflow | 1211 | 25 | Suppression | N/A[a] | N/A | None | |
| 4 | Counterflow | 1211 | 30 | Suppression | N/A | N/A | Little | |
| 5 | Counterflow | 1211 | 17 | Suppression | N/A | N/A | Medium | |
| 6 | With flow | 1211 | 10 | Suppression | N/A | N/A | Heavy | |
| 7 | Counterflow | 1211 | 15 | Suppression | 6.8 (15.1) | N/A | Medium | Handline from door |
| 8 | With flow | 1211 | 30 | No suppression | 10.5 (23.1) | 5.0 | Complet | Both doors open |
| 9 | Self extinguishment | | | Suppression (72 seconds) | 11.6 (25.6) | 0 | No chair | No oxygen |
| 10 | With flow | 2402 | 33 | Suppression | 10.0 (22.0) | 6.0 | Complete | Both doors open |

[a] N/A = Not available

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A description of each of the full-scale tests follows. Complete temperature data for these tests are contained in Appendix B.

## Tests 1 and 2

In Tests 1 and 2, the system was checked out.

## Test 3

In Test 3, the penetrator was located 3 meters (9 feet) in front of the fuel pans. The oxygen injectors were located 558 millimeters (22 inches) above the floor. The Aircraft was sealed during the test and Halon 1211 was injected into the fuselage for 25 seconds. There was a 10-second preburn and a 10-second oxygen burn before suppression started. The fire was suppressed before the Halon and oxygen were shut off. The chair was not burned.

## Test 4

In Test 4, the penetrator was located 3 meters (9 feet) in front of the fuel pans. The oxygen injectors were located 558 millimeters (22 inches) above the floor. The aircraft was sealed during the test and Halon 1211 was injected into the fuselage for 30 seconds. The preburn continued until thermocouple 02 reached 538°C (1000°F) at which point, an additional 10 seconds of oxygen was introduced into the aircraft. The fire was suppressed before the Halon and oxygen were shut off. The cloth on the chair was lightly burned.

## Test 5

In Test 5, the penetrator was located 3 meters (9 feet) in front of fuel pans. The oxygen injectors were located 152 millimeters (6 inches) above the floor. The aircraft was sealed during the test and Halon 1211 was injected into the fuselage for 17 seconds. There was a 20-second preburn and a 10-second oxygen burn before suppression started. The Halon and oxygen were shut off when suppression was obtained. Holes were burned through the cloth, charring the foam in places. Thermocouple temperature readings from the test are shown in Figure 19.
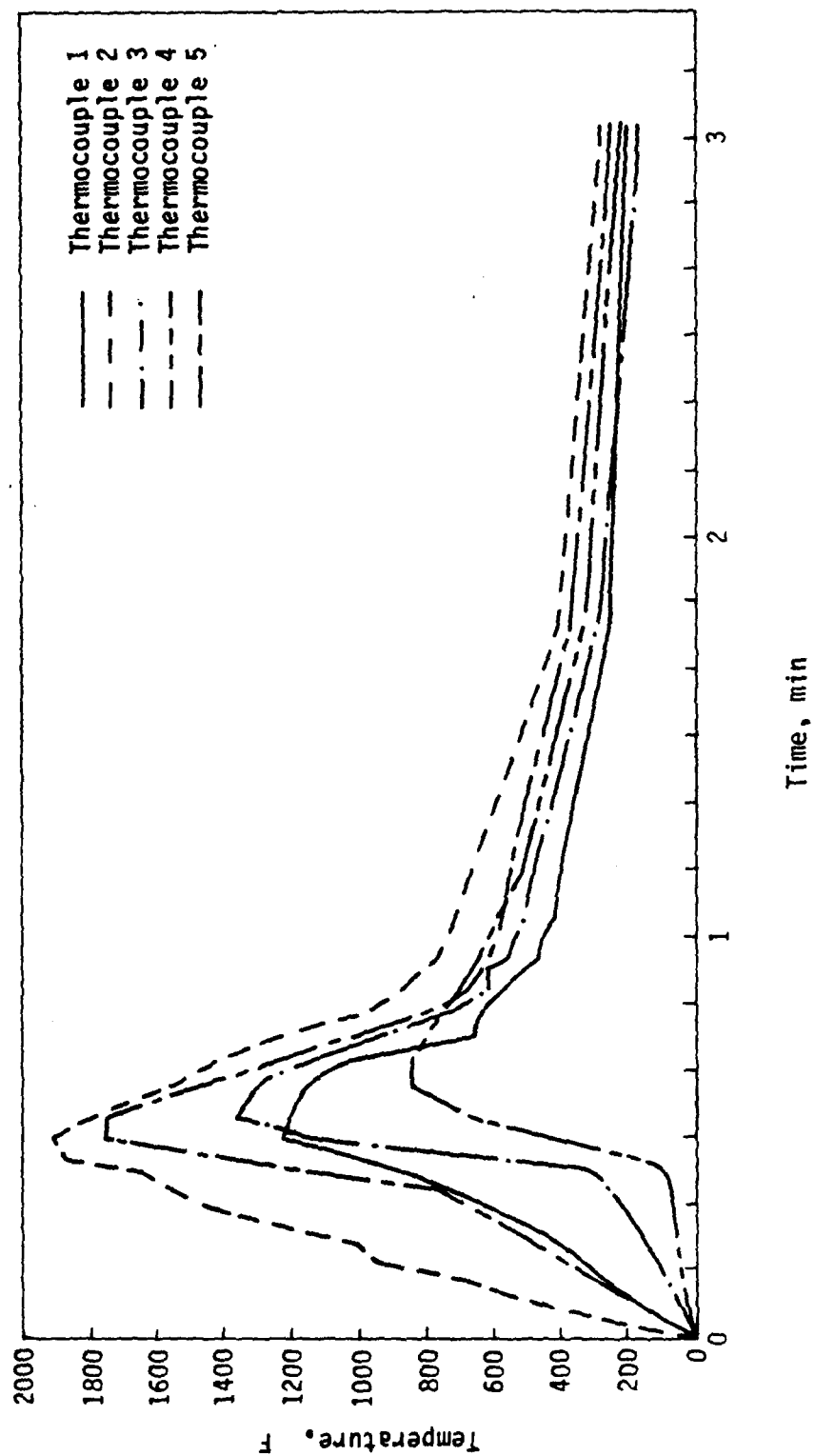
Figure 19.  Time and Temperature History, Full-Scale Test 5.

Legend:
Thermocouple 1
Thermocouple 2
Thermocouple 3
Thermocouple 4
Thermocouple 5

Time, min

Temperature, F

50

### Test 6

In Test 6, the penetrator was located 3 meters, 102 millimeters
(10 feet, 4 inches) behind the fuel pans. The oxygen injectors were located
152 millimeters (6 inches) above the floor. The aircraft was sealed during the
test. During the test, Halon 1211 was injected into the fuselage for
10 seconds. The preburn continued until thermocouple 02 reached 538°C
(1000°F), and an additional 15 seconds of oxygen was introduced into the
aircraft. The Halon and oxygen were shut off when suppression was obtained.
Holes were burned through the cloth on the chair charring the foam in places.
Thermocouple temperature readings from the test are shown in Figure 20.

### Test 7

In Test 7, a handline from the XP-13 firetruck was placed inside the
aircraft by the stairwell door. The handline nozzle was turned to the full-
stream position and mounted 7 meters (23 feet) from the fuel pans. The oxygen
injectors were located 152 meters (6 inches) above the floor. The front door
on the aircraft was open. During the test, Halon 1211 was injected at the rate
of 2.5 kg/s (5.5 lb/s) for 15 seconds into the fuselage. The preburn continued
until thermocouple 02 reached 538°C (1000°F) at which point an additional
15 seconds of oxygen was introduced into the aircraft. The oxygen and Halon
were shut off when suppression was obtained. The cloth on the chair was
lightly burned. The oxygen preweight was 250 kilograms (552.0 pounds). The
postweight was 248 kilograms (547.0 pounds).

| Fuel loss | Preweight, kg | (lb) | Postweight, kg | (lb) | Weight loss, kg | (lb) |
|---|---|---|---|---|---|---|
| Left 0.4 m² (4 ft²) pan | 35 | (77.3) | 33 | (73.0) | 2 | (4.3) |
| Right 0.4 m³ (4 ft²) pan | 37 | (81.5) | 36 | (79.1) | 1 | (2.4) |
| Center 0.7 m² (8 ft²) pan | 61 | (133.4) | 57 | (125.0) | 4 | (8.4) |
| | | | | Total | 7 | (15.1) |

### Test 8

In Test 8, the penetrator was located 3 meters, 102 millimeters
(10 feet, 4 inches) behind the fuel pans. The oxygen injectors were
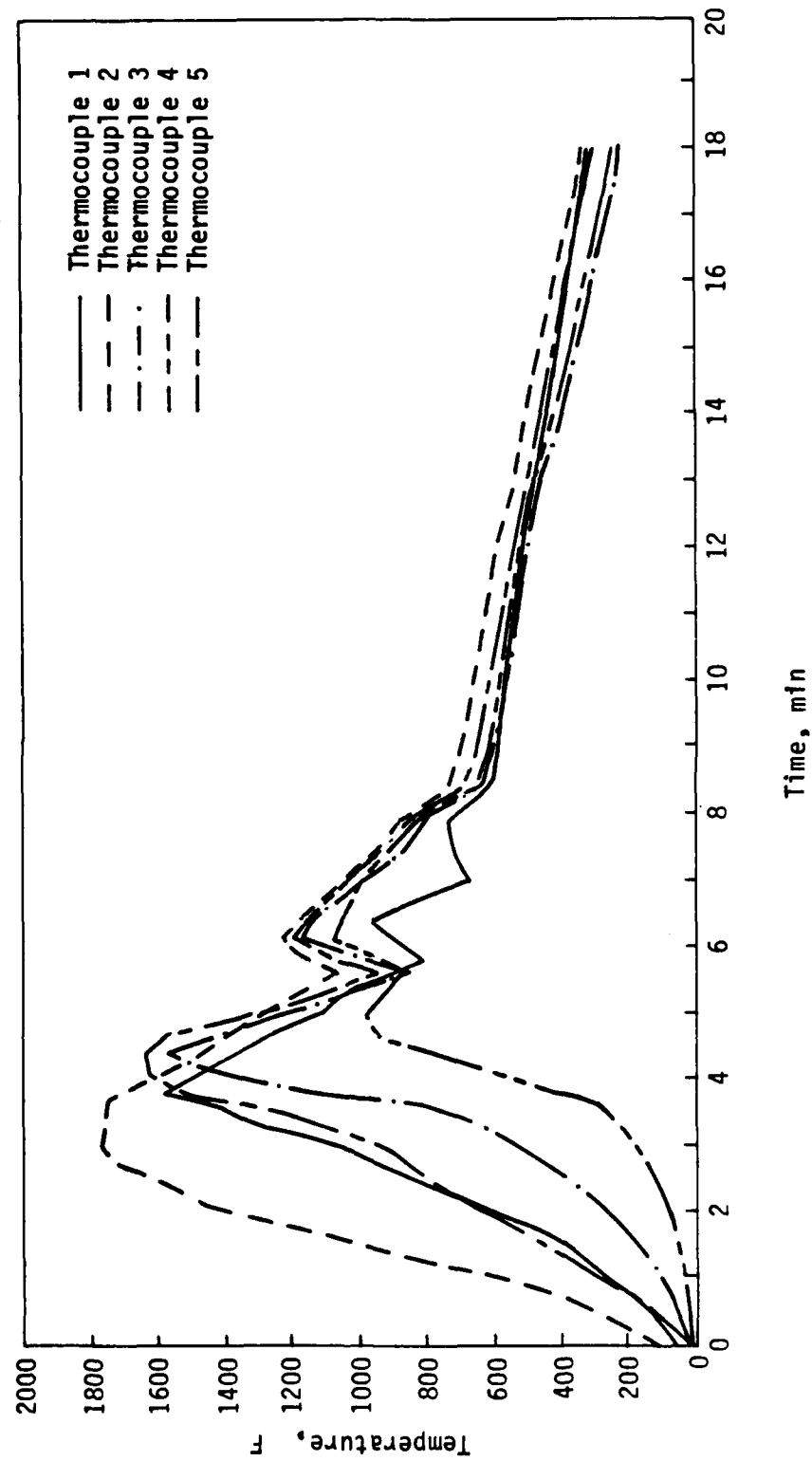
Figure 20. Time and Temperature History, Full-Scale Test 6.

