Case Study: Performance Based Sustainable Halon System Replacement
For Critical Military Jet Engine Test Facilities
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Abstract

For the US Air Force, when it comes to halon replacements protecting critical assets, choices increasingly must be made as halon stocks dwindle. Halon must be reserved for mission readiness while minimizing dependency on halon 1301. Halon is also classified as a severe Class I ozone depleting substance (ODS) and is banned from manufacture by the Montreal Protocol. That has compelled the USAF to develop alternative system solutions for other critical facilities. This session delves into a decade long review process culminating in full-scale performance testing to qualify an effective, long term sustainable equivalency to halon for the protection of Jet Engine Noise Suppressor Systems, commonly termed "hush houses."

Introduction and background

Through this decade, Jet Engine Noise Suppressor Test Facilities throughout the US Air Force will be retrofitted with new fire suppression systems that will have a significant impact on the way operations are conducted. The Support Equipment & Vehicles Division of the Agile Combat Support Directory at Robins AFB Georgia oversaw successful collaborative testing of a halon replacement system manufactured by Siemens Building Technology, Florham Park NJ. It is designed for use with clean extinguishing agent FK-5-1-12, commercially known as 3M™ Novec™ 1230 Fire Protection Fluid. This system was integrated into the facility by Vital Link, Inc., Sealy TX, a specialty Noise Suppressor contractor who, in partnership with system installer Hiller Systems, Mobile AL, submitted an Unsolicited Proposal suggesting a halon replacement solution based on FK-5-1-12 would be a safe, environmentally friendly, and effective solution to replace Halon in USAF Noise Suppressors. After extensive review and study by the USAF, it was determined to proceed with a test program. The testing was conducted in the Spring, 2012 at two Alabama locations: 3M Decatur Fire Test Facility and the Air National Guard's Dannelly Field in Montgomery.

These test fixtures – about 120 total worldwide – are enclosed noise-suppressing facilities where fighter jet engines are tested. These suppressors are required to reduce the noise level of the turbine engine(s) to a level that would not interfere with everyday operations of the base or surroundings. Should a fire occur inside, typically a halon 1301 system is manually activated to extinguish. Working with the 3M Company, Robins engineers and program managers successfully implemented the FK-5-1-12-based solution to replace Halon 1301. The move will not only have a considerable impact on personnel safety and the environment, but will be more cost-effective, be easier to maintain and sustain, save time and open the door for future fire suppression opportunities in the Department of Defense.

A Noise Arrester Jet Engine Test Facility as shown in figure 1 above is technically a piece of military support equipment that appears to look like an aircraft hangar. But, it isn’t a hangar per se. Colloquially referred to as a “hush house”, these test facilities are strategic to maintaining peak operational efficiency of military aircraft. Hush houses are very large enclosures, typically 81ft. x 65ft. x 24ft. high (25m x 20m x 7m high) Quonset style structures. They house large expensive jets from F-15 fighters to F-22 stealth military jets for engine testing. Engine only testing also takes place. There are multiple sizes and shapes of hush houses, depending on the need, which are used to run the jet engines through their regularly scheduled and necessary operational tests.

Hush houses are designed to be readily assembled, disassembled and moved multiple times, depending on where they are needed around the world. Virtually every component of a hush house has a part number, so the USAF can keep track of all parts of a facility, properly specify for new installations, remodeling or relocations, order replacement parts and so forth. That includes the fire suppression system.

Mobile hush house facilities have been protected with halon 1301 for decades and still are. The intent of the USAF, however, is to change out all hush house halon systems by decade’s end.

Halon was targeted for replacement in the mid-1990s in these fixtures for environmental reasons. Perhaps equally important, though, was that the USAF was having an unacceptable number of accidental discharges of these manually actuated hush house systems releasing 1000s of lbs/kgs each occurrence.

The halon stored in the system containers was designated reserve bank in the 1990s for "mission critical" applications in the Air Force, that is, other than for hush house. However, due to the aforementioned accidental discharges and the fact that hush houses had been designated by some but not all as "non-mission critical", the halon 1301 was required to be removed from all hush houses in the US, retained by the US Department of Defense halon bank and replaced be another agent if one could be found suitable.

