The National Center for Advanced Manufacturing

Composite Material Flammability Teleconference

Thursday, June 27, 2002, 1:00 - 4:00 p.m.

Presented by Eric Greene
ERIC GREENE ASSOCIATES, INC.
Mr. Greene received his S.B. in Naval Architecture and Marine Engineering, Massachusetts Institute of Technology in 1979. Mr. Greene founded Eric Greene Associates, Inc. in 1987 to serve the high technology engineering requirements of the marine industry. Two Ship Structure Committee projects have culminated in the second edition of MARINE COMPOSITES (www.marinecomposites.com), written by Mr. Greene.

Mr. Greene manages MANTECH composite projects for Structural Composites. He specializes in the area of composite material performance in fires.

Mr. Greene teaches a one-day seminar based on the book MARINE COMPOSITES and is the co-chair of the annual Workshop on the Fire Performance of Marine Composite Materials.
Vinyl ester resins are unsaturated resins prepared by the reaction of a monofunctional unsaturated acid, such as methacrylic or acrylic, with a bisphenol diepoxide. The resulting polymer is mixed with an unsaturated monomer, such as styrene.

The handling and performance characteristics of vinyl esters are similar to polyesters. Some advantages of the vinyl esters, which may justify their higher cost, include superior corrosion resistance, hydrolytic stability, and excellent physical properties, such as impact and fatigue resistance.
## High-Temperature Resin Systems

### Vinyl Ester

<table>
<thead>
<tr>
<th>Resin</th>
<th>UTS, MPa</th>
<th>0.2% Offset Yield Strength, MPa</th>
<th>Modulus, GPa</th>
<th>Failure Strain, %</th>
<th>Heat Deflection Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ortho-polyester</td>
<td>54.1 (4.6)(^1)</td>
<td>45.2 (2.5)</td>
<td>3.18 (0.12)</td>
<td>2.0 (0.3)</td>
<td>55 (0.9)</td>
</tr>
<tr>
<td>Iso-polyester</td>
<td>34.6 (2.8)</td>
<td>----</td>
<td>3.32 (0.14)</td>
<td>1.2 (0.2)</td>
<td>69 (1.2)</td>
</tr>
<tr>
<td>Vinyl ester 980</td>
<td>25.7 (0.3)</td>
<td>20.6 (0.5)</td>
<td>1.63 (0.02)</td>
<td>30 (15)</td>
<td>60 (1.7)</td>
</tr>
<tr>
<td>Vinyl ester 411C-50</td>
<td>57.7 (0.8)</td>
<td>50.4 (2.5)</td>
<td>3.21 (0.04)</td>
<td>2.1 (0.1)</td>
<td>78 (3.7)</td>
</tr>
<tr>
<td>Vinyl ester 8084</td>
<td>72.6 (2.7)</td>
<td>55.2 (2.4)</td>
<td>3.25 (0.15)</td>
<td>3.0 (0.3)</td>
<td>75 (1.4)</td>
</tr>
<tr>
<td>Epoxy System 41</td>
<td>52.6 (1.1)</td>
<td>52.6 (1.1)</td>
<td>3.56 (0.06)</td>
<td>1.6 (0.1)</td>
<td>56 (3.6)</td>
</tr>
<tr>
<td>Epoxy SC-12</td>
<td>44.3 (3.1)</td>
<td>----</td>
<td>3.48 (0.04)</td>
<td>1.4 (0.1)</td>
<td>95 (1.2)</td>
</tr>
<tr>
<td>Epoxy SC-14</td>
<td>68.3 (2.7)</td>
<td>48.5 (1.3)</td>
<td>2.80 (0.03)</td>
<td>3.3 (0.3)</td>
<td>83 (1.9)</td>
</tr>
</tbody>
</table>

\(^1\) Numbers in parentheses indicate the sample standard deviation.
The Mars Society announced that Infrastructure Composites International (Infracomp) will build the primary structure of the Mars Arctic Research Station (MARS). The dome-shaped structure, to be designed and built entirely by private funding, will be tested in the Canadian Arctic as a prototype shelter for future human exploration of Mars.

Teamed with Mesa Fiberglass, the Denver area-based Infracomp has been working with fiberglass honeycombs since 1961, according to a Mars Society press release.

They plan to complete the two-floor, 27-foot-diameter primary structure, including doors and windows.
High-Temperature Resin Systems
Vinyl Ester

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Mike Koonce / Mars Society
Mars Relay Radios its data to the Mars Global Surveyor.

The MR radio system consists of two elements—the antenna and the electronics.

The MR antenna is labeled in the picture at left; it is a quadrifilar helix fiberglass mast approximately 80 cm tall and 10 cm in diameter.
# High-Temperature Resin Systems
## Polyester/Vinyl Ester

<table>
<thead>
<tr>
<th>Resin</th>
<th>Description</th>
<th>Applications</th>
<th>Cure</th>
<th>Serv</th>
</tr>
</thead>
<tbody>
<tr>
<td>P600</td>
<td>Low cost, General purpose grade, Low temperature cure, Non-styrenated/Low VOC, Effective replacement for wet lay-up</td>
<td>Structural, Industrial parts</td>
<td>180°F-250°F</td>
<td>160°F</td>
</tr>
<tr>
<td>P601</td>
<td>Flame retardant version of P600</td>
<td>Geodesic radomes, Shelters, Industrial parts</td>
<td>180°F-250°F</td>
<td>160°F</td>
</tr>
<tr>
<td>P605</td>
<td>Designed for tube rolling applications, Non-styrenated/Low VOC</td>
<td>Poles and shafts</td>
<td>180°F-250°F</td>
<td>160°F</td>
</tr>
<tr>
<td>P650M</td>
<td>Modified diallylphthalate, Excellent wet electrical properties, Non-styrenated/Low VOC</td>
<td>Aircraft structures, Electrical applications</td>
<td>250°F-300°F</td>
<td>250°F</td>
</tr>
<tr>
<td>P650R</td>
<td>Designed for optical clarity, Good mechanical and electrical properties, Non-styrenated/Low VOC</td>
<td>Applications which require optical clarity, Aircraft lighting, etc.</td>
<td>250°F-300°F</td>
<td>250°F</td>
</tr>
<tr>
<td>P6701</td>
<td>High service temperature, Flame retardant, Excellent electrical and mechanical properties, Non-styrenated/Low VOC</td>
<td>Aircraft structures, Radomes</td>
<td>250°F-300°F</td>
<td>to 350°F</td>
</tr>
</tbody>
</table>

Meets Mil-R-7575C- Grade A
Epoxy resin is a polymerizable thermoset polymer containing one or more epoxide groups and curable with reaction with amines, alcohols, and other agents.

