Partial Flooding of Volumes with Halon 1301

VICTOR B. ROBINSON
Headquarters
United States Air Force

The author reports on recent experiments in low-level flooding of flight simulator rooms.

THE U.S. Air Force is engaged in a flight simulator development-and-use program aimed at maintaining pilot skills with reduced use of actual aircraft.

Though fires occurring in them are few, flight simulators are so essential that all reasonable actions to guarantee their continued availability must be taken. From the fire protection standpoint, we have three objectives:

- To provide for life safety,
- To guarantee training continuity, and
- To minimize property loss.

FLIGHT SIMULATOR CHARACTERISTICS

Flight simulators employed by the air force cover a broad range of sophistication, from the simple simulator intended to teach instrument flying to the most sophisticated simulator in which tactical missions can be simulated. Normally, flight simulators are located in a separate facility. The simulator, its actuators, and its associated electronics are often located in a high-bay area. Hydraulic pumps and power mechanisms are located in a separate room, and computer controls are normally located in a third room. Hydraulic lines from the pump room to the simulator actuators are run in channels between the rooms. Electrical lines from the computer room to the simulator are also run in subfloor raceways.

The high-bay area normally has a service platform adjacent to the motion base and the simulator cockpit. The service platform and the motion base are normally located 10 to 15 ft (3 to 4.5 m) above the floor.

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The motion base is supported by hydraulic cylinders, which control the pitch, yaw, and roll motions of the simulator.

Equipment under the motion base represents the major fire hazard. Primary combustible materials include the multitude of electric cables and hydraulic hoses. The major fire hazard is the potential development of a high-pressure leak of hydraulic oil spraying the cables and hoses. Electrical equipment malfunctions that may cause arcing or overheating represent the potential ignition sources.

Flight simulator rooms are kept clean, and no storage is permitted in them. Air temperature and relative humidity are closely controlled by a self-contained air conditioning unit. The room itself is relatively tight, and there are no closable openings.

HALON 1301 EXTINGUISHING AGENT

Several Air Force Commands have installed Halon 1301 extinguishing systems designed to completely flood the high-bay flight simulator area. Halon 1301 was selected as the most appropriate fire extinguishing agent for several reasons.

- It is fast acting and effective in suppressing flammable liquid fires and surface fires involving electrical cables and hydraulic hoses. The fast action of the agent in combination with the rapid response detection system prevents fires in cables and hoses from becoming deep-seated.
- The gaseous agent mixes quickly with air and effectively penetrates the maze of equipment concentrated in the center of the bay under the simulator cockpit.
- The agent, when used in concentrations below 7 percent, will not produce an atmosphere that is hazardous.
- The fast action of the system will minimize the generation of decomposition products.
- With controlled humidity in the facility, vision will not be obscured during system discharge.
- Halon 1301 will not damage the expensive equipment, will not affect electrical functions, and requires no cleanup.

PARTIAL FLOODING CONCEPT

Since the potential fire hazard is limited to the lower portion of the bay, considerable savings could be realized if it were possible to base the system design on protecting only the section of the simulator bay between the floor and the top of the simulator cockpit. Although there is no physical barrier to isolate the halon vapor in the lower section of the bay, it was envisioned that the same effect could be accomplished by controlling the method of halon discharge into the hazard. The mixture of halon vapor and air is more dense than air, and this difference will create an interface separating the two gaseous mixtures if the system limits the discharge to the lower area. Theoretically, partial flooding of the lower level of the simulator bay seemed feasible. However, there were some adverse considerations that needed evaluation.

- There was a potential for a loss of halon vapor into the upper portion of the simulator bay through convection currents.
- There could be further loss of halon vapor into the upper portion due to the dispersion of gaseous molecules from the more dense to the less dense mixture.

At this point, the air force published requests for technical proposals to study the feasibility of partially flooding volumes with Halon 1301. Eventually, a contract was awarded to the Ansul Company to perform the study.

STUDY OBJECTIVES

Essentially, there were three objectives in the study.

- On a laboratory scale, determine the concentration of Halon 1301 necessary to accomplish flame extinguishment in hydraulic fluid conforming to military specification MIL-H-5606C.
- Determine through full-scale experimentation, involving discharge tests and fire tests, the feasibility of providing an adequate concentration of Halon 1301 by partially flooding a high-bay area from the floor up to a preselected height.
- As a result of the experimentation, define the engineering design criteria for a partial flooding Halon 1301 system using state-of-the-art equipment.