152 millimeters (6 inches) above the floor. Both doors were open during the test. During the test, Halon 1211 was injected at the rate of 2.4 kg/s (5.4 lb/s) into the fuselage for 15 seconds. At this point the Halon had no effect on the fire. The oxygen was shut off and an additional 15 seconds of Halon was added. The preburn continued until thermocouple 02 reached 538°C (1000°F), at which point an additional 15 seconds of oxygen was introduced into the aircraft. The fire was hot and intense. Following suppression reignition occurred and more Halon was required. The chair was completely burned. The oxygen preweight was 243 kilograms (535 pounds). The postweight was 240 kilograms (530 pounds).

| Fuel loss | Preweight, kg | (lb) | Postweight, kg | (lb) | Weight loss, kg | (lb) |
|---|---|---|---|---|---|---|
| Left 0.4 m² (4 ft²) pan | 35 | (76.1) | 31 | (68.5) | 3.4 | (7.6) |
| Right 0.4 m³ (4 ft²) pan | 37 | (81.0) | 33 | (72.5) | 3.9 | (8.5) |
| Center 0.7 m² (8 ft²) pan | 67 | (147.5) | 59 | (130.5) | 8 | (7.0) |
| | | | | Total | 10.0 | (23.1) |

### Test 9

In Test 9, no Halon or oxygen was injected. The aircraft was sealed as tight as possible and allowed to burn until suppression occured. Suppression occured 72 seconds after the start of the fire.

| Fuel loss | Preweight, kg | (lb) | Postweight, kg | (lb) | Weight loss, kg | (lb) |
|---|---|---|---|---|---|---|
| Left 0.4 m² (4 ft²) pan | 34 | (75.7) | 32 | (69.7) | 3 | (6) |
| Right 0.4 m³ (4 ft²) pan | 34 | (75.7) | 32 | (71.0) | 2 | (4.7) |
| Center 0.7 m² (8 ft²) pan | 65 | (143.2) | 58 | (128.3) | 7 | (14.9) |
| | | | | Total | 12 | (25.6) |

Thermocouple temperature readings from the test are shown in Figure 21.

### Test 10

In Test 10 the penetrator was located 3 meters, 102 millimeters (10 feet, 4 inches) behind the fuel pans. The oxygen injectors were
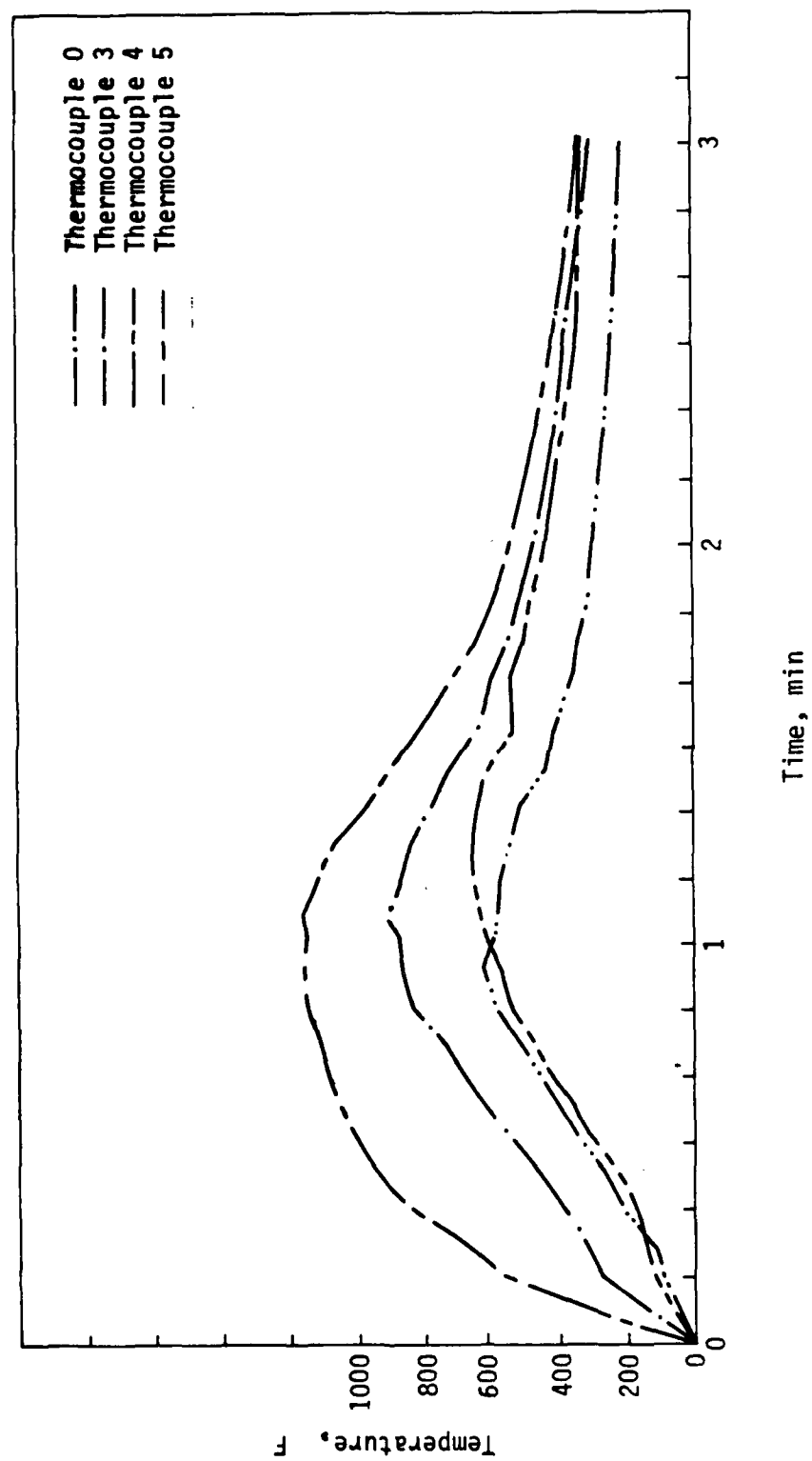
Figure 21. Time and Temperature History, Full-Scale Test 9.

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152 millimeters (6 inches) above the floor with both doors open. During the test, Halon 2402 was injected into the fuselage. The Halon 2402 was stored in a modified CB tank pressurized to 1 MPa (150 lb/in$^2$). The initial weight of the Halon was 82 kilograms (180 pounds). After the preburn the Halon 2402 line was left opened until the tank was empty. The preburn continued until thermocouple 02 reached 538°C (1000°F) at which point an additional 15 seconds of oxygen was introduced into the aircraft. The oxygen was turned off after the fire had been suppressed. There was no reignition of the fire. The chair was completely burned. The oxygen loss preweight was 232 kilograms (511 pounds). The oxygen postweight was 229 kilograms (505 pounds).

| Fuel loss | Preweight, kg | (lb) | Postweight, kg | (lb) | Weight loss, kg | (lb) |
|---|---|---|---|---|---|---|
| Left 0.4 m$^2$ (4 ft$^2$) pan | 35 | (77.0) | 33 | (71.7) | 3 | (5.3) |
| Right 0.4 m$^3$ (4 ft$^2$) pan | 36 | (78.5) | 33 | (72.0) | 3 | (6.5) |
| Center 0.7 m$^2$ (8 ft$^2$) pan | 65 | (144.0) | 61 | (133.8) | 5 | (10.2) |
| | | | | Total | 10 | (22.0) |

Thermocouple temperature readings from the test are shown in Figure 22.

CONCLUSIONS

If a fire in an atmosphere with or without oxygen enrichment is detected on an aircraft and is suppressed while it is still contained inside the aircraft, it can be extinguished with the penetrator tool. If the compartment is damaged, cooling is important. Halon 2402 was shown to have a greater knockdown ability than Halon 1211.

Also, the more dense Halon 2402 was not drafted away from the fire as easily as other Halons. In the worst case, where the fire has burned through the skin and has become fully developed, extinguishing this fire will be difficult. In all cases, cooling the inside of the aircraft is important. The penetrator tool has proven to be important in fighting aircraft fires. In all cases, the amount of air available to the fire must be reduced and a sealed aircraft must not be entered while it is still hot. Upon opening the door, air will be drafted into the fuel-rich atmosphere and cause reignition or,possibly, an explosion.
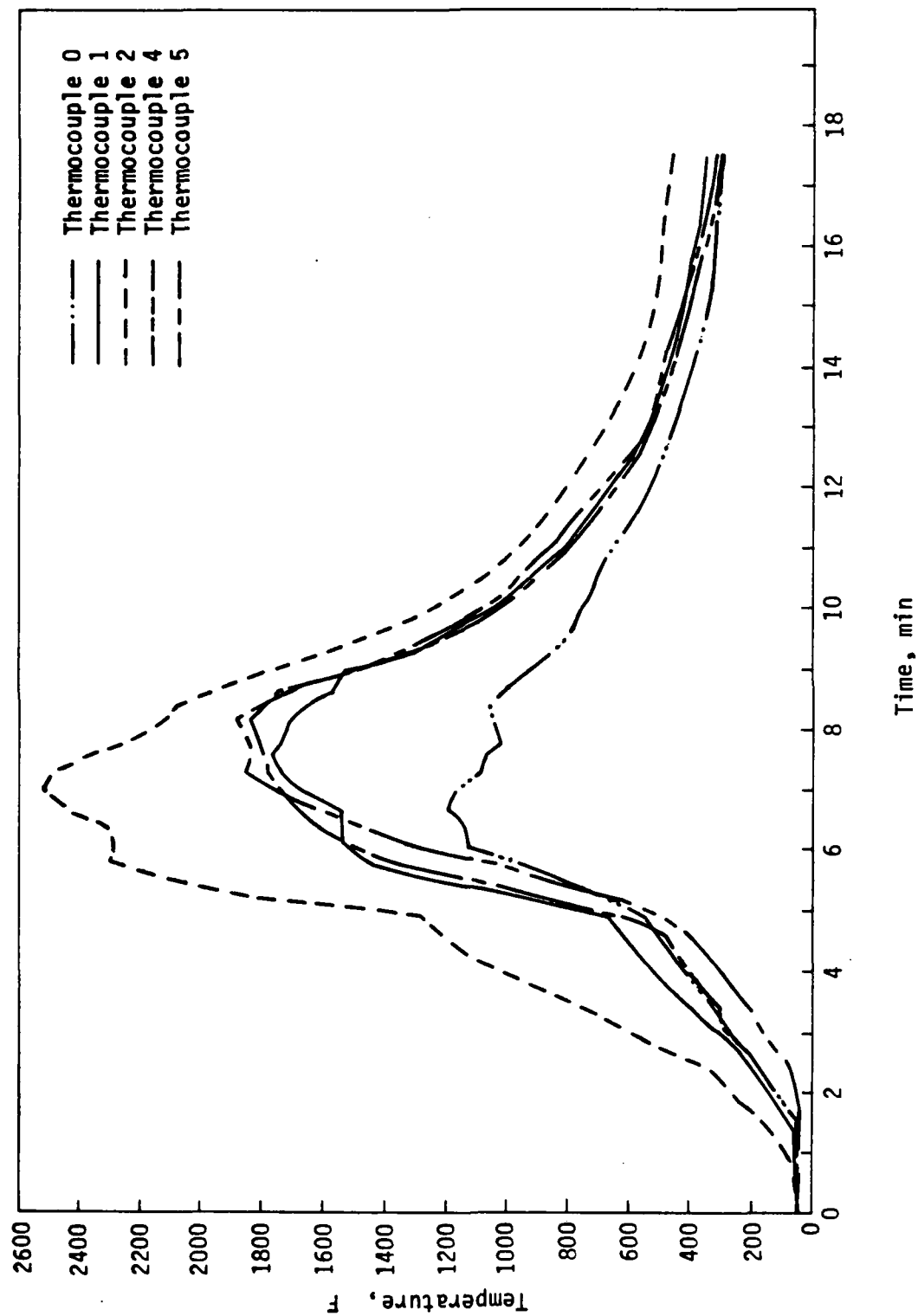
Figure 22. Time and Temperature History, Full-Scale Test 10.