Epoxy is usually preimpregnated with a fiber reinforcement or can be used in liquid form using hand or infusion methods.
Scaled-Composites engineering personnel carefully examined the launch profile and developed a low cost composite structure that would meet the OSC goals of minimizing cost per pound to orbit. The wing structure is primarily graphite/epoxy skins over Rohacell foam cores.
High-Temperature Resin Systems
Epoxy

1 Solar Panels: Epoxy carbon prepregs, aluminum honeycomb, film adhesive

3 Satellite Structures: Carbon prepreg, aluminum honeycomb, film adhesive

Hexcel
High-Temperature Resin Systems

Epoxy

Lightweight Composite Hydrogen Tank
A new lightweight composite hydrogen tank for the Delta Clipper-Experimental Advanced (DC-XA) vehicle, an unpiloted, single-stage rocket being developed by NASA and McDonnell Douglas Aerospace, has successfully completed testing at the Marshall Space Flight Center, Huntsville, AL.

"This is really quite a breakthrough," said NASA's DC-XA project manager Dan Dumbacher. "This is the largest composite hydrogen tank ever to successfully survive flight operating conditions. It demonstrates that composite tanks can be used for other reusable launch vehicles in the future." "This will be the first graphite epoxy cryogenic fuel tank to undergo flight testing," said Dave Schweikle, McDonnell Douglas DC-XA program manager. "The tank was designed and fabricated by McDonnell Douglas to hold liquid hydrogen at minus 423 degrees Fahrenheit and to serve as an integral part of the DC-XA's structure."
High-Temperature Resin Systems
Epoxy

Lightweight Composite Hydrogen Tank
High-Temperature Resin Systems
Epoxy

DC-X 1/3 Scale Demonstrator
A single female tool was fabricated from the male plug, and the four graphite/epoxy sandwich panel sections were fabricated in the female tool. The sections were installed in an assembly fixture and bonded together using in-place graphite/epoxy laminates. The landing gear receptacles, flap mechanisms and servos were then added.

An initial structural concern was the reaction of the sandwich panel structure to the possible extreme temperature differences between the inside skins and outside skins of the composite sandwich.

Scaled Composites
High-Temperature Resin Systems
Epoxy

DC-X 1/3 Scale Demonstrator

built by Scaled Composites
High-Temperature Resin Systems
Epoxy

Carbon-epoxy upper aft rudder for DC-10 transport aircraft.
High-Temperature Resin Systems
Epoxy

Completed Braided and Woven Window Frames
High-Temperature Resin Systems
Epoxy

Application of Textile Reinforced Composites in Transport Fuselage Structures from Lockheed Martin
Resin Film Infusion (RFI)
At Langley, researchers provided experimental data for the modeling and sensor efforts and investigated resin transfer molding (RTM) and resin film infusion (RFI) tooling concepts and processes. Part of the investigation dealt with new and developmental epoxy resins.

Although several resins exhibited useful properties, none produced a combination of properties and cost advantages equal to the Hercules 3501-6 resin, the baseline in all evaluations. Considering the enormous database of properties required for a new resin to be used in a commercial transport, 3501-6 resin remained unchallenged for actual applications.
High-Temperature Resin Systems
Epoxy

Design Features of Stitched/RFI Semi-Span Wing

- 8 ft chord
- 41 ft length
- 3 ft maximum depth
- Full scale, full loft definition
- All-composite construction
- Simulated engine pylon and landing gear
High-Temperature Resin Systems
Epoxy

Schematic of Stitched/RFI Semi-Span Wing Test Set-Up at the Langley Structures and Materials Laboratory
High-Temperature Resin Systems

Epoxy

Assembly of Wing Stub Box Test Component
Fibercote E-765 FAA Approved Database
The largest single regulatory obstacle to using advanced composite materials in certified aircraft applications has been the generation of design allowables which will satisfy Regulatory agency requirements. Previously, individual airframe manufacturers generated design allowable databases as a routine part of their certification effort. However, with expensive qualification costs and timelines that can be longer than 12 months, this approach has proved unfeasible for smaller manufacturers and has often led larger manufacturers with established databases to continue to use "old" material systems.

FiberCote, the FAA, Wichita State University, and NASA’s Advanced General Aviation Transport Experiments (AGATE) developed a method for composite materials suppliers to generate design allowable databases and share them with airframe manufacturers. FiberCote’s E-765 is a tough, shop-friendly, 180°F Wet service epoxy system that cures at just 250°F.
<table>
<thead>
<tr>
<th>Fibercrete Resin</th>
<th>Description</th>
<th>Applications</th>
<th>Min Cure</th>
<th>Max Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>E717</td>
<td>Self-adhesive, High peel strength, Controlled flow, Flame retardant, Low tack, Good handleability for large panels</td>
<td>Sandwich panels or solid laminates</td>
<td>250°F-325°F</td>
<td>255°F</td>
</tr>
<tr>
<td>E746</td>
<td>Designed for high temperature service, Structural grade, Excellent hot/wet properties, Extensive database</td>
<td>Aircraft structures, Radomes</td>
<td>300°F-350°F</td>
<td>to 500°F</td>
</tr>
<tr>
<td>E761</td>
<td>Self-adhesive, Flame retardant, Controlled flow, Good electrical properties, Extensive database, Versatile processing, Long out-time</td>
<td>Solid laminates or sandwich panels, Radomes</td>
<td>180°F-275°F</td>
<td>to 200°F</td>
</tr>
<tr>
<td>E763</td>
<td>Good clarity, Versatile processing, Long out-time</td>
<td>Aircraft structures, Industrial &amp; Recreation parts where clarity is desired</td>
<td>180°F-300°F</td>
<td>to 200°F</td>
</tr>
<tr>
<td>E765</td>
<td>Tough, 250°F cure system designed to replace many first generation 350°F systems, Extensive FAA Approved Databases, Versatile processing, Long out-time</td>
<td>Aircraft primary and secondary structures</td>
<td>250°F-300°F</td>
<td>to 275°F</td>
</tr>
<tr>
<td>E766</td>
<td>Self-adhesive, High peel strength, Flame retardant, Controlled flow, Good electrical properties, Extensive database, Versatile processing, Long out-time</td>
<td>Solid laminates or sandwich panels, Radomes</td>
<td>250°F-300°F</td>
<td>to 200°F</td>
</tr>
</tbody>
</table>
High-Temperature Resin Systems

Epoxy

Epoxy/Carbon Fiber Racks in the U.S. Laboratory Module on Board the International Space Station
Phenolics are based on a combination of an aromatic alcohol and an aldehyde, such as phenol with formaldehyde. They are used in applications like aircraft interior panels that require flame resistance, and commercial markets that require low-cost, flame-resistant and low-smoke products.

