NIST Technical Note 1466

FY2004 Annual Report
Next Generation Fire Suppression
Technology Program (NGP)

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Building and Fire Research Laboratory

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FY2004 ANNUAL REPORT

Next Generation Fire Suppression Technology Program (NGP)
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ABSTRACT

The Department of Defense's Next Generation Fire Suppression Technology Program (NGP) has completed its eighth 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 on new flame suppression chemistry and improved suppressant delivery has produced substantive results. The report includes a description of the research the NGP will perform en route to completing its work in FY2006.

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

Keywords: fire research, fire suppression, halon, aircraft

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I. INTRODUCTION

Initiated in 1997, the Department of Defense's Next Generation Fire Suppression Technology Program (NGP) has completed its eighth year of research with considerable accomplishment. Supported by the DoD Strategic Environmental Research and Development Program (SERDP), 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 both in peacetime and during combat operations. Production of halon 1301 (CF_3Br), long the fire suppressant of choice, ceased as of January 1, 1994 due to its high ozone depleting potential (ODP). By 1997 the DoD had identified the best available replacement for halon 1301 in aircraft, HFC-125 (C_2H_5F)[1], but it requires two to three times the mass and storage volume and contributes to global warming. The new Program was to identify fire suppression technologies with reduced compromises.

While research to identify replacement suppressants for engine nacelle and dry bay fires has declined considerably over the past five years, the demand for new approaches is unabated. New aircraft are in various stages of design. No commercial or military aircraft have yet had their halon 1301 systems replaced, while new systems are being installed in the cargo bays of commercial jetliners. The international community is questioning the necessity of maintaining the large halon 1301 reserves and even considering the requirement of a total phaseout.

The demands on the new technologies remain daunting. The requirements for environmental protection, fire suppression efficiency, materials compatibility, and personnel safety are severe constraints.

The presentation of technical progress and new products and the genesis of ideas have been abetted by the Halon Options Technical Working Conferences, founded in 1991. In 2002, the NGP assumed responsibility for these workshops. The cumulative papers have been indexed and are available on CD and at www.bfrl.nist.gov/866/HOTWC.

The systematic NGP search for new suppressant chemicals and technologies for assured, efficient delivery is continuing to produce new results.   During the past year, an Independent Review Panel (IRP) was "Impressed by the thoughtful way its recommendations have been addressed and by the tightened focus of the program" and "confident that valuable design products will be delivered by this program."

As the NGP approaches its conclusion, it is clear that the participants have generated unparalleled contributions to the published literature in the field, all of which can be obtained via the NGP web site: www.bfrl.nist.gov/866/NGP.   The following pages highlight the new knowledge gained from the NGP research and the progress made towards the NGP Goal. Recent publications are listed at the end of the Technical Progress section. A concluding section summarizes the concluding steps for the Program. Three appendices list the NGP projects to date and present both the latest IRP report and the timetable for the Program completion.

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[1] *Technology Development Plan for Alternatives to Ozone-depleting Substances for Weapons Systems Use; Final Report (TDP)*, Office of the Deputy Undersecretary of Defense (Science and Technology)/Weapons Systems, 1998.

II.   TECHNICAL PROGRESS

A.   Knowledge of the Flame Suppression Process

The NGP search for alternative suppressant technologies has included those for both volatile fluids and compounds whose vapor pressures were sufficiently low that they had to be dispensed as powders or aerosols. Research on the latter category has been completed. New technology for the dispersion of such compounds in solid propellant fire extinguishers and powder panels has been passed to the testing and evaluation community. Their preliminary efforts have been encouraging.

Through this year, NGP research has evolved the following structure for describing the potential for an agent to emerge from its storage bottle, flow through distribution plumbing, be dispersed into the engine nacelle or dry bay, transport around obstructions to reach the site of the fire, and volatilize sufficiently to overwhelm the flames. More complete exposition of some of these components is the subject of remaining NGP research.

- If the agent is above its freezing point and if the pressure in the storage bottle is maintained as the agent is ejected, then all (or nearly all) the mass of stored chemical will reach the distribution plumbing.

- In different systems, the length of the distribution plumbing ranges from well under a meter to several meters. The flow through the piping depends on the temperature, the phase distribution of the fluid, the number and severity of bends, etc. The NGP has modeled (and validated) the transport of this transient two-phase flow in past years.[2]

- The dispersed agent is generally a combination of vapor and liquid.

    o If the boiling point of the fluid is at or below the gas temperature in the nacelle, the liquid blobs that emerge from the storage bottle will flash evaporate. The fraction converted to gas is estimated using the Jakob number, the ratio of the fluid's sensible heat to its heat of vaporization. This flashing is rapid relative to the transit time of the air flow through a nacelle and imparts substantial momentum to the gas and the smaller droplets that are formed. This favors rapid and efficient dispersion throughout the nacelle.

    o If the fluid's boiling point is above the nacelle air temperature and if the fluid is dispensed, rather than atomized, gravity will cause most of the fluid to drop to the bottom surface of the nacelle. At that point its entry into the air stream is by evaporation. Unless the evaporation rate is high, the storage of large amounts of suppressant is necessary to achieve the concentration needed to extinguish flames.

    o If there are nozzles at the end of the distribution plumbing, then some ensemble of

[2] Tuzla, K., Palmer, T., Chen, J., Sundaram, R., Yeung, W., "Development Of Computer Program for Fire Suppressant Fluid Flow Final Technical Report Volume I -- Main Report," (6b1 Suppressant Flow Through Piping Final Report Vol. 1), September, 2000.

Tuzla, K., Palmer, T., Chen, J., Sundaram, R., Yeung, W., "Development Of Computer Program for Fire Suppressant Fluid Flow Final Technical Report Volume II -- Input Manual for the Program Experimental Data Assessment of the Program," (6b1 Suppressant Flow Through Piping Final Report Vol. 2), September, 2000.

droplet sizes is generated.

- o If the pressurizing gas is highly soluble in the liquid suppressant, flashing can occur at temperatures somewhat below the boiling point.

- The gaseous agent and the finer droplets are transported downstream within the nacelle. The larger droplets will generally fail to follow the main flow streamlines around any clutter and will impact the surfaces, forming pools from which evaporation is needed to resume transport downstream.

- Upon reaching the site of the flames, the agent available for suppression is the sum of the gaseous component plus that fraction of the droplets that can evaporate while in the high temperature environment of the flame. Smaller diameter droplets evaporate more efficiently than larger ones. However, the nozzles that can generate such fine sprays generally have low throughput.

- The sustaining of a sufficient concentration of agent bathing the flame zone leads to flame extinction.

The NGP has also developed a new understanding of how efficient volatile 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 necessarily 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 contribution of both effects suggests that the lower limit for a suppression concentration may be at about 1 % by volume.

With this knowledge the NGP had developed a list of criteria to guide the search for candidate suppressant fluids:

1. Fire suppression efficiency at least comparable to halon 1301 (volume fraction about 0.03) and certainly higher than the hydrofluorocarbons (HFCs). Based on prior experience, this focuses the search on compounds that contain at least one bromine, iodine or phosphorus atom, although other possible functionalities can arise. (See Section II.D.)

2. Short atmospheric lifetime (current preference of the order of a month), to keep ozone depletion potential (ODP), global warming potential (GWP) and any future unidentified environmental contamination issues to a minimum.

3. Boiling point sufficiently low that for gaseous agents, an extinguishing concentration can be achieved within a specified time following discharge. An approximate theoretical upper limit is near 30 °C if the minimum temperature in flight is -40 °C. New knowledge of this process is described in Section II.B.

4. Low toxicity relative to the concentration needed for suppression.

B.   Minimum Release Temperature

There are few viable chemicals with boiling points, T_b, below the specified minimum operating temperature of -40 ℃ (-40 ℉). Prior NGP experiments with CF_3I (T_b = -22 ℃) have shown that it does not flash at this minimum temperature. All new chemicals currently under consideration have boiling points higher than this and their dispersion is thus characterized by the ability to evaporate rapidly.

The potential for a fire suppressant fluid to attain a sufficient vapor pressure to quench flames is strongly dependent on the difference between the fluid's boiling point and the operating temperature. Incorporating the chemical features that effect low atmospheric lifetime (criterion 2) generally results in molecules that are larger than halon 1301 and thus tends toward higher boiling points. Any increase in the specification for minimum operating temperature would allow consideration of molecules with higher T_b values. As T_b rises, there are more compounds per, *e.g.*, 10 °C band, so the domain of eligible chemicals increases significantly.

In September 2004, following a year-long examination of mishaps, the DoD reaffirmed that safety should be designed into weapons systems, not added afterwards, and that systems safety risk management should be integrated into overall safety engineering.[3] In anticipation of this, the NGP revisited the basis for the operating temperature requirement for halon (replacement) fire suppression systems.

Aviation fire incident data for the years 1980 through 2002 were obtained from the U.S. Army, Navy and Air Force Safety Centers. Each Safety Center also provided information on the altitude, outside air temperature (OAT), and location associated with many of the incidents. Table 1 summarizes the number of incidents provided by the Safety Centers.

Table 1. Numbers of Military Aviation Fire Incidents 1980 to 2002

Aircraft Type	Army	Navy	Air Force	Total
Fixed Wing	92	1,212	3,932	5236
Rotary	503	834	98	1435

Each fire incident was reviewed to determine whether agent release had occurred. Only agent releases associated with discharge of systems protecting the following were considered: engine nacelle, auxiliary power unit (APU), auxiliary power plant (APP), and gas turbine compressor (GTC) compartment. For those incident reports in which the OAT was not included, it was estimated using the reported altitude and standard altitude-temperature curves. [The pertinence of these curves was verified using the incidents for which complete data were reported.] For incidents in which neither altitude nor temperature information were recorded, a methodology for assuming flight altitude based on aircraft flight phase[4] was applied, as shown in Table 2. The resulting distributions of discharges are shown in Figures 1 and 2 for fixed-wing and rotary wing aircraft, respectively.

