INTUMESCENT “INSTANT FIREWALLS” FOR LOW-COST FIRE PROTECTION

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ABSTRACT

Intumescent materials respond to impingement of a fire by swelling and forming a protective char that physically and thermally protects the structure. Intumescent materials have been used (or investigated for use) in various military platforms for all three Services. Trade-offs must be made between the various features and requirements most important to the platform.

The objective of this project is to demonstrate (in a full-scale or aircraft article) and optimize the utilization of intumescent technologies to form "instant firewalls" to control, contain, and manage damage-related fires in compartments. The effort will also identify and evaluate the potential for use on unmanned aerial vehicles and other customers needing low-cost protection. This project will build on the results of a previous study performed for the Next Generation Fire Suppression Technology Program (NGP).

BACKGROUND

AIRCRAFT ENGINE NACELLES

Aircraft engine nacelles (enclosures around the engine core) have fluid lines that are routed within the enclosure on the exterior of the machinery, to provide fuel, oil or hydraulic/brake fluid for the machinery (all of which are flammable). These enclosures/nacelles are typically ventilated with forced airflow, by a fan or by the free stream outside the aircraft, to prevent the accumulation of any flammable vapors, and to provide some cooling. In a typical fire scenario, one of the fluid lines leaks, and sprays or streams the flammable fluid onto the hot machinery, which results in a fire. The ventilation airflow continues to support the fire, and directs the orientation of the resultant flame torch downstream. An automatic extinguishing system may be discharged from upstream to apply the extinguishing agent to the fire, but due to rapid dilution by the ventilation airflow and short residence time near the fire (and robustness of a bluff-body stabilized flame), many of these fires will not be extinguished with agent quantities permissible for many of these applications. Another concern is that the fire may re-ignite due to the fluid continuing to flow onto the hot surface with replenished airflow after the extinguishant has been drawn downstream. Because of these challenges, current engine nacelle applications have serious problems with fire events, and extinguishing techniques only have limited success, or require extinguishing quantities and hardware that are impractical because of size and weight. Other diverse techniques proposed to date to avoid the limitations of traditional extinguishing systems have not been adequate for many of these applications or have additional unacceptable disadvantages.

Many aircraft currently use firewalls at some location adjacent to engine nacelles to prevent fire propagation away from the engine. Unfortunately, these locations are usually limited to areas like the engine pylon (if the engine is mounted away from the aircraft body or wing), because it is desired to avoid constriction of the ventilation airflow directly around the engine under normal operating conditions. Such firewalls can also be heavy, and are only needed when an actual fire occurs, and near the site of the fire. The intumescent material design described here could provide such protection in a lightweight form at the location of the fire, without impeding the normal flow of air.

INTUMESCENT MATERIALS

Intumescence may be defined as "thermally induced expansion of a material". The popping of corn, the expansion of perlite and vermiculite, the puffing of wheat, rice, and other grain cereals are common examples of intumescence. The pyrotechnic "snake" (fireworks) is another familiar example. It is a mixture of sugar, oxidizer, and certain fuels which generate a carbon char of highly expansive, voluminous, and friable nature.

The mechanism of intumescence may be described as the rapid release of gas or vapor from a matrix which, upon rapid heating, undergoes a plastic or viscoelastic transformation which permits it to be expanded, inflated, or dilated by the expanding vapor or gas. [1]

Intumescent materials come in several different forms that include coating/paint, tape, caulk/sealant, and putty.

The char thickness may range from between 2 and 80 times that of the original material and result in an expansion amount of between 1-30 inches. The char thickness can be characterized by either high (>15), moderate (3 to 15), or low (<3) volume expansion.

Intumescent coatings activate in a temperature range of 270 to 500°F.

POTENTIAL APPLICATION IN THE AIRCRAFT ENGINE NACELLE

The intumescent coating can be applied as a very narrow and thin strip, in a form of one or more closed rings on the exterior of the machinery, which are located to swell against the enclosure at locations where clearance is minimal. If a fire occurs in an engine nacelle (such as due to a leak of flammable fluids onto hot exterior machinery components), the resulting flame would impinge onto a portion of the intumescent material, which would swell upon heating, normally several orders of magnitude beyond its original thickness. This swelling would block off the downstream airflow path in the vicinity of the fire, depriving it of a steady flow of oxygen and facilitating self-extinguishment. If the blockage is only partial, and the flame follows the re-directed airflow around the sealed-off area, the local intumescent-covered portion in that region would also swell, sealing off a perimeter of the machinery space and depriving oxygen flow until the fire self-extinguishes. In this manner, a series of "fire-walls" can be formed using a minimal quantity of intumescent. If an extinguishing system is also used, it can improve its effectiveness or permit smaller systems by weakening the fire and reducing the airflow dilution of the extinguishant. Previous analysis performed by the USAF suggested feasible application for machinery spaces (the concept having recently been submitted by the USAF for government patent protection, but not yet physically demonstrated).

