The National Center for
Advanced Manufacturing

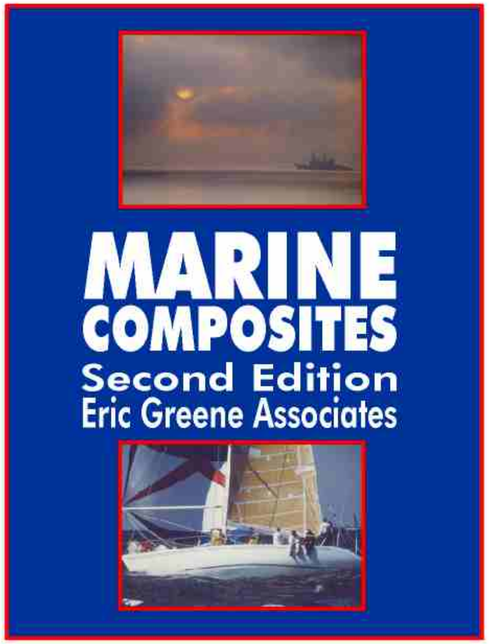
Composite Material Flammability Teleconference

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

Presented by Eric Greene
ERIC GREENE ASSOCIATES, INC.

Bio for Eric Greene

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.

High-Temperature Resin Systems
Vinyl Ester

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

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

[1] Numbers in parentheses indicate the sample standard deviation.

High-Temperature Resin Systems
Vinyl Ester

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

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

Fibercote Resin	Description	Applications	Min Cure	Max Serv
P600	Low cost, General purpose grade, Low temperature cure, Non-styrenated/Low VOC, Effective replacement for wet lay-up	Structural, Industrial parts	180°F-250°F	160°F
P601	Flame retardant version of P600	Geodesic radomes, Shelters, Industrial parts	180°F-250°F	160°F
P605	Designed for tube rolling applications, Non-styrenated/Low VOC	Poles and shafts	180°F-250°F	160°F
P650M	Modified diallyphthallate, Excellent wet electrical properties, Non-styrenated/Low VOC	Aircraft structures, Electrical applications	250°F-300°F	250°F
P650R	Designed for optical clarity, Good mechanical and electrical properties, Non-styrenated/Low VOC	Applications which require optical clarity, Aircraft lighting, etc.	250°F-300°F	250°F
P670I	High service temperature, Flame retardant, Excellent electrical and mechanical properties, Non-styrenated/Low VOC	Aircraft structures, Radomes	250°F-300°F	to 350°F

Meets Mil-R-7575C- Grade A

High-Temperature Resin Systems
Epoxy

Epoxy resin is a polymerizable thermoset polymer containing one or more epoxide groups and curable with reaction with amines, alcohols, and other agents.

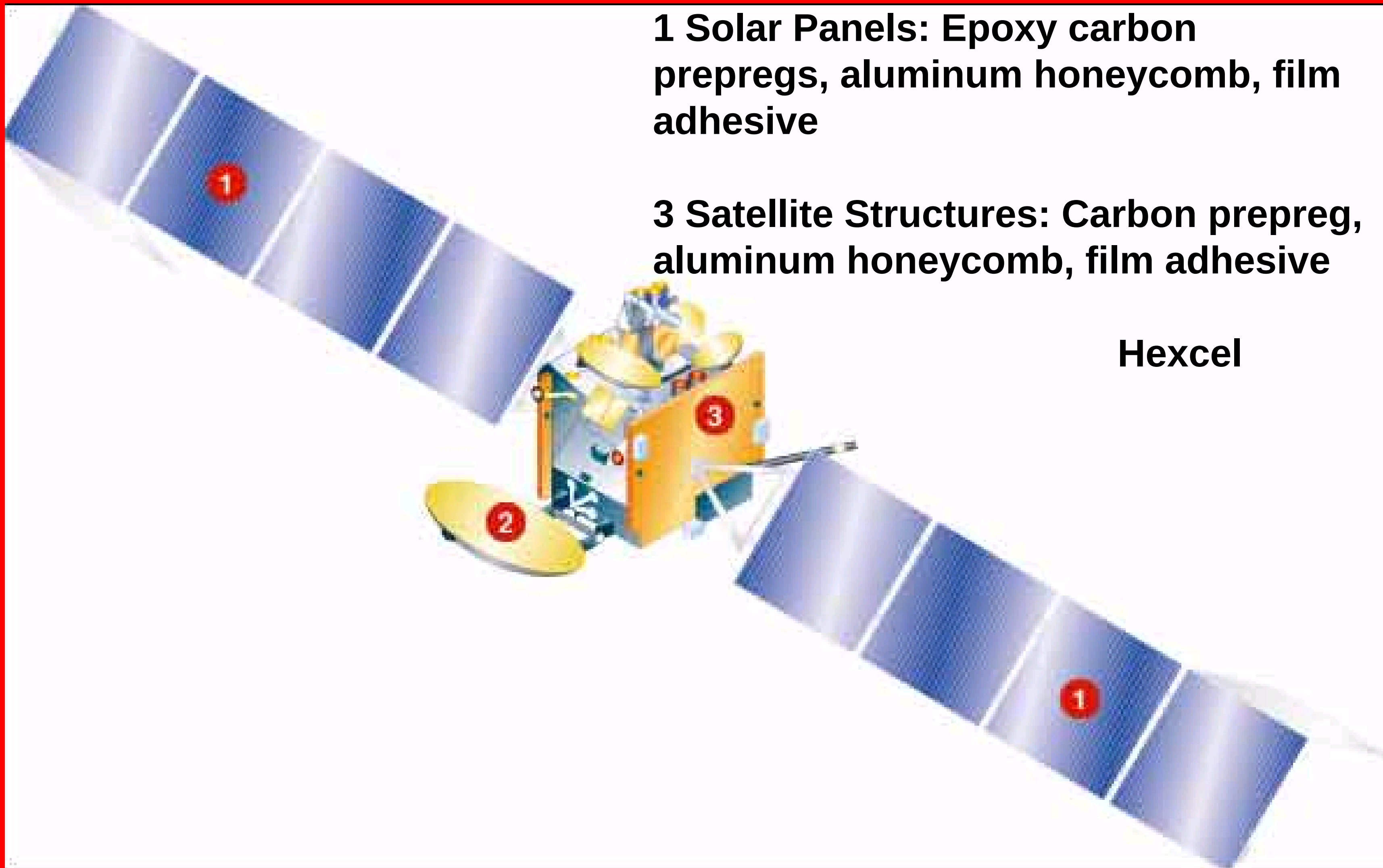
Epoxy is usually preimpregnated with a fiber reinforcement or can be used in liquid form using hand or infusion methods.

High-Temperature Resin Systems
Epoxy

Orbital Sciences Pegasus

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

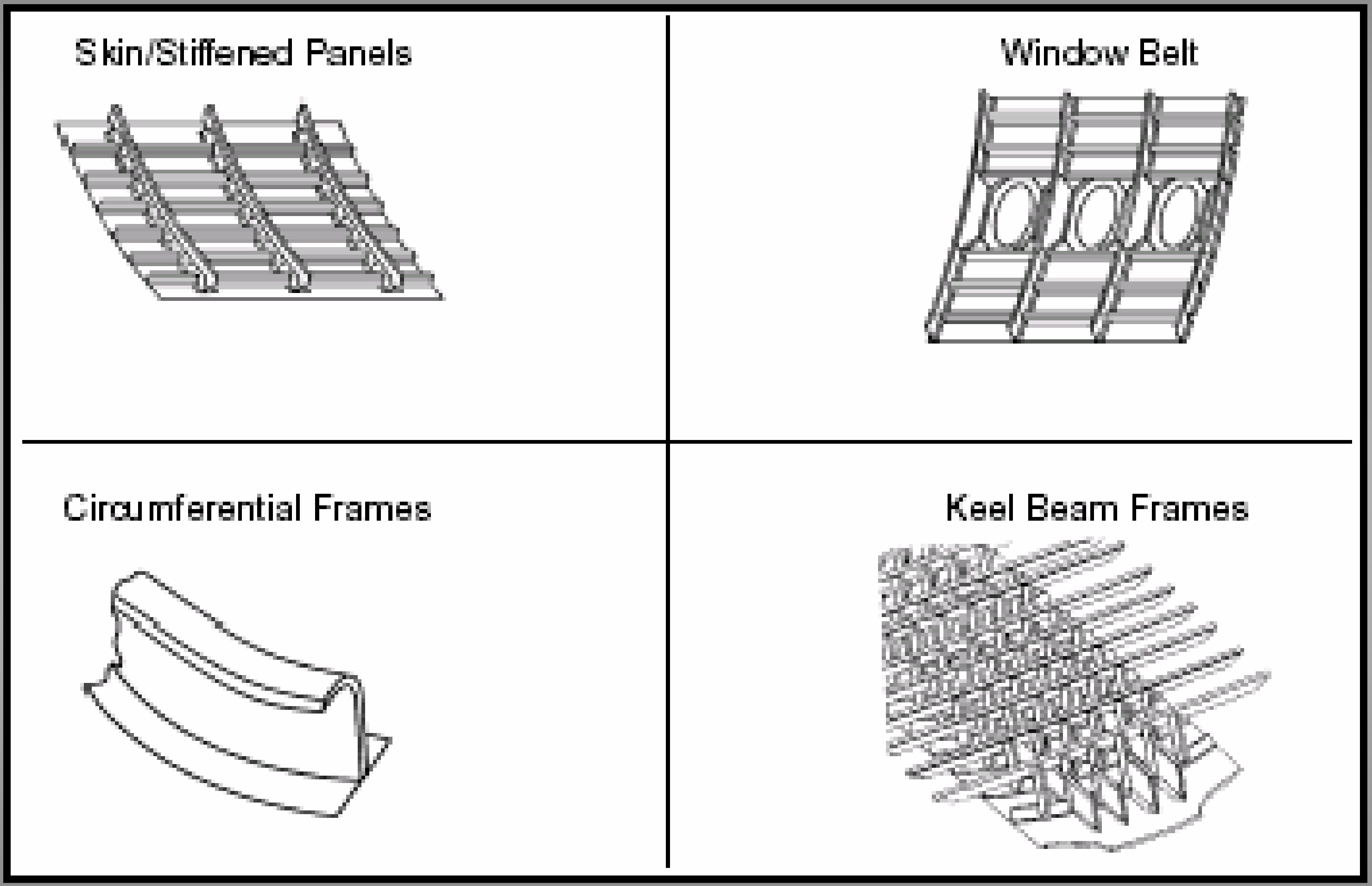
High-Temperature Resin Systems
Epoxy

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



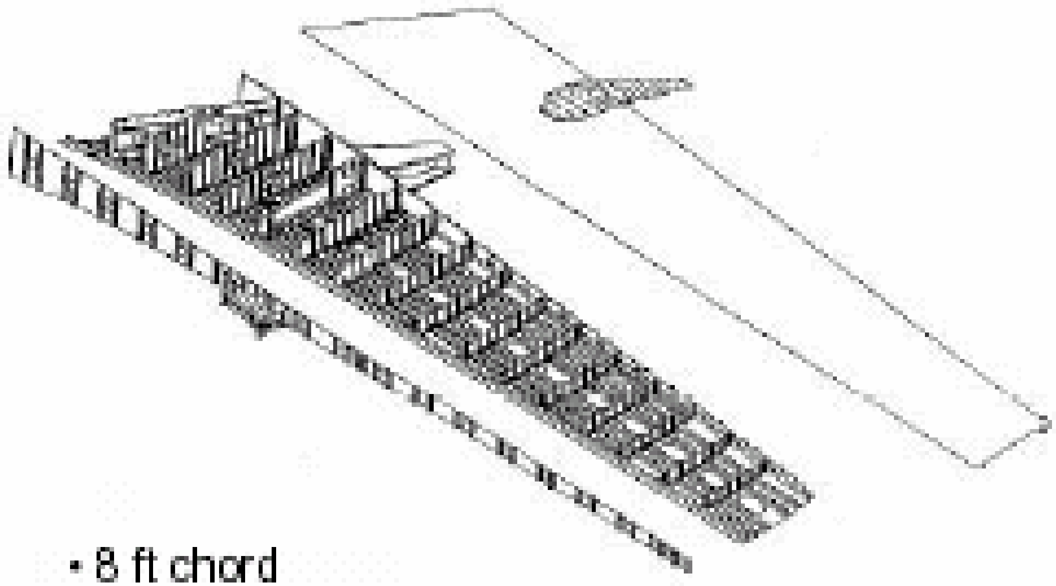
Application of Textile Reinforced Composites in Transport Fuselage Structures from Lockheed Martin

High-Temperature Resin Systems
Epoxy

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.

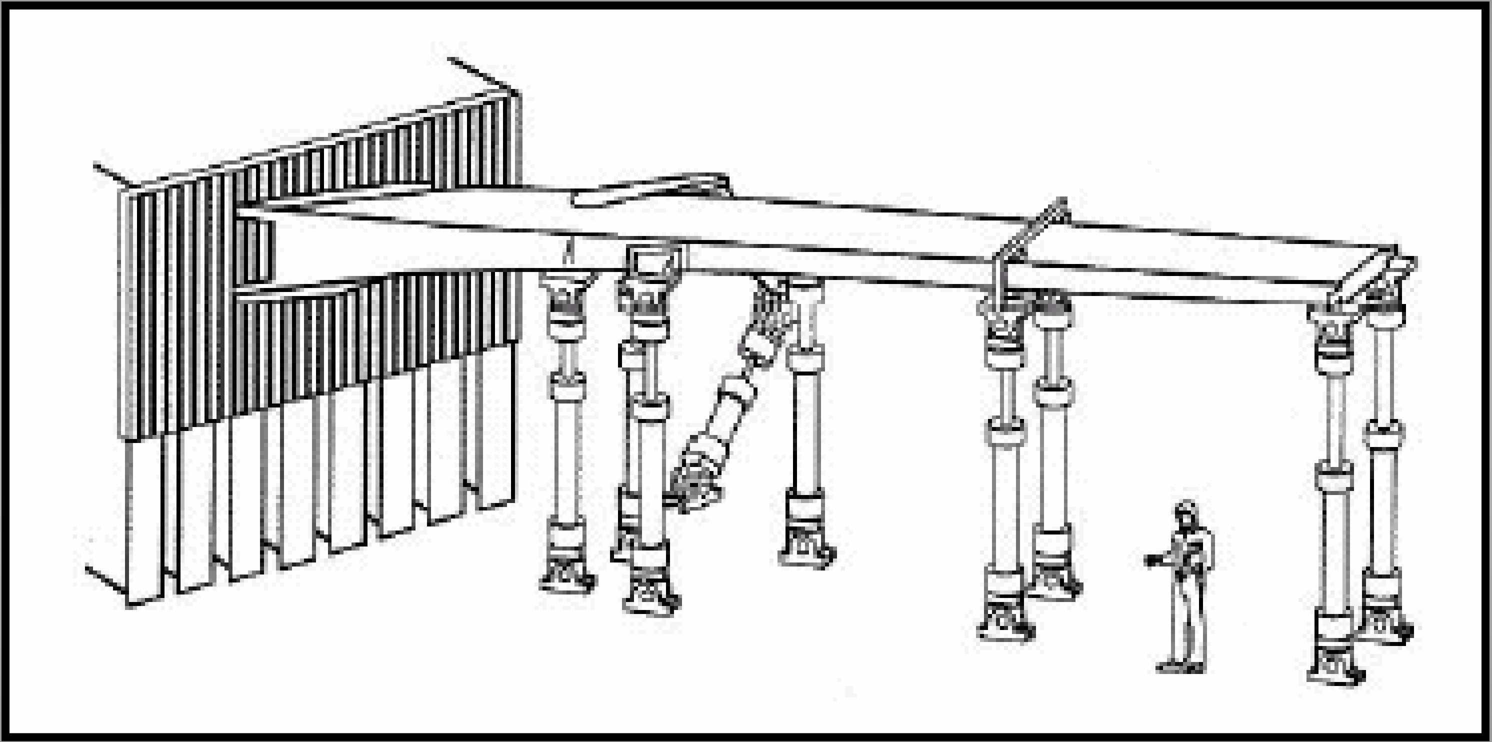
High-Temperature Resin Systems
Epoxy



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

Design Features of Stitched/RFI Semi-Span Wing

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

High-Temperature Resin Systems
Epoxy

Fibercote E-765 FAA Approved Database

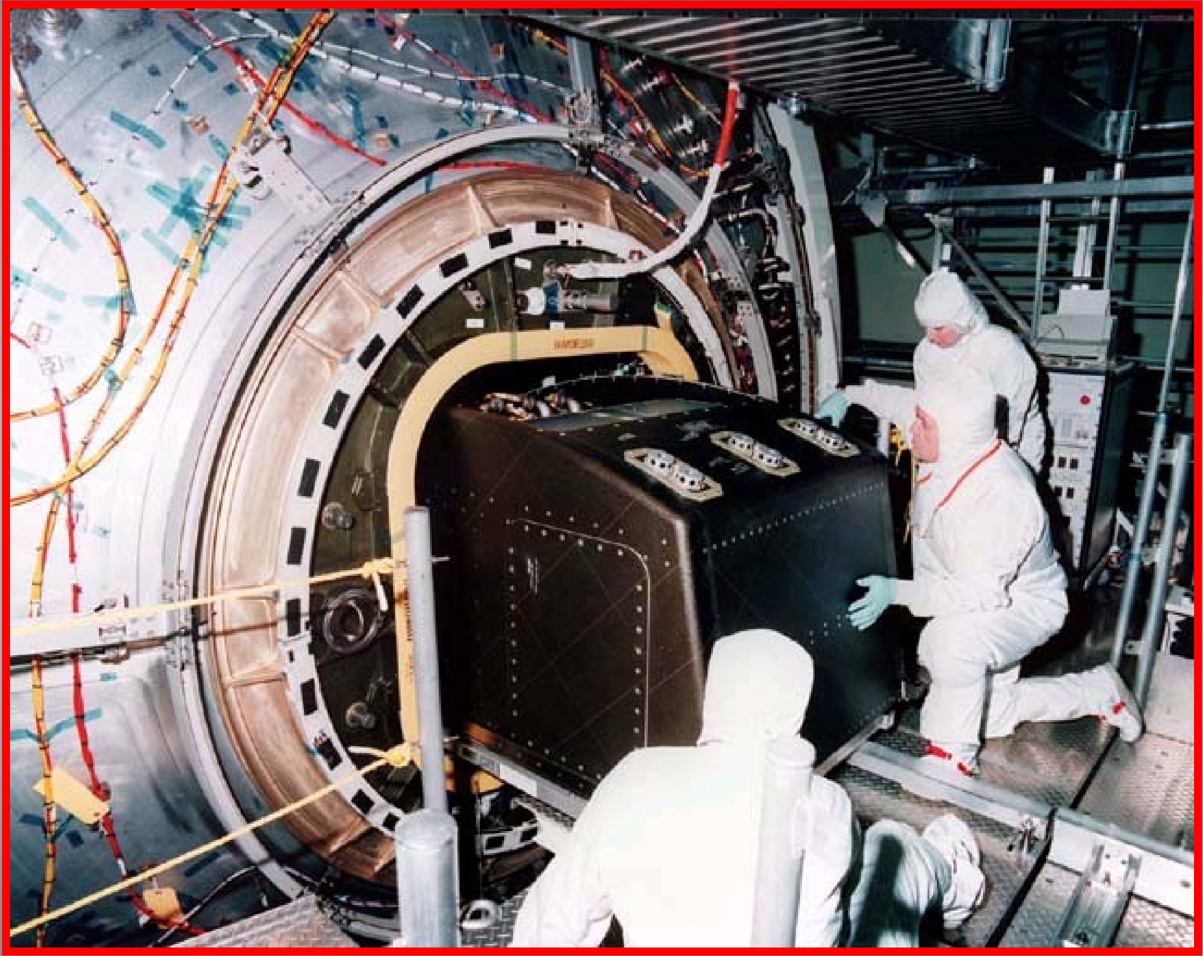
The largest single regulatory obstacle to using advanced composite materials in certified aircraft applications has been the generation of design allowables which will satisfy Regulatory agency requirements. Previously, individual airframe manufacturers generated design allowable databases as a routine 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.

