NEXT GENERATION FIRE SUPPRESSION TECHNOLOGY PROGRAM: FY2003 PROGRESS

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ABSTRACT

The Department of Defense's Next Generation Fire Suppression Technology Program (NGP) has completed its sixth year of research with a goal to develop and demonstrate technology for economically feasible, environmentally acceptable and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by halon 1301 systems in aircraft.

Research to complete a suite of suppressant screening tests has been completed. Research on new flame suppression chemistry, new and improved aerosol suppressants, improved suppressant delivery, and viability of new suppressant technologies has produced substantive results.

The NGP is supported by the DoD Strategic Environmental Research and Development Program (SERDP).

INTRODUCTION

Initiated in 1997, the Department of Defense's Next Generation Fire Suppression Technology Program (NGP) has completed its sixth year of research. The NGP goal is to

> "Develop and demonstrate technology for economically feasible, environmentally acceptable and user-safe processes, techniques, and fluids that meet the operational requirements currently satisfied by halon 1301 systems in aircraft."

Fires and explosions continue to be among the greatest threats to the safety of personnel and the survivability of military aircraft, ships, and land vehicles in peacetime and during combat operations. However, over the past six years, research to identify replacement fire suppressants has declined considerably, within the NGP, domestically and internationally, despite the continuing need. To date no commercial or military aircraft have had their halon 1301 systems replaced, while new systems are being installed in the cargo bays of commercial jetliners. Meanwhile, the international community is continuing to cast an eye on the necessity of maintaining the large halon 1301 reserves and even considering the requirement of a total phaseout. Thus, the demands on research to identify new approaches to aircraft fire suppression are unabated, nor have the demands on the new technologies lessened.

NGP technology is already having an impact on aircraft fire suppression systems, and NGP research has generated unparalleled contributions to the published literature, all of which can be obtained via the NGP web site: www.bfrl.nist.gov/866/NGP. Much of the most recent progress is being reported at this Conference.

TECHNICAL PROGRESS

NEW FLAME SUPPRESSION CHEMISTRY

In prior years, the NGP had developed a new understanding of how efficient chemicals interact with flames and eventually suppress them. This is summarized as follows:

> Flame propagation results from the fast reactions of key species (H and O atoms, OH radicals) with vaporized fuel molecules. These species exist at concentrations far above those expected from thermal equilibrium at flame temperatures. Chemically active agents catalytically reduce the radical concentrations toward equilibrium levels. While this process slows the flame, it does not extinguish it. The suppressant also increases the heat capacity of the fuel/air mixture, reducing the flame temperature and thus the flame reaction rates below the level needed to sustain combustion. These two effects are synergistic. The need for both effects suggests that the lower limit for a suppression concentration may be at about 1 % by volume**.**

With this knowledge and given the availability of HFC-125, the NGP had developed a list of criteria to guide the search:

1. Fire suppression efficiency at least comparable to halon 1301 and higher than the hydrofluorocarbons (HFCs).
2. Short atmospheric lifetime (current preference of the order of a month), to keep known and potential environmental contamination to a minimum.
3. Boiling point sufficiently low that an extinguishing concentration can be achieved quickly following discharge. Work is now underway to examine reports of the in-flight deployment of halon 1301, with an eye toward identifying whether a more realistic value could replace the current, restrictive 30 °C target.
4. Low toxicity relative to the concentration needed for suppression.

The NGP continues to examine systematically the most promising chemical families. While this search has produced additional knowledge of what makes a good suppressant, to date we have not identified a likely successor to halon 1301 for in-flight aircraft fires.

Anticipation of poor toxicological performance continues to be a concern. One of the most appealing bromoalkenes ($CF_3CBr{=}CH_2$) did well in all screens, but its LOAEL (lowest observed acute exposure level) for cardiac arrhythmia in laboratory dogs was found to be well below the extinguishing level of about 3 %. There are no recognized quantitative structure-activity relationships (QSARs) for estimating LOAEL values for members of the chemical families that comprise tropodegradable bromocarbons. An NGP re-examination of the field has led to a focus on two alternate approaches: partition coefficients and *in vitro* toxicity tests.

