NAWCWD TM 8572

Final Report
Qualification of an Acceptable Alternative to Halon 1211 DOD Flightline Extinguishers

WP-0618

by
Robert L. Darwin
Daniel P. Verdonik, Eng.Sc.D.
Hughes Associates, Inc.

John Hawk
Fire Research Group
Air Force Research Laboratory

Ross A. Davidson
Howard L. Bowman
Energetics Research Division
Naval Air Warfare Center Weapons Division

Douglas S. Dierdorf, PhD.
Applied Research Associates, Inc.

Kenneth Dormer
Air Force Consultant

Peter Mullenhard
Science Applications International Corporation

SEPTEMBER 2008

NAVAL AIR WARFARE CENTER WEAPONS DIVISION
China Lake, CA 93555-6100

FOREWORD

This report documents the procedures, test, evaluation, and comparison of commercially available alternative agent/hardware flightline firefighting systems as potential replacements for the 150-pound Halon 1211 fire extinguisher now in use. This demonstration was sponsored by the Environmental Security Technology Certification Program (ESTCP) as part of the Pollution Prevention Thrust Area (Material Substitution). The project number is WP-0618. Performance testing of viable candidate agents and delivery systems was conducted at Tyndall AFB, FL, to provide data needed to determine acceptability for use on U.S. Navy (USN), U.S. Marine Corps (USMC), and U.S. Air Force (USAF) flightlines.

John E. Wilson has reviewed this report for technical accuracy. This document was prepared for the ESTCP and is publicly released.

Therese AtienzaMoore
Head, Energetics Research Division
30 September 2008

NAWCWD TM 8572, published by Code 4L6200D, 10 copies.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, D.C. 20503.			
1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE September 2008	3. REPORT TYPE AND DATES COVERED	
4. TITLE AND SUBTITLE Final Report Qualification of an Acceptable Alternative to Halon 1211 DoD Flightline Extinguishers WP-0618 (U)			5. FUNDING NUMBERS
6. AUTHOR(S) Robert L. Darwin, Daniel P. Verdonik, Eng.Sc.D., Hughes Associates, Inc.; John Hawk, Fire Research Group, Air Force Research Laboratory; Ross A. Davidson, Howard L. Bowman, Energetics Research Division, Naval Air Warfare Center Weapons Division; Douglas S. Dierdorf, PhD., Applied Research Associates, Inc.; Kenneth Dormer, Air Force Consultant; Peter Mullenhard, Science Applications International Corporation			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Air Warfare Center Weapons Division China Lake, CA 93555-6100			8. PERFORMING ORGANIZATION REPORT NUMBER NAWCWD TP 8572
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution is unlimited.			12b. DISTRIBUTION CODE
13. ABSTRACT *(Maximum 200 words)*			

(U) The U.S. Navy and the U.S. Air Force use 150-pound Halon 1211 fire extinguishers for first-response fire suppression on flightlines. This ESTCP demonstration project was initiated to identify and test commercially available alternative agents and delivery systems as potential replacements for these extinguishers. Three agent/hardware combinations were selected for testing: DuPont's FE-36 with Ansul's FE-300 hardware; American Pacific Corporation's Halotron I with Buckeye's W-150 hardware; and Halotron I with Amerex 674 hardware. Testing was conducted at Tyndall Air Force Base (AFB), FL, using a standard F-100 Engine-Nacelle Test Fixture, to evaluate the firefighting performance of candidate agents/systems. None of the systems tested matched the extinguishing performance of the existing Halon 1211 system. Only 30 percent of the test fires were extinguished, compared to all fires being extinguished in the Halon 1211 baseline tests. There is insufficient data resulting from this testing to be able to consider whether use of one of the tested agents in larger quantities would result in greater success.

14. SUBJECT TERMS			15. NUMBER OF PAGES
Aircraft Fire Fire extinguisher Flightline fire	Halon Halon 1211		70
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF ABSTRACT	19. SECURITY CLASSIFICATION OF THIS PAGE	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
29-102

PREFACE

This report was prepared by the Energetics Research Division, Naval Air Warfare Center Weapons Division; the Fire Research Group, Air Force Research Laboratory; Hughes Associates, Inc.; Applied Research Associates, Inc.; and Science Applications International Corporation. This report was prepared for and funded by the Environmental Security Technology Certification Program (ESTCP).

The authors gratefully acknowledge the contribution of Mr. Virgil Carr, Air Force Research Laboratory, for the use of the fire test facility and staff and for outstanding support during the test program.

ABSTRACT

The U.S. Navy and the U.S. Air Force use Halon 1211 in 150-pound fire extinguishers for first-response fire suppression on flightlines. Halon 1211 production ended in the United States on 31 December 1993. This demonstration project was initiated to identify and test commercially available alternative agents and delivery systems as potential replacements for the 150-pound Halon 1211 extinguishers.

The three agent/hardware combinations selected for testing were: DuPont’s FE-36 with Ansul’s FE-300 hardware; American Pacific Corporation’s Halotron I with Buckeye’s W-150 hardware; and Halotron I with Amerex 674 hardware.

Performance testing was conducted at Tyndall Air Force Base (AFB), FL, using a standard F-100 Engine-Nacelle Test Fixture. Fuel flowing from nozzles was ignited creating essentially three fires—a spray fire within the cylindrical fixture, burning fuel flowing out of the fixture, and a pool fire beneath the fixture—that candidate systems were expected to extinguish. A second test series, the stream-reach tests, measured candidate systems ability to extinguish small fires at distances of 20, 25, 30, and 35 feet. The main performance objective was for candidate agents/systems to match the firefighting performance of the existing Halon 1211 fire extinguisher against these fires. DOD would prefer an agent/hardware system with a stream reach of at least 25 feet with the ability to extinguish the test fire within 30 seconds using less than 285 pounds of agent. The tested units also had to meet requirements for safe fire-fighter standoff distance, relative size of the unit for typical use, environmental safety, and occupational health.

Stream-reach tests showed that each of the combinations had a stream reach of at least 35 feet.

Following the testing of alternative agents the Air Force Research Laboratory (AFRL) retested the 150-lb Halon 1211 fire extinguisher against the same test protocol and previously documented baseline performance requirements.

None of the systems tested matched the extinguishing performance of the existing Halon 1211 system. Only 30 percent of the test fires were extinguished, compared to all fires being extinguished in the Halon 1211 baseline tests. There is insufficient data resulting from this testing to be able to consider whether use of one of the tested agents in larger quantities would result in greater success. A further concern from these results is that the cost-avoidance benefit from finding and fielding an alternative to Halon 1211 is now significantly in question.

TABLE OF CONTENTS

Figures:

Tables:

This page intentionally left blank.

ACRONYMS

ADUSD	Assistant Deputy Under Secretary of Defense
AFB	Air Force Base
AFI	U.S. Air Force Instruction
AFRL	Air Force Research Laboratory
APU	Auxiliary Propulsion Unit
ARA	Applied Research Associates, Inc.
ASTM	American Society for Testing and Materials
CB	chlorobromomethane
CFC	chlorofluorocarbon
COTS	commercial off the shelf
DLA	Defense Logistics Agency
DOD	Department of Defense
EC	European Commission
EPA	Environmental Protection Agency
ESOH	Environment, Safety, and Occupational Health
ESTCP	Environmental Security Technology Certification Program
EU	European Union
FAA	Federal Aviation Administration
FL	Florida
GWP	Global Warming Potential
HCl	hydrogen chloride
IASFPWG	International Aircraft Systems Fire Protection Working Group
IPCC	Intergovernmental Panel on Climate Change [WMO]
IR	Infrared
JTP	Joint Test Protocol
LOAEL	lowest observed adverse effect level
MIL-STD	Military Standard
MLQD	Manufacturing Directorate, Expeditionary Technologies Division [AFRL]
MPS	Minimum Performance Standard
MSDS	Material Safety Data Sheet
NATO	North Atlantic Treaty Organization
NAWCAD	Naval Air Warfare Center Aircraft Division
NFPA	National Fire Protection Association
NIST	National Institute of Science and Technology
NOAEL	No Observed Adverse Effect Level
NRL	Naval Research Laboratory
NSWCCD	Naval Surface Warfare Center Carderock Division
ODP	ozone depletion potential
ODS	Ozone-Depleting Substance

OEM	Original Equipment Manufacturer
PFC	perfluorocarbon
PKP	potassium bicarbonate dry chemical
R&D	research and development
RDT&E	research, development, test, and evaluation
SNAP	Significant New Alternatives Policy [EPA]
T.O.	Technical Order
TSCA	Toxic Substances Control Act of 1976 (15 USC)
U.S.	United States
UL	Underwriters Laboratory
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
VOC	Volatile Organic Content
WMO	World Meteorological Organization

1.0 INTRODUCTION

1.1 BACKGROUND

In accordance with the 1987 Montreal Protocol to Protect the Stratospheric Ozone Layer and the United States (U.S.) Clean Air Act as amended in 1990, Halon 1211 production in the U.S. ended on 31 December 1993. The U.S. Navy (USN) and the U.S. Air Force (USAF) use Halon 1211 predominantly in 150-pound fire extinguishers, which provide easy-to-use, effective, and clean first-response fire suppression on the flightline. Approximately 20,000 of these extinguishers are in use by the USN and USAF. Unless a non-ozone depleting alternative can be identified, under projected USN and USAF usage rates the DOD will run out of Halon 1211 stocks as early as 2012 (Reference 1). In order to execute an orderly, economically feasible transition to a new agent, the USN and USAF need to demonstrate and validate a Halon 1211 alternative for this application within the next few years.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this demonstration was to identify and test commercially available, alternative agents/systems as potential replacements for the Halon 1211 150-pound flightline fire extinguisher. Performance testing of viable candidate agents and delivery systems was conducted at Tyndall Air Force Base (AFB), FL, to provide data needed to determine acceptability to USN (USN and U.S. Marine Corps (USMC)) and USAF flightline fire protection stakeholders (fire departments; aircraft, aircraft subsystem, and aircraft engine program managers; logistics maintenance organizations; Environment, Safety, and Occupational Health (ESOH) professionals; and the ergonomics/human factors community).

Candidates for testing were required to be technologically mature and commercially available.

1.3 REGULATORY DRIVERS

In addition to the Montreal Protocol to Protect the Stratospheric Ozone Layer and the U.S. Clean Air Act, which ended production of Halon 1211, in 1993, the EU issued European Commission (EC) Regulation 2037/2000 on “Substances that Deplete the Ozone Layer” in 2000. This regulation goes well beyond the mandates of the Montreal Protocol, inasmuch as it establishes phase-out dates for the use and distribution of individual ozone-depleting substances (ODSs). All use of Halons in the EU was banned effective 31 December 2003, unless the use was specifically included in a list of “critical use” exemptions of Halon 1301 and 1211 for specific situations where no “technically feasible” alternative exists. Many of these exemptions are specific to the military and remain important to the DOD (ground combat vehicle crew compartments, combat aircraft fuel tank inerting, and flightline fire extinguishers). However these exemptions are not permanent, and the EC began their first review of the exemptions' necessity in September 2005.

While most DOD Halon applications are similar or identical to applications by the private sector or by EU militaries (aircraft engine nacelle fire protection, ground combat vehicle fire and explosion suppression, ship engine room fire suppression, etc.), Halon 1211 flightline fire extinguishers are not used or are rarely used outside the DOD. Most of these other sectors use less effective or "dirty" alternatives, such as PKP (Purple K potassium bicarbonate) dry chemical extinguishers. In the commercial sector and in many EU militaries, the loss of the operational use of the aircraft does not seem to be as big a concern as for the DOD. Therefore it is much more likely that the EC would try to phase out this exemption because it does not appear to be of primary importance to most sectors within the EU, and the EC is under pressure to show progress by phasing out one or more exemptions.

Although DOD operations at bases within the EU are not directly subject to EU regulation, any decision by the EC to phase out the critical use exemption for flightline fire extinguishers could directly impact DOD operations in Europe. In a letter to the Joint Staff dated 24 May 2005, Assistant Deputy Under Secretary of Defense (ADUSD), ESOH, stated that "our ability to export Halon into the European Union, transport it over 'public' road or rail, and utilize host nation skilled labor for maintenance…will be affected by this regulation if the exemptions are lost. Added to these considerations are those of interoperability and host nation relations."

If DOD flightlines within the EU—or within the Continental United States, for that matter—are forced to switch to a less effective or less "dirty" agent, then it is likely that significant additional maintenance/repair costs will be incurred, with readiness impacted as a result of increased collateral damage to engines and airframes. For example, a 1992 study performed for the USAF concluded that use of a "dirty" agent would result in $40.5 million in additional annual engine repair costs alone.

1.4 STAKEHOLDER/END-USER ISSUES

The concerns of several USAF, USN, and USMC flightline fire protection stakeholders and end-users had to be considered in developing parameters for this testing. Key stakeholders are fire departments; aircraft, aircraft subsystem, and aircraft engine program managers; ESOH professionals; and the ergonomics/human factors community. Logistics maintenance organizations are the primary end-user for the 150-pound flightline fire extinguisher. In addition, Warner Robins Air Logistics Center, as the DOD supply item manager for the current Halon 1211 extinguisher, has been involved in this project.

In response to one key end-user performance parameter, the project tested only "clean agents" that would not leave significant residue when applied to aircraft or equipment. In addition, through prior coordination with the firefighting communities, the project performers demonstrated the firefighting effectiveness of the tested fire extinguishers using the protocol described in Appendix A.