Nineteen candidate alternatives or agents were reviewed back in the 90s, which the USAF down selected to four, with a hydrofluorocarbon, HFC-23 appearing to be the front-runner from the clean agent side at the time. Perfluorocarbon (PFC) clean agents weren’t seriously considered, because the consultants in charge of comparing the agents were either not aware of the availability of PFC CEA's in reliable commercial quantities or didn't consider the supply reliable. Environmental issues also played into the decision making, which, along with cost and space requirements, was ultimately the undoing of HFC-23. Inert gas systems were never really in serious consideration due to space, nor were dry chemical or exotic solutions such as aerosols.

Fast forward to today, and until now, halon 1301 continued as the preferred agent of choice for the protection of hush houses, as no alternative technology had been deemed suitable. Other not in kind alternatives have been tried and employed to replace halon due to environmental pressures. Those, such as local application CO_2 and water spray systems, and to a lesser extent, high expansion foam used in European-based hush houses, all have their advantages and disadvantages. Finding the right balance of performance, safety, environmental acceptability and reliable supply has been a major challenge for the USAF.

What the USAF Needed

The Test Criteria

The test program for the USAF Hush House application was developed to evaluate the performance of a clean agent fire extinguishing system installed in a hush house enclosure with the most critical and likely fire hazards. Due to the high asset value of the hush house and associated equipment within, it was not possible to conduct full-scale fire tests within in the hush house enclosure. Therefore the test program was split into two parts: Fire performance testing to evaluate the agent performance and concentration tests to evaluate the fire extinguishing system within the hush house.

Fire performance

Defining the fire hazard fuel load and geometry was a critical first step. Two fire scenarios were developed. The first was a fixed size jet fuel pool fire located under an aircraft wing (pan test). The second was a dynamic flowing fuel configuration incorporating the geometry and elevation of a jet engine nacelle mock-up with a fuel spray and cascading fuel feeding a pool fire below (engine test).

Concentration validation

This portion of the test program was designed to evaluate the ability of the clean agent system to deliver the correct concentration to the enclosure within 10 seconds and to evaluate the ability of the hush house to maintain the minimum design concentration in accordance with the requirements of the 2012 edition of NFPA 2001 5.6, that is, 85% of the adjusted minimum design concentration at the highest level of combustibles for at least 10 minutes. This test was performed with the full discharge of an installed system in an operational hush house with live readings of agent concentration in five locations.

Design Concentration

Tests were conducted at a minimum design volumetric concentration of 5.9%. This is applicable for the hazards expected in a Hush House and are based on related design concentrations determined by applying a minimum 1.3 safety factor for jet fuels JP-5 and JP-8 and the requirements of NFPA 2001, 5.4.2.5 for powered electrical equipment. Hazards and related minimum design concentrations are as follows:

- JP-5 = Kerosene = 5.9% (via cup burner test in accord with the 2006 ed of ISO 14520 Annex B)
- JP-8 = Jet A = 5.4% (via cup burner test in accord with the 2006 ed of ISO 14520 Annex B)
- Electrical equipment = 4.7% (per 2012 ed of NFPA 2001, paragraph 5.4.2.5)

Test Fixtures and Test Enclosure

Construction of a half-scale engine mock-up was completed based on the full scale F100 Engine Nacelle Test Fixture and a test pad utilized by the Air Force Research Laboratory, ref. "Performance-Based Work Statement For Novec Fire Suppression System", 8/18/2011. The F100 test fixture is designed to produce three-dimensional or running fuel, fires to simulate an aircraft engine fire. It is utilized for evaluating the effect of fire fighting agents when attacking a fire from the engine intake, tailpipe or access panels. The test pad is designed to contain fuel from evaluations and regulate the ground fire size. The pan fire mock-up was based on a 3 foot by 3 foot full-scale USAF criteria with a canopy above the pan to represent an aircraft surface obstruction. For both tests, the fuel used was Jet A and was ignited directly with a propane wand. For the flowing fuel portion of the engine test, the fuel was sprayed directly into the engine nacelle test fixture at a rate of two gallons per minute.

The total volume of the protected space within an AF37T-10 Hush House is 115,960 cubic feet while the fire test enclosure had an overall volume of 5,832 cubic feet, approximately 5% of the full scale volume. The scaling of the test mock-ups is based on an expected test fire size that would have a heat release rate of one twentieth of that expected in a full scale fire. The intent was to maintain a comparable fire size to room ratio. The scaled fire sizes calculated below however, were unrealistically small to provide meaningful replication of an expected flash fire in a hush house. Because of this, the fire size for each test was increased based on either an existing commercial test protocol (pan fire) or is crafted to more physically relate to the full scale geometry (engine fire). In both cases, the test fires are significantly more challenging than a directly scaled fire size. See the heat release calculations in Appendix A.