One mechanistic hypothesis for cardiac arrhythmia is that the effect results from the absorption into or adsorption onto heart nerve and muscle cells and cell membranes. A favorable indicator is a low octanol-water partition coefficient, with solution in the aqueous environment of the cells and membranes disfavored over that in the far less polar octanol. Partition coefficients are determined experimentally using reverse phase chromatographic methods and can also be estimated from the contributions of molecular fragment-based terms plus correction factors. The algorithms can give different results, so experience is needed to select or develop an appropriate version for the particular chemicals under consideration. An indication of the disparity as well as trends in the predicted values for two calculation methods can be seen in Table 1.

Table 1. Comparison of Calculated (From Two Algorithms) and Measured Values of Log K_{ow} of Selected Halocarbons

Compound	Log K_{ow}			LOAEL (vol. %)
	Calc. - method a	Calc. - method b	Measured	
CF_3Br (halon 1301)	1.83	1.59	1.86	7.4
$CHBrF_2$	1.85	0.98	NA	3.9
CH_2=$CBrCF_3$	2.14	2.49	NA	1.0
CF_2ClBr (halon 1211)	2.17	1.90	2.1	1.0
CF_3I	2.22	2.01	NA	0.4
C_3HF_7	2.35			10.5

This use of calculated partition coefficient values should only be applied to narrowly defined groups of compounds and even then only used as a tentative predictor of LOAEL value. For example, in the last two rows, the calculated log K_{ow} value for C_3HF_7 suggests a LOAEL lower than that any of the other compounds, which is clearly not the case. To develop greater assurance in the value of using partition coefficients in estimating cardiac sensitization LOAEL values, we will expand the above table to include the experimental determination of K_{ow} values for the halons, HFCs, current candidate compounds, alternate fire suppressants, and some chemically related medical anesthetics.

While no *in vitro* method exists for evaluating the cardiac sensitization properties of compounds there is strong interest in this area by pharmaceutical companies. Their results should also be directly relatable to the abnormal clinical ECG patterns that define drug-induced arrhythmia. The NGP is evaluating its possible role in this field.

Work is continuing to assess whether there are fluoroalkyl phosphorus compounds with estimated acceptably low toxicity, ODP, and GWP. Seven such compounds have been synthesized and tested (Table 2). Some general observations are:

- Fluorine substitution does yield compounds of lower boiling point, as expected.
- Several compounds exhibited instability on exposure to air and may be reacting either with the ambient humidity and/or oxygen. A compound is listed as “not air reactive” if no heating of the glass vial container occurred on opening, and no flame or white fumes were observed on exposure of the compound to air.

To measure the extinguishment concentrations of these high boiling chemicals, the cup burner was modified to pre-heat the incoming air, nebulize the chemicals and dilute them before they enter the flame zone. It can now be used with compounds with boiling points up to 130 °C. The extinguishment data are upper limits due to the small quantity of chemical available.

Table 2. Fluoroalkyl Phosphorus Compound Cup Burner Results

ID	Compound	Boiling Point (°C)	Extinguishment (vol. %)	Air Reactivity, Ignition
1	$O{=}P(CF_3)_3$	32	No ext. at 5 %	Not air reactive
2	$P(OCH_3)(CF_3)_2$	55	Not measurable	Ignites spontaneously
3	$P(OCH_2CF_3)_3$	131	≤3.1 %	Not air reactive - no ignition
4	$O{=}P(OCH_3)(CF_3)_2$	42	≤4.6 %	Some reactivity - no ignition
5	$P(OCH_2CF_3)_2CF_3$	112	≤3.0 %	Some reactivity - no ignition
6	$P(OCH_2CF_3)(CF3)_2$	~90	≤1.8 %	Very reactive, but no spontaneous ignition
7	$O{=}P(OCH_2CF_3)(CF_3)_2$	>130	No ext. at 5 %	Not air reactive

The data suggest that phosphonates (compounds 1, 4, 7) may need sufficient hydrogen atoms in their structures to break down in the flame zone and become chemically active flame suppressants. Only compound 4 is effective and approaches the needed boiling point range. If the trade-off is between high fluorination to reduce the boiling point and moderate hydrogenation for efficient fire suppression, there may not be much further promise in this family of compounds. None of the phosphines (compounds 2, 3, 5, 6) has a sufficiently low boiling point to be of practical value for use as a compressed fluid in aircraft application, and high volatility (high fluorination) compounds tend toward spontaneous flammability. Thus, this family shows little promise. For other uses, identification of the decomposition products of compound 6 might point the way to dramatically better phosphorus-based extinguishants.