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An assessment of the information obtained during this experiment shows the worst-case fire to be one in which air can be drafted over the fire. This effect is aggravated by the velocity and turbulence caused by a broken oxygen line. The effect of the oxygen enrichment is small once a hole is burned through the skin of the aircraft and the fire has become fully established. At this time, the fire sets up a strong current, pulling air into the fire. If the aircraft has reached this point, the fire will be difficult to extinguish and cooling inside the burning compartment will be critical.

To test the drafting effect from the oxygen jets, Test 8 was conducted with both aircraft doors open. If drafting occurred, air would be pulled in one door, pushed across the fire, and exhausted out the other door. There would also be a large increase in the intensity of the fire. This is unlike the calculational results from NBS/Harvard because of the forced flows from the oxygen injectors. Since the fuel pans were located by the cargo door, a direct visual inspection of the fire could be made. A video system next to the aircraft door was set up to film the fire, which was intense and aggressive. During the test, Halon 1211 was injected behind (towards the tail section) the fuel pans and had little or no effect on the fire. The oxygen was then shutoff and the fire was quickly suppressed. Halon needed to be reinjected several times as the fire reignited several times. Eventually, enough cooling occured to extinguish the fire. In examining the videos, the Halon 1211 seemed to ride up over the fire and not react with the base of the fire. Halon 2402 was used in a second test. Halon 2402, with its high density and boiling point, was expected to penetrate the fire and suppress it. During the test, Halon 2402 did suppress the fire while the oxygen was flowing. After suppression the oxygen was shutoff and reignition did not occur. Watching the reaction between the fire and Halon 2402, indicated that suppression was attained by only a slim margin. Comparing Halon 2402 to Halon 1211 showed a substantial difference between the two Halons in this configuration.

An examination of the response of the thermocouples in Test 5 as the test progresses through the completion (Figure 18) shows that as the fire burns before the oxygen is injected, thermocouple 02 picks up the highest temperature inside the aircraft. As the oxygen flow starts, the rate of increase on 02 is temporarily reduced because the oxygen jets physically blow the fire over. Thermocouples 02 and 05 then rise quickly as they pick up the heat from the enriched fire. Halon injection causes the temperature measured by

thermocouple 02 to drop almost immediately while the temperature measured by thermocouple 05 peaks and starts to drop. The drop in temperature measured by thermocouples 02 and 05 signal the suppression of the fire. Heat drafting off the fire and injection of the oxygen and Halon mix the atmosphere inside the aircraft. This can be seen by the relatively constant temperature at all of the thermocouples during the cool-down period. The amount of time needed to cool down the aircraft makes it necessary to keep the aircraft sealed. If the aircraft had not been sealed, a constant injection of Halon would have been required to keep the fire suppressed. Reignition can and will occur if the concentration of Halon drops. If the supply of Halon is exhausted, reignition can only be stopped by cooling the inside of the aircraft with AFFF or water. Besides cooling the aircraft the spray will saturate and extinguish glowing embers on Class A materials. Care must be taken in this case to avoid the formation of pockets of oxygen. It is safer to keep the aircraft sealed and inject Halon to keep the atmosphere inert. The penetrator tool can be used to spray AFFF to cool the interior of the plane. This can be expecially advantageous if weapons or special equipment need to be immediately cooled. In this case, the penetrator tool can quickly drill through the aircraft skin and spray AFFF directly on the equipment.

# SECTION VII
## CONCLUSIONS AND RECOMMENDATIONS

Small-scale laboratory tests were performed to quantitatively measure Halon requirements for flame extinguishment and ignition prevention in atmospheres ranging from 17.6 to 100 percent oxygen. The test results were compared to previously published data with reasonable agreement. The tests extended the available data to additional Halons and fuels. For all of the Halons tested, the small-scale results confirmed the extremely rapid rise in Halon concentrations required to extinguish or prevent ignition of fires as oxygen concentration increases. A minimum 500-percent increase in Halon was required to accomplish the same effect in an atmosphere containing 40 percent oxygen over what was required in an atmosphere containing 21 percent oxygen. No one Halon appeared to be less effected by increased oxygen concentration than any of the others.

Medium-scale tests in a 3-foot diameter horizontal cylinder showed that the same relationships for Halon requirements observed in laboratory fires held true for larger fires. In a 40-percent oxygen 60-percent nitrogen atmosphere, between 12 percent and 17 percent Halon was required to extinguish JP-4 fires. The rapid depletion of oxygen enrichment was first noted in medium-scale fires, where the fire burned intensly at the leading edge of the fuel pan, but rapidly decreased in intensity towards the trailing edge of the fuel pan. This suggested the possibility of suppressing the fire with a high Halon concentration at the oxygen/fire interface using local application of partial flooding techniques.

The large-scale B-52 tests presented realistic, small-compartment oxygen-enriched fire environments found in damaged airframes. These fires proved to be the most difficult to extinguish of all of the fires in the tests performed. The partially open compartment provided a ready supply of fresh air which was drafted into the fire by the oxygen jet and the natural draft of the fire. These fires were very intense. The Halons applied to the B-52 fires were drafted away almost immediately allowing reignition to occur as soon as the Halon flow stopped. Application technique proved critical in these tests, particularly for Halon 1211 where a counterflow application was difficult. These tests demonstrated the need for early detection and extinguishment of

the fire with Halon if reignition was to be prevented. If the fire was well— established, supplemental internal cooling was required to achieve extinguishment. Considering the 1-D quality of AFFF and the need for direct access by PKP, AFFF and PKP both proved effective in extinguishing the OEA fires,when injected into the fire compartment.

The full-scale fire tests performed in the C-131A aircraft proved to be less difficult to extinguish than the B-52 fires. Two reasons were identified. When the large aircraft compartment was sealed the air contained in the fuselage was sufficient to stoichiometrically burn only half of the fuel onboard for the test. A test was performed without oxygen enrichment and the fuel fire actually burned itself out in approximately 1 minute. When oxygen was injected, a small area of intense flame was produced where the supplemental oxygen was completely consumed. Because of the large compartment volume the surface temperatures rose much more gradually than had occurred in the B-52 fires. When the large compartment was sealed extinguishment was possible using total flooding from any place in the compartment. When the cargo and personnel doors were open the fire became much more intense and direct application of the Halon to the fire/oxygen interface became essential.

Testing shows that the penetrator tool is a distinct advantage when fighting aircraft fires. As a result of its ability to apply agents close to the base of a fire, agent concentrations sufficient to suppress an OEA fire can be obtained. Testing also shows that the amount of Halon on a crash rescue truck is sufficient to extinguish an oxygen-enriched fire in an airplane of a size up to and including a C-141, as long as the outer skin of the plane is intact. Application of agent with a penetrator tool on a compartmentalized aircraft requires penetration and agent application within the specific compartment containing the fire. In this case, the location of the penetration is exceedingly important. The location of the penetration for wide-body (noncompartmentalized) aircraft is not as critical; although, better extinguishment is obtained with application nearer to the fire.

With nonintegral skin, owing to crash or fire damage, extinguishment of OEA fires is very difficult. The less intact the skin is, the more difficult the extinguishment becomes. Testing shows, however, that with application of agent through a penetrator tool, suppression can usually be obtained even with

damaged aircraft. The major problem encountered with damaged
aircraft is reignition after agents have drafted out of the
plane through damaged areas in the skin. Cooling of the
interior of damaged aircraft can prevent reignition. Thus, a
two-pronged approach is needed to extinguish a fire in a damaged
aircraft. First, the fire must be suppressed. HALONs show a
clear superiority to other extinguishing agents in fire
suppression. Second, the inside of the plane must be cooled
before enough HALON has escaped to allow the fire to reignite.

Owing to the large volume, the addition of oxygen to wide-
body aircraft has relatively little effect on the overall oxygen
concentration. In a compartmentalized plane, oxygen
concentrations can rise quickly to give a large increase in burn
rate. Compartments also allow for an increase in HALON
concentration to enhance extinguishment.

Tests show that AFFF can be applied with the penetrator tool
to give OEA fire extinguishment. However, only directly
accessible fires are extinguished with AFFF. In all cases, AFFF
cooled the inside of the plane in the full-scale tests and
extinguished directly accessible Class A fires.

Based on the above information, the following procedures are
recommended to fight aircraft fire for both OEA and standard
conditions:

1. Determine the location of the interior fire. Insert the
penetrator tool as close to the fire as possible and apply HALON
1211.

2. Apply AFFF or water to the exterior of the skin to cool
the aircraft to prevent skin burn through.

3. When HALON 1211 has extinguished the fire, cool the
interior of the aircraft to prevent reignition.

5. If the skin is damaged, cool the interior of the plane quickly with AFFF of water to prevent reignition. The penetrator tool may be used to apply interior cooling. Employ additional shots of Halon to continue suppression during the interior cooling if necessary. If the Halon supply has been depleted, continue applying AFFF or water to the interior.

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2. Manheim, J. R., **Evaluation of Halon 1301 for Fire Suppression in Oxygen-Enriched Atmospheres,** unpublished manuscript.

APPENDIX A
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   A number of surfactants were investigated for the preparation of aqueous Freon-12 solutions and emulsions. Aqueous Freon-12 solutions which are stable at 76°F were prepared.

2. Calasyn, V. D., **A Survey of Fire-Prevention Problems in Closed Oxygen-Containing Environments**, Report No. 526, Bureau of Medicine and Surgery, Navy Department, U.S. Naval Submarine Medical Center, Groton, Connecticut, May 1968.

   Oxygen percentage, oxygen partial pressure, and the presence of diluent inert gas are identified as significant parameters affecting fire ignition, flame propagation, and combustion temperature. Oxygen concentration is the most significant factor, especially at concentrations above 42 percent. A hand-held high-pressure water hose is the most effective extinguishing system. Specific prevention measures are recommended.

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   The feasibility of using high-expansion foam to extinguish fires of dry cellular fuel inside an oxygen-rich enclosure at various spacecraft operating pressures.

4. Chianta, M. A., Stoll, A. M., **Effect of Oxygen Enriched Atmosphere On Burning Rate of Fabrics**, NADC-MA-6316, Aviation Medical Acceleration Laboratory, U.S. Naval Air Development Center, Johnsville, Pennsylvania, August 1963.

   The burning pattern of several fabrics in oxygen-enriched environments at 4.6 psia were studied. A small advantage was exhibited by the synthetic material-HT-1 over the other fabrics. No optimum combination of oxygen-nitrogen for the elimination of fire hazard could be identified.

5. Cicotti, J. M., **An Analysis of Fire and Explosion Hazards in Space Flight**, American Power Jet Company, Wright Air Development, Ridgefield, New Jersey, October 1960.

   Sources of potential fire and explosion in the booster and in the space capsule are examined, and present knowledge of fire-extinguishing and explosion-suppression agents is presented, together with an analysis of their limitations in space vehicle use. Areas in which further research and development are desirable are noted.

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6. Cochran, T. H., Petrash, D. A., Andracchio, C. R., and Sotos, R. G., **Burning of Teflon-Insulated Wires in Supercritical Oxygen at Normal and Zero Gravities**, NASA TM X-2174, Lewis Research Center, NASA, Washington, D.C., February 1971.