Fire Test Facility

The fire test work was conducted at 3M's Decatur AL fire test facility in a 18ft. x 18ft. x 18ft. high, clean agent total flood test enclosure with an observation window on both the north and east sides to enable observations and video to be captured during the tests. See figure 2.

Figure 2: Fire test enclosure

Data Acquisition Set-Up for Fire Performance Tests

The 3M Fire Test Facility data setup includes Omega K type thermocouple probes located strategically in the test enclosure connected to a 16 channel A/D Thermocouple module. Pressure is measured in the system cylinder and at the nozzle by 100 mV full bridge Omega pressure transducers with a 3.3 V excitation voltage connected to a 4-channel pressure module. Both modules are installed in a National Instruments Compact DAQ connected via USB to a data collection computer running Labview 2010. Data collected are saved as excel files and backed up to a proprietary remote server. Data sample frequency is variable and can be set from 0.5 Hz to 1600 Hz. typically set to 10 Hz. Data acquisition equipment used in testing is calibrated at 3M by an ISO 9001 certified metrology laboratory. No O2 measurements were recorded during the tests, as the enclosure was well ventilated during the pre burn period.

Pan Fire Set-up

Aligned with 4.1.1.3.1 of the USAF test protocol, the pan used was that for the Class B UL 2166 fire, aligned with the following details excerpted from UL 2166, except for the fuel, which was Jet A:

> 34.3.1.2 The tests are to be conducted using a 2-1/2 ft^2 (0.25 m^2) square pan described in 34.3.1.3 located in the center of the room. The test pan is to contain at least 2 inches (5.0 cm) of heptanes [Jet-A] with the heptanes [Jet-A] 2 inches or more below the top of the pan.
>
> 34.3.1.3 The pan is to be of steel not less than 1/4 inch (6.4 mm) thick, with liquid-tight welded joints and provided with a 1-1/2 (3.8 cm) by 1-1/2 by 3/16 inch (4.8 mm) thick angle to reinforce the upper edge. The reinforcing angle is to be continuous around the perimeter of the pan and is to form a turned-out edge flush with the top edge of the pan. The top edge surface so formed is to be 1-3/4 inch (44 mm) in width. The reinforcing angle is to be continuously welded to the outside of the pan at the top edge and tack-welded at the edge of the lower leg of the angle.
>
> 34.3.1.4 The top of the pan is to be located 26 – 30 inches (66 – 76 cm) above the floor.

Using of a square steel pan, 1.58ft (0.5m) x 1.58ft (0.5m) x 4.0in (10cm) deep can be filled with 2.0 in (5.0cm) or 3.3 gallons (12.5 liters) of Jet-A. A 4.75ft x 4.75ft (145cm x 145cm) metal plate was positioned horizontally parallel to and centered on the pan and 6.0ft (1.8m) above the floor to simulate an aircraft surface obstruction. See figure 3.

Once the fire is lit and spread throughout the entire surface of the pool, a period of at least 1 minute elapsed before initiation of the fire suppression system and equilibrating to a calculated heat release of approximately 0.333MW. A successful test is considered to be extinguishment of all fire within 30 seconds from end of system discharge and with no reflash after ten (10) minutes.

Fig. 3: Pan Fire Test Setup

Fig 4: Fully Developed Pan Fire

Engine Fire Test Set-up

Aligned with 4.1.1.3.2 of the USAF test protocol, a simulated engine nacelle test fixture was used as described in publication AFRL-ML-TY-TR-2002-4604 F100 Engine Nacelle Fire Fighting Test Mockup Drawings but scaled to a more realistic fire scenario for the enclosure. The concrete fire test pan, fuel lines #1 and #3, and thermocouple sensors described in the publication are not required for this performance evaluation. Jet-A fuel flowed at a rate of 2 gal/min (7.6 L/min) through fuel line #2, and a square steel pan measuring 4.42ft (134.7cm) x 4.42ft (134.7cm) x 3in (7.5cm) deep was placed under the rear end of the mockup to catch the running fuel. The 12.83ft^2 (1.19m^2) pan was filled with 0.4in (1cm) or 0.3gal (1.0 liter) of fuel prior to commencement of the test. Note the flow rate proposed was that used by the US Navy for their modified engine nacelle flightline test protocol. See figure 5.

