N86-11286

POLYIMIDE COMPOSITES - APPLICATION HISTORIES

Leonard M. Poveromo
Grumman Aerospace Corporation

Advanced composite hardware exposed to thermal environments above 127°C (260°F) must be fabricated from materials having resin matrices whose thermal/moisture resistance is superior to that of conventional epoxy-matrix systems. A family of polyimide resins has evolved in the last 10 years that exhibits the thermal-oxidative stability required for high-temperature technology applications. The weight and structural benefits for organic-matrix composites can now be extended by designers and materials engineers to include structures exposed to 316°F (600°F). Polyimide composite materials are now commercially available that can replace metallic or epoxy composite structures in a wide range of aerospace applications.

Epoxy-matrix advanced composite materials were originally formulated to provide structurally efficient aerospace components for prolonged service at 177°C (350°F). However, due to thermal/humidity degradation their service temperature limitation is now generally recognized as 121° (250°F). The evolution of a family of Bismaleimide (BMI) polyimide resins with epoxy-like processing and excellent thermal resistance in the last few years is allowing the aerospace designer to design composite structure with 121°C - 232°C (250°F - 450°F) thermal envelopes. Graphite/BMI is commercially available from several sources, and is being used in aircraft production for the first time by Grumman on the DC-8 Nacelle Anti-Ice Plenum. Specific details of the Grumman programs and an industry overview are included in this paper.

INTRODUCTION

Polyimide advanced composite materials have reached a level of industrial maturity that make them viable construction materials offering the potential for weight reduction and improved structural performance. Polyimide composite materials are now commercially available that can replace metallic or epoxy composites for a wide range of aerospace structures. Table 1 describes the resin systems available versus structural service temperature requirements.

Epoxy-matrix advanced composite materials, as a result of long-term exposure to the environment, will absorb moisture in excess of 1% by weight. This combination of

TABLE 1. ORGANIC-MATRIX APPLICATION VS AIRCRAFT SERVICE TEMPERATURE

23° TO 127°C (73° TO 260°F)	127° TO 232°C (260 TO 450°F)	232° TO 316°C (450 TO 600°F)	> 316°C (600°F)
EPOXY • 3501 • 5208 • 976	BMI • F-178 • V378A • 4001	ADDITION POLYIMIDE • LARC-160 • PMR-15 • PMR-11	CONDENSATION POLYIMIDE • NR-150B2 • THERMID 600
• ESTABLISHED DESIGN DATA • WIDESPREAD AEROSPACE EXPERIENCE • EASILY PROCESSED • DURABILITY CUT-OFF 127°C (260°F)	• PROCESSIBILITY SIMILAR TO EPOXIES • PRELIMINARY STRUCTURAL DATA AVAILABLE • HOT-WET STATIC AND FATIGUE PROPERTIES TBD • DESIGN EXPERIENCE LIMITED	• PROCESSING PARAMETERS INCLUDE 316°C (600°F) / 1.379 MPA (200 PSI) • BLEEDER/BREATHER SYSTEMS REQUIRE OPTIMIZATION • EXCELLENT THERMAL OXIDATIVE STABILITY • DURABILITY TBD • STRUCTURAL DATA MUST BE GENERATED	• PROCESSING PARAMETERS INCLUDE 371°C (700°F)/ 1.379 MPA (200 PSI) • BLEEDER/BREATHER SYSTEMS REQUIRE OPTIMIZATION • PRELIMINARY STRUCTURAL DATA AVAILABLE • EXCELLENT THERMAL OXIDATIVE STABILITY • DURABILITY TBD • DESIGN EXPERIENCE LIMITED • RESIN COSTLY

0385-014D

absorbed moisture with corresponding reduction in glass-transition-temperature (T_g) (fig. 1) and service temperatures in excess of 121°C (250°F) greatly reduces the compressive strength of conventional epoxy-matrix composites and minimizes their potential for weight savings (fig. 2). The BMI polyimide resins can be implemented on structurally efficient, composite designs with 121°C - 232°C (250°F - 450°F) thermal envelopes. All state-of-the-art BMI resins have processing or structural limitations; the optimal system is still to be developed. However, existing BMI composites can and are being utilized in applications tailored for their individual properties.