High-Temperature Resin Systems
Epoxy

Fibercote Resin	Description	Applications	Min Cure	Max Service
E717	Self adhesive, High peel strength, Controlled flow, Flame retardant, Low tack, Good handleability for large panels	Sandwich panels or solid laminates	250°F-325°F	265°F
E746	Designed for high temperature service, Structural grade, Excellent hot/wet properties, Extensive database	Aircraft structures, Radomes	300°F-350°F	to 500°F
E761	Self-adhesive, Flame retardant, Controlled flow, Good electrical properties, Extensive database, Versatile processing, Long out-time	Solid laminates or sandwich panels, Radomes	180°F-275°F	to 200°F
E763	Good clarity, Versatile processing, Long out-time	Aircraft structures, Industrial & Recreation parts where clarity is desired	180°F-300°F	to 200°F
E765	Tough, 250°F cure system designed to replace many first generation 350°F systems, Extensive FAA Approved Databases, Versatile processing, Long out-time	Aircraft primary and secondary structures	250°F-300°F	to 275°F
E766	Self-adhesive, High peel strength, Flame retardant, Controlled flow, Good electrical properties, Extensive database, Versatile processing, Long out-time	Solid laminates or sandwich panels, Radomes	250°F-300°F	to 200°F

High-Temperature Resin Systems
Epoxy



Epoxy/Carbon Fiber Racks in the U.S. Laboratory Module on Board the International Space Station

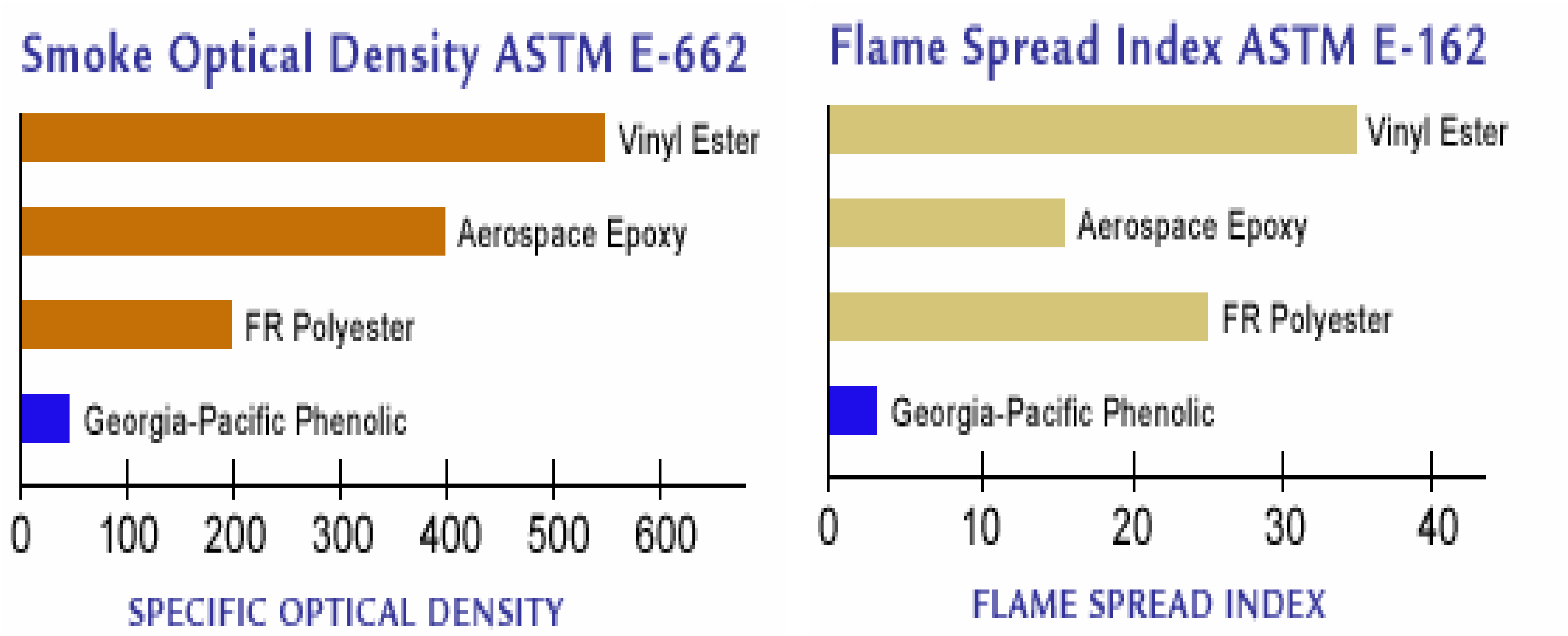
High-Temperature Resin Systems
Phenolic

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.

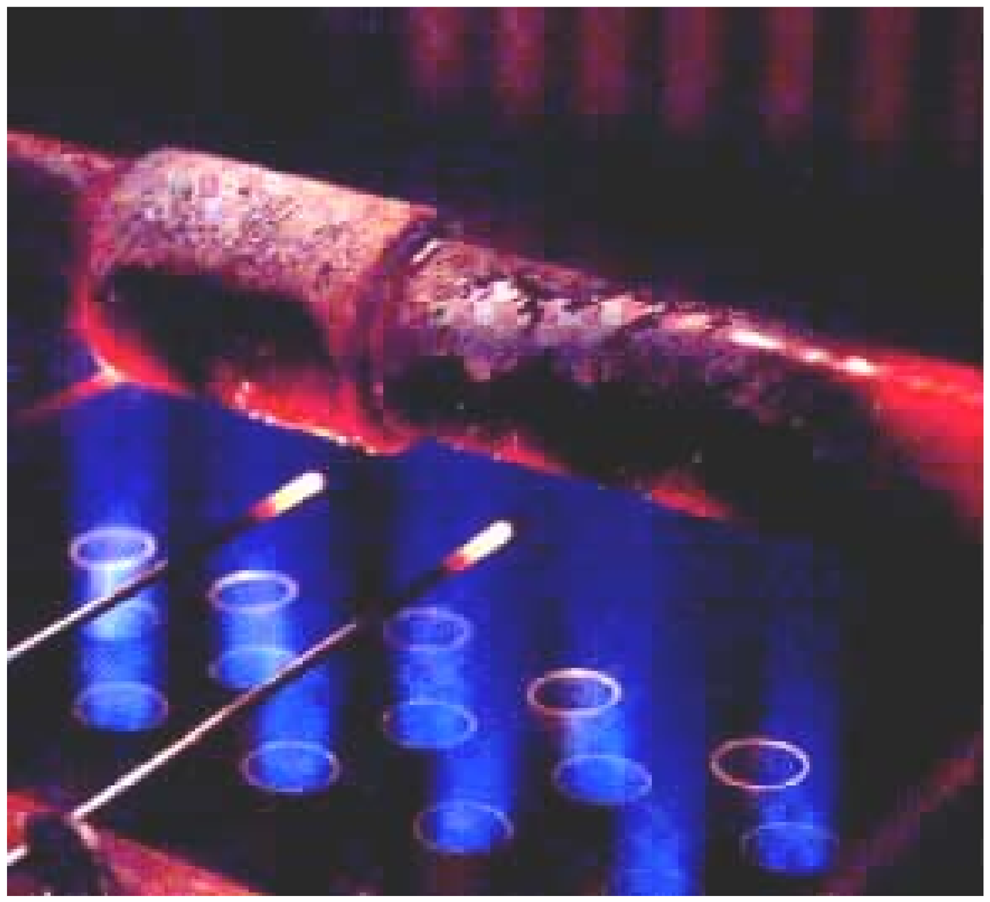
Their excellent char yield and ablative (heat-absorbing) characteristics have made phenolics longtime favorites for ablative and rocket nozzle applications. Recently, they have proven successful in offshore oil and gas platforms, mass transit and electronics applications.

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

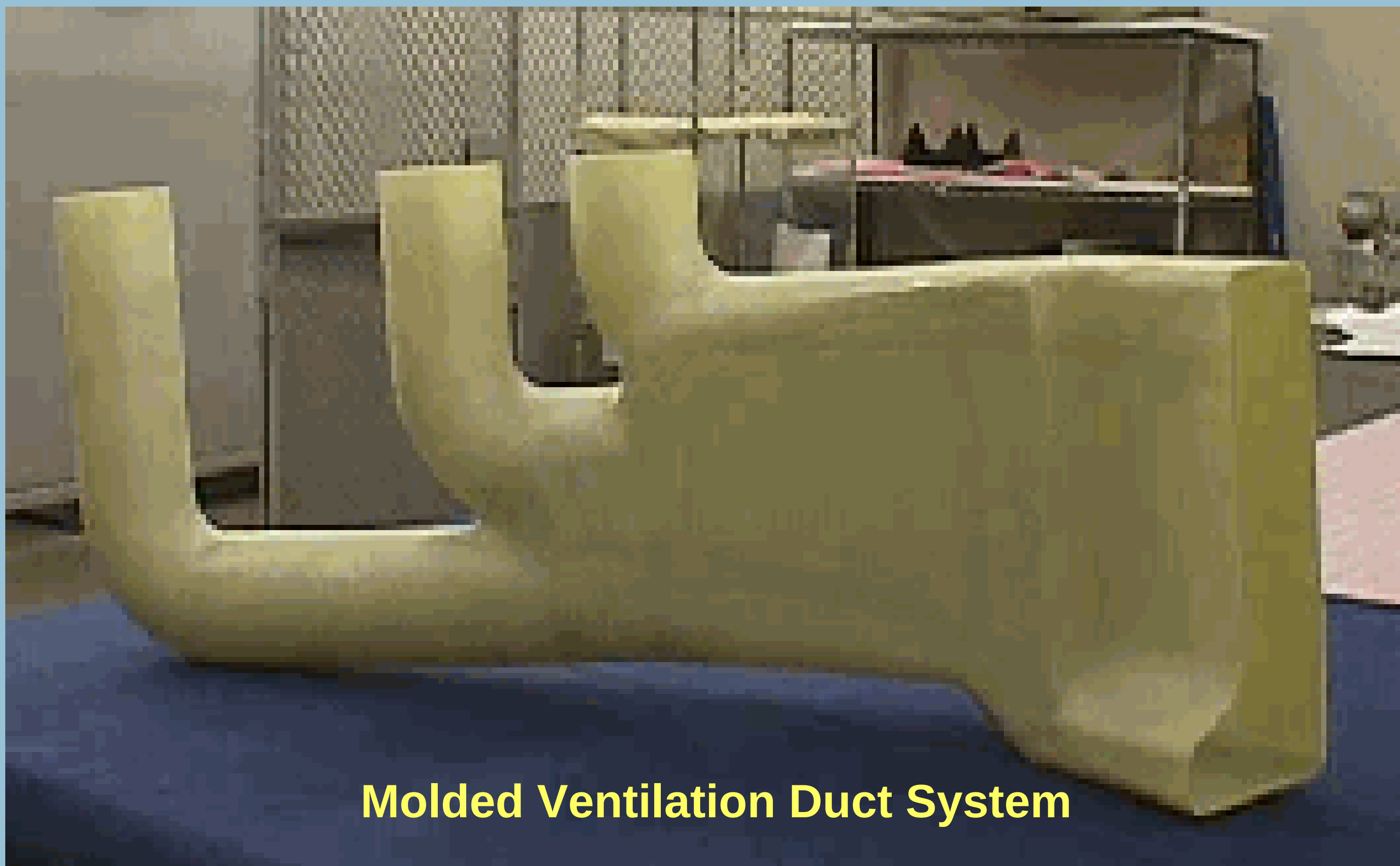


High-Temperature Resin Systems
Phenolic



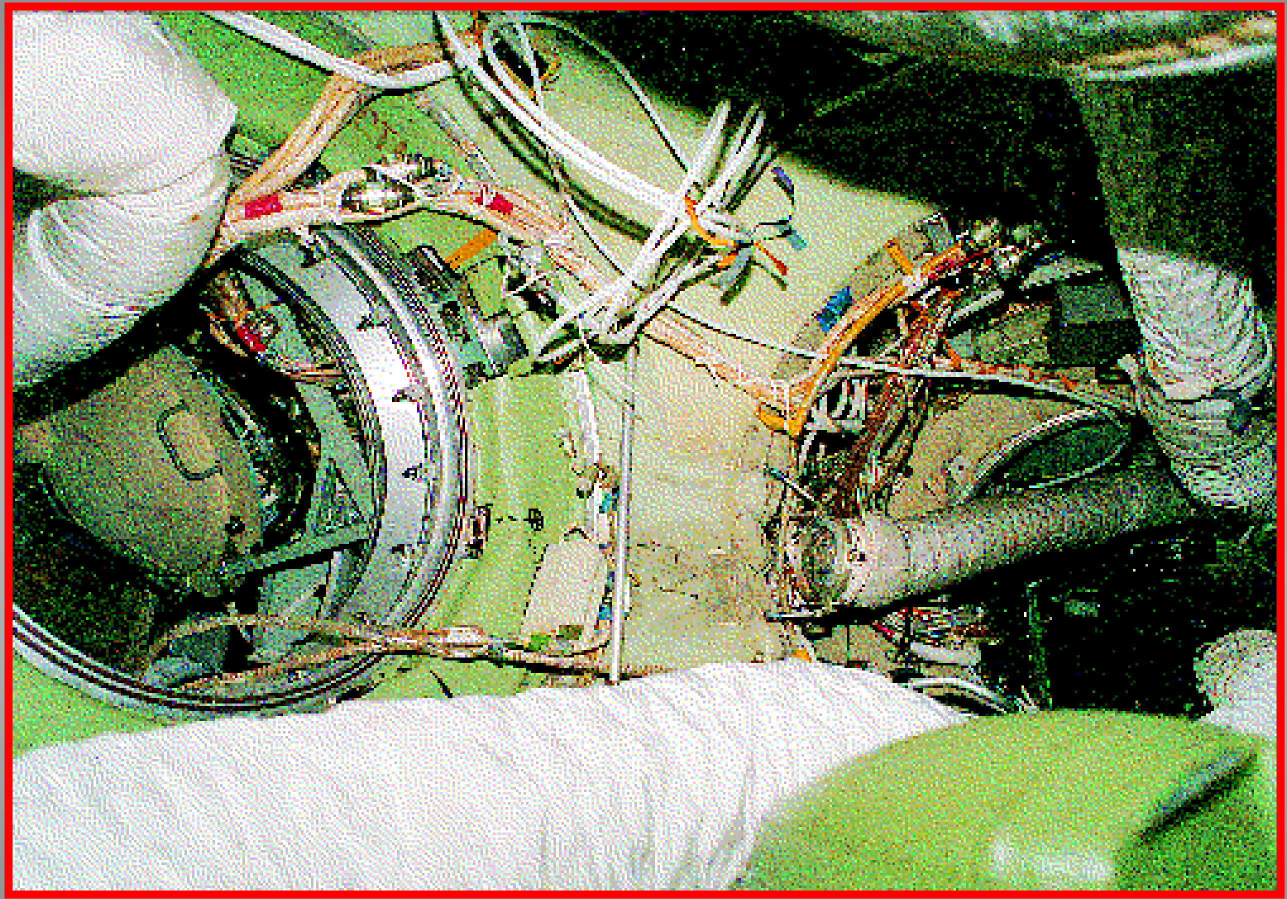
Bondstrand PSX-L3 Phenolic Pipe Passed IMO Level 3 Fire Tests That Subjected Pipe to 1000º C (1832º F)

High-Temperature Resin Systems
Phenolic



Molded Ventilation Duct System

High-Temperature Resin Systems
Phenolic



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

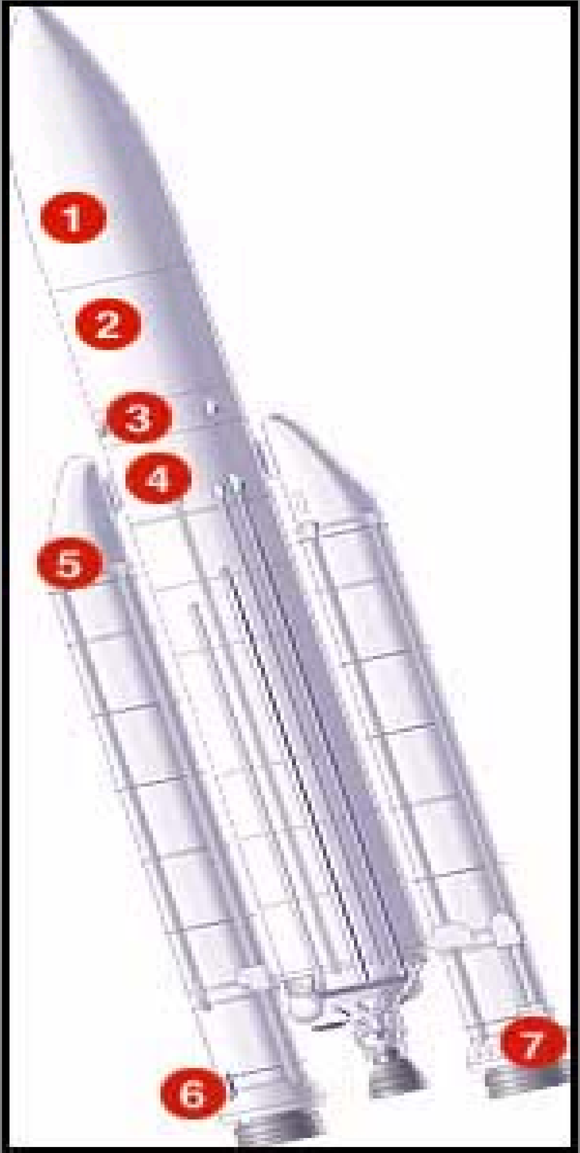
Fibercote Resin	Description	Applications	Min Cure	Max Service
F502	Structural grade system, Good tack and drape, Excellent high temperature properties, Also has good ablative characteristics	Aircraft structures, Ducts, High temperature furnace chambers, Rocket nozzles	325°F-375°F	500°F
F502 High Silica	Works well in oxidative environments, Low pressure autoclave cure, Coated onto leached glass fabric style C100-48	Liquid rocket nozzles, Combustion chambers, Blast tubes, Exit cones, Insulators	325°F-350°F	N/A
F554 High Silica	Works well in oxidative environments, Coated onto leached glass fabric style C100-48	Liquid rocket nozzles, Combustion chambers, Blast tubes, Exit cones, Insulators	350°F-400°F	N/A
F555 Carbonized Rayon	Carbon loaded, Coated on continuous filiment 8HS carbonized rayon fabric, High strength	Nozzles, Exit cones	350°F-400°F	N/A
F589 PAN	Carbon loaded, Coated on continuous filiment 6K 5HS Part Fabric, High Strenght	Aft exit cones	350°F-400°F	N/A

High-Temperature Resin Systems
Cyanate Ester

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.

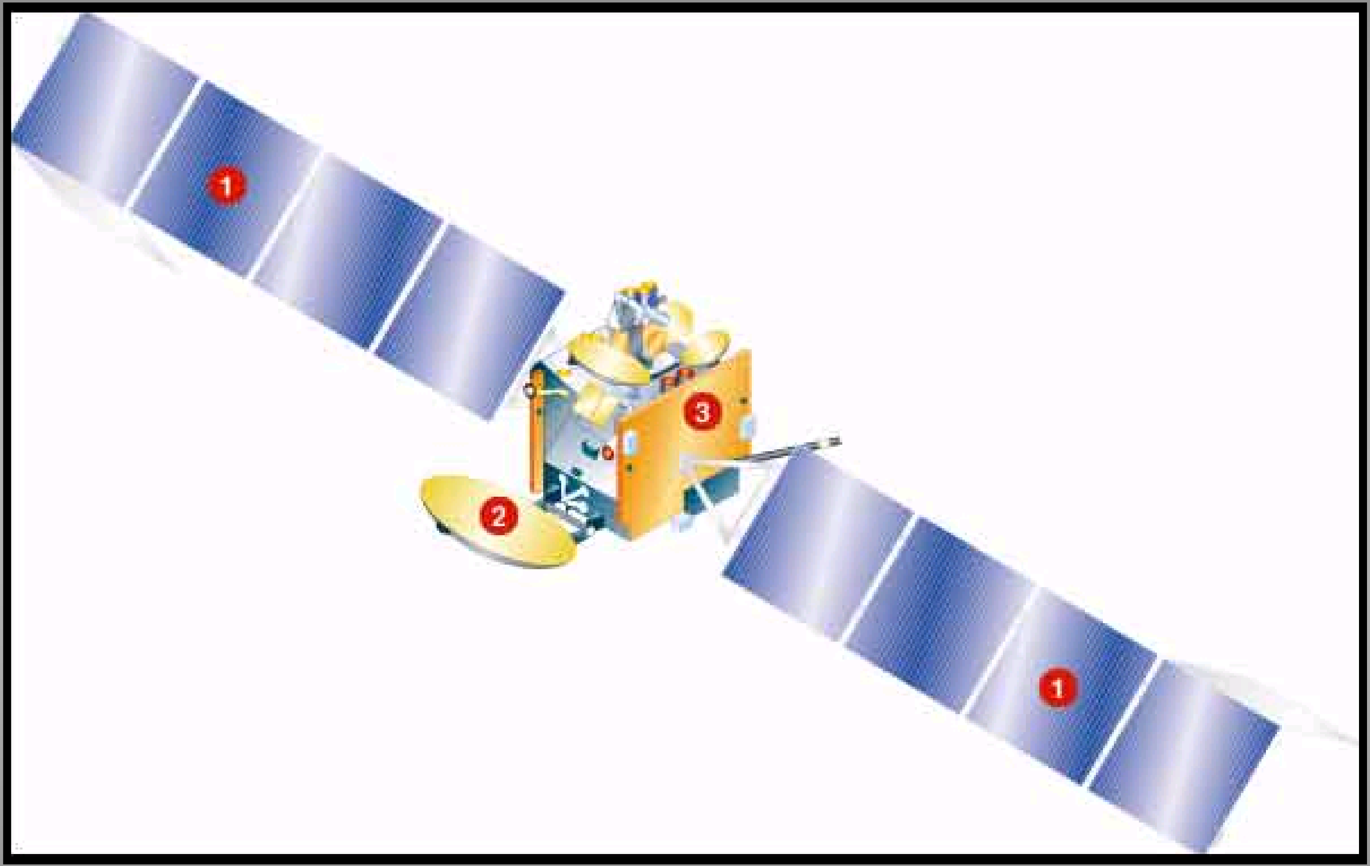
4 - Front Skirt: Carbon prepreg.

