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A Method for Extinguishing Engine Nacelle Fires by Use of Intumescent Coatings
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The objective of this program was to explore a novel approach to aircraft engine nacelle (AEN) fire protection using strategic placement of intumescent materials within the ventilated AEN. Since the funding of this program was limited, an experimental evaluation was not possible. Therefore, a review of existing literature and survey various manufacturer information was performed.

Intumescent materials respond to impingement of a fire by swelling and forming a protective char, to physically and thermally protect a structure. Intumescent materials have been used, or investigated for use, in various military platforms for all three services in the Department of Defense.

The following analyses (using an intumescent material to a notional aircraft engine nacelle environment) were conducted: assessment of the weight impact, resistance to airflow environment, and reduction in suppressant required.

Trade-offs must be made between the various features and requirements most important to the platform. The trade-offs and problems can be addressed in the design and engineering process. This study showed the feasibility of utilizing strategic placement of intumescent materials within the ventilated aircraft engine nacelle.

For full exploitation of this technology, an experimental program is recommended. Justification for utilization of intumescent materials could be supported using a cost analysis.

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1.0 Executive Summary

The objective of this program was to explore a novel approach to engine nacelle/APU 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 possible. Therefore, the purpose of this study was to evaluate the potential application of intumescent materials in an aircraft engine nacelle environment by reviewing existing literature and surveying various manufacturers.

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. Numerous literature sources were reviewed.

The intumescent material can be applied as a very narrow and thin strip, in the form of one or more closed rings on the exterior of the machinery. These rings are located so as to be able to swell against the enclosure at locations where clearance is minimal. If a fire occurs (such as due to a leak of flammable fluids onto hot exterior machinery components), the resulting flame would impinge upon a portion of the intumescent material, which would swell upon heating. Normal swelling is 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 possibly facilitating self-extinguishment. If the blockage is only partial, and the flame follows the redirected airflow around the sealed-off area, the local intumescent-covered portion in that region would also swell until a complete ring of swelled intumescent is formed, completely sealing off the perimeter of the machinery space and preventing oxygen flow to the fire until the it 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, its effectiveness can be improved, or a smaller system used, because of the weakened fire condition and the reduced airflow dilution of the extinguishant.

The approach included a survey of intumescent coating manufacturers (over 80) for the viability of the coatings, expected expansion rate, potential application in the nacelle, fraction of the nacelle flow reduced by the coating, durability of the coating during normal flight operations, and adhesiveness and vibration-resistance of the expanded char following activation of the paint by a fire. This information was then included in an estimate of the reduction in suppressant needed.

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 functional limitations of these intumescent systems. These data included aircraft operating conditions, engine materials in order to identify potential material compatibility issues, and areas of minimal clearance and other dimensional data. These data were used to examine the application of intumescent materials to a notional fighter aircraft. A fighter and/or attack aircraft provided the most feasible platform to examine the implementation of intumescent materials due to the smaller clearance between the structural ribs and the engine core. The width of the (irregular) annular air passage was commonly no more than two to six inches.

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. Values for normal and shear stresses were determined and compared with the manufacturer information given for the expanded intumescent material. It was unclear whether some of these values (particularly the tensile strength values) were of the unexpanded or expanded material. Further investigation is needed to determine this.

An estimate was made of the reduction in suppressant needed as a result of using this technology. The sealed free volume created by the intumescent material was treated as a total flood application (no airflow) and the amount of agent needed to inert the fixed volume was determined. An estimate of Halon 1301 required using MIL-E-22285 was also calculated. The intumescent material reduced the required amount of Halon 1301. However, experimentation is needed to verify these calculations.

Application of intumescent materials in the aircraft engine nacelle causes some concerns that must be recognized and accommodated. The main concerns uncovered in this investigation were the following:

- Potential toxicity,
- Fragility of char,
- Response in a high humidity environment,
- Installation in highly cluttered areas, and
- Early expansion due to low activation temperature.

Intumescent materials have properties that can positively or negatively influence its effectiveness for fire suppression. These may include the following: original thickness, expansion factor/amount, density, protection hours, activation/maximum temperature, forms, char characteristics, etc. Trade-offs must be made between these properties depending upon the requirements most important to the platform. The system can be engineered and the problems designed around. This study showed the feasibility of utilizing strategic placement of intumescent materials within the ventilated aircraft engine nacelle to reduce the amount in suppressant needed.

For full exploitation of this technology, an experimental program is recommended. Based upon the results of such a program, the utilization of intumescent materials could be recommended and justified via a cost analysis.

1.1 Task Objectives

The objective of this program is to explore a novel approach to engine nacelle/APU and other machinery space fire protection using strategic placement of intumescent materials within the ventilated aircraft engine nacelle. Intumescent materials respond to impingement of a fire by swelling and forming a protective char that physically and thermally protects the structure.

1.2 Technical Problems

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 (DoD) is seeking additional design techniques that can improve 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.

1.3 General Methodology

The first task of this effort investigated numerous literature sources. Next, a survey of approximately eighty manufacturers was conducted. From these eighty were selected relevant manufacturers whose products fell into three intumescent categories (tapes (nine manufacturers), coatings (fourteen manufacturers), and caulks (nine manufacturers)). Data available from NGP Element 1.A. as well as additional sources were utilized to obtain the physical and functional limitations in addition to system configuration data of various AEN fire suppression systems. An estimate of the reduction in suppressant required as a result of using intumescent materials in an AEN was made. Finally, recommendations for a potential proof-of-concept test program were developed.

1.4 Technical Results

The technical results of this effort include insight into the utilization and estimated performance of intumescent materials in an aircraft engine nacelle environment.

1.5 Important Findings and Conclusions

Intumescent materials have properties that can positively or negatively influence its effectiveness for fire suppression. These may include the following: original thickness, expansion factor/amount, density, protection hours, activation/maximum temperature, forms, char characteristics, etc. Trade-offs must be made between these properties depending upon the requirements most important to the platform. The system can be designed and engineered such that problems are overcome during process development.

This study showed the feasibility of utilizing strategic placement of intumescent materials within the ventilated aircraft engine nacelle to reduce the amount of suppressant needed.

1.6 Significant Hardware Developments

None.

1.7 Special Comments

None.

1.8 Implications for Further Research

For full exploitation of this technology, an experimental program is recommended. Based upon the results of such a program, the utilization of intumescent materials could be recommended and justified via a cost analysis.

2.0 Bibliography

Presented unclassified papers at:

- Halon Options Technical Working Conference, Albuquerque, New Mexico, May 2-4, 2000.
- Next Generation Fire Suppression Technology Program FY2000 Annual Research Meeting, Rockville, Maryland, November 8-9, 2000.

3.0 Detailed Description of the Project

3.1 Background

3.1.1 Aircraft Engine Nacelles

An aircraft engine nacelle is an enclosure around an engine core. It contains 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 using a fan or by the free stream outside the aircraft. This ventilation prevents the accumulation of any flammable vapors and provides 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. However, 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 due to weight and volume restrictions. Another concern is that the fire may reignite 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 nearby. 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.

3.1.2 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 a highly expansive, voluminous, and friable nature. [1]

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 that 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 may result in an expansion amount between 1 to 30 inches. The char thickness can be characterized by either high (>15), moderate (3 to 15), or low (<3) volume expansion.

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

3.1.3 Potential Application In The Aircraft Engine Nacelle

The intumescent material can be applied as a very narrow and thin strip, in the form of one or more closed rings on the exterior of the machinery. These rings are located so as to be able to swell against the enclosure at locations where clearance is minimal. If a fire occurs (such as due to a leak of flammable fluids onto hot exterior machinery components), the resulting flame would impinge upon a portion of the intumescent material, which would swell upon heating. Normal swelling is 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 possibly facilitating self-extinguishment. If the blockage is only partial, and the flame follows the redirected airflow around the sealed-off area, the local intumescent-covered portion in that region would also swell, until a complete ring of swelled intumescent is formed, completely sealing off the perimeter of the machinery space and preventing oxygen flow to the fire until the it 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, its effectiveness can be improved, or a smaller system used, because of the weakened fire condition and the reduced airflow dilution of the extinguishant.

A previous analysis performed by the United States Air Force (USAF) has suggested a feasible application for machinery spaces. (The USAF recently submitted this concept for government patent protection. However, it has not yet been 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 interior side of the enclosure if it is deemed beneficial. If the gap is relatively large between the machinery and the enclosure, 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 (DoD) is seeking additional design techniques that can improve 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 (engine core) 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 core. In this example, a region chosen in proximity to a structural rib is illustrated. The clearance between the rib and core is commonly no more than two to six 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 (which would expand upon impingement), thereby forming around the rib or component above it and blocking off the flow of air. Such a local fire block would weaken the fire due to oxygen starvation and possibly extinguish it.