Once the spray fire and the pool fire are lit and the pool fire has spread throughout the entire surface of the pool, a period of at least 1 min shall elapse before initiation of the fire suppression system equilibrating to a calculated heat release of approximately 3.040MW. A successful test was considered to be extinguishment of all fire within 30 seconds from end of system discharge and with no reflash after ten (10) minutes.

Figure 5: Engine Fire Test Setup

Fig 6: Fully Developed Engine Fire

Full Scale Concentration Test

A full scale functional system discharge test was conducted for a Fire Suppression System (FSS) designed for use with FK-5-1-12 in the AF37T-10 hush house at Dannelly Field, AL. See figure 7. The FSS was operated and agent discharged throughout the protected hush house volume in accordance with the design parameters at the design concentration used in the aforementioned fire tests.

The system will be activated and the agent will be released into the hush house with constant monitoring of volumetric concentration. A successful test was considered an initial concentration at or above the design concentration and above 85% of the design concentration after ten (10) minutes.

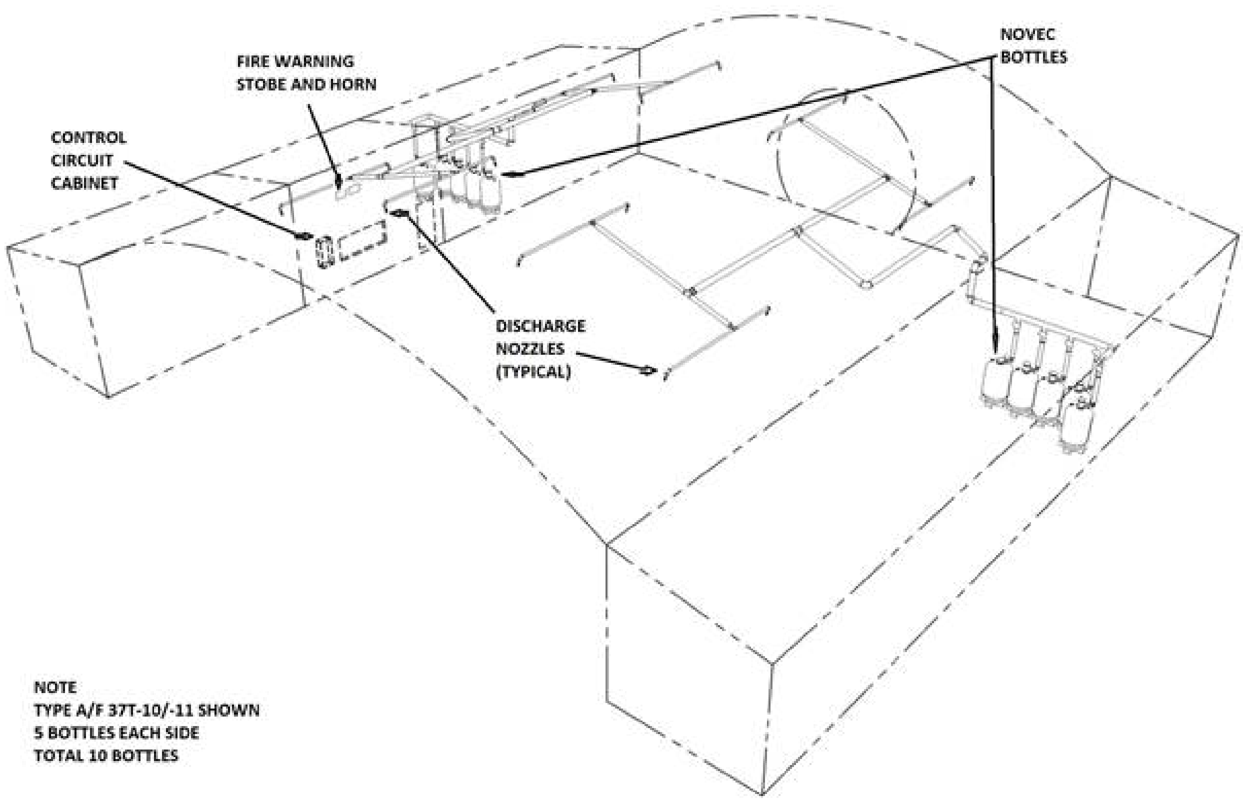


Figure 7: AF37T-10 hush house

Description of Test Setup and Instrumentation

Temperature Sensors

Temperature measurement setup include 5 type-K thermocouple probes located throughout the test enclosure measuring ambient conditions. All thermocouples are connected to a 16 channel, 24-bit C Series, A/D Thermocouple module, model number NI 9213. A calibrated Omega HHM29 digital thermometer was used to verify the accuracy of the data acquisition system temperature readings immediately prior to the test.