LABORATORY EXPERIMENTATION

The laboratory method utilized to determine the necessary extinguishing concentration for the hydraulic fluid used in the flight simulators is referred to as the cup burner technique. It was determined in laboratory experiments that the fuel would not sustain burning at the ambient temperature. Tests were therefore performed at elevated fuel temperatures of 100° C and 150° C. The experimental results indicated that a 2.5 percent concentration was required at 100° C and a 3.09 percent concentration at 150° C. Based on those results, a design concentration of 5 percent would be required to comply with NFPA 12A, *Standard on Halogenated Fire Extinguishing Agent Systems — Halon 1301.*

FULL-SCALE EXPERIMENTATION

Full-scale experiments were conducted in the Ansul Company's fire test building, which has physical characteristics resembling a flight simulator facility. The building is constructed of prestressed concrete. It has a floor area of 40 ft by 60 ft (12 m by 18 m) and is 50 ft (15 m) high from floor to ceiling. An observation room is connected to the test building to house all instrumentation and to provide for visual observation of tests.

The systems used for this program were employed in accordance with the requirements of NFPA 12A, *Standard on Halogenated Fire Extinguishing Agent Systems — Halon 1301.* The system components were specifically designed for use with Halon 1301 and were listed by a nationally recognized testing laboratory. The Ansul 180° F halon nozzles used in this program have a listed area coverage of 32 ft by 64 ft (9.7 m by 19.5 m). Since it was felt that the typical height of a hazard in a real simulator room would be approximately 15 ft (4.5 m), the system was designed to flood a volume 20 ft (6 m) high to allow some margin of safety. The delivery systems shown in Figures 1, 2, and 3 were used in this experimental program.

For the first three tests, which were designed primarily to identify the optimum nozzle orientation, only 744 lbs (337 kg) of agent were used. This amount of agent would produce a calculated concentration of 3.82 percent at 70° F (21° C) in the 48,000-ft^3 (1,358-m^3) partially flooded volume. For Tests 4, 5, and 6, the quantity of agent was doubled to 1,488 lbs (675 kg), which produced a calculated concentration of 7.35 percent at 70° F (21° C) in the 48,000-ft^3 (1,358-m^3) partially flooded volume.

The most critical data, concentration versus time, were collected automatically and recorded on continuous charts using a recording gas analyzer. The analyzer is designed to monitor three sampling lines simultaneously and record the results on individual strip charts. It is particularly applicable to testing total flooding types of fire extinguishing systems.

The operating principle is based on changing thermal conductivity of the gas being sampled as the fire extinguishing agent is dispersed into the space to be flooded. Results are printed at 5-s intervals. Samples were

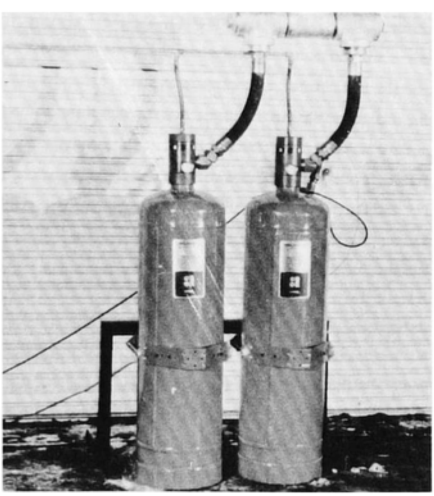

Figure 1. A two-tank manifold Halon 1301 system for Tests 1, 2, and 3.

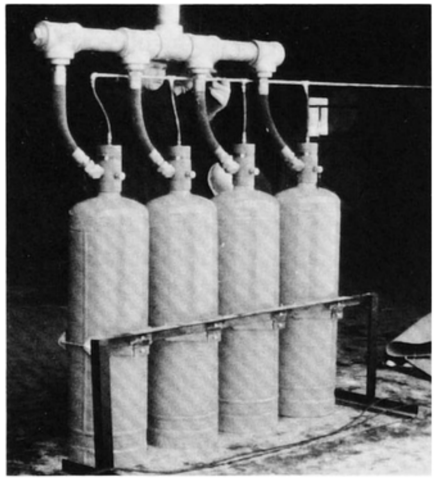

Figure 2. A four-tank manifold Halon 1301 system for Tests 4, 5, and 6.