Grumman has successfully applied polyimide composite materials to advanced aerospace structures since the early 1970s. The pertinent funded development efforts and on-going production programs are listed in figure 3. The early requirements were for resins with long-term thermal stability 260°C (500°F) on high-speed aircraft with advanced electrical systems. Of the limited high-temperature resin systems available at that time, Grumman selected a condensation polyimide based on Monsanto's Skybond 709 resin. This material is derived from the reaction of a diacidester mixture and an aromatic amine. A manufacturing methodology was developed to fabricate heat-resistant fiberglass/polyimide and quartz/polyimide radomes for the EA-6B and A-6E Navy aircraft. The largest of the latter is the 4.5 x 0.5 x 0.6 m (15 x 1.5 x 2.0 ft) EA-6B T.J. Pod radome; more than 200 of these structures have been produced to date.

Springboarding off this technology during the mid-70s, the EF-111A Weapon Bay Radome (the largest all-polyimide-reinforced aerospace structure) was successfully designed, fabricated, and tested. This 4.9 x 0.6 x 0.6 m (16 x 2 x 2 ft) A-sandwich structure consists of fiberglass/polyimide facesheets bonded to polyimide honeycomb with polyimide film adhesive. This radome is presently in production as an integral part of the Air Force's EF-111A Tactical Jamming System.

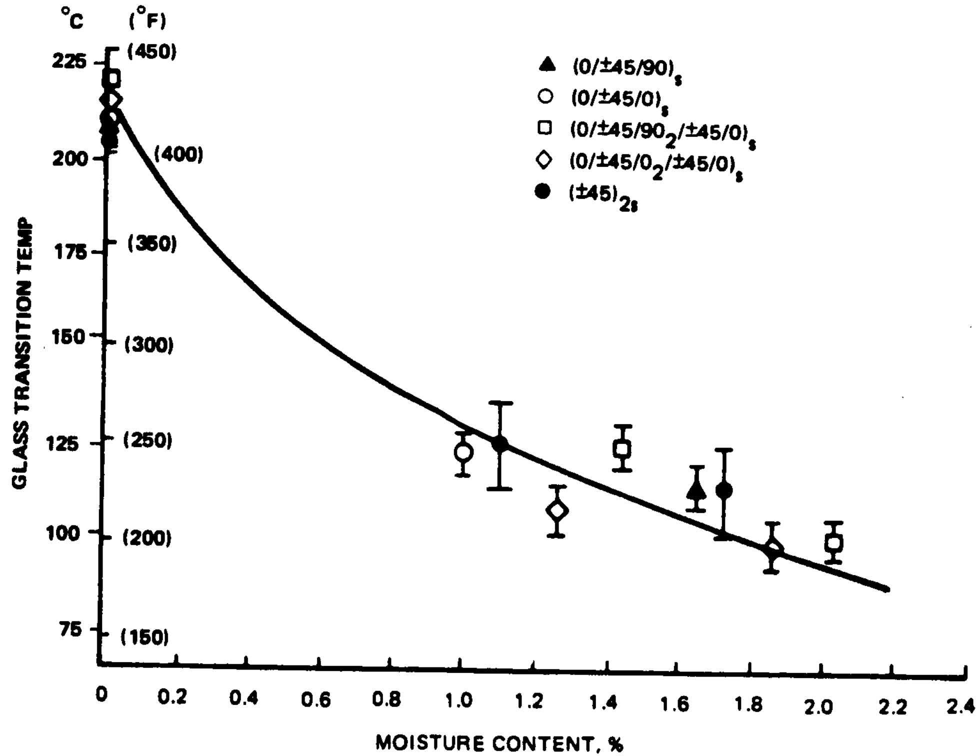


Figure 1. Effect of moisture content on the glass transition temperature of AS/3501-5 Gr/Ep as measured by TMA