   An experimental program was conducted to investigate the burning characteristics of Teflon-insulated nickel wires in supercritical oxygen in normal and zero gravities. The results indicate that the Teflon burned in both normal and zero gravities. However, the flame propagation rate in zero gravity was smaller than in normal gravity.

7. Coleman, E. H., "Effects of Compressed and Oxygen-Enriched Air on the Flammability of Fabrics," **British Welding Journal**, September 1959.

   The effects of compressed air and of air enriched with oxygen on the flammability of a number of fabrics, including some treated with flame retardants, were examined. The effects oxygen enrichment is greater than that of air pressure. There are limits of oxygen concentration or air pressure above which fabrics burn however much retardant is added.

8. Denison, Flgt. Lt. D., Ernsting, J., OBE, and Cresswell, A. W., **The Fire Risks to Man of Oxygen-Rich Gas Environments**, No. 800296, RAF Institute of Aviation Medicine, Ministry of Defense (AF Dept.), Farnborough, Hants, UK, July 1965.

   Fires were studied in gas environments with oxygen partial pressures ranging from 0.2 to 1.0 atmospheres. The effects of variations in the type, fit, and proofing of clothing and in the detailed use of the water spray extinguishing system were noted.

9. Denison, D., Ernsting, J., and Cresswell, A.W., **The Fire-Hazards to Man In Compressed-Air Environments**, RAF Institute of Aviation Medicine, Farnborough, Hants, UK, 1AM Report No. 343, September 1965.

   The effects of air at increased total atmosphere pressures (up to 5 atmospheres) on the ignitability and burning rate of denim material is compared to the effects of oxygen enrichment at total pressures of atmosphere and less.

10. Denison, D. M., Ernsting, J., Tonkins, W. J., and Cresswell, A. W., "Problem of Fire in Oxygen-Rich Surroundings," **Nature**, Vol. 218, pp. 1110-1113, June 22, 1968.

    The fire hazard presented by oxygen-rich environments in chambers, diving spheres, or space vehicles are examined.

11. Dorr, V. A., "Fire Studies in Oxygen-Enriched Atmospheres," J. **Fire & Flammability**, Vol. 1, p. 91, April 1970.

    Evaluations of the flammability of selected materials in hyperbaric and oxygen-enriched atmospheres were performed. A scale of fire resistance for measuring flammability in oxygen-enriched atmospheres is discussed.

12. Durfee, R. L., and Spurlock, J. M., **Quenching and Extinguishment of Burning Solids in Oxygen-Enriched Atmospheres**, No. NAS 9-8470, NASA Manned Spacecraft Center, Atlantic Research Corp., Alexandria, Virginia, September 1969.

Two tasks were performed in the field of fire hazards in spacecraft atmospheres. Quenching distances for a brass foil of flaming polymer materials and thin polymer films on heat sink backings were determined. Fire extinguishers that effectively utilized inert gases were designed and tested.

13. Eggleston, Lester A., **Evaluation of Fire Extinguishing Systems for Use in Oxygen Rich Atmospheres**, SWRI Project No. 02-2094, Final Report, Aerospace Medical Division, Brooks AFB, Texas, May 18, 1967.

The original scope of this project covered the installation, test, and evaluation of two complete extinguishing systems for a hypobaric chamber. One system used Freon 1301, the other utilized water spray heads. Ultraviolet detection was specified for both. The scope was later expanded to include flame detectors and ionization particle detectors and also a hypobaric chamber. Tests were conducted between April 10, 1967 and May 18, 1967.

14. Fernandez-Pello, A. C., Glassman, I., **The Effect of Oxygen Concentration on Flame Spread in an Opposed Forced Flow**, No. 79-26, Mechanical and Aerospace Engineering, Princeton University, April 1979. (WSS paper 79-26, Western States Section, The Combustion Institute, Pittsburgh, Pennsylvania.)

The velocity of flame propagation over the surface of thick sheets of PMMA were measured as a function of atmosphere velocity and oxygen concentration for gas flow opposing the direction of flame propagation. Flame propagation was retarded by increasing gas velocities at low oxygen concentrations and increased at high oxygen concentrations. A simplified model was developed.

15. Fisher, D. H., Ph.D., Gerstein, M., Ph.D., **Investigation of Material Combustibility and Fire and Explosion Suppression in a Variety of Atmospheres**, No. SN-6401, Air Force Aero Propulsion Laboratory, Dynamic Science Corporation, Monrovia, California, (no date).

The combustibility properties of polyethylene, polyvinyl chloride, and silicone rubber were evaluated for atmosphere compositions and pressures. Two candidate agents were synthesized for first-aid fire extinguishants on Class D fires. Plans for determining combustion properties of selected materials in oxygen-enriched atmospheres and zero gravity conditions are presented. A survey and selection of candidate agents for use in orbiting manned spacecraft was made and plans for evaluating these agents were presented.

16. Geyer, G. B., Neri, L. M., and Urban, C. H., **Advanced Concept in Aircraft Crash Firefighting Using Carbon Tetrafluoride**, FAA-NA-79-43, HQ AFESC/RDCF, Engineering and Services Laboratory, Federal Aviation Administration, Atlantic City, New Jersey, March 1980.

Three large-scale experiments were performed in the instrumented cabin of a DC-7 aircraft employing Class A and B fuels where a habitable inert atmosphere of 27-percent $CF_4$ discharged at a rate of 3300 cfm into the aircraft cabin extinguished nonsurvivable cabin fires within 125 seconds during which time the cabin temperature was rapidly reduced and cabin visibility improved. A fourth test using neat $CF_4$ agent discharged through simulated aircraft skin penetrator nozzles. The neat $CF_4$ extinguishment required nearly twice as long and did not improve cabin visibility.

17. Hirst, R., and Booth, K., "Measurement of Flame-Extinguishing Concentrations," **Fire Technology**, Vol. 13, No. 4, November 1977.

1) Flame extinguishing concentrations were measured for use in NFPA 12A to 12B. The cup-burner method adopted by NFPA was used.
2) Development of the cup-burner method is discussed and the apparatus and experimental method are described.
3) Experiments examined the effects of atmosphere velocity, fuel temperature, use of diluents, high boiling point agents, oxygen concentration, and burning rates. Eighteen liquid and six gaseous fuels were tested. Agents tested were Halons 1211, 1301, 2402, 1202, 1011, 1001, 113, 14, 122, 251, and 131.

18. Huggett, C., Ph.D., et al., **The Effects of 100-Percent Oxygen at Reduced Pressure on the Ignitability and Combustibility of Materials**, SA-TR-65-78, USAF School of Aerospace Medicine, Brooks AFB, Texas, December 1965.

An investigation was conducted to determine the effect of prolonged exposure to an atmosphere of 100-percent oxygen at 258 mm Hg on the fire hazards associated with space cabin materials. The ignitability and combustibility of standard materials were determined before and after a 30-day exposure to such an atmosphere.

19. Huggett, C., Ph.D., et al., **The Combustibility of Materials in Oxygen-Helium and Oxygen-Nitrogen Atmospheres**, No. 489728, USAF School of Aerospace Medicine, Aerospace Medical Center (AFSC), Brooks AFB, Texas, June 1966.

Energies required to ignite various materials and the rate of flame propagation were determined in proposed oxygen-nitrogen and oxygen-helium space cabin atmospheres to assess associated fire hazards. It was concluded that fire hazards were greater in oxygen-helium atmospheres.

20. Huggett, C., Ph.D., **Combustion Processes in the Aerospace Environment**, USAF School of Aerospace Medicine, Aerospace Medical Center (AFSC), Brooks AFB, Texas, November 1969.

Oxygen-enriched atmospheres contribute to the fire hazards in aerospace systems. A system for classifying atmospheres according to the degree of fire hazard, based on the heat capacity of the atmosphere per mole of oxygen, is suggested. A brief exploration of the dynamic of chamber fires is also made.

68

21. Kimzey, J. H., **Flammable and Toxic Materials in the Oxygen Atmosphere of Manned Spacecraft**, NASA TN D-3415, Manned Spacecraft Center, NASA, Houston, Texas, May 1968.

   The preliminary study of the considerations necessary in selecting materials for use in an oxygen-enriched atmosphere revealed the need for a major design effort directed towards reducing the toxic and flammable contaminants of the atmosphere.

22. Klein, H. A., Maj., USAFRes., **The Effects of Cabin Atmospheres on Combustion of Some Flammable Aircraft Materials**, WADC-TR-59-456, Air Research and Development Command, USAF, Wright-Patterson AFB, Ohio, April 1960.

   Ignition temperature and burning rate of certain flammable aircraft materials in atmospheres of oxygen-nitrogen and oxygen-helium mixtures at pressures ranging from sea level to 25,000 ft altitude were measured.

23. Kuchta, J. M., and Cato, R. J., **Review of Ignition and Flammability Properties of Lubricants**, AFAPL-TR-67-126, Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, January 1968.

   This report provides a compilation and review of ignition temperatures and flammability properties for over 90 lubricants and hydraulic fluids. Data is presented for fluids in air, oxygen, and oxygen-nitrogen atmospheres at pressures from 1/8 to 1000 atmospheres using a variety of ignition sources.

24. Litchfield, E. L., and Kubala, T. A., "Flammability of Fabrics and Other Materials in Oxygen-Enriched Atmospheres," **Fire Technology**, (no date).

   The electrical energy required to ignite certain solids in air and oxygen at both atmosphere and hyperbaric pressures were examined.

25. Litchfield, E. L., and Perlee, H. E., **Fire and Explosion Hazards of Flight Vehicle Combustibles**, AFAPL-TR-65-28, AD 614694, Bureau of Mines, U.S. Department of the Interior, Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, March 1965.

   Liquid hydrogen + solid oxygen + diluent and liquid oxygen + solid hydrocarbon + diluent systems were investigated for shock sensitivity and explosive yield with both gaseous and solid powder diluents. Haligenated hydrocarbons were also considered.

26. Manheim, J. R., **Evaluation of Halon 1301 for Fire Suppression in Oxygen-Enriched Atmospheres**, Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson AFB, Ohio, (no date).

   This report documents the evaluation of Halon 1301 as a candidate extinguishing agent for fires in hypobaric oxygen-enriched atmospheres. Performance criteria for agent evaluation and characteristics of Halon 1301 are discussed. Two series of tests were performed. The first series investigated the ignition limits of combustible materials in premix oxygen-helium-Halon 1301 atmospheres. The second investigated the effects of discharge rate on fire suppression. This research quantitatively established the fire suppression effectiveness of Halon 1301 for a variety of atmospheres (oxygen

concentration and total pressure) in total flooding applications, agent concentration and discharge rate were shown to depend on material type, oxygen concentration, and total atmosphere pressure.

27. McHale, E. T., **Hydrogen Suppression Study and Testing of Halon 1301-Phases I and II**, MA-RD-920-77035, Department of Commerce, Atlantic Research Corporation, Alexandria, Virginia, December, 1976.

This report describes the evaluation of the feasibility of employing a Halon 1301 explosion suppression system for maritime nuclear reactors. The quantity of Halon 1301 required to inert $H_2$, $O_2$, $N_2$ mixtures was measured. The results of this study support the concept of using Halon 1301.

28. **Review of Factors Affecting Ignition of Metals in High-Pressure Oxygen Systems**, TMX-67201, NASA Manned Spacecraft Center, Houston, Texas, October 1970.

Sufficient work was performed to permit the following observations:
1) Ignition temperatures of metals in LOX is independent of pressure, convection, and oxygen percentage.
2) The effect of halogen impurities on the ignition temperature of metals cannot be determined from existing data.
3) Ignition temperatures appear to be depressed by impurities.

29. Robertson, A. F., and Rappaport, M. W., **Fire Extinguishment in Oxygen-Enriched Atmospheres**, NASA CR-121150, National Bureau of Standards, Fire Technology Division, NASA, Washington, D.C., February 1973.

Current state-of-the-art of fire suppression and extinguishment techniques in oxygen-enriched atmospheres were reviewed. Four classes of extinguishment action were identified. Fast-acting water spray systems are preferred for ground-based applications.