With the conclusion of this project, it is expected that USAF, USN, and USMC acquisition decision makers will use the test results and other existing information about the extinguishers to evaluate them against the full set of stakeholder/end-user requirements. These will include, but are not limited to, fire extinguishment performance, cost, logistics footprint, materials compatibility, ergonomics, ESOH, and industrial base considerations.

1.4.1 Fire Extinguishing Performance

Through prior coordination with the firefighting communities, the fire extinguishing performance of the candidate agents was evaluated against performance requirements shown in Reference 3. The joint test protocol measured candidate agents' performance against very challenging, standardized fires. The project performers expected that, with larger flow rates and agent capacities, one or more commercially available agents/systems would meet the threshold requirement.

1.4.2 Materials Compatibility

Stakeholders were queried for their requirements for materials compatibility of the agent, because one of the primary characteristics that must be replicated by any alternative to Halon 1211 is its "clean agent" characteristic—its ability to be sprayed on an engine or airframe without agent collateral damage to the aircraft or surrounding aircraft. It was anticipated that compatibility requirements would be in the form of standard American Society for Testing and Materials (ASTM) or airframe/engine original-equipment- manufacturer (OEM) materials compatibility tests. This type of test data was readily available from clean-agent manufacturers and was requested as part of the solicitations for clean-agent OEMs. Additionally, compatibility data from previous DOD Halon and chlorofluorocarbon (CFC) refrigerant alternative test programs was leveraged. For example, data on HFC-227ea were readily available from numerous DOD research, development, test, and evaluation (RDT&E) programs such as the Naval Research Laboratory's (NRL's) shipboard Halon replacement program and Naval Air Warfare Center Aircraft Division (NAWCAD) and AFRL aircraft Halon 1301 replacement programs. Data on HFC-236fa, which is being used as a refrigerant on USN ships, was readily available from the Naval Surface Warfare Center Carderock Division's (NSWCCD's) shipboard refrigerant replacement program. After review of supplied and collected compatibility data, when additional testing or data was required, the project attempted to leverage clean-agent OEMs to do the additional testing in order to keep the cost of the DOD program to a minimum.

1.4.3 Environment, Safety, and Occupational Health Performance

Because this program focused on commercially available alternative agents/systems, existing data on environmental effects (atmospheric lifetime, Global Warming Potential (GWP), Ozone-Depleting Potential (ODP), Volatile Organic Content (VOC), etc.) was generally available. Additionally, because the USN and USAF offices that sponsored and supported this project had close working relationships with the Environmental Protection Agency (EPA) Office of Atmospheric Programs, their knowledge was also leveraged. Because only commercially available agents were considered for testing, all agents had already received toxicity screening via the EPA's Toxic Substances Control Act (TSCA) and Significant New Alternatives Policy (SNAP) programs, and OEMs provided Material Safety Data Sheets (MSDSs) and other safety and health information for evaluation. Project evaluation of the existing data prioritized alternative agents that did not increase the safety and health risks and costs over those of Halon 1211. Primary characteristics that were used for screening included chronic and acute occupational exposure limits and cardiotoxicity. Alternatives that were carcinogens or that had any adverse developmental toxicity results were excluded from consideration.

2.0 TECHNOLOGY DESCRIPTION

2.1 EXISTING TECHNOLOGY

The existing Halon 1211 flightline extinguishers were procured by DOD using a purchase description prepared by Warner Robins AFB (Reference 4). Figure 2-1 shows the current unit.

FIGURE 2-1. DOD Halon 1211 Flightline Extinguisher.

The extinguisher holds 150 pounds of 1211, which is discharged through a hand-held nozzle connected to 50 feet of 0.75-inch hose. The agent container is of the stored-pressure type, using nitrogen as the expelling medium. The overall discharge time is approximately 46 seconds, yielding an average flow rate over the entire discharge of 3.3 pounds per second. The unit has a 30A:240 BC rating from Underwriters Laboratory (UL) based on UL testing conducted in accordance with UL Standard 711 (Reference 5).

2.2 TECHNOLOGY DEVELOPMENT AND APPLICATION

Alternative agent/system OEMs were solicited to provide their commercially available technologies that meet DOD requirements. It was anticipated that submissions would include FK-5-1-12 (3M™ Novec™ 1230), HFC-236fa (Dupont FE-36™), and HFC-227ea (GLC FM 200®, Dupont FE-227™) as a minimum. Because all of these agents are available commercially as Halon alternatives in total flooding and/or streaming applications, no significant demonstration or validation issues were anticipated. Extensive scientific test data are available on most of these agents from scientific, research, and testing organizations such as NRL, AFRL, NAWCAD, NSWCCD, Underwriters Laboratory (UL), the National Institute of Science and Technology (NIST), and the National Fire Protection Association (NFPA). Although all of these agents have been tested and/or are being used in fire extinguishing applications, application of these technologies to large flightline fire extinguishers has not been pursued in the commercial sector.

As discussed above, only technologies that are commercially available and currently marketed for firefighting applications (and, therefore, fully mature) were included in the proposed project.

DOD conducted at least two previous efforts to identify alternatives for 150-pound flightline fire extinguishers in the 1990s, neither of which delivered an acceptable alternative. Some of this work was research and development (R&D)-focused, with an emphasis on identifying novel or little-exploited chemistries that could match the performance of Halon 1211. Other work focused on evaluating the commercial products that were commercially available at the time. During the same time frame, the only successful USN and USAF Halon 1211 alternative project addressed the small, handheld, portable extinguishers for USN aircraft carrier deck P-25 fire trucks.

The hastening depletion of USN and USAF Halon 1211 reserves, the negative results of past DOD R&D efforts in this area, and the larger set of commercial Halon 1211 alternatives available in 2005 all strongly suggested that the USN and USAF needed to take a demonstration and validation approach that, to the greatest extent possible, would leverage existing data and exploit mature, commercial technologies. The project would build upon the knowledge base of flightline fire extinguisher performance requirements, the military and commercial partnerships built in previous efforts, and the demonstration and validation methodologies that were developed in previous projects.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

Under the auspices of the International Aircraft Systems Fire Protection Working Group (IASFPWG), originally established in 1993 by the U.S. Federal Aviation Administration (FAA) and cooperating agencies and known then as the International Halon Replacement Working Group, a Minimum Performance Standard (MPS) for hand-held extinguishers for on-board passenger aircraft was developed. The MPS described the required extinguishment of two important in-flight fires, a hidden fire and a gasoline-drenched seat fire. A hidden fire extinguishment test method was developed and standardized by the IASFPWG. Underwriters Laboratories provides the testing services to demonstrate that a hand-held extinguisher complies with the hidden fire extinguishment criteria contained in the MPS. UL has listed the following commercially available extinguishers as being MPS-compliant: HCFC Blend B, HFC-227ea and HFC-236fa. In addition, FAA full-scale fire tests showed that gasoline-drenched seat fires were extinguished by these UL-listed extinguishers and did not create hazardous levels of agent decomposition gases, which is also an MPS requirement.

In addition to the IASFPWG requirements, these extinguishers are also evaluated and tested to UL 711 and for halocarbon extinguishers to UL 2129, to determine their suitability and durability for extinguishing specific classes of fires. Full-scale wood fire (Class A) and flammable liquid (Class B) tests and tests to determine suitability for use on energized electrical systems (Class C) are conducted to determine the type and size, known as the rating, of extinguished fires. UL currently lists HCFC Blend B and HFC-236fa hand-portable extinguishers with ratings ranging from 2B:C to 2A:10B:C, and HFC-227ea hand-portable extinguishers with ratings of 2B:C and 5B:C.

2.4 FACTORS AFFECTING COST AND PERFORMANCE

There are currently approximately 20,000 flightline fire extinguishers in use by the USN and USAF. The unit cost for each existing extinguisher (including market value of the agent) is approximately $3,700. The cost of replacement units should be comparable to the Halon extinguisher. It was believed that, if the USN and USAF could identify an alternative within the next 3 years, Halon 1211 supplies would be sufficient to enable their replacement through attrition, as the service life of each Halon 1211 extinguisher expires.

But the longer the demonstration and validation of an alternative was delayed, the greater the transition cost, because dwindling Halon 1211 supplies would require replacement of Halon 1211 equipment before its normal retirement cycle. For every year of delay, the USN and USAF estimated that approximately one-fifteenth of the existing inventory (approximately 1,300 of the 20,000 fire extinguishers in service) would have to be replaced out-of-cycle. This would increase transition costs by approximately $4.8 million for every year of demonstration and validation delay. If demonstration and validation of a suitable alternative were delayed until Halon 1211 supplies ran out, ultimate transition costs could range toward $74 million.

Finally, it is important to note that the U.S. Army has already fielded what they consider an acceptable alternative for Halon 1211 flightline fire extinguishers: dry chemical extinguishers. However dry chemical extinguishers are not “clean agents”—a current, critical performance requirement for USN and USAF jet engines. So far, the Army has accepted the corrosion effects that accompany the use of dry chemical agents. But if an acceptable clean agent is proven and accepted by both the USN and USAF, the Army would likely reevaluate their use of dry chemical extinguishers.

2.5 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The primary advantage of the “clean” fire suppression agents that were tested is that they leave no significant residue when applied to aircraft or equipment. This unique attribute satisfies one of the key USN and USAF operational requirements for the flightline fire extinguishers: they must be capable of putting out small fires in the vicinity of the engine without then requiring the engine to be removed for cleaning. Other agents that were not tested cannot meet the key “clean agent” performance parameter. However they do present other advantages:

(1) They are effective, easy-to-use fire suppressants.
(2) They are widely used in commercial aviation.
(3) They are less expensive.

Some examples of flightline fire suppressing alternative technologies that were not pursued are compressed air foam, aqueous film forming foam, and dry chemical agent.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Table 3-1 lists the performance objectives required for an alternative to the Halon 1211 fire extinguisher.

TABLE 3-1. Performance Objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Quantitative	1. Standoff distance for personnel in normal flightline gear to fight the fires	Does not exceed pain threshold for exposed skin	Each unit tested met this performance objective
	2. Firefighting effectiveness	Perform as well as the current Halon 1211, 150-pound flightline extinguisher	None of the commercial units evaluated met this objective
	3. Footprint	Size of extinguisher shall be no larger than the 20-gallon CB extinguisher previously fielded	Each unit tested met this objective
	4. Weight	Ability for the systems to be moved and/or deployed by typical personnel on the flightline	Each unit tested met this objective
Qualitative	1. EPA approved	Approved under the U.S. EPA SNAP Program as a streaming agent replacement for Halon	Each unit tested met this objective
	2. Materials compatibility	Clean agent as defined in NFPA	Each unit tested met this objective
	3. Commercially available	Sold commercially as a fire extinguishing agent in streaming and/or flooding applications	Each unit met this objective, but in each case unit was a prototype and is not sold commercially
	4. Environmental	Not an ozone depleter Climate change considerations Reduce non-fire and emergency emissions from servicing	Halotron I is a Class II ODS due to be phased out in 2015; units containing Halotron I do not meet this requirement
	5. Occupational Health	Agent does not create new safety or occupational health risks	All units tested met this requirement

3.2 SELECTING TEST PLATFORMS/FACILITIES

The test facility was located at AFRL Test Site 1, Tyndall AFB. The test fixture conformed to the design specification in Reference 3. More detailed information on the fixture is provided in Section 3.12.

3.3 TEST PLATFORM/FACILITY HISTORY/CHARACTERISTICS

For more than 15 years the test facility, fixture, and protocol had been used to evaluate candidate agents for Halon 1211 replacements.

3.4 AGENTS SELECTED FOR TESTING

In addition to SNAP listing and commercial availability (see 1.2), other criteria used in selecting candidate agents for testing were as follows:

- Agent had to be “clean” (leave no residue and be electrically non-conductive) as defined in National Fire Protection Association (NFPA) 2001 and UL 2129.
- Agent could not be a Class I ozone depleting substance (ODS), and preferably not a Class II ODS either
- Agent Atmospheric Lifetime must be less than 250 years
- Agent 100-yr Global Warming Potential must be less than 10,000
- Agent could not increase safety or occupational health risks
- Agent had to possess known effectiveness on both Class A and B fires
- Agent had to demonstrate an effective throw range of no less than 25 feet

The following agents met the criteria listed above:

- HFC-236fa (DuPont trade name “FE-36”)
- FK-5-1-12 (3M Company trade name “NOVEC 1230”)
- HCFC Blend B (American Pacific Corp trade name “Halotron I”)

NOVEC 1230 has not yet been tested. The manufacturer requested additional time to optimize the design of the proposed dispensing hardware. If this agent is tested in the future it will be reported separately.

Halotron I does not strictly meet all of the selection criteria. A minor constituent of the blend is CF_4, a perfluorocarbon (PFC), which has an atmospheric lifetime of 50,000 years. In addition, its main constituent, HCFC-123, is a Class II ODS subject to a Clean Air Act mandatory use phase-out by 2015. It was accepted for testing for three reasons: (1) it is currently approved by FAA for use at commercial airports and has gained wide acceptance for that application, (2) the manufacturer has initiated a dialogue with the EPA in hopes of getting relief from the mandatory phase-out, and (3) the manufacturer is pursuing replacement of the PFC component with an acceptable substitute gas. The manufacturer submitted his agent for testing with the understanding that based on the current formulation and the existing phase-out rules for Class II ODS, the agent is unlikely to be deemed acceptable by DOD.

