HALON 1211 ALTERNATIVES FOR FIGHTING JET ENGINE FIRES ON FLIGHT DECKS AND FLIGHT LINES

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INTRODUCTION

The Naval Air Systems Command, in conjunction with the Naval Research Laboratory, Hughes Associates, Inc., and Naval Air Warfare Center China Lake, has been conducting an evaluation for the replacement of Halon 1211 systems on flight decks and flight lines. A study was commenced in 1996 to provide an overall assessment of the Halon 1211 Replacement Plan for the **US** Navy. This study was divided into four parts: (1) Halon 1211 Alternative Development Status [1], (2) Halon 1211 Requirements Review [2], *(3)* Halon 1211 Mission Critical Reserve Evaluation [3], and (4) Halon 1211 Replacement Program Plan [4].

Based on Part 2 – Halon 1211 Requirements Review, the predominant "small" fire threat on flight decks and flight lines was from engine fires. "Small" fires were those fires where collateral damage from the firefighting agent was a concern for materials not intimate with the fire. To evaluate potential Halon 1211 replacement systems for flight deck use, a program was established to identify the threats from engine fires and determine suitable replacement systems. The use of a systems engineering approach was employed rather than the approach of looking for a drop-in replacement. With this type of approach, it was critical to understand the fire threats and extinguishing requirements prior to recommending a system to replace Halon 1211 on flight decks.

This systems approach required the use of a realistic test article that adequately simulated the small 2-D and 3-D engine fires encountered in the field. To measure system performance accurately, the apparatus simulated actual conditions such as height and distance from personnel, clutter, obstacles, and flight deck wind in addition to key fire parameters such as fire size and severity (e.g., quantity and flow rate of fuel).

This program focussed on both internal engine fires and nacelle fires. An internal engine fire may occur during startup or shutdown and may be a result of improper procedures, severe ambient conditions, or mechanical failure. In the case of improper starting procedures or severe ambient conditions, the engine does not ignite properly during startup and excess fuel is dumped into the combustor. The fuel can be blown into the turbine and tailpipe, subsequently igniting. In the case of a mechanical failure, a fuel line may rupture, the pressure and drain (P&D) valve may fail, or the engine bearings may fail. Fuel can accumulate in the combustor, turbine, or tailpipe and may subsequently ignite. These internal fires are colloquially referred to as "tailpipe fires." Though less common, fires have also occurred "external" to the engine core, in the nacelle (the engine bay consisting of the void space between the engine and the exterior skin of the aircraft).

The purpose of this paper is to provide a summary of the work that has been completed on the engine fire testing.

APPROACH

This test program was divided into three discrete phases: (1) test article development, (2) scoping and baseline tests, and (3) systems evaluation tests. Test article development consisted of collecting relevant information on engine fires on flight decks and using this information to design a test article representative of a typical worst case scenario. This information included design specifics about the engines, e.g., height above the ground, clutter, and fuel flow rate. The purpose of the scoping tests was to gain a practical understanding of how internal engine fires occur, where they occur, and how to reproduce them. These tests were also helpful in verifying the parameters that were initially deemed important. Results from the scoping tests were used to develop a more refined test matrix for baseline resting. The baseline tests for the internal engine fire scenario were conducted with the intent of developing a fire scenario that was repeatable and representative of fires encountered in the field. Using the baseline scenario that was developed, systems evaluation tests were conducted to determine the fire extinguishing capability of selected Halon 1211 alternatives when discharged from handheld extinguishers. The measure of effectiveness was fire extinguishing success as a function of agent mass flow rate.

EXPERIMENTAL SETUP

TEST ARTICLE

After reviewing the data collected in the background survey, it was determined that an actual aircraft engine would be more realistic than a simulated engine for use as the test article. The test article was developed using a Pratt & Whitney TF30-P-1 aircraft engine. This engine was similar to the F-14 TF30-P-414A Pratt & Whitney engine, an engine with one of the highest fuel flow rates (of those surveyed). JP-8 was used as the fuel instead of JP-5. Although JP-S is currently used **in** Navy carrier-based aircraft, the use of JP-8 provided for a more conservative evaluation since the flashpoint of JP-8 is lower than that of JP-5 (38 °C [100 °F] versus 60 °C [140 °F]) [5]. A tube was attached in front of the compressor section of the engine to simulate the air inlet on an F-14. Figure 1 shows an overall view of the test site. Figure 2 shows a side view of the engine.