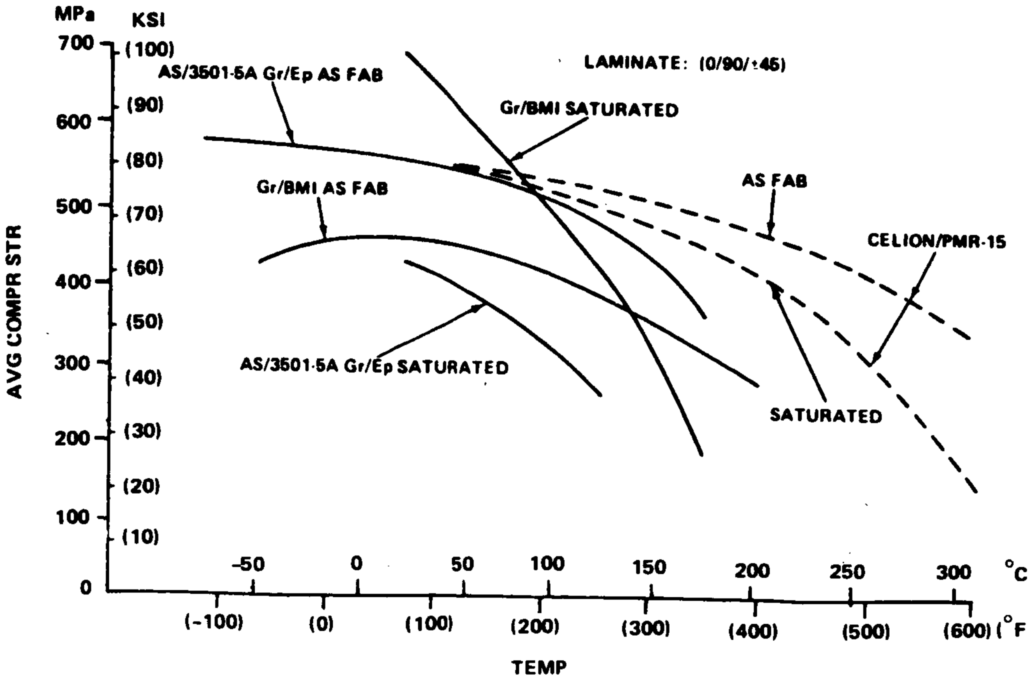


Figure 2. Comparison of compression strength of AS-1/3501-5A Gr/Ep, AS-4/4001 Gr/BMI and Celion/PMR-15 Gr/Pi laminates (as fabricated and saturated at 95% RH)