30. Roth, E. M., **Space Cabin Atmospheres, Part II-Fire and Blast Hazards**, NASA SP-48, NASA, Washington, D.C., 1964.

This report provides a summary of the open literature in the field. Definitions of ignition, flame propagation, detonation, flame extinguishment, and environmental factors are reviewed and the effects of atmospheric environment on the flammability of solids, liquids, and gases as well as electrical fire hazards are presented. The fire and blast hazards from meteoroid penetration are discussed. Problems of fire prevention and extinguishment in space cabins and the role of fire and blast hazard in the selection of space-cabin atmospheres are presented.

31. Somerville, G. R., **Fire Control Feasibility Study**, SWRI Project No. 01-2114-01, NASA Manned Spacecraft Center, Southwest Research Institute, Houston, Texas, June 1967.

Foamed Aqueous gels were developed and proved effective in combatting fires in pure oxygen atmospheres. Several materials were found to significantly retard fire spread.

32. Somerville, G. R., **Prototype Apollo Fire Extinguisher**, NASA CR-92233, NASA Manned Spacecraft Center, Southwest Research Institute, Houston, Texas, March 1966.

A fire extinguisher for use in zero-g and Apollo spacecraft environments was designed, fabricated, and evaluated.

33. Tewarson, A., Lee, J. L., and Pion, R. F., **The Influence of Oxygen Concentration on Fuel Parameters for Fire Modeling**, Factory Mutual Research Corporation, Norwood, Massachusetts, 1981 (18th Symposium on Combustion, The Combustion Institute).

The influence of oxygen concentration on mass loss rate, combustion efficiency, convective and radiative fractions of heat of combustion, and yields of $CO_2$, CO, soot, and low-vapor-pressure liquid products for pool fires of various sizes and fuels is described.

34. White, E. L., and Ward, J. J., **Ignition of Metals in Oxygen**, DMIC Report 224, Office of the Director of Defense Research and Engineering, Defense Metals Information Center, Columbus, Ohio, February 1966.

The ignition of metals in oxygen and oxygen atmospheres was reviewed with respect to a) methods that have been used to study behavior, b) experimental values that have been obtained, c) the status of theories that permit the calculation of ignition temperatures.

# APPENDIX B
## FULL-SCALE TEMPERATURE READOUTS

Test 5

| | 2s | | | 5s | | | 8s | |
|---|---|---|---|---|---|---|---|---|
| 005 | 137 | DEG F | --- | --- | DEG F | 005 | 287 | DEG F |
| 004 | 39 | DEG F | 004 | 40 | DEG F | 004 | 41 | DEG F |
| 003 | 51 | DEG F | 003 | 66 | DEG F | 003 | 94 | DEG F |
| 002 | 331 | DEG F | 002 | 478 | DEG F | 002 | 662 | DEG F |
| 001 | 131 | DEG F | 001 | 189 | DEG F | 001 | 261 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| | 20:40:52 | | | 20:40:55 | | | 20:40:58 | |

| | 11s | | | 14s | | | 15s | |
|---|---|---|---|---|---|---|---|---|
| 005 | 394 | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| 004 | 47 | DEG F | --- | --- | DEG F | 004 | 57 | DEG F |
| 003 | 124 | DEG F | 003 | 151 | DEG F | 003 | 163 | DEG F |
| 002 | 942 | DEG F | 002 | 1112 | DEG F | 002 | 1164 | DEG F |
| 001 | 337 | DEG F | 001 | 417 | DEG F | 001 | 452 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| | 20:41:01 | | | 20:41:04 | | | 20:41:05 | |

| | 19s | | | 22s | | | 25s | |
|---|---|---|---|---|---|---|---|---|
| 005 | 664 | DEG F | 005 | 742 | DEG F | --- | --- | DEG F |
| 004 | 71 | DEG F | 004 | 81 | DEG F | 004 | 100 | DEG F |
| 003 | 208 | DEG F | 003 | 252 | DEG F | 003 | 322 | DEG F |
| 002 | 1412 | DEG F | 002 | 1568 | DEG F | 002 | 1642 | DEG F |
| 001 | 598 | DEG F | 001 | 729 | DEG F | 001 | 889 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| | 20:41:09 | | | 20:41:12 | | | 20:41:15 | |

| | 27s | | | 30s | | | 33s | |
|---|---|---|---|---|---|---|---|---|
| 005 | 1468 | DEG F | 005 | 1787 | DEG F | 005 | 1756 | DEG F |
| 004 | 182 | DEG F | 004 | 406 | DEG F | 004 | 652 | DEG F |
| 003 | 652 | DEG F | 003 | 1145 | DEG F | 003 | 1381 | DEG F |
| 002 | 1873 | DEG F | 002 | 1904 | DEG F | 002 | 1824 | DEG F |
| 001 | 1116 | DEG F | 001 | 1234 | DEG F | 001 | 1217 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| | 20:41:17 | | | 20:41:20 | | | 20:41:23 | |

Note: 000 faulty data.

|  | 36s |  |  |  | 38s |  |  |  | 41s |  |
|---|---|---|---|---|---|---|---|---|---|---|
| --- | --- | DEG F |  | 005 | 1462 | DEG F |  | 005 | 1285 | DEG F |
| 004 | 795 | DEG F |  | 004 | 848 | DEG F |  | 004 | 861 | DEG F |
| 003 | 1391 | DEG F |  | 003 | 1304 | DEG F |  | 003 | 1192 | DEG F |
| 002 | 1720 | DEG F |  | 002 | 1546 | DEG F |  | 002 | 1436 | DEG F |
| 001 | 1178 | DEG F |  | 001 | 1153 | DEG F |  | 001 | 1064 | DEG F |
| --- | --- | DEG F |  | --- | --- | DEG F |  | --- | --- | DEG F |
|  | 20:41:26 |  |  |  | 20:41:28 |  |  |  | 20:41:31 |  |

|  | 44s |  |  |  | 49s |  |  |  | 52s |  |
|---|---|---|---|---|---|---|---|---|---|---|
| --- | --- | DEG F |  | 005 | 756 | DEG F |  | 005 | 671 | DEG F |
| --- | --- | DEG F |  | 004 | 738 | DEG F |  | 004 | 705 | DEG F |
| --- | --- | DEG F |  | 003 | 721 | DEG F |  | 003 | 669 | DEG F |
| 002 | 1272 | DEG F |  | 002 | 998 | DEG F |  | 002 | 896 | DEG F |
| 001 | 865 | DEG F |  | 001 | 642 | DEG F |  | 001 | 572 | DEG F |
| --- | --- | DEG F |  | --- | --- | DEG F |  | --- | --- | DEG F |
|  | 20:41:34 |  |  |  | 20:41:39 |  |  |  | 20:41:42 |  |

|  | 55s |  |  |  | 57s |  |  |  | 60s |  |
|---|---|---|---|---|---|---|---|---|---|---|
| --- | --- | DEG F |  | 005 | 628 | DEG F |  | 005 | 617 | DEG F |
| 004 | 672 | DEG F |  | 004 | 649 | DEG F |  | 004 | 623 | DEG F |
| 003 | 634 | DEG F |  | 003 | 584 | DEG F |  | 003 | 555 | DEG F |
| 002 | 828 | DEG F |  | 002 | 779 | DEG F |  | 002 | 741 | DEG F |
| 001 | 511 | DEG F |  | 001 | 467 | DEG F |  | 001 | 436 | DEG F |
| --- | --- | DEG F |  | --- | --- | DEG F |  | --- | --- | DEG F |
|  | 20:41:45 |  |  |  | 20:41:47 |  |  |  | 20:41:50 |  |

|  | 63s |  |  |  | 66s |  |  |  | 68s |  |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 605 | DEG F |  | --- | --- | DEG F |  | 005 | 581 | DEG F |
| 004 | 603 | DEG F |  | 004 | 583 | DEG F |  | 004 | 568 | DEG F |
| 003 | 534 | DEG F |  | 003 | 521 | DEG F |  | 003 | 507 | DEG F |
| 002 | 718 | DEG F |  | 002 | 703 | DEG F |  | 002 | 683 | DEG F |
| 001 | 428 | DEG F |  | 001 | 418 | DEG F |  | 001 | 403 | DEG F |
| --- | --- | DEG F |  | --- | --- | DEG F |  | --- | --- | DEG F |
|  | 20:41:53 |  |  |  | 20:41:56 |  |  |  | 20:41:58 |  |

75

|  | 71s |  |  |  | 74s |  |  | 79s |  |
|---|---|---|---|---|---|---|---|---|---|
| 005 | 565 | DEG F | --- | --- | DEG F | 005 | 533 | DEG F |
| 004 | 547 | DEG F | --- | --- | DEG F | 004 | 509 | DEG F |
| 003 | 485 | DEG F | --- | --- | DEG F | 003 | 448 | DEG F |
| 002 | 658 | DEG F | 002 | 637 | DEG F | 002 | 598 | DEG F |
| 001 | 387 | DEG F | 001 | 388 | DEG F | 001 | 367 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
|  | 20:42:01 |  |  | 20:42:04 |  |  | 20:42:09 |  |

|  | 82s |  |  |  | 85s |  |  | 87s |  |
|---|---|---|---|---|---|---|---|---|---|
| 005 | 520 | DEG F | --- | --- | DEG F | 005 | 495 | DEG F |
| 004 | 500 | DEG F | 004 | 489 | DEG F | 004 | 478 | DEG F |
| 003 | 434 | DEG F | 003 | 422 | DEG F | 003 | 404 | DEG F |
| 002 | 583 | DEG F | 002 | 572 | DEG F | 002 | 555 | DEG F |
| 001 | 354 | DEG F | 001 | 342 | DEG F | 001 | 334 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
|  | 20:42:12 |  |  | 20:42:15 |  |  | 20:42:17 |  |

|  | 90s |  |  | 93s |  |  | 96s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 484 | DEG F | 005 | 471 | DEG F | --- | --- | DEG F |
| 004 | 466 | DEG F | 004 | 455 | DEG F | 004 | 445 | DEG F |
| 003 | 391 | DEG F | 003 | 379 | DEG F | 003 | 368 | DEG F |
| 002 | 540 | DEG F | 002 | 526 | DEG F | 002 | 514 | DEG F |
| 001 | 327 | DEG F | 001 | 319 | DEG F | 001 | 308 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
|  | 20:42:20 |  |  | 20:42:23 |  |  | 20:42:26 |  |

|  | 98s |  |  | 101s |  |  | 104s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 451 | DEG F | 005 | 437 | DEG F | --- | --- | DEG F |
| 004 | 436 | DEG F | 004 | 424 | DEG F | --- | --- | DEG F |
| 003 | 356 | DEG F | 003 | 342 | DEG F | --- | --- | DEG F |
| 002 | 502 | DEG F | 002 | 487 | DEG F | 002 | 475 | DEG F |
| 001 | 298 | DEG F | 001 | 287 | DEG F | 001 | 282 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
|  | 20:42:28 |  |  | 20:42:31 |  |  | 20:42:34 |  |

| | 109s | | | 112s | | | 115s | |
|---|---|---|---|---|---|---|---|---|
| 005 | 408 | DEG F | 005 | 399 | DEG F | --- | --- | DEG F |
| 004 | 389 | DEG F | 004 | 379 | DEG F | 004 | 371 | DEG F |
| 003 | 320 | DEG F | 003 | 308 | DEG F | 003 | 302 | DEG F |
| 002 | 455 | DEG F | 002 | 440 | DEG F | 002 | 430 | DEG F |
| 001 | 274 | DEG F | 001 | 273 | DEG F | 001 | 271 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| | 20:42:39 | | | 20:42:42 | | | 20:42:45 | |

| | 117s | | | 120s | | | 126s | |
|---|---|---|---|---|---|---|---|---|
| 005 | 380 | DEG F | 005 | 370 | DEG F | --- | --- | DEG F |
| 004 | 364 | DEG F | 004 | 358 | DEG F | 004 | 247 | DEG F |
| 003 | 289 | DEG F | 003 | 276 | DEG F | 003 | 200 | DEG F |
| 002 | 419 | DEG F | 002 | 409 | DEG F | 002 | 297 | DEG F |
| 001 | 270 | DEG F | 001 | 272 | DEG F | 001 | 225 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| | 20:42:47 | | | 20:42:50 | | | 20:43:56 | |

| | 129s | | | 132s | | | 179s | |
|---|---|---|---|---|---|---|---|---|
| 005 | 252 | DEG F | 005 | 249 | DEG F | --- | --- | DEG F |
| 004 | 239 | DEG F | 004 | 236 | DEG F | 004 | 196 | DEG F |
| 003 | 195 | DEG F | 003 | 194 | DEG F | 003 | 175 | DEG F |
| 002 | 295 | DEG F | 002 | 287 | DEG F | 002 | 257 | DEG F |
| 001 | 224 | DEG F | 001 | 216 | DEG F | 001 | 211 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| | 20:43:59 | | | 20:44:02 | | | 20:44:49 | |

| | 182s | |
|---|---|---|
| 005 | 232 | DEG F |
| 004 | 194 | DEG F |
| 003 | 173 | DEG F |
| 002 | 253 | DEG F |
| 001 | 207 | DEG F |
| --- | --- | DEG F |
| | 20:44:52 | |