For the nacelle fire tests, a simulated nacelle enclosure was mounted around the engine. According to the survey data, the largest nacelle free volume was for the F-18 C/D aircraft. This volume was 1.3 m^3 (47 ft^3). To provide for a conservative evaluation, the test article nacelle was designed with a free volume of 1.6 m' (55 ft^3). **A** simulated air inlet scope and an emergency firefighting knock-out panel similar to those installed on F-14 aircraft was provided. Figure 3 shows the engine with the nacelle enclosure in place.

If an engine fire occurs while an aircraft is sitting on the tlight deck, firefighting could be hampered by normal flight deck winds. For realism, external wind was generated by means of three airboat engines. Each engine consisted of a 1.8-m (6-ft) propeller driven by a 5.7-L (350-in') Chevrolet automobile engine. This provided the capability of generating wind conditions of at least 30 knots. The speed (rpm) of each engine could be adjusted to vary the wind speed and to compensate for ambient winds. The three airboat engines can be seen mounted on a trailer on the left side of Figure 1.

Figure 1. View of test site.

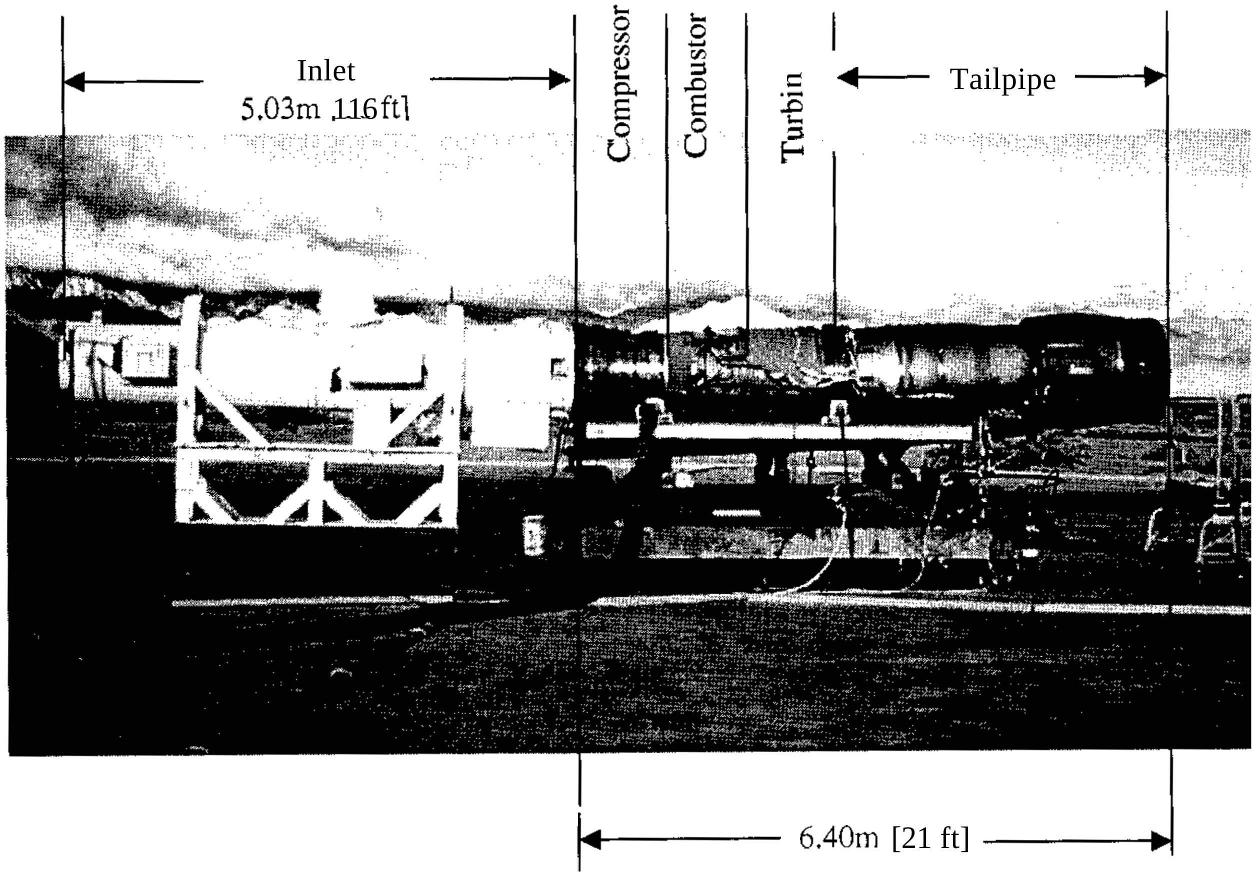

Figure 2. Test article (engine and inlet) from port side.