Pressure Sensors

System pressure was measured in two locations: the valve body above the primary system cylinder to determine activation time and at a discharge nozzle to determine discharge timing. Pressure was measured by 500 psi rated, calibrated PX-102 full bridge pressure transducers with 3.3 V excitation voltage and 100 mV output. Both pressure transducers are electronically balanced and verified against a calibrated Omegadyne DPG-1KG Digital Pressure gauge immediately prior to the test. Analog outputs from the pressure transducers were connected to a 4 channel, 50 kS/s per Channel, 24-Bit Bridge, analog input module, model number, NI 9237

Concentration Sampling

FK-5-1-12 concentration level was sampled in 5 locations from 1/8 inch I.D. tubing located throughout the test enclosure. Sampled air was continuously analyzed by two PERCO Model 113 Gas Analyzers. One K-type thermocouple probe located within the air sampling tubing measures a baseline reference temperature of concentration air samples. The measurement sampling rate was 0.2 Hz while the volumetric flow rate was 1.5 L/min for 3 sampling channels with an approximate lag time of 12 to 24 seconds. DC Voltage output from the gas analyzers are connected to a 4 channel, 50 kS/s per Channel, 24-Bit Bridge, Analog Input module, model number, NI 9237. Certified FK-5-1-12 gas standards supplied by Airgas USA, LLC. at 6.981 mol% and 7.000 mol% were used to calibrate the gas analyzers immediately prior to the test.

Data Acquisition Hardware and Software

All data collection modules are installed in a National Instruments 8-slot CompactDAQ chassis, model number cDAQ-9178 sampling at a frequency of 1,613 Hz connected via USB to an HP EliteBook data collection computer running Labview 2011 SP1. Data collected are saved as National Instruments TDM Streaming file (*.TDMS) and are analyzed and plotted using NI DIAdem 2011 software.

Fire Test Results and Discussion

All fire tests for this program were conducted at the 3M Fire Test Facility in Decatur, AL. See figures 4 and 6. Each fire test was successful and was replicated once with similar results, see table 1. All fires were extinguished completely within 30 seconds of the end of discharge. Temperatures and video were monitored for 10 minutes following the tests confirming no re-flash occurred. The discharge time was adjusted between tests to bring it in line with a maximum 10 second discharge window. Additionally, the lower measured flame temperature in test 3 was due to thermocouples positioned below the flame and not directly impinged near the flame/air interface. The full data collected during the final tests was plotted and is available in Appendix B.

Fire Test Results

Test Location	3M Fire Test Facility			
Fuel	Jet A			
Agent	FK-5-1-12			
System	Siemens Sinorix			
System Pressure	360 psi			
Design Conc.	5.9%			
Pre-burn	60 sec.			
Test Description	Pan Fire w/ Canopy		Engine Fire	
Test Number	1	2	3	4
Test Date	02/24/2012	03/01/2012	02/24/2012	03/01/2012
Fire Size	333 kW	333 kW	3040 kW	3040 kW
Flame Temp.	1,300 F	1,300 F	400 F*	1,300 F
Discharge Time	13 sec.	8.8 sec.	12.5 sec.	9.0 sec.
Extinguishment	6.3 sec.	6.7 sec.	20 sec.	18.3 sec.
10 Minute Re-flash	None	None	None	None
Test Results	Successful	Successful	Successful	Successful

Table 1: Fire Performance Test Results

Concentration Test Results

The full system discharge with concentration monitoring was conducted at Dannelly Field, Montgomery, AL. See figure 8 below. The test was successful with a discharge time of 9.9 seconds, minimum design concentration was met and held for over 10 minutes. The concentration was monitored at the hazard elevations of floor level (2’) and typical engine level (6’) at two locations within the main hush house as well as a side area (6’) where control equipment was utilized. Five locations total. See Appendix B