Their excellent char yield and ablative (heat-absorbing) characteristics have made phenolics longtime favorites for ablative and rocket nozzle applications. Recently, they have proven successful in offshore oil and gas platforms, mass transit and electronics applications.

However, because phenolics release water vapor and formaldehyde during cure that produce voids in the composite, their mechanical properties may be inferior to those of epoxies and most other high-performance resins.
High-Temperature Resin Systems
Phenolic

**Smoke Optical Density ASTM E-662**
- Vinyl Ester
- Aerospace Epoxy
- FR Polyester
- Georgia-Pacific Phenolic

**Flame Spread Index ASTM E-162**
- Vinyl Ester
- Aerospace Epoxy
- FR Polyester
- Georgia-Pacific Phenolic

Specific Optical Density

Flame Spread Index
Phenolic High-Temperature Resin Systems

Phenolic Pipe Passed IMO Level 3 Fire Tests That Subjected Pipe to 1000º C (1832º F)

Bondstrand PSX-L3 Phenolic Pipe Passed IMO Level 3 Fire Tests That Subjected Pipe to 1000º C (1832º F)
High-Temperature Resin Systems
Phenolic

Molded Ventilation Duct System
Seen here is some of Mir's flexible ventilation ducting where air exchange between the various modules takes place via flexible ventilation ducts shown at right, driven by ventilators, installed at 5 to 7 m intervals.
# High-Temperature Resin Systems

## Phenolic

<table>
<thead>
<tr>
<th>Resin</th>
<th>Description</th>
<th>Applications</th>
<th>Cure</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>F502</td>
<td>Structural grade system, Good tack and drape, Excellent high temperature properties, Also has good ablative characteristics</td>
<td>Aircraft structures, Ducts, High temperature furnace chambers, Rocket nozzles</td>
<td>325°F - 375°F</td>
<td>500°F</td>
</tr>
<tr>
<td>F502 High Silica</td>
<td>Works well in oxidative environments, Low pressure autoclave cure, Coated onto leached glass fabric style C100-48</td>
<td>Liquid rocket nozzles, Combustion chambers, Blast tubes, Exit cones, Insulators</td>
<td>325°F - 350°F</td>
<td>N/A</td>
</tr>
<tr>
<td>F554 High Silica</td>
<td>Works well in oxidative environments, Coated onto leached glass fabric style C100-48</td>
<td>Liquid rocket nozzles, Combustion chambers, Blast tubes, Exit cones, Insulators</td>
<td>350°F - 400°F</td>
<td>N/A</td>
</tr>
<tr>
<td>F555 Carbonized Rayon</td>
<td>Carbon loaded, Coated on continuous filament 8HS carbonized rayon fabric, High strength</td>
<td>Nozzles, Exit cones</td>
<td>350°F - 400°F</td>
<td>N/A</td>
</tr>
<tr>
<td>F589 PAN</td>
<td>Carbon loaded, Coated on continuous filament 6K 5HS Part Fabric, High Strength</td>
<td>Aft exit cones</td>
<td>350°F - 400°F</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Cyanate esters (CEs) are costly, yet versatile matrices that provide excellent strength and toughness, very low moisture absorption and superior electrical properties, compared to other polymer matrices. They offer processing similar to that of epoxies, combined with hot/wet service temperatures to 300°F. Applications range from radomes, antennae, missiles and ablatives to microelectronics and microwave products.

Cyanate Esters have become the predominant resin in a large diversity of applications. Very low moisture uptake and low outgassing make them ideal for space environments where thermal and hygroscopic stability are critical. In addition, features such as excellent hot/wet and dielectric properties make them well suited for antenna and radome application.
High-Temperature Resin Systems
Cyanate Ester

1 - Fairings: Carbon prepregs. Aluminium honeycomb and adhesives.

2 - External Payload Carrier Assembly (SPELTRA): Carbon prepregs, aluminium honeycombs and adhesives.

3 - EPS Ring: Epoxy/carbon prepreg or RTM.

4 - Front Skirt: Carbon prepreg.

5 - Booster Capotage: Epoxy glass/non-metallic honeycomb.

6 - Yoke: Epoxy carbon filament winding.

7 - Heat Shield: Carbon prepreg/high temperature resistant glass fabric. Hexcel
High-Temperature Resin Systems
Cyanate Ester

2 - Reflectors Antennae: Epoxy/aramid prepreg, cyanate carbon prepreg, aramid/aluminum honeycomb
3 - Satellite Structures: Carbon prepreg, aluminum honeycomb, film adhesive

Hexcel
High-Temperature Resin Systems
Polyimide

For high temperature performance, NASA developed polyimide polymers. The temperature capability was about 316 degrees C but the resins were brittle, difficult to process (+343 degrees C cure required) and a condensation reaction which produces water during the cure occurs. High water absorption (5-8%) was also a problem.

A new thermoset resin system was invented at NASA and is now commercially available from Unitech. Originally seen as a safe alternative to existing pre-pregged polyimides in the aerospace industry, RP46 now sees utilization across a broad spectrum of applications where extreme operating conditions cause failure of lesser materials. In composite form, RP46 has a continuous operating temperature of 700°F. Its closed bond configuration means little to no moisture absorption and the weight to strength ratio is extraordinary.
High-Temperature Resin Systems
Polyimide

Rods
Rods are available in several different diameters from 1/8" to 3 1/2". Lengths of 9 1/2" and 38" are available.

Plaques
Plaques are sold in 5 thicknesses, from 1/8" to 2". Face dimensions offered are 10" × 10", 10" × 5" and 8" × 5".

Tubes
Heavy-walled tubes are available in 3/8" lengths with ODs ranging from 1.8" to 7.1". Some tubes are also offered in 8" lengths.

Bars
Bars are 2" × 4" × 38" in length.

Direct Formed Rings
A variety of rings and discs are offered in diameters ranging from 1/8" to 2 1/2" with thickness of 1/8" and 1/4".

Standard Size Balls
Balls are available in diameters ranging from 1/8" to 1/4".

DUPONT
U.S. Navy Uses VESPEL Adapter in Improved Spline Coupling for Aircraft

In airplane spline couplings, used to drive generators, hydraulic pumps, and other equipment, adapters made with DuPont’s VESPEL were designed to replace all metal couplings.