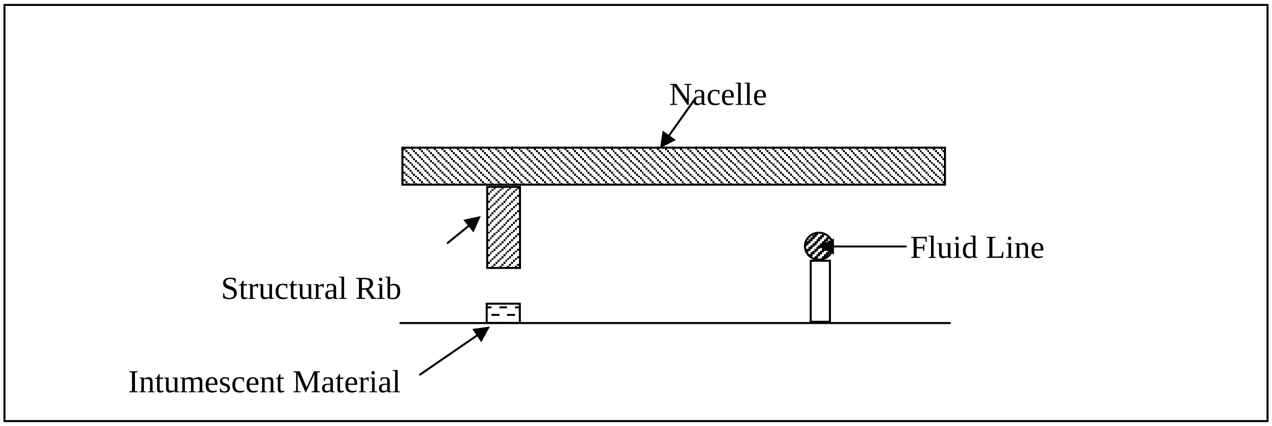

Figure 1. Cross Section View of Region Between Nacelle and Hot Engine Surface

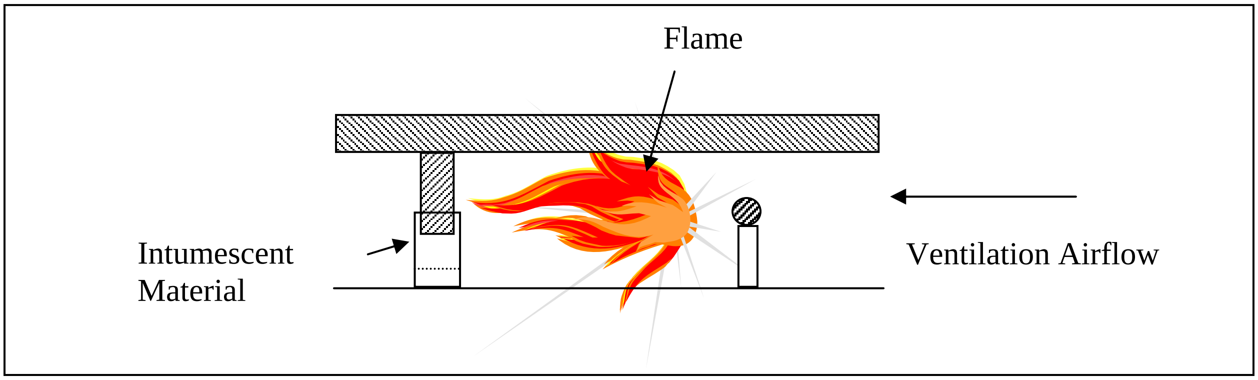

Figure 2. Fluid Leak and Subsequent Fire

3.1.4 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 (Appendix A). 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 (Appendix A). 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

3.2 Data Collected

Approximately 30 reports/papers (listed in Appendix A) were reviewed for this effort. The sources include:

- Federal Aviation Administration
- National Highway Traffic Safety Administration
- U.S. Department of Transportation
- Air Force Wright Aeronautical Laboratories
- National Institutes of Standards and Technology
- Air Force Propulsion Laboratory
- US Army Combat Systems Test Activity
- Joint Technical Coordinating Group on Aircraft Survivability
- Naval Surface Warfare Center
- Naval Weapons Center
- Naval Air Systems Command
- U.S. Army Air Mobility R&D Laboratory
- Naval Research Laboratory
- U.S. Patent and Trade Office

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.

3.3 Technologies Surveyed

Approximately 80 manufacturers (listed in Appendix B) were reviewed for this effort. From these 80 were selected those manufacturers whose products fell 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.

3.4 Analyses Conducted

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.

3.4.1 Groundrules And Assumptions

Prior to performing these analyses, ground rules and assumptions were developed to bound this assessment. These are noted in the individual analyses conducted.

3.4.2 System Configuration Data

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

3.4.2.1 Operating Conditions

The following sources were used to select operational conditions for these notional aircraft analyses. Table 3 compiles information from these sources:

- "Halon Replacement Program for Aviation, Aircraft Engine Nacelle Application, Phase I – Operational Parameters Study".
- Next Generation Fire Suppression Technology Program (NGP) Element 1A ("Fires Experienced And Halon 1301 Fire Suppression Systems In Current Weapon Systems").
- "Halon Fire Protection Systems for Aviation – Existing System Configuration and Operational Environment Specifications".
- "Fire Suppression System Performance of Alternative Agent in Aircraft Engine and Aircraft Dry Bay Simulations".

Table 3. Range of Operating Conditions in Aircraft Engine Nacelle Environment

Parameter	Minimum	Maximum
Air Pressure (psi)	1	14.7
Air Temperature (°F)	-65	630
Internal Air Flow (lb./s)	1.25	2.75
Surface Temperature (°F)	175	1300
Fire Initiation Temperature (°F)	540	790
Free Volume (ft^3)	5	100

3.4.2.2 Materials Used In Aircraft Engines

A brief review of structural and engine components was performed to identify potential material compatibility issues. These materials could be exposed to residual and combustion products in the post-deployment process.

Some typical and future aircraft engine materials include: titanium, aluminum, Inconel, stainless steel, titanium aluminide, silicon carbide fiber/silicon carbide ceramic matrix composite, and nickel aluminide.

3.4.2.3 Clearance And Dimensional Data

A fighter and/or attack aircraft provides the most feasible platform to examine the implementation of intumescent materials due to the smaller clearance between the structural ribs and the engine core (as shown in Figure 3). The width of the irregular annular air passage is commonly no more than two to six inches.

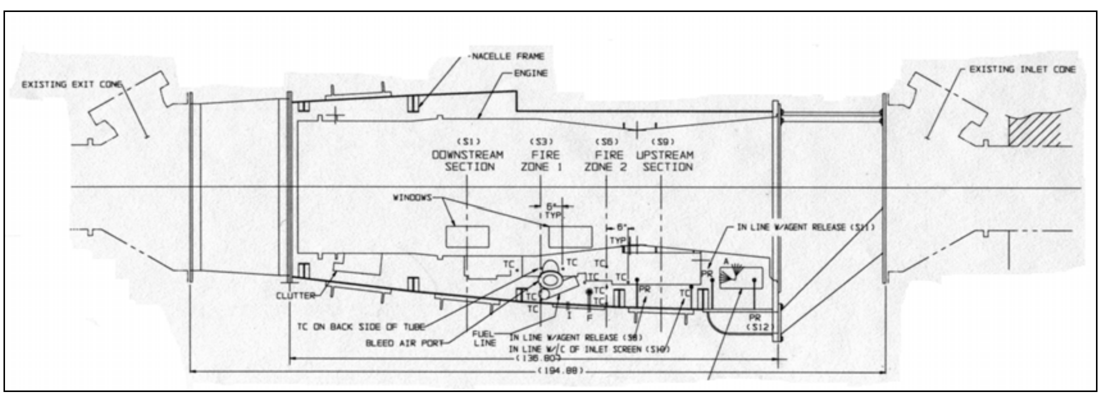

Figure 3. Aircraft Engine Nacelle Schematic

3.4.3 Weight Impact

Many types of intumescent materials are currently in use. If one considers a strip of 0.5-inch width, 0.12-inch 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 F-22 type engine), then a total volume of 0.00365 cubic feet per ring would result. Using an example density of 63 pound per cubic foot, a weight 0.23 pound per ring would exist. Even if four rings were used at various regions of the nacelle, then a total weight of only 0.92 pound 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 pounds total weight per engine.

Tables 4-6 display relevant information from the various intumescent manufacturers (tape, coating, and caulks).

Table 4. Relevant Information from Intumescent Tape Manufacturers

	Manufacturer	Coating Name	Length	Height	Width	Volume	Density	Weight	Activation Temperature	Expansion Factor	Expansion Amount
			in.	in.	in.	ft^3	$lb./ft^3$	lb.	°F(°C)		in.
1 A	3M Specialty Materials	Graphite Intumescent Seal (GIS)	113.1	0.06	0.50	0.00	70	0.14	expansion begins: 390°F(200°C); significant expansion: 555°F(290°C)	8	0.50
1 B	3M Specialty Materials	Interam	113.1	0.13	2.00	0.02	70	1.15	expansion begins: 410°F(210°C); significant expansion: 555°F(290°C)	25	3.13
2 A	Flame Safe Chemical Corporation	Wrap Strip (FSWS 100)	113.1	0.25	1.00	0.02	70	1.15	expansion begins: 250°F(121°C); significant expansion: 500°F(260°C)	40	10.00
2 B	Flame Safe Chemical Corporation	Wrap Strip (FSWS 150)	113.1	0.25	1.50	0.02	70	1.72	expansion begins: 250°F (121°C); significant expansion: 500°F(260°C)	40	10.00
3 A	Tremco	TREMstop WS1 (wrap strip)	113.1	0.10	1.50	0.01	68	0.67	expansion begins: 300°F(150°C)	12	1.20
3 B	Tremco	TREMstop WS2 (wrap strip)	113.1	0.10	2.25	0.01	68	1.00	expansion begins: 300°F(150°C)	12	1.20
4	Specified Technologies, Inc.	SSW Intumescent Wrap Strips	113.1	0.19	2.00	0.02	70	1.72	1st stage expansion: 250°F(121°C); 2nd stage expansion: 350°F(177°C); expansion continues until 1000°F	30	5.63
5	FIREPRO Fire Protective Building Materials	Firepro System 90, Firepro System 36/6	113.1	0.10	0.50	0.00	70	0.23			0.00

Items in shaded region are estimates.

Table 4. Relevant Information from Intumescent Tape Manufacturers (Continued)

	Manufacturer	Coating Name	Length	Height	Width	Volume	Density	Weight	Activation Temperature	Expansion Factor	Expansion Amount
			in.	in.	in.	ft^3	$lb./ft^3$	lb.	°F(°C)		in.
6	ASTROFLAME	ASTROTAPE	113.1	0.12	0.47	0.00	70	0.26		20	2.36
7	Zero International	INTUMET FS2003	113.1	0.25	0.38	0.01	70	0.43	expansion begins: 250°F(121°C)	20	5.00
8 A	Intumescent.com	Fireseal	113.1	0.16	0.39	0.00	64	0.26	expansion begins: 392°F(200°C)	20	3.15
8 B	Intumescent.com	Glazing Tape	113.1	0.12	0.47	0.00	64	0.23	expansion begins: 392°F(200°C)	20	2.36
9 A	Unifrax Corporation	Fiberfrax Expanding Fyre Paper	113.1	0.10	0.50	0.00	70	0.23	expansion begins: 620°F(325°C)	3	0.30
9 B	Unifrax Corporation	Fiberfrax Expanding Fyre Paper	113.1	0.15	0.50	0.00	70	0.34	expansion begins: 620°F(325°C)	3	0.45
9 C	Unifrax Corporation	Fiberfrax Expanding Fyre Paper	113.1	0.20	0.50	0.01	70	0.46	expansion begins: 620°F(325°C)	3	0.60
9 D	Unifrax Corporation	Fiberfrax Expanding Fyre Paper	113.1	0.25	0.50	0.01	70	0.57	expansion begins: 620°F(325°C)	3	0.75

Items in shaded region are estimates.