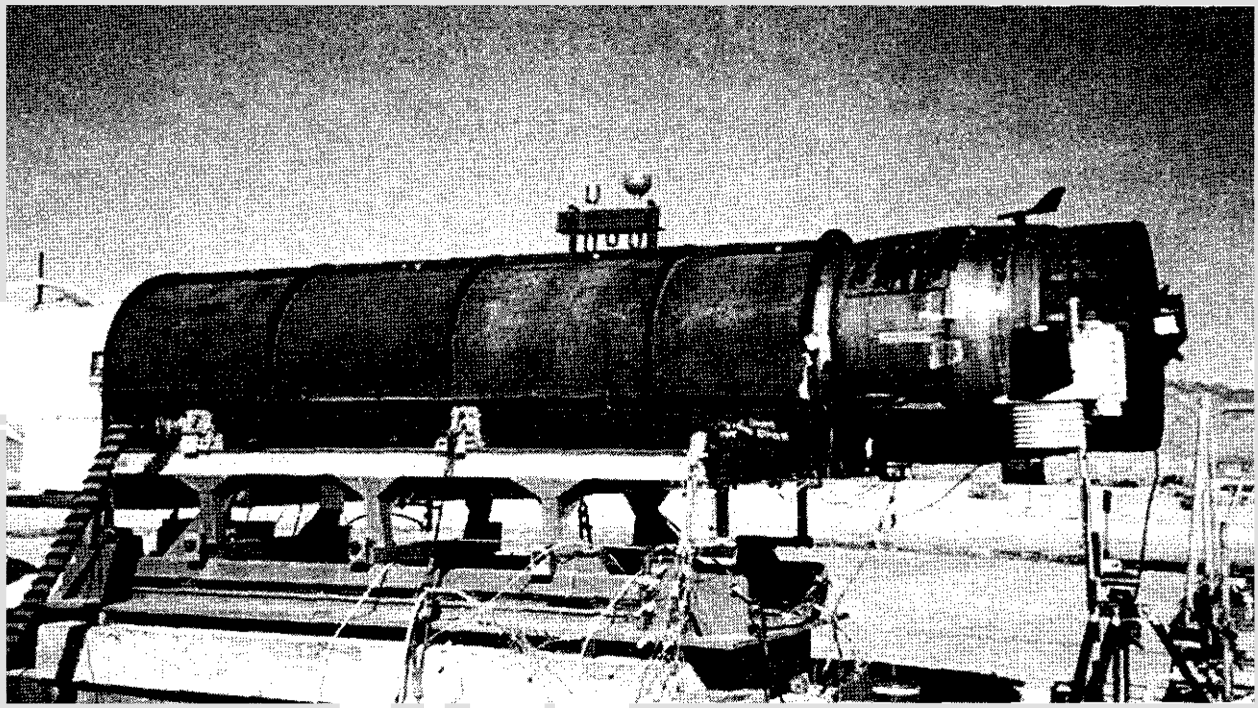

Figure 3. Test article with nacelle in place.

STANDARD TEST FIRES

After evaluating several different fire scenarios in the scoping and baseline tests. the following fire was used for all internal engine fire tests in the systems evaluation phase: a *30.5* x *30.5* x 4.4 cm (12 x 12 x 1.75 in) steel pan was placed approximately 10 cm (4 in) forward of the afterburner spray bar in the engine. The pan was filled with 1.4 L (48 oz) of JP-8 prior to each test. After the fuel was poured and the data acquisition started, a safety officer ignited the pan with a torch. A preburn time of *60* sec was used for all tests. All unburned fuel was drained from the pan after each test.

Additionally. 1.1 L *(36* oz) of JP-8 was allowed to trickle down a piece of 90 deg, 4.4 cm (1.75 in) angle iron and into the pan at a rate of 0.24 L/min (8 oz/min). The angle iron had 11 slots cut through the 'V' to allow the fuel to drip through the angle iron and into the pan. The trickle was started approximately 10 sec after the fire was ignited, during the prcburn stage of the tests. The trickle added a third dimension to the pan fire and also served to replenish the fuel in the pan during the tests.