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

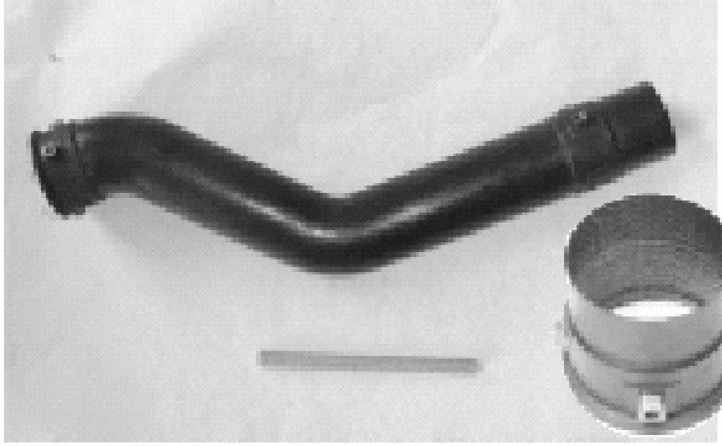
High-Temperature Resin Systems
Polyimide

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

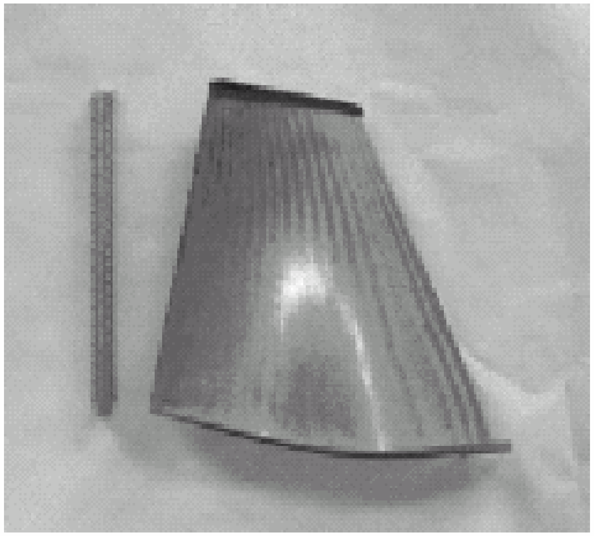
In airplane spline couplings, used to drive generators, hydraulic pumps, and other equipment, adapters made with DuPont's VESPEL were designed to replace all metal couplings.

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



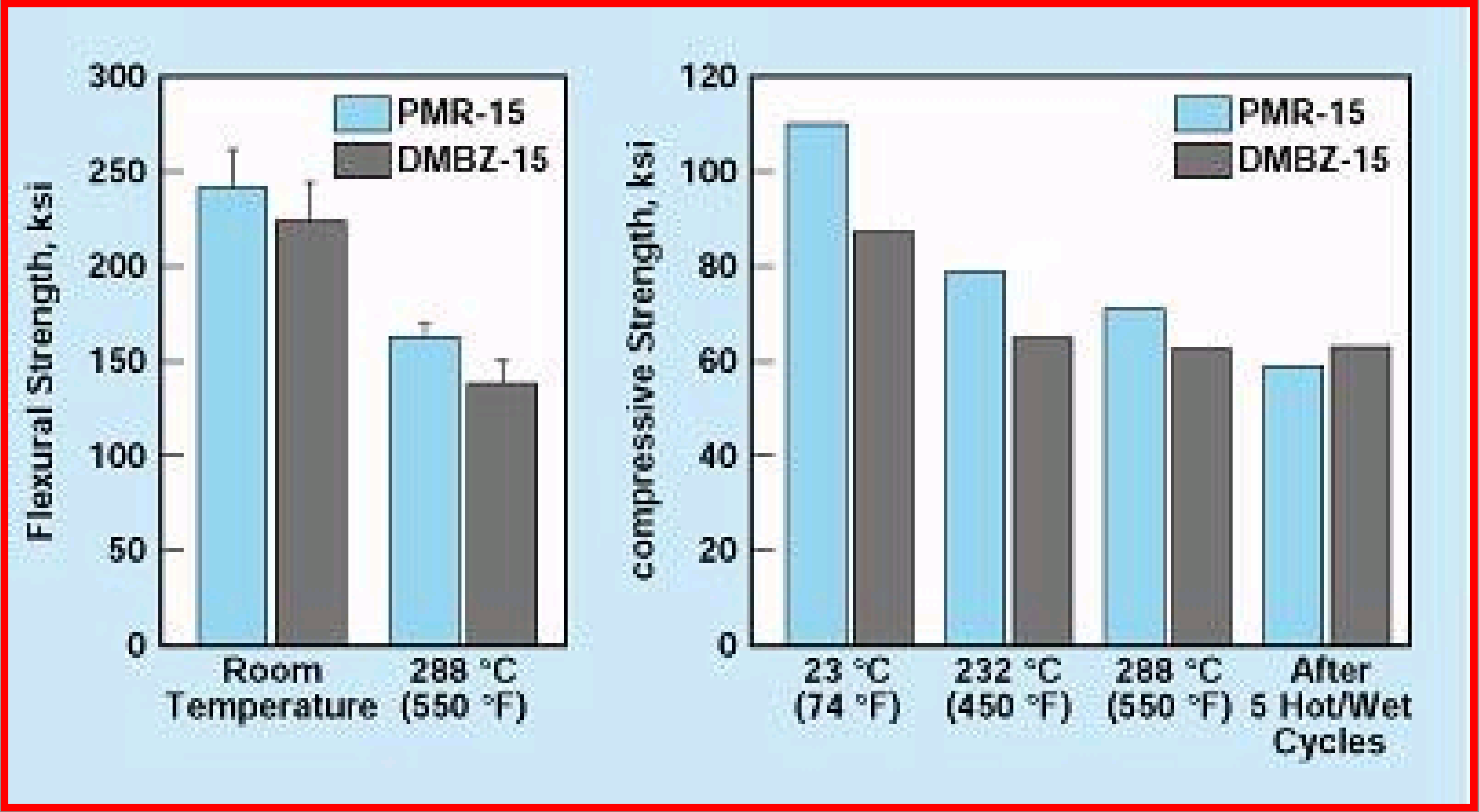
GE-90 HP Cooling Tube PMR-15, BIP-17S.



F-414 Front Frame AFR-700B

Stabilizer flaps, space mirror tube framing, jet engine vane assemblies, shoulder-launched weapon systems are candidates for polyimide resin

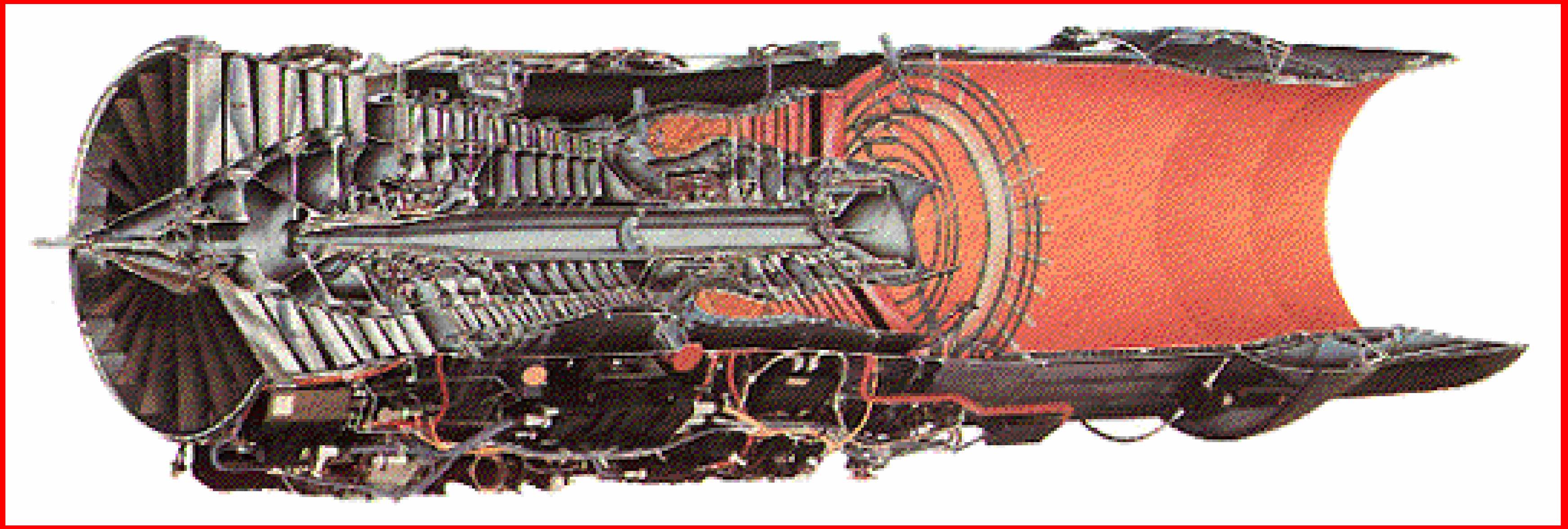
High-Temperature Resin Systems
Polyimide



High-Temperature Resin Systems
Polyimide

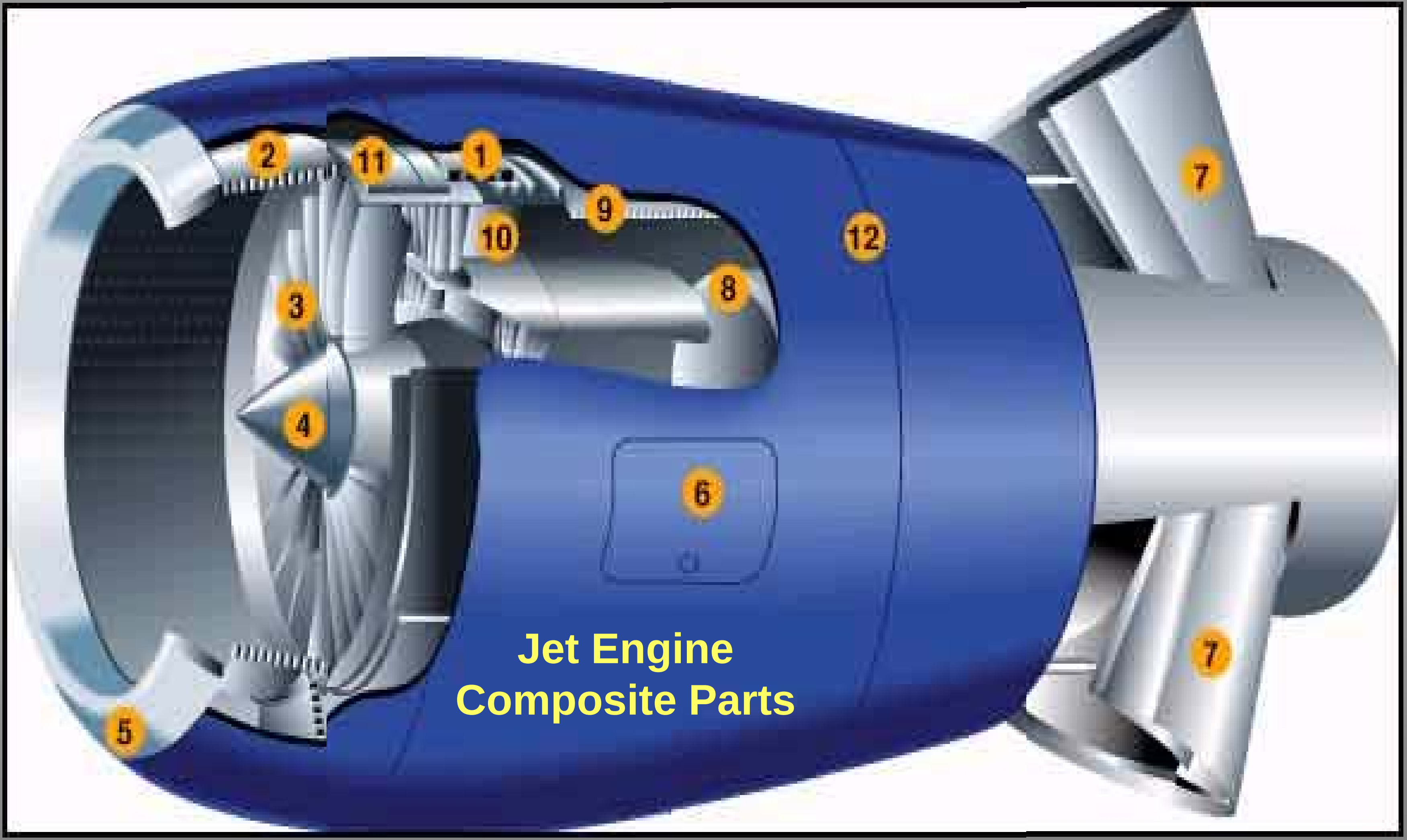
Strike Eagle jet engine change
Crew Chiefs from the 48th Fighter Wing, United Kingdom, pull out a Pratt & Whitney F100-229 engine from a F-15E Strike Eagle

High-Temperature Resin Systems
Polyimide



Pratt and Whitney F100-229 Afterburning Turbofan Engine

High-Temperature Resin Systems
Polyimide



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

High-Temperature Resin Systems
Bismaleimide

Bismaleimides(BMIs) are suitable for applications requiring a service temperature of 260-450°F.

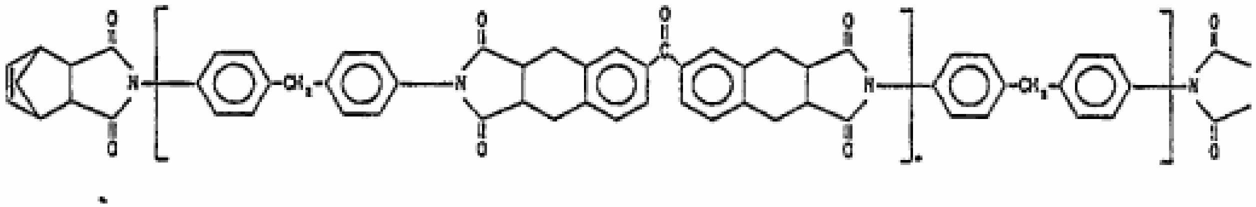
For high temperature performance, NASA developed polyimide polymers. The temperature capability was about 600°F but the resins were brittle, difficult to process (+650 °F cure required) and a condensation reaction which produces water during the cure occurs.

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.

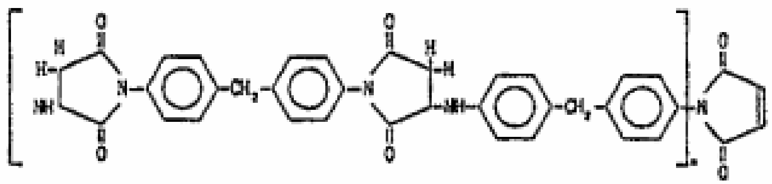
High-Temperature Resin Systems
Bismaleimide

- **Satellite Structures**
- **Aerospace/Missile Structures**
- **Electromagnetic/Dielectric Structures**

(Fig 10) Structure of PMR-15 Polyimide



(Fig 11) Structure of a Commercial Bismaleimide

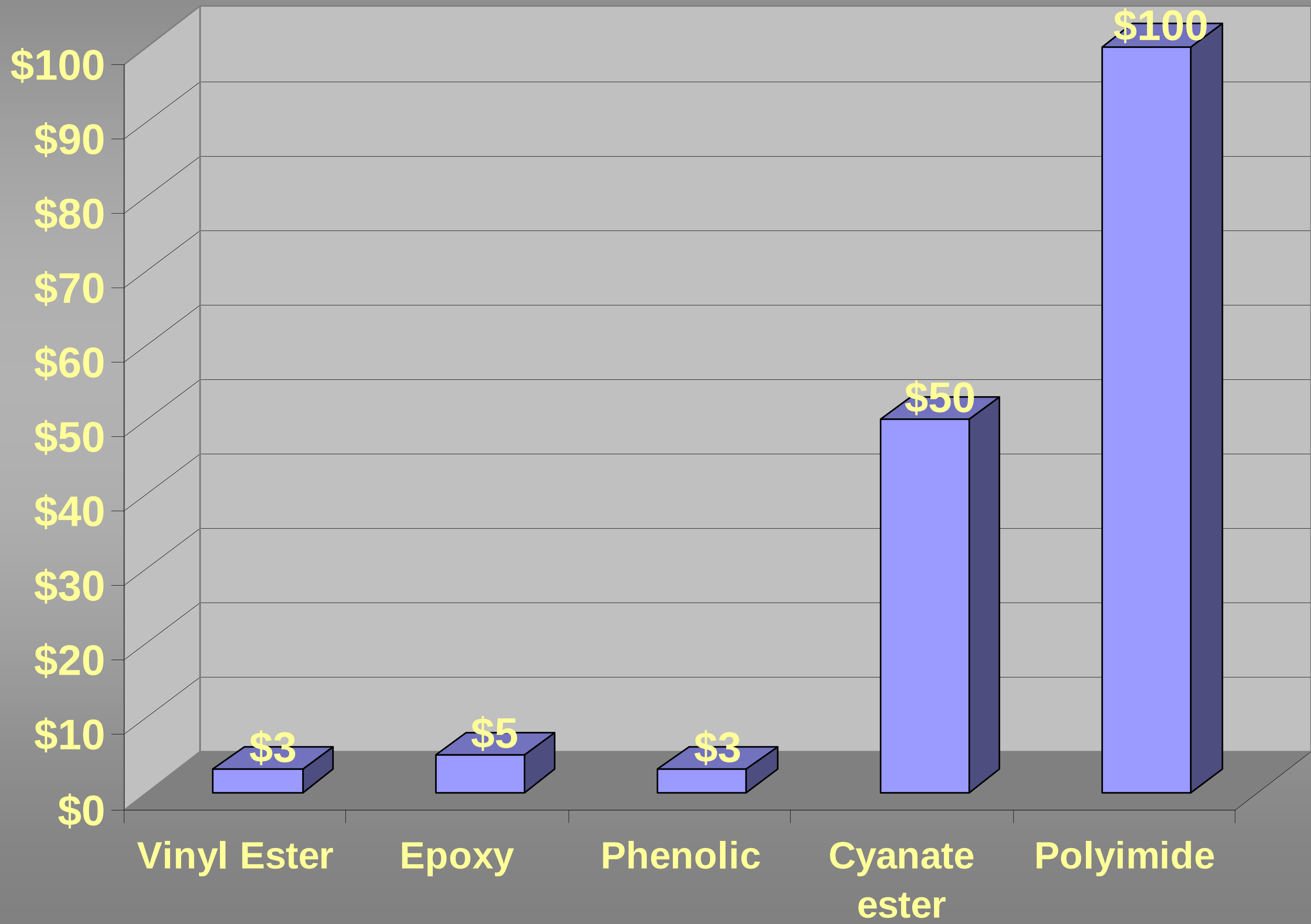


High-Temperature Resin Systems
Bismaleimide

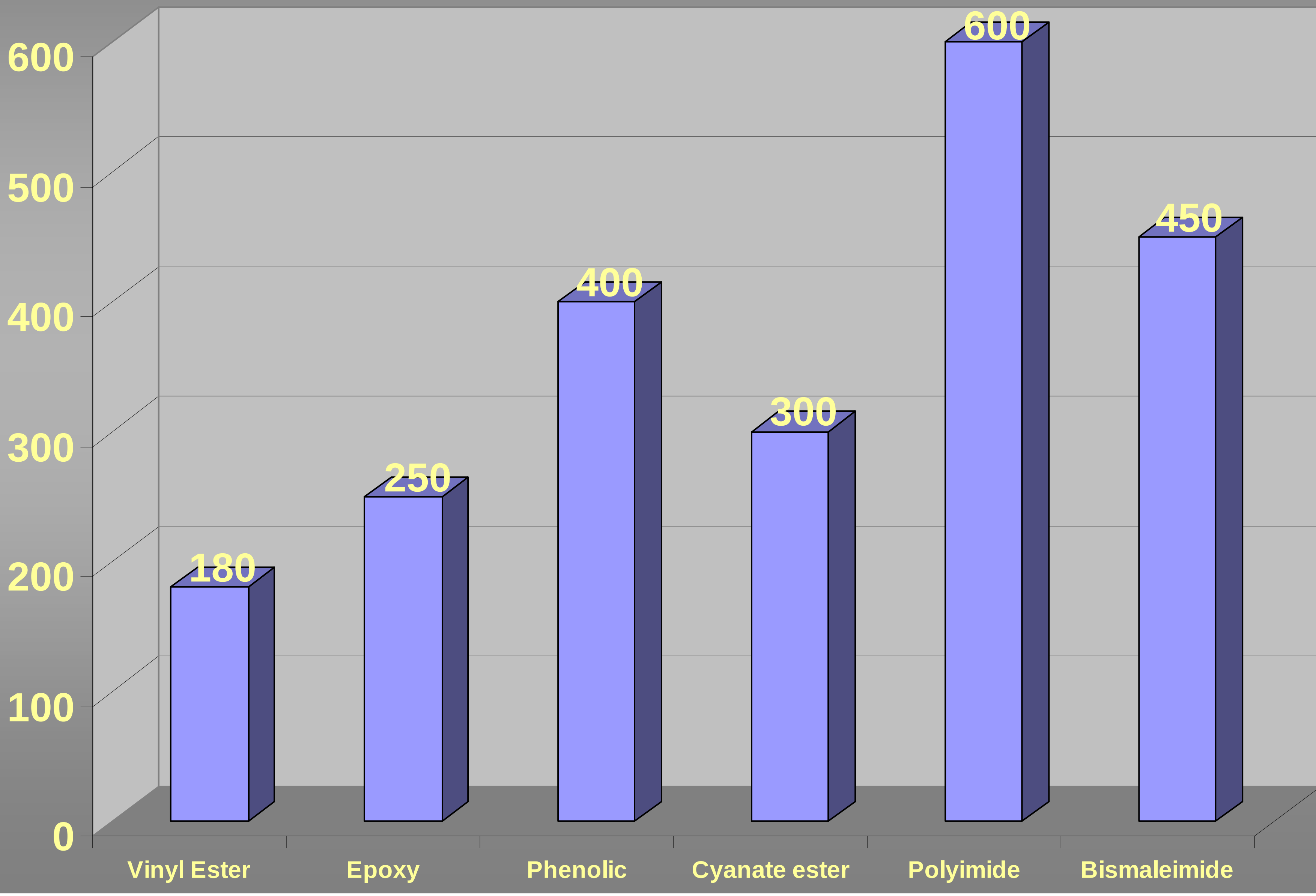
Powder versions are available for compression molding into virtually indestructible bearings, slip-rings or races.

