NGP ADVANCES IN POWDER PANEL & PROPELLANT TECHNOLOGIES

William Grosshandler
National Institute of Standards and Technology, Gaithersburg, MD 20899-8660 USA
Tel: (301) 975-2310; Fax (301) 975-4052
wgrosshandler@nist.gov

Daniel Cyphers
Skyward, Ltd., Dayton, OH 45431 USA
Tel: (937) 252-2710, x102; Fax (937) 252-3486
dcyphers@skywardltd.com

Gary Holland
Aerojet, P.O. Box 97009, Redmond, WA 98073-9709 USA
Tel: (425) 885-5000
gfh@rocket.com

INTRODUCTION

Halon 1301 has a vapor pressure high enough to propel it from a storage bottle and through distribution piping rapidly enough to suppress even fast growing fires. Nitrogen gas is used to pressurize halon 1301 storage bottles to ensure that even at temperatures as low as -40 ^oC, when halon 1301 is a liquid, the pressure is sufficient for rapid discharge of the fire suppressing fluid. Hydrofluorocarbon alternatives to halon 1301 such as HFC 125 are discharged in a similar manner, but because around three times the amount of agent is required to ensure the fire is extinguished, the amount of nitrogen needed to pressurize the fluid is also increased, leading to a system that is considerably bulkier and heavier than the halon 1301 system.

Two technologies were explored in the Next Generation Program (NGP) that avoid the need for a high pressure storage vessel to operate effectively. These technologies are (1) powder panels, and (2) solid propellant gas generators. Both of these technologies have the ability to discharge fire fighting agent in less than 100 ms, which makes them suitable for protecting dry bays (enclosed spaces adjacent to a fuel cell). The solid propellant gas generator can be adapted to aircraft engine nacelles, as well.

Powder panels consist of powdered fire extinguishing agents sandwiched, unpressurized, between two rigid membranes that, as a unit, can be attached to or used in place of the skin of the aircraft confining a dry bay. The powder is released and dispersed into the dry bay when the panel is pierced by a projectile, forming an aerosol cloud sufficiently dense to prevent ignition or suppress a fire resulting from the rupture of the adjacent fuel tank. The system is entirely passive.

The powder panel designs that existed prior to the NGP were inefficient. The research conducted as part of the NGP was aimed at enhancing the powder panel in three ways: (1) using more chemically active fire suppressant materials, (2) enhancing the dispersion of the powder, and (3) decreasing the system weight.

Solid propellant gas generators (SPGGs) contain no fluids and are at atmospheric pressure prior to activation. The propellant within a chamber is activated by a spark and burns rapidly to produce large quantities of gases. These materials either can be dispersed directly into the volume being protected or through a manifold of piping similar to what is used for halon 1301. The focus of the NGP research was to better adapt SPGG technology for aircraft fire protection by finding ways (1) to reduce the temperature of the gases dispersed by the generator, (2) to reduce/control the exhaust momentum through control of the burning rate, and (3) to increase the suppression effectiveness of the products (including finely dispersed particulates) by changing the chemical reactants, their stoichiometry and morphology, by the geometry of the containment vessel, and by various additives thought to be adept at retarding ignition or at quenching the combustion process. In addition, a hybrid application was evaluated, with an SPPG used as a compact source of high pressure gas to vaporize and propel a liquid agent.

ENHANCED POWDER PANELS [1][*†]

In order to become a viable concept for combat fire protection in aircraft, two major technical problems for powder panels needed to be addressed. These two major problems, performance and practicality, are intertwined. Previous powder panel testing evaluated a number of different powder panel designs and materials and showed limited ranges of effectiveness. This project demonstrated the feasibility of completely re-designing a powder panel so that it could release a greater amount of powder. Additional work was required to optimize these panels for attaining potential design requirements. The problem was one of developing a powder panel that is competitive with other fire extinguishing technologies by releasing sufficient powder when penetrated by a ballistic projectile to prevent fire ignition, while remaining acceptable under tightly controlled aircraft environment requirements.

EXPERIMENTAL PROGRAM

An experimental test device (dry bay/fuel tank simulator) was designed and fabricated to enable a direct comparison of powder panel materials and designs, both existing and improved concepts. Through an impact dynamics study, various characteristics critical to the fire extinguishing effectiveness of powder panels were examined. The test device shown in Figure 1 allowed for the experimental screening of candidate powder panels by comparing these characteristics in a highly repeatable fashion. Among the characteristics examined were panel impact dynamics, including cracking and material removal, the amount of fire extinguishing powder released into the test article, the dispersion of this powder, and the time the powder remained suspended in the dry bay. The test device simulated a 0.057 m^3 aircraft dry bay and a 0.028 m^3 fuel tank, with a projectile entering the dry bay prior to the fuel tank (dry-to-wet shotline). The fuel tank was capable of holding fluid, and the dry bay was designed with Lexan windows to allow visual

[*] The section on enhanced powder panels is based entirely on reference [1]. Portions of the text and figures have been used verbatim without further attribution. Consult the original document for details.