The fire scenario developed for the nacelle tests consisted of two steel fuel cups placed in different locations within the nacelle. Both cups were 7.6 cm *(3* in) in diameter. One cup was 5 cm (2 in) deep and the other was 7.6 cm *(3* in) deep. The cups were filled with *30* mL (1 oz) of JP-8 and enough water to leave 1.3 cm *(0.5* in) freeboard.

INSTRUMENTATION

The engine was instrumented to measure air velocity, fuel flow rate and fire temperatures. Type K thermocouples were used to measure the air temperatures in the combustor, air and surface temperatures in the tailpipe, and air temperatures at the turbine exit. Engine speed was measured using the onboard tachometer. The air velocity through the engine was measured using a hot wire anemometer positioned in the engine inlet just forward of the entrance to the compressor.

Wind speed and direction were measured by two weather stations, one positioned at the inlet and one positioned at the outlet. All instrumentation was interfaced with a data acquisition system that recorded data once a second (1 Hz). Two video cameras were also used to record each test.

AGENT AND EXTINGUISHER SPECIFICATIONS

Table 1 compares the physical and chemical properties of the extinguishing agents included in the systems evaluation phase. Table 2 summarizes the portable extinguisher specifications. It should be noted that all extinguishers had flow rates (based on the first 10 sec of discharge) that averaged less than 2 pounds/sec (pps). Where higher flow rates were necessary to achieve extinguishment, two or more extinguishers were discharged simultaneously.

TEST PROCEDURE

The following test sequence, utilizing the pan fire with trickle fuel flow, was adopted for the internal engine fire tests as part of the systems evaluation:

1. Weigh the extinguishers to he used.
2. Pour the fuel.
3. Ignite the fire and start the trickle.
4. Preburn for 60 sec.
5. Load the engine and windmill for 60 sec, initiate the wind.
6. Unload the engine.
7. Attack the fire through the inlet 40 sec after unloading the engine or the tailpipe 15 sec after unloading the engine.
8. If an inlet attack is unsuccessful after discharging a predetermined quantity of extinguishers, move to the tailpipe and attack the fire.
9. Reweigh all extinguishers to determine the quantity of agent used.

For the nacelle tests, the fuel cup fires were attacked by discharging the extinguishers into either the air inlet scoop or the side knock-out panel. Glass covered observation ports installed in the body of the nacelle allowed determination of extinguishment times.

RESULTS

In total, 240 individual tests were conducted to evaluate the performance of each agent against internal engine fires as a function of flow rate for varying wind conditions. The discharge of agent into the engine inlet ("inlet attack") was compared to discharge of agent into the tailpipe ("tailpipe attack"). The testing showed that the most meaningful benchmark of performance for extinguishing an engine fire is an inlet attack with a 30-knot head wind (wind blowing directly into the engine inlet). This proved to be the worst case scenario for the various conditions that were evaluated, no doubt due to the tendency of the increased air flow through the engine to dilute the agent and reduce the residence time of the agent on the fire. This case is considered to be especially applicable to typical aircraft parking patterns on the flight deck where aircraft are positioned with their tails over the edge of the deck while the relative wind is blowing toward the

TABLE 1. AGENT CHARACTERISTICS.

Agent	CO_2	Halon 1211	FE-36	FM-200	Halotron I (HCFC-123)
Chemical Formula	CO_2	$CBrF_2Cl$	$CF_3CH_2CF_3$	C_3F_7H	$C_2HCl_2F_3$ + 7% Inert Gas Mixture
Molecular Weight	44	165	152	170	150
Specific Volume at 70 °F (ft^3/lb)	8.83	2.34	2.54	1.26	2.57
Minimum Total-Flooding Extinguishing Concentration (%)	29	3-5	5.6-6.5	5.8-6.6	6-7
Boiling Point at 1 atm (°F)	-110	26	29.3	2.6	X0.6
Vapor Pressure at 77 °F (psia)	900	38.7	39.5	66.4	95
Ozone Depletion Potential	*0*	4	*0*	*0*	0.014
Global Warming Potential	1	Not calculated	9400	3x00	90
Atmospheric Lifetime (yrs)	N/A	15	226	36.5	7*
LC_{50} (ppm)	70,000	31,000-100,000	>189,000	>800,000	>32,000
NOAEL (%)[†]	N/A	*0.5*	10	9	1.0
LOAEL (%)[†]	N/A	1.0	15	10.5	2.0

* Weighted average of the constituents.