3.5 AGENT/HARDWARE COMBINATIONS

FE-36 was submitted for testing using dispensing hardware manufactured by Ansul Inc., a subsidiary of Tyco International. Halotron I was submitted for testing using dispensing hardware from two different manufacturers: Buckeye Fire Equipment Company and Amerex Corp. Accordingly, the agent/hardware combinations are referred to in this report as FE-36/Ansul, Halotron/Buckeye, and Halotron/Amerex. Table 3-2 is a comparison of agent specifications, and Table-3-3 is a comparison of hardware specifications. Figures 3-1 through 3-3 depict the three agent/hardware combinations that were tested.

TABLE 3-2. Agent Specifications.

Specification	FE-36	Halotron I
Trade Name	FE-36	Halotron I
Manufacturer	DuPont	American Pacific Corporation
Chemical Formula	$CF_3CH_2CF_3$	$C_2HCl_2F_3$ (98% of blend), CF_4, Argon
Chemical Name	1,1,1,2,3,3,3 Hexafluoropropane	
Halocarbon Name	HFC-236fa	HCFC-123
EPA SNAP Approval	Flooding and Streaming	Streaming (“HCFC Blend B”)
Molecular Weight	152	150.7
Boiling Point @ 1 atm	29.5°F	80.6°F
Liquid Density	84.9 lb/ft^3 @ 77°F	92.3 lb/ft^3 @ 77°F
Vapor Pressure	39.5 psia @ 77°F	109.7 psia @ 77°F
Heat of Vaporization	69 BTU/lb @ boiling point	TBD
Cup Burner	6.3%	6-7%
NOAEL	10%	1%
LOAEL	15%	2%
ODP	0	0.014
GWP	6,300 (100 yr, CO_2 = 1)	120 (100 yr, CO_2 = 1) (based on HCFC-123)
Atmospheric Lifetime	209 years	3.5-11 years

TABLE 3-3. Hardware Specifications.

Specification	Ansul	Buckeye	Amerex
Manufacturer	Ansul/Tyco, Marinette, WI	Buckeye Fire Equipment, Kings Mountain, NC	Amerex Corporation, Trussville, AL
Manufacturer's Designation	FE-300 Prototype	W-150 Halotron	Halotron I Model 674
UL Rating	None	10A:80BC	10A:80BC
Maximum Height	58 inches	63 inches	62 inches
Net Agent Weight	260 lbs	150 lbs	150 lbs
Gross System Wt.	545 lbs	388 lbs	388 lbs
Agent Tank Diam.	16 inches	14 inches	16 inches
Agent Tank Height	36 inches	50 inches	42 inches
Agent Tank Volume		6500 $inches^3$	7450 $inches^3$
Agent Tank Type	DOT 4BW450 (900 psi hydro every 10 years)	DOT 4BW240	DOT 4BW500
Agent Tank Test Pressure		480 psi	480 psi
Agent Tank Burst Pressure		1200 psi minimum	1200 psi minimum
Agent Tank Fill Ratio		43%	37%
Nominal Discharge Time		23 seconds	38 seconds
Tires	Solid rubber, 15 inches diameter	Rubber, Semi-pneumatic, 15 inches diameter	Rubber, Semi-pneumatic, 16 inches diameter
Propelling Gas	Nitrogen (external N_2 Tank)	Argon, stored pressure	Argon, stored pressure
Regulator Pressure Setting	Nitrogen Cylinder: 23 ft^3, 2500 psi normal charge		
Charging Pressure	140 psi at regulator, 120 - 125 psi in agent tank	125psi	125psi
Hose	50 ft, 0.75-inch diameter	40 ft, 1-inch diameter	50 ft, 0.75-inch diameter
Nozzle Barrel	3.25 inch cylindrical barrel, 8.5 inches long	5.5-inch tapered barrel	5.5-inch tapered barrel
Nozzle Type	Pistol grip w/bale handle	Bale handle, no pistol grip	Bale handle, no pistol grip
Internal Nozzle Orifice	0.6 inch	0.63 inch	0.63 inch
Nominal Flow Rate	5 - 7 lbs/sec	5.5 lbs/sec	4 lbs/sec

FIGURE 3-1. Ansul's FE-300 Prototype Dispensing System.

FIGURE 3-2. Buckeye's W-150 Halotron I Dispensing System.

FIGURE 3-3. Amerex's Halotron I Model 674 Dispensing System.

3.6 FACILITY OPERATIONS

The facility was test operated by the AFRL Manufacturing Directorate, Expeditionary Technologies Division (MLQD), Air Base Technologies Branch for R&D experiments in the area of firefighting technology.

3.7 PRE-DEMONSTRATION TESTING AND ANALYSIS

AFRL/MLQD conducted extensive evaluations of Halon 1211 performance during Fiscal Year (FY) 02 to characterize the performance of the Halon 1211, 150-pound, flightline fire extinguisher and to develop metrics for selecting alternative extinguishers that would provide equivalent levels of protection for flightline operations. The Air Force Civil Engineering Fire Panel and the Fire Chief of the Air Force evaluated the results and supported publication of the Minimum Performance Requirement.

3.8 TESTING AND EVALUATION PLAN

3.8.1 Demonstration Test Setup and Start-Up

The test facility was an established RDT&E site for conducting the demonstration of flightline extinguisher and agent performance.

3.8.2 Period of Operation

Testing was conducted during October 2007.

3.8.3 Demobilization

Excess extinguishing agents were returned to their manufacturers for use or disposal.

3.8.4 Health and Safety Plan

The test facility complied with all local, state, federal, DOD, and USAF requirements for the required evaluations. Individual test plans were reviewed and signed by the designated AFRL/MLQ Safety Officer.

3.9 SELECTION OF ANALYTICAL/TESTING METHODS

Each agent/delivery hardware configuration was evaluated by conducting firefighting tests using the F-100 engine nacelle test fixture at Tyndall Air Force Base. This simulator is discussed in detail in Appendix A. The use of a fire test apparatus, such as the F-100 engine nacelle test fixture, is the standard methodology used within the Air

Force and Navy for evaluating firefighting performance of agents and delivery hardware. Performance of agent/delivery hardware was judged by its ability to extinguish the test fire.

3.10 MANAGEMENT AND STAFFING

Mr. Les Bowman from the Naval Air Warfare Center Weapons Division (NAWCWD), China Lake, California, maintained overall responsibility for project coordination and execution. He also acted as the quality control point for the project. Additionally, each service assigned representatives to the project. Mr. Sherman Forbes and Mr. Ken Dormer, Office of Secretary of the Air Force (AQRE), coordinated and managed Air Force activities undertaken during the project. Air Force activities included support of project planning, scheduling, and testing. Mr. Ross Davidson coordinated and managed Navy participation in the project. Mr. Peter Mullenhard of Science Applications International Corporation (SAIC) provided project support and coordinated team efforts with interested parties within the Navy environmental community.

Testing activities were managed and coordinated by Mr. Virgil Carr at Tyndall AFB with support from Dr. Doug Dierdorf and Mr. John Hawk with Applied Research Associates, Inc. Applied Research Associates, Inc. (ARA) also participated in the planning aspects of the project. Mr. Robert Darwin and Dr. Dan Verdonik of Hughes Associates, Inc. (HAI) provided project support throughout the project and supported collection, analysis, and reporting of testing conducted during the project. See Figure 3-4.

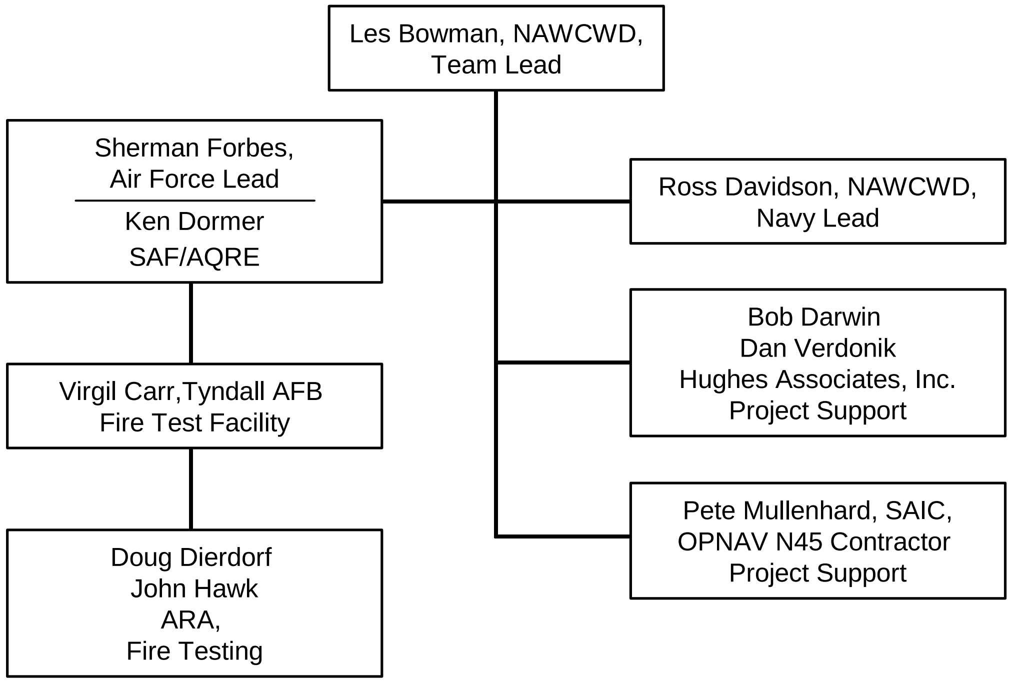

FIGURE 3-4. Management and Staffing.

3.11 DEMONSTRATION SCHEDULE

Figure 3-5 is a schedule of milestones.

3.12 TESTING AND EVALUATION

Testing and evaluation included both the Fire Test and the Stream-Reach Test.

3.12.1 Fire Test

3.12.1.1 Number of Tests. The original plan was to run a total of ten fire tests for each candidate agent/hardware combination. There was one repeat test for each series due to concern that the wind was excessive (greater than 8 mph) or blowing in the wrong direction (a crosswind more than +/- 30 degrees from the fixture centerline).

3.12.1.2 Fire Test Fixture. The F-100 Engine-Nacelle Test Fixture is described in detail in References 3 and 6. Figures 3-6 through 3-8 show photos and drawings of the fixture.

Review of Program Goals and Status	2006		2007												2008		
	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Task I: Refined Capabilities																	
Development of required capabilities (each service)	■	■	■														
Coordination and documentation of joint required capabilities		■	■	■													
Agent evaluation				■	■												
Agent down selection					■	■	■										
Task II: Agent/Delivery System Testing																	
Test Preparation (including finalization of joint test protocol)							■	■	■								
Agent/delivery system testing and Tyndall AFB									■	■	■	■					
Task III: Data Evaluation and Reporting																	
Data Analysis												■	■	■			
Report Documentation														■	■	■	■

FIGURE 3-5. Milestones.

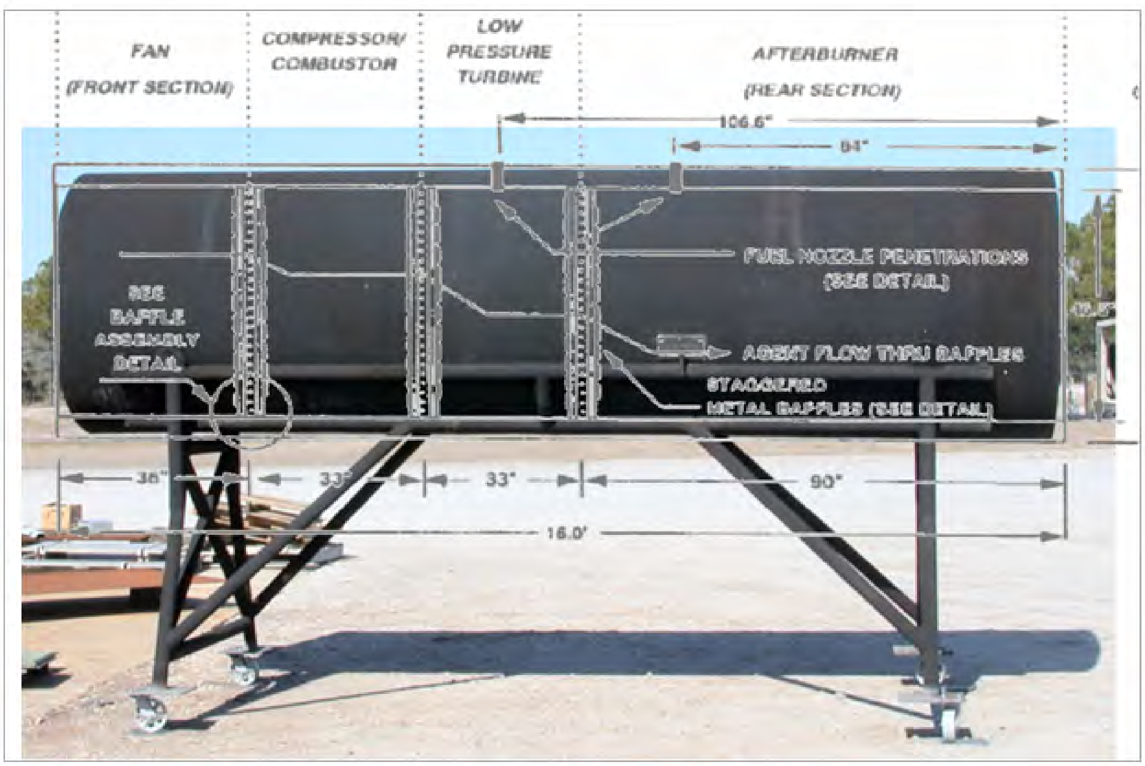

FIGURE 3-6. Side View of Test Fixture. Fire was attacked from the right side in this view.