# TEST 6

| | 0s | | | | 4s | | | | 7s | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 54 | DEG F | | 005 | 110 | DEG F | | 005 | 177 | DEG F |
| 004 | 33 | DEG F | | 004 | 34 | DEG F | | 004 | 34 | DEG F |
| 003 | 33 | DEG F | | 003 | 46 | DEG F | | 003 | 65 | DEG F |
| 002 | 133 | DEG F | | 002 | 263 | DEG F | | 002 | 395 | DEG F |
| 001 | 65 | DEG F | | 001 | 115 | DEG F | | 001 | 180 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| | 00:26:08 | | | | 00:26:12 | | | | 00:26:15 | |

| | 9s | | | | 12s | | | | 15s | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 225 | DEG F | | 005 | 364 | DEG F | | 005 | 465 | DEG F |
| 004 | 35 | DEG F | | 004 | 41 | DEG F | | 004 | 49 | DEG F |
| 003 | 95 | DEG F | | 003 | 135 | DEG F | | 003 | 181 | DEG F |
| 002 | 544 | DEG F | | 002 | 795 | DEG F | | 002 | 1023 | DEG F |
| 001 | 241 | DEG F | | 001 | 319 | DEG F | | 001 | 392 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| | 00:26:17 | | | | 00:26:20 | | | | 00:26:23 | |

| | 18s | | | | 21s | | | | 24s | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 578 | DEG F | | 005 | 686 | DEG F | | 005 | 768 | DEG F |
| 004 | 63 | DEG F | | 004 | 89 | DEG F | | 004 | 112 | DEG F |
| 003 | 229 | DEG F | | 003 | 283 | DEG F | | 003 | 368 | DEG F |
| 002 | 1281 | DEG F | | 002 | 1472 | DEG F | | 002 | 1578 | DEG F |
| 001 | 512 | DEG F | | 001 | 642 | DEG F | | 001 | 795 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| | 00:26:26 | | | | 00:26:29 | | | | 00:26:32 | |

| | 27s | | | | 30s | | | | 33s | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 848 | DEG F | | 005 | 935 | DEG F | | 005 | 1094 | DEG F |
| 004 | 144 | DEG F | | 004 | 179 | DEG F | | 004 | 228 | DEG F |
| 003 | 451 | DEG F | | 003 | 532 | DEG F | | 003 | 641 | DEG F |
| 002 | 1712 | DEG F | | 002 | 1771 | DEG F | | 002 | 1775 | DEG F |
| 001 | 930 | DEG F | | 001 | 1072 | DEG F | | 001 | 1297 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| | 00:26:35 | | | | 00:26:38 | | | | 00:26:41 | |

78                    Note: 000 faulty data.

|       | 36s  |       |       | 38s  |       |       | 41s  |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 1328 | DEG F | 005   | 1516 | DEG F | 005   | 1625 | DEG F |
| 004   | 282  | DEG F | 004   | 403  | DEG F | 004   | 609  | DEG F |
| 003   | 792  | DEG F | 003   | 1141 | DEG F | 003   | 1434 | DEG F |
| 002   | 1855 | DEG F | 002   | 1745 | DEG F | 002   | 1575 | DEG F |
| 001   | 1431 | DEG F | 001   | 1562 | DEG F | 001   | 1495 | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
|       | 00:26:44 | |       | 00:26:46 | |      | 00:26:49 | |

|       | 44s  |       |       | 47s  |       |       | 50s  |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 1639 | DEG F | 005   | 1565 | DEG F | 005   | 1307 | DEG F |
| 004   | 795  | DEG F | 004   | 961  | DEG F | 004   | 993  | DEG F |
| 003   | 1571 | DEG F | 003   | 1440 | DEG F | 003   | 1216 | DEG F |
| 002   | 1475 | DEG F | 002   | 1399 | DEG F | 002   | 1290 | DEG F |
| 001   | 1366 | DEG F | 001   | 1254 | DEG F | 001   | 1114 | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
|       | 00:26:52 | |       | 00:26:55 | |      | 00:26:58 | |

|       | 53s  |       |       | 56s  |       |       | 58s  |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 1095 | DEG F | 005   | 944  | DEG F | 005   | 1078 | DEG F |
| 004   | 929  | DEG F | 004   | 868  | DEG F | 004   | 936  | DEG F |
| 003   | 1011 | DEG F | 003   | 878  | DEG F | 003   | 982  | DEG F |
| 002   | 1176 | DEG F | 002   | 1081 | DEG F | 002   | 1162 | DEG F |
| 001   | 949  | DEG F | 001   | 852  | DEG F | 001   | 812  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
|       | 00:27:01 | |       | 00:27:04 | |      | 00:27:06 | |

|       | 61s  |       |       | 64s  |       |       | 67s  |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 1186 | DEG F | 005   | 1168 | DEG F | 005   | 1099 | DEG F |
| 004   | 1077 | DEG F | 004   | 1065 | DEG F | 004   | 1032 | DEG F |
| 003   | 1171 | DEG F | 003   | 1152 | DEG F | 003   | 1071 | DEG F |
| 002   | 1228 | DEG F | 002   | 1188 | DEG F | 002   | 1122 | DEG F |
| 001   | 898  | DEG F | 001   | 965  | DEG F | 001   | 862  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
|       | 00:27:09 | |       | 00:27:12 | |      | 00:27:15 | |

79

|       | 70s  |       |       | 73   |       |       | 76s  |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 1046 | DEG F | 005   | 968  | DEG F | 005   | 914  | DEG F |
| 004   | 990  | DEG F | 004   | 928  | DEG F | 004   | 878  | DEG F |
| 003   | 984  | DEG F | 003   | 904  | DEG F | 003   | 854  | DEG F |
| 002   | 1055 | DEG F | 002   | 978  | DEG F | 002   | 926  | DEG F |
| 001   | 676  | DEG F | 001   | 703  | DEG F | 001   | 728  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
|       | 00:27:18 | |      | 00:27:21 | |      | 00:27:24 | |

|       | 79s  |       |       | 83s  |       |       | 85s  |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 868  | DEG F | 005   | 699  | DEG F | 005   | 678  | DEG F |
| 004   | 831  | DEG F | 004   | 663  | DEG F | 004   | 641  | DEG F |
| 003   | 816  | DEG F | 003   | 645  | DEG F | 003   | 623  | DEG F |
| 002   | 883  | DEG F | 002   | 749  | DEG F | 002   | 730  | DEG F |
| 001   | 728  | DEG F | 001   | 628  | DEG F | 001   | 614  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
|       | 00:27:27 | |      | 00:27:41 | |      | 00:27:43 | |

|       | 88s  |       |       | 120s |       |       | 123s |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 661  | DEG F | 005   | 538  | DEG F | 005   | 524  | DEG F |
| 004   | 622  | DEG F | 004   | 501  | DEG F | 004   | 487  | DEG F |
| 003   | 606  | DEG F | 003   | 504  | DEG F | 003   | 490  | DEG F |
| 002   | 711  | DEG F | 002   | 587  | DEG F | 002   | 572  | DEG F |
| 001   | 606  | DEG F | 001   | 506  | DEG F | 001   | 488  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
|       | 00:27:46 | |      | 00:28:08 | |      | 00:28:11 | |

|       | 126s |       |       | 129s |       |       | 132s |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 512  | DEG F | 005   | 501  | DEG F | 005   | 488  | DEG F |
| 004   | 475  | DEG F | 004   | 463  | DEG F | 004   | 451  | DEG F |
| 003   | 479  | DEG F | 003   | 465  | DEG F | 003   | 443  | DEG F |
| 002   | 559  | DEG F | 002   | 549  | DEG F | 002   | 538  | DEG F |
| 001   | 476  | DEG F | 001   | 468  | DEG F | 001   | 451  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
|       | 00:28:14 | |      | 00:28:17 | |      | 00:28:20 | |

|      | 135s |       |      | 137s |       |      | 177s |       |
|------|------|-------|------|------|-------|------|------|-------|
| 005  | 477  | DEG F | 005  | 467  | DEG F | 005  | 306  | DEG F |
| 004  | 442  | DEG F | 004  | 432  | DEG F | 004  | 249  | DEG F |
| 003  | 423  | DEG F | 003  | 407  | DEG F | 003  | 231  | DEG F |
| 002  | 528  | DEG F | 002  | 519  | DEG F | 002  | 331  | DEG F |
| 001  | 446  | DEG F | 001  | 433  | DEG F | 001  | 307  | DEG F |
| ---  | ---  | DEG F | ---  | ---  | DEG F | ---  | ---  | DEG F |
|      | 00:28:23 |   |      | 00:28:25 |   |      | 00:30:05 |   |

|      | 180s |       |      | 183s |       |
|------|------|-------|------|------|-------|
| 005  | 303  | DEG F | 005  | 301  | DEG F |
| 004  | 247  | DEG F | 004  | 245  | DEG F |
| 003  | 230  | DEG F | 003  | 229  | DEG F |
| 002  | 327  | DEG F | 002  | 324  | DEG F |
| 001  | 306  | DEG F | 001  | 303  | DEG F |
| ---  | ---  | DEG F | ---  | ---  | DEG F |
|      | 00:30:08 |   |      | 00:30:11 |   |

Test 9

| | 0s | | | | 3s | | | | 6s | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 229 | DEG F | | 005 | 296 | DEG F | | 005 | 379 | DEG F |
| 004 | 54 | DEG F | | 004 | 62 | DEG F | | 004 | 71 | DEG F |
| 003 | 120 | DEG F | | 003 | 148 | DEG F | | 003 | 184 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 000 | 66 | DEG F | | 000 | 76 | DEG F | | 000 | 89 | DEG F |
| | 00:34:50 | | | | 00:34:53 | | | | 00:34:56 | |

| | 8s | | | | 11s | | | | 14s | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 458 | DEG F | | 005 | 570 | DEG F | | 005 | 655 | DEG F |
| 004 | 94 | DEG F | | 004 | 111 | DEG F | | 004 | 133 | DEG F |
| 003 | 224 | DEG F | | 003 | 271 | DEG F | | 003 | 310 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 000 | 107 | DEG F | | 000 | 137 | DEG F | | 000 | 164 | DEG F |
| | 00:34:58 | | | | 00:35:01 | | | | 00:35:04 | |

| | 17s | | | | 18s | | | | 21s | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 720 | DEG F | | 005 | 800 | DEG F | | 005 | 863 | DEG F |
| 004 | 154 | DEG F | | 004 | 179 | DEG F | | 004 | 211 | DEG F |
| 003 | 347 | DEG F | | 003 | 384 | DEG F | | 003 | 426 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 000 | 188 | DEG F | | 000 | 210 | DEG F | | 000 | 244 | DEG F |
| | 00:35:07 | | | | 00:35:09 | | | | 00:35:12 | |

| | 24s | | | | 27s | | | | 30s | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 928 | DEG F | | 005 | 972 | DEG F | | 005 | 1004 | DEG F |
| 004 | 238 | DEG F | | 004 | 279 | DEG F | | 004 | 311 | DEG F |
| 003 | 472 | DEG F | | 003 | 522 | DEG F | | 003 | 567 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 000 | 279 | DEG F | | 000 | 309 | DEG F | | 000 | 345 | DEG F |
| | 00:35:15 | | | | 00:35:18 | | | | 00:35:21 | |

|     | 33s  |       |     | 35s  |       |     | 38s  |       |
|-----|------|-------|-----|------|-------|-----|------|-------|
| 005 | 1034 | DEG F | 005 | 1069 | DEG F | 005 | 1095 | DEG F |
| 004 | 348  | DEG F | 004 | 383  | DEG F | 004 | 418  | DEG F |
| 003 | 606  | DEG F | 003 | 642  | DEG F | 003 | 681  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| 000 | 375  | DEG F | 000 | 407  | DEG F | 000 | 447  | DEG F |