[†] Threshold level for onset of harmful effects per *NFPA Fire Protection Handbook* (18th Edition).

engine inlet. NAWC China Lake will soon release a report (approved for public release) that will provide detailed results for all tests. Due to length considerations, internal engine results reported in this paper will be limited to performance against the worst case scenario (inlet attack with 30-knot head wind). Figure 4 summarizes the performance of each agent as a function of mass flow rate for the worst case scenario. The mass flow rates for each agent in Figure 4 are divided into three regimes: (1) an unsuccessful, or partially successful range, (2) a "not tested" range for which no data are available, and (3) a "success" point or range above which extinguishment was successful for 100% of the attempts. A total of 13 tests were conducted involving nacelle fires. Table 3 summarizes the nacelle tests.

EXTINGUISHER SPECIFICATIONS

Agent	Manufacturer and Model Number	Gross Weight (lbs)	Agent Quantity (lbs)	– First 10 Seconds (lbs/sec)	Range (ft)	[illegible]
CO_2	Various	42-56	15	MILSPEC – 0.5 Commercial – 1.0	7-10	
Halon 1211	Amerex Model 372	37	20	1.2	12-18	
FE-36	Ansul CleanGuard 14, Model CA-1481 P/N 422612	26	14	1.0	14-16	
FE-36	Ansul Prototype	32	20	1.1	14-16	
FM-200	Metalcraft Prototype	15.5	10.75	0.74	10-12	
FM-200	Metalcraft Prototype	35	20	1.2	10-12	
Water Mist	Amerex Model 272	28	2.5 gal.	NA	NA	
Water Mist	HAI Experimental	33	1.5 gal.	NA	NA	
Halotron I	Amerex Model 388	28	15.5	1.2	12-18	
Halotron I	Badger Model 15.5 HB P/N 23097	25.5	15.5	1.2	12-18	[illegible]
Halotron I	Buckeye Model 15, P/N 71550	25.5	15.5	1.3	12-18	2A:10B:C
Halotron I	Buckeye Model 20, P/N 72001	33	20	1.6	12-18	2A:10B:C