[†] NIST policy is to use metric units and to provide statements of uncertainty for all original measurements; however, all data shown in this paper are from organizations outside of NIST, and may not comply with this policy.

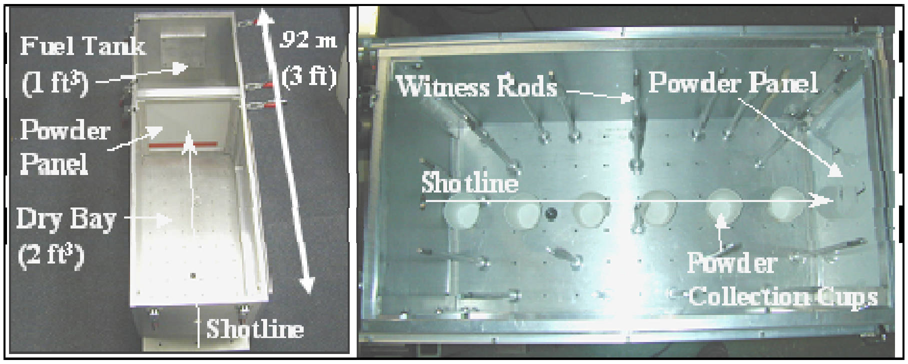

Figure 1. Experimental Test Device and Powder Collection Methods

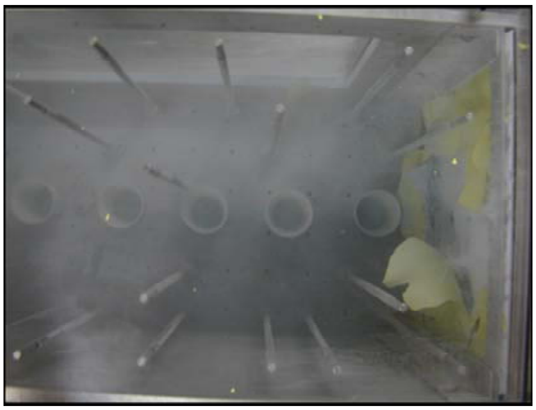

Figure 2. Test Example of Effective Powder Release and Dispersion

observation of each test. Replaceable 7075-T6 aluminum panels of 2.0 mm thickness were inserted to represent the fuel tank wall adjacent to the dry bay.

In most of the tests, powder panels were secured directly in front of the fuel tank wall. This offered the worst-case scenario, without fluid in the tank, for evaluating the amount of powder released into the dry bay. The test device also allowed for the installation of powder panels directly behind the dry bay wall where the projectile entered the test article.

The test device was designed to capture powder dispersion information, so a direct comparison between candidate powder panels could be made. Figure 1 (right side) shows the powder collection methods used in the dry bay. Witness rods were located throughout the dry bay. Plastic tubes were slid over the rods to capture released powder during each test. The plastic tubes were examined for signs of powder after each test. Powder collection cups were also located in the dry bay along the shotline, where the powder concentration is most important during a ballistic projectile impact. Each panel was weighed before and after each test to determine the amount of powder released. Panel components were also individually weighed to assist in determining the mass of powder loaded into each panel. The removed area of the front face (dry bay side) of the powder panel was also determined.

A total of 32 powder panel tests were conducted using the light-gas gun at Wright-Patterson Air Force Base (WPAFB) during the first phase of this program. Among the materials tested were thin aluminum (0.41 mm thick) and aluminum foil panels. Also examined were 3.2 mm and 6.4 mm thicknesses of 5052 aluminum honeycomb, acting as the rib structure for various panels. A Nomex[‡] (aramid fiber paper) honeycomb core of 9.5 mm thickness was also tested. Thermoplastic and thermoset materials were the focus of most testing. For the front panel face (dry bay side), materials that exhibited brittle properties upon impact, but durability in handling, were of utmost interest. The goal was to find a front face material and powder panel design that resulted in significant front face material loss and powder release into the dry bay during a ballistic impact event. Front face materials evaluated included polycarbonate, polystyrene, polypropylene, and poly-methylmethacrylate. The use of intentional surface scoring of flat

[‡] Certain trade names are used to properly describe materials or products used in this program. This does not imply that NIST endorses these materials or products nor that they are the best for the purpose stated.

acrylic panels was also examined using a couple of different scoring patterns and different techniques for implementing the scoring lines. The intent was to determine if surface scoring could be used to enhance the fracture characteristics of the material. Figure 2 is a photograph showing the degree to which the powder was dispersed, with the fractured powder panel on the right (corresponding to the right side of Figure 1).