We re-visited the compatibility of CF_3I during long-term storage. Under the DoD Technology Development Plan[1] a number of candidate suppressants had been assessed for compatibility with metal storage bottle materials at temperatures up to 150 °C and a pressure of 4.13 MPa over a four-year period. For all compounds there were some metals for which the exposures showed no ill effects. CF_3I had manifested the most serious interactions. Re-examination of those samples, stored for an additional five years at *ca.* 23 °C, showed no significant changes in the CF_3I concentration and no new peaks were found, indicating stability during the five-year period at ambient temperature. [Note that the combination of copper and Nitronic 40 had already resulted in a complete breakdown of CF_3I during storage at 150 ˚C.]

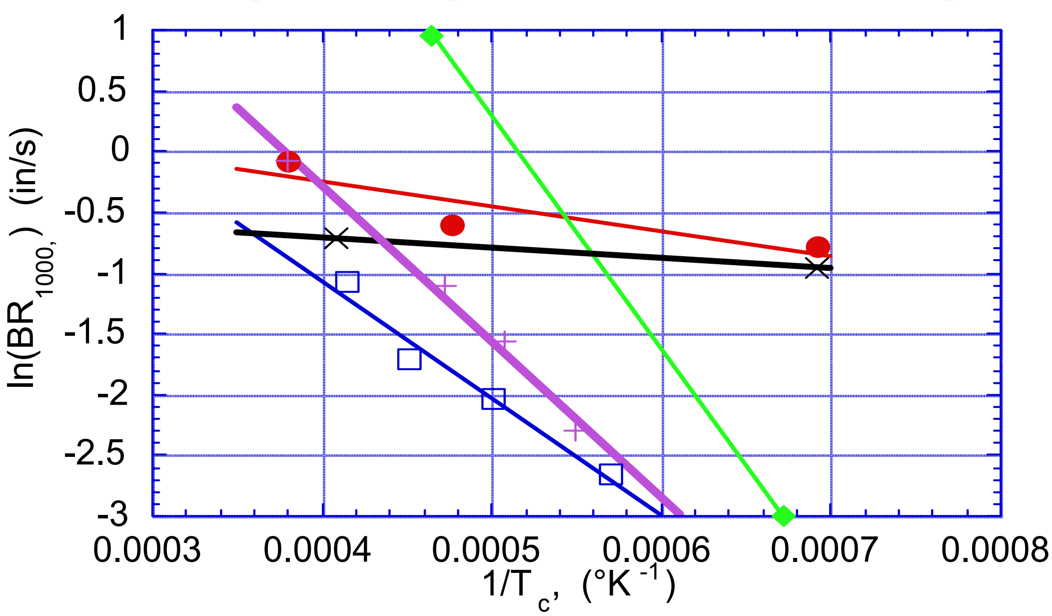
IMPROVED SUPPRESSANT DELIVERY

NGP research is developing new solid propellant gas generators (SPGGs) that have both reduced combustion temperatures and increased flame suppression efficiency, which in turn will enable freedom of selection of the momentum of the suppressant stream. The approaches include modification of the solid propellant, inclusion of additives in the propellant formulations, and entrainment of a chemically active additive into the gas stream. There are two different design categories: solid propellant gas generators (SPGGs), in which the coolant or chemical additive is incorporated directly into the propellant composition, and hybrid fire extinguishers (HFEs), in which the additive comprises an auxiliary fluid that is discharged with the propellant effluent.

Direct incorporation of coolant compounds into the propellant composition was shown to be an effective means for reducing exhaust temperatures. However, the effect of coolant level upon ballistic performance is not consistent for different propellant families (Figure 1). These findings suggest that the benefits of decreased exhaust temperatures are often offset by a decrease in the burn rate of the propellant, which in turn relates to a decrease in the rate of suppressant delivery.

Propellant formulations incorporating the new, high nitrogen compound BTATZ ($C_4H_4N_{14}$) enables reducing propellant combustion temperatures while maintaining agent delivery rates sufficient for rapid flame extinction. Preliminary testing indicates that burn rates may be maintained within workable constraints at the same time that exhaust temperatures are reduced as much as 30 % below current baseline levels. The preparation of BTATZ has progressed to the kg scale. Further safety data on BTATZ shows acceptable friction and impact sensitivity. When formulated into a molding powder with poly(ethylacrylate), electrostatic sensitivity is a concern, even when 0.5 % carbon black is added; however, when pressed into pellets or deposited as a thin layer the material meets the criteria set for routine handling of energetics.