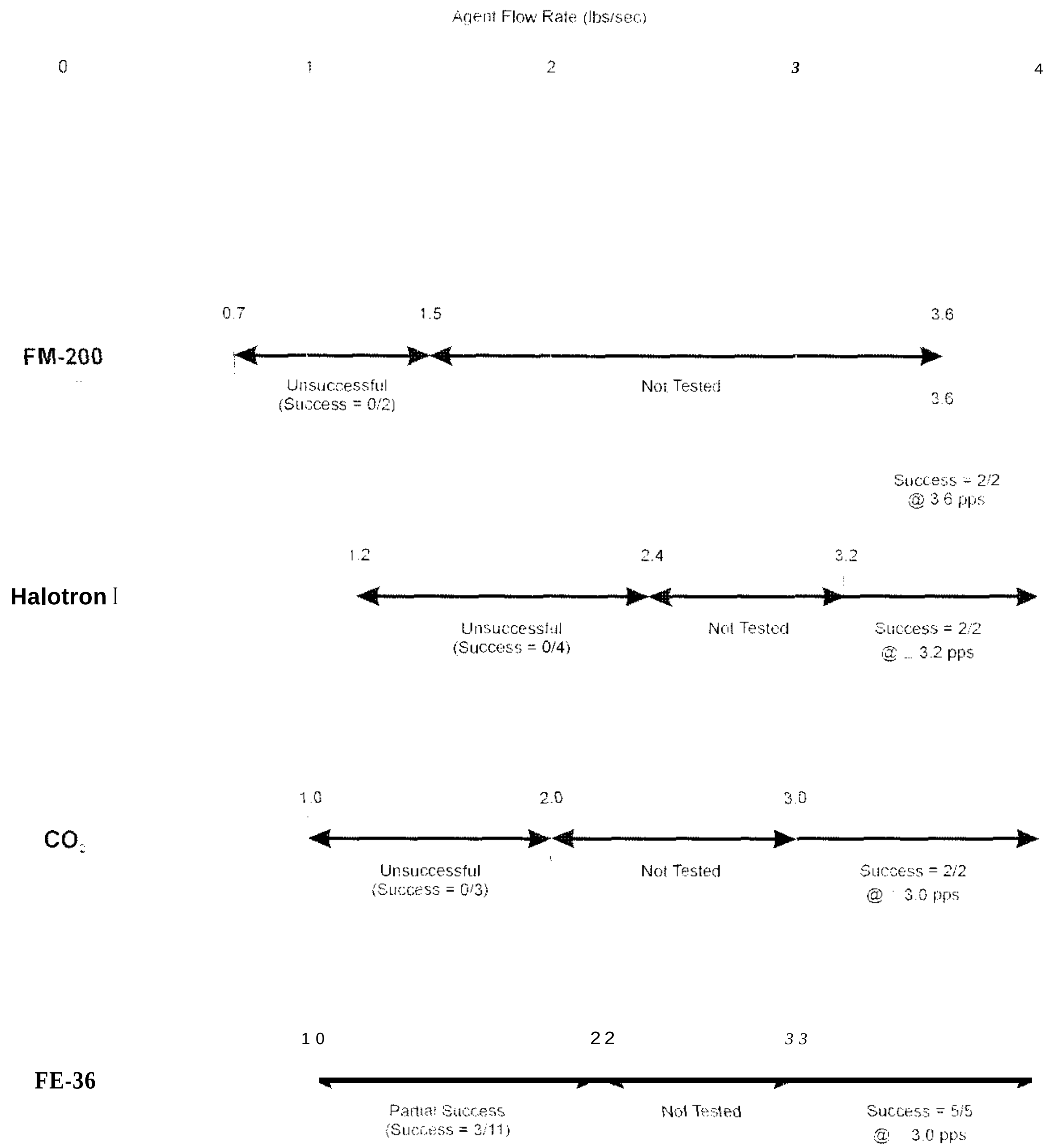

Figure 4. Success regime for inlet attack with 30-knot head wind.

TABLE 3. SUMMARY OF NACELLE TESTS.

Test Number	Cup Location	Wind Conditions	Air Flow at Nacelle scoop	Agent Discharge Location	Agent	Time to Extinguishment of Fire(s) (min:sec)
PN_1	None*	No Wind	None	None	None	27:05
PN_2	Aft	No Wind	None	None	None	14:55
PN_3	Forward	No Wind	None	None	None	15:32
PN_4	Aft	No Wind	None	Inlet Scoop	CO_2	0:04
PN_5	Forward	No Wind	None	Inlet Scoop	CO_2	0:08
PN_6	Forward	No Wind	None	Side Knock-out Panel	CO_2	0:06
PN_7	Forward	No Wind	None	Inlet Scoop	CO_2	0:05
PN_8	Forward and Aft	No Wind	None	Inlet Scoop	CO_2	0:10
PN_9	Forward and Aft	No Wind	None	Side Knock-out Panel	CO_2	007
PN_10	Forward and Aft	No Wind	None	Inlet Scoop	FE-36	005
PN_11	Forward and Aft	No Wind	None	Side Knock-out Panel	FE-36	005
PN_12	Forward and Aft	12 knot head wind	–500 ft/min	Inlet Scoop	FM-200	0:07
PN_13	Forward and Aft	15 knot head wind	–500 ft/min	Side Knock-out panel	FM-200	0:07

* Fire located outside nacelle to determine size and duration of the fire.

TABLE 4. COMPARISON OF MINIMUM AGENT REQUIREMENTS FOR FIRE EXTINGUISHMENT IN THE NACELLE.

Agent	Minimum Total-Flooding Concentration (%) (Cup Burner +20%)	Agent Required" (lbs)
Halon 1211	4.8	**1.2**
Carbon Dioxide	34.8	3.3
FE-36	7.3	1.7
FM-200	7.4	1.9

* Calculated per NFPA **2001**

CONCLUSIONS

Conclusions reached relative to internal engine fires were as follows:

- There was very little difference in performance between the halon alternative agents when the agent mass flow rates were the same.
- For the halon alternatives tested, a nominal mass flow rate of 3 lbs/sec would handle the "worst case" engine fire.
- For current commercialized hand portables discharging halon alternatives, consistent success for an inlet attack with a 30-knot headwind required the simultaneous deployment of at least three extinguishers.
- CO_2 extinguishers performed comparable to the newer halon alternative extinguishers when the flow rate was the same.
- Current commercialized halon alternatives are clearly inferior to Halon 1211 in terms of fire performance.
- All existing commercialized halon alternatives exhibit some objectionable environmental properties.
- Extinguishment of a tailpipe fire using an inlet attack is extremely difficult if the engine is turning.

The following conclusions were drawn from the nacelle testing:

- The discharge of a single hand portable into the nacelle easily achieved agent concentrations greater than the minimum necessary for extinguisment (Table 4).
- Because nacelle volumes are *so* small, even CO_2 was successful. A 15-pound CO_2 portable produces 120 ft^3 of gas, which is more than twice the volume of the largest nacelle on the flight deck.

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