collected at heights of 0, 10, and 20 ft (0, 3, and 6 m) for Tests 1 through 5. During Test 6, samples were taken at levels of 10, 15, and 20 ft (3, 4.5, and 6 m). In addition to the gas analyzer, evacuated cylinders were used to take samples at 1, 3, and 5 min after agent discharge at an elevation of 30 ft (9 m). These samples were collected during the concentration distribution tests, Tests 1 through 4. In Test 5, a fire test, evacuated cylinder samples were taken at the 10-ft (3-m) level to verify the data collected on the recording gas analyzer, which might have been questionable under fire conditions. The data from this test verified the reliability of the recording gas analyzer. Test 6 was a repeat of Test 5, except that the evacuated cylinder samples were not taken.

The contents of the cylinders were analyzed by gas chromotography to determine the volumetric concentrations of Halon 1301 in the air. Previous experience had shown that the standard deviation of the overall sampling and analysis procedure is 0.2 percent by volume.

Test One

The first test in the series was planned to check instrumentation and the test procedure and to provide a preliminary indication of the feasibility

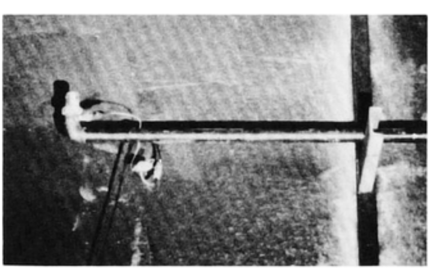

Figure 3. One of the four Halon 1301 discharge nozzles.

of the concept. For the first three tests, a reduced design concentration was used to satisfy the objective of determining the concentration distribution. The specific design concentration for this test was 3.55 percent at 33° F (0.6° C), the ambient temperature in the facility on the day of the test. The nozzles, which were located on the walls at an elevation of 20 ft (6 m), were directed in such a manner that their orifices were pointing at an angle of 45° below horizontal (Figure 4).

Figure 5 is a plot of the measured concentration data, which indicates that the initial concentration was 2.8 percent; however, the concentration decayed rapidly, especially at elevations of 10 and 20 ft (3 and 6 m). During this test, a 25-ft² (2.3-m²) louvered opening located in the sidewall at the base of the building was not covered. It was felt that the rapid decay was due to leakage through this opening.

Figure 5 also shows that the evacuated cylinder samples taken at an elevation of 30 ft (9 m) indicated low concentrations (0.17 percent) initially with only a trace remaining after 5 min. This clearly indicates that the bulk of the agent was being delivered to the lower portion of the test house volume.

During this test, two observers mounted a scaffold in the enclosure to view the discharge at a level of 20 ft (6 m). After the test, they reported a remarkable visual stratification at their feet — approximately 20 ft (6 m) from the floor. They described the sight as very much like the view experienced when flying above the clouds. The actual data, along with the visual observation, were used as the basis for Test 2.

Test Two

Test 2 was similar to the first test, but the louvers at the base of the building were covered. In addition, photographic records were made to document the interface between the air-halon mixture and the air above.

The plot of the data is shown in Figure 6 and indicates an initial concentration of 2.5 to 2.8 percent. However, this time the rate of decay was not as rapid, indicating the effects of sealing the louvers at the base of the building. Somewhat disappointing in this test was the poor photographic documentation of the stratification effect. A check with the weather bureau

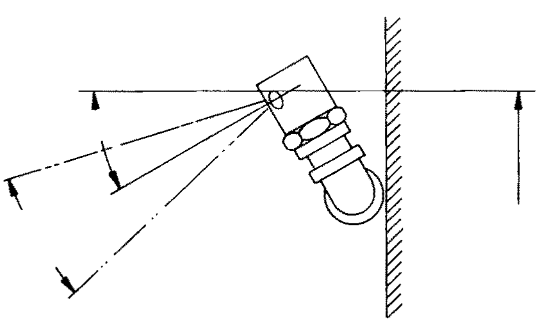

Figure 4. Orientation of the Halon 1301 discharge nozzle (45° for Tests 1 and 2; 30° for Tests 3, 4, 5, and 6).