High-Temperature Resin Systems
Bismaleimide

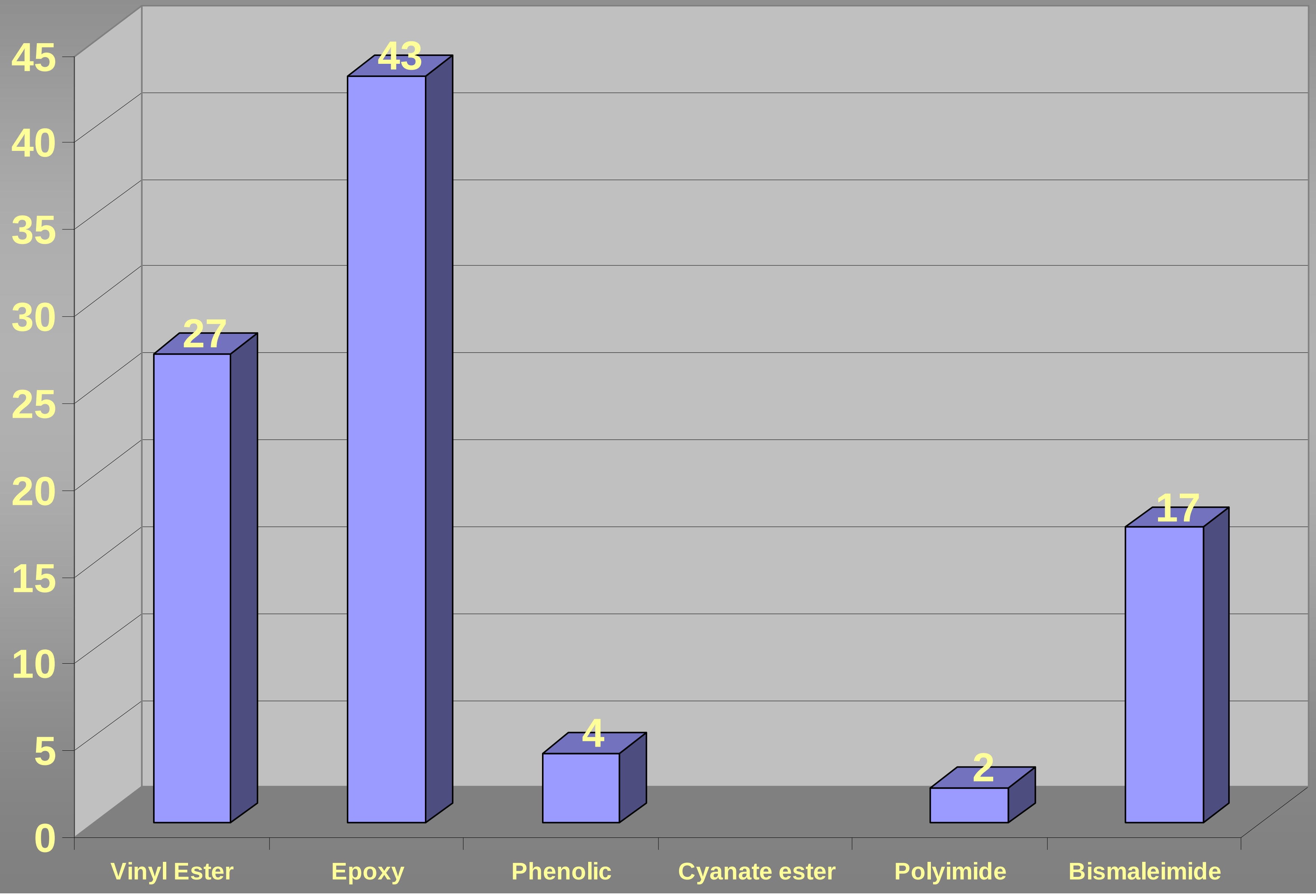
High-Temperature Resin Systems Cost, $/pound



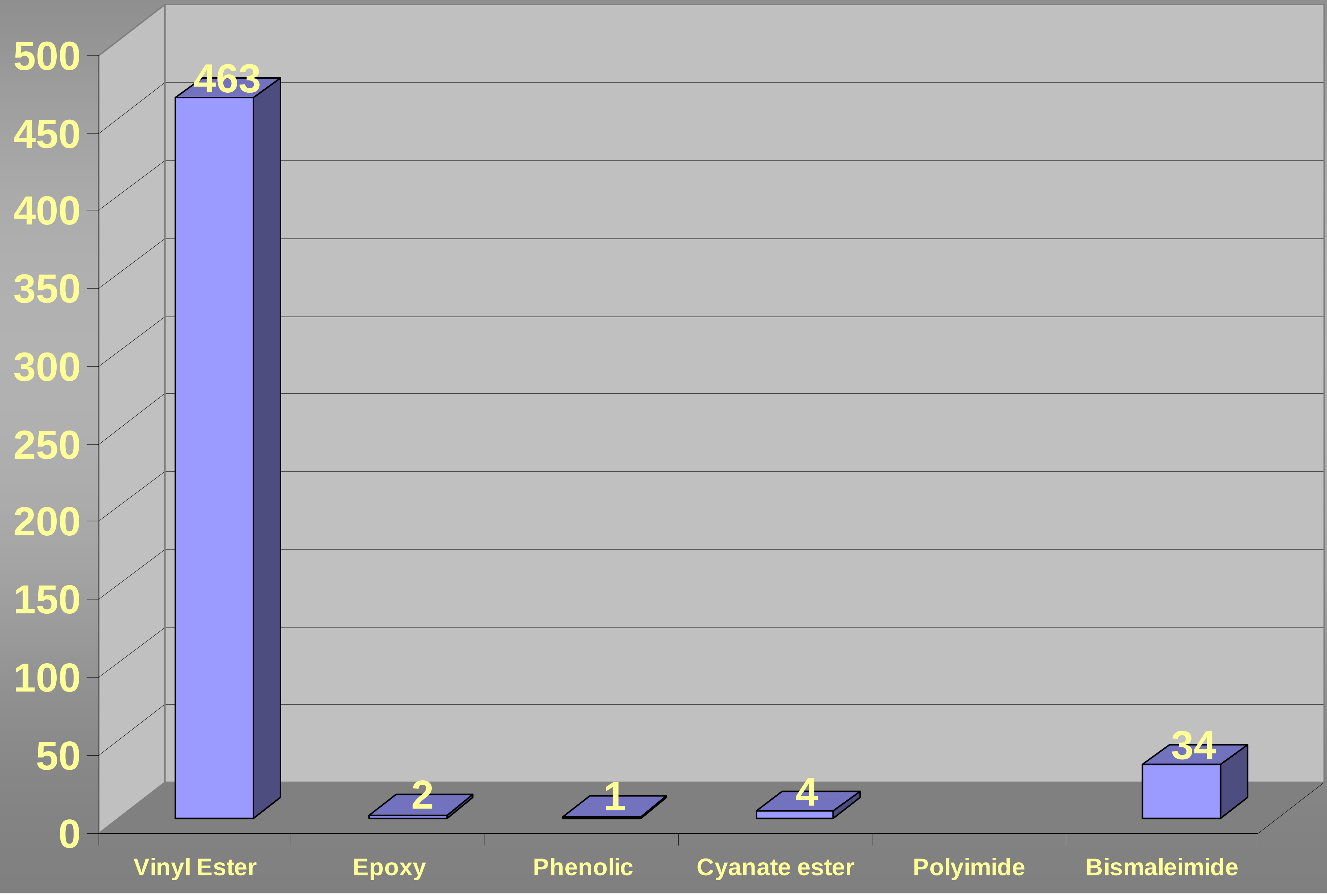
High-Temperature Resin Systems Hot-Wet Service Temperature, °F



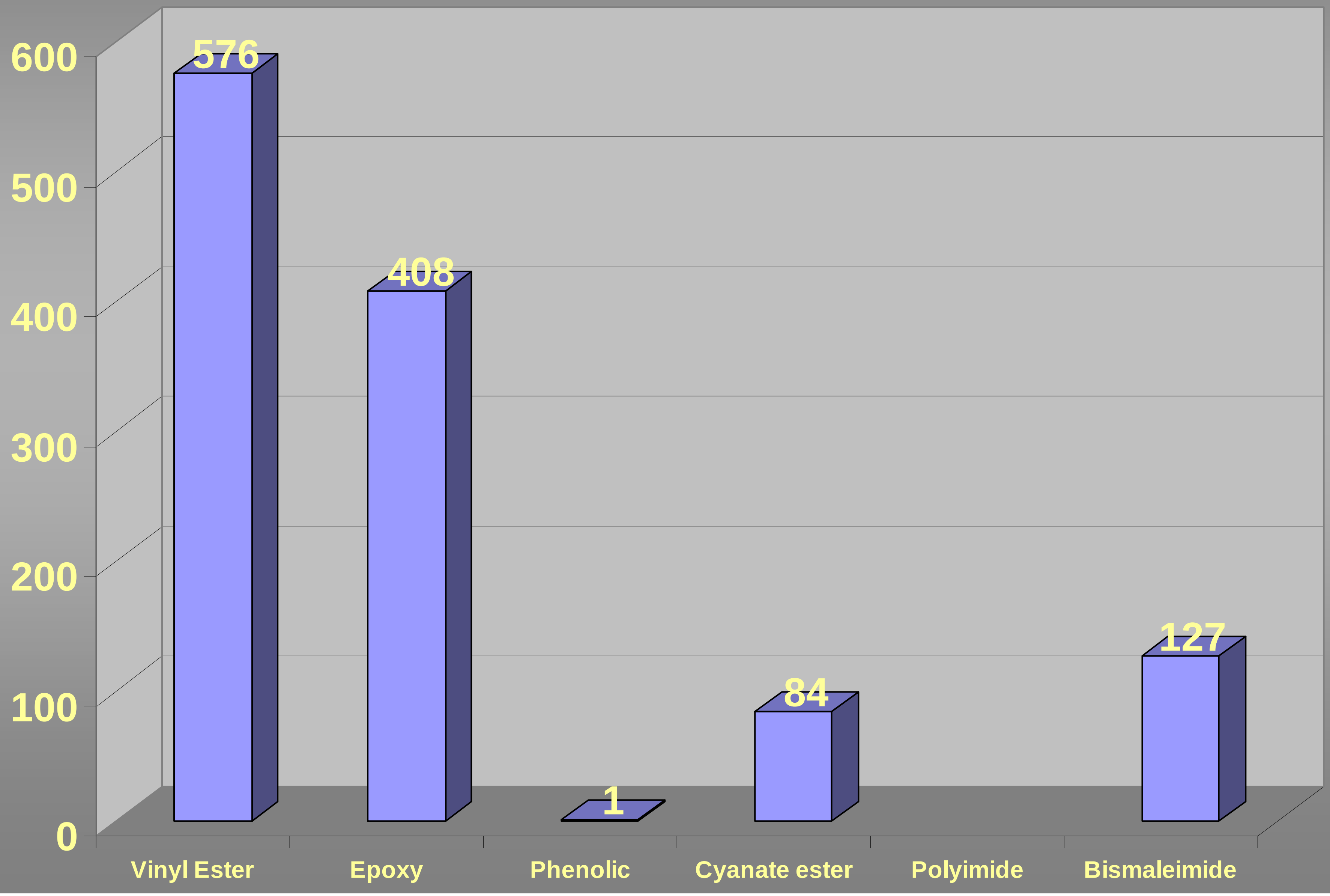
High-Temperature Resin Systems Flame Spread Index (ASTM E-162)



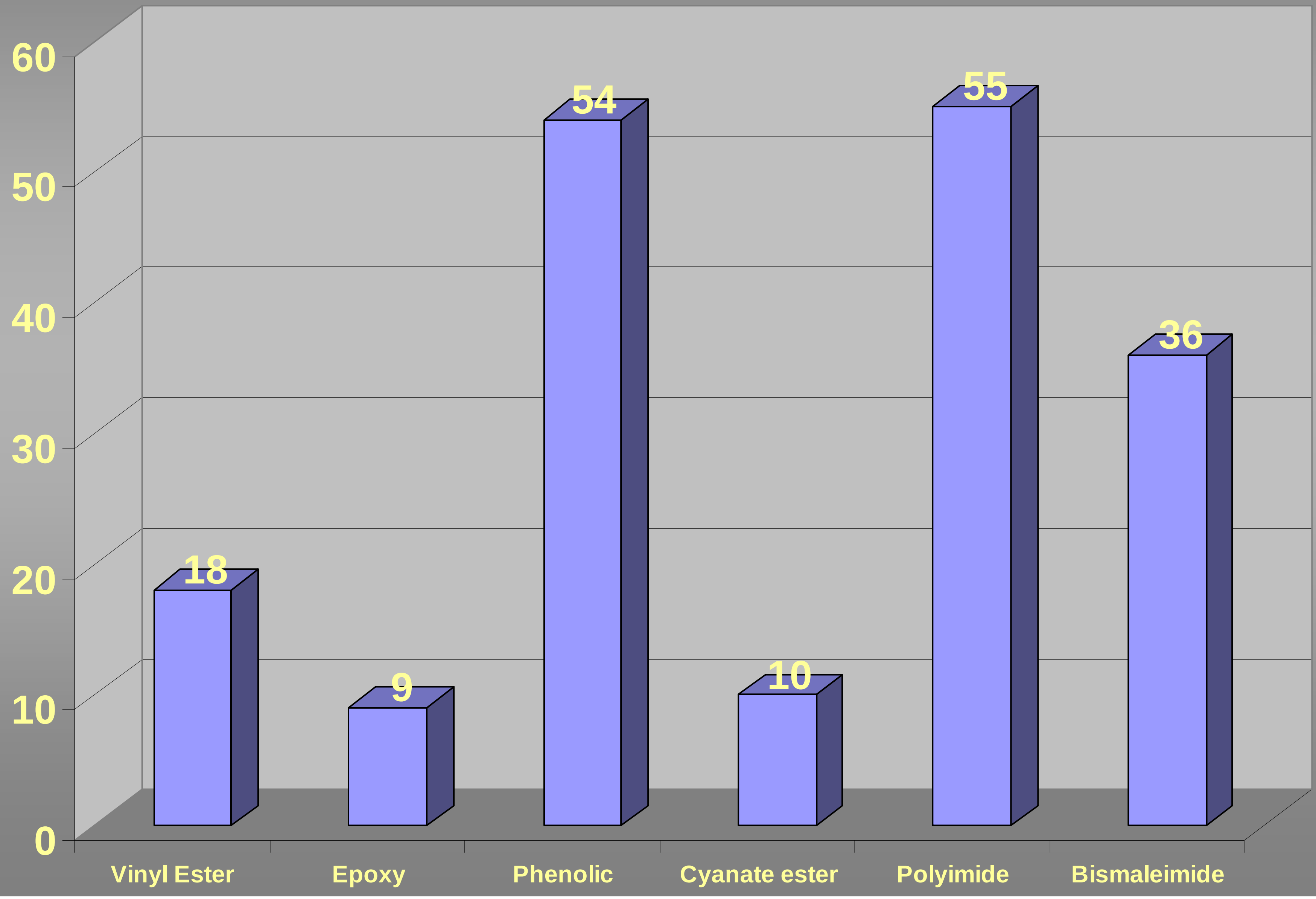
High-Temperature Resin Systems Average Smoke, Ds 300 sec, ppm



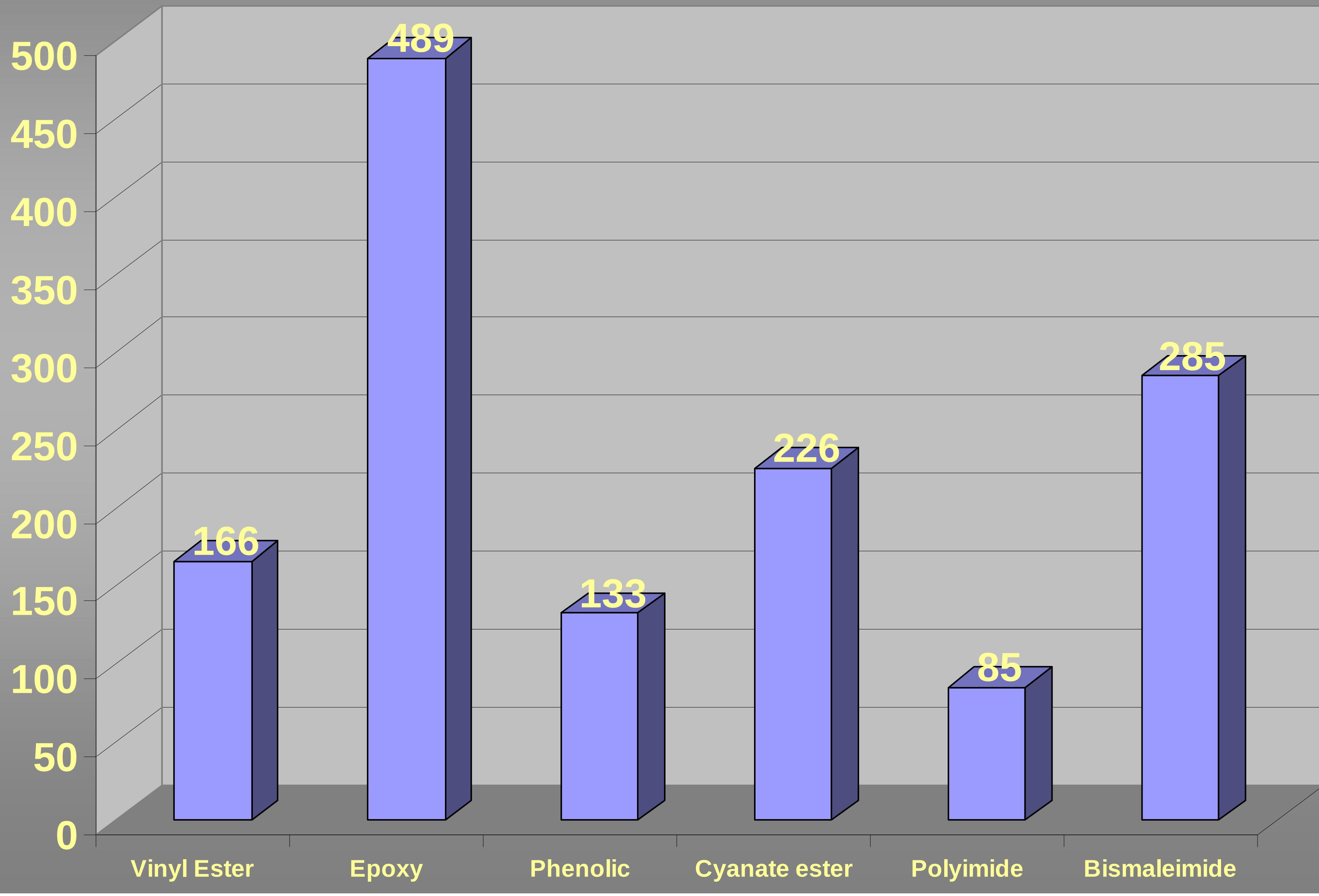
High-Temperature Resin Systems
Maximum Smoke, Dmax, ppm



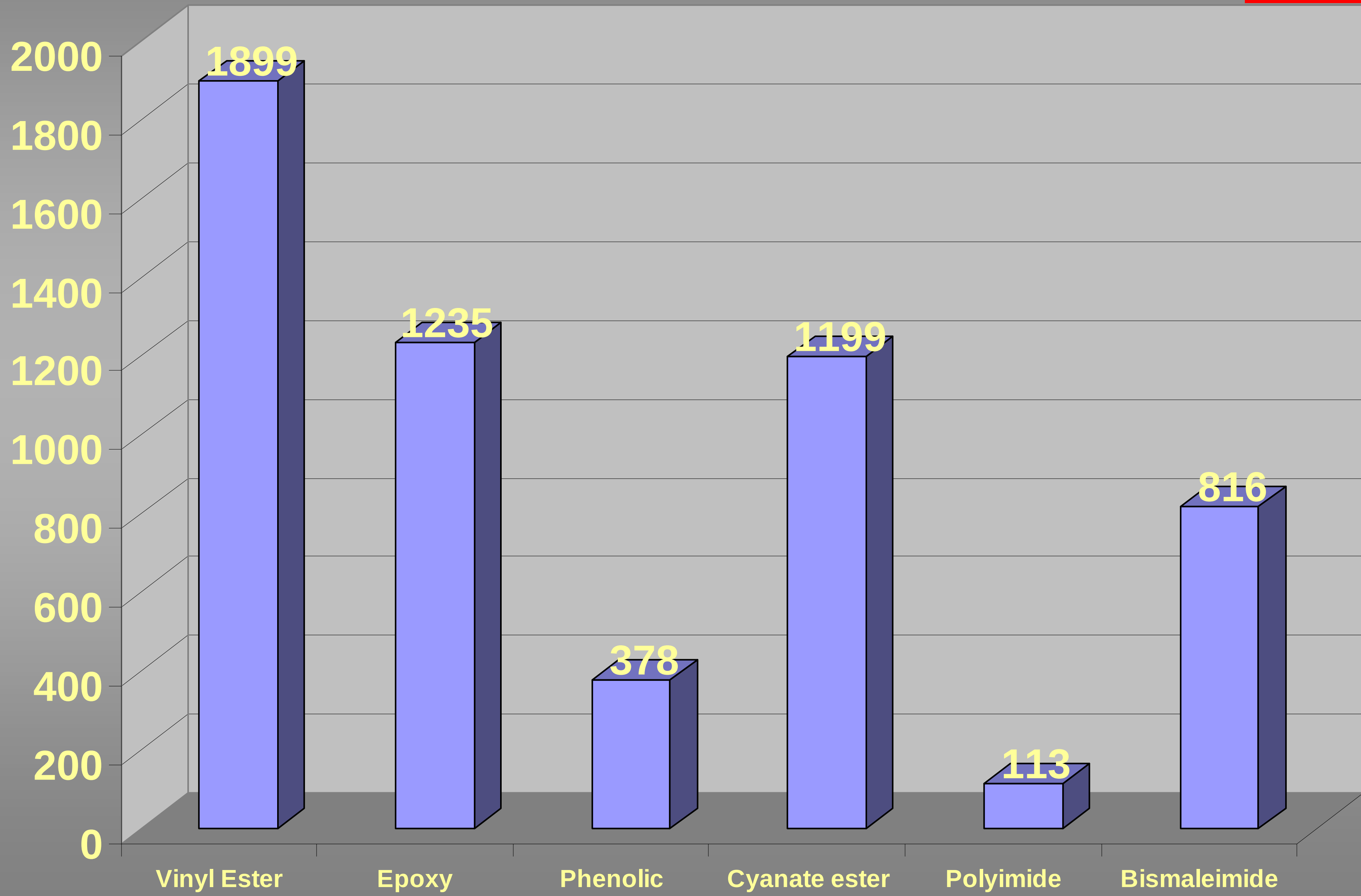
High-Temperature Resin Systems
Time to Ignition (secs)