The configuration and compressive strength of the VESPEL parts allows them to carry high torque loadings without lubrication. In U.S. Navy fixed wing aircraft generators, they increased wear life 50 times over that for conventional greased couplings. The VESPEL adapters are self-lubricating, making special lubrication or cleaning of the splines unnecessary.
High-Temperature Resin Systems
Polyimide

Stabilizer flaps, space mirror tube framing, jet engine vane assemblies, shoulder-launched weapon systems are candidates for polyimide resin.
High-Temperature Resin Systems
Polyimide
High-Temperature Resin Systems
Polyimide

Strike Eagle jet engine change
Crew Chiefs from the 48th Fighter Wing, United Kingdom, pull out a Pratt & Whitney F100-229 engine from a F-15E Strike Eagle
High-Temperature Resin Systems
Polyimide

Pratt and Whitney F100-229 Afterburning Turbofan Engine
High-Temperature Resin Systems
Polyimide
Jet Engine
Composite Parts
High-Temperature Resin Systems
Polyimide

1 Electronic Control Unit Casing: Epoxy carbon Prepregs
2 Acoustic Lining Panels: Carbon/glass Prepregs, high temp adhesives, alum honeycomb
3 Fan Blades: Epoxy carbon Prepregs or Resin Transfer Molding (RTM) construction
4 Nose Cone: Epoxy glass Prepreg, or RTM
5 Nose Cowl: Epoxy glass Prepreg or RTM construction
6 Engine Access Doors: Woven and UD carbon/glass Prepregs, honeycomb and adhesives
7 Thrust Reverser Buckets: Epoxy woven carbon Prepregs or RTM materials, and adhesives
8 Compressor Fairing: BMI/epoxy carbon Prepreg. Honeycomb and adhesives
9 Bypass Duct: Epoxy carbon Prepreg, non-metallic honeycomb and adhesives
10 Guide Vanes: Epoxy carbon RFI/RTM construction
11 Fan Containment Ring: Woven aramid fabric
12 Nacelle Cowling: Carbon/glass Prepregs and honeycomb
Bismaleimides (BMIs) are suitable for applications requiring a service temperature of 260-450°F.

For high temperature performance, NASA developed polyimide polymers. The temperature capability was about 600°F but the resins were brittle, difficult to process (+650 °F cure required) and a condensation reaction which produces water during the cure occurs.

High water absorption (5-8%) was also a problem. To ease processing, bismaleimides were developed. However this lowered the temperature capability to 455°F and these resins were also brittle. Both of the polyimide polymers have high aromatic backbones causing brittleness.
High-Temperature Resin Systems
Bismaleimide

- Satellite Structures
- Aerospace/Missile Structures
- Electromagnetic/Dielectric Structures
High-Temperature Resin Systems
Bismaleimide

Powder versions are available for compression molding into virtually indestructible bearings, slip-rings or races.
High-Temperature Resin Systems
Bismaleimide
High-Temperature Resin Systems
Cost, $/pound

- Vinyl Ester: $3
- Epoxy: $5
- Phenolic: $3
- Cyanate Ester: $50
- Polyimide: $100
High-Temperature Resin Systems
Flame Spread Index (ASTM E-162)
High-Temperature Resin Systems
Maximum Smoke, Dmax, ppm

Vinyl Ester: 576 ppm
Epoxy: 408 ppm
Phenolic: 1 ppm
Cyanate ester: 84 ppm
Polyimide: 127 ppm
Bismaleimide: 127 ppm
High-Temperature Resin Systems
Time to Ignition (secs)

- Vinyl Ester: 18
- Epoxy: 9
- Phenolic: 54
- Cyanate ester: 10
- Polyimide: 55
- Bismaleimide: 36
High-Temperature Resin Systems

Peak Heat Release (kW/sq-mtr)

Vinyl Ester: 166
Epoxy: 489
Phenolic: 133
Cyanate ester: 226
Polyimide: 85
Bismaleimide: 285
High-Temperature Resin Systems
Smoke Extinction Area (sq-mtr/kg)

- Vinyl Ester: 1899
- Epoxy: 1235
- Phenolic: 378
- Cyanate ester: 1199
- Polyimide: 113
- Bismaleimide: 816
It is very difficult to simulate actual fires in a laboratory environment. Geometries of a compartment and air movement don't often conform to the standard conditions needed for a repeatable test. Fire scientists like to categorize the size of fires using guidelines such as the following:

- Small smoldering fire: 2 - 10 kW
- Trash can fire: 10 - 50 kW
- Room fire: 50 - 100 kW
- Post-flashover fire: > 100 kW
Fire Test Methods
Fire Performance Characteristics

- Time-to-Ignition
- Rate of Heat Release
- Smoke Production
- Flame Spread
- Burn Through Resistance
**Fire Test Methods**

**Cone Calorimeter**

**ASTM 1354, Cone Calorimeter**

The Cone Calorimeter is emerging as the internationally accepted small-scale fire test method. Sample size is 100 by 100-mm (4 by 4 inches) and heat exposure is provided by a cone shaped heater. Samples are weighed and smoke analyzed during the test to indicate how much to sample contributes to the fire. Ignitability is also measured. This test has proven useful for screening resin systems, but is not useful for sandwich laminates or fire protection systems.
Fire Test Methods
Cone Calorimeter

Cone Calorimeter
### Fire Test Methods

**Cone Calorimeter Requirements for U.S. Navy Submarines**

<table>
<thead>
<tr>
<th>Ignitability (seconds)</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 kW/m² Flux</td>
</tr>
<tr>
<td></td>
<td>75 kW/m² Flux</td>
</tr>
<tr>
<td></td>
<td>50 kW/m² Flux</td>
</tr>
<tr>
<td></td>
<td>25 kW/m² Flux</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Heat Release Rate (kW/m²)</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 kW/m² Flux Peak</td>
<td>150</td>
</tr>
<tr>
<td>Average 300 secs</td>
<td>120</td>
</tr>
<tr>
<td>75 kW/m² Flux Peak</td>
<td>100</td>
</tr>
<tr>
<td>Average 300 secs</td>
<td>100</td>
</tr>
<tr>
<td>50 kW/m² Flux Peak</td>
<td>65</td>
</tr>
<tr>
<td>Average 300 secs</td>
<td>50</td>
</tr>
<tr>
<td>25 kW/m² Flux Peak</td>
<td>50</td>
</tr>
<tr>
<td>Average 300 secs</td>
<td>50</td>
</tr>
</tbody>
</table>
The OSU Rate of Heat Release Device measures total heat and the rate of heat release of various materials when exposed to a radiant energy heat source.
In the OSU test, the specimen’s exposure is determined by a radiant heat source. The changes in the temperature and optical density of the gas leaving the chamber is monitored. At left is the heat flux model associated with the test.
ASTM E 1317-90, Standard Test Method for Flammability of Marine Finishes
A description and background contained in the test standard provide insight as to why this test may be appropriate for intermediate-scale evaluation of shipboard composite material systems. The test method describes a procedure for measuring fire properties associated with flammable surfaces finishes used on noncombustible substrates aboard ships. The International Safety of Life at Sea (SOLAS) Convention requires the use of marine finishes of limited flame spread characteristics in commercial vessel construction.
Fire Test Methods
Lateral Ignition & Flame Transport (LIFT)