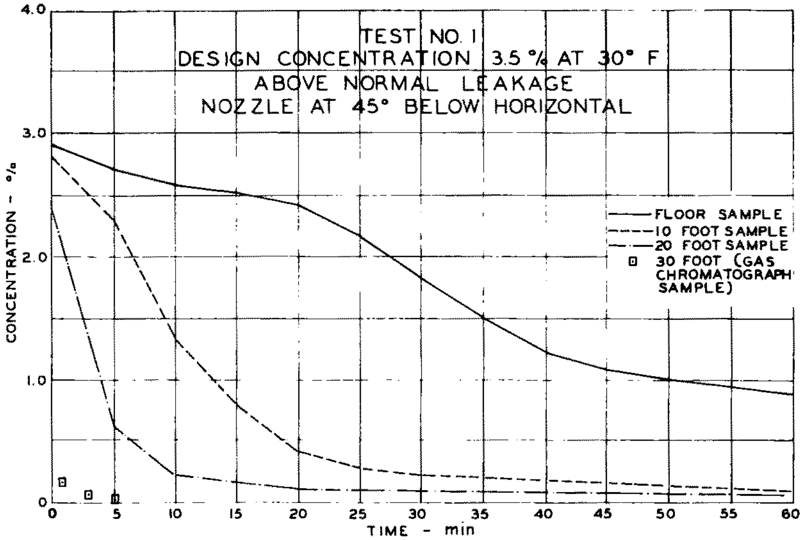

Figure 5. Test 1 concentration plot.

indicated that the relative humidity during the first test was 77 percent; whereas the humidity during the second test was 66 percent, which was inadequate to produce fogging or misting. In a normal installation, fogging or misting would be undesirable due to the visual obscuration it would create and probably would not be encountered at all because of the controlled humidity in the flight simulator area.

Test Three

Analysis of photographs of Tests 1 and 2 indicated that the discharge from the nozzle orifices approximated a 30° cone. As the nozzles were directed down at a 45° angle in the first two tests, it was felt that the agent could be distributed more uniformly in the design volume by raising the nozzles' angle of discharge to 30° below horizontal. A steam generator was used to raise the relative humidity to 83 percent in the facility prior to the test. The photographer was once again stationed on the scaffold to document the interface effect.

During this test, an initial lower concentration of 2.25 to 2.5 percent was achieved. This was due primarily to the fact that this test was run at a temperature of 24° F (− 4.4° C). As shown in Figure 7, the concentration remained essentially equal at the floor and at 10 ft (3 m) for 30 min, decaying only to 2.2 percent.

Based on these results, it was concluded that the optimum angle for the halon nozzle discharge direction was 30° below horizontal. The nozzles were fixed at this angle for the balance of the testing.

There was an increase in concentration at an elevation of 30 ft (9 m),

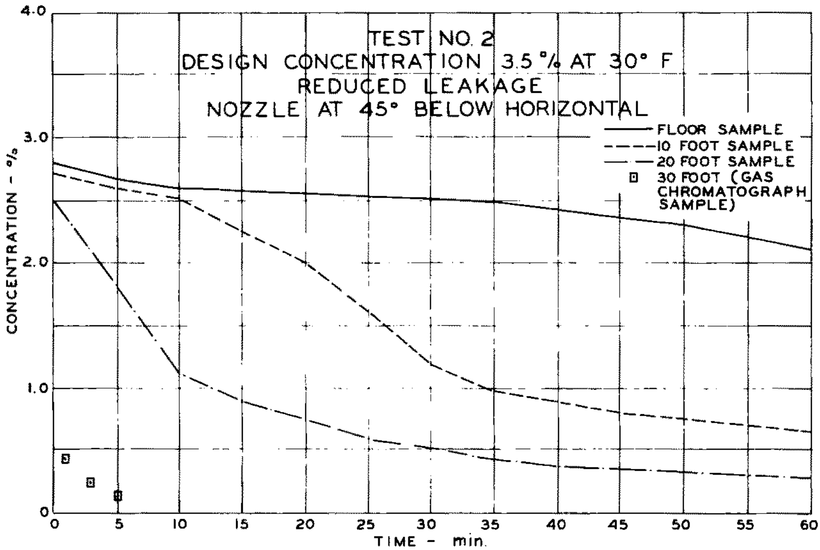

Figure 6. Test 2 concentration plot.

as detected by the evacuated cylinder samples, due to the increased elevation of the nozzles.