High-Temperature Resin Systems
Peak Heat Release (kW/sq-mtr)



High-Temperature Resin Systems
Smoke Extinction Area (sq-mtr/kg)



Fire Test Methods
Fire Performance Characteristics

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

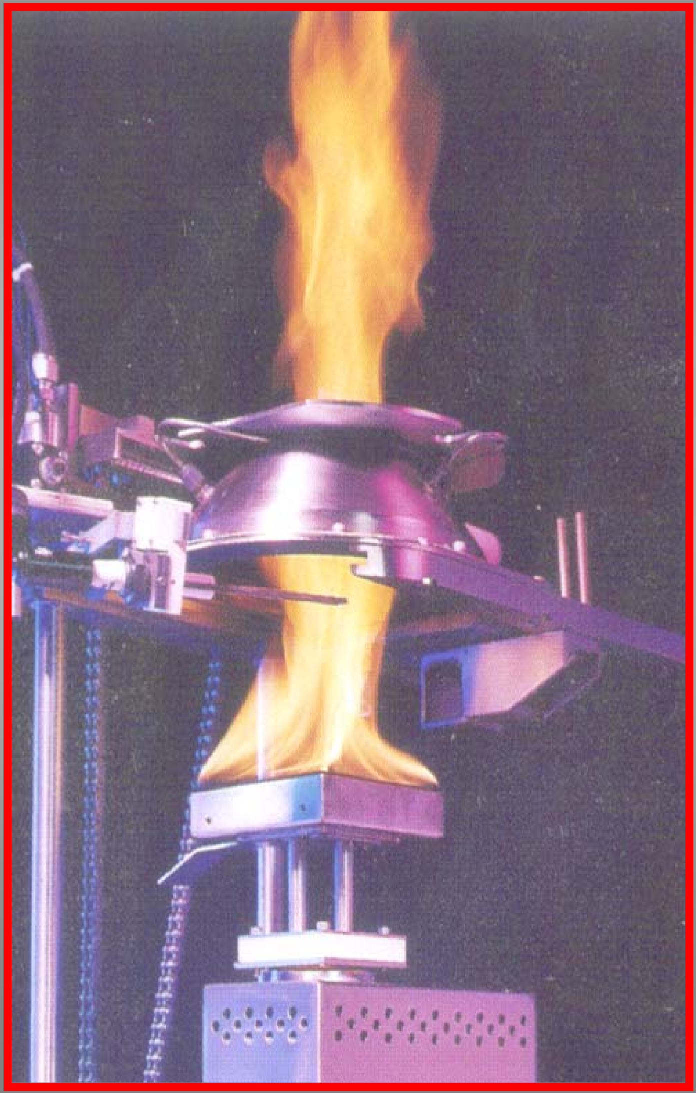
- **Time-to-Ignition**
- **Rate of Heat Release**
- **Smoke Production**
- **Flame Spread**
- **Burn Through Resistance**

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

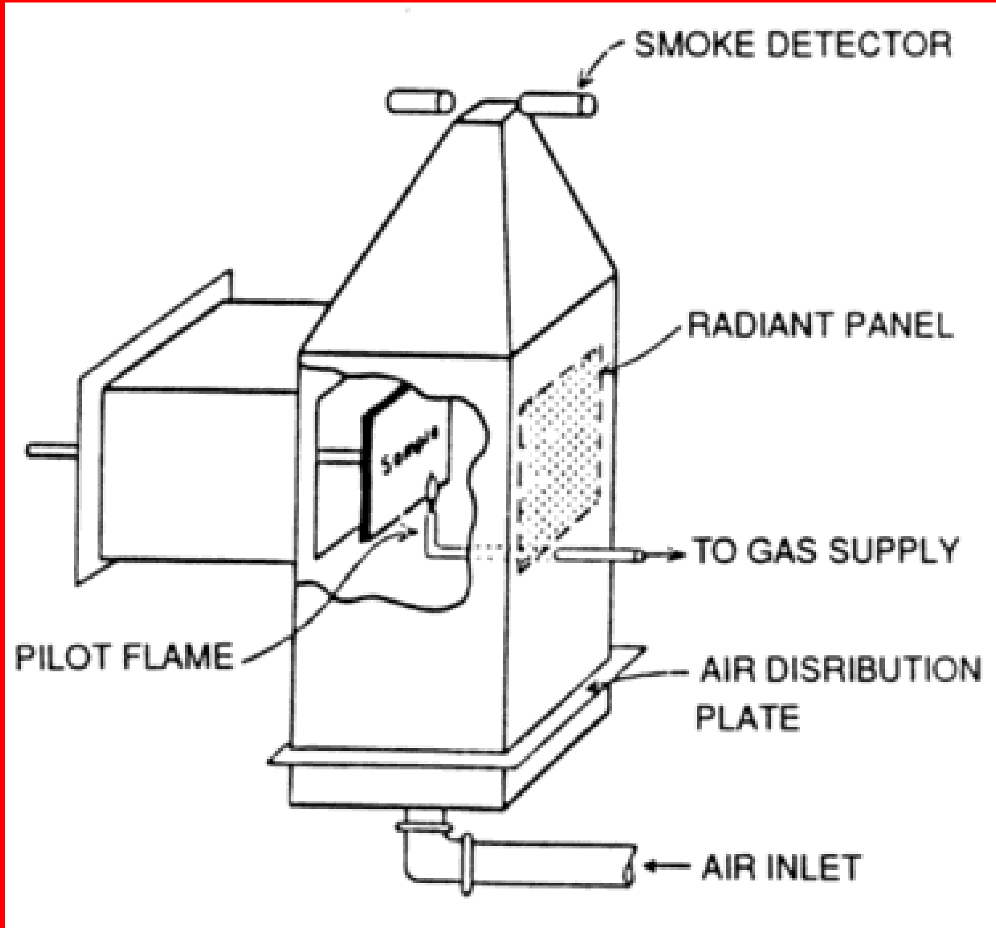


Cone Calorimeter

Fire Test Methods
Cone Calorimeter Requirements for U.S. Navy Submarines

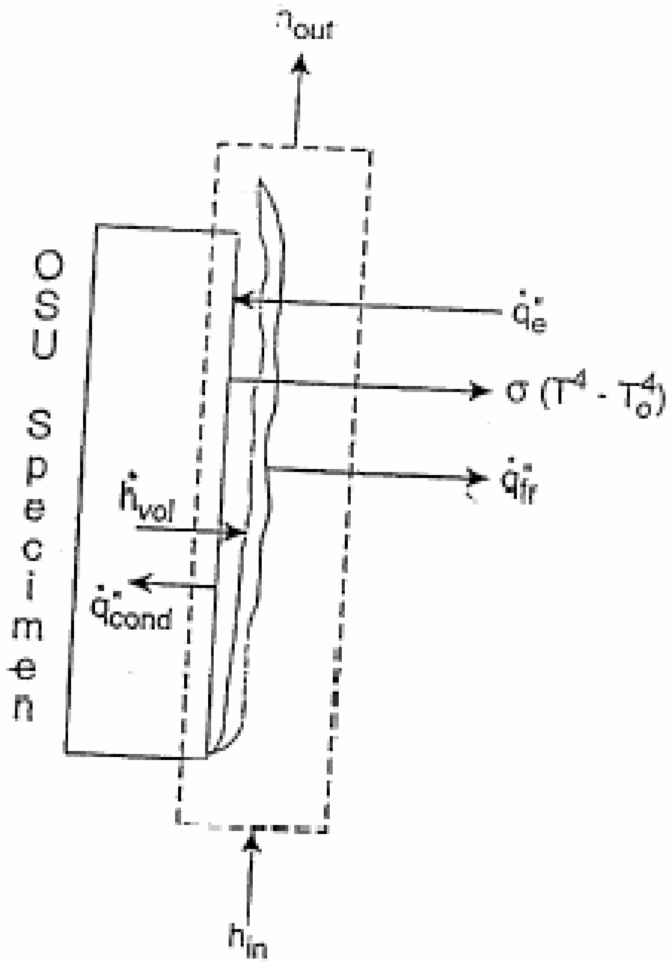
Ignitability (seconds)	The ease of ignition, as measured by the time to ignite in seconds, at a specified heat flux with a pilot flame.		**Minimum**
		100 kW/m^2 Flux	60
		75 kW/m^2 Flux	90
		50 kW/m^2 Flux	150
		25 kW/m^2 Flux	300
Heat Release Rate (kW/m^2)	Heat produced by a material, expressed per unit of exposed area, per unit of time.		**Maximum**
		100 kW/m^2 Flux	
		Peak	150
		Average 300 secs	120
		75 kW/m^2 Flux	
		Peak	100
		Average 300 secs	100
		50 kW/m^2 Flux	
		Peak	65
		Average 300 secs	50
		25 kW/m^2 Flux	
		Peak	50
		Average 300 secs	50

Fire Test Methods
OSU Calorimeter



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.

Fire Test Methods
OSU Calorimeter



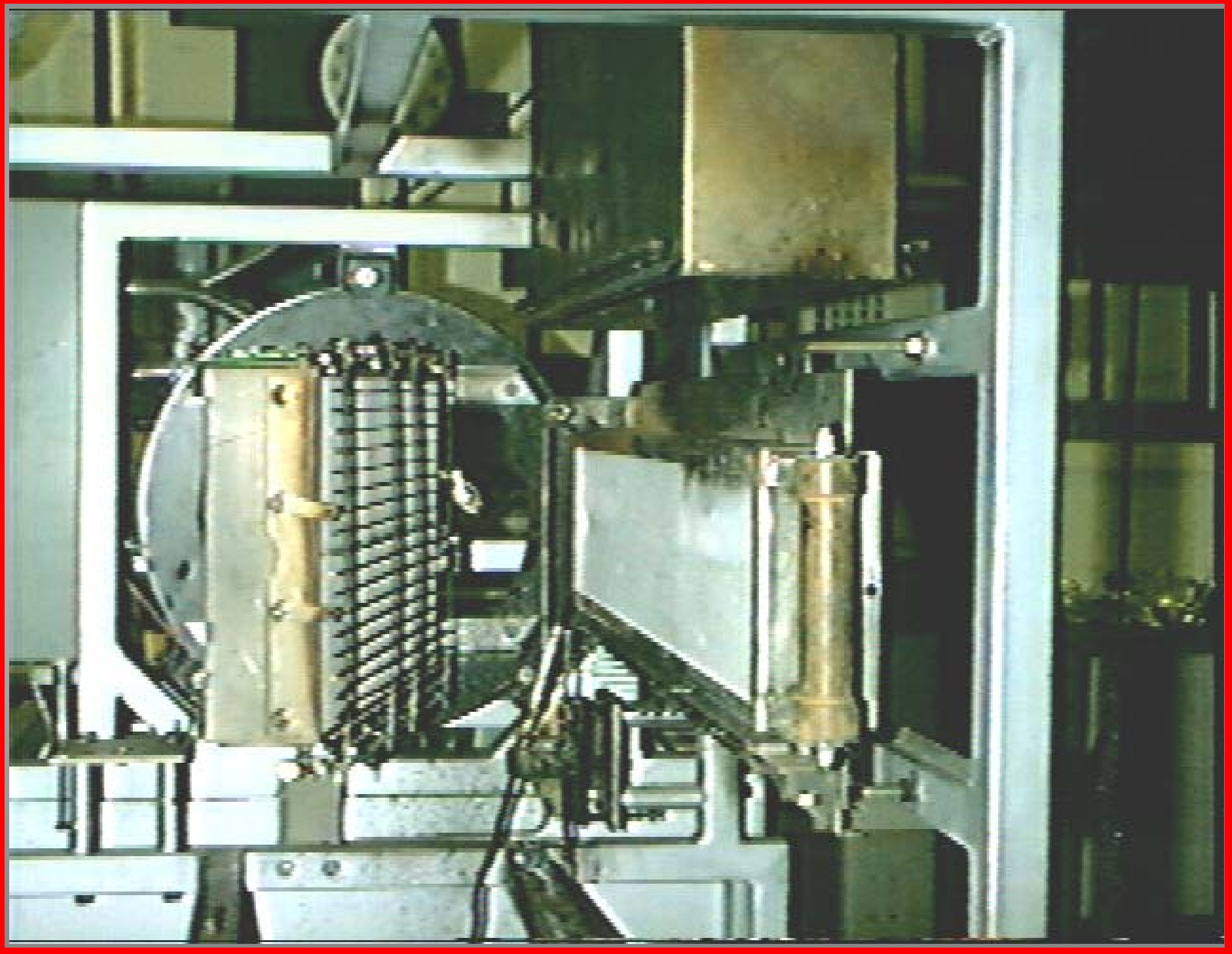
In the OSU test, the specimen's exposure is determined by a radiant heat source. The changes in the temperature and optical density of the gas leaving the chamber is monitored. At left is the heat flux model associated with the test.

Fire Test Methods
Lateral Ignition & Flame Transport (LIFT)

ASTM E 1317-90, Standard Test Method for Flammability of Marine Finishes

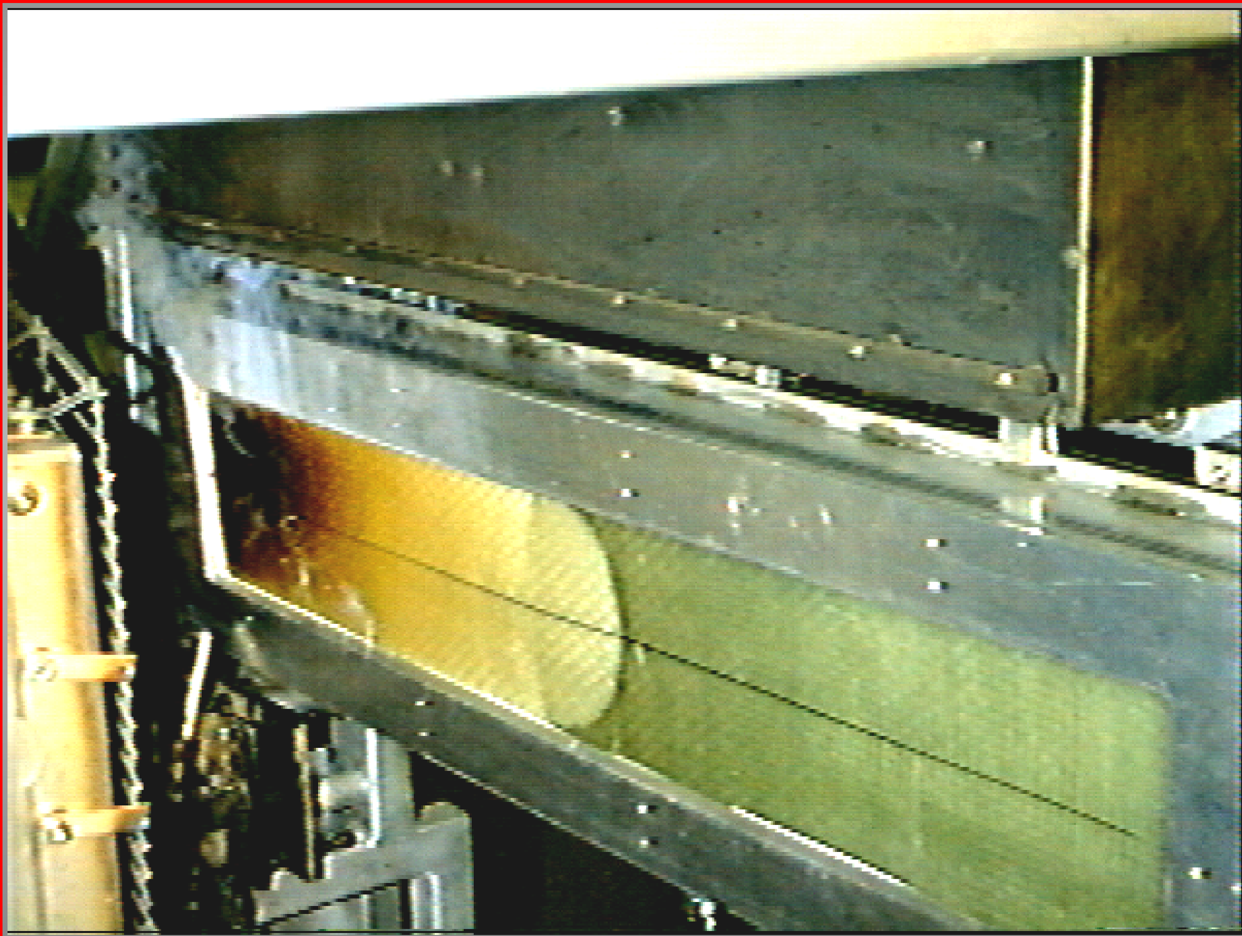
A description and background contained in the test standard provide insight as to why this test may be appropriate for intermediate-scale evaluation of shipboard composite material systems. The test method describes a procedure for measuring fire properties associated with flammable surfaces finishes 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)

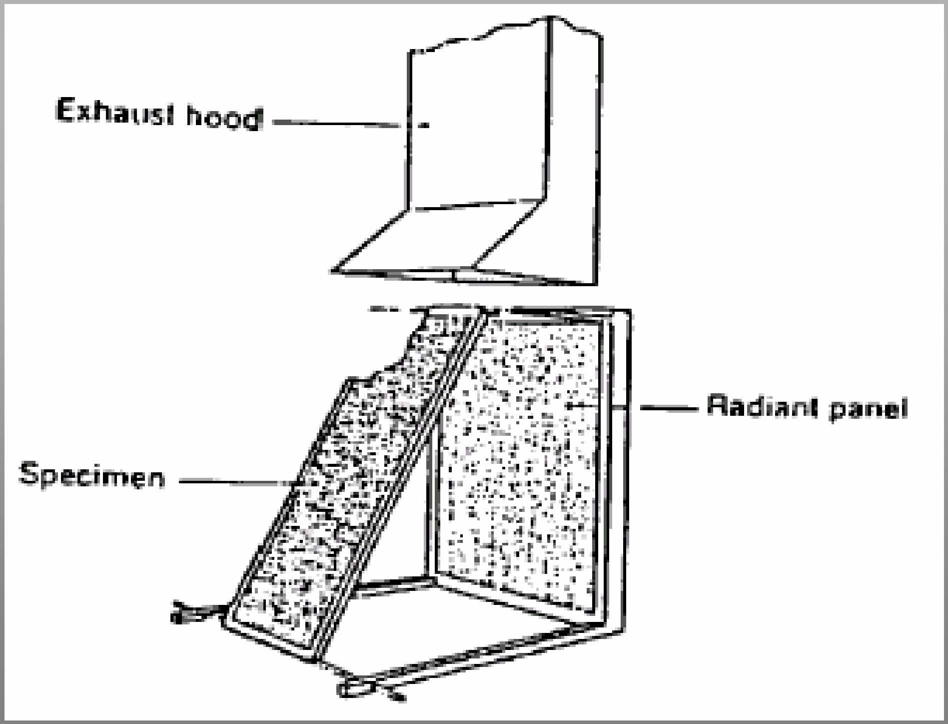


Flame Front Measurement During LIFT Test

Fire Test Methods
Flame Spread Testing

Radiant Panel - ASTM E 162

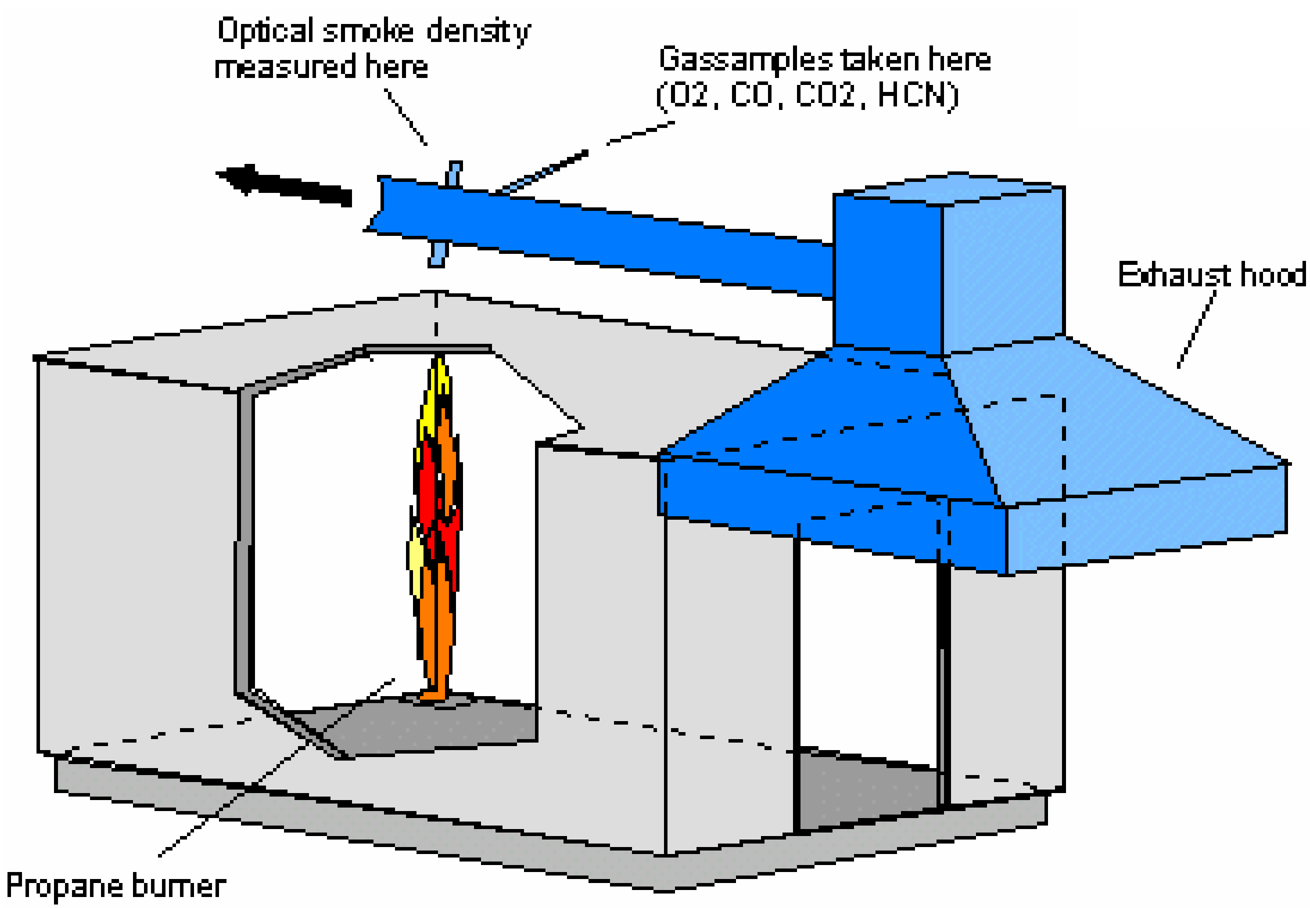
This test procedure is intended to quantify the surface flammability of a material as a function of flame spread and heat contribution. The ability of a panel to stop the spread of fire and limit heat generated by the material is measured. A 6" x 18" specimen is exposed to heat from a 12" x 18" radiant heater. The specimen is held at a 45° angle, as shown at right.