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[3] Memorandum on Defense Acquisition System Safety from M.W. Wynne, USD(AT&L) of 23 September 2004.
[4] Kolleck, M. L. and Jeffery, K., *Halon Discharges at Altitude*, Booz-Allen, Dayton, OH, June 1994.

Table 2. Altitude Assumptions from Previous Halon Discharge Analysis[4]

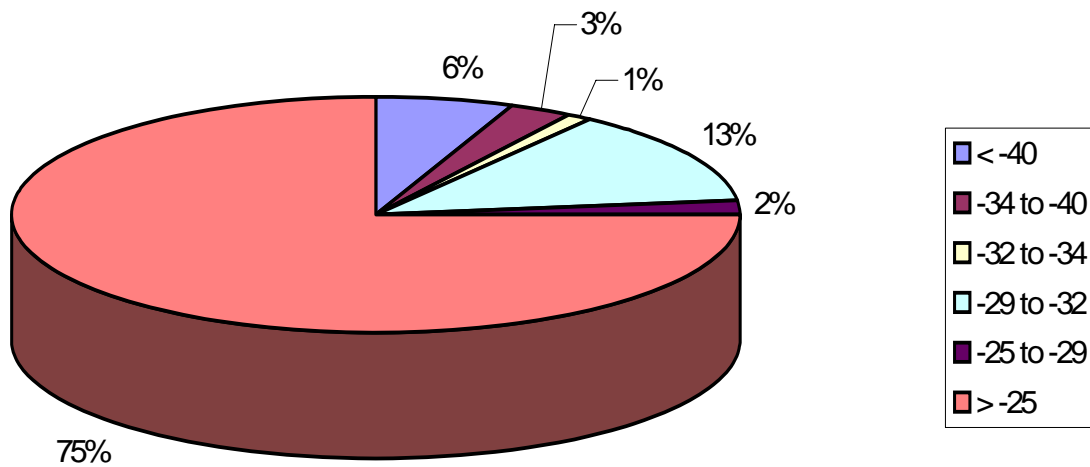| Phase	Altitude Range (km)	Assumed Altitude (km)	Assumed Altitude (ft)
Low	below 1.5	1.00	3280
Range work	below 1.5	1.00	3280
Bomb run	below 1.5	1.00	3280
After takeoff	below 1.5	1.00	3280
Cruise-fighter	6.06 to 7.58	6.82	22375
Cruise-cargo	9.14 to 10.67	9.90	32480
Refueling	8.79	8.79	28838

Figure 1. Ambient Temperature (ºC) at Halon 1301 Discharge for Fixed-wing Aircraft
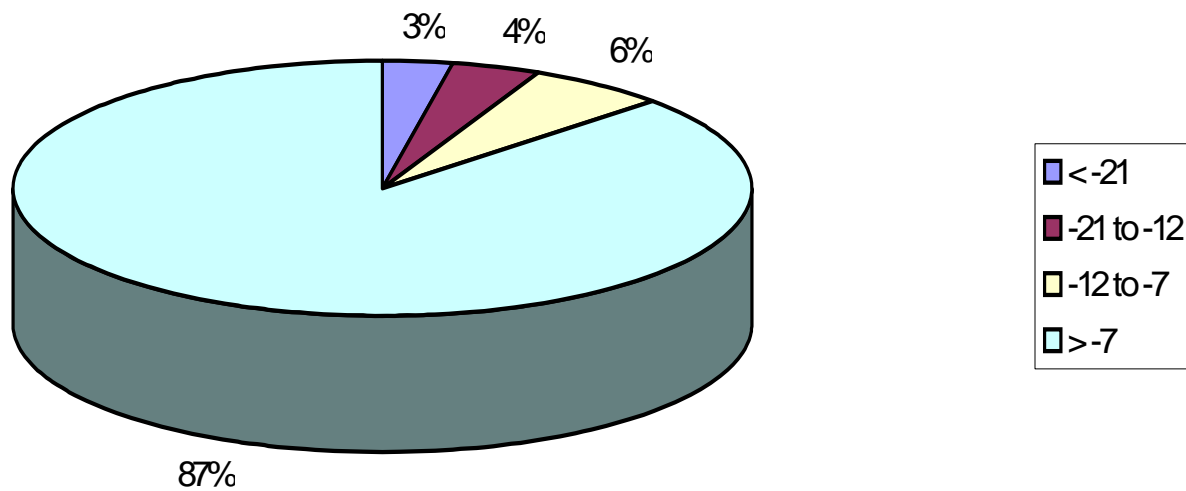
Figure 2. Ambient Temperature (ºC) at Halon 1301 Discharge for Rotary Wing Aircraft

The evaporation rate of a fire suppressant is also affected by the air temperature within the engine nacelle. Accordingly, an in-flight nacelle air temperature model was constructed to estimate nacelle air temperature during flight conditions. The model treats the nacelle as an air heat exchanger and computes the terminal temperature difference based on average, bulk values. The inlet conditions at the ram scoop are computed to be the stagnation properties for the given flight conditions, and these are taken to be the same as those inside the nacelle, close to the inlet. The effects of conduction and radiation heat transfer are assumed negligible; i.e., heat losses from air through the nacelle wall to the ambient outside by convection and conduction. The inputs to the model include the average nacelle clearance, diameter, ventilation air velocity and length; the aircraft altitude; the engine surface temperature, and the airspeed. The model was run for about 1000 cases, covering 8 altitudes between ground level and 9 km (30,000 ft), and for two airspeeds: 26 m/s and 206 m/s (50 knots and 400 knots, respectively).

88 % of the cases indicated nacelle air temperatures greater than -18 °C (0 ºF). Nearly all the other cases were for altitudes of 6 km (20,000 ft) or greater and airspeeds of 26 m/s (50 knots). These cases are artifacts because (a) military rotorcraft typically have operational ceilings less than 6 km and (b) 50 knots is below the stall speed for military fixed-wing aircraft that have nacelle fire suppression capability. The remaining 1.5 % of the cases were for input conditions at 9 km (30,000 feet) and 206 m/s and indicated nacelle air temperatures ranging between -23 °C (-10°F) and -24°C (-12°F).

The accuracy of the model was checked using data from recent in-flight temperature measurements in rotary aircraft. The model tended to predict temperatures lower than those measured and is thus conservative.

Since some halon 1301 discharges occurred shortly after take-off, consideration was given to the possibility that the system was "cold soaked," i.e., the temperatures had equilibrated with very cold ambient conditions. The data indicate that only about 1 % of the incidents (ground or in-flight) occurred in cold or severe cold climates

Thus, the principal findings of this analysis are:

- Nearly all releases of halon 1301 in military aircraft have been at temperatures higher than the design temperature of -40 °C. For fixed-wing aircraft, 75 % of the releases were at OATs above -25 °C (-13 °F); for rotary aircraft, 97 % were above -21°C (-6 °F).

- The gas temperature in the engine nacelle has almost always been above -18 °C (0 °F).

This does not, of course, represent relief from the current specification; that is a DoD policy matter. Moreover, even if the specification were raised to -25 °C (-13 °F), this would not increase the list of otherwise acceptable chemicals that could flash. It would, however, increase the evaporation rate of those chemicals with moderately higher boiling points.

As a result, the NGP will flag for possible further consideration any compounds that have desirable values of the other pertinent properties, but marginally high boiling points. The DoD can then perform risk analyses that would assist in the consideration of an alternate suppressant for a particular aircraft or the entire fleet.

C. CF_3I Properties

This chemical has flame suppression capability similar to halon 1301, but a higher boiling point and toxic potency. To date, it has been rejected for use within the U.S., but is being considered for application in other countries. The NGP has been conducting two small efforts on this chemical.

A fire extinguishing agent must be able to be stored for long periods of time at high pressure in metal containers without degrading and losing its effectiveness. CF_3I (and a variety of other candidate suppressants) had been placed in individual PTFE-lined steel stainless cylinders that also contained coupons of various metals from which agent storage bottles might be fabricated. These cylinders were stored at temperatures ranging from 22 °C to 150 °C for three years. At that time, samples were extracted and analyzed using Fourier transform infrared (FTIR) spectroscopy. Most of the samples showed no degradation. However, the combination of elevated temperature and copper-containing metals had caused serious degradation of the CF_3I in some of the vessels. The samples were then stored at about 22 °C for another five years. The subsequent FTIR analyses indicated no new spectral peaks, little change in any fluoroalkene peaks, and general stability of the CF_3I peak within the experimental uncertainty of 1.2 %.

Were CF_3I to be substituted for halon 1301, it would likely be released to the environment in a similar manner and frequency. The NGP was created because of the effect of halon 1301 releases on stratospheric ozone. CF_3I is readily degraded at altitudes below the stratosphere, and has a very short atmospheric lifetime compared to halon 1301. Thus, it might well have a far smaller deleterious environmental effect, depending on the altitude of its release. A prior analysis of such a substitution for fuel tank inerting in the F-16 showed that the substitution

might not have a significant benefit for that application.

The historic profile and magnitude of halon 1301 releases for engine nacelle fire suppression are different from that for fuel tank inerting. As recommended by the Independent Review Panel (see the 2003 NGP Annual Report), the NGP commissioned a calculation to estimate the effect of the substitution for the nacelle application. The data for the altitude release profile came from the compilation discussed in the prior section of this Report. A report on the atmospheric computation results is expected early in calendar 2005.