Test Four

The objective of this test was to determine the effects of increased agent quantity. In Test 3, a design concentration of 3.25 percent at 20° F (6.7° C) yielded a measured concentration at the end of discharge of 2.5 percent. By doubling the amount of agent, a design concentration of 6.25 percent at 20° F (6.7° C) was calculated and a measured concentration of 5 percent was anticipated. The system was redesigned to accommodate the increased agent quantity, and the nozzles were changed to provide twice the discharge rate of the previous tests. The test procedure included increasing the humidity prior to the test.

The results depicted in Figure 8 show an initial concentration range of 4.4 to 4.6 percent, with the concentration at the floor and at 10 ft (3 m) holding at 4.2 percent after 15 min. The concentration at 20 ft (6 m) decayed to 3.5 percent after 5 min. The calculated concentration of 5 percent was not achieved, indicating an increased rate of agent leakage with increased agent quantity. However, if the concentration of 4.6 percent had been related to a design ambient of 70° F (21° C), a concentration of 5.1 percent would have been achieved.

Once again, it should be noted that the evacuated cylinder samples taken at 30 ft (9 m) indicated twice the concentration encountered in previous tests, which was not expected. The constant distribution traces behaved as in previous tests with the reduced amount of agent; that is,

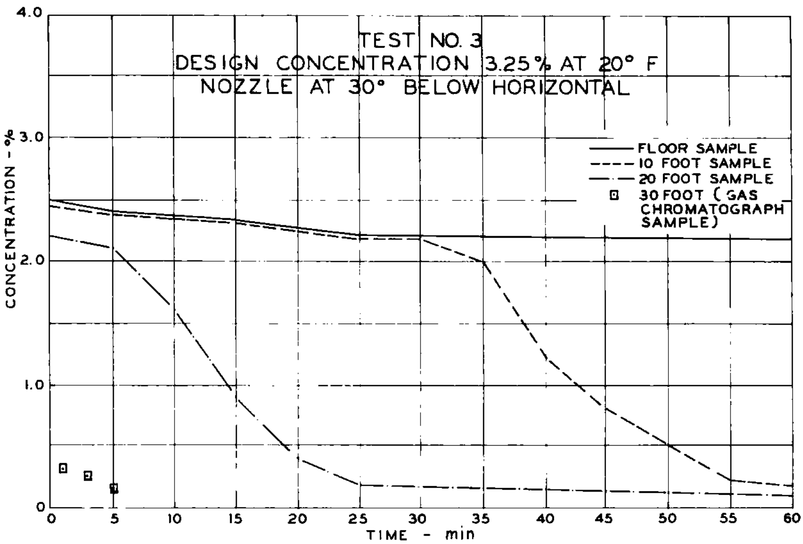

Figure 7. Test 3 concentration plot.

the concentration up to 10 ft (3 m) held very well for 15 min, while the concentration above that level provided protection for about 5 min before rapid decay.

Test Five

The objective of this test was to determine whether updrafts and turbulence due to a fire condition would disrupt the concentration distribution. A 20-ft^2 (1.85-m^2) pan with a 6-in. (15.2-cm) freeboard containing 2 in. (4.7 cm) of hydraulic oil complying with MIL-H-5606C was used for the fire test. In addition, a pressurized stream of hydraulic oil was directed over the pan to simulate a pressure fire. The relatively low pressure stream, 220 psig (15 bar), was flowing at a rate of approximately 2.5 gpm (9.5 liters per min). A flame from a propane torch was directed over the surface of the hydraulic oil in the pan until the oil sustained burning by itself. Once the fuel sustained combustion, a 20-s preburn was allowed before the system was discharged. In the initial planning of the test, a longer preburn interval was desired. However, a pretest revealed that, with a 30-s or longer preburn, the test house became filled with smoke, which precluded any visual or photographic observation.