Fire Test Methods
Flame Spread Testing

Sorathia (1990)	Graphite/Phenolic	**6**
	Graphite/BMI	**12**
	Graphite/Epoxy	**20**
	Glass/Vinylester with Phenolic Skin	**19**
	Glass/Vinylester with Intumescent Coating	38
	Glass/Vinylester	156
Silvergleit (1977)	Glass/Polyester	31 - 39
	Glass/Fire Retardant Polyester	**5** - 22
	Glass/Epoxy	**1** - 45
	Graphite/Epoxy	32
	Graphite/Fire Retardant Epoxy	**9**
	Graphite/Polyimide	**1** - 59
Rollhauser (1991)	Fire Tests of Joiner Bulkhead Panels	
	Nomex® Honeycomb	**19** - 23
	FMI (GRP/Syntactic core)	**2 - 3**
	Large Scale Composite Module Fire Testing	
	All GRP Module	238
	Phenolic-Clad GRP	36

Fire Test Methods
ISO 9705 Room Corner Test

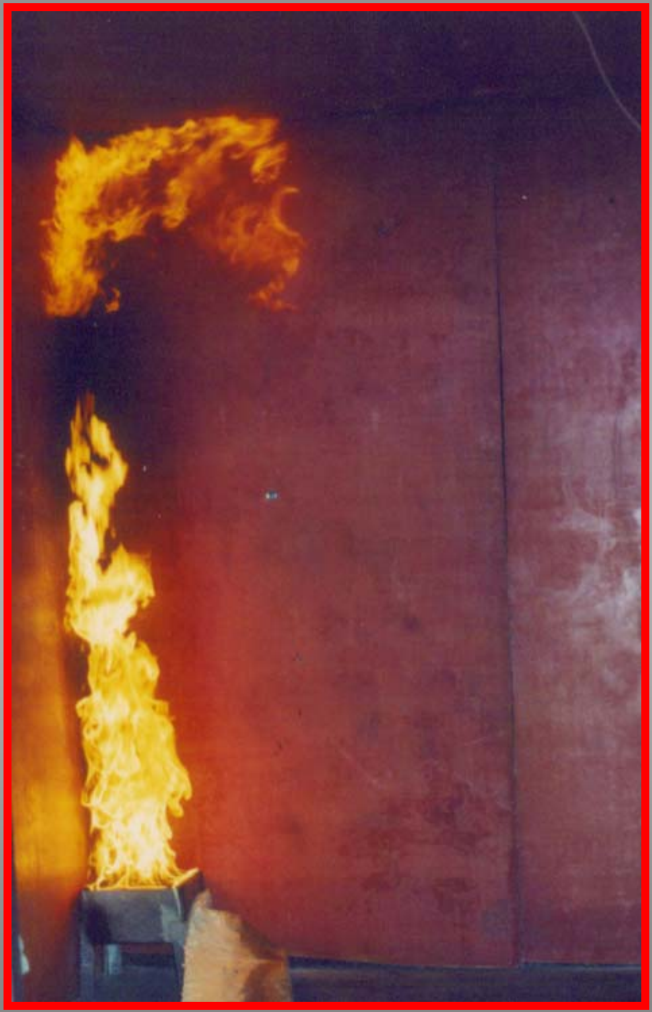


Schematic of ISO 9705 Room Corner Test to Determine Flame Spread and Smoke Generation

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 El19 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.

Fire Test Methods
Burn Through Resistance

Test Arrangement for Burn Through Resistance of 10 x 10 - foot Panel

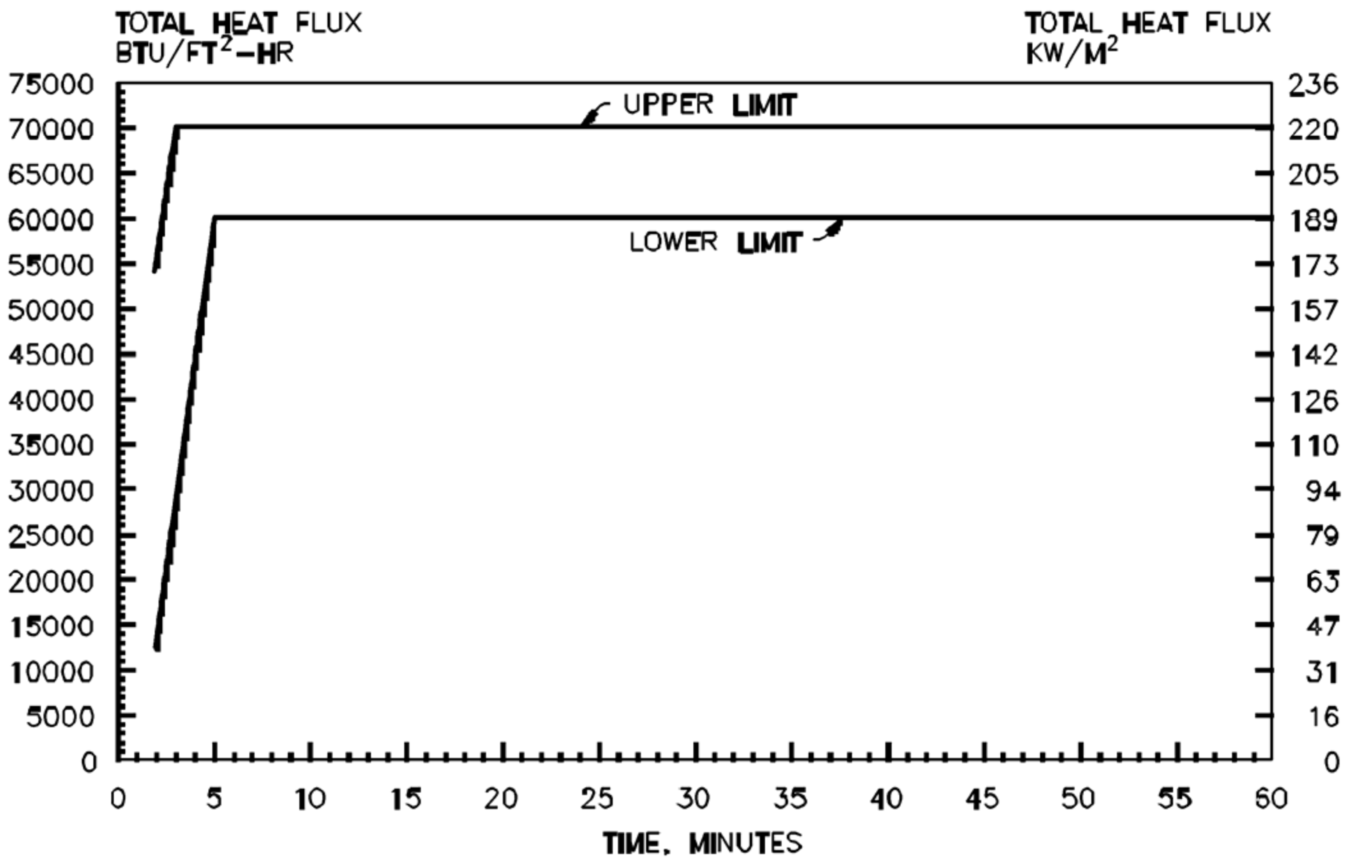
Fire Test Methods
Full-Scale UL 1709

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.

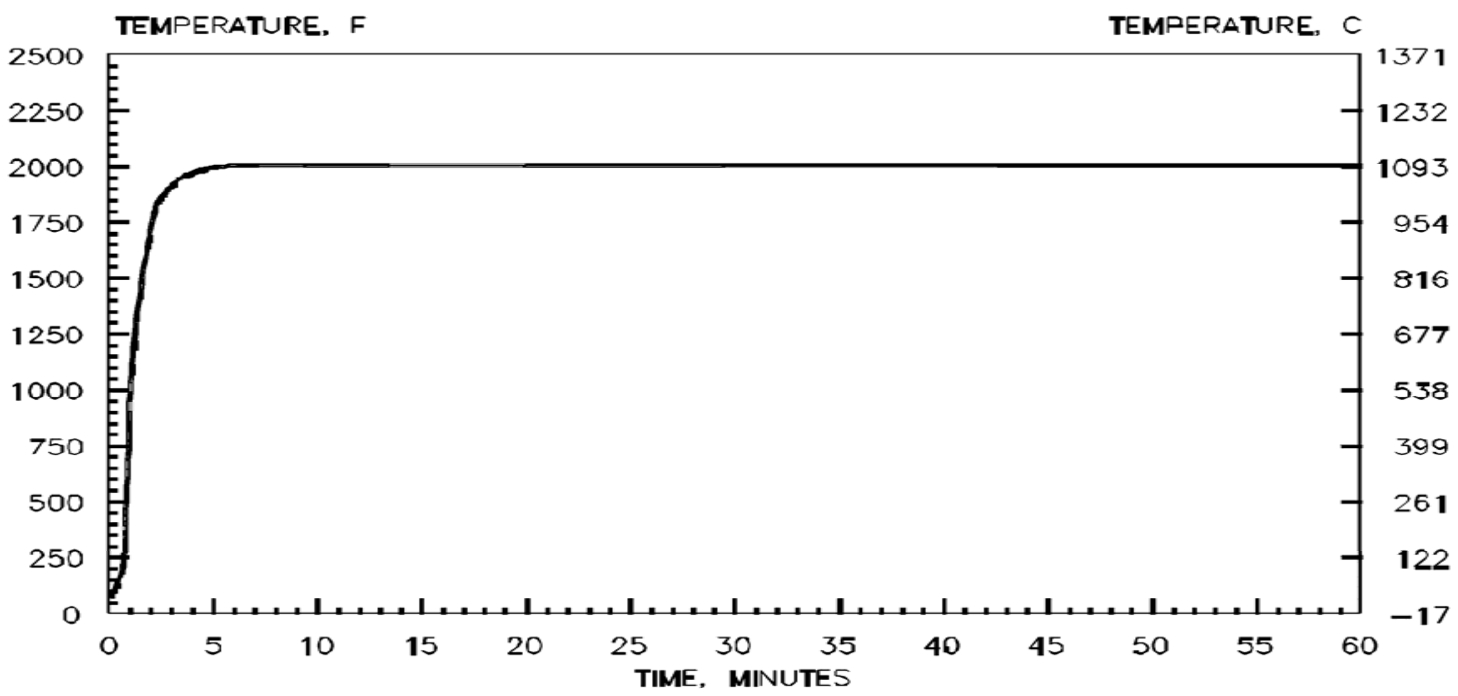
The fire environment within the furnace is to develop a total heat flux of 65,000±5000 Btu/ft-hour (204±16 kW/m) and an average temperature of 2000±200°F (1093±111°C) within 5 minutes from the start of the test.

Fire Test Methods
Full-Scale UL 1709



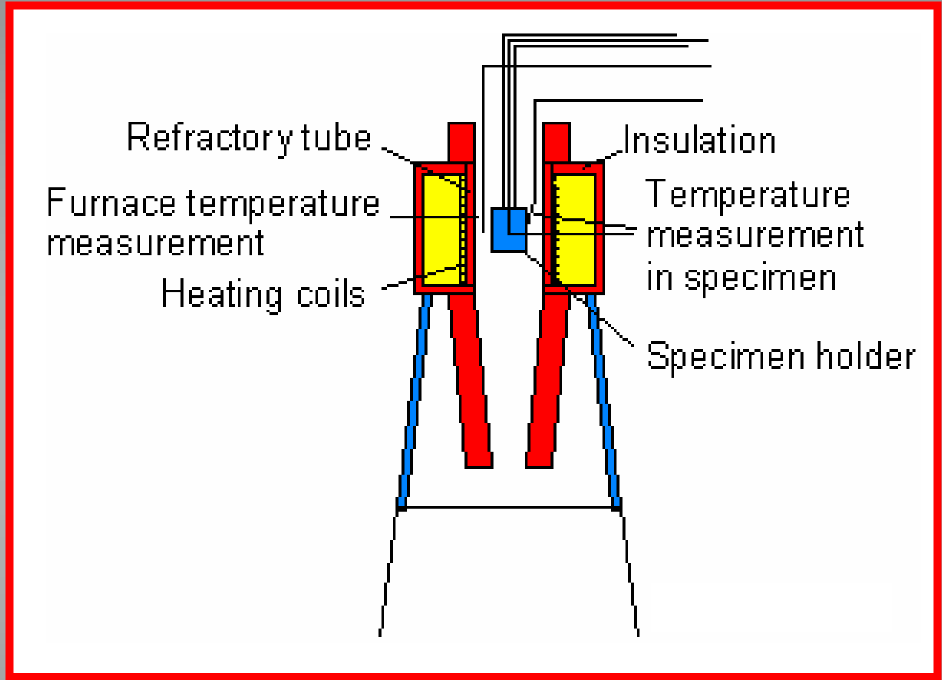
Heat Flux for UL 1709 Test

Fire Test Methods
Full-Scale UL 1709



Time/Temperature Curve for UL 1709 Test

Fire Test Methods
Large Passenger Ships
Noncombustibility Standard



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.

Fire Test Methods
NASA-STD-6001

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

Fire Test Methods
NASA-STD-6001

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)

Fire Test Methods
NASA-STD-6001

These requirements are implemented through various NASA program and Materials and Processes (M&P) requirements documents:

– JSC SE-R-0006/MSFC-STD-506, *General M&P Standard (Shuttle)*

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

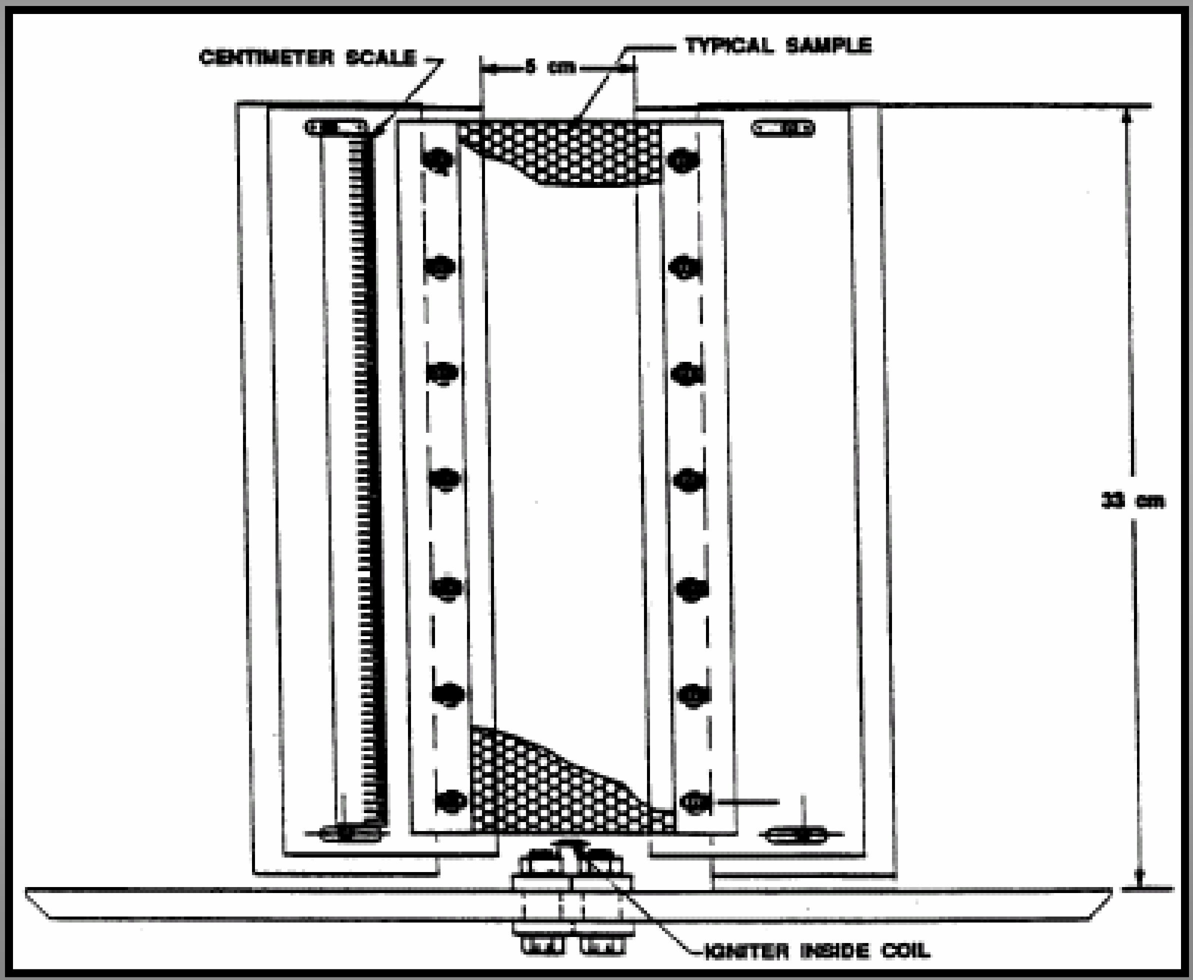
– NSTS 1700.7, *Safety Policy & Requirements for Payloads Using the Space Transportation System* and (same requirements in the) *ISS Addendum*

Fire Test Methods
NASA-STD-6001
Upward Flame Probagation, Test 1

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.

Fire Test Methods
NASA-STD-6001
Upward Flame Probagation, Test 1



Typical Sample Holder for Test 1

Fire Test Methods
NASA-STD-6001
Cone Calorimeter, Test 2

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 ft^2 (0.37 m^2) 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/m^2):

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.

Fire Test Methods
NASA-STD-6001
Offgassed Products, Test 7

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 Kenetics Apparatus (VODKATM) is a turn-key test chamber for performing standardized ASTM E1559 testing used by QCM Research, Lake Forest, CA

Fire Test Methods
Offgassed Products, ASTM E1559

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.

Fire Test Methods
Offgassed Products, ASTM E1559

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.

Fire Test Methods
Offgassed Products, ASTM E1559

Description	%TML	%CVCM	%WVR
UL-94 V0 Polyimide Glass	0.52	0.00	0.21
UL-94V1 Polyimide Glass	0.42	0.01	0.26
Polyimide Glass	0.78	0.01	0.27
Polyimide Thermount®	1.91	0.00	0.93
Epoxy Thermount®	1.32	0.00	0.58
No-Flow Polyimide	0.77	0.00	0.39
No-Flow Epoxy	0.62	0.01	0.15
Low Loss Laminate	0.17	0.01	0.02
UL-94 V0 Low Loss	0.24	0.00	0.07
PTFE/Ceramic Laminate	0.00	0.00	0.00

Arlon (Rancho Cucamonga, CA) products that have undergone NASA/ASTM E595-93 testing

Fire Test Methods
Offgassed Products, Marine Laminates

Toxic Constituent	C_f (ppm for human fatality after 30 min exposure)*	Maximum Allowable Concentration (7-day ppm - NASA)**	MIL-STD 2031 (SH) Max Allowable @ 25 kW/m^2	Cone Calorimeter Tests of Glass/Vinyl Ester Panels***	Detector Tube
Carbon Dioxide CO_2	100,000		40,000	15,000	MSA 85976
Carbon Monoxide CO	4,000	25	200	295	Dräger 10/b
Hydrogen Sulphide H_2S	750	2			Dräger 100/a
Ammonia NH_3	750	17			Dräger 5/a
Formaldehyde HCHO	500	0.1			MSA 93963
Hydrogen Chloride HCl	500		100	1	MSA 91636

Fire Test Methods
Offgassed Products, Marine Laminates

Potential Toxic Constituent	Occupational Safety and Health Administration		Maximum Allowable Concentration (7-day ppm - NASA)**	Estimated Range of Concentrations***		
	Time Weighted Average (TWA, ppm)*	Short Term Exposure Limit (STEL, ppm)		E-Glass Vinyl Ester, ppm	E-Glass Polyester, ppm	E-Glass Epoxy, ppm
Styrene	50	100	10	300 - 900	60	
Toulene	0.005	0.02	20			1 - 10
Benzene			0.1			
Vinyl Chloride			0.1			

* "Safe Handling of Advanced Composite Materials Components: Health Information," Society of Advanced Composite Materials Association, April 1989.