LIFT Test Arrangement
Fire Test Methods
Lateral Ignition & Flame Transport (LIFT)

Flame Front Measurement During LIFT Test
Radiant Panel - ASTM E 162
This test procedure is intended to quantify the surface flammability of a material as a function of flame spread and heat contribution. The ability of a panel to stop the spread of fire and limit heat generated by the material is measured. A 6" x 18" specimen is exposed to heat from a 12" x 18" radiant heater. The specimen is held at a 45° angle, as shown at right.
## Fire Test Methods
### Flame Spread Testing

<table>
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</thead>
<tbody>
<tr>
<td></td>
<td>Graphite/Phenolic 6</td>
<td>Glass/Polyester 31 - 39</td>
<td>Fire Tests of Joiner Bulkhead Panels</td>
</tr>
<tr>
<td></td>
<td>Graphite/BMI 12</td>
<td></td>
<td>Nomex® Honeycomb 19 - 23</td>
</tr>
<tr>
<td></td>
<td>Glass/Epoxy 20</td>
<td>Glass/Fire Retardant Polyester 5 - 22</td>
<td>FMI (GRP/Syntactic core) 2 - 3</td>
</tr>
<tr>
<td></td>
<td>Glass/Vinylester with Phenolic Skin 19</td>
<td>Glass/Epoxy 1 - 45</td>
<td>Large Scale Composite Module Fire Testing</td>
</tr>
<tr>
<td></td>
<td>Glass/Vinylester with Intumescent Coating 38</td>
<td>Graphite/Epoxy 32</td>
<td>All GRP Module 238</td>
</tr>
<tr>
<td></td>
<td>Glass/Vinylester 156</td>
<td></td>
<td>Phenolic-Clad GRP 36</td>
</tr>
</tbody>
</table>
Fire Test Methods
ISO 9705 Room Corner Test

Schematic of ISO 9705 Room Corner Test to Determine Flame Spread and Smoke Generation
Fire Test Methods
ISO 9705 Room Corner Test

Lighting of Burner
to Start Modified
ISO 9705 Room
Corner Test at VTEC
Laboratories
Fire Test Methods
ISO 9705 Room Corner Test

100 kW Fire

300 kW Fire
Fire Test Methods
Burn Through Resistance

Full-Scale Vertical Furnace
The full-scale vertical furnace is 10 ft wide, 10 ft high and 2 ft deep, with six-inch thick sides. The furnace consists of a structural steel frame, clad in sheet metal, and insulated with six inches of ceramic fiber insulation. The furnace is equipped with 39 self-inspiring burners, evenly distributed across the rear wall and adjusted to run with no input air. The result is a diffuse, yellow flame, which closely simulates those found in a real fire.

Fired by propane, this furnace is capable of meeting both the ASTM E119 and UL 1709 (high rise) heating curves, and is capable of running with the neutral pressure plane as low as approximately 40 inches above the floor.
Test Arrangement for Burn Through Resistance of 10 x 10 - foot Panel
UL 1709 Test Fire Exposure
The test method covers a full-scale fire exposure, intended to evaluate the thermal resistance of protective material applied to structural members and the ability of the protective material to withstand the fire exposure.

The fire environment within the furnace is to develop a total heat flux of 65,000±5000 Btu/ft-hour (204±16 kW/m) and an average temperature of 2000±200°F (1093±111°C) within 5 minutes from the start of the test.
Fire Test Methods
Full-Scale UL 1709

Time/Temperature Curve for UL 1709 Test
TEST PROCEDURE
The testing is performed in an open, vertically positioned cylindrical furnace. The furnace is preheated to 750 °C before the test specimen is introduced. The specimens are cylindrical with diameter 45 mm and height 50 mm.
All flight hardware used in NASA manned space programs must comply with the flammability requirements of NASA-STD-6001, “Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion” for the following environments:

- Habitable flight compartments (internal)
- Locations outside habitable areas (external)
- Ground Support Equipment & specified test facilities
- Vented and sealed containers
- Liquid and gaseous oxygen (LOX/GOX)
- Breathing gases
NASA-STD-6001 contains several flammability & ignition tests:
1 - Upward Flame Propagation (fundamental test for solid materials)
2 - Heat and Visible Smoke Release Rates (cone calorimeter)
3 - Flash Point of Liquids (ASTM D 93 Pensky-Martens closed tester)
4 - Electrical Wire Insulation Flammability
   (15° inclined @ 125°C/ overload)
7 - Determination of Offgassed Products
8 - Flammability Test for Materials in Vented or Sealed Containers
10 - Simulated Panel or Major Assembly Flammability (config 1)
12 - Total Spacecraft Offgassing Test
13 - Mechanical Impact for Materials in Ambient/Pressurized LOX/GOX
14 - Pressurized Gaseous Oxygen (GOX) Pneumatic Impact for Nonmetals
17 - Upward Flammability of Materials in GOX (only for pressurized \( O_2 \) sys.)
18 - Arc Tracking (for electrical wire insulation)
These requirements are implemented through various NASA program and Materials and Processes (M&P) requirements documents:


- SSP 30233, *Space Station Requirements for M&P (ISS)*

- NSTS 1700.7, *Safety Policy & Requirements for Payloads Using the Space Transportation System and (same requirements in the) ISS Addendum*
The purpose of this test is to determine if a material, when exposed to a standard ignition source, will self-extinguish and not transfer burning debris, which can ignite adjacent materials.

To determine if a material will self-extinguish using this test method, the burn lengths for at least three standard-sized samples must be less than 6 in. (15 cm). These tests must be conducted on samples at worst-case thickness and in the worst-case environment.
Upward Flame Propagation, Test 1

Typical Sample Holder for Test 1
The purpose of this test is to provide supplemental information on the flammability of materials that fail to meet the criteria of Test 1. In addition, this test is required for nonmetals where greater than 4 ft² (0.37 m²) is exposed to habitable environments.

The following must be determined using a minimum of three samples for each applied heat flux (25, 50, and 75 kW/m²):

a. Ignitability.
b. Maximum and average rate of heat released during the first minute, the first 3 minutes, and the first 5 minutes after ignition.
c. Total heat released.
d. Amount of smoke obscuration.

The tests must be conducted on samples at worst-case thickness and in the worst-case conditions.
The purpose of this test is to determine the identity and quantity of volatile offgassed products from materials and assembled articles.