Table 5. Relevant Information from Intumescent Coating Manufacturers

	Manufacturer	**Coating Name**	**Length**	**Height**	**Width**	**Volume**	**Density**	**Weight**	**Activation Temperature**	**Expansion Factor**	**Expansion Amount**
			in.	**in.**	**in.**	**ft^3**	**$lb./ft^3$**	**lb.**	**°F(°C)**		**in.**
1	Solutia	Resimene AQ-7550	113.1	0.10	1.00	0.01	70	0.46		20	2.00
2A	Firefilm Technical Info.	A/D FIREFILM II	113.1	0.02	1.00	0.00	75	0.08		30	0.48
2B	Firefilm Technical Info.	A/D FIREFILM II	113.1	0.13	1.00	0.01	75	0.64		30	3.90
3	Corolon Coatings & Corrosion Control Technologies Inc.	Corolon IFRC	113.1	0.10	1.00	0.01	70	0.46	expansion begins: 400°F(200°C)	50	5.00
4A	Hensotherm	NOVATHERM 1FR	113.1	0.10	1.00	0.01	84	0.55	expansion begins: 212°F(100°C)	20	2.00
4B	Hensotherm	NOVATHERM 2FR	113.1	0.10	1.00	0.01	80	0.52	expansion begins: 212°F(100°C)	20	2.00
5A	No Fire Engineering, Inc.	NoFire A	113.1	0.10	1.00	0.01	83	0.54	expansion begins: 300°F(149°C)	40	4.00
5B	No Fire Engineering, Inc.	NoFire A18	113.1	0.10	1.00	0.01	87	0.57	expansion begins: 300°F(149°C)	40	4.00
5C	No Fire Engineering, Inc.	FX-100	113.1	0.10	1.00	0.01	82	0.54	expansion begins: 300°F(149°C)	40	4.00
6	FIREPRO Fire Protective Building Materials	Firepro System 90, Firepro System 36/6	113.1	0.10	1.00	0.01	70	0.46		20	2.00

Items in shaded region are estimates.

Table 5. Relevant Information from Intumescent Coating Manufacturers (Continued)

	Manufacturer	Coating Name	Length	Height	Width	Volume	Density	Weight	Activation Temperature	Expansion Factor	Expansion Amount
			in.	in.	in.	ft^3	$lb./ft^3$	lb.	°F(°C)		in.
7	Albi Manufacturing	Albi Clad TF	113.1	0.10	1.00	0.01	85	0.56			0.00
8	Flame Seal Products, Inc.	FX-100	113.1	0.10	1.00	0.01	90	0.59		100	10.00
9	PPG Industries Inc.	Pitt-Char XP Fire Protective Coating	113.1	0.10	1.00	0.01	72	0.47	expansion begins: 200°F(93°C)	5	0.50
10	Herberts Fire Protection Systems	unitherm	113.1	0.10	1.00	0.01	70	0.46		20	2.00
11	Firetherm	Firesteel Classic 60	113.1	0.04	1.00	0.00	70	0.18	expansion begins: 428°F(220°C)	100	3.94
12 A	Cafco	CAFCO SprayFilm	113.1	0.02	1.00	0.00	70	0.11	expansion begins: 400°F(200°C)	50	1.20
12 B	Cafco	CAFCO SprayFilm	113.1	0.24	1.00	0.02	70	1.11	expansion begins: 400°F(200°C)	50	12.10
13	Abesco Ltd.	Abesco Protecta System	113.1	0.10	1.00	0.01	70	0.46		50	5.00
14	Hevi-Duty Nelson	Nelson FSC	113.1	0.06	1.00	0.00	74	0.30	expansion begins: 212°F(100°C)	6	0.38

Items in shaded region are estimates.

Table 6. Relevant Information from Intumescent Caulk Manufacturers

	Manufacturer	Coating Name	Length	Height	Width	Volume	Density	Weight	Activation Temperature	Expansion Factor	Expansion Amount
			in.	in.	in.	ft^3	$lb./ft^3$	lb.	°F(°C)		in.
1	3M	Fire Barrier Caulk	113.1	0.10	1.00	0.01	70	0.46	expansion begins: 300°F(149°C)	3	0.30
2A	Flame Safe Chemical Corporation	FS 1900 Series Sealant	113.1	0.10	1.00	0.01	74.8	0.49		7	0.70
2B	Flame Safe Chemical Corporation	FSP 1000 Intumescent Putty	113.1	0.10	1.00	0.01	67	0.44	expansion begins: 250°F (121°C)	2	0.20
3	Tremco	Fyre-Sshield, TREMstop WBM	113.1	0.10	1.00	0.01	70	0.46			0.00
4A	Specified Technologies, Inc.	SSS Intumescent Sealant	113.1	0.63	1.00	0.04	70	2.86	expansion begins: 230°F(110°C)	8	5.00
4B	Specified Technologies, Inc.	Firestop Putty	113.1	0.50	1.00	0.03	10	0.33	expansion begins: 350°F(177°C)	5	2.50
5	ASTROFLAME	ASTROMASTIC	113.1	0.10	1.00	0.01	70	0.46		5	0.50
6	Albi Manufacturing	Albi Clad 800	113.1	0.10	1.00	0.01	68	0.45		5	0.50
7	Abesco Ltd.	Abesco Protecta System	113.1	0.10	1.00	0.01	70	0.46		50	5.00
8	Intumescent.com		113.1	0.10	1.00	0.01	70	0.46		5	0.50
9	Hevi-Duty Nelson	Nelson FSP	113.1	0.28	1.00	0.02	85	1.53	expansion begins: 500°F(260°C)	2	0.50

Items in shaded region are estimates.

3.4.4 Resistance To Aircraft Operating Environment

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.

However, the following methodology was employed to assess these characteristics:

- Determine area of aircraft engine nacelle,
- Determine distributed load (pressure profile) using fluid mechanics (ideal gas law, continuity equation, and Bernoulli's equation),
- Determine shear and normal stresses using mechanics of materials, and
- Compare shear and normal stresses with manufacturer information.

3.4.4.1 Determine Area Of Aircraft Engine Nacelle

The equation for the area of a cylinder (given below) was used to determine the values of the areas at locations 1 (A_1) and 2 (A_2) that are shown below in Figure 4. These area values are given in Table 7.

$$A = \frac{\pi d^2}{4}$$

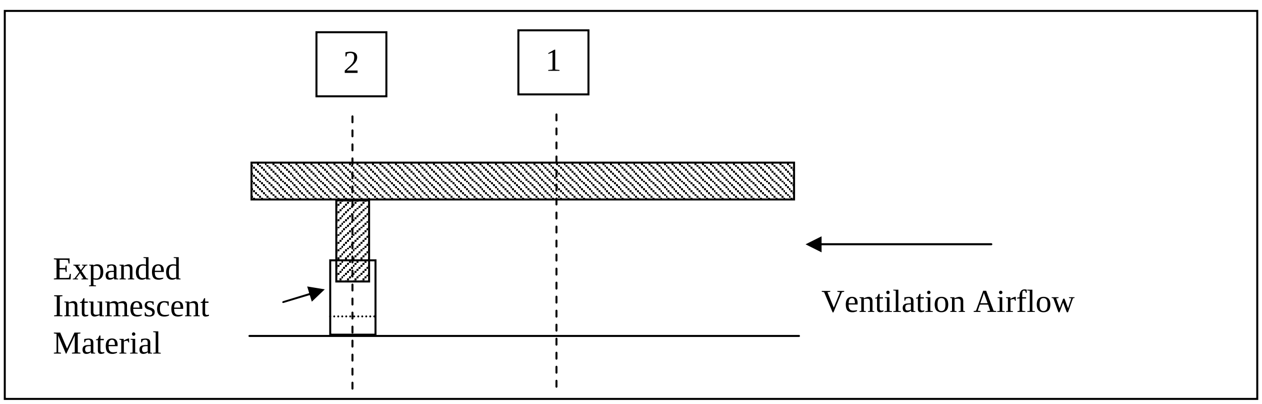

Figure 4. Cross Sectional View of Region Between Nacelle and Hot Engine Surface (Locations 1 and 2)

Table 7. Parameters for Area Calculation

Parameters	Symbol	Units	Value
Nacelle Diameter	d_N	in.	52
Core diameter	d_C	in.	36
Area $_{nacelle}$	A_N	ft^2	14.75
Area $_{rib}$	A_R	ft^2	10.56
Area $_{core}$	A_C	ft^2	5.94
Area $_1 = A_N - A_C$	A_1	ft^2	8.81
Area $_2 = A_R - A_C - A_{INT}$	A_2	ft^2	≈ 0

3.4.4.2 Determine Distributed Load (Pressure Profile)

Next, the Ideal Gas Law, the Continuity Equation, and Bernoulli's Equation [6] along with the parameters in Table 8 were used to estimate the pressure profile on the expanded char.

$$p = \rho RT \text{ (Ideal Gas Law)}$$

$$\dot{m} = \rho Q = \rho AV \text{ (Continuity Equation)}$$

$$\frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 = \frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 \text{ (Bernoulli's Equation)}$$

Table 8. Parameters for Distributed Load Calculation

Parameters	Symbol	Value
Pressure (lb/ft^2)	p	---
Density (lb/ft^3)	ρ	0.04
gas constant (ft-lbf)/(lb-mole-R)	R_{bar}	1545
gas constant for air = R_{bar}/MW (((ft-lbf)/(lb-mole-R))/MW (lb/lb-mole))	R	53.33
Molecular Weight $_{AIR}$ (lb/lb-mole)	MW	28.97
Temperature (°F)	T	500
Temperature (R)	T	959.67
Internal Mass flow rate (lb/sec)	Mdot	2.2
Volumetric flow rate (ft^3/min)	Q	3191.5
Cross-section of area of flow (ft_2)	A	---
Average velocity of flow (ft/sec)	V	---
Specific Weight of air (lb/ft^3)	γ	0.077
Average velocity of the fluid at location 1 (ft/sec)	v_1	1026.67
Average velocity of the fluid at location 2	v_2	0
Acceleration due to gravity (ft/sec^2)	g	32.17
Vertical distance from a datum (potential energy) (in)	z_1, z_2	0

It is assumed that the dynamic pressures as a result of the airflow are the loading on the intumescent material.