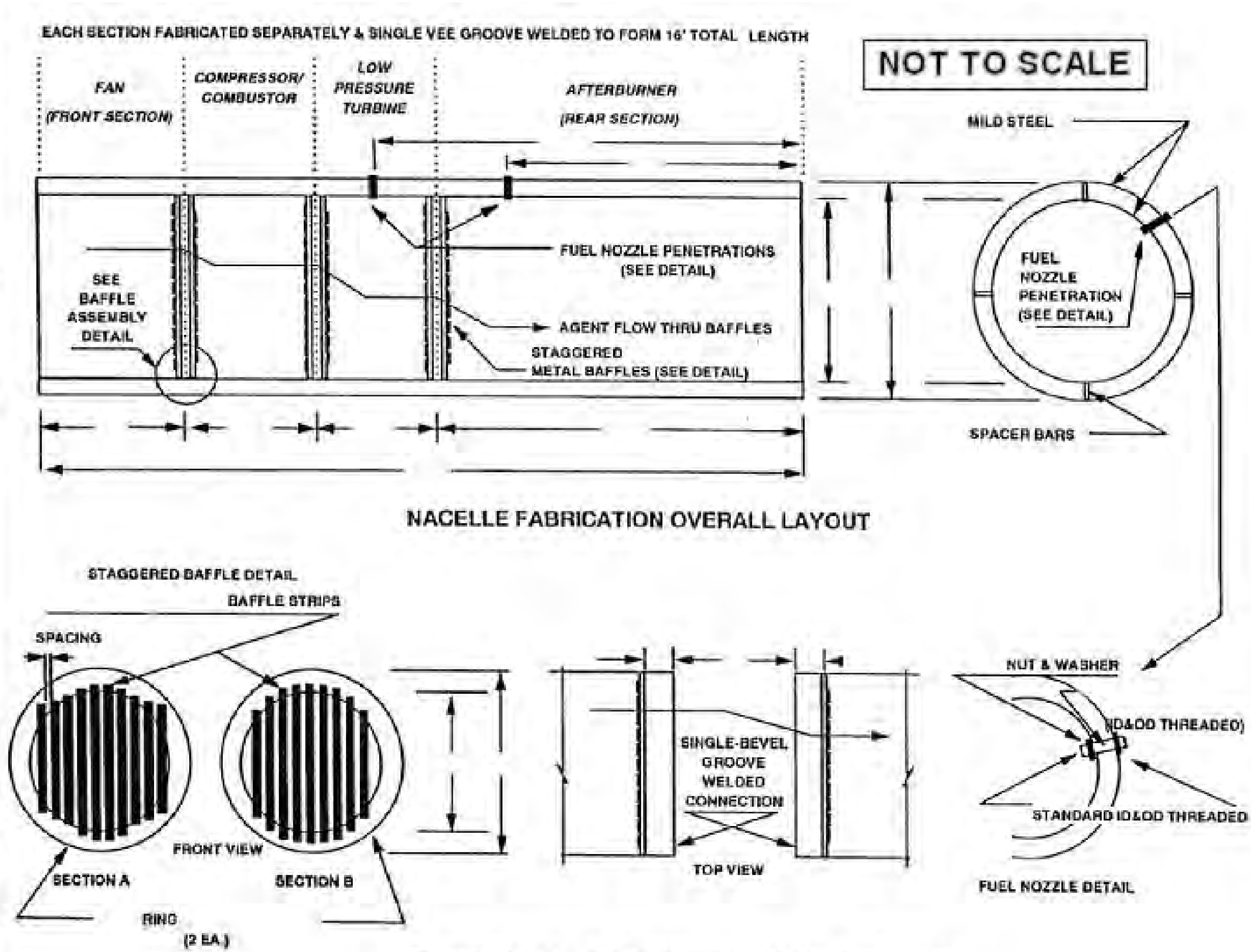

FIGURE 3-7. F-100 Engine-Nacelle Test Fixture; Fabrication Drawing.

FIGURE 3-8. End View of Test Fixture.
Fire was attacked from this side.

The overall length was 16 feet. The diameter of the outermost tube was 51 inches, which was only 5 inches greater than the diameter of the inner tube. The centerline of the fixture was approximately 69 inches above the ground. Three baffles were installed as shown. The closest baffle was 90 inches from the end from which the fire was attacked. Figure 3-9 shows a close-up view of the baffle.

FIGURE 3-9. Baffle Detail.
Two-inch stainless steel strips alternate in two layers 4 inches apart.

For these tests, fuel flowed into the fixture from two different fuel nozzles. The fuel nozzle that sprayed into the Low-Pressure Turbine section was designated as Fuel Nozzle 2. The fuel nozzle that sprayed into the afterburner section was designated as Fuel Nozzle 3. Figure 3-10 shows the location of Fuel Nozzle 3. During a test, JP-8 fuel flowed from each of the fuel nozzles at a nominal flow rate of 2 gpm.

FIGURE 3-10. Sample Nozzle Location.
The hole adjacent to the baffle is the position of the #3 fuel spray nozzle.

Figure 3-11 shows the fire threat presented by the fixture for these tests. This photo was taken just prior to an extinguishment attempt. As can be seen, there are essentially three simultaneous fires: the spray fire within the tube, the burning fuel flowing out of the tailpipe, and a pool fire of approximately 100 sq. ft.

FIGURE 3-11. Test Fixture in Operation.

3.12.1.3 Required Equipment and Supplies. The list below contains required equipment and supplies, while Appendix B contains a list of instrumentation used.

(1) Concave concrete test surface: 11 feet in diameter, center 3 inches lower than rim

(2) F-100 test fixture (see Figure (A-7))

(3) Handheld IR thermometer

(4) 50 gallons of JP-8 fuel per test fire

(5) Fuel pump with sufficient capacity to supply 4-gpm JP-8 with test nozzles 2 and 3 open (2-gpm each)

(6) Charged test extinguisher

(7) Cleanup equipment appropriate for test extinguisher

(8) Scale suitable for weighing the extinguisher before and after each test

(9) A load cell with data-recording capability to continuously measure and record extinguisher weight during agent discharge (Note: loss of this measurement capability will not necessarily cause stoppage of the test program. Testing without a load cell will continue at the discretion of the AFRL Test Director.)

(10) Video cameras to record all tests

3.12.1.4 Fire Test Procedure. The following procedure was followed for each evolution:

Pretest Phase

a. Determine and record extinguisher full weight

b. Turn on load-cell data acquisition computer

c. Start video cameras

d. Ignite low-pressure turbine fuel nozzle (Nozzle 2) fuel spray (JP-8, 1.0 +/- 0.25 gpm)

e. Heat tailpipe to 550 ± 25°F

f. Shut off fuel

g. Allow metal to cool to 475 ± 25°F

h. Initiate fuel flow through Nozzles 2 and 3 (4.0 +/- 0.25 gpm total)

i. Flow 25 gallons of JP-8 through the fixture into the concrete pan

j. If spontaneous ignition occurs, shut off fuel and allow metal to cool to a lower temperature. Return to item f.

Test Phase

a. Ignite low-pressure turbine and afterburner fuel sprays with a suitable torch applied through the ignition port or from the tailpipe (2 gpm each)

b. Ignite fuel in the concrete pan

c. Allow to burn for 15 seconds

d. Apply fire extinguisher according to manufacturer's instructions

f. Stop fuel flow when fire is out or extinguisher is expended

g. Shut off video cameras

h. Weigh extinguisher after test

i. Record time to extinguish

j. Record weight of agent used

k. Shut off load-cell computer

3.12.1.5 Personnel/Safety. The same firefighter was used for all tests. He wore full protective clothing (standard DOD crash firefighter's reflective proximity gear) and a self-contained breathing apparatus.

3.12.2 Stream-Reach Test

Stream-reach was determined based on the ability to extinguish small fires at given distances. Testing was conducted indoors with no perceptible ambient wind. Agent discharge was from a fixed location, but nozzle elevation during discharge was permitted. Four small steel cups (approximately three inches in diameter and two inches tall) were placed on level ground at measured distances of 20, 25, 30, and 35 feet from the agent discharge nozzle. Each cup was filled with 0.5 inches of JP-8 floated on one inch of water. After a pre-burn period of at least 15 seconds for the last cup ignited, agent was discharged from the nozzle, held at hip height, in an attempt to extinguish as many cups as possible.

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE CRITERIA

Table 4-1 lists the performance criteria for an alternative to the Halon 1211 fire extinguisher.

TABLE 4-1. Performance Criteria.

Performance Criteria	Description	Primary or Secondary
Standoff distance for personnel in normal flightline gear to fight the fires	Effective throw range 25 ft or more with no wind (meets pain threshold for exposed skin for 15 (to 20) s, which is approximately half of the anticipated discharge duration of the extinguisher.	Primary
Firefighting effectiveness	Extinguishes fire in the JTP at least 3 out of 5 times in 30 s or less using: a) for an extinguishing system, no more than 75% of the agent capacity of the extinguisher or b) for agent only, no more than 285 lb of agent (based on percentage of agent weight versus whole system weight (51%) for 20-gal CB extinguisher and requirement to use 75% or less of agent in the system.	Primary
EPA approved	Approved under the U.S. EPA SNAP Program as a streaming agent replacement for Halon 1211 with no significant restrictions for use in industrial and military applications.	Primary
Materials compatibility	Clean agent as defined in NFPA 2001, “Electrically non-conducting, volatile, or gaseous fire extinguishant that does not leave a residue upon evaporation, and meets the following chemical quality requirements: Mole percent, 99.0 min; Acidity, ppm (by wt HCl equivalent), 3.0 max; Water content, wt %, 0.001 max; Nonvolatile residues, grams/100 mL, 0.05 max	Primary
Commercially available	Sold commercially as a fire extinguishing agent in streaming and/or flooding applications.	Primary
Environmental (part a)	Not considered to be an ozone depleter by U.S. EPA. All constituents of the agent shall have: Global Warming Potential (100-yr) < 10,000 Atmospheric Lifetime (e-folding) < 250 years	Primary
Occupational Health	Agent does not create new safety or occupational health risks, per USAF Instruction (AFI) 32-7086 of 1 Nov 04.	Primary

TABLE 4-1. (Contd.)

Performance Criteria	Description	Primary or Secondary
Footprint	The overall height of the extinguisher in the upright position shall not exceed 60 in. The width of the extinguisher across the wheels shall not exceed 40 in. and the width across the cylinder and hose box shall not exceed 47 in.	Secondary
Weight	Ability for the systems to be moved and/or deployed by typical personnel on the flightline. For systems: agent, carriage, and hardware max wt is 750 lb (based on best estimate of max wt from MIL-STD-1472F, Design Criteria Standard, Human Engineering, Table XVIII, for a high traction surface using two hands or one shoulder or the back, a typical male can push 70 lb in order to set an object in motion. The typical value for a female is 2/3 the male value (46.6 lb, rounded up to 47 lb). For a coefficient of friction of one, and 16-in. tires, the max wt is estimated to be 750 lb. For a most reasonable, worst case scenario of a 2% grade and a coefficient of friction of 1.37 (low air, rough surface, etc.) a 750-lb system with 24-in. wheels can still be set in motion at 47 lb. For agent only candidates: max wt is 285 lb.	Secondary
Environmental (Part b)	Agent can be recovered in the field and recovered material is recyclable directly into usable agent using a machine similar to Halon 1301 Recovery/Recycle machine.	Secondary

4.2 PERFORMANCE CONFIRMATION METHODS

The performance of the agents/delivery systems tested during this project was evaluated by experienced Air Force and Navy firefighting personnel. Performance criteria used to evaluate agents and hardware are shown in Table 4-1. The primary metric for each test was the ability of the systems being tested to extinguish the simulator fire. The criterion established in Table 4-1 for firefighting performance required that the simulator fire be extinguished in 3 out of 5 tests, or in 60 percent of the tests.

Additionally, firefighting extinguishers were required to demonstrate a stream reach of 25 feet in order to be acceptable for flightline usage.

Many of the performance metrics discussed in Table 4-1 are related to required capabilities other than firefighting performance. Several of these metrics relate to human factors and logistics of the systems. These metrics were applied after completion of testing and review of test data to provide an indication of suitability of use of equipment by "typical" personnel on the flightline. The performance criteria include footprint and ease of handling by the firefighters. Other criteria were evaluated during the down-selection process to determine which agents and delivery systems would be tested. Agents had to be on the SNAP list and acceptable from the standpoint of human exposure and environment. Appendix C contains a copy of the Data Collection Sheet used for each test.

Fire fighting performance of agents and delivery systems tested is shown in Table 4-2.

TABLE 4-2. Expected Performance and Performance Confirmation Methods.