Live fire tests of enhanced powder panels without reactive backing were conducted at the Naval Air Warfare Center (NAWC) in China Lake, CA, in a realistic size dry bay (0.45 m^3), with an actual ballistic threat (12.7 mm armor piercing incendiary, or API), and about 50 L of JP-8. Projectiles were fired at a nominal velocity of 760 m/s at a 0° angle into the dry bay, impacting an aluminum striker plate, which was separated from the powder panel/fuel tank by approximately 0.30 m. The projectiles functioned upon impact of the striker plate and then continued through the powder panel, penetrating the fuel tank and releasing JP-8 fuel. The powder panel was attached to this removable bulkhead panel with a 2-part epoxy adhesive. Tests were also conducted with commercial powder panels to provide a basis of comparison with the enhanced powder panel tests. An additional test was conducted at NAWC using a test article designed for the Federal Aviation Administration (FAA) to replicate a baggage area separated with a powder panel from an adjacent dry bay with fuel lines. Enhanced powder panels prevented ignition in all five tests they conducted (four in the first test article and one in an FAA test). Conversely, fires resulted in all four commercial powder panel tests in both test article.

Figure 3 shows some images captured from high-speed video demonstrating the fire mitigation capability of enhanced powder panel designs. Powder discharge was estimated to be at least 90 % of the pretest powder loading for the enhanced powder panels, compared to 5 % to 10 % for commercial powder panels. Greater powder dispersion throughout the dry bays was also evident for the enhanced powder panels.

Following successful testing of enhanced powder panel concepts, optimization testing was conducted on the gun range at WPAFB, focusing on three areas: front face fracture and powder release; weight reduction, panel thickness reduction, and practical production issues; and reliability improvement. Testing primarily involved the use of Al_2O_3, even though $KHCO_3$ and other powders have been demonstrated to be more effective as fire extinguishing agents. Al_2O_3 is the only known powder panel agent to be incorporated into an aircraft due to its lack of reactivity with aircraft structure. Additionally, since Al_2O_3 has a much higher specific gravity than $KHCO_3$ (3.95 compared to 0.88), it was

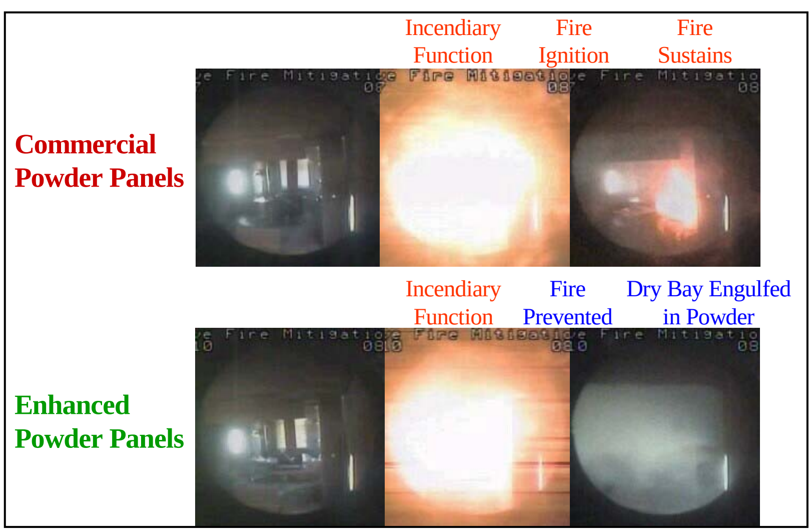

Figure 3. Enhanced Powder Panel Fire Mitigation Capability Demonstrated

Table 1. Wing Leading Edge Dry Bay Total Fire Extinguishing System Weight Estimates

Fire Extinguishing System	Total System Weight
Solid Propellant Gas Generator System Weight	21.4 kg
Lighter Enhanced Powder Panel Design 1 Weight - 1.60 kg/m^2 (0.327 lb/ft^2)	22.2 kg
Heavier Enhanced Powder Panel Design 2 Weight - 2.05 kg/m^2 (0.420 lb/ft^2)	27.8 kg
Commercial Powder Panel Weight - 1.92 kg/m^2 (0.394 lb/ft^2)	26.2 kg

thought to be worst-case and would help to determine success in weight reduction efforts. The Al_2O_3 tested was 5 μm in average size compared to an average of approximately 30 μm for the $KHCO_3$.

Enhanced powder panels evaluated in final demonstrations ranged in weight from 141 g to 227 g, with four of the six panels being lighter than the commercial powder panel evaluated (189 g). Thicknesses ranged from 1.9 mm to 2.2 mm, while the commercial powder panel thickness was 2.7 mm. (Table 1 summarizes the result of a weight comparison for complete alternative fire extinguishing schemes installed on a wing leading edge dry bay.)

In four of five tests, the enhanced powder panels prevented fire ignition. The cause of the lone unsuccessful test resulting in a fire was attributed to an inadequate attachment adhesive on the back of the enhanced powder panel. The test of a commercial powder panel resulted in a fire; however, the attachment adhesive again failed to hold. Although the commercial panel test was not conclusive, a further examination of the test results indicated a significant increase in vital performance characteristics for the enhanced powder panels. In the FAA test, a fire starting from an existing pool of fuel was quickly extinguished (after only 0.28 s) by an enhanced powder panel.