The intumescent coating may only be needed in a limited region of the compartment, where the origin of fires is most likely. The intumescent material could also be mounted on the enclosure interior side if it is deemed beneficial. If the gap is relatively large between the machinery and the enclosure, then a strip of coating may be placed on both the enclosure and machinery surfaces, which upon expansion could meet in the middle.

There is a need to find replacement extinguishing agents to the currently used halons because production has been banned due to environmental concerns. However, to date such replacement chemicals have shown reduced performance relative to halons. As a result, the Department of Defense is seeking additional design techniques that can assist in the performance of these replacement agents. This concept is ideal for this purpose because it weakens the flame due to oxygen starvation, and by restricting airflow increases its local concentration and residence time near the fire. This technique may be sufficient in many cases to permit the omission of an extinguishing system altogether.

Figure 1 is a cross-sectional view of the region between the exterior of a piece of hot machinery and the enclosure (or nacelle) that surrounds the machinery. The machinery exterior is hot enough to ignite fluids in this region, or ignition may occur near a source of electrical energy, such as a wire bundle or connection. The outer enclosure or nacelle is some distance from the heated machinery. In this example, a region chosen in proximity to a structural rib is illustrated. The clearance between the rib and machinery is commonly no more than 1-3 inches. Other components may also be present or used as substitutes to the ribs that also result in local small clearances. They may be general enclosure contours, conduits or other components. In addition, some components may be present on the machinery surface itself, which may reduce the clearance with the enclosure. An intumescent coating could be applied in the form of a narrow strip onto the machinery surface, or the components attached on it, in the region of reduced clearance. This region is just downstream of a location where a fluid line is mounted. Intumescent materials expand greatly in size when impacted by a flame or extreme heat, forming a carbonaceous structure, possibly with an outer char layer, to form an effective thermal barrier against extreme fire conditions, and are widely used in many applications. Intumescent materials come in several different forms that include coating/paint, tape, caulk/sealant, and putty. The char thickness may range from between 2 and 80 times that of the original material and result in an expansion amount of between 1-30 inches. The char thickness can be characterized by either high (>15), moderate (3 to 15), or low (<3) volume expansion.

As illustrated in Figure 2, the fluid line may have a leak, which would result in sprayed or leaking fluid that can ignite on or near the hot surface. The flame would thus orient itself downstream in the direction of ventilation airflow. Such a flame would impinge upon the strip of intumescent material that is placed downstream. Upon impingement, the intumescent material would expand, thereby forming around the rib or component above it and blocking off the flow of air locally. Such a local fire block would weaken the fire due to oxygen starvation (by preventing airflow in that direction) and possibly extinguish it.

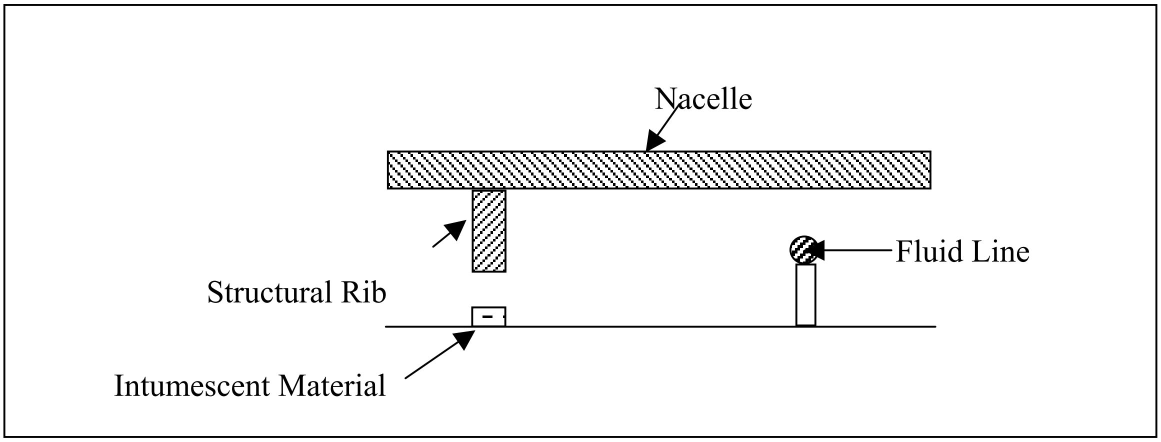

Figure 1. Cross Section View of Region Between Nacelle and Hot Machinery.