There was some concern in this test that the products of combustion could conceivably distort the readings of the gas analyzer. It was decided that evacuated cylinder samples would be taken at an elevation of 10 ft (3 m) and the results compared with the analyzer readings. In the actual test, the fire was extinguished before the end of discharge. The concentration distribution plot in Figure 9 shows little change from previous tests,

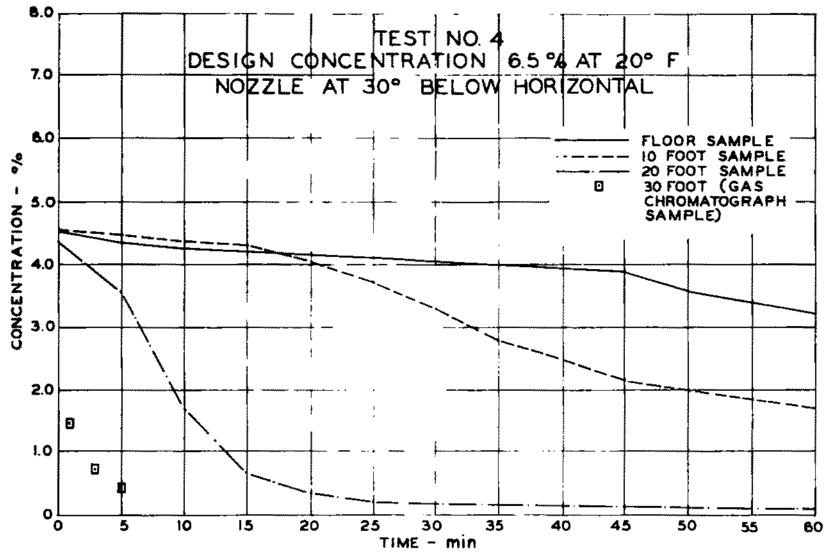

Figure 8. Test 4 concentration plot.

indicating that the fire had little or no effect on test results. The evacuated cylinder samples taken at 10 ft (3 m) agreed with the analyzer readings within 5 percent. This was considered an acceptable deviation and within the accuracy of the instrumentation.

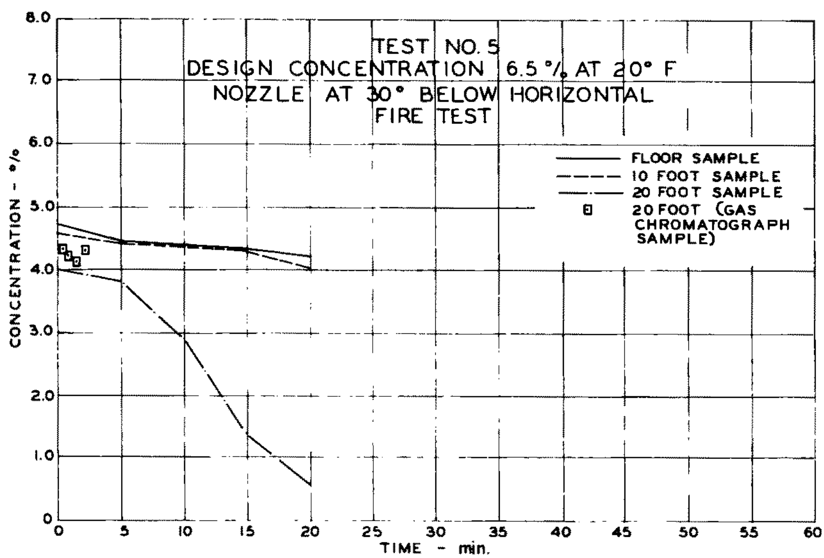

Figure 9. Test 5 concentration plot.

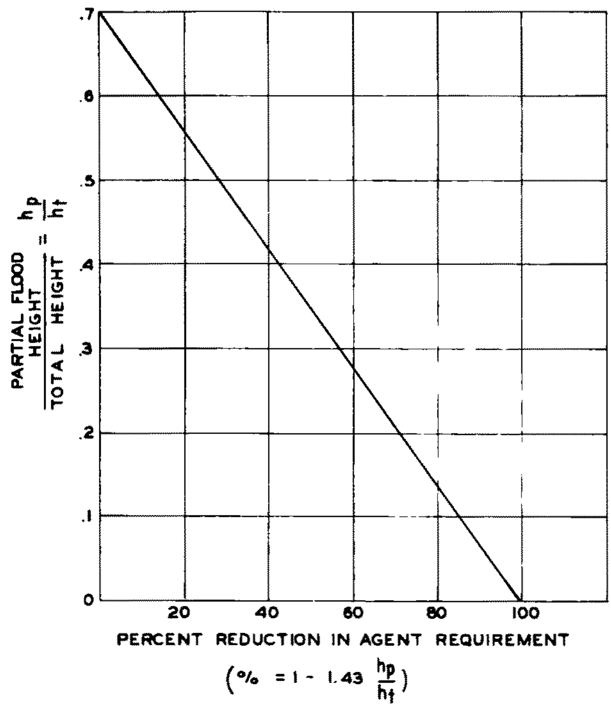

Figure 10. Percentage reduction in agent versus ratio of partially flooded height to total height.