It is assumed that the velocity is the outside airflow velocity (approximately 700 miles per hour).

The resulting distributed load (pressure profile = p_2-p_1) is 8.70 lbf/in^2.

3.4.4.3 Determine Normal And Shear Stresses

Next, equations in mechanics of materials were used to estimate the normal and shear stresses on the expanded char. Figure 5 depicts the expanded intumescent material being represented as a cantilever beam.

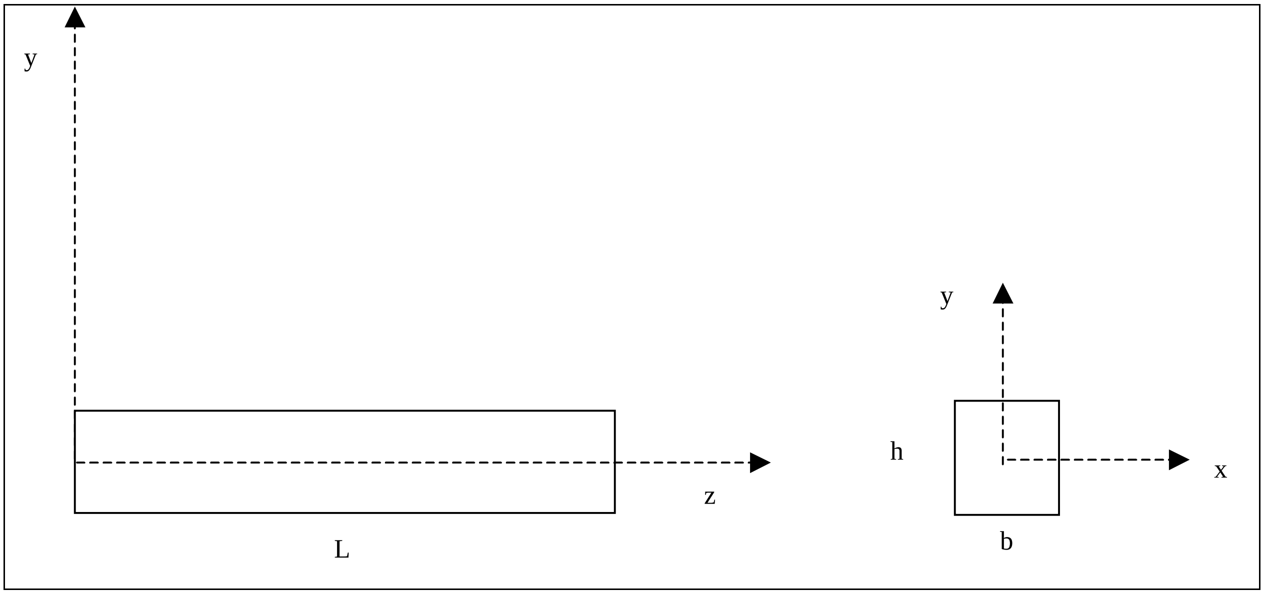

Figure 5. Expanded Intumescent Material Represented as a Cantilever Beam

The following equations represent the normal and shear stresses [6].

$$\sigma = -\frac{M_x y}{I_{x_C}} = \frac{\frac{-wL^2}{2}\frac{-h}{2}}{\frac{bh^3}{12}} = \frac{12hwL^2}{4bh^3} = \frac{3wL^2}{bh^2} = \text{ (normal stress)}$$

$$\tau = \frac{VQ}{I_X t} = \frac{wL}{\frac{bh^3}{12}} \frac{\frac{bh^2}{8}}{b} = \frac{3wL}{2hb} = \text{ (shear stress)}$$

where:
L = height of expanded char
h = width of intumescent material
b = section unit length of intumescent ring

Table 9 shows values for normal and shear stresses versus various values of L and versus various pressures.

Table 9. Pressure Vs. Normal and Shear Stress

	L = 0.5		**L = 1**		**L = 1.5**		**L = 2**		**L = 2.5**		**L = 3**		**L = 3.5**		**L = 4**		**L = 4.5**		**L = 5**		**L = 5.5**		**L = 6**	
Press	**norm stress**	**shear stress**	**norm stress**	**shear stress**	**Norm stress**	**shear stress**	**Norm stress**	**shear stress**	**Norm stress**	**shear stress**	**Norm stress**	**shear stress**	**Norm stress**	**shear stress**	**Norm stress**	**shear stress**	**Norm stress**	**shear stress**	**Norm stress**	**shear stress**	**Norm stress**	**shear stress**	**Norm stress**	**shear stress**
psi	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**	**psi**
0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
0.01	0.03	0.015	0.12	0.03	0.27	0.045	0.48	0.06	0.75	0.075	1.08	0.09	1.47	0.105	1.92	0.12	2.43	0.135	3.00	0.15	3.63	0.165	4.32	0.18
0.02	0.06	0.03	0.24	0.06	0.54	0.09	0.96	0.12	1.50	0.15	2.16	0.18	2.94	0.21	3.84	0.24	4.86	0.27	6.00	0.3	7.26	0.33	8.64	0.36
0.03	0.09	0.045	0.36	0.09	0.81	0.135	1.44	0.18	2.25	0.225	3.24	0.27	4.41	0.315	5.76	0.36	7.29	0.405	9.00	0.45	10.89	0.495	12.96	0.54
0.04	0.12	0.06	0.48	0.12	1.08	0.18	1.92	0.24	3.00	0.3	4.32	0.36	5.88	0.42	7.68	0.48	9.72	0.54	12.00	0.6	14.52	0.66	17.28	0.72
0.05	0.15	0.075	0.60	0.15	1.35	0.225	2.40	0.3	3.75	0.375	5.40	0.45	7.35	0.525	9.60	0.6	12.15	0.675	15.00	0.75	18.15	0.825	21.60	0.9
0.06	0.18	0.09	0.72	0.18	1.62	0.27	2.88	0.36	4.50	0.45	6.48	0.54	8.82	0.63	11.52	0.72	14.58	0.81	18.00	0.9	21.78	0.99	25.92	1.08
0.07	0.21	0.105	0.84	0.21	1.89	0.315	3.36	0.42	5.25	0.525	7.56	0.63	10.29	0.735	13.44	0.84	17.01	0.945	21.00	1.05	25.41	1.155	30.24	1.26
0.08	0.24	0.12	0.96	0.24	2.16	0.36	3.84	0.48	6.00	0.6	8.64	0.72	11.76	0.84	15.36	0.96	19.44	1.08	24.00	1.2	29.04	1.32	34.56	1.44
0.09	0.27	0.135	1.08	0.27	2.43	0.405	4.32	0.54	6.75	0.675	9.72	0.81	13.23	0.945	17.28	1.08	21.87	1.215	27.00	1.35	32.67	1.485	38.88	1.62
0.1	0.30	0.15	1.20	0.3	2.70	0.45	4.80	0.6	7.50	0.75	10.80	0.9	14.70	1.05	19.20	1.2	24.30	1.35	30.00	1.5	36.30	1.65	43.20	1.8
0.2	0.60	0.3	2.40	0.6	5.40	0.9	9.60	1.2	15.00	1.5	21.60	1.8	29.40	2.1	38.40	2.4	48.60	2.7	60.00	3	72.60	3.3	86.40	3.6
0.3	0.90	0.45	3.60	0.9	8.10	1.35	14.40	1.8	22.50	2.25	32.40	2.7	44.10	3.15	57.60	3.6	72.90	4.05	90.00	4.5	108.90	4.95	129.60	5.4
0.4	1.20	0.6	4.80	1.2	10.80	1.8	19.20	2.4	30.00	3	43.20	3.6	58.80	4.2	76.80	4.8	97.20	5.4	120.00	6	145.20	6.6	172.80	7.2
0.5	1.50	0.75	6.00	1.5	13.50	2.25	24.00	3	37.50	3.75	54.00	4.5	73.50	5.25	96.00	6	121.50	6.75	150.00	7.5	181.50	8.25	216.00	9
0.6	1.80	0.9	7.20	1.8	16.20	2.7	28.80	3.6	45.00	4.5	64.80	5.4	88.20	6.3	115.20	7.2	145.80	8.1	180.00	9	217.80	9.9	259.20	10.8
0.7	2.10	1.05	8.40	2.1	18.90	3.15	33.60	4.2	52.50	5.25	75.60	6.3	102.90	7.35	134.40	8.4	170.10	9.45	210.00	10.5	254.10	11.55	302.40	12.6
0.8	2.40	1.2	9.60	2.4	21.60	3.6	38.40	4.8	60.00	6	86.40	7.2	117.60	8.4	153.60	9.6	194.40	10.8	240.00	12	290.40	13.2	345.60	14.4
0.9	2.70	1.35	10.80	2.7	24.30	4.05	43.20	5.4	67.50	6.75	97.20	8.1	132.30	9.45	172.80	10.8	218.70	12.15	270.00	13.5	326.70	14.85	388.80	16.2
1	3.00	1.5	12.00	3	27.00	4.5	48.00	6	75.00	7.5	108.00	9	147.00	10.5	192.00	12	243.00	13.5	300.00	15	363.00	16.5	432.00	18
5	15.0	7.5	60.0	15	135.0	22.5	240.0	30	375.0	37.5	540.0	45	735.0	2.5	960.0	60	1215.0	67.5	1500.0	75	1815.0	82.5	2160.0	90
6	18.0	9	72.0	18	162.0	27	288.0	36	450.0	45	648.0	54	882.0	63	1152.0	72	1458.0	81	1800.0	90	2178.0	99	2592.0	108
7	21.0	10.5	84.0	21	189.0	31.5	336.0	42	525.0	52.5	756.0	63	1029.0	73.5	1344.0	84	1701.0	94.5	2100.0	105	2541.0	115.5	3024.0	126
8	24.0	12	96.0	24	216.0	36	384.0	48	600.0	60	864.0	72	1176.0	84	1536.0	96	1944.0	108	2400.0	120	2904.0	132	3456.0	144
9	27.0	13.5	108.0	27	243.0	40.5	432.0	54	675.0	67.5	972.0	81	1323.0	94.5	1728.0	108	2187.0	121.5	2700.0	135	3267.0	148.5	3888.0	162
10	30.0	15	120.0	30	270.0	45	480.0	60	750.0	75	1080.0	90	1470.0	105	1920.0	120	2430.0	135	3000.0	150	3630.0	165	4320.0	180