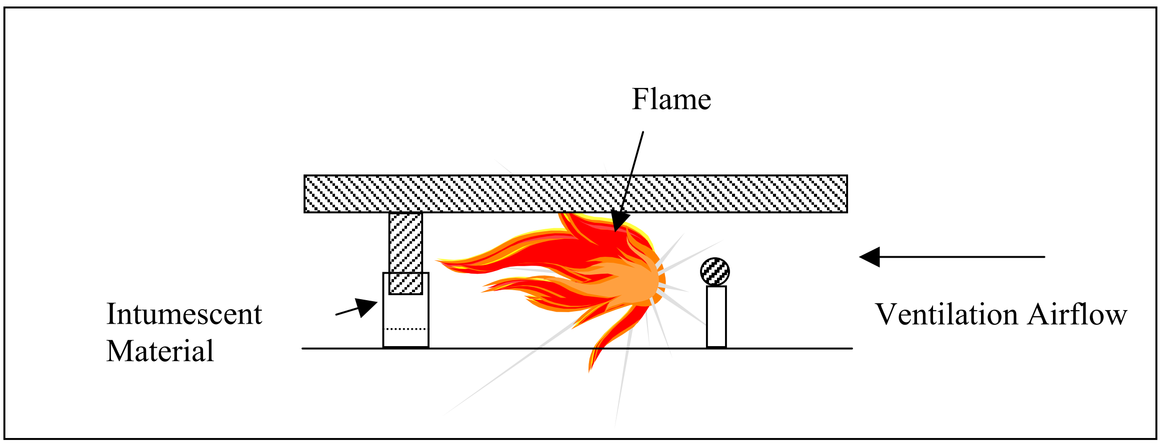

Figure 2. Fluid Leak and Subsequent Fire.

CURRENT APPLICATIONS OF INTUMESCENT MATERIALS

Intumescent materials have been used (or investigated for use) in various military platforms for all three Services. Numerous literature sources were reviewed. The following applications, protected areas, and uses were found and are listed in Table 1.

Table 1. Application, Protected Areas, and Uses in Various Military Platforms.

APPLICATION	PROTECTED AREAS	USES
Aircraft	fuel tanks, fire zone bulkheads, military ordnance, stored munitions, dry bays, self-sealing fuel lines, cockpit	Thermal barriers, insulators, prevent burnthrough, prevent toxic fume, smoke, and fire penetration
Ships (aircraft carriers)	fire zone bulkheads, aircraft fuel tank spillage, military ordnance	Thermal barriers, insulators, prevent burnthrough, prevent toxic fume, smoke, and fire penetration
submarines	fire zone bulkheads, military ordnance	Thermal barriers, insulators, prevent burnthrough, prevent toxic fume, smoke, and fire penetration

Intumescent materials have been used (or investigated for use) in various commercial applications. Numerous literature sources were reviewed. The following applications, protected areas, and uses were found and are listed in Table 2.

Table 2. Application, Protected Areas, and Uses in Various Commercial Applications.

APPLICATION	PROTECTED AREAS	USES
Aircraft	fire zone bulkheads, military ordnance, stored munitions, dry bays, self-sealing fuel lines, cockpit, engine struts	Thermal barriers, insulators, prevent burnthrough, prevent toxic fume, smoke, and fire penetration, crashworthiness, structural integrity
Residential and commercial buildings	Doorways, vents, openings, steel	prevent toxic fume, smoke, and fire penetration, structural integrity
automobiles	body panels separating the passenger compartment from the engine compartment, underbody, and the trunk compartment	prevent toxic fume, smoke, and fire penetration, crashworthiness
Off-shore oil platforms	Metal structures and fuel valves	Protect flammable materials

OBJECTIVE, APPROACH, AND RESULTS FROM THE PREVIOUS INVESTIGATION

The objective of this previous program was to explore a novel approach to engine nacelle fire protection using strategic placement of intumescent materials within the ventilated aircraft engine nacelle. Since the funding of this program was limited, an experimental evaluation was not allowable. Therefore, the purpose of this study was to evaluate to potential application of intumescent materials in an aircraft engine nacelle environment by reviewing existing literature and surveying various manufacturers.

Approximately thirty reports/papers were reviewed for this effort. Relevant data gained from them included the following:

- definition,
- activation temperature,
- methods to increase char strength,
- issues (toxicity, heat exposure, fragility of char, installation, humidity),
- applications (military and commercial),
- protected areas,
- uses, and
- hazards protected against.