D.   New Candidate Suppressants

Last year, the NGP had identified nine chemical families whose consideration would complete the screening for new alternatives to halon 1301. Based on commercial availability and a scouring of the community for sources to synthesize these compounds, combined with the above findings regarding volatility, the list has been refined, as described in Table 3.

Table 3.   Representative Compounds for Screening

Chemical Family	Initial Compound(s)	Notes
bromofluoroalkenes	$CHF_2CBr=CF_2$	A sample of this compound was acquired. T_b was estimated to be about 30 °C. The cup burner extinguishment volume fraction was measured as 0.033, as expected for a bromine-containing compound with only one hydrogen atom. Prior work indicated that lower atmospheric lifetimes and lower boiling points than the trifluoro counterparts were likely and that the lower boilers would likely be of low toxicity. Other compounds will be acquired only if they have lower T_b values.
bromofluoroalkylethers	$CBrHFOCF_3$ $CBrF_2OCHF_2$	Two prior compounds had high boiling points of 39 °C and 70 °C, but good cup burner values of 0.032 and 0.036. The values of T_b for these compounds were expected to be 5 °C to 15 °C. However, attempts at synthesizing them failed. Other approaches are being considered.
	$CF_2HCFBrOCF_3$ $CFBrHCFHOCF_3$	These compounds have been ordered. T_b values have been estimated as about 42 °C and 37 °C, respectively, but these and the cup burner values will be checked Other compounds will be acquired only if they have lower T_b values.
bromofluorovinylethers	$CF_2BrCF_2OCF=CF_2$	A small sample of this compound has been acquired. T_b was determined to be about 55 °C, and the cup burner value was 0.045. Other compounds will be acquired only if they have lower T_b values. Changes in the bromination site might help.
fluoronitriles	CF_3CN	This commercially available compound has a very low T_b of -64 °C. However, the cup burner value was determined to be 0.09. Thus, there is no chemical activity from the CN group. The compound is no better than HFC-125, and no further compounds from this group being acquired.

Chemical Family	Initial Compound(s)	Notes
bromofluoronitriles	CF_2BrCN	A small sample of this compound was acquired. T_b is 3 °C and the cup burner value is less than 0.04. This compound should have a short atmospheric lifetime due to OH reactivity and is now a candidate for tropodegradability screening. We are also considering an acute toxicity screen test and perhaps an evaporation rate measurement. Recently, there has been a report of unpublished data indicating this compound is highly toxic. An attempt is underway to identify and contact the source of the finding. Additional compounds to be considered only if they have lower T_b, not a likely occurrence.
bromofluoropropeneoxides	$CF_3CBr(O)CF_2$	A sample of this compound was acquired, with T_b estimated to be 20 °C. The measured cup burner value was a marginal 0.049. A low atmospheric lifetime was expected. However, additional compounds to be considered only if they have lower T_b, not a likely occurrence.
N-bromofluoroalkylamines	$(CF_3)_2NBr$	Published syntheses of this compound appear favorable, and the compound has been ordered. The published T_b is about 22 °C. Additional compounds will be considered only if they have lower T_b.
bromofluoroalkylamines		No sources of any compounds in this family have been found, despite a worldwide search.
N-bromofluoroimines	$CF_2=NBr$	There is a reported synthesis for this compound, with a T_b of 14 °C. The weight percent of bromine is higher than that of halon 1301, indicating the potential for high flame suppression efficiency. The compound has been ordered. Additional low boiling analogs may be worth considering if the first suppression result is favorable.

E.   Limits to Effectiveness of Metal-containing Compounds

There has been extensive research on the extraordinary flame *inhibition* effectiveness of iron-containing compounds. In these laboratory tests, small amounts of the compounds fractionally reduced the flame burning velocity far more efficiently than did halon 1301. However, in no cases were the flames extinguished. NGP research has developed an explanation for this binary behavior. The addition of small amounts of the compound catalytically recombines hydrogen atoms, reducing the concentration of the prime attacker of fuel molecules. As more of the compound is added, the higher concentration favors condensation to inert iron oxide particles. Thus there is never enough of the flame retarding species to drive the flame all the way to extinction.

Compounds of other metals, if they were effective flame suppressants, would likely be either solids or viscous liquids, not suitable for use as suppressant fluids. They could, however, be incorporated into solid propellant fire extinguishers (SPFE). [In fact, it was NGP SPFE experiments with ferrocene that demonstrated the inability of an iron-containing compound to quench larger flames.]   It was thus important to know whether any other metal-containing compounds might have potential for this use.

The NGP thus undertook a review and analysis of the literature to understand metal chemistry in flames. This included a detailed examination of the mechanism of inhibition of iron and the reasons for its loss of effectiveness. This was followed by summarizing the demonstrated flame inhibiting properties of other metals and composing a description of the potential loss of effectiveness for them.   The literature analyzed included that on engine knock, premixed and diffusion flames, flame retardancy, ignition, rocket nozzles, and NO formation. The metals covered were chromium, lead, manganese, tungsten, molybdenum, tin, cobalt copper, and antimony. This work has uncovered that tungsten, molybdenum and cobalt are likely to be effective inhibitors at low concentrations, results that have not been suggested in previous reviews of flame inhibition by metal-containing compounds.

There exist several screens for estimating whether other metallics will have a loss of effectiveness similar to that of iron, including:

- Experimental data for flame systems in which the loss of effectiveness is evident. This requires that the inhibitor be added at volume fractions high enough to observe the loss of effectiveness.

- Reported presence of particles in some flame system. Although the presence of particles will depend upon the temperature of the flame, the concentration at which the metallic compound is added, and the residence time for particle formation, the observed presence of particles in one flame system is an indication that it may be important in other flame systems as well.

- Consideration of saturation (volume fraction as compared to local vapor pressure) in the flame of the local metal species. A limitation of this method is that it relies upon knowledge of the metal species present in a flame system, the mechanism of inhibition, as well as the vapor pressure (or gas-phase and condensed-phase thermodynamic data). Often, this information is incomplete. Further, the kinetic rates of the formation of more

stable oxides of the metal must be known to assess the contribution of those compounds to condensed-phase particles.

Table 4 summarizes the results of this screening analysis for whatever compounds of these metals have been examined. The metals are listed in roughly decreasing order of inhibition effectiveness, based on the literature review. A prospective SPFE additive should have a mark in the first column and no marks in the three right-hand columns. The absence of a mark indicates that there are no reported studies or that the results are inconclusive.

Table 4. Evidence Regarding Potential for High Flame Suppression Efficiency of Metal-containing Compounds

Metal	High Inhibition Efficiency	Loss of Effectiveness	Presence of Particles	Evidence of Saturation
Cr	Y	Y	Y	Y
Pb	Y	Y	Y	Y
Mn	Y	Y	Y	Y
W				
Mo				
Sn	Y	Y	Y	Y
Co	Y			
Cu				
Sb	Y	Y	Y	Y

For W, Mo, Co, and Cu, there is no direct evidence of the potential for loss of effectiveness, and the vapor pressures of the suggested flame-quenching species (for which data are available) are reasonably high. For Co, the monoxide CoO is likely to be an important intermediate in the inhibition cycle. Its low vapor pressure can be taken as evidence for the potential for condensation. Nonetheless, the potential for condensation of metal species really depends upon the local super-saturation ratio in the inhibited flame. Calculation of the super-saturation ratio depends upon knowing both the detailed kinetic mechanism of inhibition as well as the vapor pressure of all of the intermediate species. Further, the kinetics of the condensation (and potential re-evaporation of particles) will be highly dependent on the flow-field of the particular flame system to be extinguished. *Prediction* of the potential loss of effectiveness due to condensation is beyond the current state-of-the-art.

Prior NGP experiments with K_2CO_3 added to an SPFE have shown a significant increase in flame extinguishment efficiency relative to the same formulation without the potassium salt. These results were verified in real-scale engine nacelle fire tests. Thus, the current results provide backup only in case potassium salts manifest some other undesirable behavior.

Should more definitive information on compounds containing these metals be desired, two possible screening experiments are suggested:

- Cup burner tests would determine the amount of a diluent (e.g., CO_2, or N_2) added to the air stream necessary to cause blow-off of the cup-burner flame, both with and without the metal agent added at increasing concentration in the oxidizer stream. Since, to some extent, the flames resemble the low-strain conditions of fires, there is expected to be a reasonable correlation between the behavior in this system and in actual suppressed fires. By adding the metal compounds in the form of organometallic agents (rather than metal salts), the complicating effects of particle evaporation and decomposition can be avoided.

- Addition of metal-containing compounds to an SPFE. There is inert gas in the effluent, as well as fragmented metal-containing species, so that by proper application to an appropriate fire, the utility of the metal additive could be assessed at larger scale. The challenge would be to find a configuration that has the proper sensitivity to the inert gas flow so that the effects of the additive could be quantified.

F.   Fire Suppressant Dynamics in Cluttered Engine Nacelles

The objective in this portion of the NGP is to provide the basis for optimizing the distribution of suppressants, thereby improving the suppression efficiency of gases and aerosols that are less effective than halon 1301. The tool by which this guidance is to be delivered is a validated computational fluid dynamic (CFD) model of suppressant flow, a fire, and fire extinguishment in cluttered environments. Earlier components of this effort had been:

- Laboratory experiments to develop understanding of suppressant droplet dynamics around obstacles and upon impact on cold and heated surfaces.

- Extension of this knowledge to spray-clutter interactions in a wind tunnel.

- Adaptation of the Vulcan CFD model for simulating these suppressant-laden flows.

- Examination of the effect on agent distribution of varying the number of agent injection nozzles.

This year, a first series of fire suppression tests were conducted in the NAVAIR F-18 E/F Ground Engine Nacelle Simulator and the results compared with simulations previously made using the CFD computer code. The 25 experiments were designed to explore the envelope of test conditions under which flame extinguishment did and did not occur.