Fig 8: U.S.A.F. AF37T-10 hush house Full-scale Agent Concentration Test

Test Configuration	
Agent:	FK-5-1-12
System:	Siemens Sinorix
System Pressure:	360 psi
RoomSize:	116,000 c.f.
Mass of Agent	8,210 lbs.
Test Conditions	
Test Location	Dannelly Field, Montgomery, AL
Test Time	9:38 am, 16 May 2012
Temperature:	76 deg. F
Relative Humidity:	64%
Dew Point:	63 deg. F
Atm. Pressure	30.1 inHg
Design Criteria Measured Result	
Discharge Time 9.4 +/- 1 (sec.):	9.9
Design Concentration 6.8 min (vol. %)	7.1
Concentration at 600 sec. 5.8 min (vol%)	6.8
Test Results	Successful

Table 2: Concentration Test Results

Summary and Conclusions

After over a decade of work and review of many the possible solutions for halon 1301 replacement to protect their strategic Noise Arrester Jet Engine Test Facilities – hush houses – around the world, engineers at the USAF's Support Equipment & Vehicles Division of the Aerospace Sustainment Directorate at Robins AFB Georgia selected an integrated system solution that met all the sustainable requirements of superior performance, personnel safety, lack of environmental and regulatory risk and a reliable, commercial component supply that is available globally. The solution now specified is based on FK-5-1-12, an in-kind halon replacement commercially known as 3M™ Novec™ 1230 Fire Protection Fluid that will be employed to replace hush house halon 1301 systems globally through the end of the decade.

Appendix A

Heat Release Rate calculations

Detailed Calculations of Scaled Fire Size Using Equivalent Fire Size to Room Volume Ratio

Assumptions:

1. Scaled pool fire size was based on equivalent fire size to room volume ratio (kw/m^3)
2. Full scale test protocol called for kerosene or JP-8. The following calculations are based on the widely available published fuel properties of kerosene which has similar thermo chemical properties to Jet A or JP-8 fuel.
3. Calculations are based on an equivalent area circular pool
4. Burning was primarily in the radiative regime
5. No external heat flux augmentation

Hush house volume:
Main room = 1,375 s.f. cross section area x 81.3ft. length = 111,823 c.f.
Side room = 13.5ft. average height x 21.4ft. length x 14.3ft. width = 4,131 c.f.
Total volume = 115,960 c.f.

Test enclosure volume:
18ft. width x 18ft. length x 18ft. height = 5,832 c.f.
Test enclosure scale = 5,832 / 115,960 = 0.050, or 1:20 scale
Heat release rate of the fire was calculated with the following equation from Babrauskas, SFPE Handbook of Fire Protection Engineering, 4th ed. Ch. 3-1: "Heat Release Rates".

Q = Hc x m x (1 – exp(-kd)) x A

Q = Heat release rate of fire (MW)
Hc = Net heat of combustion of kerosene, 43.2 (MJ/kg)
m = Mass burning rate per unit area of kerosene, 0.039 (kg/m^2 x s)
k = Mass loss rate per unit area of kerosene, 3.5 (1/m^2)
d = Pool diameter
(m) A = Pool Area
(m^2)

Pan Test

Heat release rate for pan test, 3ft. x 3ft. pan fire = 1.37 MW

Scaled heat release rate for pan test = 1.37 MW x 0.050 = 68.5 kW

Pool area required for 68.5 kW fire = 0.70 s.f. (0.065m^2), 10” x 10” pan (25.4 cm x 25.4 cm)

Actual pan size for pan test = 2.5 s.f. (0.23 m^2) with Heat Release Rate of 333 kW, 4.8 times larger than scaled fire of 68.5 kW.

Engine Test

Heat release rate for engine test, 5ft. x 5ft. pan fire = 3.90 MW

Scaled heat release rate for engine test = 3.90 MW x 0.050 = 195.2 kW

Pool area required for 195.2 kW fire = 1.60 s.f. (0.149m^2), 15.2” x 15.2” pan (38.6 cm x 38.6 cm)

Actual pan size for engine test = 19.5 s.f. (1.81m^2) with Heat Release Rate of 3.04 MW, 15.5 times larger than scaled fire of 195.2 kW.

- The fire test enclosure was 1/20th of the volume of a typical hush house. The test fixtures and pans are scaled such that the fire size/room volume (kW/m^3) are greater than what would be present in a full scale test.
- The pan test requires a minimum scaled fire size of 68.5 kW. The actual fire size was 333 kW or 4.8 times larger
- The engine mock-up requires a minimum scaled fire size of 195 kW. The actual fire size was 3,040 kW, over 15 times larger.