00:35:24          00:35:26          00:35:29

|     | 41s  |       |     | 44s  |       |     | 46s  |       |
|-----|------|-------|-----|------|-------|-----|------|-------|
| 005 | 1110 | DEG F | 005 | 1117 | DEG F | 005 | 1147 | DEG F |
| 004 | 452  | DEG F | 004 | 485  | DEG F | 004 | 514  | DEG F |
| 003 | 733  | DEG F | 003 | 757  | DEG F | 003 | 803  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| 000 | 483  | DEG F | 000 | 523  | DEG F | 000 | 558  | DEG F |

00:35:32          00:35:35          00:35:37

|     | 49s  |       |     | 52s  |       |     | 55s  |       |
|-----|------|-------|-----|------|-------|-----|------|-------|
| 005 | 1150 | DEG F | 005 | 1143 | DEG F | 005 | 1159 | DEG F |
| 004 | 549  | DEG F | 004 | 568  | DEG F | 004 | 588  | DEG F |
| 003 | 828  | DEG F | 003 | 853  | DEG F | 003 | 874  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| 000 | 596  | DEG F | 000 | 598  | DEG F | 000 | 603  | DEG F |

00:35:40          00:35:43          00:35:46

|     | 57s  |       |     | 60s  |       |     | 63s  |       |
|-----|------|-------|-----|------|-------|-----|------|-------|
| 005 | 1152 | DEG F | 005 | 1147 | DEG F | 005 | 1151 | DEG F |
| 004 | 609  | DEG F | 004 | 623  | DEG F | 004 | 635  | DEG F |
| 003 | 888  | DEG F | 003 | 892  | DEG F | 003 | 918  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| 000 | 606  | DEG F | 000 | 599  | DEG F | 000 | 599  | DEG F |

00:35:48          00:35:51          00:35:54

|  | 66s |  |  |  | 68s |  |  |  | 71s |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 1129 | DEG F | | 005 | 1123 | DEG F | | 005 | 1094 | DEG F |
| 004 | 646 | DEG F | | 004 | 653 | DEG F | | 004 | 655 | DEG F |
| 003 | 903 | DEG F | | 003 | 894 | DEG F | | 003 | 879 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 000 | 592 | DEG F | | 000 | 585 | DEG F | | 000 | 578 | DEG F |
|  | 00:35:57 |  | |  | 00:35:59 |  | |  | 00:36:02 |  |

|  | 74s |  |  |  | 76s |  |  |  | 80s |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 1085 | DEG F | | 005 | 1047 | DEG F | | 005 | 983 | DEG F |
| 004 | 654 | DEG F | | 004 | 649 | DEG F | | 004 | 638 | DEG F |
| 003 | 861 | DEG F | | 003 | 836 | DEG F | | 003 | 798 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 000 | 553 | DEG F | | 000 | 537 | DEG F | | 000 | 508 | DEG F |
|  | 00:36:05 |  | |  | 00:36:07 |  | |  | 00:36:11 |  |

|  | 82s |  |  |  | 85s |  |  |  | 88s |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 958 | DEG F | | 005 | 918 | DEG F | | 005 | 869 | DEG F |
| 004 | 626 | DEG F | | 004 | 613 | DEG F | | 004 | 600 | DEG F |
| 003 | 772 | DEG F | | 003 | 744 | DEG F | | 003 | 715 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 000 | 482 | DEG F | | 000 | 454 | DEG F | | 000 | 436 | DEG F |
|  | 00:36:13 |  | |  | 00:36:16 |  | |  | 00:36:19 |  |

|  | 91s |  |  |  | 93s |  |  |  | 96s |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 818 | DEG F | | 005 | 779 | DEG F | | 005 | 744 | DEG F |
| 004 | 585 | DEG F | | 004 | 571 | DEG F | | 004 | 557 | DEG F |
| 003 | 681 | DEG F | | 003 | 654 | DEG F | | 003 | 627 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 000 | 419 | DEG F | | 000 | 403 | DEG F | | 000 | 386 | DEG F |
|  | 00:36:22 |  | |  | 00:36:24 |  | |  | 00:36:27 |  |

|  | 99s |  |  | 102s |  |  | 104s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 707 | DEG F | 005 | 679 | DEG F | 005 | 654 | DEG F |
| 004 | 543 | DEG F | 004 | 530 | DEG F | 004 | 518 | DEG F |
| 003 | 603 | DEG F | 003 | 584 | DEG F | 003 | 565 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| 000 | 369 | DEG F | 000 | 358 | DEG F | 000 | 350 | DEG F |
|  | 00:36:30 |  |  | 00:36:33 |  |  | 00:36:35 |  |

|  | 107s |  |  | 110s |  |  | 113s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 632 | DEG F | 005 | 608 | DEG F | 005 | 589 | DEG F |
| 004 | 506 | DEG F | 004 | 494 | DEG F | 004 | 483 | DEG F |
| 003 | 547 | DEG F | 003 | 530 | DEG F | 003 | 518 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| 000 | 337 | DEG F | 000 | 327 | DEG F | 000 | 320 | DEG F |
|  | 00:36:38 |  |  | 00:36:41 |  |  | 00:36:44 |  |

|  | 115s |  |  | 118s |  |  | 121s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 571 | DEG F | 005 | 553 | DEG F | 005 | 539 | DEG F |
| 004 | 473 | DEG F | 004 | 464 | DEG F | 004 | 452 | DEG F |
| 003 | 506 | DEG F | 003 | 495 | DEG F | 003 | 482 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| 000 | 314 | DEG F | 000 | 309 | DEG F | 000 | 305 | DEG F |
|  | 00:36:46 |  |  | 00:36:49 |  |  | 00:36:52 |  |

|  | 123s |  |  | 126s |  |  | 128s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 526 | DEG F | 005 | 514 | DEG F | 005 | 501 | DEG F |
| 004 | 443 | DEG F | 004 | 434 | DEG F | 004 | 427 | DEG F |
| 003 | 471 | DEG F | 003 | 461 | DEG F | 003 | 451 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| 000 | 302 | DEG F | 000 | 298 | DEG F | 000 | 294 | DEG F |
|  | 00:36:54 |  |  | 00:36:57 |  |  | 00:36:59 |  |

|  | 131 |  |  | 134s |  |  | 136s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 489 | DEG F | 005 | 480 | DEG F | 005 | 472 | DEG F |
| 004 | 418 | DEG F | 004 | 411 | DEG F | 004 | 404 | DEG F |
| 003 | 442 | DEG F | 003 | 434 | DEG F | 003 | 426 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| 000 | 289 | DEG F | 000 | 284 | DEG F | 000 | 278 | DEG F |
|  | 00:37:02 |  |  | 00:37:05 |  |  | 00:37:07 |  |

|  | 139s |  |  | 142s |  |  | 144s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 462 | DEG F | 005 | 453 | DEG F | 005 | 446 | DEG F |
| 004 | 397 | DEG F | 004 | 390 | DEG F | 004 | 384 | DEG F |
| 003 | 417 | DEG F | 003 | 410 | DEG F | 003 | 404 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| 000 | 270 | DEG F | 000 | 264 | DEG F | 000 | 259 | DEG F |
|  | 00:37:10 |  |  | 00:37:13 |  |  | 00:37:15 |  |

|  | 147s |  |  | 158s |  |  | 161s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 438 | DEG F | 005 | 410 | DEG F | 005 | 403 | DEG F |
| 004 | 378 | DEG F | 004 | 355 | DEG F | 004 | 351 | DEG F |
| 003 | 398 | DEG F | 003 | 375 | DEG F | 003 | 370 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| 000 | 255 | DEG F | 000 | 244 | DEG F | 000 | 244 | DEG F |
|  | 00:37:18 |  |  | 00:37:29 |  |  | 00:37:32 |  |

|  | 163s |  |  | 166s |  |  | 188s |  |
|---|---|---|---|---|---|---|---|---|
| 005 | 346 | DEG F | 005 | 393 | DEG F | 005 | 359 | DEG F |
| 004 | 366 | DEG F | 004 | 341 | DEG F | 004 | 308 | DEG F |
| 003 | 397 | DEG F | 003 | 360 | DEG F | 003 | 323 | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| --- | --- | DEG F | --- | --- | DEG F | --- | --- | DEG F |
| 000 | 243 | DEG F | 000 | 241 | DEG F | 000 | 227 | DEG F |
|  | 00:37:34 |  |  | 00:37:37 |  |  | 00:37:59 |  |

|     | 191s |       |     | 194s |       |     | 196s |       |
|-----|------|-------|-----|------|-------|-----|------|-------|
| 005 | 335  | DEG F | 005 | 352  | DEG F | 005 | 349  | DEG F |
| 004 | 304  | DEG F | 004 | 300  | DEG F | 004 | 297  | DEG F |
| 003 | 320  | DEG F | 003 | 316  | DEG F | 003 | 313  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| 000 | 225  | DEG F | 000 | 224  | DEG F | 000 | 222  | DEG F |
|     | 00:38:02 |   |     | 00:38:05 |   |     | 00:38:07 |   |

Test 10

| 0s | | | | 3s | | | | 6s | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 34 | DEG F | | 005 | 34 | DEG F | | 005 | 34 | DEG F |
| 004 | 35 | DEG F | | 004 | 35 | DEG F | | 004 | 35 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 002 | 34 | DEG F | | 002 | 34 | DEG F | | 002 | 35 | DEG F |
| 001 | 34 | DEG F | | 001 | 33 | DEG F | | 001 | 34 | DEG F |
| 000 | 42 | DEG F | | 000 | 42 | DEG F | | 000 | 41 | DEG F |
| | 14:27:11 | | | | 14:27:14 | | | | 14:27:17 | |

| 10s | | | | 13s | | | | 16s | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 34 | DEG F | | 005 | 39 | DEG F | | 005 | 65 | DEG F |
| 004 | 36 | DEG F | | 004 | 38 | DEG F | | 004 | 42 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 002 | 85 | DEG F | | 002 | 131 | DEG F | | 002 | 178 | DEG F |
| 001 | 42 | DEG F | | 001 | 59 | DEG F | | 001 | 89 | DEG F |
| 000 | 45 | DEG F | | 000 | 53 | DEG F | | 000 | 82 | DEG F |
| | 14:27:21 | | | | 14:27:24 | | | | 14:27:27 | |

| 19s | | | | 22s | | | | 25s | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 124 | DEG F | | 005 | 159 | DEG F | | 005 | 185 | DEG F |
| 004 | 51 | DEG F | | 004 | 65 | DEG F | | 004 | 92 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 002 | 254 | DEG F | | 002 | 299 | DEG F | | 002 | 380 | DEG F |
| 001 | 132 | DEG F | | 001 | 169 | DEG F | | 001 | 211 | DEG F |
| 000 | 115 | DEG F | | 000 | 149 | DEG F | | 000 | 185 | DEG F |
| | 14:27:30 | | | | 14:27:33 | | | | 14:27:36 | |