Figure 3 is a photograph of the test fixture. The nacelle is ca. 3.18 m (125 in.) in length. The height and width vary along the length, but they are contained within a region 1.45 m high and 1.15 m wide. The engine surface, a hollow cylinder, has a diameter of 0.77 m in the front (the left in the Figure), narrowing to 0.62 m at the rear. Air and agent are introduced into the nacelle through the diagonal pipe at the lower left of the photograph. The intake air flow is turbulent even without the clutter-induced mixing.

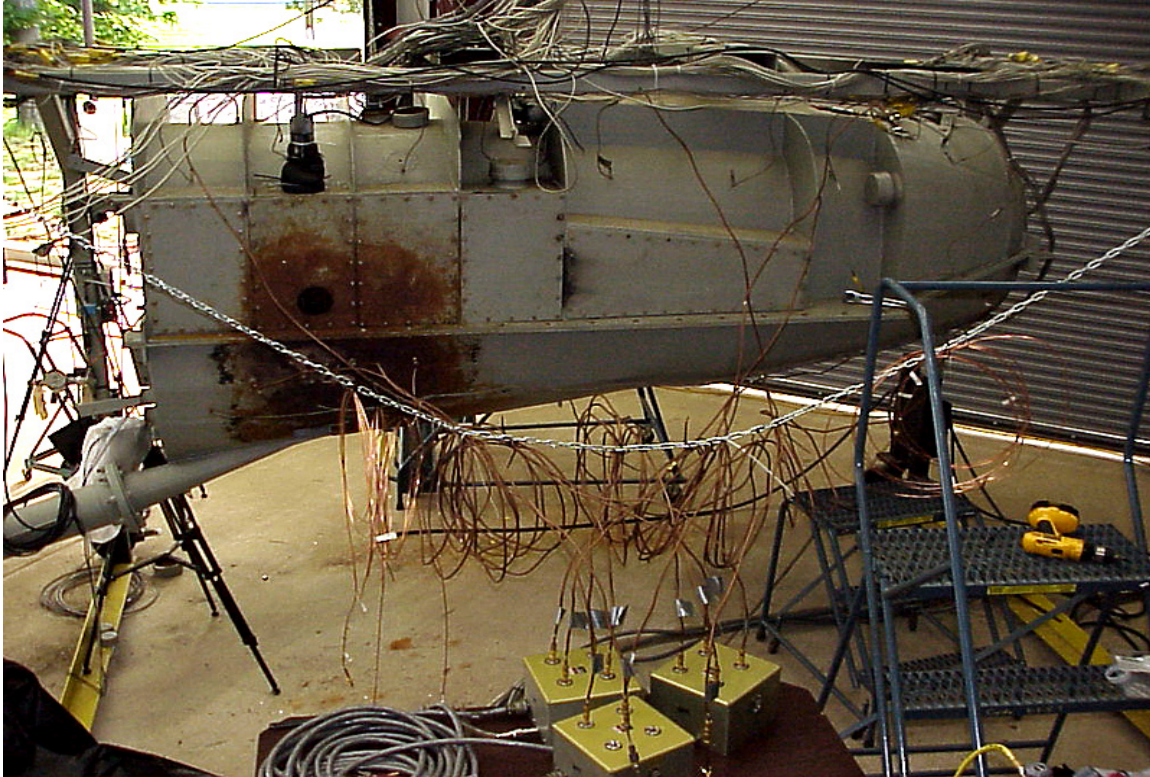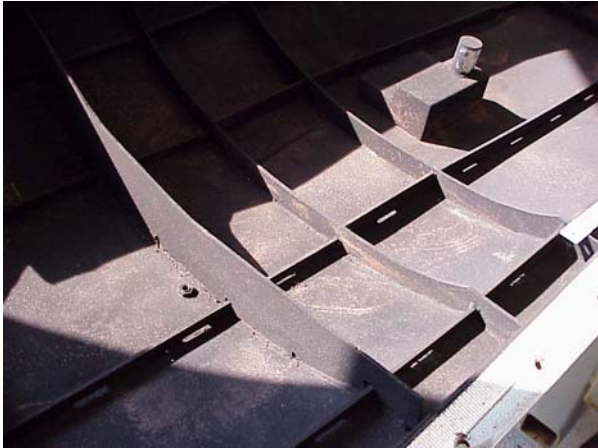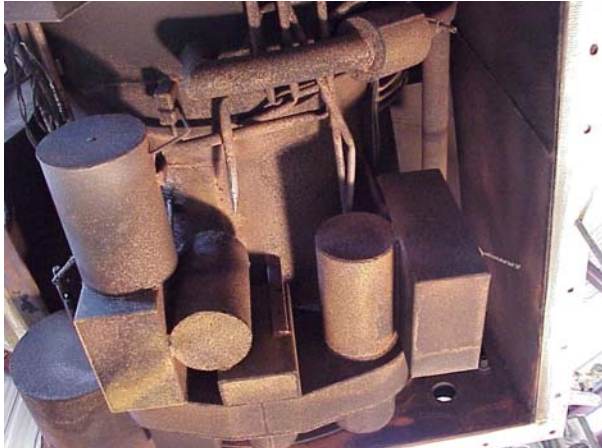**Figure 3. Photograph of the NAVAIR F-18 E/F Ground Engine Nacelle Simulator**

Clutter objects are located along its length. There are ribs and longerons, along with other clutter, along the length of the nacelle (Figure 4a) and a gearbox assembly located 0.1 m to 0.75 m from the forward end and mostly below the engine (Figure 4b).

4a

4b

Figure 4. Photographs of Ribs/Longerons and Gear Box Assembly

Before conducting fire suppression tests, determinations were made of the accuracy with which the model simulated the distribution of fire suppressant in the fixture. Measurements of HFC-125 (C_2HF_5) were made at 12 locations using a Halonyzer II. Figure 5 compares the predicted concentration of HFC-125 at two of those locations with the predicted concentrations for two different injection durations. The actual agent release duration was 2.7 s. As the agent concentration rises, the simulation with a 3 s injection period replicates both sets of test data well. The model reasonably replicates the flushing of the agent from the nacelle at location 3. For location 1, the model flushes the agent too quickly. The discrepancy is likely due to two idealizations in the model. First, the agent dispensing is simulated as a square wave, while in the test there is a "tail" to the ejection as the pressure in the storage bottle decreases. Second, the model assumes that the agent flashes completely upon injection, while in the tests there was some downstream evaporation of liquid. The discrepancies on the "down" side of the curves are relatively unimportant since the fires will typically be quenched before the peak concentration of agent is reached.
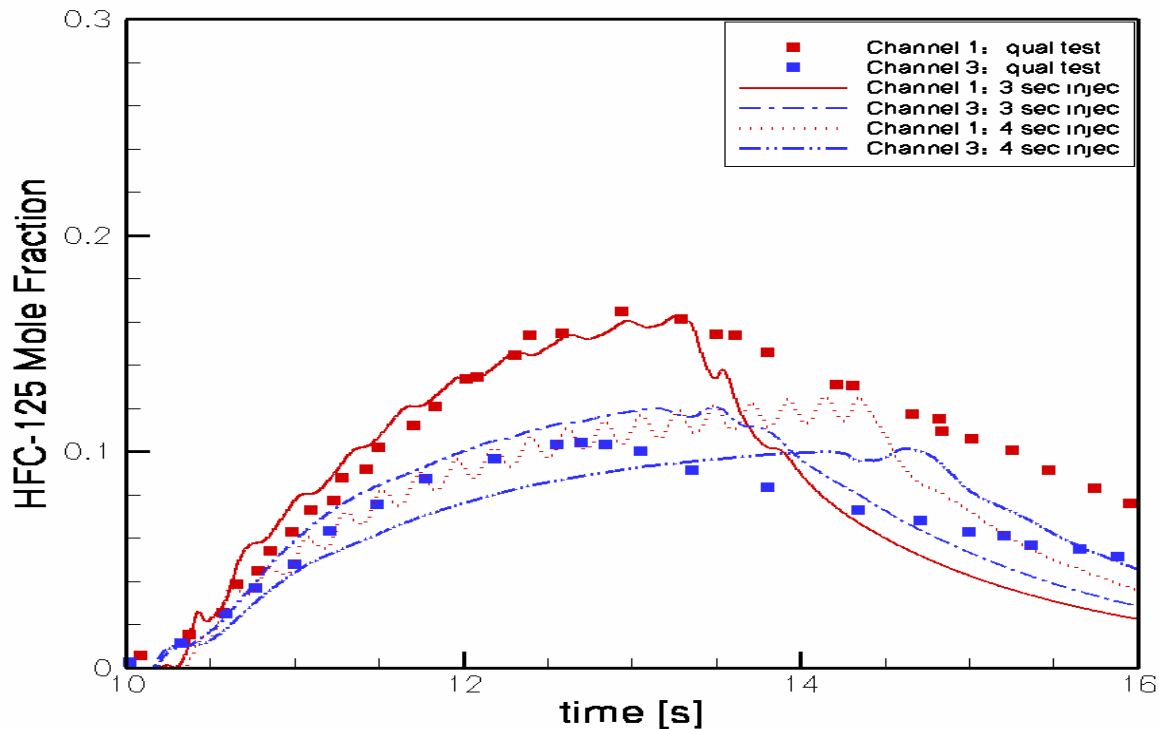
Figure 5. Comparison of Measured and Simulated Concentration Throughout a Discharge Test

For the fire suppression tests, pools of JP-8, each 0.09 m^2 in area, were situated at three locations (all downstream of ribs) on the nacelle floor below the engine. Variables in the tests included mass of suppressant in the storage bottle, discharge rate of the agent, air flow, and one-at-a-time capping of three of the four agent injection nozzles. Within the apparatus geometric limits and the physical properties of the suppressant, it was not possible to replicate exactly the Vulcan simulations in all cases. However, the test matrix did preserve the trends of configuration and flows from the simulations.