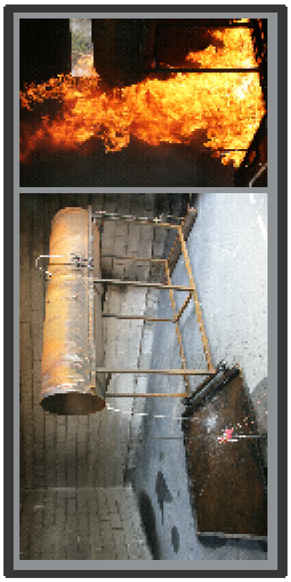
Appendix B

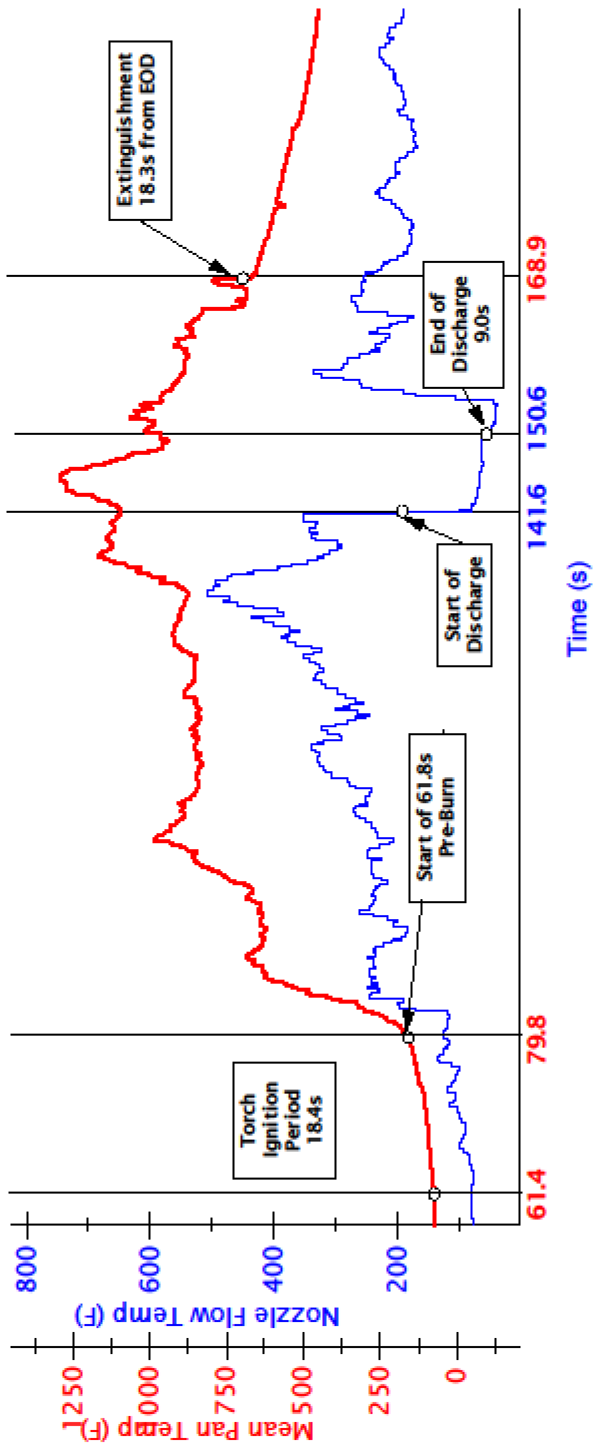
3M™ Novec™ 1230 Fire Protection Fluid
Electronics Markets Materials Division
Fire Protection Fluids

USAF Scaled Hush House Fire Tests
Test Location: 3M Decatur, AL
1 March 2012

Engine Fire Test #2

Agent:	Novec 1230
System:	Siemens Sinorix
System Pressure:	360 psi
Design Conc.:	5.9%
Pre-burn:	60 sec.
Fuel:	Jet A
Fire Size:	3040 kW
Discharge Time:	9.0 sec.
Extinguishment:	18.3 sec.
10 Minute Reflash:	None
Test Results:	Successful