| 28s | | | | 31s | | | | 34s | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 256 | DEG F | | 005 | 289 | DEG F | | 005 | 315 | DEG F |
| 004 | 139 | DEG F | | 004 | 178 | DEG F | | 004 | 216 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 002 | 542 | DEG F | | 002 | 640 | DEG F | | 002 | 761 | DEG F |
| 001 | 256 | DEG F | | 001 | 343 | DEG F | | 001 | 390 | DEG F |
| 000 | 224 | DEG F | | 000 | 292 | DEG F | | 000 | 324 | DEG F |
| | 14:27:39 | | | | 14:27:42 | | | | 14:27:45 | |

|  | 37s |  |  |  | 40s |  |  |  | 43s |  |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 361 | DEG F | | 005 | 409 | DEG F | | 005 | 455 | DEG F |
| 004 | 265 | DEG F | | 004 | 309 | DEG F | | 004 | 352 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 002 | 898 | DEG F | | 002 | 1010 | DEG F | | 002 | 1129 | DEG F |
| 001 | 461 | DEG F | | 001 | 523 | DEG F | | 001 | 572 | DEG F |
| 000 | 370 | DEG F | | 000 | 416 | DEG F | | 000 | 454 | DEG F |
|  | 14:27:48 | | | | 14:27:51 | | | | 14:27:54 | |

|  | 46s |  |  |  | 49s |  |  |  | 52s |  |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 485 | DEG F | | 005 | 619 | DEG F | | 005 | 846 | DEG F |
| 004 | 407 | DEG F | | 004 | 496 | DEG F | | 004 | 647 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 002 | 1212 | DEG F | | 002 | 1272 | DEG F | | 002 | 1802 | DEG F |
| 001 | 621 | DEG F | | 001 | 671 | DEG F | | 001 | 934 | DEG F |
| 000 | 494 | DEG F | | 000 | 548 | DEG F | | 000 | 662 | DEG F |
|  | 14:27:57 | | | | 14:28:00 | | | | 14:28:03 | |

|  | 55s |  |  |  | 58s |  |  |  | 61s |  |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 1098 | DEG F | | 005 | 1359 | DEG F | | 005 | 1521 | DEG F |
| 004 | 863 | DEG F | | 004 | 1044 | DEG F | | 004 | 1339 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 002 | 2100 | DEG F | | 002 | 2302 | DEG F | | 002 | 2282 | DEG F |
| 001 | 1248 | DEG F | | 001 | 1454 | DEG F | | 001 | 1544 | DEG F |
| 000 | 826 | DEG F | | 000 | 974 | DEG F | | 000 | 1123 | DEG F |
|  | 14:28:06 | | | | 14:28:09 | | | | 14:28:12 | |

|  | 64s |  |  |  | 67s |  |  |  | 70s |  |
|---|---|---|---|---|---|---|---|---|---|---|
| 005 | 1629 | DEG F | | 005 | 1684 | DEG F | | 005 | 1749 | DEG F |
| 004 | 1499 | DEG F | | 004 | 1624 | DEG F | | 004 | 1773 | DEG F |
| --- | --- | DEG F | | --- | --- | DEG F | | --- | --- | DEG F |
| 002 | 2312 | DEG F | | 002 | 2445 | DEG F | | 002 | 2521 | DEG F |
| 001 | 1544 | DEG F | | 001 | 1559 | DEG F | | 001 | 1677 | DEG F |
| 000 | 1137 | DEG F | | 000 | 1095 | DEG F | | 000 | 1072 | DEG F |
|  | 14:28:15 | | | | 14:28:18 | | | | 14:28:21 | |

|       | 73s  |       |       | 76s  |       |       | 78s  |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 1792 | DEG F | 005   | 1793 | DEG F | 005   | 1810 | DEG F |
| 004   | 1867 | DEG F | 004   | 1836 | DEG F | 004   | 1842 | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
| 002   | 2491 | DEG F | 002   | 2376 | DEG F | 002   | 2254 | DEG F |
| 001   | 1742 | DEG F | 001   | 1772 | DEG F | 001   | 1742 | DEG F |
| 000   | 1087 | DEG F | 000   | 1071 | DEG F | 000   | 1020 | DEG F |
|       | 14:28:24 |   |       | 14:28:27 |   |       | 14:28:29 |   |

|       | 82s  |       |       | 84s  |       |       | 87s  |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 1841 | DEG F | 005   | 1790 | DEG F | 005   | 1736 | DEG F |
| 004   | 1884 | DEG F | 004   | 1818 | DEG F | 004   | 1687 | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
| 002   | 2110 | DEG F | 002   | 2079 | DEG F | 002   | 1941 | DEG F |
| 001   | 1714 | DEG F | 001   | 1674 | DEG F | 001   | 1575 | DEG F |
| 000   | 1052 | DEG F | 000   | 1057 | DEG F | 000   | 1015 | DEG F |
|       | 14:28:33 |   |       | 14:28:35 |   |       | 14:28:38 |   |

|       | 90s  |       |       | 93s  |       |       | 96s  |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 1505 | DEG F | 005   | 1330 | DEG F | 005   | 1186 | DEG F |
| 004   | 1480 | DEG F | 004   | 1340 | DEG F | 004   | 1245 | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
| 002   | 1762 | DEG F | 002   | 1599 | DEG F | 002   | 1432 | DEG F |
| 001   | 1429 | DEG F | 001   | 1302 | DEG F | 001   | 1197 | DEG F |
| 000   | 922  | DEG F | 000   | 846  | DEG F | 000   | 791  | DEG F |
|       | 14:28:41 |   |       | 14:28:44 |   |       | 14:28:47 |   |

|       | 99s  |       |       | 102s |       |       | 105s |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 1073 | DEG F | 005   | 980  | DEG F | 005   | 912  | DEG F |
| 004   | 1111 | DEG F | 004   | 1031 | DEG F | 004   | 971  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
| 002   | 1293 | DEG F | 002   | 1180 | DEG F | 002   | 1084 | DEG F |
| 001   | 1081 | DEG F | 001   | 995  | DEG F | 001   | 923  | DEG F |
| 000   | 762  | DEG F | 000   | 732  | DEG F | 000   | 708  | DEG F |
|       | 14:28:50 |   |       | 14:28:53 |   |       | 14:28:56 |   |

|       | 108s |       |       | 111s |       |       | 114s |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 838  | DEG F | 005   | 789  | DEG F | 005   | 743  | DEG F |
| 004   | 909  | DEG F | 004   | 853  | DEG F | 004   | 799  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
| 002   | 1006 | DEG F | 002   | 944  | DEG F | 002   | 899  | DEG F |
| 001   | 859  | DEG F | 001   | 795  | DEG F | 001   | 752  | DEG F |
| 000   | 678  | DEG F | 000   | 643  | DEG F | 000   | 600  | DEG F |
|       | 14:28:59 |   |       | 14:29:02 |   |       | 14:29:05 |   |

|       | 117s |       |       | 120s |       |       | 123s |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 700  | DEG F | 005   | 652  | DEG F | 005   | 614  | DEG F |
| 004   | 754  | DEG F | 004   | 694  | DEG F | 004   | 646  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
| 002   | 859  | DEG F | 002   | 805  | DEG F | 002   | 777  | DEG F |
| 001   | 711  | DEG F | 001   | 663  | DEG F | 001   | 624  | DEG F |
| 000   | 566  | DEG F | 000   | 541  | DEG F | 000   | 520  | DEG F |
|       | 14:29:08 |   |       | 14:29:11 |   |       | 14:29:14 |   |

|       | 125s |       |       | 128s |       |       | 131s |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 583  | DEG F | 005   | 561  | DEG F | 005   | 536  | DEG F |
| 004   | 603  | DEG F | 004   | 560  | DEG F | 004   | 529  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
| 002   | 748  | DEG F | 002   | 702  | DEG F | 002   | 675  | DEG F |
| 001   | 587  | DEG F | 001   | 561  | DEG F | 001   | 530  | DEG F |
| 000   | 499  | DEG F | 000   | 477  | DEG F | 000   | 455  | DEG F |
|       | 14:29:16 |   |       | 14:29:19 |   |       | 14:29:22 |   |

|       | 134s |       |       | 137s |       |       | 140s |       |
|-------|------|-------|-------|------|-------|-------|------|-------|
| 005   | 515  | DEG F | 005   | 498  | DEG F | 005   | 477  | DEG F |
| 004   | 512  | DEG F | 004   | 499  | DEG F | 004   | 483  | DEG F |
| ---   | ---  | DEG F | ---   | ---  | DEG F | ---   | ---  | DEG F |
| 002   | 636  | DEG F | 002   | 601  | DEG F | 002   | 578  | DEG F |
| 001   | 509  | DEG F | 001   | 484  | DEG F | 001   | 468  | DEG F |
| 000   | 436  | DEG F | 000   | 415  | DEG F | 000   | 408  | DEG F |
|       | 14:29:25 |   |       | 14:29:28 |   |       | 14:29:31 |   |

|     | 143s |       |     | 146s |       |     | 149s |       |
|-----|------|-------|-----|------|-------|-----|------|-------|
| 005 | 456  | DEG F | 005 | 438  | DEG F | 005 | 428  | DEG F |
| 004 | 474  | DEG F | 004 | 460  | DEG F | 004 | 440  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| 002 | 562  | DEG F | 002 | 545  | DEG F | 002 | 528  | DEG F |
| 001 | 452  | DEG F | 001 | 434  | DEG F | 001 | 412  | DEG F |
| 000 | 388  | DEG F | 000 | 362  | DEG F | 000 | 347  | DEG F |
|     | 14:29:34 |   |     | 14:29:37 |   |     | 14:29:40 |   |

|     | 152s |       |     | 155s |       |     | 157s |       |
|-----|------|-------|-----|------|-------|-----|------|-------|
| 005 | 413  | DEG F | 005 | 404  | DEG F | 005 | 384  | DEG F |
| 004 | 412  | DEG F | 004 | 395  | DEG F | 004 | 372  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| 002 | 517  | DEG F | 002 | 511  | DEG F | 002 | 501  | DEG F |
| 001 | 400  | DEG F | 001 | 391  | DEG F | 001 | 384  | DEG F |
| 000 | 336  | DEG F | 000 | 331  | DEG F | 000 | 327  | DEG F |
|     | 14:29:43 |   |     | 14:29:46 |   |     | 14:29:48 |   |

|     | 160s |       |     | 163s |       |     | 166s |       |
|-----|------|-------|-----|------|-------|-----|------|-------|
| 005 | 372  | DEG F | 005 | 359  | DEG F | 005 | 354  | DEG F |
| 004 | 350  | DEG F | 004 | 336  | DEG F | 004 | 327  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| 002 | 500  | DEG F | 002 | 498  | DEG F | 002 | 486  | DEG F |
| 001 | 380  | DEG F | 001 | 374  | DEG F | 001 | 369  | DEG F |
| 000 | 326  | DEG F | 000 | 318  | DEG F | 000 | 314  | DEG F |
|     | 14:29:51 |   |     | 14:29:54 |   |     | 14:29:57 |   |

|     | 168s |       |     | 172s |       |     | 175s |       |
|-----|------|-------|-----|------|-------|-----|------|-------|
| 005 | 343  | DEG F | 005 | 928  | DEG F | 005 | 320  | DEG F |
| 004 | 321  | DEG F | 004 | 309  | DEG F | 004 | 306  | DEG F |
| --- | ---  | DEG F | --- | ---  | DEG F | --- | ---  | DEG F |
| 002 | 480  | DEG F | 002 | 474  | DEG F | 002 | 465  | DEG F |
| 001 | 363  | DEG F | 001 | 357  | DEG F | 001 | 352  | DEG F |
| 000 | 307  | DEG F | 000 | 304  | DEG F | 000 | 301  | DEG F |
|     | 14:29:59 |   |     | 14:30:03 |   |     | 14:30:06 |   |