Despite being as much as 26 % lighter and 29 % thinner, the enhanced powder panel tests resulted in at least 34 % greater area opening and at least four times greater powder release. Powder was evident on surfaces throughout the dry bay following enhanced powder panel tests and was visibly suspended in the dry bay up to five minutes after some of the enhanced powder panel tests. No evidence was present of dispersed and/or suspended powder in the commercial powder panel test.

FINDINGS AND CONCLUSIONS REGARDING POWDER PANELS

A number of lessons were learned about effective powder panel design. Some, previously discovered, were reaffirmed. Among the key lessons learned were:

- brittle or frangible front face materials outperform ductile or tough materials,
- front face crack growth optimization can be designed into the powder panel through the use of particular front face materials, thicknesses, rib designs, attachment methods to the ribs,

and even surface scoring,
- a strong synergism exists between the rib structure and the front face design, and
- the back face can be designed to aid in powder dispersion and/or to reduce fluid leakage.

Another key finding in this program was that there are design features associated with enhanced powder panels that can make them very resistant to accidental leakage. With the use of plastics and certain composites, there are adhesives to attach the various elements of the panel that form extremely tight bonds. The selection of a front face material and thickness can take into account the likely harsh environment to which the powder panel will be exposed. Accidental leakage has been a significant concern for aircraft designers considering powder panels and is the primary reason that Al_2O_3 has been the only chemical fire extinguishing powder finding production usage. With this resistance to accidental leakage in certain designs, perhaps other lighter weight and improved performance fire extinguishing agents can be considered. Not only are other powders lighter in weight, but improved effectiveness of these powders may lead to reduced requirements for powder loading.

Despite significant increases in powder release for enhanced powder panels, a balance must be achieved between weight/thickness and effectiveness. For protection against larger threats, it may be warranted to consider higher powder loading, which is the significant weight driver. For strict weight restrictions, testing may be required for the given powder panel to determine the type and size of the threat for which protection is afforded. Further examination of the more promising designs should be performed for potential qualification test requirements. These include operating temperature, humidity, chemical exposure, vibration, and impact resistance.

Findings from this research revealed that realistic powder panel concepts could significantly enhance the fire extinguishing effectiveness of this vulnerability reduction method. Enhanced powder panel designs have the potential to afford the following benefits over current commercial powder panel designs:
- greater front face area removal to allow more powder to escape;
- greater powder release into the dry bay;
- better dispersion of powder to prevent ignition off-shotline;
- longer powder suspension to prevent fire ignition for a longer period of time;
- design flexibility of enhanced powder panels to target weight, durability and application-specific design goals; and
- significantly improved fire extinguishing effectiveness over commercial powder panels at an equal or lighter weight and thickness.

SOLID PROPELLANT GAS GENERATORS [2, 3]§

The SPGG program sponsored by the NGP was a collaborative effort between Aerojet (formerly Rocket Research Company) and the Naval Air Warfare Center - Weapons Division. The objectives of this program were to develop new highly efficient, environmentally acceptable,

§ The section on solid propellant gas generators is based on references [2] and [3]. Large portions of the text from these documents have been used verbatim without further attribution. The original reports contain many details not included here.

chemically active fire suppressant capabilities based upon solid propellant gas generators; and to improve understanding of propellant and additive effectiveness in fire suppression. The program was designed to accomplish the following:

- Establish baseline SPGG performance with a standard Aerojet propellant (22 % CH_3N_5, 38 % $Sr(NO_3)_2$, 40 % $MgCO_3$).
- Develop techniques for reducing the combustion temperature of the propellant, such as tailoring the propellant formulations, and for incorporating chemical additives.
- Develop techniques for cooling the combustion products to allay such problems as physical deformation or failure of distribution lines and threat to occupants.
- Modify existing hybrid extinguisher technology using additional gaseous and liquid suppressants, assuring operability at low ambient operating temperatures.
- Measure the exhaust temperature, burning rates, and suppression effectiveness of the new propellants with and without additives
- Characterize the extinguishment mechanisms of solid propellant systems by determining the relative contributions of oxygen displacement, cooling and flame strain effects upon the SPGG-driven suppression event.
- Correlate laboratory- and mid-scale results.
- Perform tests on real platforms defined by the weapon systems community on those agents that performed best in mid-scale tests.

EXPERIMENTAL PROGRAM

The developmental propellants described here were made in 50 g to 1 kg batches, according to (a) initial computational evaluation of candidate mixtures of fuel, oxidizer, processing additives and coolants, followed by (b) small-scale processing of compositions down-selected from (a), and then (c) scale-up of formulations down-selected from (b) in order to facilitate fire suppression effectiveness testing.

Burn rate testing was performed by either a strand burner or a window bomb. In the strand burn technique, compression molded cylindrical grains (pills) of approximately 12.7 mm diameter and 12.7 mm thickness were prepared with a non-burning inhibitor (e.g., epoxy). The window bomb is a closed vessel, filled with an inert gas to a static pressure, and equipped with two optical windows. The pressure limit of this apparatus extended to 55 MPa, the higher end of nominal gas generator internal pressure maxima.