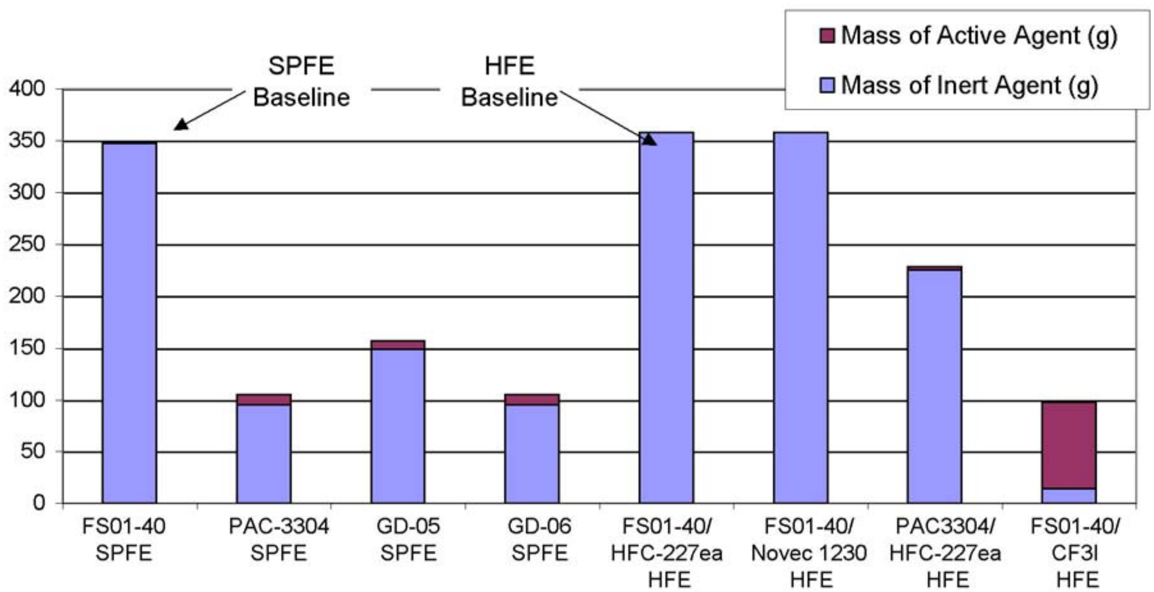
Figure 1. Relationship Between Propellant Burn Rate and Exhaust Temperature



A JP-8 spray burner was used to test the effectiveness of various formulations. The residence time through the fire zone was calculated to be 1.2 s and the discharge time of the SPGG and HFE units was *ca*. 100-200 ms. Typical flame extinguishment times were generally *ca*. 100 ms. Sample test results are shown in Figure 2. The presence of chemically active additives greatly enhances the fire suppression efficiency of both SPGG and HFE devices. An SPGG formulation incorporating potassium carbonate was the most effective, *ca.* 3x more effective per unit mass than the inert baseline FS01-40. Fire testing using hybrid fire extinguisher (HFE) configurations showed that CF_3I hybrids and other high-boiling agents perform well at low temperatures, their low vapor pressures offset by the heating and pressurizing power of the solid propellant driven HFE. FS01-40/Novec-1230 HFEs were as effective as FS01-40/HFC-227 HFEs on a mass basis. Hence other factors (*e.g.*, atmospheric lifetime) may provide the discrimination among them. An inert propellant configuration with water was found to require higher agent loads than the same propellant plus HFC-227. Testing with FS01-40/water/potassium acetate HFEs showed a 36 % reduction in the mass needed for flame extinguishment.

This NGP solid propellant technology forms the basis for fire protection products currently installed on both the Navy F/A-18 E/F and V-22 aircraft. Advanced fire protection products incorporating improvements supported by this NGP project are currently being examined by each branch of the U.S. military as well as other government organizations.