Two parameters determined the average overall suppressant mass fraction in the test fixture:

1. The ratio of "suppressant" mass inflow to "suppressant plus air" mass flow determined the maximum value attainable for long times, referred to as the inflow ratio.

2. The "suppressant plus air" flow determined the time to reach these maximum values. This time was generally much less than the injection duration, indicating that the maximum values were closely approached.

It was a very successful series of tests. In all but two cases, the model and the test agreed as to whether the fire was extinguished or not. Figure 6 shows the inflow ratio in the tests for which Vulcan simulation had been performed. For each test, the top three bars are the estimated inflow ratio based on the measured pressure drop at the storage bottle over 1 s, 2 s, and 3, s. The "target" bar represents the theoretical fraction, as employed in the Vulcan simulations.
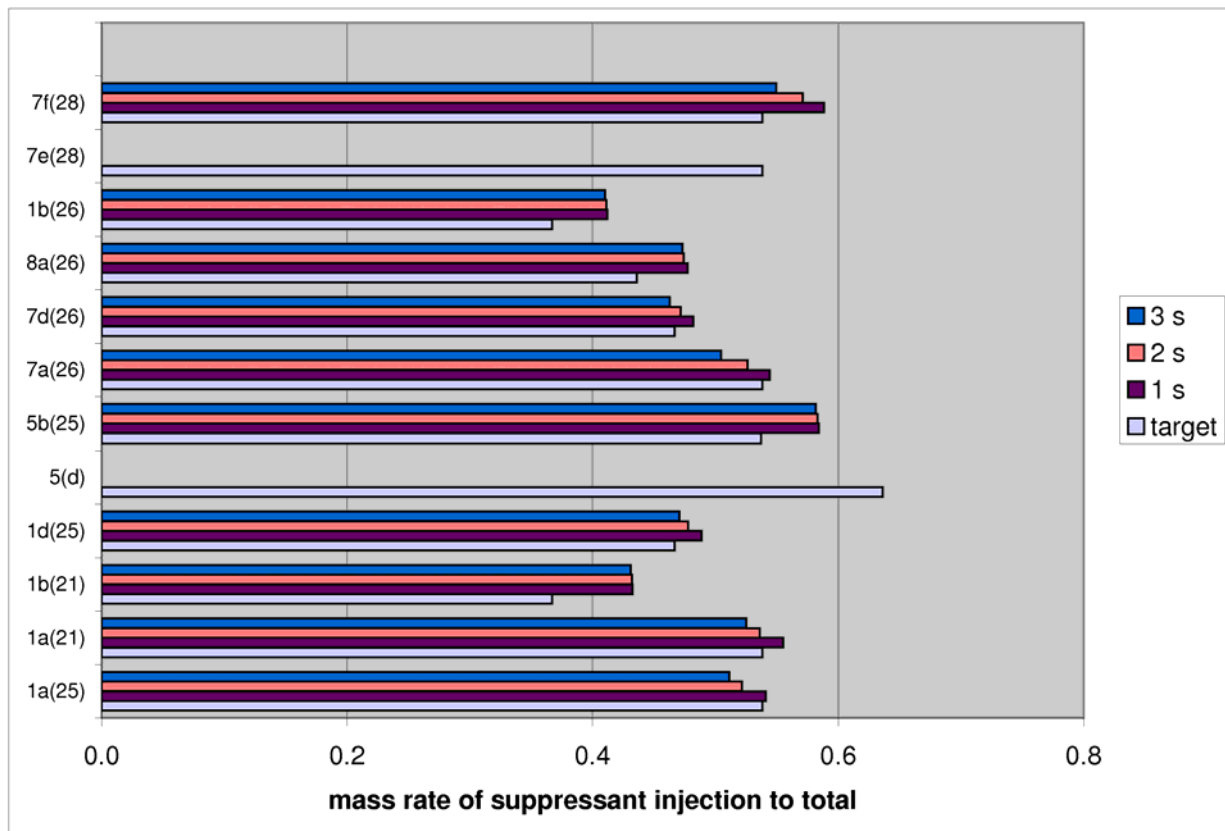
Figure 6.   Agent Injection Ratios

When the agent inflow ratio, based on the bottle discharge was below about 0.43 (mole fraction about 0.15), the fires were not extinguished. This inflow ratio corresponds to an average mole fraction of 0.15, almost twice the cup burner suppression value. This indicates the significance of inhomogeneities within the nacelle, i.e., some regions have a much lower mole fraction than the average.

Figures 7 and 8 are plots of the midsection of the nacelle from a simulation of a successful flame suppression. The air flow is from the left, and the blue cylinder indicates the location of the engine. The dimensions along the y-axis are measured from the nose of the airplane; all

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dimensions are in meters. The three pool fires are located along the x = 0.5 line centered at about y = 15.5 m, y = 16.0 m, and y = 16.6 m. Two agent introduction ports are located just to the starboard of the middle pool fire, with one directed upward and the other directed horizontally toward the center of the nacelle. A third injector is located above the third pool fire and is directed upward at a roughly 45 ° angle. The fourth port is downstream of the third pool fire, high in the nacelle and pointing downward.

In Figure 7, the heating of the lower level gas flow by the pre-burning pool fires just prior to discharge is evident. Figure 8 shows the agent distribution (mass fraction) 1 s after the start of the discharge. The black surfaces indicate the expanse of the heat from the fires. Prior to discharge, only the air inlet is cool, while 1 s after the start of injection, the pool fires are already nearly fully suppressed and the nacelle has cooled substantially.
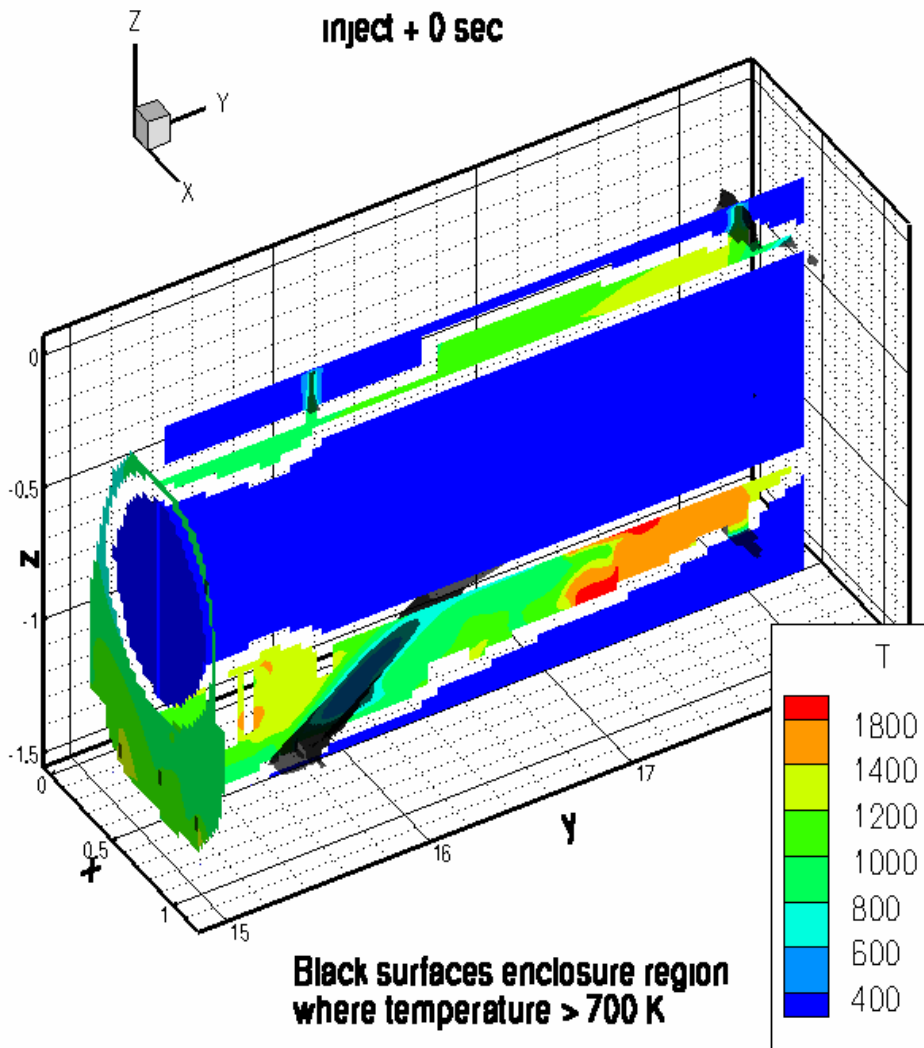
Figure 7. Contour Plot of Simulated Temperatures Just Before Agent Injection