*Spacecraft maximum allowable concentration (SMAC).* The maximum concentration of an offgassed product that is allowed in the habitable area of the spacecraft for a specified flight duration. SMAC values for manned spacecraft are listed in MAPTIS.
Fire Test Methods
Offgassed Products, ASTM E1559

Vacuum Outgassing/Deposition Kinetics Apparatus (VODKATM) is a turn-key test chamber for performing standardized ASTM E1559 testing used by QCM Research, Lake Forest, CA.
Collected Volatile Condensable Material (CVCM): Quantity of outgassed matter from a test specimen that condenses on a collector maintained at a specific constant temperature for a specified time. CVCM is expressed as a percentage for the initial specimen mass and is calculated from the condensate mass determined from the difference in mass of the collector plate before and after the test.
Total Mass Loss (TML): Total mass of material outgassed from a specimen that is maintained at a specified constant temperature and operating pressure for a specified time. TML is calculated from the mass of the specimen as measured before and after the test and is expressed as a percentage of the initial specimen mass.

Water Vapor Regained (WVR): Amount of water reabsorbed in 24 hours when a test specimen is exposed to 25°C and 50% relative humidity.
<table>
<thead>
<tr>
<th>Description</th>
<th>%TML</th>
<th>%CVCM</th>
<th>%WVR</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL-94 V0 Polyimide Glass</td>
<td>0.52</td>
<td>0.00</td>
<td>0.21</td>
</tr>
<tr>
<td>UL-94V1 Polyimide Glass</td>
<td>0.42</td>
<td>0.01</td>
<td>0.26</td>
</tr>
<tr>
<td>Polyimide Glass</td>
<td>0.78</td>
<td>0.01</td>
<td>0.27</td>
</tr>
<tr>
<td>Polyimide Thermount®</td>
<td>1.91</td>
<td>0.00</td>
<td>0.93</td>
</tr>
<tr>
<td>Epoxy Thermount®</td>
<td>1.32</td>
<td>0.00</td>
<td>0.58</td>
</tr>
<tr>
<td>No-Flow Polyimide</td>
<td>0.77</td>
<td>0.00</td>
<td>0.39</td>
</tr>
<tr>
<td>No-Flow Epoxy</td>
<td>0.62</td>
<td>0.01</td>
<td>0.15</td>
</tr>
<tr>
<td>Low Loss Laminate</td>
<td>0.17</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>UL-94 V0 Low Loss</td>
<td>0.24</td>
<td>0.00</td>
<td>0.07</td>
</tr>
<tr>
<td>PTFE/Ceramic Laminate</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Arlon (Rancho Cucamonga, CA) products that have undergone NASA/ASTM E595-93 testing
<table>
<thead>
<tr>
<th>Toxic Constituent</th>
<th>Cf (ppm for human fatality after 30 min exposure)*</th>
<th>Maximum Allowable Concentration (7-day ppm - NASA)**</th>
<th>MIL-STD 2031 (SH) Max Allowable @ 25 kW/m²</th>
<th>Cone Calorimeter Tests of Glass/Vinyl Ester Panels***</th>
<th>Detector Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>100,000</td>
<td></td>
<td>40,000</td>
<td>15,000</td>
<td>MSA 85976</td>
</tr>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>4,000</td>
<td>25</td>
<td>200</td>
<td>295</td>
<td>Dräger 10/b</td>
</tr>
<tr>
<td>Hydrogen Sulphide (H₂S)</td>
<td>750</td>
<td>2</td>
<td></td>
<td></td>
<td>Dräger 100/a</td>
</tr>
<tr>
<td>Ammonia (NH₃)</td>
<td>750</td>
<td>17</td>
<td></td>
<td></td>
<td>Dräger 5/a</td>
</tr>
<tr>
<td>Formaldehyde (HCHO)</td>
<td>500</td>
<td>0.1</td>
<td></td>
<td></td>
<td>MSA 93963</td>
</tr>
<tr>
<td>Hydrogen Chloride (HCl)</td>
<td>500</td>
<td></td>
<td>100</td>
<td>1</td>
<td>MSA 91636</td>
</tr>
</tbody>
</table>
## Fire Test Methods

### Offgassed Products, Marine Laminates

<table>
<thead>
<tr>
<th>Potential Toxic Constituent</th>
<th>Occupational Safety and Health Administration</th>
<th>Maximum Allowable Concentration (7-day ppm - NASA)**</th>
<th>Estimated Range of Concentrations***</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time Weighted Average (TWA, ppm)*</td>
<td>Short Term Exposure Limit (STEL, ppm)</td>
<td>E-Glass Vinyl Ester, ppm</td>
</tr>
<tr>
<td>Styrene</td>
<td>50</td>
<td>100</td>
<td>300 - 900</td>
</tr>
<tr>
<td>Toulene</td>
<td>0.005</td>
<td>0.02</td>
<td>60</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.1</td>
<td></td>
<td>1 - 10</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td></td>
<td>.1</td>
<td></td>
</tr>
</tbody>
</table>


The purpose of this test is to provide supplemental information on whether particular assemblies, such as a functional assembly, subsystem, system, or crew module, propagate a fire when exposed to ignition sources.

The test article should be a portion of the spacecraft or assembled article that has been defined as being vulnerable to a potential fire. Suitable simulations for the ignition source should be chosen. Once this has been completed, the flammability test should be based on the fire hazard analysis.
Configuration Analysis
Determination, based on configuration, of the portion of the article that is most vulnerable to ignition and fire propagation.

Fire Hazard Analysis
Determination of the scenario that best describes the area that is most vulnerable to a potential fire and also most likely to propagate a fire from the test article to adjacent equipment. This analysis should include a materials inventory, configuration analysis, and thermal analysis.

Thermal Analysis
Determination, based on heat transfer calculations, of the portion of the article that is most vulnerable to ignition and fire propagation.
Fire Test Methods
Total Spacecraft Offgassing, Test 12

The purpose of this test is to determine the identities and quantities of contaminant gases offgassed in areas of spacecraft where the crew will breathe the atmosphere. The results of this test will be used in the toxicological assessment of the spacecraft.

Toxic contamination levels must meet requirements given in JSC 20584, "Spacecraft Maximum Allowable Concentration for Airborne Contaminants."
The purpose of Test 13 is to determine if materials in oxygen environments react when mechanically impacted.