Test Six

Since extinguishment occurred so quickly in Test 5, an attempt was made in Test 6 to shield the fire on one side from the direct path of the agent discharge. This was accomplished by erecting a combination plywood and canvas barricade. In addition, the louvered opening in the sidewall of the building was left uncovered. Another change from Test 5 was to use normal heptane as a fuel for the pressure fire in order to create a more violent fire. The atomized hydraulic fuel used earlier would not sustain combustion after it had passed through the flame front. Only the gas analyzer was used for concentration recording during this test.

Again, the fires were extinguished before the end of discharge — approximately 3 s after the agent started discharging from the nozzles. The barricade seemed to have little effect on extinguishment. Initial halon concentrations were similar to those in Test 5. However, there was a rapid decay after 5 min due to the uncovered opening at the base of the fire test house.

CONCLUSIONS

This test series provides positive evidence of the feasibility of the design concept of partial flooding with Halon 1301 vapor. The marked interface between the halon vapor mixture and the air above it was substantiated both with instrumentation and with photographic documentation. However, some of the halon vapor does escape to the space above the target design level as indicated by measurement of the vapor concentration in that area. The data indicate that, to obtain a design concentration of 5 percent halon vapor below the target design level, the quantity of halon required would have to be computed on the basis of the hazard volume between the floor and the target level with an additional 43 percent, by weight, of agent to account for losses to the upper space.

Since, by weight, 43 percent more agent than the amount determined theoretically is required to produce a 5 percent concentration in the partially flooded volume, a mathematical analysis shows that the height of the partially flooded volume must be less than 70 percent of the total height of the exposure or there will be no economic gains attained by the partial flooding technique. This relationship is shown in Figure 10.

According to Figure 10, partially flooding a 50-ft-high (15-m) flight simulator room to a height of 20 ft (6 m) will require 43 percent less agent than if total flooding were used. This is a significant saving and is worthy of consideration for implementation in air force flight simulator facilities. Although the object of this entire investigation was related to flight simulator rooms, the technique has obvious applications in any volume where the hazard is restricted to lower portions of the volume.

ENGINEERING DESIGN CRITERIA

As a result of this experimental program, certain engineering design criteria were developed in order to establish the basis for the employment of the partial flooding technique. For the most part, an approach similar to that normally used for total flooding must be followed. There are, however, some deviations.

- *Hazard Definition* — In this most critical step, the system designer must define the maximum height of the hazard. Additional height should be added to the maximum hazard height as a safety factor. The results of the test program indicate that an additional 5 ft (1.5 m) is a reasonable value. For example, if the designer determines that the entirety of the hazard is below 10 ft (3 m), a design volume height of 15 ft (4.5 m) would be selected.
- *Openings* — Tests 1 and 6 proved that openings, especially at the base of the hazard volume, permit agent leakage in such quantities that they cannot be permitted. Therefore, all floor openings or sidewall openings within the protected height must be sealed prior to agent application.
- *Minimum Design Concentration* — Since some of the halon vapor is lost to the upper volume due to currents and dispersion, provisions must

be made to compensate for these losses. The test program indicated that a reasonable guideline is to design for a 7 percent concentration to achieve a nominal 5 percent concentration in the protected volume. This is equivalent to a 43 percent increase in the amount of agent.

- *Nozzle Selection* — Nozzle placement and discharge characteristics must be known to achieve adequate results. It was found in the test program that the upper unprotected volume could be effectively shielded by changing the normal discharge angle of the nozzles. Therefore, to avoid discharging an excessive amount of agent in the upper volume, the nozzles should be directed at an angle of 30° below horizontal.

- *Agent Distribution* — Since all hazards are unique in that they have different "leakage" characteristics and physical arrangements, it is recommended that an actual halon discharge test be performed to physically check the system design and concentration distribution.

The U.S. Air Force is encouraged by the results of this program and anticipates that this technique can provide installation savings for Halon 1301 systems in flight simulator rooms of up to 48 percent, depending upon the configuration of the facility.