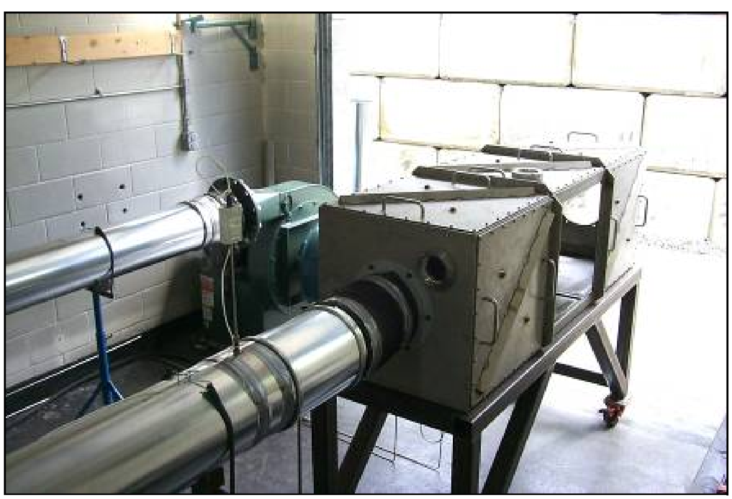

Figure 4. Aerojet Fire Test Fixture (FTF)

The mid-scale Fire Test Fixture (FTF) was used to test the effectiveness of various agents under repeatable test conditions. (See Figure 4.) The SPGG discharge times were generally maintained at ~150 ms to 200 ms. The SPGG device used for most testing