Twenty samples must not react when impacted at 72 ft-lbs (98 J). If one sample out of 20 reacts, 40 additional samples must be tested without any reactions.
Fire Test Methods
NASA Criteria for Fiber Reinforced Laminates

• Fiber-reinforced laminates are used as structural materials
• Laminates may be flammable if used in thickness < 0.125 inches
• Flammability characteristics of thin laminates should be verified by test or the laminates should be protected
• Flammable laminates may be used in external payloads provided that ignition sources (electrical wires, heaters, etc.) are not located within 6 inches of the laminates
• Otherwise firebreaks should be placed on the exposed surfaces of these laminates at 12 inch intervals, e.g. Aluminum tape 3 mils thick X 3 inches wide (Federal Standard L-T-80)
Fire Test Methods
FAR 25.853 For Aircraft

Requirements for Compartment Interiors:
Crew and passengers.

a) Meet Part I Appendix F. (finishes, decorative surfaces).
b) Reserved.
c) Seat Cushions. meet Part I Appendix. F and Part II.
d) >20 passengers: Meet Part I, IV, V.
  d1) Interior ceilings, wall panels.
  d2) Partitions.
  d3) Galley Structure, stowed cars, std. containers, cavity walls.
  d4) Large Cabinets, stowage.
e) Components isolated from main passenger, e.g. pilot, galleys, lavatories: Meet part I.
Fire Test Methods
FAR 25.853 For Aircraft

Vertical and 45° Flammability Test Chambers for Federal Test Method Standard 191 Model 5903
# Fire Test Methods

FAR 25.853 For Aircraft

## Appendix F. Part I: test criteria and Procedures

<table>
<thead>
<tr>
<th>Section a1: Interior compartments occupied by crew and passengers:</th>
<th>Burn Length</th>
<th>Flame Time After Removal</th>
<th>Drippings flame extinguish</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Ceilings, walls, galley, floor.</td>
<td>Vertical 6 inches</td>
<td>15 seconds</td>
<td>3 seconds</td>
</tr>
<tr>
<td>ii) Floor cover, textiles, seat cushions</td>
<td>Vertical 8 inches</td>
<td>15 seconds</td>
<td>5 seconds</td>
</tr>
<tr>
<td>iii) ducts for film</td>
<td>Vertical 8 inches</td>
<td>15 seconds</td>
<td>5 seconds</td>
</tr>
<tr>
<td>iv) Clear Plastic Window</td>
<td>Horizontal 2.5&quot;/min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>v) others</td>
<td>Horizontal 4.0&quot;/min</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Fire Test Methods
### FAR 25.853 For Aircraft

### Section 2.2: Cargo, baggage not occupied by crew and passengers

| 2i) Thermal, acoustic insulate | Vertical 8 inches | 15 seconds | 5 seconds |
| 2ii) Liner for cargo baggage | Vertical 8 inches | 15 seconds | 5 seconds |

**Class B or E of 25.857**

<table>
<thead>
<tr>
<th>Flame penetration</th>
<th>Flame Time After Removal</th>
<th>Glow Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>15 seconds</td>
<td>10 seconds</td>
</tr>
</tbody>
</table>

| 2iii) Cargo, baggage Compartment Class B, C, D, E of 25.857 | Vertical 8 inches | 15 seconds | 5 seconds |

<table>
<thead>
<tr>
<th>Flame penetration</th>
<th>Flame Time After Removal</th>
<th>Glow time</th>
</tr>
</thead>
<tbody>
<tr>
<td>No penetration</td>
<td>15 seconds</td>
<td>10 seconds</td>
</tr>
</tbody>
</table>

| 2iv) Insulated blankets, covers | Vertical 8 inches | 15 seconds | 5 seconds |

| Tie-downs: Containers, bins: | Horizontal 4.0"/min |   |   |

**45 Degree Angle Test**
**Part IV of Appendix F:**

Test method to determine the Heat Release Rate From Cabin Materials exposed to Radiant Heat.

1) OSU, ASTM-E-906 @ 3.5 W/cm² for 6 mins.; Req. 65/65 Kw/m², 2-mins/peak.

**Part V of Appendix F:**


*Optical Smoke Density (Ds) after 4 minutes. Req. = 200 Max*
Fire Test Methods
Naval Composites Applications

Composite Helicopter Hanger for DDG 51 Flight IIA Destroyer Built at Northrop Grumman Gulfport Facility
Fire Test Methods
Naval Composites Applications

Forward Director Room
Built by Northrop Grumman as Technology Demonstrator for DDG 51
Fire Test Methods
Naval Composites Applications

Composite Ventilation Ducts on FFG 58
Family of Composite Pumps Developed to Reduce Maintenance Cost and Reduce Parts Inventory
# Fire Test Methods

**Fire Source Data for Naval Combatants**

<table>
<thead>
<tr>
<th>FIRE SOURCE</th>
<th><strong>Surface Ships</strong>&lt;sup&gt;1&lt;/sup&gt;</th>
<th></th>
<th><strong>Submarines</strong>&lt;sup&gt;2&lt;/sup&gt;</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Number</strong></td>
<td><strong>Percent</strong></td>
<td><strong>Number</strong></td>
<td><strong>Percent</strong></td>
</tr>
<tr>
<td>Electrical</td>
<td>285</td>
<td>39%</td>
<td>100</td>
<td>61%</td>
</tr>
<tr>
<td>Open Flame/Welding</td>
<td>141</td>
<td>19%</td>
<td>23</td>
<td>14%</td>
</tr>
<tr>
<td>Flammable Liquid/Gas</td>
<td>0</td>
<td>0%</td>
<td>13</td>
<td>8%</td>
</tr>
<tr>
<td>Radiant Heat</td>
<td>102</td>
<td>14%</td>
<td>8</td>
<td>5%</td>
</tr>
<tr>
<td>Matches/Smoking</td>
<td>40</td>
<td>5%</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>Explosion</td>
<td>7</td>
<td>1%</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>Other</td>
<td>89</td>
<td>12%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Unknown</td>
<td>68</td>
<td>9%</td>
<td>18</td>
<td>11%</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td>732</td>
<td>100%</td>
<td>164</td>
<td>100%</td>
</tr>
</tbody>
</table>

<sup>1</sup>Navy Safety Center Database, Report 5102.2  
<sup>2</sup>NAVSEA Contract N00024-25-C-2128, “Fire Protection Study,” Newport News Shipbuilding
Fire Test Methods
U.S. Navy Use of Composites
Surface Ship Criteria

- Small Fires (<200 kW) should not grow quickly.
- Fire and Smoke should not generate untenable conditions quickly.
- Bulkheads, decks and structural members should resist post flashover UL 1709 fire for 30 minutes under load with No holing, and far side average temperatures rise less than 250°F.
- Fire should be capable of being extinguished by agents on board ship.
- Melting, and dripping spreads fire, and are considered unacceptable.
- Passive fire protection system shall be attached so as to survive the fire and other loads.