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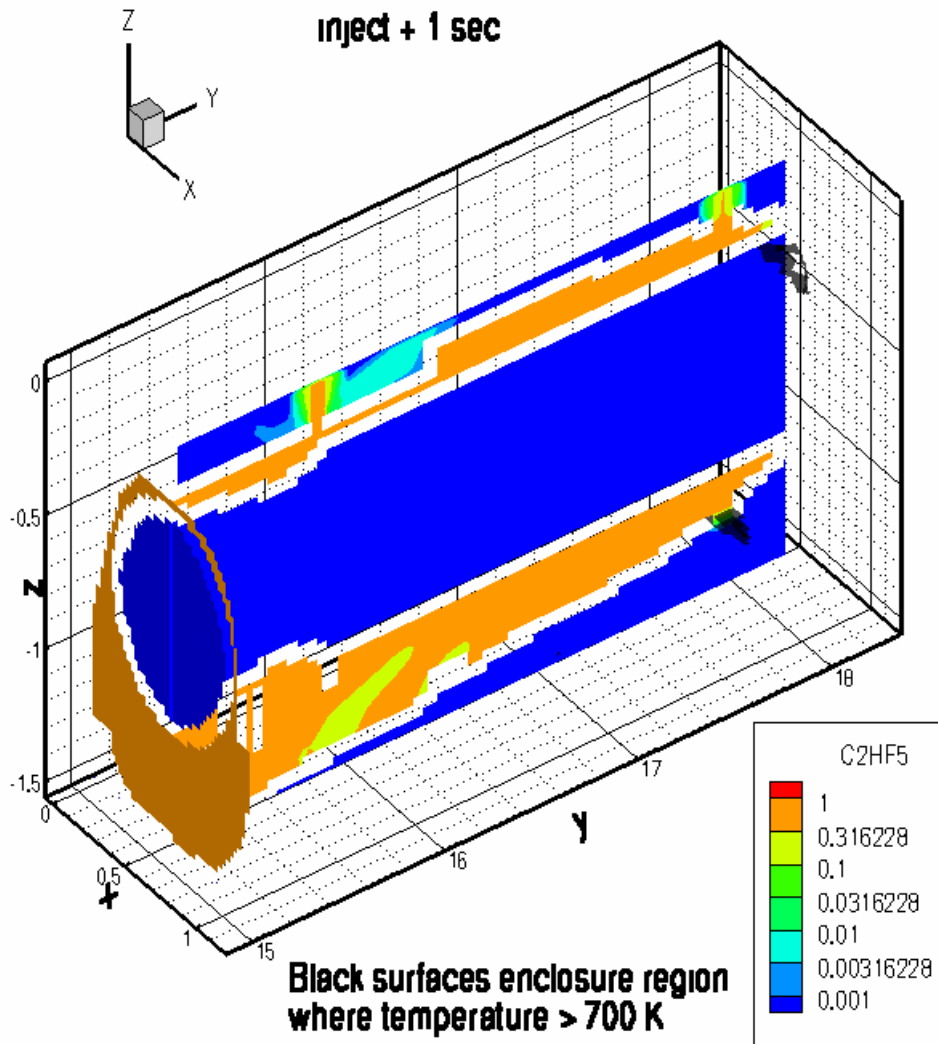
Figure 8. Contour Plot of Simulated Agent Distribution 1 s After Initiation of Discharge

Additional tests were also conducted where individual nozzles were removed to increase the degree of inhomogeneity of agent distribution. The results indicate that Vulcan predicts somewhat greater sensitivity to removing nozzles than is observed in the tests. Analysis of all the data from the experiments and simulations is underway.

G.   Verification of NGP-Developed Fire Suppression Principles

Planning is underway for a series of about 1000 real-scale engine nacelle fire suppression tests. These are scheduled for summer 2005. Their purposes will be (a) to verify the fire suppression principles developed in the NGP by comparing the outcome of the tests with predictions based on NGP-developed technology and (b) to identify any as-yet unexplained suppression phenomena. Candidates for test variables include:

- Nacelle temperature
    - Low in-flight value
    - Moderate in-flight value
    - Value related to the minimum volatility of a fluid suppressant

- Agent storage temperature
    - Same as nacelle temperature
    - Below nacelle temperature (simulating cold soak)

- Length and nature of distribution plumbing
    - Short, straight run
    - Longer, bent run

- Number, nature and location of injection ports (based on outcome of modeling and experiments in Project 6A/1)
    - Two to three different numbers of ports
    - Two nozzle designs, possibly tuned to the suppressant properties
   - Two location sets

- Agent injection momentum
    - High value, indicative of rapid release
    - Low value, to provide most effective flooding of the nacelle volume

- Agent chemistry and thermophysical properties. Some agents likely would be introduced as compressed fluids, others from solid propellant fire extinguishers.
    - Three fluids, one non-catalytic, two catalytic (probably bromine-containing) with different boiling points relative to the nacelle temperatures
    - Two SPFEs, one with an additive to the propellant, one an HFE

- Fire
    - One exposed location, one occluded location
    - Spray, pool

- Agent mass
    - To generate concentration predicted for direct flame extinguishment
    - To generate concentration estimated (from prior experiments) to quench relight
    - An intermediate concentration (if relight is quenched) or a larger concentration (if relight is not quenched)

Each test sequence involves tests at several agent concentrations (to determine the mass needed for flame extinguishment) and replicate tests (to mitigate the occurrence of single anomalous results). A factorial experimental design will be used to extract the maximum amount of information from the modest number of tests.

H.   Recent Publications

(* indicates archival publications)

Bein, D., "In-Flight Suppressant Deployment Temperatures," in Gann, R.G., Burgess, S.R., Whisner, K.C., and Reneke, P.A., eds., Papers from 1991-2004 Halon Options Technical Working Conferences (HOTWC), CD-ROM, NIST SP 984-2, National Institute of Standards and Technology, Gaithersburg, MD, (2004).

Mather, J.D., and Tapscott, R.E., "Environmentally Acceptable Flame Extinguishants," in Gann, R.G., Burgess, S.R., Whisner, K.C., and Reneke, P.A., eds., Papers from 1991-2004 Halon Options Technical Working Conferences (HOTWC), CD-ROM, NIST SP 984-2, National Institute of Standards and Technology, Gaithersburg, MD, (2004).

Mather, J.D., and Tapscott, R.E., "Tropodegradable Bromocarbon Extinguishants II," Final Report to SERDP, 2004.

Linteris, G.T., "Limits to the Effectiveness of Metal-containing Fire Suppressants," Final Report to SERDP, December 2004; and NISTIR 7177, National Institute of Standards and Technology, Gaithersburg, MD, 2004.

*Linteris, G.T., Katta, V.R., and Takahashi, F., "Experimental and Numerical Evaluation of Metallic Compounds for Suppressing Cup-burner Flames, *Combustion and Flame* **138**, 78-96 (2004).

Donnelly, M.K., Harris, R.H., and Yang, J.C., "CF_3I Stability Under Storage," NIST Technical Note 15452, National institute of Standards and Technology, Gaithersburg, MD, 2004.

Fleming, J.W., and Yang, J.C., Modeling Study of the Behavior of Liquid Fire Suppressant Agents in a Simulated Engine Nacelle," in Gann, R.G., Burgess, S.R., Whisner, K.C., and Reneke, P.A., eds., Papers from 1991-2004 Halon Options Technical Working Conferences (HOTWC), CD-ROM, NIST SP 984-2, National Institute of Standards and Technology, Gaithersburg, MD, (2004).

*Disimile, P.J., Tucker, .R., Croswell, B., and Davis, "The Transport of Water Sprays Past Generic Clutter Elements Found Within Engine Nacelles," *Fire Safety Journal* **40**, 65-78, 2005.

Keyser, D.R., and Hewson, J.C., "Fire Suppressant Distribution in an F-18 E/F Nacelle," in Gann, R.G., Burgess, S.R., Whisner, K.C., and Reneke, P.A., eds., Papers from 1991-2004 Halon Options Technical Working Conferences (HOTWC), CD-ROM, NIST SP 984-2, National Institute of Standards and Technology, Gaithersburg, MD, (2004).

Hewson, J.C., and Keyser, D.R., "Predicting Fire Suppression in an F-18 E/F Engine Nacelle," in Gann, R.G., Burgess, S.R., Whisner, K.C., and Reneke, P.A., eds., Papers from 1991-2004 Halon Options Technical Working Conferences (HOTWC), CD-ROM, NIST SP 984-2, National Institute of Standards and Technology, Gaithersburg, MD, (2004).

Disimile, P.J., and Davis, J.M., "The Effect of Optical Configuration Selection on Phase Doppler Anemometer Fire Suppressant Nozzle Characterizations," in Gann, R.G., Burgess, S.R.,

Whisner, K.C., and Reneke, P.A., eds., Papers from 1991-2004 Halon Options Technical Working Conferences (HOTWC), CD-ROM, NIST SP 984-2, National Institute of Standards and Technology, Gaithersburg, MD, (2004).

Disimile, P.J., Tucker, J.R., Stern, J., Mehl, L., and Croswell, B., "Velocity and Drop Distributions Downstream Generic Clutter Elements Found Within Engine Nacelles," in Gann, R.G., Burgess, S.R., Whisner, K.C., and Reneke, P.A., eds., Papers from 1991-2004 Halon Options Technical Working Conferences (HOTWC), CD-ROM, NIST SP 984-2, National Institute of Standards and Technology, Gaithersburg, MD, (2004).

*S. S. Yoon, P. E. DesJardin, J. C. Hewson, C. Presser, C. T. Avedisian, "Numerical Modeling and Experimental Measurements of Water Spray Impact and Transport over a Cylinder," *International Journal of Multiphase Flow*, submitted for publication, 2004.

Davis, J., and Disimile, P.J., "The Effect of Lens/Aperture Selection on Phase Doppler Anemometer Measurements," AIAA 42th Aerospace Sciences Meeting and Exhibit, January 14-17th 2004, Reno, Nevada.

*Ghee, T.A., and Keyser, D.R., "Aerodynamics of Circular Cylinder Shapes in Low-Speed, Highly Turbulent Flow," *AIAA Journal of Aerodynamics*, submitted for publication, 2004.

Presser, C., Avedisian, C.T., and Johnson, B.S., "Phase Doppler Measurements of Liquid Fire Suppressants over a Heated Cylinder," AIAA 2004-0479, American Institute for Aeronautics and Astronautics, Washington, DC, 2004.

Cyphers, D.C., "Enhanced Powder Panels," Final Report to SERDP, Skyward, Inc., 2004.