Performance Criteria	Expected Performance Metric (pre demo)	Performance Confirmation Method	Actual Performance (post demo)
Primary Criteria (Performance Objectives) (Quantitative)			
Provide needed standoff distance for personnel in normal flightline gear to fight the fires	Effective throw range 25 ft or more with no wind (meets pain threshold for exposed skin for 15 (to 20) s, which is approximately half of the anticipated discharge duration of the extinguisher.	Test in the JTP	All units tested met this requirement
Firefighting effectiveness	Extinguishes fire in the JTP at least 3 out of 5 times in 30 s or less using: a) for an extinguishing system, no more than 75% of the agent capacity of the extinguisher or b) for agent only, no more than 285 lb of agent (based on percentage of agent weight versus whole system weight (51%) for 20-gal CB extinguisher and requirement to use 75% or less of agent in the system.	Test in the JTP	None of the units tested met this requirement

TABLE 4-2. (Contd.)

Performance Criteria	**Expected Performance Metric (pre demo)**	**Performance Confirmation Method**	**Actual Performance (post demo)**
Primary Criteria (Performance Objectives) (Qualitative)			
EPA approved	Approved under the U.S. EPA SNAP Program as a streaming agent replacement for Halon 1211 with no significant restrictions for use in industrial and military applications.	SNAP listing	All units tested met this requirement
Materials compatibility	Clean agent as defined in NFPA 2001, "Electrically non-conducting, volatile, or gaseous fire extinguishant that does not leave a residue upon evaporation and meets the following chemical quality requirements: Mole percent, 99.0 min; Acidity, ppm (by wt HCI equivalent), 3.0 max; Water content, wt %, 0.001 max; Nonvolatile residues, grams/100 mL, 0.05 max	Listing in NFPA 2001	All units tested met this requirement
Commercially available	Sold commercially as a fire extinguishing agent in streaming and/or flooding applications.	Published listing by UL	All units tested met this requirement
Environmental (Part a)	Not considered to be an ozone depleter by U.S. EPA. All constituents of the agent shall have: GWP (100-yr) < 10,000 Atmospheric Life < 250 years As verified from one of the following sources: The Scientific Assessment of Ozone Depletion, *2002,* World Meteorological Organization (WMO) Climate Change *2001, IPCC* Climate Change *2007, IPCC Safeguarding the Ozone Layer and the Climate System, IPCC/TEAP* Data provided by U.S. EPA as accepted (or acceptable) for SNAP	Published data from cited references only	Halotron I does not meet this requirement. It is considered a Class II ODS subject to mandatory EPA phase-out in 2015. FE-36 met this requirement.
Occupational Health	Agent does not create new safety or occupational health risks, per USAF Instruction (AFI) 32-7086 of 1 Nov 04, as measured by the ratio of the NOAEL* divided by the n-heptane cupburner extinguishing concentration shall be ≥ 0.15.	Published data	All units tested met this requirement.

*NOAEL = No observed adverse effect level.

TABLE 4-2. (Contd.)

Performance Criteria	**Expected Performance Metric (pre demo)**	**Performance Confirmation Method**	**Actual Performance (post demo)**
Secondary Criteria (Performance Objectives) (Quantitative)			
Footprint	The overall height of the extinguisher in the upright position shall not exceed 60 in. The width of the extinguisher across the wheels shall not exceed 40 in. and the width across the cylinder and hose box shall not exceed 47 in.	Measurements	Halotron extingiushers tested did not meet this requirement. The Ansul extinguisher with FE-36 did meet this requirement.
Ability for the systems to be moved and/or deployed by typical personnel on the flightline (weight of system)	For systems: agent, carriage, and hardware maximum weight is 750 lb (based on best estimate of max wt from MIL-STD-1472F, Design Criteria Standard, Human Engineering, Table XVIII, for a high traction surface using two hands or one shoulder or the back, a typical male can push 70 lb in order to set an object in motion. The typical value for a female is 2/3 the male value (46.6 lb, rounded up to 47 lb). For a coefficient of friction of one, and 16-in. tires, the max wt is estimated to be 750 lb. For a most reasonable, worst case scenario of a 2% grade and a coefficient of friction of 1.37 (low air, rough surface, etc.) a 750-lb system with 24-in. wheels can still be set in motion at 47 lb. For agent only candidates: max wet is 285 lb.	Weight	All units tested met this requirement.
Secondary Criteria (Performance Objectives) (Qualitative)			
Environmental (Part b) Reduce non-fire / emergency emissions from servicing	Agent can be recovered in the field and is recyclable directly into usable agent using a machine similar to Halon 1301 Recovery/Recycle machine.	Published data	FE-36 meets this requirement. Halotron I is recoverable, but because it is a chemical blend, recycling may be problematic.

4.2.1 Fire Test Performance

Figure 4-1 shows a typical successful extinguishment. First the pool fire is pushed back beyond the end of the fixture, past the running fuel. Next the running fuel is extinguished and pushed back into the fixture while agent continues to flow into the fixture putting out the internal spray fires. Once the interior fire is extinguished the agent stream is brought back down to put out the remaining pool fire. Fuel flow is shut off when fire is extinguished.

(a) Pool fire extinguished beyond running fuel fire.

(b) Running fuel fire extinguished and agent directed into fixture.

(c) After internal fires are out, remaining pool fire is extinguished.

FIGURE 4-1. Typical Successful Extinguishment.

4.2.2 Stream-Reach Test Performance

A typical stream-reach test is shown in Figure 4-2. In this figure the extinguisher was out of view to the right. The last cup being ignited in the center photo is 35 feet from the extinguisher nozzle. The photo on the right shows the most distant cups shortly after discharge. Stream-reach in this case was judged to be at least 35 feet.

(a) Fuel cup.

(b) Four cups ignited.

FIGURE 4-2. Typical Stream-Reach Test.

(c) Cup extinguished.

FIGURE 4-2. (Contd.)

4.3 TEST RESULTS

4.3.1 Fire Test Results

Overall a total of 30 valid fire tests were conducted with the three agent/hardware combinations. The fire was extinguished in 10 of the 30 attempts.

4.3.1.1 FE-36/Ansul Results. The test fixture was successfully extinguished on four tests (2, 3, 4 and 8). Since Test 1 had wind conditions outside the protocol limits, the overall success rate was four out of ten. Summary data is shown in Table 4-3.

4.3.1.2 Halotron/Buckeye Results. The test fixture was successfully extinguished on three tests (6, 7, and 11). Since Test 5 had wind conditions outside the protocol limits, the overall success rate was three out of ten. Summary data is shown in Table 4-4.

TABLE 4-3. Summary of Data – FE-36/Ansul
2-4 October 2007 Tyndall AFB.

Test No.	See Note	Wind Speed (mph)	Air Temp (°F)	Ext Time (secs)	Disch Time (secs)	Quantity Discharged (lbs)	Aver Flow Rate (lbs/sec)
1	1	4-10	88	NA	46	249	5.4
2	2	3-5	78	23	30	207	6.9
3		3-5	81	20	29	192	6.6
4		4-7	81	17	27	180	6.7
5		4-7	82	NA	44	248	5.6
6		3-7	90	NA	44	236	5.4
7		3-4	92	NA	42	241	5.7
8	3	3-5	75	19	27	188	7.0
9		4-6	76	NA	40	243	6.1
10	4	3-7	82	NA	41	242	5.9
11	5	3-7	86	NA	41	241	5.9

Notes:
(1) Wind direction 90 degrees from fixture centerline (considered as invalid test)
(2) Small amount burning fuel noticed flowing out opposite end. Placed 1-inch board under legs at opposite end for remainder of tests.
(3) Fuel temp: 81°F. Regulated pressure in agent tank increased from 120 psi to 140 psi for Tests 8 and 9
(4) Fuel temp: 90° F
(5) Fuel temp: 97° F (only measured fuel temp three times)

TABLE 4-4. Summary of Data – Halotron/Buckeye
10-12 October 2007 Tyndall AFB.

Test No.	Wind Speed (mph)	Air Temp (°F)	Ext Time (secs)	Disch Time (secs)	Quantity Discharged (lbs)	Aver Flow Rate (lbs/sec)
1	2-5	74	NA	29	130	4.5
2	1-4	78	NA	29	129	4.4
3	1-3	79	NA	28	128	4.6
4	1-7	82	NA	27	130	4.8
5[1]	1-8	84	NA	30	130	4.3
6	0-3	68	21	29	131	4.5
7	1-6	70	16	22	129	5.8
8	3-4	77	NA	27	129	4.8
9	3-8	79	NA	27	131	4.9
10	3-7	82	NA	28	131	4.7
11	1-3	57	20	27	127	4.7

Note 1: In Test 5 wind direction was 90 degrees from fixture centerline (considered as invalid test).

Two additional tests, not part of the official protocol tests, were run to observe any possible effect of increasing the agent quantity from 150 to 190 pounds (corresponding to an increase in fill ratio from 43 percent to 54 percent). In the first additional test the pressure was kept at 125 psi. In the second additional test the pressure was increased to 150 psi. Data from the two additional tests are shown in Table 4-5.

TABLE 4-5. Additional Tests – Agent Quantity Increased to 190 Lbs.

Tank Pressure (psi)	Wind Speed (mph)	Air Temp (°F)	Ext Time (secs)	Disch Time (secs)	Quantity Discharged (lbs)	Avg Flow Rate (lbs/sec)
125	1-4	62	19	45	173	3.8
150	2-6	75	NA	37	167	4.5

4.3.1.3 Halotron/Amerex Results. The test fixture was successfully extinguished on three tests (1, 2, and 11). Since Test 6 had wind conditions slightly outside the protocol limits, the overall success rate was three out of ten. Summary data is shown below in Table 4-6.

TABLE 4-6. Summary of Data – Halotron/Amerex
16-18 October 2007 Tyndall AFB.

Test No.	Wind Speed (mph)	Air Temp (°F)	Ext Time (secs)	Disch Time (secs)	Quantity Discharged (lbs)	Aver Flow Rate (lbs/sec)
1	0-3	72	44	45	136	3.02
2	0-6	73	17	20	89	4.45
3	0-3	76	NA	45	140	3.11
4	0-5	81	NA	44	138	3.14
5	2-6	82	NA	42	136	3.24
6[1]	8-10	86	NA	42	136	3.24
7	0-1	78	NA	42	136	3.24
8	2-5	80	NA	42	136	3.24
9	0-5	80	NA	44	135	3.06
10	3-7	80	NA	42	136	3.24
11	5-8	80	26	34	131	3.85

Note 1. In Test 6 wind velocity 8-10 mph (considered as invalid test).

4.3.1.4 Load-cell Data. The flow rates shown in the last column of Tables 4-3 through 4-6 represent average flow rates over the entire discharge time, having been calculated by dividing the total delivered agent quantity by the total discharge time.

The flow rate from a pressurized container will be much higher than the average at the start and then gradually decrease to the average. This is especially true of stored pressure extinguishers such as the Halotron/Buckeye of Halotron/Amerex units.

Each extinguisher was placed on a load cell during each test. The scan rate was two weight readings per second. The load-cell data, as shown in Table 4-7 provides an accurate profile of the flow rate over time for each test in which the fire was successfully extinguished. The wide column in Table 4-7 shows the average agent flow rate for 5-second intervals for the first 25 seconds of discharge. The next to last column shows the average agent flow rate from the start of agent discharge until extinguishment was achieved. The final column shows the quantity of agent discharged up to the point of fire extinguishment.

TABLE 4-7. Load-cell Readings.

Agent/ Hardware	Test #	Ext Time (secs)	Avg Flow Rate in 5-Sec Intervals (0-5, 5-10, 10-15, 15-20, 20-25 secs) (lbs/sec)	Avg Flow Rate to Ext (lbs/sec)	Agent Quantity to Ext (lbs)
FE-36/ Ansul	2	23	6.2 - 6.2 - 6.2 - 6.2	6.2	144
	3	20	6.4 – 6.5 – 6.5 – 6.5	6.5	132
	4	17	6.4 – 6.5 – 6.5	6.5	111
	8	19	7.2 – 7.3 – 7.3	7.2	136
				Average =	131
Halo/ Buckeye	6	21	6.6 – 5.7 – 5.1 – 4.7	5.4	114
	7	16	6.9 – 6.0 – 5.4	5.7	92
	11	20	6.6 – 5.8 – 4.9 - 4.7	5.7	114
				Average =	107
Halo/ Amerex	1	44	5.0 – 4.2 – 3.9 – 3.5 – 3.4	3.1	135
	2	17	4.9 – 4.1 – 4.0	4.2	73
	11	26	4.2 – 4.0 – 4.0 – 3.6 – 3.3	3.8	100
				Average =	103

As would be expected with an externally pressurized extinguisher, such as the FE-36/Ansul unit, the flow rate remains essentially constant throughout the discharge. Note that, as indicated in the footnote under Table 4-3, the pressure in the agent tank was increased from 120 psi to 140 psi for Test 8, which accounts for the higher flow rate for that particular test.

As would be expected for stored pressure extinguishers, the flow rate for both the Halotron/Buckeye and Halotron/Amerex units decreases considerably over time. For example, in Halotron/Buckeye Test 6, the average flow rate for the first five seconds of discharge was 6.6 lbs/sec. This average flow rate decreased to 4.7 lbs/sec after 15 seconds of discharge.

The FE-36/Ansul unit extinguished four out of ten fires. For the four successes, the quantity required to achieve extinguishment averaged 131 lbs. The average agent flow rates up to the point of extinguishment varied from 6.2 to 7.2 lbs/sec. Extinguishment times varied from 17 to 23 seconds, for an average successful extinguishment time of 20 seconds.

The Halotron/Buckeye unit extinguished three out of ten fires. For the three successes, the quantity required to achieve extinguishment averaged 107 lbs. The average agent flow rates up to the point of extinguishment varied from 5.4 to 5.7 lbs/sec. Extinguishment times varied from 16 to 21 seconds, for an average successful extinguishment time of 19 seconds.