Approximately eighty manufacturers were reviewed for this effort. Then, these were downselected and divided into three intumescent categories (tapes (nine manufacturers), coatings (fourteen manufacturers), and caulks (nine manufacturers)). Relevant data gained from the survey of manufacturers included:

- expected expansion factor and resulting expansion amount based upon original thickness,
- durability of the coating,
- adhesiveness and vibration-resistance of the expanded char following activation by fire,
- physical properties of the expanded char,
- activation temperature, and
- intumescent forms.

The following analyses were conducted using a notional aircraft:

- weight impact due to addition of intumescent material,
- resistance of intumescent material to airflow environment, and
- reduction in suppressant required due to presence of intumescent material.

Current aircraft engine nacelle configuration data were obtained and were utilized for the physical and function limitations of these intumescent systems. These data included aircraft operating conditions, engine materials, and areas of minimal clearance and other dimensional data. This data were used to examine the application of intumescent materials to a notional fighter aircraft.

Many types of intumescent materials are currently in use. If one considers a strip 0.5 inches in width, 0.12 inches thick (to seal up a clearance gap of 2 inches or more) spread over an engine core of 36 inches diameter (which would represent an fighter type engine), then a total volume of 0.00365 cubic feet per ring would result. Accounting for the densities of the example product just mentioned, a weight 0.23 lb. per ring would exist. Even if four rings were used at various regions of the nacelle, then a total weight of only 0.93 lb. would be added. This weight is minimal in comparison to the size of extinguisher systems that are currently used, which can range from 10 to 20 lbs. total weight per engine.

Without experimental results, it is difficult to accurately determine the response of the intumescent material to the aircraft operating environment because it is configuration and flight condition dependant.

An estimate was made of the reduction in suppressant needed as a result of using this technology. To accomplish this, scenarios were examined: inerting the full free volume (100 ft^3), two-thirds of the free volume (66 ft^3), and one-third of the free volume (33 ft^3). The following assumptions were made to accomplish this estimate.

- Assumed the free volume has been sealed by the expanded intumescent material and thus creating the three scenarios (full free volume (100 ft^3), two-thirds of the free volume (66 ft^3), and one-third of the free volume (33 ft^3)).
- Treated the free volume as a total flood application (no airflow) and determine the amount of agent needed to inert the fixed volume.
- Assumed that six percent by volume of Halon 1301 is required to inert the space.
- Utilized the following information: One mole of gas = 22.4 liters/gram-mole. The molecular weight of Halon 1301 is 148.91 gram/gram-mole.

The values calculated to inert the fixed volume are less than the values calculated using MIL-E-22285 and the values used in a certified system. All of these engine nacelle systems are "certified" in a given design configuration for a particular fire zone application and aircraft. The current specifications for Halon 1301 require a minimum of six percent concentration by volume in air be present simultaneously at all points in the engine nacelle for a minimum of 500 ms. Therefore to obtain this simultaneous concentration at several points (typically twelve), additional Halon 1301 is added to ensure the system fully meets this requirement. The intumescent material reduces the required amount of Halon 1301. However, experimentation is needed to verify these calculations.

Recommendations for a potential test program were developed as a result of this effort and are given below. It is recommended that a proof-of-concept test program be performed first and then a full-scale test program. A test plan would be developed to determine whether sufficient blockage would occur from the intumescent swelling to reduce the sustaining airflow rate below which fires can be supported. Various compartment clearance widths, intumescent types and thicknesses, fire types, and ventilation airflow rates would be tested. Government laboratory equipment and facilities would be used to optimize the use of resources. For the proof-of-concept program, the test apparatus would be a smaller scale version of generic engine bays and would be non-platform specific.
The proof-of concept testing would consist of the following:

- baseline tests to validate conditions for a successful fire,
- tests with only the use of the intumescent coating,
- tests with only the use of the halon alternatives, and
- final tests to evaluate the synergistic effect of the intumescent coating and the halon alternative.

A test matrix and would be constructed which would contain the following parameters: compartment clearance widths, intumescent types and thicknesses, fire types, and ventilation airflow rates. Design of Experiments (DOE) methodology would be utilized to define a test program which would reduce overall program costs and maximize the generation of data. Following the proof-of-concept program, this technology would be optimized and demonstrated in full-scale or aircraft test article.