Cyphers, D.C., "Enhanced Powder Panels - Applying New Ideas to an Old Fire Extinguishing Method," Military Fire Protection Systems Edition, FS-World.com Magazine, 2004

Johnsson, E.L., Mulholland, G.W., Fraser, G.T., Leonov, I.I., and Golubiatnikov, G.Y., "Description and Usage of a Fast-response Fire Suppressant Concentration Meter," NIST Technical Note 1463, National Institute of Standards and Technology, Gaithersburg, MD, (2004).

Johnsson, E.L., Mulholland, G.W., Fraser, G.T., Leonov, I.I., and Golubiatnikov, G.Y., "Development of a Fast-response Fire Suppressant Concentration Meter," NIST Technical Note 1464, National Institute of Standards and Technology, Gaithersburg, MD, (2004).

III. INDEPENDENT PROGRAM ASSESSMENT

For a third year, the NGP Independent Review Panel (IRP) was asked to assess progress to date and to recommend actions that could enhance the prospects for NGP research to result in viable and practical alternative fire suppression technologies with NGP resources remaining at or near currently projected levels.

The IRP was impressed by the thoughtful way their prior recommendations have been addressed and by the tightened focus of the program.   They made no additional recommendations that entailed either course changes or significant project modification. Rather, their report comprises a series of observations on the content and output of the individual projects. These are contained in the draft report (Appendix B).

This will be the last report from the Panel. One of the members has retired and another is deceased. Since the sitting Panel had commented on all current and planned NGP projects, the decision was taken not to re-constitute the IRP for the last year of NGP research.

IV.   WHAT LIES AHEAD?

The Next Generation Fire Suppression Technology Program will reach completion in FY2006. At that time, the NGP will have met its 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*. The completion of the NGP will mark the end of DDR&E's program in fire suppression and will provide a sound technical basis for future fire suppression systems and research efforts.

There are a small number of key technical tasks, mostly underway but yet to be completed, needed in order to deliver the intended products:

- A well documented and archived science base for fire suppression research;

- Identification of the best chemicals to consider as alternatives to halon 1301 for extinguishing in-flight fires in aircraft engine nacelles and dry bays;

- Guidance for engineering the fire suppression system to obtain the most efficient use of the suppressant chemicals;

- Development of practicable non-fluid-based suppression technologies (completed); and

- Creation of means for deciding among candidate solutions for a given application (completed).

The remaining tasks are:

- Completion of assessment of the nine chemical families listed in Table 3.

- Completion of guidance for efficient agent delivery, as described in Section 3.F.

- Verification of the effectiveness of the new distribution principles and the relative performance of chemicals, as described in Section III.G.

- Preparation of the NGP final report. Due to the quantity of the material and the interactive nature of the NGP projects, this extensive undertaking will be in book form. The NGP has re-established the disciplinary science of fire suppression, creating a viable foundation and framework for future R&D in fire suppression, particularly for weapon systems and even for needs in outer space. This book will pull together the new knowledge into a unified package.

In addition to these, the NGP expects to continue sponsorship of the Halon Options Technical Working Conferences through FY2006. This focused meeting is a prime venue for ensuring that the latest developments are incorporated in NGP results and for efficient transfer of the NGP results to a wide national and international user community.

The estimated timeline for completion of the NGP is shown in Appendix C.

The prognosis for successfully meeting the NGP goal is excellent, given the technical infrastructure and cadre of experts advanced by the NGP. The Department of Defense has already made use of NGP technology in testing, selecting, and designing suppression technologies for some Military Service aircraft. More such test series are being planned and presumably will become the norm for the remaining platforms.

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APPENDIX A. NGP PROJECTS

The system for the identifier codes for the projects was developed at the beginning of the NGP and follows the now outdated program structure in the original NGP Strategy Document, which is available at the NGP web site. For current use, the important information is located following the second slash (*e.g.*, 3A/1/**789**). In this example, the project was funded in fiscal years 1997, 1998, and 1999.

A.　　SUPPRESSANT SCREENING TESTS

3A/1/789.　　DISPERSED LIQUID AGENT FIRE SUPPRESSION SCREEN; Principal Investigator: Jiann C. Yang, NIST

3A/2/890.　　TRANSIENT-APPLICATION-RECIRCULATING-POOL-FIRE AGENT EFFECTIVENESS SCREEN; Principal Investigator: William Grosshandler, NIST

3B/1/89.　　TOXICOLOGICAL ASSESSMENT OF HUMAN HEALTH CONSEQUENCES ASSOCIATED WITH INHALATION OF HALON REPLACEMENT CHEMICALS; Principal Investigator: Darol Dodd, AFRL

3B/2/8.　　AGENT COMPATIBILITY WITH PEOPLE, MATERIALS AND THE ENVIRONMENT; Principal Investigators: Marc Nyden, NIST, and Stephanie Skaggs, Universal Technical Services

B.　　NEW FLAME SUPPRESSION CHEMISTRY

2A/1/7890, /2/890.　　MECHANISMS OF ULTRA-HIGH EFFICIENCY CHEMICAL SUPPRESSANTS; Principal Investigators: James Fleming, NRL, and Kevin McNesby, ARL

4D/2/7.　　IDENTIFICATION AND PROOF TESTING OF NEW TOTAL FLOODING AGENTS; Principal Investigator: Robert E. Tapscott, NMERI; COR: Andrzej Miziolek, ARL

4D/5/8.　　MAIN GROUP COMPOUNDS AS EXTINGUISHANTS; Principal Investigator: J. Douglas Mather, NMERI; COR: Ronald Sheinson, NRL.

4B/1/8,4D/15/01.　　TROPODEGRADABLE BROMOCARBON EXTINGUISHANTS; Principal Investigator: J. Douglas Mather, NMERI; COR: Ronald Sheinson, NRL

4B/2/8,4D/3/7. FLAME INHIBITION BY PHOSPHORUS-CONTAINING COMPOUNDS; Principal Investigator: Elizabeth M. Fisher, Cornell University; COR: Andrzej Miziolek, ARL

4D/14/1.　　FLUOROALKYL PHOSPHOROUS COMPOUNDS; Principal Investigator: Douglas Mather, NMERI

4C/1/890.　　SUPER-EFFECTIVE THERMAL SUPPRESSANTS; Principal Investigator: William Pitts, NIST

4D/13/1.   EFFECTIVE, NON-TOXIC METALLIC FIRE SUPPRESSANTS; Principal Investigator: Gregory Linteris, NIST

4B/3/8901.   ENVIRONMENTAL IMPACT OF NEW CHEMICAL AGENTS FOR FIRE SUPPRESSION; Principal Investigators: Robert Huie and Marc Nyden, NIST; Andrzej Miziolek, ARL

4B/4/01234.   LOW TEMPERATURE PERFORMANCE OF HIGH BOILING POINT SUPPRESSANTS; Principal Investigator: Jiann Yang, NIST

4B/5/01234.   ALTERNATIVE SUPPRESSANT CHEMICALS; Principal Investigator: Richard Gann, NIST

4B/6/234.   ENVIRONMENTALLY ACCEPTABLE SUPPRESSANTS; Principal Investigator: Douglas Mather, Chemical Development Systems; Scientific Officer: Richard Gann, NIST

C.   NEW AND IMPROVED AEROSOL SUPPRESSANTS

2B/1/78901.   SUPPRESSION EFFECTIVENESS OF AEROSOLS AND PARTICLES; Principal Investigator: Ronald Sheinson, NRL

2B/2/89.   DROPLET INTERACTIONS WITH HOT SURFACES; Principal Investigator: Yudaya Sivathanu, En'Urga, Inc.; COR: William Grosshandler, NIST

2B/3/89.   TECHNICAL SUPPORT FOR THE STUDY OF DROPLET INTERACTIONS WITH HOT SURFACES; Principal Investigator: Jiann Yang, NIST

4A/1/890.   POWDER-MATRIX SYSTEMS; Principal Investigator: Gregory Linteris, NIST

4D/1/7.   ELECTRICALLY CHARGED WATER MISTS FOR EXTINGUISHING FIRES; Principal Investigator: Charles H. Berman, Titan Corp.; COR: Ronald Sheinson, NRL

4D/4/7.   DEVELOPMENT OF A SELF ATOMIZING FORM OF WATER; Principal Investigator: Richard K. Lyon, EER, Inc.; COR: William Grosshandler, NIST

4D/7/8.   DENDRITIC POLYMERS AS FIRE SUPPRESSANTS; Principal Investigator: Nora Beck Tan, ARL

D.   IMPROVED SUPPRESSANT DELIVERY

2C/1/789.   STABILIZATION OF FLAMES; Principal Investigator: Vincent Belovich, AFRL

4D/6/8.   DUAL AGENT APPROACH TO CREW COMPARTMENT EXPLOSION SUPPRESSION; Principal Investigator: Douglas Dierdorf, ARA Corp.; COR: Andrzej Miziolek, ARL

4D/17/0.   A METHOD FOR EXTINGUISHING ENGINE NACELLE FIRES BY USE OF INTUMESCENT COATINGS; Principal Investigator: Leonard Truett, Eglin AFB

5A/1/012.   PARAMETRIC INVESTIGATION OF DROPLET ATOMIZATION AND

DISPERSION OF LIQUID FIRE SUPPRESSANTS; Principal Investigator: Cary Presser, NIST

5D/1/9013. ADVANCED PROPELLANT/ADDITIVE DEVELOPMENT FOR GAS GENERATORS; Principal Investigators: Gary Holland, Aerojet, and Russell Reed, NAWC-WPNS; COR: Richard Gann, NIST

5E/1/12. ENHANCED POWDER PANELS; Principal Investigator: Dan Cyphers, Skyward, Ltd.; COR: Martin Lentz, Eglin AFB

6A/1/01234. FIRE SUPPRESSANT DYNAMICS IN CLUTTERED WEAPONS SYSTEM COMPARTMENTS; Principal Investigator: David Keyser, INS, Inc.