The Halotron/Amerex unit extinguished three out of ten fires. For the three successes, the quantity required to achieve extinguishment averaged 103 lbs. The average agent flow rates up to the point of extinguishment varied from 3.1 to 4.2 lbs/sec. Extinguishment times varied from 17 to 44 seconds, for an average successful extinguishment time of 29 seconds.

4.3.1.5 Relevance of Ambient Air and Fuel Temperatures. As testing progressed it became apparent that there was a correlation between temperature (air, fuel, or both) and the likelihood of success.

During the first week of testing with FE-36/Ansul, the ambient air temperature ranged from 75 – 92°F. As indicated in Table 4-3 the median air temperature was about 81°F (of the ten valid tests there were five run above 81°F and five at 81°F or lower). Of the four successes, none occurred when the air temperature was above 81°F. This trend continued throughout the testing.

FE-36/Ansul extinguished no fires at ambient temperatures above 81°F. Halotron/Buckeye extinguished no fires at ambient temperatures above 70°F. Halotron/Amerex extinguished no fires at ambient temperatures above 80°F.

Because of concerns about the possible relationship between ambient air temperature, fuel temperature, and difficulty of extinguishment, it was decided to take additional temperature readings during Tests 1 through 10 of the Halotron/Amerex test series.

Fuel temperatures during testing with Halotron/Amerex were measured as follows:

- At the fuel-flow meter at the end of the fixture heat-up period. Since the meter was at the end of 35 feet of 1.25-inch hose coming right off the fuel pump, this would essentially measure the fuel temperature in the bottom of the fuel tank.

- At the fuel-flow meter at approximately 2 minutes prior to ignition.

- In the fuel outflow as it fell from the nacelle into the pool approximately 1 minute prior to ignition. This would show how the fuel is heated by the warm fixture and perhaps the warm fuel piping near the fixture.

In addition, an infrared (IR) handheld thermometer was used to measure the surface temperature of the inside of the nacelle approximately 1 minute prior to ignition. The same reference point was used each time: at the mid-height point halfway between the end of the nacelle and the first baffle.

Temperature readings are shown in Table 4-8.

TABLE 4-8. Temperature Readings During Halotron/Amerex Test Series.

Test No.	**Time Of Day**	**Air Temp (°F)**	**Fuel Temp (1) (°F)**	**Fuel Temp (2) (°F)**	**Fuel Temp (3) (°F)**
1[1]	0830	72	71	74	115
2[1]	1400	73	74	74	113
3	0830	76	72	77	133
4	0930	81	82	83	125
5	1015	82	84	86	132
6	1400	86	91	89	126
7	1045	78	79	79	139
8	1130	80	80	80	120
9	1215	80	81	81	122
10	1300	80	81	81	122

Note 1: Successful extinguishment (Tests 1 and 2)
Fuel Temp (1): Measured at flow meter at end of heat-up.
Fuel Temp (2): Measured at flow meter after 15 gals delivered to fixture (approximately 2 minutes prior to ignition).
Fuel Temp (3): Temp of fuel pouring from nacelle (approximately 1 minute prior to ignition).

The fuel temperature at the flow meter closely mimicked the air temperature and in some cases was even higher, probably due to solar heating of the fuel tank. It is also apparent that as fuel flows through the pre-heated fixture it is heated considerably: the temperature of the fuel pouring from the nacelle 1 minute prior to ignition ranged from 113 – 139°F. This is well above the minimum flash point of JP-8 (100°F) and is representative of fuel temperatures where rapid fuel vaporization would occur. Not surprisingly, the two extinguishment successes occurred when both the fuel pouring from the nacelle and the fixture temperatures were the lowest.

An increase in difficulty of extinguishment as fuel temperature increases has been documented in previous fire test reports. In 1992 the Naval Research Laboratory examined how fuel temperature affects the ability to extinguish JP-8 running fuel fires in the midst of simulated aircraft crash debris. For controlled tests where the fire could be extinguished in 30 seconds if the temperature of JP-8 was 100°F prior to ignition, the extinguishment time would almost double if the fuel was preheated to 120°F and more than double if the fuel was preheated to 140°F (Reference 6).

The conclusion of this discussion is that temperature does affect extinguishment due to the effect on the vaporization of fuel and the vaporization of the firefighting agents themselves. For physical-acting agents any alteration of the phase change from liquid to gas will in turn affect cooling and smothering. A detailed analysis of temperature effects is beyond the scope of this report. It is mentioned here so that temperature effects will be considered in any future testing of Halon alternatives.

4.3.1.6 Confirmation of Halon 1211 Baseline Performance. A few weeks after the testing of the alternative agents, the staff at AFRL obtained Halon 1211 and repeated the exact test sequence using the standard DOD 150-lb Halon 1211 flightline extinguisher. The goal was to confirm the previously reported baseline performance capability of Halon 1211 (Reference 7). A total of five fire tests were conducted using the same test fixture and same procedures as used with the alternatives. Testing was conducted only on days where the ambient temperatures would be similar to testing conducted on the alternative agents. The results with Halon 1211 are shown in Tables 4-9 and 4-10.

TABLE 4-9. Summary of Data – Halon 1211
23 Oct – 14 Nov 2007 Tyndall AFB.

Test No.	Air Temp (°F)	Ext Time (secs)	Disch Time (secs)	Quantity Discharged (lbs)	Aver Flow Rate (lbs/sec)
1	79	34	41	127	3.1
2	82	17	25	74	3.0
3	85	11	15	52	3.5
4	79	10	18	58	3.2
5	78	18	26	88	3.4

TABLE 4-10. Load-cell Readings – Halon 1211.

Test #	Ext Time (secs)	Avg Flow Rate in 5 Second Intervals 0-5, 5-10, 10-15, 15-20, 20-25 secs (lbs/sec)	Avg Flow Rate to Ext (lbs/sec)	Agent Quantity to Ext (lbs)
1	34	4.0 – 3.6 – 3.4 – 3.4- 3.2	3.3	112
2	17	3.6 – 3.1 – 3.0	3.1	53
3	11	3.9 – 3.4	3.6	40
4	10	3.8 – 3.3	3.6	36
5	18	3.9 – 3.7 – 3.5	3.6	64

The following summary of the results with Halon 1211 are derived from Tables 4-9 and 4-10:

- Fire tests were conducted at ambient temperatures of 79°, 82°, 85°, 79°, and 78°F.
- The fire was extinguished by Halon 1211 in five out of five attempts.
- The average quantity of Halon 1211 to achieve extinguishment was 61 pounds.
- The flow rate to achieve extinguishment varied from 3.1 to 3.6 lbs/sec.
- The average extinguishing time for the five tests was 18 seconds.

Note especially that Halon 1211 was successful in two out of two tests where the ambient temperature was above 81°F. None of the three alternative agent/hardware combinations extinguished any fires when the ambient temperature was that high (collective total of zero for nine when the temperature was above 81°F).

Table 4-11 compares Halon 1211 with the three alternative agent/hardware combinations based on success rate, average extinguishment time, average quantity to achieve extinguishment, and average flow rates for extinguishment.

TABLE 4-11. Performance Comparison of Halon 1211 to Alternatives.

Agent	Success Rate	Success Rate %	Average Ext Time (secs)	Average Quantity to Ext (lbs)	Average Flow Rate to Ext (lb/sec)
FE-36/Ansul	4/10	40	20	131 lbs	6.2 – 7.2
Halo/Buckeye	3/10	30	19	107 lbs	5.4 – 5.7
Halo/Amerex	3/10	30	29	103 lbs	3.1 – 4.2
Halon1211	5/5	100	18	61 lbs	3.1 – 3.6

The superiority of Halon 1211 is clearly shown in Table 4-9.

4.3.2 Stream-Reach Test Results

Stream-reach was determined based on the ability to extinguish small cups of JP-8 fuel. Testing was conducted indoors to eliminate any wind effects. Four fuel cups were positioned at 20, 25, 30, and 35 feet from the nozzle. In every test, the agent/hardware combinations described above were able to extinguish all four cups of burning fuel.

Accordingly, stream-reach is considered to be at least 35 feet in still air for each of the three agent/hardware combinations.

5.0 COST ASSESSMENT

5.1 COST REPORTING

The primary benefit of the project was to enable the USN and USAF to execute the orderly and economically feasible transition to the alternative fire suppressant before running out of Halon 1211; otherwise there would be direct mission impact to flightline fire safety. As such, the benefits were expected to be mainly cost avoidance and mission impact-avoidance.

There are currently approximately 20,000 flightline fire extinguishers in use by the USN and USAF. The unit cost for each existing extinguisher (including market value of recycled agent) is approximately $3,700. The cost of replacement units should be comparable to the Halon extinguisher. If the Halon alternative extinguisher is fielded quickly, Halon 1211 supplies should be sufficient to enable their replacement through attrition, as the service life of each Halon 1211 extinguisher expires. But the longer it takes to begin the transition, the greater the transition cost, because dwindling Halon 1211 supplies will require replacement of Halon 1211 equipment before its normal retirement cycle. For every year of delay, the USN and USAF estimate that approximately one-fifteenth of the existing inventory (approximately 1,300 of the 20,000 fire extinguishers in service) would have to be replaced out-of-cycle. This would increase transition costs by approximately $4.8 million for every year of delay. If implementation cost was delayed until Halon 1211 supplies ran out, ultimate transition costs could range toward $74 million.

An alternate approach would be to procure additional stocks of Halon 1211. Currently, Halon 1211 is in very short supply in the U.S. and is difficult to get in the quantities required to significantly delay the USN and USAF from running out. While there are excess quantities in other countries, particularly China, their import is very expensive (because of a U.S. excise tax applied to newly produced or imported Halon 1211). The tax rate is based on the stratospheric ozone depleting capability of the chemical and was originally set at $1.37 per ODP pound. The tax rate was increased to $5.35 per ODP pound for 1995 by the National Energy Policy Act of 1992. After 1995, the tax rate was set to increase by an additional $0.45 per year. The ODP of Halon 1211 set by the Montreal Protocol and the Clean Air Act is 3 (recent scientific evidence points to higher ODPs for halons but the “official” value of 3 is used for determining the excise tax). Therefore, the excise tax alone to import Halon 1211 in 2008 would be $33.60 per pound, and the minimum cost for 150 pounds of Halon would be over $5,000. The excise tax alone exceeds the anticipated cost of purchasing new systems—both hardware and agent—by more than a third, and that cost does not include the cost to purchase the used Halon, recycle it, and ship it to the U.S., or produce it new. Therefore the cost avoidance of fielding a non Halon system is even greater than the one-third lower cost of the excise tax alone.

5.2 COST ANALYSIS

Another cost consideration is the cost of the potential replacement agents per equivalency to Halon 1211. The current costs of the agents are approximately as follows:

(1) Halotron I: $7.50 per pound
(2) HFC-236fa: $7.50 per pound
(3) FK 5-1-12 1230: $10 per pound
(4) HFC-227ea: $8.00 to $8.50 per pound

It is important to consider the cost of the quantity of potential alternatives needed to replace the firefighting capability of the current 150-pound Halon 1211 extinguisher, rather than purely on a one-to-one per-pound basis. In addition, while there are currently no specific legal requirements to consider the potential impacts on climate change, it would behoove the U.S. military to also consider the potential future costs associated with using a high climate-change chemical versus a lower one. For example, the cost on a per-pound and/or system basis for HFC-236fa may be lower than for FK 5-1-12, but the Global Warming Potential (the ratio of the amount of global warming caused by a unit mass of the chemical versus CO_2, which is set to 1) of 6300 for HFC-23fa versus 1 for FK-5-1-12 may be well worth any difference in agent costs. It is also important to consider the potential trade-off of a small amount of ozone depletion from HCFC-123 in Halotron I with its smaller global warming impacts, than either HFC-236fa or HFC-227ea.

Finally, while not quantifiable by cost, another mission benefit of the successful completion of the project would have been the entire elimination of potential mission risks concerning overseas operations in countries such as the EU nations that have more aggressive ozone depleting substance regulations than either the international or the U.S. standard. In the future, Halon 1211 supply of and transportation among U.S. military activities in foreign countries could become more challenging due to these more aggressive restrictions. With a proven, acceptable alternative to Halon 1211, interoperability with NATO allies on flightline fire protection would also be enhanced.

6.0 IMPLEMENTATION ISSUES

6.1 ENVIRONMENTAL PERMITS

There were no environmental regulations that applied to the demonstration and no permits were required.

6.2 OTHER REGULATORY ISSUES

Halotron I does not strictly meet all of the selection criteria. A minor constituent of the blend is CF_4, a perfluorocarbon (PFC), which has an atmospheric lifetime of 50,000 years. In addition, its main constituent, HCFC-123, is a Class II ODS subject to a Clean Air Act mandatory use phase-out by 2015. It was accepted for testing for three reasons: (1) it is currently approved by FAA for use at commercial airports and has gained wide acceptance for that application, (2) the manufacturer has initiated a dialogue with the EPA in hopes of getting relief from the mandatory phase-out, and (3) the manufacturer is pursuing replacement of the PFC component with an acceptable substitute gas. The manufacturer submitted his agent for testing with the understanding that based on the current formulation and the existing phase-out rules for Class II ODS, the agent is unlikely to be deemed acceptable by DOD.

6.3 END-USER/ORIGINAL EQUIPMENT MANUFACTURER (OEM) ISSUES

As expected, the alternatives are clearly not as effective as Halon1211.