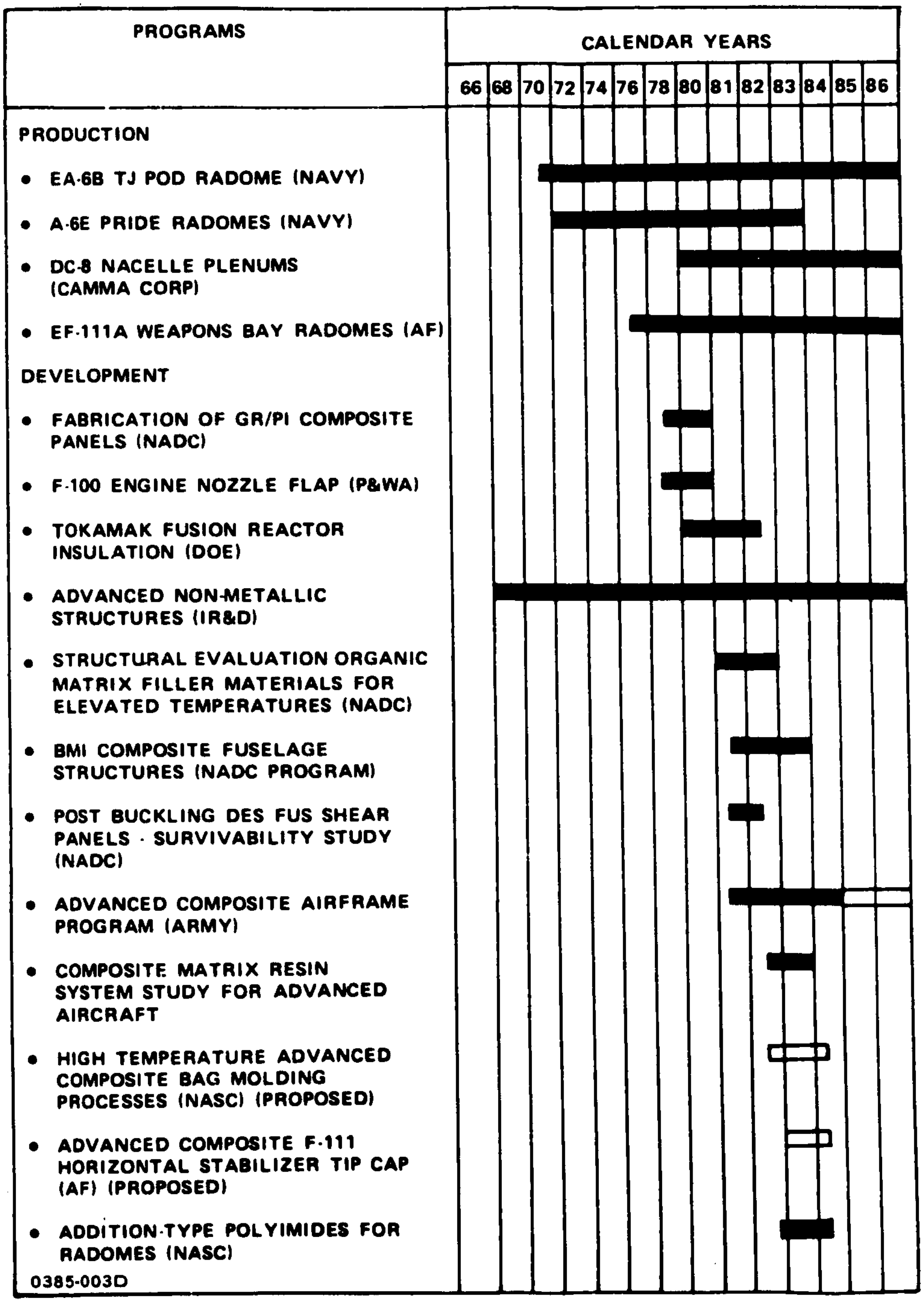


Figure 3. Grumman polyimide composite programs

ORIGINAL PAGE IS
OF POOR QUALITY

DC-8/CFM 56 NACELLE ANTI-ICER PLENUM

Grumman designed and is fabricating the nacelles for Cammacorp's DC-8 re-engining program. The severe thermal/acoustic environment of the nacelle de-icer plenum (fig. 4) presented a design problem. A study of the maintenance records of the baseline titanium anti-ice skins in service showed high failure rates typified by multiple fatigue cracks with a tendency towards fragmentation. Since the cause was determined to be acoustic/thermal fatigue, a graphite/polyimide design with excellent fatigue resistance was developed. The processing requirements and 232°C (450°F) maximum service temperature of the part drove the matrix selection toward the bismalimide (BMI) addition-curing polyimides. Grumman has extensive experience in processing BMI polyimides since their introduction in the mid-70s. Initially, the resin was developed for substitution in fiberglass/polyimide radomes fabricated with condensation polyimides that had exhibited extensive processing problems. The two commercially available matrix systems were Hexcel's F-178 and USP's V-378A. The early Grumman BMI work involved development of woven graphite cloth/F-178 resin for advanced composite aircraft structures subjected to thermal environments between 127°C and 232°C (260°F and 450°F). In addition, Grumman has been working with the V-378A resin since its introduction and has established in-house materials and processing requirements for this system. The advantages of these BMI systems are that they are fully imidized and supplied without solvent. These resins do not emit volatile byproducts during the addition/free-radical curing mechanism. Void-free laminates are produced using standard 177°C (350°F) epoxy-prepreg bagging and curing procedures and production facilities.