EXPERIMENTAL PROGRAM

OBJECTIVES

The objective of this project is to demonstrate and optimize the utilization of intumescent technologies to form "instant firewalls" to control, contain, and manage damage-related fires in compartments. The effort will identify and evaluate the potential for the use of intumescent materials as a low-cost fire protection method on unmanned aerial vehicles. To accomplish this, this project will provide support for testing (to determine the physical feasibility) as well as perform a cost analysis (to determine the financial feasibility) for utilizing intumescent materials for low-cost fire protection. This project is in its initial stages and therefore no results are available at this time.

JUSTIFICATION

The effort will identify and evaluate the potential for the use of intumescent materials as a low-cost fire protection method on unmanned aerial vehicles. These platforms are unmanned and therefore loss of personnel is not an issue. However, the loss of mission capability and loss of assets could be significant.

In addition, program managers of single engine aircraft might be interested in this technology. Single engine aircraft have no onboard fire extinguishing system because the first step in an aircraft engine nacelle fire is to shut down the engine, once the proximity fire detector confirms a fire is present, and the pilot is satisfied that a true fire event has occurred. In a single engine aircraft, this protocol is not acceptable. Therefore, other measures for aircraft engine nacelle protection need to be investigated (such as the utilization of intumescent materials).

Current halon substitute extinguisher systems may be too costly and/or too heavy for some aircraft systems. These platforms prefer a passive system such as the technology proposed in this effort. With passive systems come the benefits of reductions in false alarms, weight, maintenance, and costs. In addition, fire containment/management may be better than not having a system at all.

Even if an extinguishing system is also used, its effectiveness can be improved, or a smaller system used, because of the weakened fire condition and the reduced airflow dilution of the extinguishant as a result of the utilization of the technology.

APPROACH

This project will review and expand a database of intumescent material information collected during a previous project sponsored by the NGP (as described in the "Objective, Approach, And Results From The Previous Investigation" section of this paper). The information collected previously included: methods to increase char strength, issues (toxicity, heat exposure, fragility of char, installation, humidity), expected expansion factor and resulting expansion amount based upon original thickness, durability of the coating, adhesiveness and vibration-resistance of the expanded char following activation by fire, physical properties of the expanded char, activation temperature, and intumescent forms. The candidates most suitable for this unmanned aerial vehicle application will be identified.

In addition, this project will document requirements and most promising platforms. This will be accomplished by acquiring fire zone data for the representative unmanned aerial vehicle platform. These data will include, but not be limited to, operating conditions, engine materials, and areas of minimal clearance and other dimensional/geometric data. These additional data will assist in the potential successful placement of the intumescent materials to form firewalls to block off the downstream airflow path in the vicinity of the fire, depriving it of a steady flow of oxygen and possibly facilitating self-extinguishment.

This project will demonstrate and evaluate candidate intumescent materials in a small-scale simulator. The purpose of this demonstration and evaluation will be to study the effects of airflow, thermal and fire exposure, and sealing capability. The following technical issues will be examined:

- Width of intumescent strips necessary to resist shear force of airflow while sealing,
- Resistance to expansion from engine heat, tolerance of aircraft environment, and
- Total expansion heights possible to seal against surrounding structure.

Following the successful completions of this test program, recommendations will be for a large-scale testing phase (a future/follow-on phase) of this project. During this phase, an unmanned aerial vehicle engine nacelle simulator will be designed and constructed. This simulator will be placed in the Aircraft Engine Nacelle Test Facility to optimize and demonstrate the utilization of intumescent materials in a full-scale environment.

This project will also perform a cost of ownership assessment (and cost savings due to unmanned aerial vehicle assets preserved) for utilizing intumescent materials for low-cost fire protection.

EXPECTED PAYOFFS

Successful completion of the project effort will result in the following products available to the survivability community for further exploitation:

- Demonstrated intumescent configuration to provide lower cost/weight fire management option to traditional fire extinguishing systems.

- Product and technique to provide enhancement to halon alternative systems that would incorporate the synergistic effects of the intumescent materials and the less efficient halon alternatives.
- Development and documentation of design criteria for customers.

ACKNOWLEDGEMENT

This project is funded by the Joint Technical Coordinating Group for Aircraft Survivability under DSS-W contract number SP0700-96-D-4000. The COTR for this effort is Mr. Martin L. Lentz (46th TW/OGM/OL-AC).

REFERENCE

1. Proceedings and Report – Volume I Of II; Fire Safety/Survivability Symposium – '90; SURVIAC 18708; "Intumescent Coatings, Low Cost Foam Insulation, and Use Of Gel Water For Fire Protection and/or Suppression; November 1990; William A. Mallow And Patrick H. Zabel.