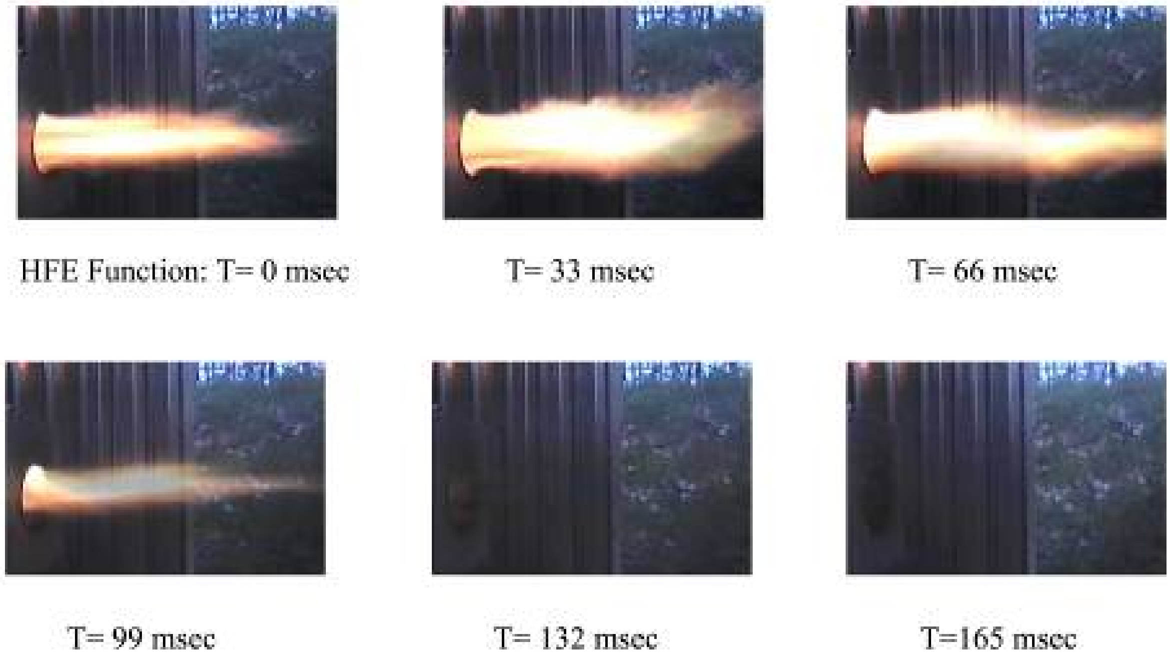

Figure 5. Consecutive frames during SPGG suppression of a fire in the FTF

was mounted within the FTF, and could be re-used for additional testing. The relative efficiency of different suppressants was ranked based upon their threshold quantity, defined as the amount of agent needed to extinguish the fire at least two out of three times. Figure 5 presents video frames documenting the extinction of a fire in the FTF. A number of high nitrogen component formulations based on bis(5-aminotetrazolyl) tetrazine ($C_4H_4N_{14}$, or BTATZ) have been evaluated for their suitability in agent generation devices as a function of the amount of coolant added. Gas temperatures were reduced in some cases by up to 20% when compared to the baseline formulation. Burning properties of three high nitrogen formulations based upon BTATZ are shown in Table 2 (rows 2, 3 and 4), compared to the baseline formulation (listed in the first row). The first column in the table provides the percentages of fuel, oxidizer, and coolants within the propellant mixture. The volume percentages of gases produced (assuming complete reaction) and the mass of condensed material formed are shown in the second column, followed by the calculated gas output per 100 gram of propellant in the third column. Thermodynamic calculations of the adiabatic temperature, T_c, at the chamber pressure, P_c, and of the exhaust temperature after undergoing expansion to the atmosphere, T_{ex}, are included in the next columns. The last two columns are kinetic parameters determined from experiments: the propellant burning rate at 6.89 MPa (1000 psi), BR_{1000}; and the pressure exponent, n, which is a measure of the sensitivity of the burning rate to the pressure in the combustion chamber. The findings of increased burn rate BTATZ compositions, while maintaining moderate gas temperatures, provides a means for further increases in agent cooling when these compositions are modified with endothermic chemical coolants.

Chemical additives were incorporated into formulations wherein the chemically active agent was liberated upon combustion of the solid propellant, the exhaust consisting of inert gases plus entrained additives. These additives were blended directly into the propellant, or the additive was blended into a hybrid fluid. Several compositions were developed such that a common

Table 2. Compositions and Burning Parameters of Chemically Active Developmental Propellants

Propellant Composition, wt %	Exhaust species, vol % @ T_c	Gas output, mol/100 g	Temperature, K		Measured BR_{1000}, cm/s	Measured Pressure expon., n
			T_c	T_{exh}		
Baseline: 5AT[**] 22,[††] $Sr(NO_3)_2$ 38, $MgCO_3$ 40	N_2 45, CO_2 35, H_2O 20	2	1450	1000	1.27	0.5
BTATZ-2: BTATZ 86.0, KP 10.0, PBA 3.0 C-black 0.5, Mica 0.5	N_2 68, H_2 23, CO 9	3.68	2290	1140	5.46	0.55
BTATZ-3: BTATZ 86.0, KN 10.0, PBA 3.0, C-black 0.5, Mica 0.5	N_2 69, H_2 23, CO 8	3.72	2080	1090	4.57	0.57
5AT/BTATZ-3: 5AT 43.0, BTATZ 43.0, KP 10.0, PBA 3.0, C-black 0.5, Mica 0.5	N_2 63, H_2 28, CO 6, KCl (s) 5.3 g	4.01	1960	970	3.85	0.7 (6.89-18.9 MPa)
CA-01: 5AT 17.2, $Sr(NO_3)_2$ 30.0, $MgCO_3$ 30.0, KI 21.3, Graphite 0.5	N_2 47, CO_2 31, H_2O 22 KI 21.3 g, 0.13 mol K	1.47	1450	970	1.27	0.55
CA-03: 5AT 20.0, $Sr(NO_3)_2$ 34.7, $MgCO_3$ 36.4, K_2CO_3 8.9	N_2 47, CO_2 31, H_2O 22 K_2CO_3 9.0 g, 0.13 mol K	1.78	1450	1210	1.32	0.59
CA-04: 5AT 19.7 $Sr(NO_3)_2$ 34.3, $MgCO_3$ 36.0, $K_2CO_3$10.	N_2 47, CO_2 32, H_2O 22 K_2CO_3 10.0 g, 0.15 mol K	1.75	1440	1110	1.27	0.44
CA-06: 5AT 22.1, $Sr(NO_3)_2$ 24.8, $MgCO_3$ 39.5, KNO_3 13.1, Graphite 0.5	N_2 47, CO_2 31, H_2O 22 K_2CO_3 9.0 g, 0.13 mol K	1.61	1440	1100	1.04	0.66
CA-07: 5AT 22.1, $Sr(NO_3)_2$ 22.9, $MgCO_3$ 40.0, KNO_3 15.0	N_2 47, CO_2 31, H_2O 22 K_2CO_3 10.2 g, 0.15 mol K	1.78	1440	1090	1.62	0.52
CA-08: 5AT 22.1, $Sr(NO_3)_2$ 22.9, $MgCO_3$ 40.0, KNO_3 30.0	N_2 47, CO_2 31, H_2O 22 K_2CO_3 20.5 g, 0.3 mol K	1.79	1470	990	.68	1.77
CA-10: 5AT 81.0, KP 10.0, DBPE 5.0, PBA 3.0, C-black 0.5, Mica 0.5	N_2 60, H_2 28, CO 3, CH_4 4, KCl(s) 2.0 g, KBr(s) 5.4g	4.24	1630	870	0.25	1.0

[**] 5AT is refers to 5-aminotetrazole, CH_3N_5.
[††] numbers represent mass percentages in formulations or in exhaust products