3.4.4.4 Compare Shear And Normal Stresses With Manufacturer Information

Finally, the values determined previously for normal and shear stresses were compared with the manufacturer information given for the expanded intumescent material. Table 10 shows physical properties, including the char strength, of the various intumescent materials (tapes, coatings, and caulks) investigated during this study.

It is assumed that the data provided by the manufacturers are accurate and verifiable.

It is unclear whether some of these values (particularly the tensile strength values) are of the unexpanded or expanded material. Further investigation needs to be performed to determine this.

Table 10. Properties of Intumescent Materials

Properties	Tapes	Coatings	Caulks
Char characteristics	rapid expansion forms dense char good stability after expansion soft puff (begins intumescing at relatively low temperatures, expands gradually with low force and forms a firm char) tensile strength: 2.8 Shore A DIN 53504: 80+/-5 char strength: 18 psi (0.12 Mpa) if compressed 50%	hardness: Shore D 8.8/25/45-50 compressive strength: 1095 psi/300 psi impact resistance: 286 in-lb (3.3 kg-m)/700 in-lb impact: 0.77 ft-lb/inch of notch/1.46 ft-lb./in bond strength: 1051 psi abrasion resistance: 508 cycles per mil @ 65 mil/0.90 gm loss tensile strength: 707 psi elongation: 19.4%; compressive strength: 2264 psi modulus: 4660 psi	modulus of elasticity: 94800 psi flexural strength: 1420 psi tensile strength: 756 psi abrasion resistance: 0.40 gm loss 1000 cycles impact resistance: 0.54 ft-lb/in of notch hardness Shore D: 65-70 compressive strength: 2100 psi
Installation	self adhesive backing can be razor cut or die cut to fit irregular shapes quick installation Highly flexible, resilient strip easy to cut and fabricate	can be manufactured to meet specific project requirements flexible	excellent adhesion can be manufactured to meet specific project requirements
Corrosion	N/A	no corrosivity effects in virgin state minor corrosion products in fire on unplated steel or aluminum	N/A
Toxicity	N/A	zero toxicity/ toxicity index: 1.9 no asbestos no halogens	asbestos free
Cost	cost-effective	$75/gallon $60/lot	N/A
Other	demonstrated stability and performance over a variety of extreme environments	durable survive even the most severe fire and its associated turbulent air currents greater resistance to environmental conditions deflection resistance: pass without spalling, cracking or delaminating;	will not dust, flake outstanding wear-resistance exterior durability and performance withstand weathering maintains excellent fire protective properties when exposed to years of extreme abuse and vibration

3.4.5 Reduction In Suppressant Required

An estimate was made of the reduction in suppressant needed as a result of using this technology.

To accomplish this, the following three scenarios were examined and the results are given in Table 11: 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 (shown in Table 11).
- 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.

Table 11. Estimate of Halon 1301 Required To Inert Free Volume

AEN	**V**	**6% V**	**Halon 1301**	**Halon 1301**	**Halon 1301**
	ft^3	**ft^3**	**liters**	**gram**	**lb.**
free volume (ft^3)	100	6	169.88	1129.34	2.49
2/3 free volume (ft^3)	66	3.96	112.12	745.36	1.64
1/3 free volume (ft^3)	33	1.98	56.06	372.68	0.82
APU	**V**	**6% V**	**Halon 1301**	**Halon 1301**	**Halon 1301**
	ft^3	**ft^3**	**liters**	**gram**	**lb.**
free volume (ft^3)	5	0.3	8.49	56.47	0.12
2/3 free volume (ft^3)	3.3	0.198	5.61	37.27	0.08
1/3 free volume (ft^3)	1.65	0.099	2.80	18.63	0.04

Also calculated was the estimate of Halon 1301 required using MIL-E-22285 (given in Table 12)[7].

Table 12. Estimate of Halon 1301 Required Using MIL-E-22285

AEN		**Halon 1301**	**Halon 1301**	**Halon 1301**	**Halon 1301**	**Halon 1301**
		lb.	**lb.**	**lb.**	**lb.**	**lb.**
		W=0.05V	**W=0.02V+0.25Wa**	**W=3(0.02V+0.25Wa)**	**W=0.16V+0.56Wa**	**Calculated from inerting (Table 11)**
		Rough nacelle/low airflow	**Rough nacelle/low airflow**	**Rough nacelle/high airflow**	**Deep frame nacelle/high airflow**	
free volume (ft^3)	100	5.00	2.55	7.65	17.232	2.49
2/3 free volume (ft^3)	66	3.30	1.87	5.61	11.792	1.64
1/3 free volume (ft^3)	33	1.65	1.21	3.63	6.512	0.82
APU		**Halon 1301**	**Halon 1301**	**Halon 1301**	**Halon 1301**	**Halon 1301**
		lb.	**lb.**	**lb.**	**lb.**	**lb.**
		W=0.05V	**W=0.02V+0.25Wa**	**W=3(0.02V+0.25Wa)**	**W=0.16V+0.56Wa**	**Calculated from inerting (Table 11)**
		Rough nacelle/low airflow	**Rough nacelle/low airflow**	**Rough nacelle/high airflow**	**Deep frame nacelle/high airflow**	
free volume (ft^3)	5	0.25	0.65	1.95	2.032	0.12
2/3 free volume (ft^3)	3.3	0.17	0.616	1.848	1.76	0.08
1/3 free volume (ft^3)	1.65	0.08	0.583	1.749	1.496	0.04

As evidenced by this table, 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. [3] 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.

3.5 Concerns And Potential Solutions

Application of intumescent materials in the aircraft engine nacelle causes some concerns that must be recognized and accommodated. However, these concerns can be addressed during process development.

The main concerns uncovered in this investigation were the following:

- Potential toxicity,
- Fragility of char,
- Response in a high humidity environment,
- Installation in highly cluttered areas, and
- Early expansion due to low activation temperature.

Table 13 below presents a potential solution for each of the concerns presented above.

Table 13. Concerns and Potential Solutions

POTENTIAL TOXICITY		**ADDITIONAL SOURCES**
Concern	Past studies revealed concern over the emission of noxious gases, nonflammable gases, toxic phosgene gas, water vapor, carbon dioxide, and ammonia during the intumescing process as well as the combustion process.	1, 8, 9, 10
Potential Solution	This area (aircraft engine nacelle) is a normally unoccupied space. This emission of gases occurs only during a fire event. The addition of perlite and vermiculite should decrease the amount of toxic gases liberated during expansion.	11
FRAGILITY OF CHAR		**ADDITIONAL SOURCES**
Concern	Past studies revealed concern over the fragility of the intumesced char after expansion. Additional concerns include: cracking, flaking, blistering, and dislodgment.	10, 11, 12, 13, 14, 15, 16, 17
Potential Solution	Reinforcement of char by addition of up to 3% chopped glass fibers (short fibers – 1/32 inch), chopped quartz fibers, short length silica fibers, Kevlar, perlite, and/or vermiculite.	11, 13, 14, 15, 17, 18, 19, 20
RESPONSE IN A HIGH HUMIDITY ENVIRONMENT		**ADDITIONAL SOURCES**
Concern	Past studies revealed concern over the reduction in intumescence due to a high humidity environment.	12
Potential Solution	The typical USAF aircraft environment is not exposed to a high humidity environment for an extended period of time. This is not the case for USN aircraft on aircraft carriers. The addition of short length silica fibers was suggested to increase the char stability in high humidity.	17
INSTALLATION IN HIGHLY CLUTTERED AREAS		**ADDITIONAL SOURCES**
Concern	Past studies revealed concern over the installation time required in a highly cluttered area.	18
Potential Solution	Intumescent materials are available in several different forms (tapes, coatings, and caulks) as discussed previously. The easiest material to install based upon this study seems to be the intumescent tape.	Tables 4-6 in this study
EARLY EXPANSION DUE TO LOW ACTIVATION TEMPERATURE		**ADDITIONAL SOURCES**
Concern	Past studies revealed concern over the potential activation of the intumescent material in the normal aircraft engine operating environment.	13
Potential Solution	This could be reduced/eliminated with the addition of an insulating material layer between the intumescent material and the engine core.	15

4.0 Technical Problems

Based upon the calculations performed during this effort, the intumescent material reduces the required amount of Halon 1301. However, experimentation is needed to verify these calculations.

The values determined previously for normal and shear stresses were compared with the manufacturer information given for the expanded intumescent material. It is assumed that the data provided by the manufacturers are accurate and verifiable. It is unclear whether some of these values (particularly the tensile strength values) are of the unexpanded or expanded material. Further investigation needs to be performed to determine this.