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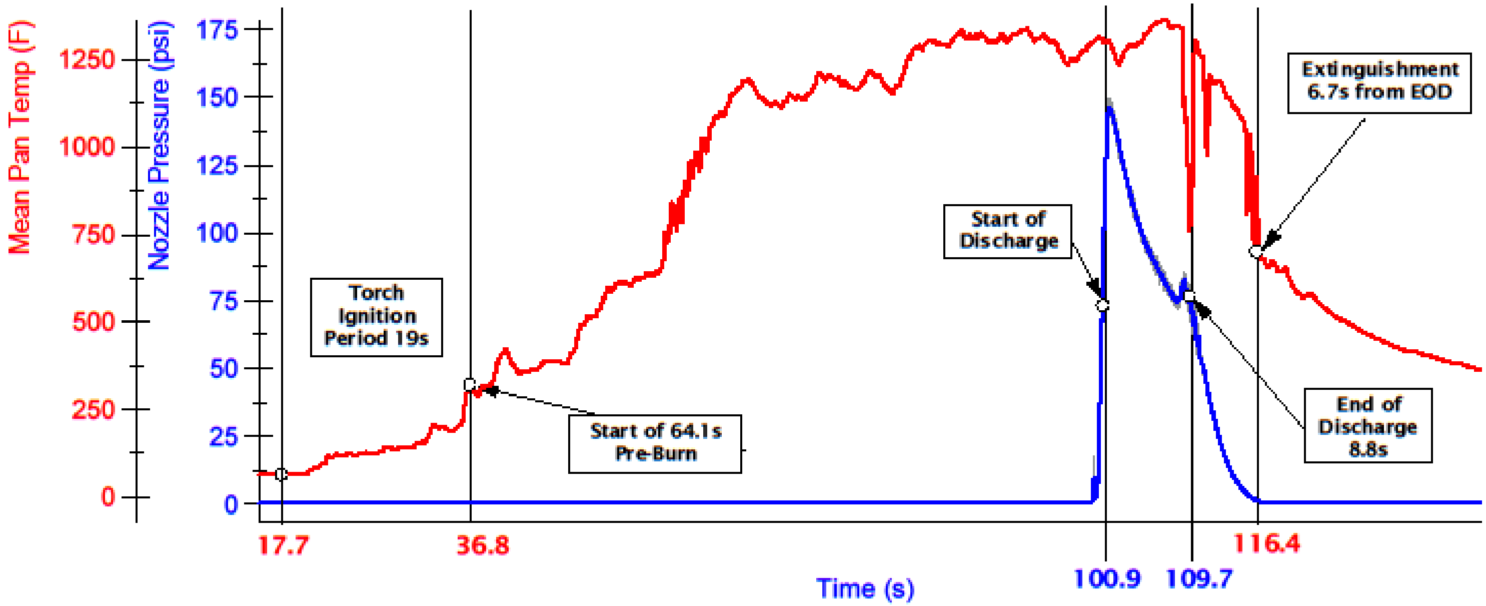
3M™ Novec™ 1230 Fire Protection Fluid
Electronics Markets Materials Division
Fire Protection Fluids

USAF Scaled Hush House Fire Tests

Test Location: 3M Decatur, AL
1 March 2012

Pan Fire Test #1

Agent:	Novec 1230
System:	Siemens Sinorix
System Pressure:	360 psi
Design Conc.:	5.9%
Pre-burn:	60 sec.
Fuel:	Jet A
Fire Size:	333 kW
Discharge Time:	8.8 sec.
Extinguishment:	6.7 sec.
10 Minute Reflash:	None
Test Results:	Successful



3M™ Novec™ 1230 Fire Protection Fluid
Electronics Markets Materials Division
Fire Protection Fluids

U.S.A.F. T-10 Hush House
Full-scale Agent Concentration Test

Test Configuration	
Agent:	Novec 1230
System:	Siemens Sinorix
System Pressure:	360 psi
RoomSize:	116,000 c.f.
Mass of Agent	8,210 lbs.

Test Conditions

Dannelly Field, Montgomery, AL
9:38 am, 16 May 2012

Temperature:	76 deg. F
Relative Humidity:	64%
Dew Point:	63 deg. F
Atm. Pressure	30.1 inHg

Design	Criteria	Measured	Result
Discharge Time (sec.):	9.4 +/- 1	9.9	Pass
Design Concentration (vol. %)	6.8 minimum	7.1	Pass
Concentration at 600 sec. (vol%)	5.8 minimum	6.8	Pass