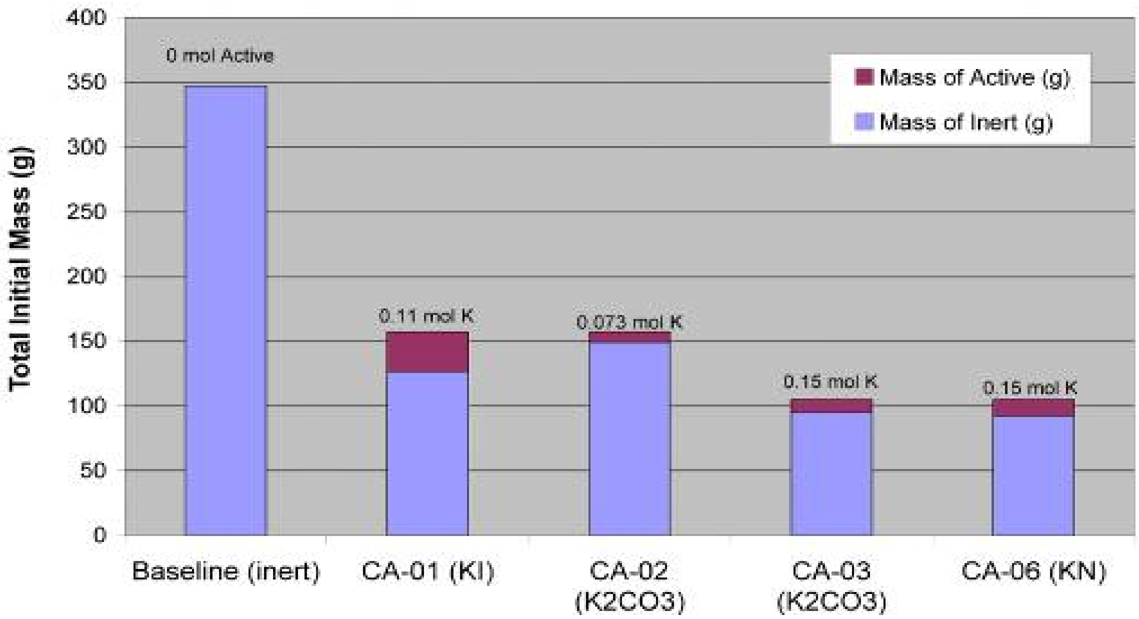

Figure 6. Threshold mass of inert propellant plus potassium compound for suppression in FTF

composition family evolved having different percentages of additive. Burning properties of several of these compositions containing potassium are summarized in the last seven rows of Table 2.

SUMMARY OF SOLID PROPELLANT GAS GENERATOR PROGRAM

Several different paths to cooler propellant compositions were demonstrated in this program. Cooler propellant compositions were used in conjunction with chemically active additives, or combustion radical scavengers. Adding radical traps to the exhaust provided means for cooling, dilution and chemical termination of the combustion process, hence increasing the overall effectiveness of the fire suppressant.

Propellant formulations incorporating the new high nitrogen compound BTATZ appeared to provide increased means for reducing propellant combustion temperatures. The preparation of BTATZ progressed to the half kilogram scale. This increased production capability plus the attractive burn rate and pressure sensitivity of BTATZ formulations make them good candidates for future work, including re-formulation with additional chemical coolants as well as suppression effectiveness testing in the FTF. Direct incorporation of coolant species into the propellant composition may reduce exhaust temperatures by as much as 30 % vs. current baselines.

Testing of propellant compositions containing potassium iodide and potassium carbonate as chemically active additives demonstrated enhanced effectiveness in the FTF as compared to chemically inert compositions. Incorporation of 0.1 mole additive into inert fire suppressants had a dramatic effect upon suppression efficiency. The otherwise similar propellant compositions examined during this testing indicated a 50 % to 70 % reduction (by mass) of agent loading for suppression. On an equimolar basis, potassium carbonate appears to be a more effective chemical additive than potassium iodide. The greater effectiveness of potassium carbonate (vs.

potassium iodide) may be related to more facile vaporization of the carbonate-based species after melting, or to an antagonistic interaction between the halogen and alkali metal species in the flame region.

Fire testing with chemically active compositions indicated that the CA-04 composition (20 % 5AT, 34 % $Sr(NO_3)_2$, 36 % $MgCO_3$, 10 % K_2CO_3) is the most effective. This composition incorporates potassium carbonate in its discharge, and is three times more effective per unit mass than the inert baseline propellant (22 % 5AT, 38 % $Sr(NO_3)_2$, 40 % $MgCO_3$). Testing with compositions of lower active-agent loading resulted in less effective performance. This indicates that the additive loading in CA-04 is below (or at) the saturation level reported in sub-scale testing with numerous other chemically active suppressants. See Figure 6 for a comparison of the agent mass and the amount of potassium in several of these formulations at suppression thresholds.

Testing of hybrid SPGGs with HFC-227ea and Novec-1230 indicated that high boiling point, low vapor pressure agents such as these could be delivered efficiently to the fire zone by heating and pressurizing the liquid with an SPGG. Both agents produced comparable results (on a mass basis) in fire suppression tests. Incorporation of CF_3I into a hybrid SPGG proved convenient for overcoming poor cold-temperature dispersion of the CF_3I. The water-based hybrids did not perform any better than the HFC-227 hybrid; however, blending potassium acetate into the water was shown to significantly improve suppression effectiveness in the FTF.