5.0 Recommendations

For full exploitation of this technology, an experimental program is recommended. Based upon the results of such a program, the utilization of intumescent materials could be recommended and justified via a cost analysis.

5.1 Experimental Validation

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.

5.2 Cost Analysis Of Intumescent Material Utilization

It is recommended that a cost analysis be performed to compare the existing Halon 1301 system and a system that utilized intumescent materials in conjunction with a less efficient Halon 1301 alternative. The net cost each of the two fire suppression systems would be determined. This would be accomplished by determining the cost of each system (a function of system size/weight) and the cost savings provided by the system (which are a function of extinguishant effectiveness and subsequent aircraft saved). The net cost is the cost of the system minus the cost savings.

Additional cost issues to consider include the following:

- The cost to clean the engine nacelle and core after utilization of the intumescent material should be investigated. To put this cost in perspective, the normal cost (man-hours and equipment required) to clean the engine nacelle and core after utilization of a Halon 1301 system should be determined.
- Maintenance costs to install the intumescent material should be estimated.
- The cost of employing the intumescent materials in conjunction with a less efficient Halon 1301 alternative should be estimated.
- The cost of utilizing the intumescent material alone should be estimated.

The fire suppression system detailed cost element structure (CES) (given in Table 14) is based on the DoD 5000.4-M and MIL-HDBK-881 CES. It would be customized for this particular system and approach.

SURVIAC has used this process to perform a similar cost analysis for the C-17. Currently, this process is also being used for the F/A-18 E/F, RAH-66, and B-1.

6.0 Conclusions

Intumescent materials have properties that can positively or negatively influence its effectiveness for fire suppression. These may include the following: original thickness, expansion factor/amount, density, protection hours, activation/maximum temperature, forms, char characteristics, etc. Trade-offs must be made between these properties depending upon the requirements most important to the platform. The system can be designed and engineered such that problems are overcome during process development.

This study showed the feasibility of utilizing strategic placement of intumescent materials within the ventilated aircraft engine nacelle to reduce the amount of suppressant needed.

Table 14. Detailed Cost Element Structure

1.0	**RDT&E (3600)**
1.1	Concept Exploration
1.2	Prototype EMD Cost Sharing (Fire Suppression System Prototype)
1.2.1	Subsystem
1.2.1.1	Group A Kit (Hardware to install/mount fire suppression system)
1.2.1.2	Group B Kit (Fire suppression system)
1.2.2	COTS/GOTS Software – N/A
1.2.3	Development Software – N/A
1.2.4	Integration, Assembly, Test and Checkout
1.3	System/Platform Integration
1.4	System Engineering/Program Management
1.4.1	Systems Engineering
1.4.2	Program Management
1.4.3	Travel
1.5	System Test and Evaluation
1.5.1	Developmental Test and Evaluation (DT&E)
1.5.2	Operational Test and Evaluation (OT&E)
1.6	Data
1.7	Training
1.8	Evolutionary Technology Insertions (ETIs) - N/A
1.8.1	Program Management
1.8.2	Prototype and Test Bed
1.8.3	Market Surveys
1.9	Support Equipment
1.9.1	Common Support Equipment
1.9.2	Peculiar Support Equipment

Table 14. Detailed Cost Element Structure (Continued).

2.0	**PROCUREMENT (3010)**
2.1	Prime Mission Product (Fire Suppression System)
2.1.1	Subsystems
2.1.1.1	Group A Kit (Hardware to install/mount fire suppression system)
2.1.1.2	Group B Kit (Fire suppression system)
2.1.2	Non-Recurring Engineering – N/A
2.1.3	Software Integration – N/A
2.1.4	Integration, Assembly, Test and Checkout
2.2	System/Platform Integration and Assembly (Cost of installation)
2.3	Systems Engineering/Program Management
2.3.1	Systems Engineering
2.3.2	Program Management
2.3.3	Logistics Management
2.4	System Test and Evaluation
2.4.1	Operational Test and Evaluation
2.5	Engineering Change Orders (ECOs)
2.6	Initial Cadre Training
2.7	Data
2.8	Operational Fielding/Site Activation
2.9	Depot Setup - N/A
2.10	Support Equipment
2.10.1	Common Support Equipment
2.10.2	Peculiar Support Equipment
2.11	Initial Spares and Repair Parts
2.12	Warranty
2.13	Evolutionary Technology Insertions (ETIs) - N/A
2.14	Interim Contractor Support (ICS)
2.15	Flexible Sustainment Support (Maintenance Support)

Table 14. Detailed Cost Element Structure (Continued).

3.0	**OPERATIONS AND MAINTENANCE (3400)**
3.1	Program Administration
3.1.1	Program Management Support
3.1.1.1	Miscellaneous Contract Services
3.1.1.2	Government Technical Support
3.1.1.3	Travel
3.1.2	Life-Cycle Sustainment Management (LCSM)
3.2	Program Operational Support
3.2.1	Recurring Training
3.2.2	Technical Data Revision
3.2.3	Software Maintenance - N/A
3.2.4	Hardware Maintenance
3.2.4.1	Organic Support
3.2.4.2	Contractor Maintenance
3.2.5	Replenishment Spares
3.2.6	Repair Parts and Materials
3.2.7	Transportation, Packaging, and Handling
3.2.8	Storage
3.2.9	Disposal
3.2.10	Facility Projects/Upgrades/Leases
3.2.11	Operational O&M Impacts of ETIs - N/A
3.2.12	Program Operations
3.2.13	Unit Level Support
3.2.13.1	Recurring Training (Unit Travel/TDY Costs)
3.2.13.2	Operating Consumables
3.2.13.3	Unit Level O&M Impacts of ETIs
3.2.14	Depot Level Support
3.2.15	Contractor Logistics Support (CLS)
4.0	**MILITARY PERSONNEL (3500)**
5.0	**MILITARY CONSTRUCTION – N/A**

7.0 References

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.
2. WL-TR-95-3077, Halon Replacement Program for Aviation, Aircraft Engine Nacelle Application, Phase I – Operational Parameters Study, April 1997.
3. SURVIAC-TR-00-XX, "Fires Experienced and Halon 1301 Fire Suppression Systems In Current Weapon Systems", July 1999.
4. SURVIAC-TR-92-XX "Halon Fire Protection Systems for Aviation – Existing System Configuration and Operational Environment Specifications", December 1992.
5. NIST SP 890 Volume II, "Fire Suppression System Performance of Alternative Agent in Aircraft Engine and Aircraft Dry Bay Simulations", November 1995.
6. Fundamentals of Engineering (FE) Reference Handbook, National Council of Examiners for Engineering and Surveying, pp. 22-23 and 47-48, 1993.
7. MIL-E-22285, Military Specification, "Extinguishing System, Fire, Aircraft, High-Rate-Discharge Type, Installation and Test of", April 27, 1960.
8. MIL-HDBK-684 "Design Of Combat Vehicles for Fire Survivability", Chapter 7, Extinguishing Agents And Systems, 7-40 – 7-41, February 15, 1995.
9. Manual Paint Glossary, Http://Www.Flexbon.Com/Glossary.Html, Paint And Coatings Glossary, July 5, 2000.
10. Evaluation of Intumescent Body Panels Coatings In Simulated Post-Accident Vehicle Fires, NISTIR 6157, April 1998.
11. ADA031035, SURVIAC # 09967, "Thermal Protective Coatings", March 31, 1976.
12. JTCG/AS-75-T-007, "Fire Resistant Aircraft Fuel Cell Installations", July 1978.
13. ERR-FW-1578, ADH6923, SURVIAC 11984, "Advanced Integrated Fire Protection System Study For Aircraft" December 31, 1974.
14. AD870435, SURVIAC 06628, "Fuel Vulnerability Reduction", April 1970.
15. AFWAL-TR-82-2111, "Fire Resistance Tests Of Intumescent-Coated Self-Sealing Fuel Lines", January 1983.
16. "Bench-Scale Evaluations and Mechanistic Studies Of Intumescent/Fire-Protective Coatings For Polyvinyl Chloride Nitrile Rubber", Fire And Materials Vol. 18, 277-287 (1994).
17. Letter – From: Commanding Officer, Naval Research Laboratory; To: Commander, Naval Sea Systems Command (PMS 393, C. Boova); Subject: Intumescent Coatings For Submarine Interior Applications: Candidates For PVC Nitrile Rubber Identified For Subsequent Evaluation; 29 September 1992.

18. ASD-TR-77-73, "A-7 Fuselage Survivability Improvement Program Realistic Testing", November 1977.

19. "Basic Facts About Perlite", <Http://Www.Perlite.Net>, pp. 4, March 6, 2001.

20. "Vermiculite Home Page For Information About Vermiculite—A Mineral With Many Uses", <Http://Vermiculite.Net/>, pp. 4, March 6, 2001.