6A/2/3. GUIDANCE FOR RE-IGNITION SUPPRESSION; Principal Investigator: Anthony Hamins, NIST

6B/1/89. SUPPRESSANT FLOW THROUGH PIPING; Principal Investigator: John Chen, Lehigh University; COR: William Grosshandler, NIST

6C/1/1. MECHANISM OF UNWANTED ACCELERATED BURNING; Principal Investigator: Anthony Hamins, NIST

E.   VIABILITY OF NEW SUPPRESSANT TECHNOLOGIES

1A/1/78. DEVELOPMENT OF MODEL FIRES FOR FIRE SUPPRESSION RESEARCH; Principal Investigator: Anthony Finnerty, ARL; Associate Investigators: James Tucker, AFRL and Juan Vitali, ARA; Ronald Sheinson, NRL

1C/1/8901. RELATIVE BENEFIT ASSESSMENT OF FIRE PROTECTION SYSTEM CHANGES; Principal Investigator: Michael Bennett, Eglin AFB

3C/1/789. LASER-BASED INSTRUMENTATION FOR REAL-TIME, IN-SITU MEASUREMENTS OF COMBUSTIBLE GASES, COMBUSTION BY-PRODUCTS, AND SUPPRESSANT CONCENTRATIONS; Principal Investigator: Kevin McNesby, ARL

3C/2/890. FAST RESPONSE SPECIES CHARACTERIZATION DURING FLAME SUPPRESSION; Principal Investigator: George Mulholland, NIST

6E/1/34. VERIFICATION OF SUPPRESSION PRINCIPLES; Principal Investigator: Michael Bennett, Bennettech; COR: Martin Lentz, Eglin AFB

F.   FUEL TANK INERTION

5C/1/9. ACTIVE SUPPRESSION FOR FUEL TANK EXPLOSIONS; Principal Investigator: Leonard Truett, Eglin AFB

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APPENDIX B. REPORT OF THE INDEPENDENT REVIEW PANEL

February 20 Draft

REPORT OF THE INDEPENDENT REVIEW PANEL

ON THE

NEXT GENERATION FIRE SUPPRESSION TECHNOLOGY PROGRAM (NGP)

February 20, 2004

Documenting the November 2003 Review

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The 2003 Independent Review Panel Report
on the
Next Generation Fire Suppression Technology Program (NGP)

<u>**Summary:**</u>

The 2003 Independent Review Panel (IRP) met December 4-5, 2003, coincident with the 2003 Annual Research Meeting (ARM) of NGP at NIST in Gaithersburg MD.

The IRP is impressed by the thoughtful way the 2001 and 2002 recommendations have been addressed and by the tightened focus of the program.   The following general observations are presented:

<u>**General Comments:**</u>

    a. The 6E/1/3 Project (Bennett) is the real key to transition the long-term value of the NGP to future aviation programs and fire protection engineers. We recommend that the program management insures that all PIs for each NGP element be actively involved in generating the lessons learned to insure that no important positive or negative results are lost, and that everyone concentrate on the needs of the end user, whether he or she be some future fire protection engineer or R&D scientist.

    b. The relight work reported in 2002 (6C/1/1) was promising with reasonable focus on the end user. The continuation of the 2003 work, as presented to the IRP, suggests the possibility of less focus on the end user. Should that be true, an increased emphasis on how the end user might use the results of this work would be valuable.

    c. Progress on some of the elements is not as rapid as some might like but is as much or more than would be expected with the limited budget allotted.

    d. The droplet work by Presser (5A/1/012) and the gas generator work by Holland (5D/1/9013) are particularly impressive.

<u>**Specific on Specific Programs:**</u>

  1) **5E/1/12 Enhanced Powder Panels**

    a. The program is ending and the IRP sees no reason to extend it.

    b. The traditional aircraft environment "Shake and Bake" testing (vibration, shock, thermal cycling, humidity, etc.) will need to be performed before the concept can be fully accepted. The design changes that give this concept the improved performance may degrade performance in these environmental tests.

2) 5D/1/9013 Advanced Propellant / Additive Development for Gas Generators

    a. The progress of this element is one of the high points of the 2003 review.

    b. The improved performance resulting from the presence of active species can significantly reduce installation penalties however, the following issues need to be considered:

        i. Residual powders may cause clean-up problem

        ii. Residual powders may not follow the gas flow path. There needs to be a test to determine how well it follows the gas streamlines through complex paths if we intend to certify aircraft with this technology by only measuring gas species.

    c. The reduced performance variation with temperature of the new design can be a significant benefit in new applications.

    d. The reduced exhaust gas temperature of the new design can also be a significant benefit in new applications.

3) 4B/4/013 Low Temp Performance of High Boiling Point Suppressants

    a. Vapor loading is an important part of this effort.

    b. This analysis is appropriate for the experimental simulation device.

    c. Not enough data was presented to evaluate the end product fully at this time

4) 6A/2/3 Guidance for Re-ignition Suppression

    a. Responds to earlier recommendation (2001 and reaffirmed in 2002)

    b. Addresses a fundamental and important consideration in real life applications. The IRP has some concern that the present approach may not lead to realistic guidance to the design community. The fire protection engineer really needs guidance on how to address ventilation rate, air temperature, surface temperature, fuel volatility, etc. to establish re- ignition limits.

    c. The PI should insure that the pre-1990 work (Clodfelter, Goodal and Ingle, Mullin, etc.) has been properly considered.

    d. The resources needed to fully address this issue may be beyond the limits of the funds available. Maybe this needs to become a guideline document for addressing certification issues with re-ignition issues in mind.

    e. A study of the "eddying" in the chamber may explain some of the apparent inconsistencies in earlier data.

5) 6A/1/0123 Fire Suppression Dynamics in Fire Compartments

    a. The data and automation presented appear to show progress and seem to be developing insight into agent dispersion.

    b. There is the suggestion that this may eventually be adapted into a design tool. If this is one of the goals, management must insure that it does not become much too complicated or labor hour intensive for that purpose.

    c. The IRP would like to see more prominent expression of the fire suppression mechanism and models used in this effort to improve understanding (species concentration, strain rate, fuel volatility, etc.).

    d. It was not clear how the concentration threshold was being set or what its validity is.

6) 5A/1/012 Parametric Investigation of Droplet Atomization and Dispersion of Liquid Fire Suppressants

    a. This work seems technically sound and several elements will be useful (vaporization, impingement, etc.).

    b. We are comfortable with the progress, and we are pleased to see work with additional High Boiling Point (HBP) fluids and the results formed related to vaporization and rebounding.

    c. The physics illuminated have strong relevance to practical applications.

    d. This element is also relevant for test methods (difference between water and chemical agents.)

    e. This element also has possible use of HBP agents in mist form, screening of HBP agents, etc.

7) 6E/1/3 Verification of Suppression Principles

    a. This program is likely to be the primary method of transitioning many of the more valuable results of this program to fire protection engineers and future researchers.

    b. The "lessons-learned" portion of this program will be valuable and will respond to the previous recommendations of the IRP.

    c. Management must insure that the original PIs for each of the elements of the NGP participate fully in contributing to the database.

    d. The lessons learned should include both positive and negative results and be focused on both future researchers (Science, R&D Process, etc.) and fire protection engineers (Condensed engineering guidelines and data).

    e. The test portion of this program is important but may exceed the resources available.

8) 4B/5/0123 Assessment of the Search for Alternate Chemicals

   a. Coming to closure on some of the chemical families is important and needs to continue.

   b. Establishing rational and realistic low-temperature performance limits is particularly satisfying. These limits can easily eliminate promising chemicals if the limits are too tight or casually established. This work needs to continue.

   c. The "In Place" IR based detection system reports now planned needs to continue, but should concentrate on the methodology, architecture and fundamental principals involved because of the advances in technology which are likely to occur by the time the concept is likely to be deployed.

9) 4B/6/23 Environmental Acceptable Suppressants

   a. There is a need for this type of program, especially for the early screening tools.

   b. This program now shows progress on an expanded list of candidate chemicals and more information on some chemicals, which may hold promise. The 2004 work is expected to provide an expanded set of test data.

   c. The more detailed plan on a cardiac sensitivity-screening tool is particularly satisfying.

   d. The 2004 work is expected to provide an expanded set of test data, which may offer new opportunities.

   e. This element is maturing fairly late in the program. Anything that can expedite this work is encouraged.

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APPENDIX C. TIME LINE FOR COMPLETION OF THE NGP

	FY 04	FY05	FY06
10/1/03		10/1/04	10/1/05	9/30/06

HOTWC 2005 (5/05) →| HOTWC 2006 (5/06) →|

Project 4B/6 |----------------------------| Procure and test set 1 agents (2/04-12/04)

→ | Complete final set of agents (6/05)

→| Final project report (9/05)

Project 6A/1 |----------------------| Conduct cold flow nacelle tests (3/04-10/04)

→ | Complete agent transport/extinguishment model (3/05)

→ | Final report on model (6/05)

|--------------------------|Conduct fire extinguishment tests; compare predictions (11/04-6/05)

→|Final project report (9/05)

Project 6E/1 →|Complete analysis of lessons learned (1/05)

→| Complete test plan (4/05)

|------------------| Conduct verification tests (6/05-10/05)

→|Final project report (12/05)

Index and archive NGP publications (3/06-6/06) |-------------|

Final Report Annotated outline (1/05) |---|

Review Draft (2/05-11/05) |------------------------------|

Review and Completion (12/05-3/06)|------------|

Publication (6/06) →|

Complete PP-1059 (≈7/06) →|

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