Source: Usman Sorathia, NSWCCD Code 643
Fire Test Methods
High Speed Craft Code
Fire Resistive Materials

Criteria for Qualifying Products as “Fire Restricting Materials”

- The time average of HRR excluding the ignition source does not exceed 100 kW;
- The maximum HRR excluding the HRR from the ignition source does not exceed 500 kW averaged over any 30 second period of the test;
- The time average of the smoke production rate does not exceed 1.4 m²/s;
- The maximum value of smoke production rate does not exceed 8.3 m²/s averaged over any period of 60 seconds during the test;
- Flame spread must not reach any further down the walls of the test room than 0.5 m from the floor excluding the area which is within 1.2 meters from the corner where the ignition source is located;
- No flaming drops or debris of the test sample may reach the floor of the test room outside the area which is within 1.2 meters from the corner where the ignition source is located.
IMO Resolution MSC 40(64) on ISO 9705 Test: Tests should be performed according to the standard ISO 9705, the Room/Corner Test. This standard gives alternatives for choice of ignition source and sampling mounting technique. For the purpose of testing products to be qualified as “fire restricting materials” under the IMO High-Speed Craft Code, the following should apply:

Ignition source: Standard ignition source according to Annex A in ISO 9705, i.e. 100 kW heat output for 10 minutes and thereafter 300 kW heat output for another 10 min. Total testing time is 20 minutes.
Fire Test Methods
NAVIC 03-01 on Equivalency

Fire Safety Objectives

OR gate

Prevent Fire Ignition
- Control Heat-Energy Source(s)
- Control Source Fuel Interaction
- Control Fuel

Manage Fire Impact
- Manage Fire
- Manage Exposed

Upper Level of Fire Safety Tree
Fire Test Methods
Fire Protection Schemes

- Resins with Improved Fire Performance Characteristics
  - Fire Retardant Additives
  - Phenolic Resins

- Structural Fire Protection
  - Insulation Blankets
  - Intumescent Coatings
  - Spray Insulation Systems

- Fire Hazard Analysis
  - Fire Characteristics of Room Lining & Geometry
  - Fire Detection and Suppression
Fire Test Methods
Structural Fire Protection

Spray Insulation Systems

Insulation Blankets
Fire Test Methods
Structural Fire Protection

Detail of Insulation Blanket Installation
Fire Test Methods
Fire Hazard Analysis

Fire Hazard Analysis by Hughes Associates Predicts Thermal Profile of Composite Structure During Full-Scale Fire Test
Testing of Water Mist Systems on the ex-USS SHADWELL
NASA's Space Launch Initiative (SLI) is poised to revolutionize space travel. A focused investment in risk reduction and technology development, SLI is a comprehensive, long range plan to increase the safety, reliability and affordability of space transportation, including access to the International Space Station.

It is critical that the airframe of any future vehicle be optimized for safety, cost and performance while incorporating minimum weight - the classic aerospace dilemma.
Vital to attaining the SLI goal of safety, reliability and affordability is the development of a reusable launch vehicle (RLV) - "reusable" being the key word. Toward this end, the focus of the airframe systems team is on developing and demonstrating:

- Advanced airframe design and integration methods to improve reliability and reduce design cycle time
- Robust, low-cost, low-maintenance structures, tanks, thermal protection systems and thermal structures
- Aerodynamic and aero thermodynamic assessments which yield higher-fidelity information early in the design process
Future Composite Material Requirements
Space Launch Initiative

One of 15 industry concepts. (Boeing)
Future Composite Material Requirements
Space Launch Initiative

One of 15 industry concepts. (Lockheed)
Future Composite Material Requirements
Space Launch Initiative

One of 15 industry concepts. (Northrop Grumman/Orbital Sciences)
Future Composite Material Requirements
X-33 Launch

Reusable Launch Vehicle Technology Program
Future Composite Material Requirements
X-37

NASA's X-37 Vehicle

X-37 Body Flap Test Article
A new polymer composite matrix material developed under NASA's High Speed Research (HSR) Program is being evaluated for use on future reusable launch vehicles (RLV's). The polymer material, PETI-5 (Phenyl Ethynyl Terminated Imide), developed at NASA Langley Research Center for use as a composite matrix and adhesive, has temperature capabilities of 350°F for 60,000 hours.

PETI-5 has the potential to be used at operating temperatures (450°F to 500°F) that are higher than current state-of-the-art bismaleimide (BMI) polymer matrix composites.
Future Composite Material Requirements
X-38 Launch

X-38 Flight Tape 3 of 7
Dryden Flight Research Center
Future Composite Material Requirements
International Space Station
Future Composite Material Requirements
International Space Station

Deployment of Antenna on Z1 Truss Structure
Future Composite Material Requirements
International Space Station

Cutaway of Transhab Module to be installed on the International Space Station
Future Composite Material Requirements
Solar Sails

A solar sail consists of a large, lightweight and highly reflective surface that relies on the momentum transferred from solar photons for passive propulsion.

By making use of this innovative means of low-thrust propulsion, extended missions in our Solar System which require a velocity of several tens of kilometres per second would become possible.

For missions needing such high propulsion energies, solar sails could either complement other more traditional means of space propulsion, or provide all of the propulsion needed.
Future Composite Material Requirements
Solar Sails

ESA/DLR Concept for Solar Sailing

Epoxy/Carbon Fiber Deployable Boom
Future Composite Material Requirements
Aerospace Needs for High Temp Resin

Needs
• Organic Matrix Composites (OMC’s) for aircraft engine parts (stator’s, ducts, back end stuff)
  – >600°F
• OMC’s for aircraft skins (STOVL, exhaust wash areas)
  – >425°F

Issues
• Use of OMC’s in high temperature environments has been limited
• Materials are difficult to process
  – AFR700B expensive, long cure cycles
  – PMR-15 OHS
• “NASA materials” don’t have high enough operating limit
  – Still questionable processing
  • High solvent content

Jeff Hendrix
Future Composite Material Requirements
Naval Aviation Requirements

F-18 Carrier Launch
Future Composite Material Requirements
Aerospace Needs for High Temp Resin

GLOBAL HAWK-High Altitude Endurance
Unmanned Aerial Vehicle
Future Composite Material Requirements
Aerospace Needs for High Temp Resin

This artist's depiction shows a Hyper-X research vehicle under scramjet power in free-flight following separation from its booster rocket.
Utilization of high temperature polymer matrix-carbon fiber composites for structural application in future high speed civil transport (HSCT) commercial aircraft will be exposed to temperatures of up to ~400°F for 60,000h under stress and, also, will be exposed to flowing oxygen/ozone/nitrogen atmospheres associated with vehicle speeds in the 2.0-2.5 mach range.
Future Composite Material Requirements

UCAV
Future Composite Material Requirements
DARPA Accelerated Insertion of Materials (AIM)

AIM Methodology Improves Confidence More Rapidly & Effectively by Analysis Supported By Test / Demonstration - Focusing on the Designer Knowledge Base Needs