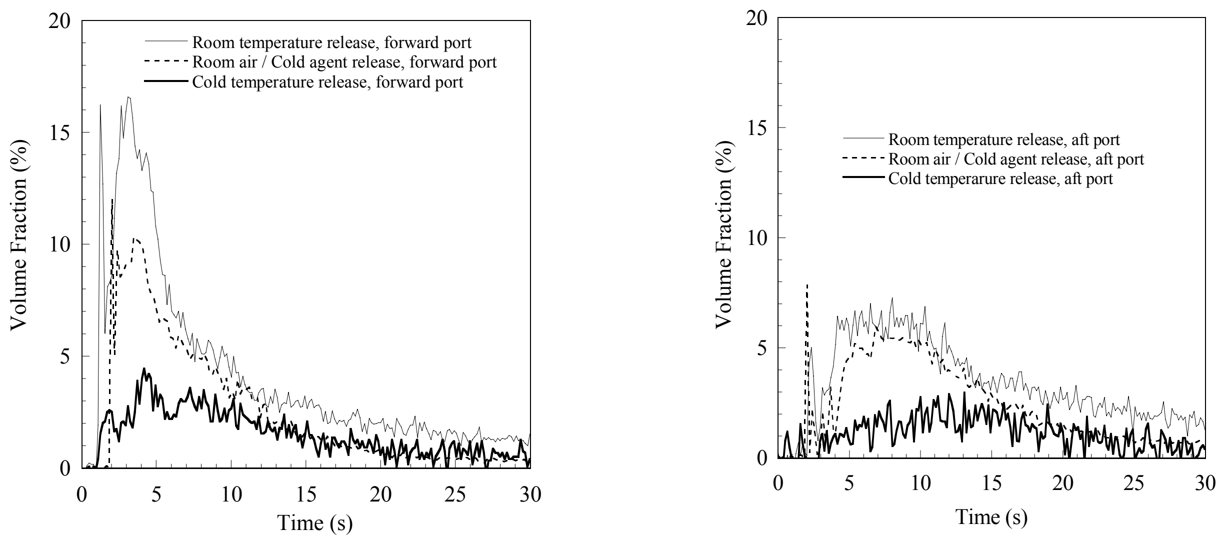
Figure 2. Performance Summary of Fire Testing



Dispersion of Suppressants at Low Temperature

Based on prior TDP and NGP work, there is reason to believe that fluid suppressants with boiling points considerably higher than that of halon 1301 might not disperse efficiently throughout the volume of a cold nacelle or dry bay. Experiments using fluids with differing boiling points are continuing to explore the temperature regime where difficulty might be encountered. The initial experiments involved examination of CF_3I (boiling point of -22 °C) discharges in a simulated engine nacelle under different thermal conditions: a low temperature of -40 ºC and an ambient temperature of 22 ºC. The measurements were made using two UV/VIS fiber-optic spectrometers. The initial time (t = 0) in Figure 3 corresponds to the initiation of the agent release. The data indicate that inefficient dispersion should be expected when discharging a suppressant fluid into a system whose temperature is well below the fluid boiling point. In the low temperature release shown here, much of the liquid deposited on the nacelle floor and evaporated over many seconds. Clearly, then, basing the design mass of agent for an engine nacelle on room temperature test data could lead to significant underestimation of the mass needed for in-flight fire suppression. Similar examination of compounds with other boiling points will complete this effort in the coming year.

Figure 3. Concentration Profiles of CF_3I in the Engine Nacelle Simulator



Suppressant Dynamics in Engine Nacelles

Guidance on preferred locations for and styling of suppressant discharge can best be developed from validated computer modeling of the process. The NGP computational fluid dynamic (CFD) model will include gaseous and aerosol suppressant flow, a fire, and fire extinguishment in cluttered environments. Several flow facilities are being used concurrently to provide both input and validation data in a timely manner.

Droplet spray flow around obstacles was characterized by seeding an air flow with fine water droplets (*ca.* 1 μm diameter) and using 3-D particle image velocimetry (PIV). The obstacle was either a cylinder or a body-centered cube (BCC) arrangement of spheres and connecting posts. The recirculation zone is larger for the spray than for the seed-only flow. Larger size droplets require a longer distance to interact with the turbulent flow field, to reduce their higher momentum, and to be entrained into the recirculation zone, if at all. Fine droplets were entrained into the recirculation region behind the cylinder while the larger droplets impacted the cylinder surface, accumulated and dripped off, and/or rebounded and dispersed radially outward into the free stream. Even with nearly two thirds of the flow path blocked by the BCC, only about 5 % of the (large droplet) inlet water flow impacted the surfaces and dripped into the collector. An even lower fraction was observed for the cylinder. Nonetheless, significant spray cooling of the surface was observed for the heated cylinder. The research is continuing with sprays of two additional fluids: HFE-7000 (boiling point of 307 K) and HFE-7100 (boiling point of 334 K). Phase Doppler interferometry will be used to obtain spatial profiles of the droplet size, velocity distributions, and number density, and to allow comparison of the different liquid physical properties to droplet transport processes.