APPENDICES

APPENDIX A

LITERATURE SOURCES

Literature Sources

	File Number	Title	Author	DTIC Number	Government Report Number	Report Date	Originating Activity	Sponsoring Activity
1	5664	Aerospace Vehicle Hazard Protection Program: Detectors; Materials; Fuel Vulnerability	O Neill, J.H.; Sommers, D.E.; Nicholas, E.B.	NA	AFAPL TR-73-87	10/1/73	National Aviation Facilities Experimental Center, Federal Aviation Administration, US Department Of Transportation	AF Aero Propulsion Laboratory
2	11782	Hypersonic Weapon Vehicle Technology(HWVT)Structural Materials Evaluation	Bausch,K.D.; Bennett,B.K.; Miller,J.,Et Al	NA	AFATL TP-90-12	2/1/91	McDonnell Douglas Missile Systems Company	Flight Vehicles Branch, Aeromechanics Division, Air Force Armament Laboratory
3	3571	Fire Resistance Tests Of Intumescent-Coated Self-Sealing Fuel Lines	Boris,P.; Na; Na	NA	AFWAL TR-82-2111	1/1/83	Federal Aviation Administration, Technical Center	Aero Propulsion Laboratory (Afwal/Posh), AF Wright Aeronautical Laboratories
4	07684w	Influence Of Matrix Properties On The Erosion Resistance Of Carbon-Carbon Composites (Proceedings Of The AFWAL/ONR Workshop: Matrix Properties In Carbon-Carbon Composites)	Isbell,W.M.; Na; Na	ADB080984L	AFWAL TR-82-4200	8/1/83	Office Of Naval Research	ONR, & AFWAL/Ml,
5	11941	Air Force Technical Objective Document	NA	NA	AFWAL TR-86-3000	7/1/86	Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory, AFWAL/GLXRF	Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory, AFWAL/GLXRF,
6	8453	A-7d Fuselage Survivability Improvement Program Realistic Testing	Herron,D.L.; Hollis,C.P.; Na	ADB025946L	ASD TR-77-73	11/1/77	Vought Corporation	Aeronautical Systems Division,Fighter/Attack Spo,Wright-Patterson Afb, Oh 45433
7	10143	Fire Resistant Barriers For Composites	Usman,S.; Na; Na	ADB126777	DTRC/SME-88-28	5/1/88	David Taylor Research Center, Code 2844	NA
8	11984	Advanced Integrated Fire Protection System Study For Aircraft	Mcclure,J.D.; Na; Na	NA	ERR FW-1578	12/1/74	General Dynamics	NA

Literature Sources (Continued)

	File Number	Title	Author	DTIC Number	Government Report Number	Report Date	Originating Activity	Sponsoring Activity
9	2145	Fire Resistant Aircraft Fuel Cell Installations	Mahood,L.; Na; Na	ADB029853L	JTCG AS 75-T-007	7/1/78	Falcon Research And Development	Joint Technical Coordinating Group On Aircraft Survivability, Central Office, Air-5204j, Naval Air Systems Command
10	15675	Ablative And Thermal Barriers For Aircraft Dry Bays	Smith, Benjamin D.; Musselman, Kenneth A.; Kurtz,Alex	ADB207073	JTCG/AS-95-V-002 NSWCDD/TR-95/132	9/1/95	Naval Surface Warfare Center Dahlgren Div	NA
11	6628	Fuel Tank Vulnerability Reduction	Winehester,H.F.; Denlinger,J.F.; Vickers,G.A., Et Al	AD870435	MDC J0044	3/1/70	Douglas Aircraft Company, Mcdonnell Douglas Corporation	Naval Air Systems Command, Department Of The Navy
12	6064	Electrical Cable Burn Test	Burt, W.T.; San Miguel, A.; Riggs, D.	NA	NA	12/1/74	Survivability And Lethality Division, Aircraft Systems Department, Naval Weapons Center, China Lake	NA
13	18708	Proceedings And Report Volume I Of Ii Fire Safety/Survivability Symposium 90 Responding To The Challenges Of The Post-Halon Era	Na;Na;Na	NA	NA	11/6/90	US Army Combat Systems Test Activity	Live Fire Test Office
14	03708z	Development, Test And Evaluation Of Techniques To Improve The Cook-Off Characteristics Of In-Service Rocket Motors (Retrofit Program), (Proceedings Of Aircraft Carrier Flight Deck Fire Survivability Workshop)	Kamo,S.M.; Yeakey,J.A.; Na	NA	NWC TM-4185	5/1/80	Naval Weapons Center, China Lake	Naval Weapons Center, China Lake

Literature Sources (Continued)

	File Number	Title	Author	DTIC Number	Government Report Number	Report Date	Originating Activity	Sponsoring Activity
15	03708w	Development Of Thermal Coating For Missile Warhead Fire Protection, (Proceedings Of Aircraft Carrier Flight Deck Fire Survivability Workshop)	Hogenson,P.A.; Na; Na	NA	NWC TM-4185	5/1/80	Rockwell International, Space Division	Naval Weapons Center, China Lake
16	03709k	Review Of Some Hazard Abatement Techniques For Weapon Systems Subjected To Fuel Fires And Fragment Attack,(Proceedings Of Aircraft Carrier Flight Deck Fire Survivability Workshop)	Sindall,J.H.; Na; Na	NA	NWC TM-4185	5/1/80	Imi Summerfield,Summerfield,Kedderminster,Worcestershire,England	Naval Weapons Center, China Lake
17	3049	Reduction Of Fuel Ingestion Vulnerability Of The F/A-18 Aircraft, An Interim Report	Burgner,G.; Dixon,G.P.; Na	NA	NWC TM-6785	9/1/90	Naval Weapons Center, China Lake	Naval Weapons Center, China Lake
18	6051	Aircraft Fire Simulator Testing Of Candidate Fire Barrier Systems	Hoffman, H.H.; Fontenot, J.S.; Na	NA	NWC TP-5915	11/1/76	Naval Weapons Center, China Lake	Naval Weapons Center, China Lake
19	6052	F-14a Fire Protection Test Program	Moncsko, G.E.; Hoffman, H.J.; Na	NA	NWC TP-5942	2/1/77	Naval Weapons Center, China Lake	Naval Weapons Center, China Lake
20	18240	Description, Installation, Cost Information On Passive Protection Concepts For The A-4 Aircraft	Fontenot,J.;Na;Na	NA	NWC-TM-408-001-75	1/1/75	Naval Weapons Center, China Lake	NA
21	9967	Thermal Protective Coatings	Perry ,J.L.; Wittman, G.R.; Na	ADA031035	U-6213	3/1/76	Aeronutronic Ford, Aeronutronic Division	Naval Weapons Center, China Lake
22	5570	Investigation And Evaluation Of Nonflammable, Fire-Retardant Materials	Atallah, S.; Buccigross, H.L.; Na	AD906699	USAAMRDL TR-72-52	11/1/72	Arthur D. Little, Inc.	Eustis Directorate, Us Army Air Mobility R&D Laboratory
23		Development Of Improved Flammability Criteria For Aircraft Thermal Acoustic Insulation			DOT/FAA/AR-99/44	9/1/00		
24		Evaluation Of Intumescent Body Panel Coatings In Simulated Post-Accident Vehicle Fires			NISTIR 6157	4/1/98		

Literature Sources (Continued)

	File Number	Title	Author	DTIC Number	Government Report Number	Report Date	Originating Activity	Sponsoring Activity
25		NRL Letter Report: Intumescent Coatings For Submarine Interior Applications: Candidates For PVC Nitrile Rubber Identified For Subsequent Evaluation				9/29/92		
26		NRL Letter Report: Evaluation Of Intumescent And Other Fire Protective Coatings For Submarine Interior Applications				5/26/93		
27		NRL Paper In "Fire & Materials"; Bench-Scale Evaluations And Mechanistic Studies Of Intumescent/Fire-Protective Coatings For Polyvinyl Chloride Nitrile Rubber				1/20/94		

APPENDIX B

LIST OF MANUFACTURERS

List of Manufacturers

	Manufacturer	Point of Contact	Address	City	ST	Zip Code	Phone Number	Fax Number	Email Address	Website	Coating Name
1	NULLFIRE LIMITED	Mr. Kevin Burke	29	COVENTRY		CV4 9TJ	01203 855563	01203 469547		www.energyweb.net	FIREC; SYSTEM E; MANDOLITE 990
2	A.J. Evans Painting	John Qualls	4545 W. Hacienda Ste 104	Las Vegas	NV	89118	702-461-7224	702-251-8832		www.xww.net/ajpainting/service/html	intumescent fireproofing
3	Master Painters Institute									www.mpda.net/mpi/approved/mpi063.htm	MPI #63
4	STI/Specified Technologies Inc.			Somerville	NJ		1-800-992-1180	908-526-9623			Firestop
5	STI/RAM Tool & Supply			Tucker	GA		770-270-1300	770-270-9400			Firestop
6	Construction Industry Associates Inc.			Coral Springs	FL		954-344-8306	954-344-8638			Fire Shield
7	All-State Products Inc.			Miami	FL		305-499-3244	305-499-3245			Flamesafe
8	Eagle Insulation Distributors Inc.			Long Island City	NY		718-937-9300	718-937-9337			
9	Firestop Specialties Inc.			Miami	FL		305-718-8897	305-718-8827			3M, STI
10	New York Firestopping Installers Corp.			Long Island City	NY		718-472-3107	718-937-9337			
11	DSD Contract Services		Victoria Chambers, Firvale Rd.	Bournemouth, Dorset		BHI 2JN	01202 780123			www.dsd-coatings.co.uk/	

List of Manufacturers (Continued)

	Manufacturer	Point of Contact	Address	City	ST	Zip Code	Phone Number	Fax Number	Email Address	Website	Coating Name
12	National Certified Fire Retardant, Inc.			Huntington Beach	CA		714-848-4770	714-848-6631			NCFR-1000 Intumescent; flame Out II C-139.01
13	3M	Product Information Center	Bldg 304-1-01	St. Paul	MN	55144-1000	1-800-364-3577	1-800-713-63		www.mmm.com/product/opunits.html	Interam
14	3M Specialty Materials	Brandon Corots		St. Paul	MN	55144-1000	651-733-5580				
15	American Fire Safety			Clearwater	FL		813-781-3660	813-781-6900	afsp@mindspring.com	www.oilfield-source.com/html/paints-intumescent.html	
16	Alfas Industries Limited		Bentall Business Park, Washington, Tyne & Wear NE37 3JD, UK				44 191 419 0505	44 191 419 2200	alfasind@aol.com	N/A	
17	Prometheus Developments Ltd.		19 Mosely St. Ripley Derbyshire DE5 3DA England				44(0)1773 741424	44(0)1773 741434	prometheus.dev@btinternet.com	www.prometheus-developments.co.uk/Page1.html	
18	Albi Intumescent U.L. Fireproofing			Orlando	FL						
19	Albi Intumescent U.L. Fireproofing			Boca Raton	FL		1-800-945-5273	561-802-6979			
20	The National Paint & Coatings Association		1500 Rhode Island Ave. NW	Washington	DC	200005	202-462-6272	202-462-8549			

List of Manufacturers (Continued)