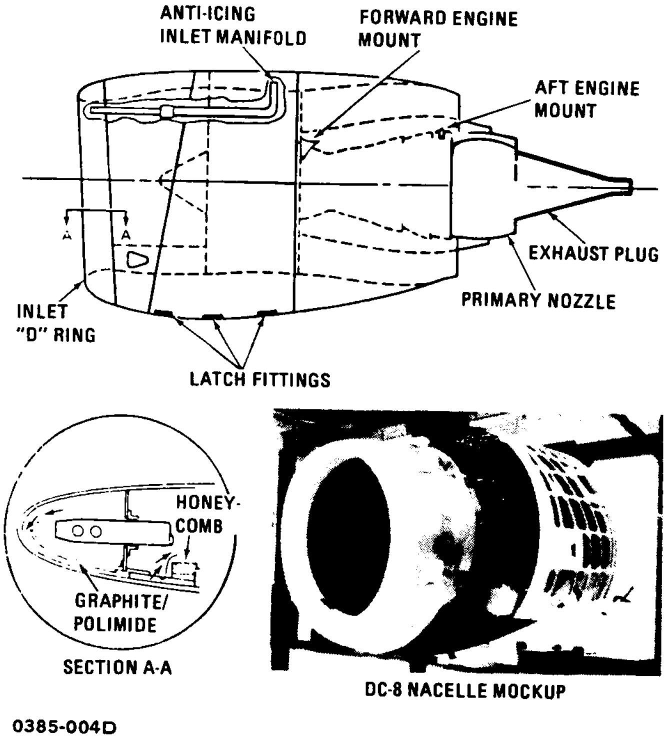


Figure 4. Grumman-fabricated graphite/polyimide anti-ice plenum for DC-8 engine nacelle mockup

Since the principal plenum design condition was thermal/acoustic fatigue, a test sequence involving noise levels up to 158 dB and 232°C (450°F) was developed (fig. 5) and a series of candidate laminates (table 2) were tested. The combinations included woven graphite/F-178, woven graphite/V-378A, woven fiberglass/unidirectional graphite/F-178 hybrid, and woven fiberglass/unidirectional graphite/V-378A hybrid. All the laminates successfully withstood the thermal/acoustic fatigue test. The woven graphite/BMI laminate was selected for use in the nacelle anti-ice plenum (fig. 6) because of ease of layup and thickness considerations. Subsequent fatigue and static tests (table 3) were conducted to verify the structural integrity of the graphite/BMI plenum configuration for FAA certification. The composite design resulted in a 30% weight savings and significant manufacturing/tooling cost savings over the alternative titanium plenum. A considerable amount of data was accumulated with respect to basic material properties and analytical procedures that helped to minimize batch-to-batch variations of incoming graphite/BMI prepreg.

TABLE 2. ADVANCED COMPOSITE ACOUSTIC FATIGUE TEST PANELS

PANEL DESCRIPTION	NUMBER OF PLIES	THEORETICAL THICKNESS, MM (IN.)	LAYUP SEQUENCE
HYBRID {7781 GL/F-178 PI T-300 GR/F-178 PI)}	16	3.2 (0.124)	$+45_{GR}/-45_{GR}/0_{GR}/+45_{GL}/90_{GR}/-45_{GL}/0_{GL}/90_{GL}/90_{GL}/0_{GL}/-45_{GL}/90_{GR}/+45_{GL}/0_{GR}/-45_{GR}/+45_{GR}$
WOVEN GR/PI {24X23 8HS GR CLOTH F-178 & V-378A PI}	9	3.0 (0.117)	$+45_{GR}/0_{GR}/90_{GR}/-45_{GR}/0_{GR}/-45_{GR}/90_{GR}/0_{GR}/+45_{GR}$
HYBRID {7781 GL/V-378A PI T-300 GR/V-378A PI}	20	4.2 (0.164)	$+45_{GR}/-45_{GR}/0_{GR}/+45_{GL}/90_{GR}/-45_{GL}/0_{GL}/90_{GL}/90_{GL}/0_{GL}/-45_{GL}/-45_{GL}/0_{GL}/90_{GL}/0_{GL}/-45_{GL}/90_{GR}/+45_{GL}/0_{GR}/-45_{GR}/+45_{GR}$

LEGEND:

GR – UNIDIRECTIONAL GRAPHITE/POLYIMIDE
GL – WOVEN FIBERGLASS/POLYIMIDE

0385-015D

BMI POLYIMIDE DEVELOPMENT PROGRAMS

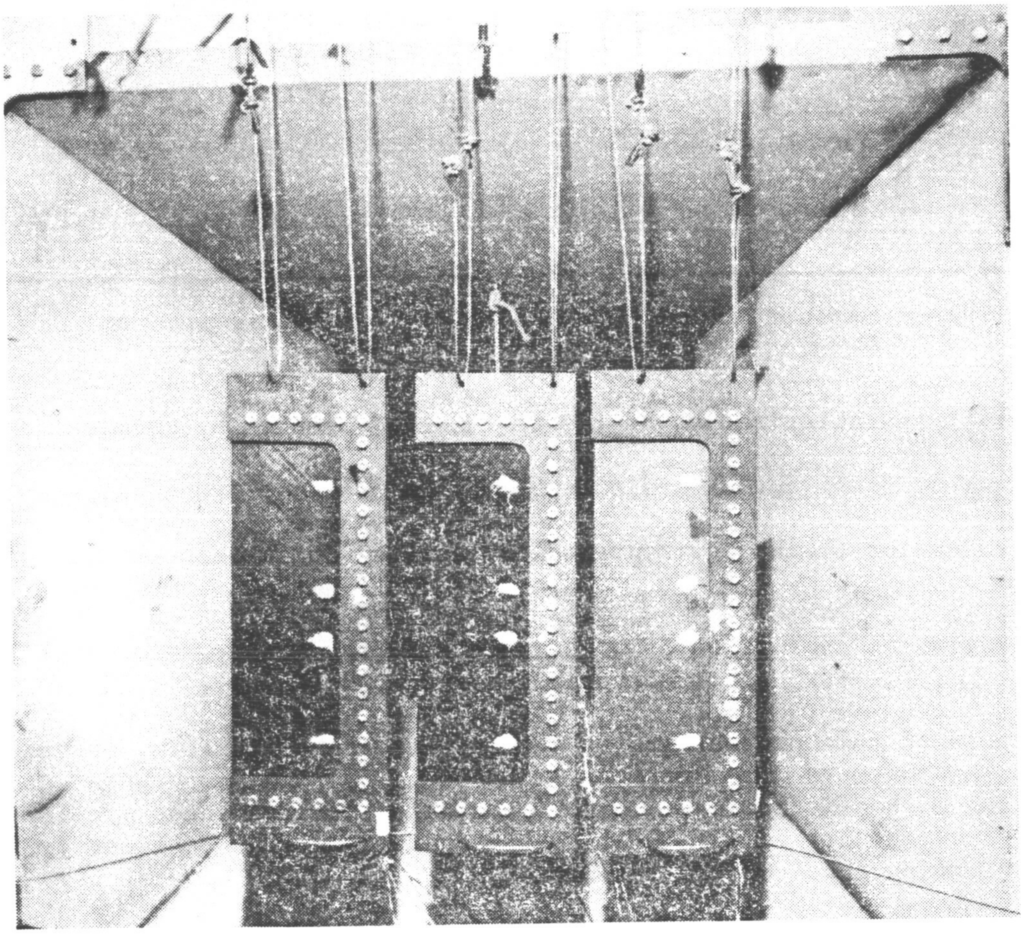
Prior to and during the above pioneering production program, Grumman was actively involved in development programs geared to generating BMI polyimide composite properties and structures. These programs are listed in figure 3. The specific details of the selected efforts are briefly described in the following subsections.

Fabrication of Graphite/Polyimide Panels (Naval Air Development Center-NADC)

The overall objective of this early program was the fabrication of over 300 T-300/F-178 graphite/BMI panels for environmental exposure to provide data for an NADC composite data base. Specific objectives included:

TEST PHASE	ELAPSED TIME, HR	TEST NOISE LEVEL IN ONE-THIRD OCTAVE BAND, dB	TEST TEMP, °C (°F)
1	10.0	152	23(73)
2	19.5	152	232(450)
3	42.5	155	232(450)
4	3.0	158	232(450)
	75.0 (TOTAL)		