** "Flammability, Odor and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion," NASA Office of Space Transportation Systems, NHB 8060.1B, September, 1981.

*** "Effects of Composite Materials in Submarines," prepared for NAVSEA Code PMS 350TB by Structural Composites, Inc., contract N00024-90-C-3801, October, 1990.

Fire Test Methods
Simulated Panel Assembly, Test 10

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.

Fire Test Methods
Simulated Panel Assembly, Test 10

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."

Fire Test Methods
Mechanical Impact in LOX/GOX, Test 13

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		**[SELF-EXTINGUISHING]**	
Section a1: Interior compartments occupied by crew and passengers:			
	Burn Length	**Flame Time After Removal**	**Drippings flame extinguish**
i) Ceilings, walls, galley, floor.	Vertical 6 inches	15 seconds	3 seconds
ii) Floor cover, textiles, seat cushions	Vertical 8 inches	15 seconds	5 seconds
iii) ducts for film	Vertical 8 inches	15 seconds	5 seconds
iv) Clear Plastic Window	Horizontal 2.5"/min		
v) others	Horizontal 4.0"/min		

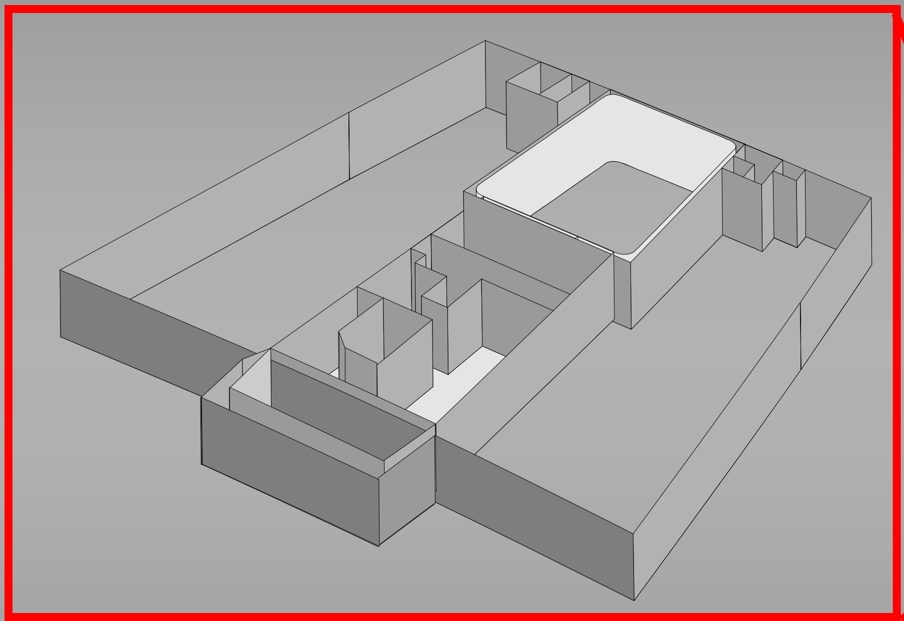
Fire Test Methods
FAR 25.853 For Aircraft

Section a2 : 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	45 Degree Angle Test		
	Flame penetration None	**Flame Time After Removal** 15 seconds	**Glow Time** 10 seconds
2iii) Cargo, baggage Compartment Class B, C, D, E of 25.857	Vertical 8 inches	15 seconds	5 seconds
	45 Degree Angle test		
	Flame penetration No pentration	**Flame Time After Removal** 15 seconds	**Glow time** 10 seconds
2iv) Insulated blankets, covers	Vertical 8 inches	15 seconds	5seconds
Tie-downs: Containers, bins:	Horizontal 4.0"/min		

Fire Test Methods
FAR 25.853 For Aircraft

Part IV of Appendix F:	
Test method to determine the Heat Release Rate From Cabin Materials exposed to Radiant Heat. *1) OSU, ASTME-906 @ 3.5 W/cm² for 6 mins.: Req. 65/65 Kw/m², 2-mins/peak.*	
Part V of Appendix F:	
Test Method to Determine the Smoke Emission Characteristics of Cabin Materials. ASTM F814-83. *Optical Smoke Density (Ds) after 4 minutes. Req. = 200 Max*	

Fire Test Methods
Naval Composites Applications

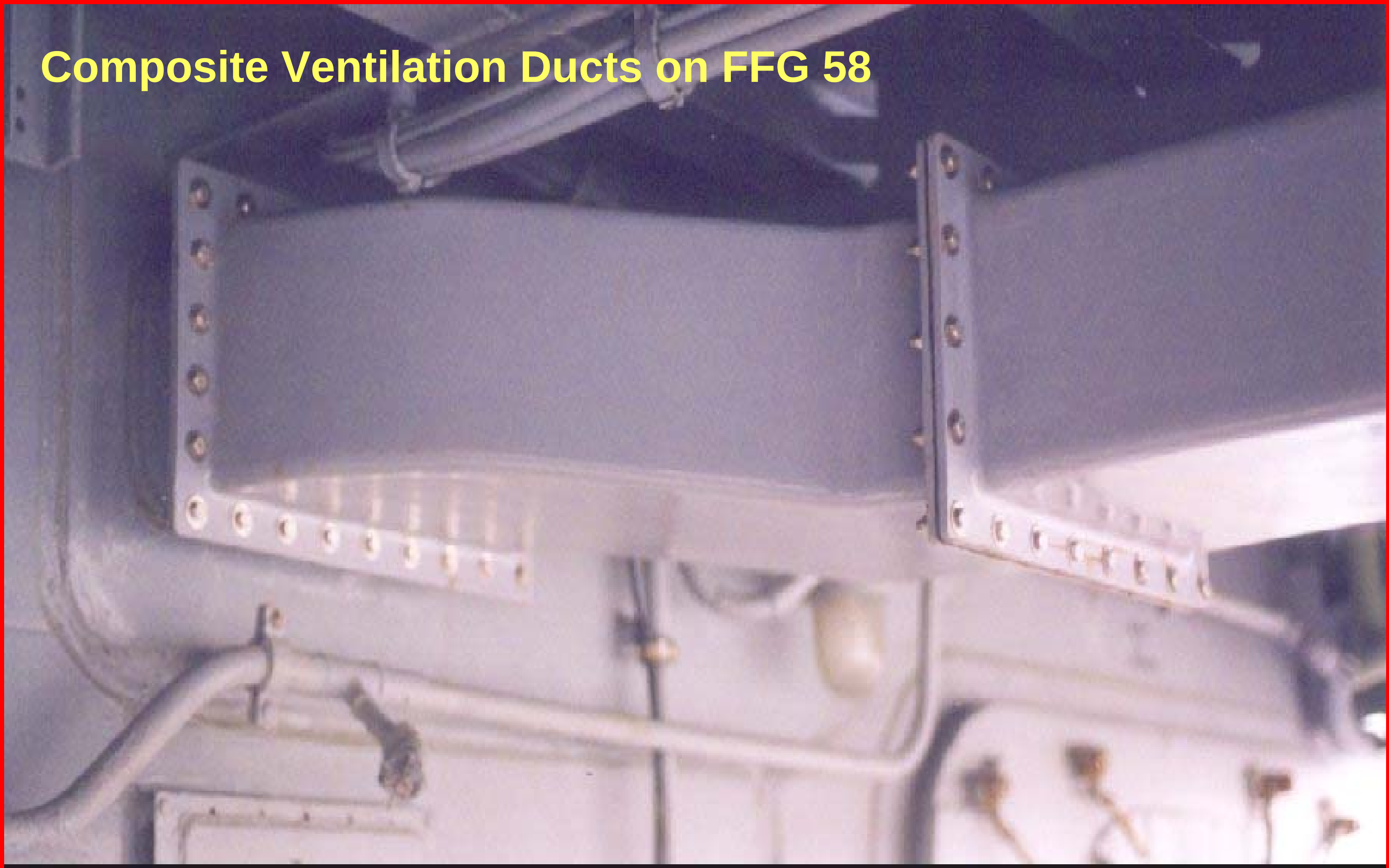


Composite Helicopter Hanger for DDG 51 Flight IIA Destroyer Built at Northrop Grumman Gulfport Facility

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



Fire Test Methods
Naval Composites Applications

Family of Composite Pumps Developed to Reduce Maintenance Cost and Reduce Parts Inventory

Fire Test Methods
Fire Source Data for Naval Combatants

FIRE SOURCE	Surface Ships[1] 1983 - 1987		Submarines[2] 1980 - 1985	
	Number	Percent	Number	Percent
Electrical	285	39%	100	61%
Open Flame/Welding	141	19%	23	14%
Flammable Liquid/Gas	0	0%	13	8%
Radiant Heat	102	14%	8	5%
Matches/Smoking	40	5%	1	1%
Explosion	7	1%	1	1%
Other	89	12%	0	0%
Unknown	68	9%	18	11%
TOTAL:	732	100%	164	100%

[1]Navy Safety Center Database, Report 5102.2
[2]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 250ºF.
- 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* m^2/s;

- The *maximum value of smoke production rate* does not exceed *8.3*m^2/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;

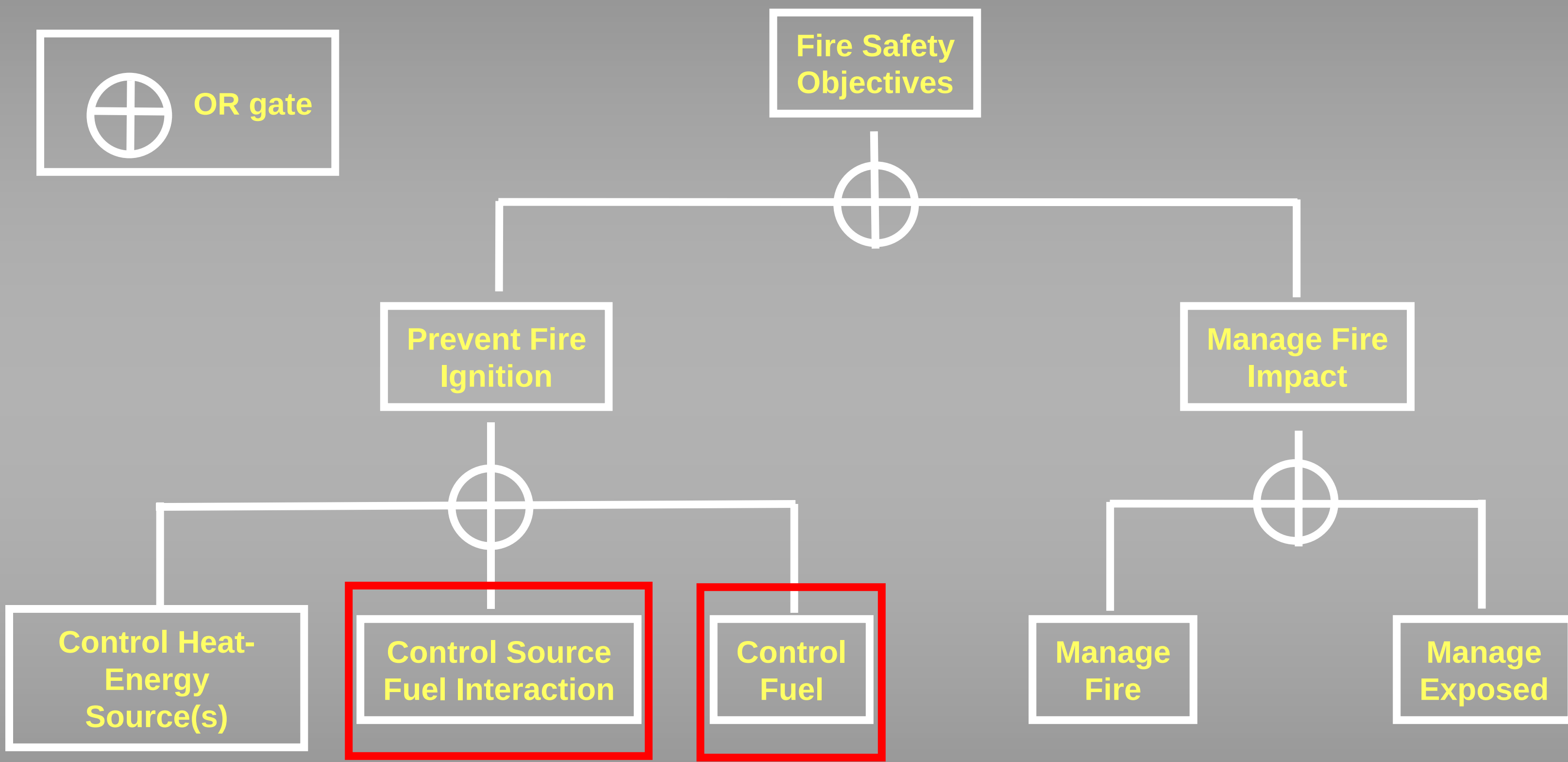
- *No flaming drops or debris* of the test sample may reach the floor of the test room outside the area which is within 1.2 meters from the corner where the ignition source is located

Fire Test Methods
High Speed Craft Code
Fire Resistive Materials

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



Upper Level of Fire Safety Tree

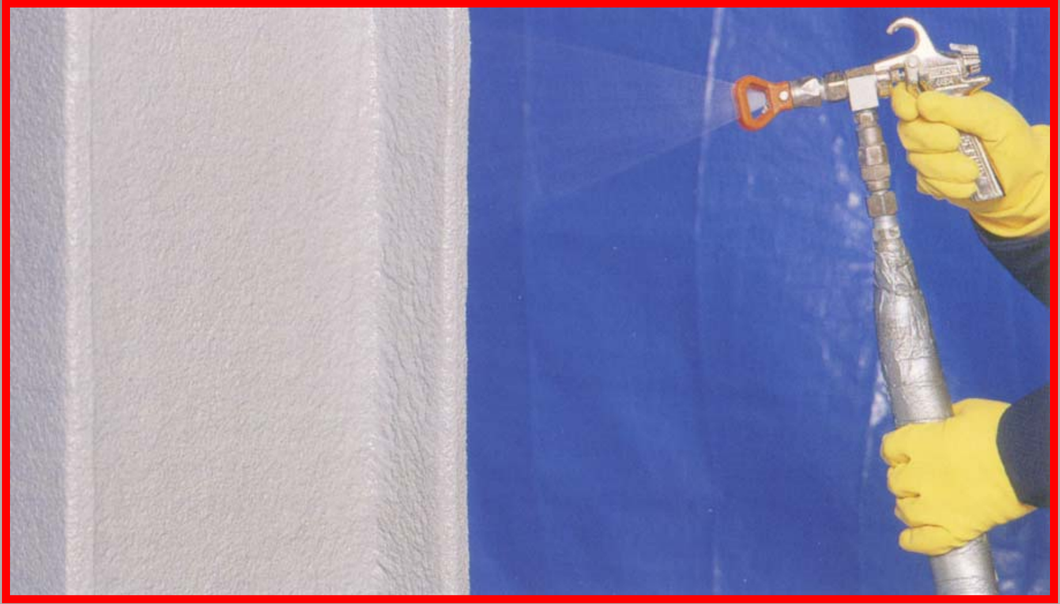
Fire Test Methods
Fire Protection Schemes

- 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

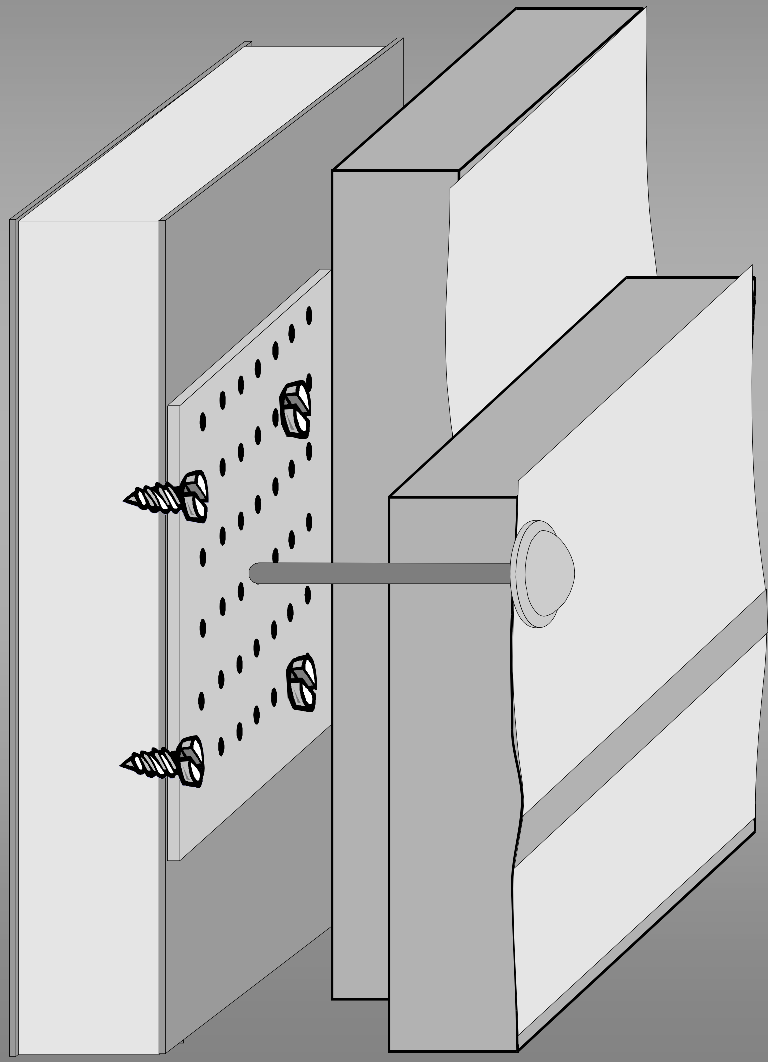
Fire Test Methods
Structural Fire Protection



Spray Insulation Systems

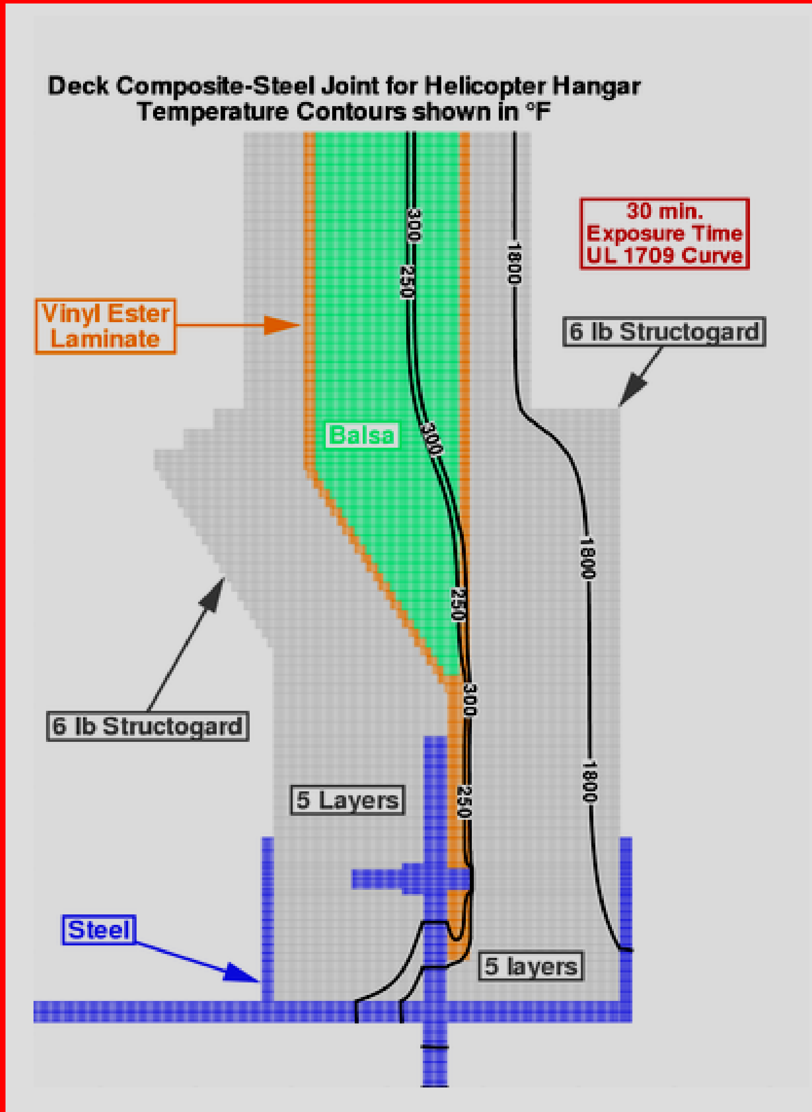
Insulation Blankets

Fire Test Methods
Structural Fire Protection



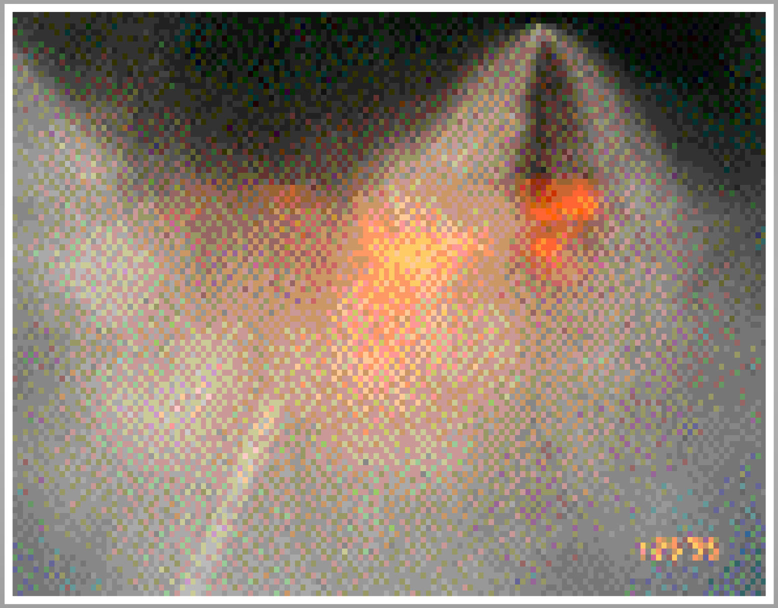
Detail of Insulation Blanket Installation

Fire Test Methods
Fire Hazard Analysis



Fire Hazard Analysis by Hughes Associates Predicts Thermal Profile of Composite Structure During Full-Scale Fire Test

Fire Test Methods
Fire Detection and Suppression



Testing of Water Mist Systems on the ex-*USS SHADWELL*

Future Composite Material Requirements
Space Launch Initiative

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.