For the next step in complexity, a low-speed flow visualization tunnel has been modified to investigate liquid fire suppressant spray dynamics in the presence of generic clutter. The performance of a dual-fluid spray nozzle has been documented using a three-dimensional particle dynamics anemometer (PDA) and used to obtain flow patterns in and around clutter elements. A full-scale F/A-18 E/F Nacelle Ground Test Fire Simulator has been fabricated to be the eventual test bed for the predictions of suppressant dispersion.

A preliminary phenomenological model describing the interaction of sprays with objects in the flow has been formulated for use with the VULCAN spray model. The model has been evaluated using HFE-7100 as the fluid. For different initial droplet velocity and size distributions, the results range from droplets sticking to the cylinder to droplets shattering upon impact into smaller droplets.

A numerical study of flow past a rib protruding from a wall was conducted to analyze the effectiveness of the subgrid clutter model. Simulations were conducted with a pool fire near the end of the recirculation zone that exists behind the rib. Results indicate that the fire is convected upstream through the recirculation zone and that the fire zone behind the rib is significantly wider than the pool itself because of the secondary flow generated by the pool fire.

Enhanced Powder Panels for Dry Bay Fire Protection

Powder panels have been applied to the lining of aircraft dry bays to provide passive, lightweight, effective fire protection against ballistic impact. Projectile penetration of the dry bay and adjacent fuel tank releases agent from the powder panel into the fire zone to inert the space before the adjoining fuel spills into the space and is ignited by incendiaries. An NGP survey indicates that U.S. fixed wing aircraft do not employ powder panels, but there is growing interest. Their use in rotary wing aircraft is established and growing. The NGP continues experiments to examine means for effecting, greater powder release into dry bay, better dispersion of powder to prevent ignition off-shotline, longer powder suspension to prevent fire ignition for longer period of time, and design flexibility for enhanced powder panels that can be utilized to target weight, durability, and application-specific design goals

NGP success with enhanced powder panel designs has sparked interest for dry bay fire protection by several aircraft programs, such as the V-22, RAH-66, and F-35 Joint Strike Fighter. In addition, under sponsorship of the DoD Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS), NGP researchers participated in live fire proof-of-concept testing. The tests examined the concept of reactive powder panels that add an energetic backing to any design to enhance powder delivery effectiveness. In tests involving JP-8 fuel and armor piercing incendiary projectiles, the NGP enhanced powder panels prevented fire ignition in all tests.

Additional examination of NGP enhanced powder panel designs by the Federal Aviation Administration (FAA) reflected interest in the feasibility of using powder panels to prevent commercial aircraft fuselage fires caused by the impact of an uncontained engine rotor blade with flammable fluid lines. The impact of the enhanced powder panel by a rotor blade resulted in release of all the fire extinguishing agent and prevented ignition, while baseline testing showed that unprotected fuselage areas did indeed result in sustained fires.

Mechanisms of Unwanted Accelerated Burning

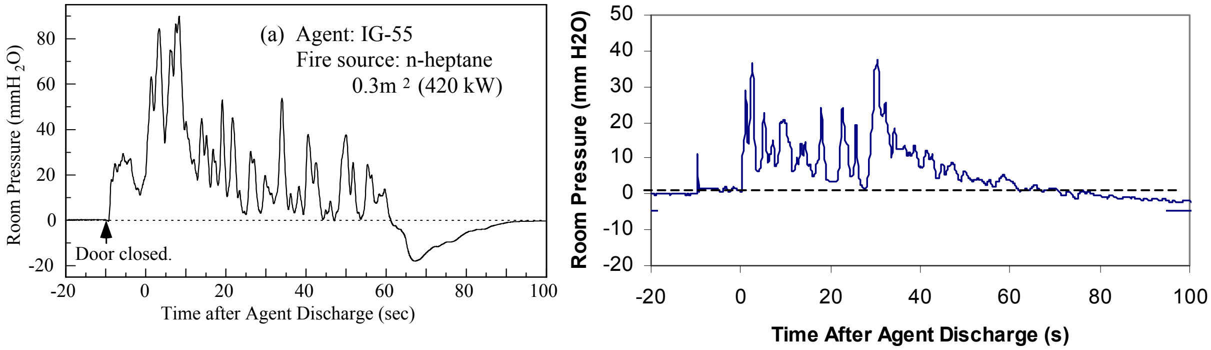
Fire flare-ups and pressure surges have been observed as the agent is applied in real-scale suppression tests. If experienced during flight, this could have a negative effect on aircraft survivability. The cause appears to be enhanced combustion of vaporizing liquid fuel that mixes with air more efficiently in the turbulence accompanying suppressant delivery.