On a mass basis, the inert hybrid and standard SPGG systems appear to provide similar suppression protection. Incorporation of chemically active species into the hybrid propellant improves the suppression efficiency. Testing conducted with additives incorporated into the hybrid fluid produced results similar to results with active agents added into the propellant. This indicates that active additives in the hybrid fluid may be just as effective as active additives in the propellant.

The Aerojet/NAWC program sponsored by the NGP has advanced solid propellant-based fire suppression technology in multiple directions. These include:

- developing a methodology for screening candidate propellants;
- developing a medium scale Fire Test Facility to evaluate alternative SPGG fire suppression technologies for a cluttered space such as a dry bay or small engine nacelle;
- scaling up production of BTATZ to half kilogram quantities;
- calculating exhaust temperature and composition of new, high nitrogen propellants;
- measuring burning rate and pressure exponent for these new, high nitrogen propellants;
- tabulating the effect of different coolants on the effect of propellant burning rate and exhaust temperature;
- examining the effect of various halogen, alkali, and iron compounds on fire suppression effectiveness of SPGG fire extinguishers; and
- determining the effectiveness of SPGG hybrid fire extinguishers using fluorocarbon and aqueous fluids.

Since initiation of this project in 1999, when inert SPGGs were installed in the first V-22 and F/A-18 dry bay fire protection systems, gas generator devices using advanced propellants and advanced additives have been demonstrated, developed and manufactured for three new platforms. Developments in improved, chemically active SPGGs are being implemented on the JSF F-35 dry bay fire protection system. Testing in 2005 validated the effectiveness of chemically active HFC-227ea hybrid devices in suppressing fires arising from ballistic events upon the US Army's M1114 HMMWV. Figure 7 summarizes how the performance of SPGGs, as measured by suppression effectiveness, has improved over this period.

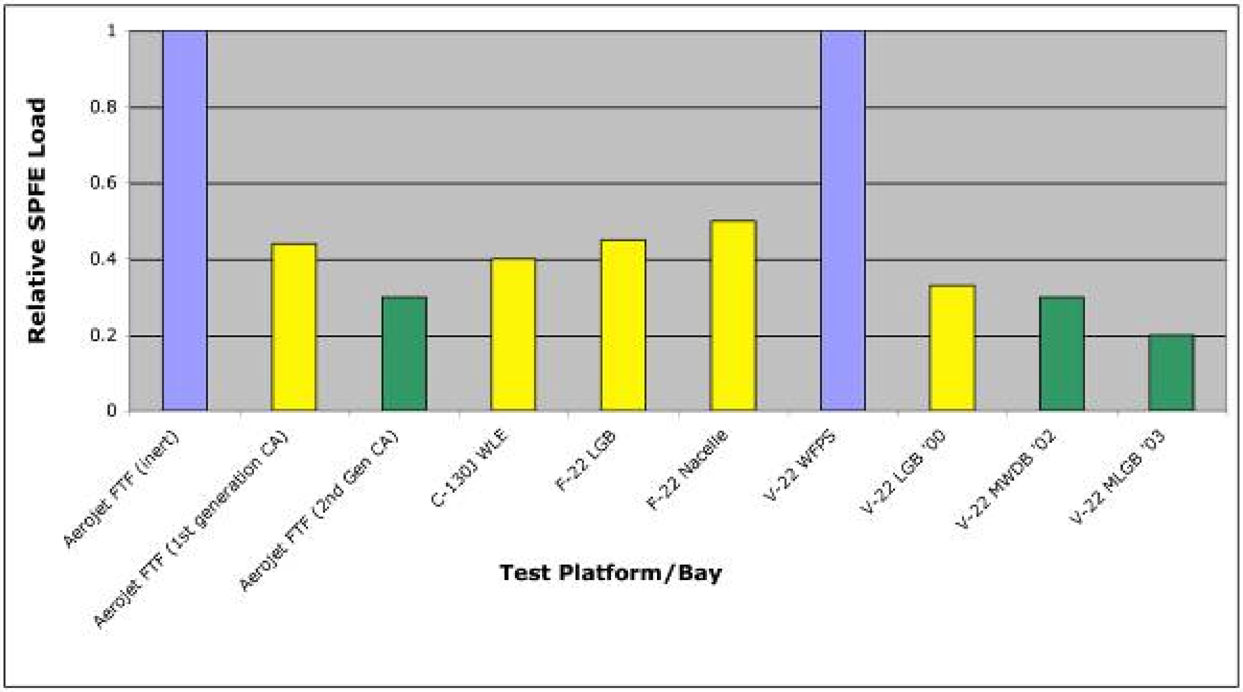

Figure 7. Relative effectiveness of various SPGG fire extinguishers: blue, inert effluent; yellow, 1st generation chemically active systems; green, 2nd generation chemically active systems. [SPFE (solid propellant fire extinguisher) is an alternative term for SPGG.]

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