Future Composite Material Requirements
Space Launch Initiative

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 aerothermodynamic 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

Future Composite Material Requirements
X-37

NASA's X-37 Vehicle

X-37 Body Flap Test Article

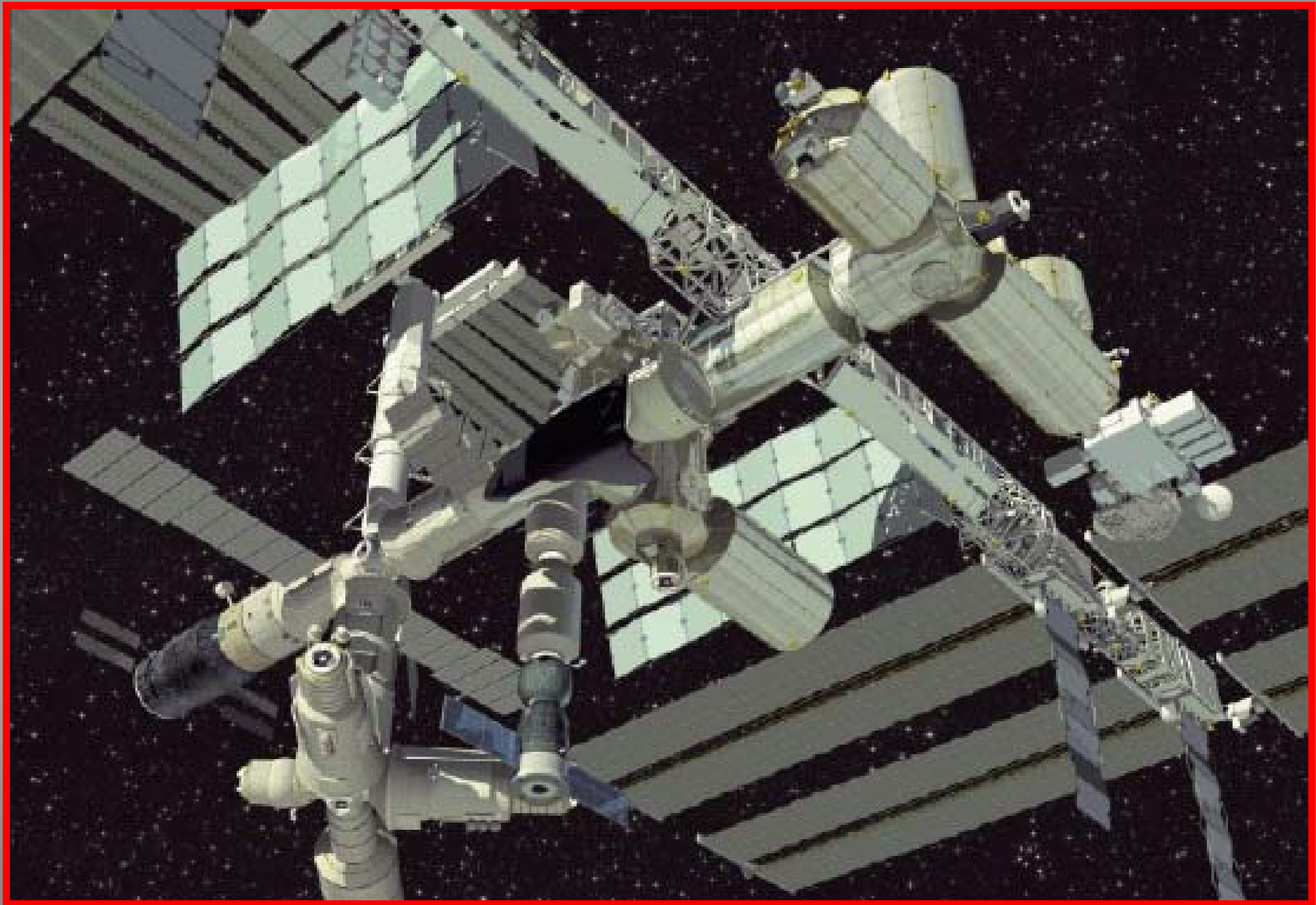
Future Composite Material Requirements
PETI-5 for X-37

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.

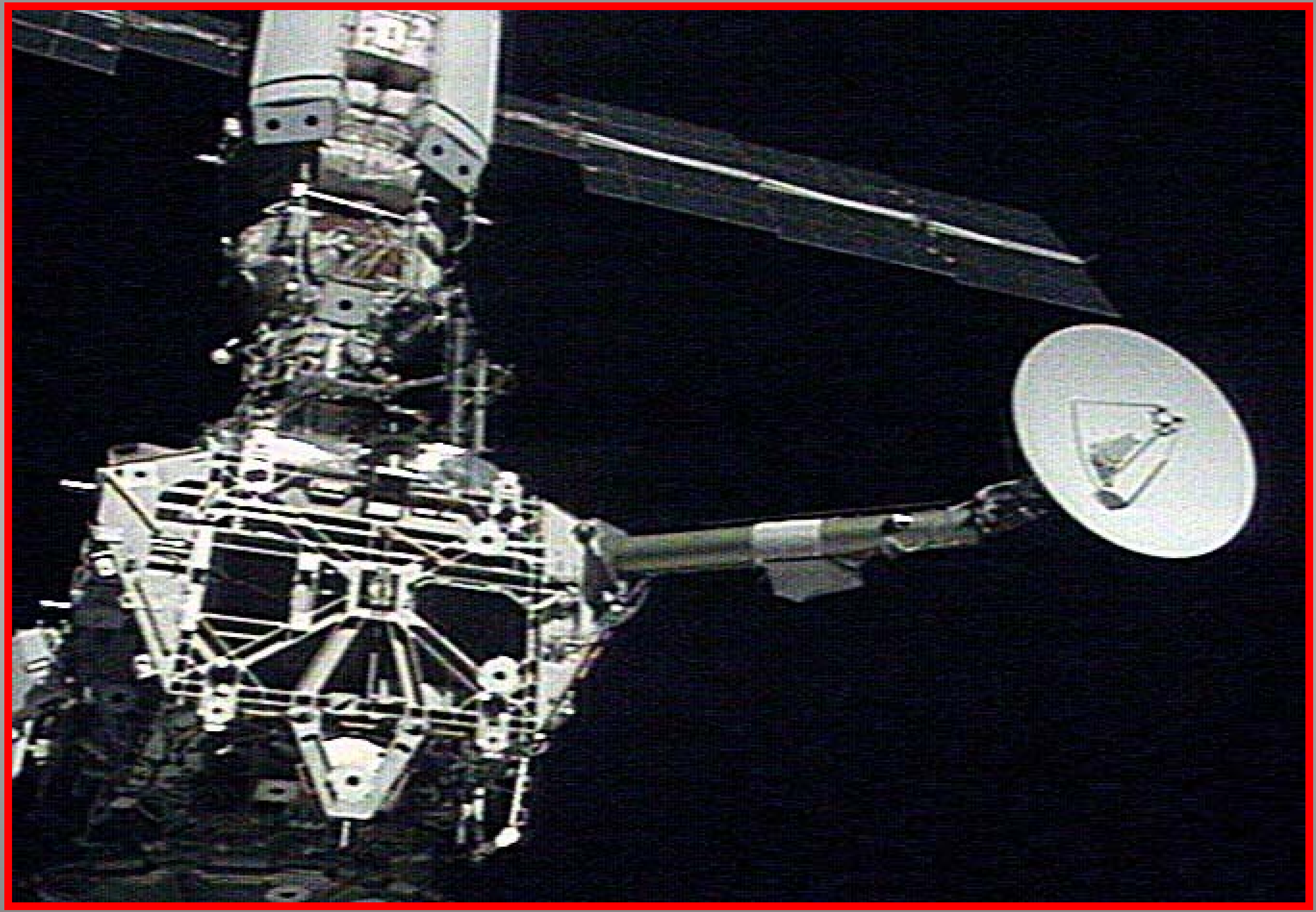
PETI-5 has the potential to be used at operating temperatures (450°F to 500°F) that are higher than current state-of-the-art bismaleimide (BMI) polymer matrix composites.

Future Composite Material Requirements
X-38 Launch

Future Composite Material Requirements
International Space Station

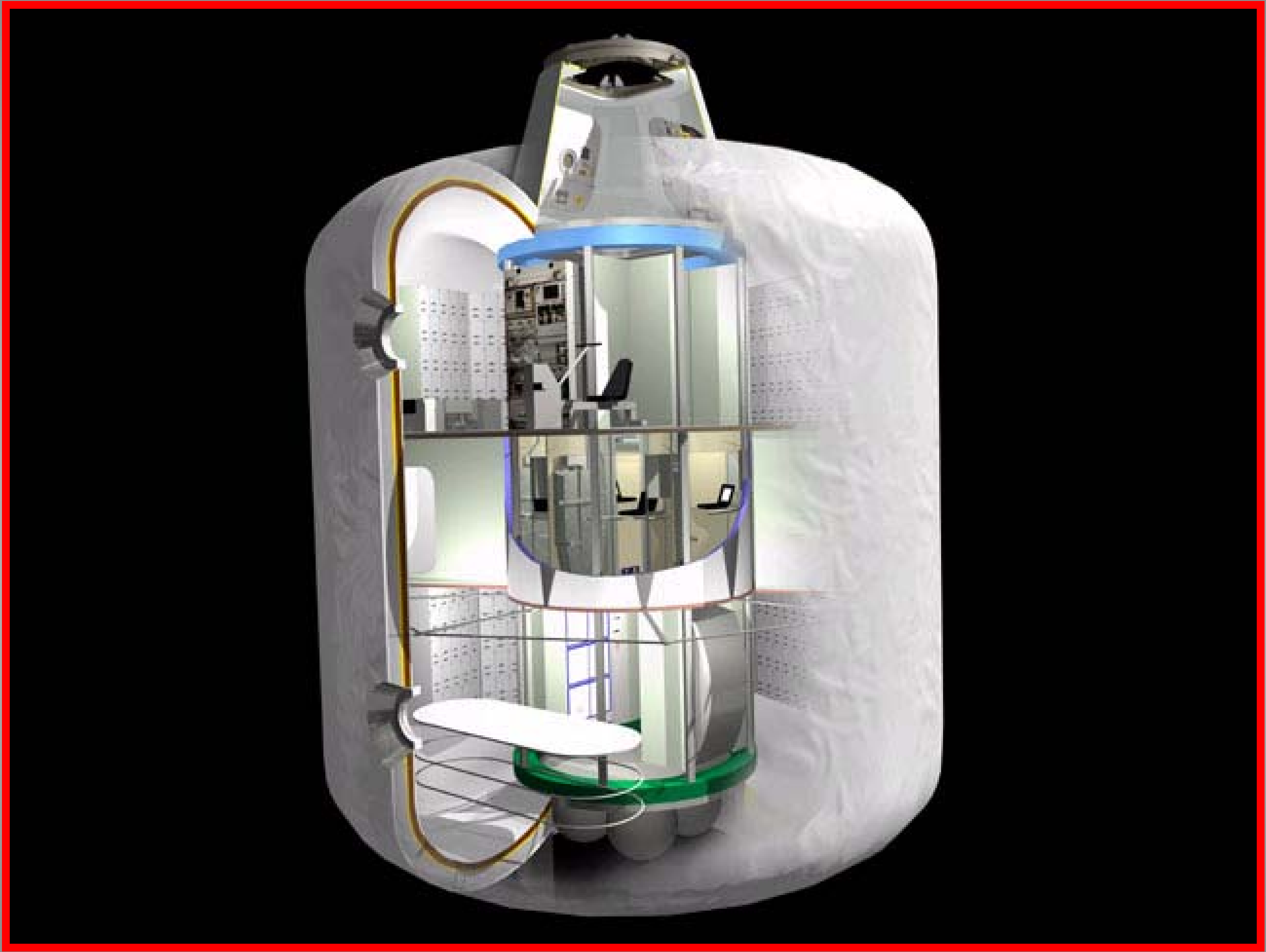


Future Composite Material Requirements International Space Station



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

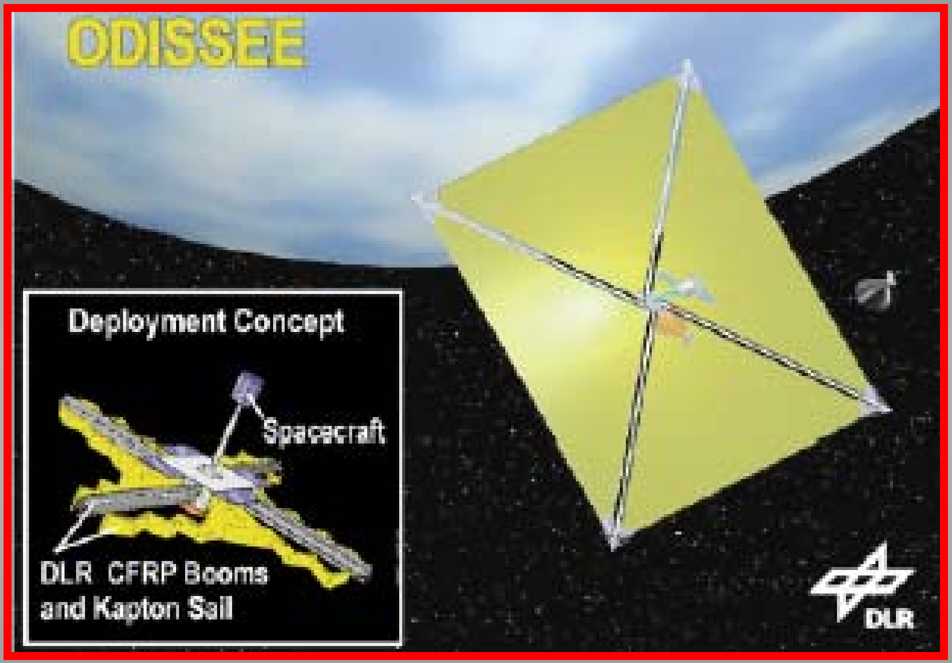
Future Composite Material Requirements
Solar Sails

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



Epoxy/Carbon Fiber Deployable Boom

ESA/DLR Concept for Solar Sailing

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

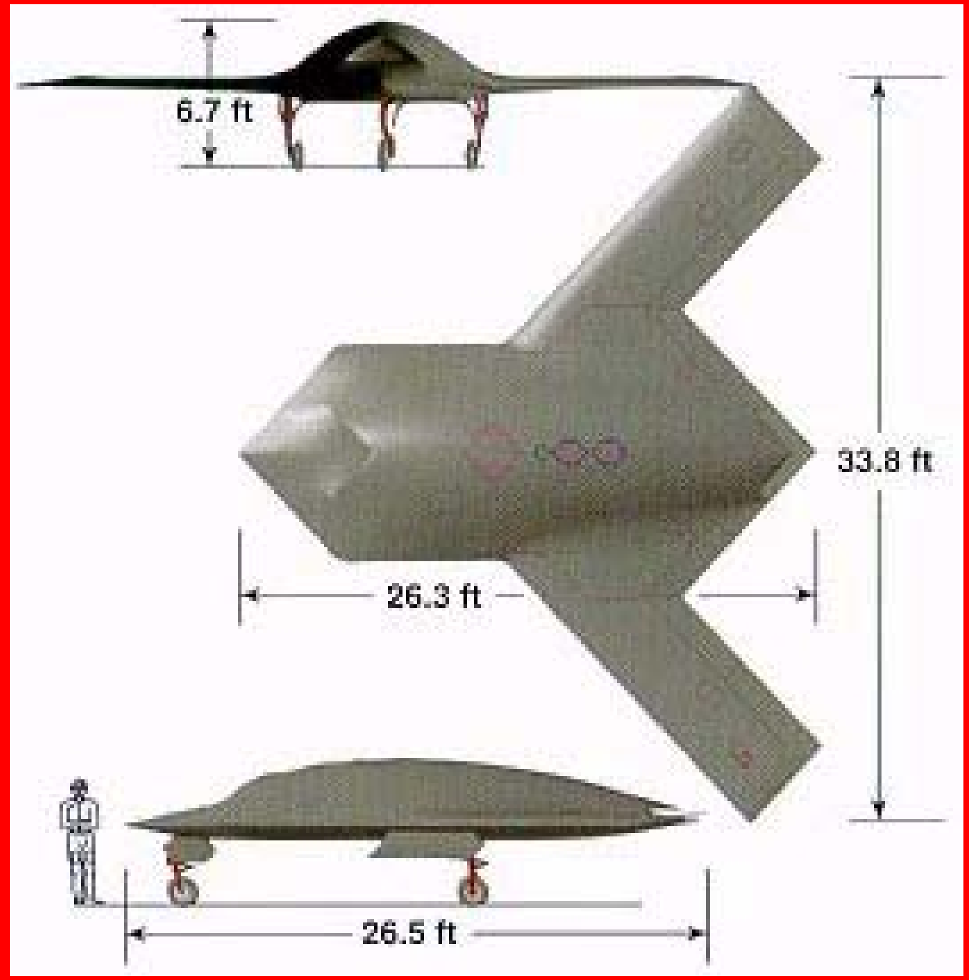
GLOBAL HAWK-High Altitude Endurance Unmanned Aerial Vehicle

Future Composite Material Requirements
Aerospace Needs for High Temp Resin

Future Composite Material Requirements
Aerospace Needs for High Temp Resin

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.

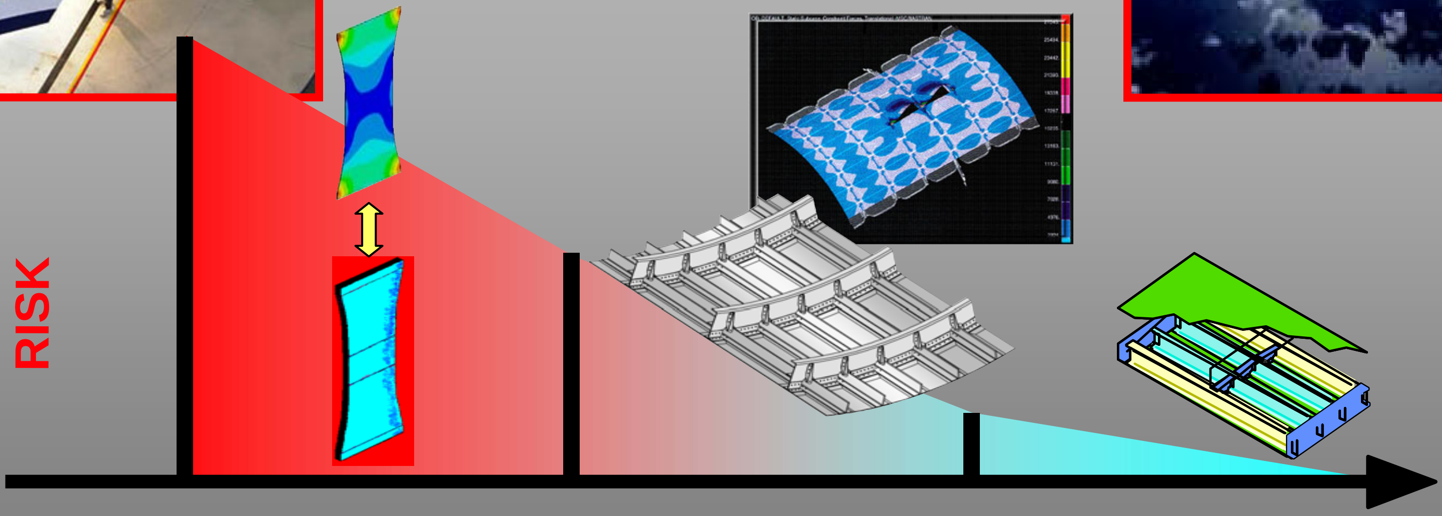
Future Composite Material Requirements UCAV



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



Time to Insertion Readiness