To understand this process, NGP staff analyzed three sets of fire suppression tests. The three cases, all with a liquid fuel, varied in the timescale of the suppression events and the geometric configuration of the experiments. When wood was substituted for the liquid fuel in one of these series, the large pressure fluctuations were not observed.

In the first series of enclosure fires[2] significant fire flare-up and pressure increases were observed for HFC agents, water mist, and hybrid agents involving HFC/powder mixtures. All the deflagrations observed were in the presence of a hot (~550 ^{o}C) ignition source. The investigators suggested that these unwanted burning effects occurred when there was insufficient suppressant to assure quenching and prevention of re-ignition. In this sense, unwanted accelerated burning effects are already embedded in the resulting design equations**.**

Figure 4 shows that the NIST Fire Dynamics Simulator (FDS) calculates pressure fluctuations similar to the experimental observations for suppression of *ca*. 400 kW heptane pool fires in an enclosure.[3]

Figure 4. Comparison of the Room Pressure Measured Experimentally (Left) and Calculated Using FDS (Right)



The third case was the unanticipated over-pressurization that destroyed a C-130 Wing Leading Edge Dry Bay Test Facility during real-scale fire suppression testing. Six previous tests using N_2-pressurized HFC-125 had led to routine suppression. The seventh test, designed to test the impact of the pressurizing N_2, used an N_2 concentration that was 0.4% of the cup burner value, an amount that would have little impact on the stability of the fire and certainly would not extinguish the fire. The fire scenario was complex due to the presence of a ballistic round, accompanying shock waves, fuel splashing (two-phase flow), multiple ignition sources (hot shrapnel), etc. To better understand the conditions in the dry bay during fire suppression, an analytic approach was taken to simulate the pressure in the enclosure. Two results emerged:

- Only a small difference in the sensible enthalpy release could have caused failure of the fixture and
- The pressure rise is larger for smaller vent sizes (small diameter projectiles).

The most important overall finding from analysis of these three cases is that the overpressure risk is low unless insufficient amounts of suppressant are applied to a fire. The viability of design equations derived from full-scale tests hinges on the assumption that the tests are representative of the range of actual fire conditions. The fire conditions in full-scale suppression tests should be carefully designed to be worst-case, or else extreme or unanticipated unwanted burning effects may occur in actual applications.

Enhancing Engine Nacelle Extinguishment with Intumescent Coatings

Quenching a fire in an engine nacelle requires maintaining a sufficient concentration of agent in the flame zone for a sufficient time interval. This must be accomplished while a forced air flow through the nacelle (to prevent the accumulation of any flammable vapors, and possibly also provide some machinery cooling) serves to sweep the suppressant out the exhaust.

The NGP had pioneered the novel approach of using strategic placement of an intumescent material to reduce the cross sectional area of the nacelle in the event of a fire. This “instant firewall” allows achieving the needed residence time with a smaller amount of suppressant. Now, a project funded by the JTCG/AS will demonstrate and optimize the use of these intumescent materials, and identify and evaluate the potential for use on unmanned aerial vehicles and rotorcraft.

The first phase of the project is already underway, evaluating the expansion ratios and response times of candidate intumescent materials and designs in a mini-nacelle fire test fixture. Successful candidates will then be tested in a full-size mock-up of an X-45 UCAV engine nacelle supplied by Boeing Aerospace, the manufacturer of the X-45 UCAV.