	Manufacturer	Point of Contact	Address	City	ST	Zip Code	Phone Number	Fax Number	Email Address	Website	Coating Name
21	Solutia		10300 Olive Boulevard PO Box 66760	St. Louis	MO	63166-6760	413-730-3241	413-730-3394		www.coatings-solutia.com	Phos-Chek Fire Retardants; Resimene Amino Crosslinker Resins; Butvar Polyvinyl Butyral (PVB) Resin; Santolink Advanced Crosslinkers; Santicizer Plasticizers; Modaflow Flow & Leveling Aids; Santosol Dimethyl Esters
22	RO-AN Corporation			Menomonee Falls	WI	53052	1-800-922-1600		sales@roancorp.com	www.roancorp.com	
23	Flame Safe Chemical Corporation			Ft. Worth	TX		1-800-334-8796		info@flamesafe.com	www.flamesafe.com/	
24	International Protective Coatings Corp.		1330 Industry Rd.	Hatfield	PA	19440	1-800-334-8796	1-888-531-5192		www.roancorp.com	
25	Chicago Flameproof and Wood Specialties		1200 S. Lake St. PO Box 318	Montgomery	IL	60538	603-859-0009	630-896-4773			
26	Intek Construction Products Inc.		1192 East 40th St.	Cleveland	OH	44114	216-241-7880	216-241-6525			Specified Technologies, STI, Tremco, Unifrax, Premier, Pecora

List of Manufacturers (Continued)

	Manufacturer	Point of Contact	Address	City	ST	Zip Code	Phone Number	Fax Number	Email Address	Website	Coating Name
27	Hard, Harold D. Co.		2040 Oakland Park Ave.	Columbus	OH	43224	614-471-9700	614-471-9317			
28	Midwest Sealant Supply		6999-N Huntley Rd.	Columbus	OH	43229	614-847-4075	614-847-4148			
29	Atlas Wholesale Supply Inc.									www.atlaswholesale.com	
30	Energy User News									www.energyusernews.com	
31	Firefilm Technical Info.		420 Tapscott Road	Scarborough	ON	M1B 1Y4	416-292-2361	416-298-5887		www.adfire.com/firefilmtech.htm	A/D FIREFILM
32	Corolon Coatings & Corrosion Control Technologies Inc.		2405 Winston Park Drive	Oakville	ON	L6H 5V4	905-829-4523	905-829-5779		www.corolon.com/intumescent.html	
33	Hensotherm		Verkstadsgatan 6 B, 231 66 Trelleborg, SWEDEN				46(0)410-567 80	46(0)410-567 89	info@hensotherm.se	www.hensotherm.se/hensotherm1.html	NOVATHERM 1FR and 2FR
34	NoFire Technologies Inc.		21 Industrial Avenue	Upper Saddle River	NJ	07458	201-818-1616	201-818-8775		www.nofiretechnologies.com/	NoFire A and A18; FX-100; FLAMESTOP III;
35	No Fire Engineering, Inc.	Dr. Sam Gottfried	21 Industrial Avenue	Saddle River	NJ	07458-2301	201-818-1616; 201-818-1616	201-818-8775			No Fire A18
36	SEMO Paint								smlee@semo.co.kr	www.semo.co.kr/gmc/paint.htm	
37	Tremco						1-800-321-7906			www.tremcosealants.com/html/firestopping.htm	Fyre-Sshield, TREMstop

List of Manufacturers (Continued)

	Manufacturer	Point of Contact	Address	City	ST	Zip Code	Phone Number	Fax Number	Email Address	Website	Coating Name
38	Specified Technologies, Inc.			Sommerville	NJ		1-800-992-1180	908-526-9623	specseal@stifirestop.com	www.stifirestop.com	SSS Intumescent Sealant; SSW Intumescent Wrap Strips
39	Protect It									www.protect.it/intpnt/htm	
40	British Steel									www.civl.port.ac.uk/britishsteel/media/Fire%20brochure/Section5.htm	
41	FIREPRO Fire Protective Building Materials		P.O. Box 12636	Auckland	New Zealand		64 9 579 0367			www.centrabuild.co.nz/~firepro/datasheets/sect4.htm	Firepro System 90, Firepro System 36/6
42	ASTROFLAME		Unit 1, Bridge Farm Industries Curbridge Southampton England S030 2HB							www.astroflame.com	ASTROMASTIC
43	Albi Manufacturing		401 Berlin Street	East Berlin	CT	06023	860-828-0571	860-828-3297	info@albi.com	www.albi.com/clad900.html	Albi Clad
44	Flamort Co. Inc.		746 Natoma St.	San Francisco	CA	94103	415-621-7825	415-621-6750		www.sweets.com/index/mfg/2330/P10703.htm	FLAM-GARD
45	Flame Seal Products, Inc.		4025 Willowbend Blvd. #310	Houston	TX	77025	713-668-4291	713-668-3526	flameseal@flameseal.com	www.flameseal.com	N-111, FX-100
46	Complete Fire Protection Limited		1 Queen Victoria Street	St. Philips	Bristol	BS2 0QR	0117 941 3330	0117 940 4770	mail@cfpltd.co.uk	www.cfpltd.co.uk/mainrhs.html	Fireplug
47	PPG Industries Inc.	Tim Figore	151 Colfax Street	Springdale	PA	15144	412-274-4500	412-274-3420		www.ppgaf.com/pittchar/intumescent.htm	Pitt-Char XP Fire Protective Coating

List of Manufacturers (Continued)

	Manufacturer	Point of Contact	Address	City	ST	Zip Code	Phone Number	Fax Number	Email Address	Website	Coating Name
48	Herberts Fire Protection Systems		Hemming Rd., Washford Industrial Estate Redditch, Worcestershire, B98 0DH, UK				44(0) 1527 514111	44(0) 1527 516787	sales@praybourne.co.uk	www.praybourne.co.uk	unitherm
49	No Burn of West Texas		Route 9 Box 159R	Lubbock	TX	79423	806-745-8371	806-748-0524			
50	NO-BURN Inc.		P.O. Box 185	St. Clair	MI	48079	810-329-6762	810-329-8604	info@noburn.com	www.noburn.com/	No-Burn
51	Zero International									www.zerointernational.com	INTUMET
52	Firetherm									www.firetherm.com	
53	Cafco									www.cafco.com/intcoapa.htm	CAFCO SprayFilm
54	Sylpyl									www.sylpyl.com/innovai.htm	
55	ibermineral									www.ibermineral.es/html/intumin.htm	
56	Abesco Ltd.									www.abesco.co.uk/main.htm	Abesco Protecta System
57	Lorient North America Inc.		800 Fifth Avenue, Suite 4100	Seattle	WA	98104	1(0) 206-447-1418	1(0) 206-470-1150	sales@lorientna.com	www.lorientna.com/lornortham_home.htm	
58	National Guard Products, Inc.		4985 East Raines Rd.	Memphis	TN	38118	1-800-647-7874	1-800-255-7874			

List of Manufacturers (Continued)

	Manufacturer	Point of Contact	Address	City	ST	Zip Code	Phone Number	Fax Number	Email Address	Website	Coating Name
59	Intumescent.com		Unit 1, Bridge Farm Industries Curbridge Southampton England S030 2HB				44 01489 785 733	44 01489 784 887	sales@intumescent.com	www.intumescent.com	
60	Unifrax Corporation		2351 Whirlpool Street	Niagra Falls	NY	14305-2413	716-278-3800	1-800-329-3427	info@unifrax.com	www.unifrax.com/web/pages.nsf	Fiberfrax
61	Federal Process Company		3737 Park East Drive, Suite 203	Cleveland	OH	44122	216-464-6440				Gasoila Sealant
62	Goal Chemical Sealants Corp.	Robert A. Miller	3137 East 26th Street	Los Angeles	CA	90023	213-269-0461				Fuel Tank Sealant
63	James S. Priamos Productions, Inc.		P.O. Box 3194	Ontario	CA	91761	213-860-6870				Mega-temp Coating
64	Master Bond Inc.	James Brenner	154 Hobart Street	Hoboken	NJ	07601	201-343-8983				Epoxy Sealants
65	Textron Specialty Materials	George Castle		Lowell	MA		508-937-7521				Chartex 59C, Flamarest 1600 BTX, Avcoat 8039
66	Dow Corning	Kent Larson		Midland	MI	48686-0994	517-496-5541				Dow Corning 93-104 Ablative Material; Dow Corning3-6077RTV Silicone Ablative; Dow Corning 3-6376 Fast Cure Silicone Elastomer
67	Pfizer Inc.	William Hendershot		Easton	PA		1-800-962-8586				Firex 2390

List of Manufacturers (Continued)

	Manufacturer	Point of Contact	Address	City	ST	Zip Code	Phone Number	Fax Number	Email Address	Website	Coating Name
68	Fiber Materials Inc.	Scott Stephenson		Biddeford	ME		207-282-5911				Flexfram 805
69	Fire Research Lab.	Charles Bratcher		Albuquerque	NM		1-800-877-3473				Ocean 477, Ocean 9788
70	Hevi-Duty Nelson	Gerald Thomas		Tulsa	OK		918-627-5530				Firestop CTG 100
71	Fire and Thermal Protection	Larry Eskind		Carmel	CA		408-646-1966				Pyroplus ITM
72	FRC Technologies, Inc.	Roger Youngs		Addison	IL		708-628-1120				Pyrocide V93
73	Space Age Technology Products Inc.	Harry Shayman		Chicago	IL		312-725-0404				Fire Shield, Tough Coat
74	Vidox Patent Group Inc.	Hank Stawinski		Laurel	MD		301-490-2605				Vidox 92149
75	HeatShield Technologies Inc.	Paul Arena		Tamarac	FL		305-726-2774				HeatShield
76	Battelle	Wirth/R. Dick		Columbus	OH						Formulation 14B
77	New York Builders Supply Corp			New York	NY						
78	Carboline			Westerfield	NJ						
79	Fire Retardant Service and Supplies		P.O. Box 38709	Vancouver	BC	V7M 3NI	604-990-0893	604-990-0832	info@fire.ca	www.fire.ca	