The DOD Halon 1211 flightline extinguisher is rated 30A:240BC, while the Halotron/Buckeye and Halotron/Amerex units are rated 10A:80BC. The FE-36/Ansul unit does not have a UL rating, but it is considered likely that it would also achieve a 10A:80BC. The Halon 1211 unit put out all fires, while the three alternative units put out about one third of the fires. That is, they had one-third the success rate with one-third the UL rating. This might suggest that the UL Rating may be a reasonably good indicator of performance against this test protocol.

Temperature affects performance against the protocol fire test.

The test protocol fire adequately measures relative performance of an agent against Halon 1211. While it is useful as a baseline comparison test, it is too challenging to be considered as the actual fire threat that a flightline person would be expected to handle alone. It is extremely doubtful that a typical unprotected and untrained flightline person could extinguish the test protocol fire, even with the standard DOD Halon 1211 unit. Without protective clothing and breathing apparatus, it would be unreasonable to expect a flightline person to get close enough to mount a successful attack on such a fire. Also, successful extinguishment necessitates actually walking into the fuel pool, which is prohibited for an unprotected person.

There does not appear to be sufficient data to predict the optimum trade-off between agent flow rate and discharge duration. The results of the two extra tests shown in Table 4-5 were unexpected and counter-intuitive. When the pressure in the agent container was 125 psi the fire was extinguished, yet at 150 psi it was not. There is also insufficient data to define the size and flow rate of the tested agents necessary to equal the performance of Halon 1211. An educated guess might be roughly 300 lbs with an initial flow rate of 8 to 9 lbs/sec.

Though it wasn’t tested, it is likely that a dual attack would show considerable synergy. Two 150-lb Halotron units might be much more effective than a double-sized single unit and could likely equal the performance of the DOD Halon 1211 extinguisher against this test protocol, since one person could concentrate on the pool while the other attacks the engine fixture. The downside of such an approach, of course, is the need for two firefighters.

The flightline fire threat needs to be defined so a reasonable fire-protection approach can be developed.

The impact of selecting an agent less capable than the current Halon 1211 unit has not been established. If for example, all existing Halon 1211 flightline units were replaced with units having the capability of 150-lbs of Halotron 1 or FE-36, what would the impact be on flightline fire losses? How good is good enough?

As stated in the test protocol, the results of the fire-performance and stream-reach tests described above will be one of many factors to be considered by appropriate DOD components in determining the ultimate replacement for Halon 1211 flightline extinguishers. Ideally, DOD would prefer an agent having a stream reach of at least 25 feet with the ability to extinguish the test fire within 30 seconds using less than 285 pounds of agent. Other factors that may ultimately be considered include, but are not limited to, ability to extinguish Class A fires, fire performance rating per a nationally recognized laboratory such as Underwriters Lab, performance against the FAA Hidden Fire test, life-cycle costs, system weight and ground footprint, personnel safety, materials compatibility, environmental compliance, reliability, human factors, maintainability, and logistic support considerations. As such, there were no firm pass/fail criteria for the tests described herein.

7.0 REFERENCES

1. October 2004 DOD Ozone Depleting Substance Services Steering Committee Meeting, Arlington, VA.

2. "Joint Test Protocol for Assessing the Performance of Halon 1211 Alternative Fire Fighting Agents for U.S. Air Force and U.S. Navy Flightlines," Test Procedure Prepared Jointly by: Fire Science and Technology Office, Naval Air Warfare Center/Weapons Division, China Lake, CA, and Fire Research Group, Air Force Research Laboratory Tyndall AFB, FL, dated 4 September 2007.

3. "Minimum Performance Requirements for Air Force Flightline Fire Extinguishers: Extinguishing Performance Against 3-Dimensional and Hidden Fires," AFRL-ML-TY-02-4540, May 2002.

4. Warner Robins Air Logistics Center, Purchase Description PD 99LECF02, "Extinguisher, Fire Liquified Gas (Halon 1211) 150 Pound, Wheeled," dated 19 Feb 1999.

5. Underwriters Laboratory Standard 711, "Rating and Fire Testing of Fire Extinguishers" dated 17 December 2004.

6. Leonard, J.T., *et al*, "Fire Hazards of Mixed Fuels on the Flight Deck," Naval Research Laboratory, Washington, DC, NRL/MR-6180-92-6975 dated April 28, 1992.

7. Dierdorf, D.S., and Kiel, J.C., "HALON Flightline Extinguisher Evaluation: Data Supporting Standard Development," AFRL-ML-TY-TR-2005-4583, October 2005.

8.0 POINTS OF CONTACT

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone/Fax/email	Role in Project
Howard L. Bowman	Energetic Sciences Division, M/S 1109, Naval Air Warfare Center, 1 Administration Circle, China Lake, CA 93555-6100	(760) 939-8813 / (760) 939-2597 / howard.bowman@navy.mil	Project Coordinator
Robert L. Darwin	Hughes Associates, Inc., 3610 Commerce Drive, Suite 817, Baltimore, MD 21227-1652	(410) 737-8677 / (410) 737-8688 / bdarwin@haifire.com	Consultant
Ross A. Davidson	Energetic Sciences Division, M/S 1109, Naval Air Warfare Center, 1 Administration Circle, China Lake, CA 93555-6100	(760) 939-2569 / (760) 939-3597 / ross.davidson@navy.mil	Navy Project Coordinator
Douglas S. Dierdorf	Applied Research Laboratory, 4300 San Mateo Blvd. N.E., Suite A220, Albuquerque, NM, 87110	(505) 883-3636 / (505) 872-0794 / DDierdorf@ara.com	Consultant
Kenneth Dormer	SAF/AQRE, 1060 Air Force, Pentagon, Washington D.C. 20330-1060	(703) 588-7102 / (703) 696-9333 / DormerK.ctr@pentagon.af.mil	Air Force Project Coordinator
John Hawk	Air Force Research Laboratory/MLQD, 139 Barnes Drive, Suite 2, Tyndall AFB, Fl, 32403	(850) 383-3736 / (850) 283-9797 / john.hawk@tyndall.af.mil	Test Manager
Peter M. Mullenhard	Science Application International Corporation (SAIC), 2001 Jefferson Davis Highway, Suite 307, Arlington, VA 22202	(703) 562-4135 / (703) 416-1178 / peter.m.mullenhard@saic.com	Consultant
Dan Verdonik	Hughes Associates, Inc., 3610 Commerce Drive, Suite 817, Baltimore, MD 21227-1652	(410) 737-8677 / (410) 737-8688 / dverdonik@haifire.com	Consultant

This page intentionally left blank.

Appendix A

JOINT TEST PROTOCOL FOR ASSESSING THE PERFORMANCE OF HALON 1211 ALTERNATIVE FIREFIGHTING AGENTS FOR U.S. AIR FORCE AND U.S. NAVY FLIGHTLINES

4 September 2007

Procedure for Conducting Tests Under
ESTCP 06-E-PP3-026
DOD Flightline Fire Extinguishers

Test Procedure prepared jointly by:

Hughes Associates, Inc.
Baltimore, MD

Fire Science and Technology Office
Naval Air Warfare Center Weapons Division
China Lake, CA

Fire Research Group
Air Force Research Laboratory
Tyndall Air Force Base, FL

1.0 Introduction

The current DoD flightline extinguisher uses Halon 1211, an ODS. DoD desires to identify and select an alternative agent, and ultimately a dispensing system, to replace the existing, Halon 1211, 150-pound flightline units. A program has been established under the DoD ESTCP to test and evaluate alternative agents for this application.

Any agent used in an extinguisher proposed for testing would be considered a replacement for an ODS. As a replacement under Section 612 of the Clean Air Act of 1990, the agent would have to be approved as an Acceptable Halon 1211 Replacement through the EPA’s SNAP Program prior to testing.

Candidate fire extinguishers to be tested under this requirement must not employ agents that will adversely affect the internal components of DoD aircraft engines to the extent that extinguishment of “cold start” fires (small fires within the tailpipe) will require removal of the engine and depot level inspection and/or refurbishment. The engine manufacturers have determined the impact of commonly used fire extinguishing agents and the results are included in the pertinent engine maintenance manuals (T.O. 2J-F100-46-2). New agents proposed for this application will ultimately require evaluation to determine if there are any detrimental effects on engine components. Final approval for use of the agent rests with the cognizant USN and USAF propulsion engineering authority.

2.0 Background

This report contains the test protocol for assessing the performance of firefighting agents proposed as alternatives to Halon 1211 under ESTCP 06-E-PP3-026. Specifically, the test procedure contained herein will determine the ability of an agent to extinguish pooled and flowing fuel tailpipe fires.

The test procedures contained herein are derived from a previously published USAF/AFRL report on establishing minimum performance requirements for USAF flightline fire extinguishers (Reference A-1).

These criteria are provided for the sole purpose of assessing the capability of fire extinguishers to suppress aircraft engine fires on the flightline. They are not the complete criteria for commercial item descriptions, purchase descriptions, or similar documents as they do not cover the totality of operational performance requirements (including toxicity, environmental constraints, impact on internal engine components, size, weight, winterization, paint, maintainability, and towing).

NRL, under contract to the USAF, conducted an extensive review of flightline fire incidents from 1984 through 1990 (Reference A-2). This review documented the success of flightline fire extinguishers in minimizing the cost per incident of aircraft fires. At that time, incident reports to the Navy Safety Office were inadequate to establish detailed locations of each fire: engine, engine nacelle, and Auxiliary Propulsion Unit (APU) fires were thought to represent the majority of fires extinguished by flightline fire extinguishers. These data led to the development of the F-100 Engine Nacelle Test Fixture and to improved incident reporting to more fully understand the functionality of flightline fire extinguishers.

Recent research, also conducted by the USN (Reference A-3), used the improved incident reports from 1993 through 1995 to validate the conclusions of the earlier report.

The purpose of this report is to provide the test protocol and test apparatus requirements for assessing the capability of fire extinguishers to suppress a specific aircraft engine fire frequently occurring on the flightline:

> *The extinguisher must effectively extinguish fuel fire in a flowing state (commonly called 3-dimensional or flowing fuel fires) expected in engine tailpipes.*

In addition to measuring the firefighting capability, the effective stream reach of the agent will be measured.

3.0 F-100 Test Fixture

The test fixture is constructed according to the design provided here. Specific features are illustrated in Figures (A-1) through (A-6).

Note that Figures (A-2) and (A-5) refer to an “Access Panel Test.” The Access Panel Test will not be included in this test protocol; only the Rear Engine Test will be part of the protocol for purposes of this document. Also note that Figure (A-3) indicates that thermocouple readings will be used for fixture temperature control. In this protocol, a handheld infrared (IR) thermometer will be used for that purpose.

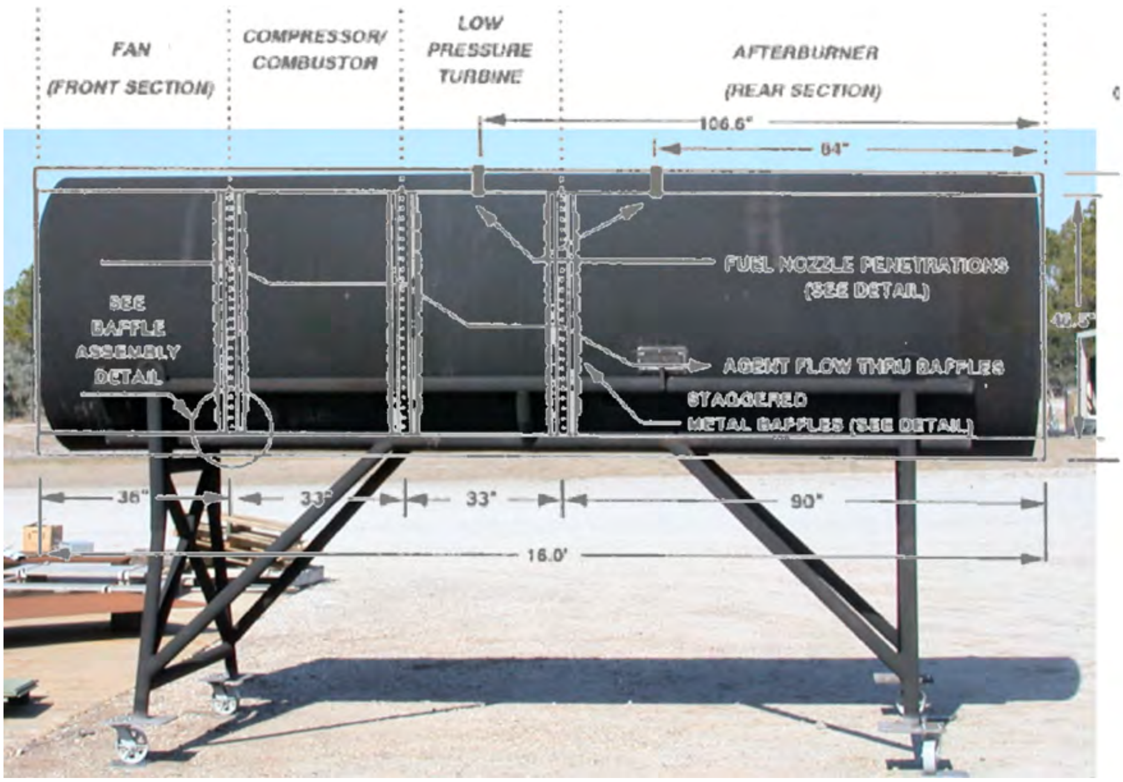

Figure (A-1) Overall Fixture (Side View)

Figure (A-2) Aft View F-100 Fixture

The concentric tube design provides the hidden fire space for the Access Panel Test.