VIABILITY OF NEW SUPPRESSANT TECHNOLOGIES

Both objective cost factors and subjective value factors must be considered when making a decision on whether and how to retrofit a fire suppression system. Accordingly, the NGP has developed a methodology to quantify a fire suppression technology by its total, life cycle cost and to enable superimposing on this a subjective value system. The purpose is to provide a means of identifying a halon alternative agent/system option that provides the best cost-of-ownership value to specific aircraft customers over the operating lifetime of their platform.

The methodology determines the net cost of the fire suppression system: the cost of the system minus the cost savings provided by the system (which are a function of extinguishant effectiveness and result in aircraft saved). The developed examples:

- compare an existing halon 1301 system and a system of equivalent and altered performance using an off-the-shelf-alternative, HFC-125;
- include both legacy platforms (for decision makers who must consider retrofit costs for existing platforms) and future platforms (for decision makers currently designing new platforms); and
- apply to engine nacelle applications for representative and rotary wing aircraft in addition to the cargo and fighter aircraft present in last year's Annual Report.

In all cases, the benefit of having either fire protection system substantially outweighs its cost, and the difference in total cost of the two systems is modest compared to the total cost of owning and operating the aircraft.

Using the rotary wing aircraft fire suppression system cost and cost savings information, the following conclusions were reached:

- Even if the rotary-wing aircraft fire suppression system only saved 8 % of the aircraft assets it was designed to protect, the benefit would still be greater than the cost of the system.
- Using a conservative value of 60 % fire suppression system effectiveness, a system cost of up to $307 k per aircraft could be justified. [Both the current and forecast system costs are an order of magnitude less than this.]

The U.S. Army is now using this methodology, with the baseline cases for halon 1301 and HFC-125, as part of their evaluation of three additional fire suppression alternatives (CF_3I, Novec 1230, and gas generators) for the Comanche rotorcraft. This same model will be used by the Army Chinook, Apache and Blackhawk rotorcraft Programs for their retrofit selection criteria.

WHAT LIES AHEAD?

From this point forward, NGP research will be focusing on two technical components:

- Evaluating the "world of chemistry" for new flame suppression chemicals that are operable in aircraft dry bays and engine nacelles. It is essential that as many candidates as possible are identified and screened as potential halon 1301 alternatives. It is equally important that chemical families with no potential be so designated, along with the reasons for the designation. Thus, for other applications or should suppressant requirements change for fire suppression in aircraft, future investigators will have the benefit of the current program findings.
- Developing principles for optimizing suppressant storage and delivery. Both research and engineering experimentation have shown that there is much system effectiveness to

be gained if the suppressant is deployed efficiently and much to be lost for a delivery design that is incompatible with the suppressant properties.

As these efforts near completion, a modest series of real-scale fire suppression tests will be conducted with the purpose of demonstrating the validity of the above findings.

RECENT PUBLICATIONS

New Flame Suppression Chemistry

Mather, J.D., and Tapscott, R.E., "Tropodegradable Bromocarbon Extinguishants – Compound Selection and Testing Issues," *Proceedings of the 2002 Halon Options Technical Working Conference*, NIST Special Publication 984 (CD), National Institute of Standards and Technology, Gaithersburg, MD, 2002.

Tapscott, R.E., Shreeve, J.M. and Mather, J.D., "Fluoroalkyl Phosphorus Fire Extinguishing Agents," *Proceedings of the 2002 Halon Options Technical Working Conference*, NIST Special Publication 984 (CD), National Institute of Standards and Technology, Gaithersburg, MD, 2002.

Mather, J.D., and Tapscott, R.E., "Tropodegradable Bromocarbon Extinguishants –Compound Selection and Testing Issues," *Proceedings of the 2002 Halon Options Technical Working Conference*, NIST Special Publication 984 (CD), National Institute of Standards and Technology, Gaithersburg, MD, 2002.

Tapscott, R.E., Shreeve, J.M. and Mather, J.D., "Fluoroalkyl Phosphorus Fire Extinguishing Agents," *Proceedings of the 2002 Halon Options Technical Working Conference*, NIST Special Publication 984 (CD), National Institute of Standards and Technology, Gaithersburg, MD, 2002.

Improved Suppressant Delivery

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Presser, C., Papadopoulos, G., and Widmann, J.F., "Droplet laden Homogeneous Turbulent Flow past Heated and Unheated Cylinders," 4th ASME/JSME Joint Fluids Engineering Conf., Honolulu, Hawaii, accepted, 2003.

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Viability of New Suppressant Technologies

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