Figure (A-3) Baffle Detail
Two-inch stainless steel strips alternate in two layers 4 inches apart. Also note the location of the thermocouple used for fixture temperature control.

Figure (A-4) Access Port (Covered)
This configuration is used for the Rear Engine Fire Test.

Figure (A-5) Access Port (Open)

This configuration is used for the Access Panel Fire Test.

Figure (A-6) View Through Ignition Opening

The hole adjacent to the baffle is the position of the #3 fuel spray nozzle.

4.0 Test Protocol

4.1 General Requirements

(1) Wind Direction. The test apparatus orientation will be adjusted based on the direction of the prevailing wind for that test day. The wind direction shall be from the firefighter's back, ±30 degrees.

(2) Wind Speed. Testing will not commence if wind speed exceeds 8 mph.

(3) Thunderstorm. No test will take place when lightning storms are within 5 miles of the test site.

4.2 Rear Engine Fire Test

4.2.1 Critical Performance Parameters

(1) Time to full extinguishment

(2) Amount of extinguishing agent used

4.2.2 Test Specifications

4.2.2.1 Required Equipment and Supplies

(1) Concave concrete test surface: 11 feet in diameter, center 3 inches lower than rim

(2) F-100 test fixture (see Figure (A-7))

(3) Handheld IR thermometer

(4) 50 gallons of JP-8 fuel per test fire

(5) Fuel pump with sufficient capacity to supply 4-gpm JP-8 with test nozzles 2 and 3 open (2-gpm each)

(6) Charged test extinguisher

(7) Cleanup equipment appropriate for test extinguisher

(8) Scale suitable for weighing the extinguisher before and after each test

(9) A load cell with data-recording capability to continuously measure and record extinguisher weight during agent discharge (Note: loss of this measurement capability will not necessarily cause stoppage of the test program. Testing without a load cell will continue at the discretion of the AFRL Test Director.)

(10) Video cameras to record all tests

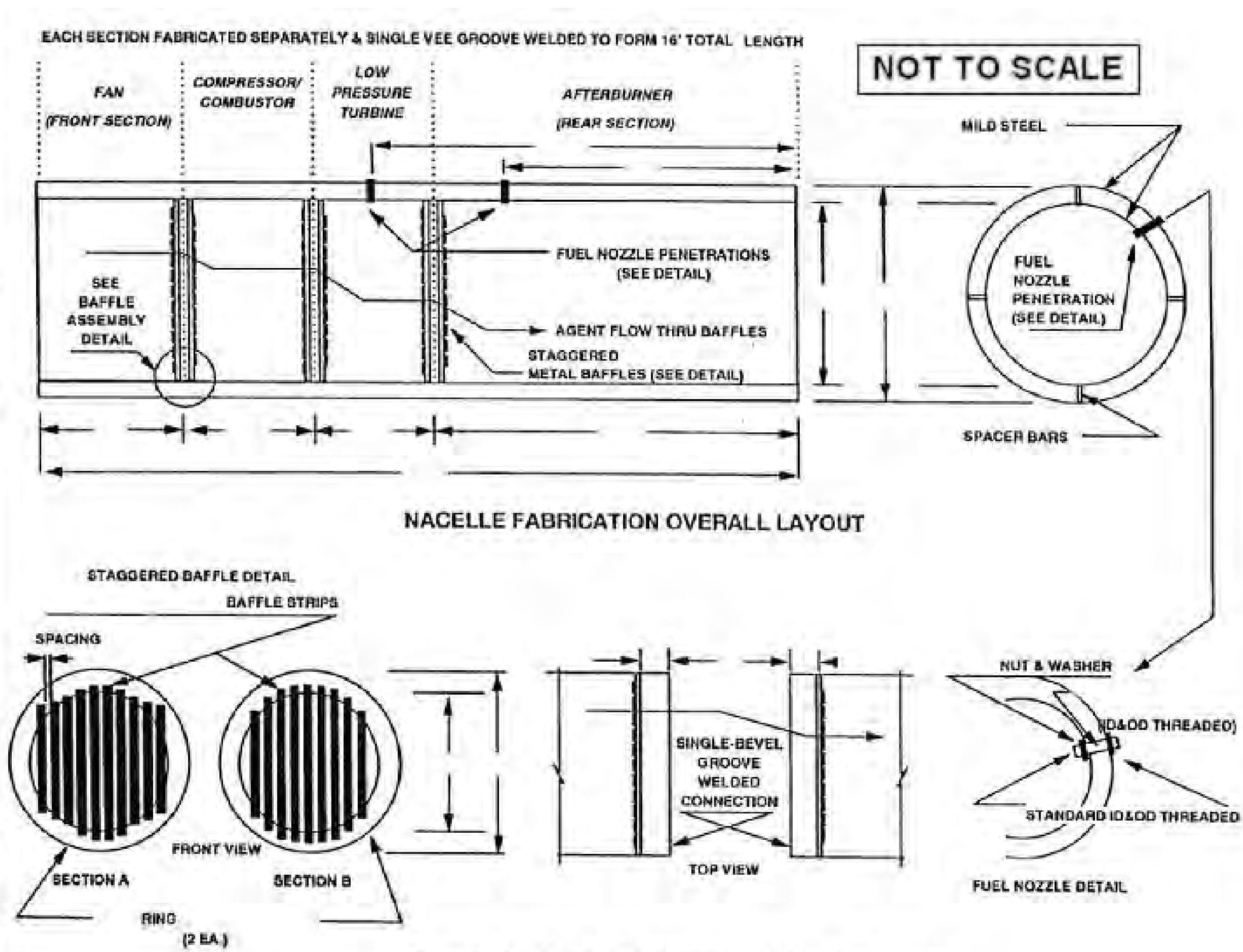

Figure (A-7) F-100 Engine-Nacelle Test Apparatus; Fabrication Drawing

4.2.3 Test Operating Procedure

4.2.3.1 Pre-Test Phase

(1) Determine and record extinguisher full weight.

(2) Start video cameras.

(3) Ignite low pressure turbine fuel nozzle (nozzle 2) fuel spray (JP-8, 1.0 ± 0.25 gpm).

(4) Heat tailpipe to 550 ± 25°F.

(5) Shut off fuel.

(6) Allow metal to cool to 475 ± 25°F.

(7) Initiate fuel flow through nozzles 2 and 3 (4.0 ± 0.25 gpm total).

(8) Flow 25 gallons of JP-8 through the fixture into the concrete pan.

(9) If spontaneous ignition occurs, shut off fuel and allow metal to cool to a lower temperature. Return to item (6) above.

4.2.3.2 Test

(1) Ignite low pressure turbine and afterburner fuel sprays with a suitable torch applied through the ignition port and/or from the tailpipe (2 gpm each).

(2) Ignite pan.

(3) Allow to burn for 15 seconds.

(4) Apply fire extinguisher according to manufacturer's instructions.

(5) Stop fuel flow when fire is out or extinguisher is expended.

(6) Shut off video cameras.

(7) Weigh extinguisher after test.

(8) Record time to extinguish.

(9) Record weight of agent used.

4.3 Number of Fire Tests

Ten fire tests will be conducted for each candidate agent.

5.0 Stream Reach Test

5.1 Test Procedure

Stream reach will be determined based on the ability to extinguish small fires at given distances.

Testing will be conducted in still air, indoors or outdoors, with no perceptible ambient wind. Agent discharge will be from a fixed location, but nozzle elevation during discharge is acceptable. Four small steel cups (approximately 3 inches in diameter and 2 inches tall) will be placed on level ground at measured distances of 20, 25, 30, and 35 feet from the agent discharge nozzle. Each cup will be filled with 0.5 inch of JP-8 floated on 1 inch of water. After a pre-burn period of at least 15 seconds after the fourth cup is ignited, agent will be discharged from the nozzle, held at hip height, in an attempt to extinguish as many cups as possible.

Three stream reach tests will be conducted. A written record will be maintained of the number and distance of cups extinguished, and each test will be video taped.

6.0 Evaluation of Results

An official archival record of all data will be maintained (see Figure (A-8)). Data to be recorded are listed in Appendix B. Additionally, all tests will be videotaped.

The results of the fire performance and stream reach tests described above will be one of many factors to be considered by appropriate DoD components in determining the ultimate replacement for Halon 1211 flightline extinguishers. Ideally, DoD would prefer an agent having a stream reach of at least 25 feet with the ability to extinguish the rear engine test fire within 30 seconds using less than 285 pounds of agent.

Other factors that may be considered include but are not limited to ability to extinguish Class A fires, fire performance rating per a nationally recognized laboratory such as Underwriters Laboratory, performance against the FAA Hidden Fire test, life cycle costs, system weight and ground footprint, personnel safety, materials compatibility, environmental compliance, reliability, human factors, maintainability, and logistic support.

As such, there are no firm pass/fail criteria for the tests described herein.

Test No. ________ Date: _________ Time: _________ Firefighter __________________

Wind Velocity: __________ Wind Direction: _________ Temperature: __________

Humidity: ___________

Agent: __________________________ Agent Manufacturer: ___________________

Dispensing Hardware (Trade Name/Model Number): _____________________________

Hardware Manufacturer: _________ UL Rating (if any): ________ Stream Reach: ______ ft

Gross Weight (Start): _____________ lbs Gross Weight (End): _____________ lbs

Net Agent used: _____________ lbs

Quantity of JP-8 Prior to Ignition: ___________ gals

JP-8 Flow Rate During Heat-Up: __________ gpm

Fixture Pre-Heat Temp: ___________ºF Fixture Cool Down Temp: ___________ºF

JP-8 Flow Rate During Attack: _________ gpm Total Fuel Flowed ____________gals

Pre-Burn Time (ignition to agent on): _____________ secs

Extinguishment Time: Observer # 1 ________ secs # 2 _________ secs # 3 ________ secs

Average Extinguishment Time: ____________ secs

Systems Discharge Time: Observer # 1 ________ secs # 2 _______secs #3 _________ secs

Average System Discharge Time: __________ secs
Average Agent Flow Rate: _____________ pps

Observations: ____

____

____

Figure (A-8) Data Collection Sheets

7.0 References

A-1. AFRL-ML-TY-02-4540 (Minimum Performance Requirements for Air Force Flightline Fire Extinguishers: Extinguishing Performance Against 3-Dimensional and Hidden Fires) Dated: May 2002

A-2. WL-TR-93-3519 (Flightline Aircraft Fire Incidents and Suppression Agent Effects: Field Inquiries and Incident Analysis, by J. T. Leonard, E. K. Budnick, E. R. Rosenbaum, D. J. Perrault, and E. D. Hayes) Dated: April 1994

A-3. NRL/MR/6180 99-8411 (U.S. Navy Halon 1211 Replacement Plan Part 2 – Halon 1211 Requirements Review, by S. T. Laramee, D. P. Verdonik, P. J. DiNenno, and F. W. Williams) Dated: 1 November 1999

Appendix B

INSTRUMENTATION LIST

Fuel Flow Meter:
GPI Electronic Digital Meter Model # G2S07N09GMA
Great Plains Industries
Wichita, KS

Load Cell:
Cardinal Weight Indicator Model 204
Cardinal Scale Manufacturing Co.
Webb City, MO 64870
(load cell output hooked to a laptop with Labview, and then transferred to Excel)

Wind Anemometer:
Omega Model # HHF802
Vane Anemometer
Range: 0.9 – 55.9 mph
Omega Engineering Co.
Stamford, CT 06907

Hand Held IR Thermometer:
Extech Model # 42520
Extech Instruments

Digital Thermometer:
Omega Model # 871 (with Type K TC)
Omega Engineering Co.,
Stamford, CT

Sling Psychrometer (temperature and relative humidity)
Omega Model # RHSP
Omega Engineering Co.,
Stamford, CT 06907

This page intentionally left blank.

Appendix C

DATA COLLECTION SHEET

Test No. _____ Date: ___________ Time: ________ Fire Fighter: _______________

Wind Velocity: _________ Wind Direction: ________ Temperature: ______ ºF

Humidity: _________ % Fuel Temperature: ________ ºF

Agent: _______________________ Agent Manufacturer: _________________

Dispensing Hardware (Trade Name/Model Number): __________________________

Hardware Manufacturer: ________ UL Rating (if any): _______ Stream Reach: _____ ft

Gross Weight (Start): ____________ lbs Gross Weight (End): ____________ lbs

Net Agent used: ____________ lbs

Quantity of JP-8 Prior to Ignition: __________ gals (after cool-down)

JP-8 Flow Rate During Heat-Up: _________ gpm _______ gals During Heat-Up

Fixture Pre-Heat Temp: ___________ ºF Fixture Cool Down Temp: __________ ºF

JP-8 Flow Rate During Attack: ________ gpm Total Fuel Flowed: ___________gals

Pre-Burn Time (full involvement to agent on): ______secs ____ secs (ign to agent on)

Extinguishment Time: Observer # 1 _______ secs # 2 ________ secs # 3 _______ secs

Average Extinguishment Time: ___________ secs

Systems Discharge Time: Observer # 1 _______ secs # 2 ______secs #3 ________ secs

Average System Discharge Time: _________ secs
Average Agent Flow Rate: ____________ lbs/sec

Observations: ____

____

This page intentionally left blank.