A. SEQUENCE



B. SETUP

0385-005D

Figure 5. Test procedure

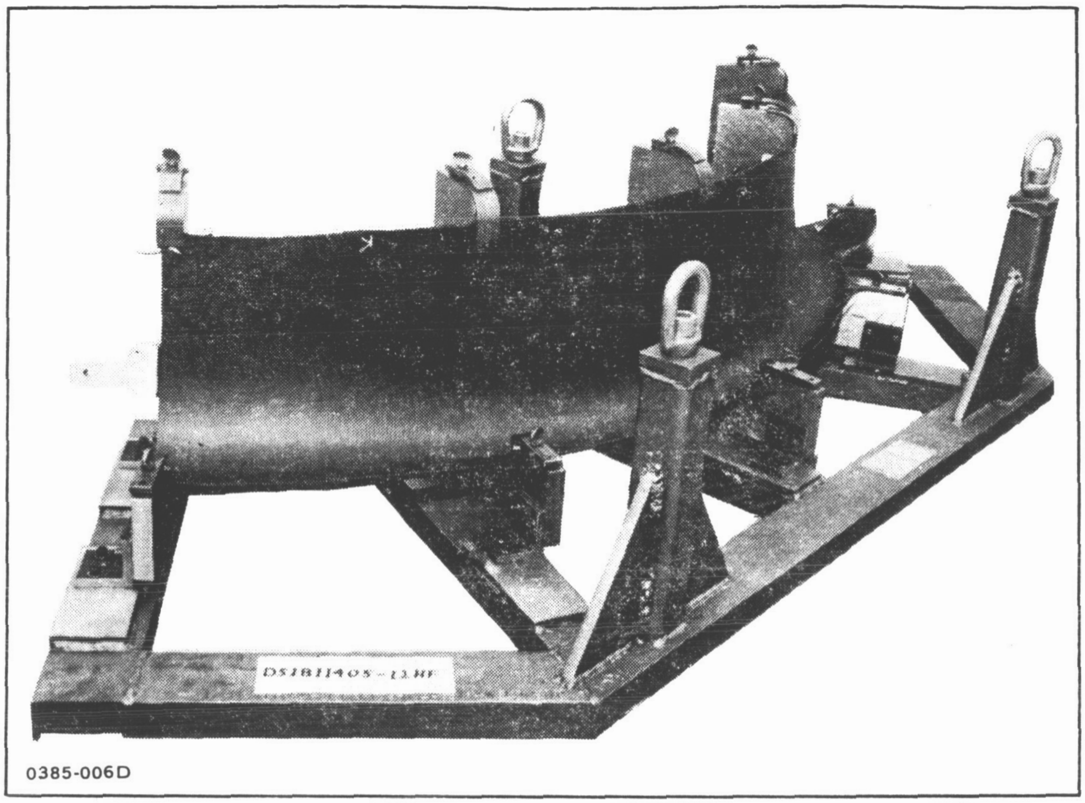


Figure 6. Section of graphite/polyimide DC-8 nacelle anti-ice plenum in postcuring fixture

- Material characterization of the as-received prepreg by chemical analysis
- Determination of the mechanical properties of autoclave-cured panels
- Determination of the environmental durability of autoclave-cured panels.

Structural Evaluation of Organic Matrix Filamentary Materials for Use at Elevated Temperatures (NADC)

The purpose of this project was to demonstrate the suitability of graphite/BMI polyimide for high-temperature structural applications through the static and fatigue testing of quasi-isotropic coupons and hat-stiffened shear panels at room temperature-"dry" and at 177°C (350°F) "wet" conditions. The test matrix is shown in table 4. Testing involved the following:

- Static testing of unnotched and notched tension and compression coupons
- Static testing of horizontal shear specimens
- Constant-amplitude (R=0, R=-1) fatigue testing of unnotched and notched tension and compression coupons
- Spectrum fatigue testing of notched coupons

TABLE 3. SUMMARY OF STATIC TEST RESULTS (1) OF GM3014-11 WOVEN GRAPHITE/POLYIMIDE (F-178)

TEST	LAYUP(2) ORIENTATION	TEST TEMP, °C(°F)	ULTIMATE STRENGTH MPa(KSI)	MODULUS GPa(MSI)
TENSION	MULTI	23(73)WET	356(51.9)	48.0(6.98)
		232(450)	340(49.3)	42.7(6.21)
	0/90	23(73)WET	466(67.8)	62.1(9.07)
		232(450)	500(72.6)	57.5(8.38)
TENSION (OPEN-HOLE)	MULTI	23(73)WET	327(47.5)	–
		232(450)	336(48.8)	–
	0/90	23(73)WET	422(61.2)	–
		232(450)	381(55.3)	–
COMPRESSION (IITRI)	MULTI	23(73)WET	429(62.1)	–
		232(450)	284(41.2)	–
	0/90	23(73)	562(81.8)	–
		232(450)	375(54.2)	
FLEXURE	MULTI	23(73)WET	430(62.4)	48.5(7.07)
RAIL SHEAR	MULTI	23(73)WET	142(20.6)	–
		232(450)	110(16.0)	–
	0/90	23(73)WET	76(11.1)	–
		232(450)	55(8.0)	–
BEARING AT 4% DEFLECTION	MULTI	23(73)WET	436(63.2)	–
		232(450)	334(48.4)	–
CTE	MULTI	–	$1.5\text{X}10^{-6}$ (3)	–

NOTES:

(1) AVERAGE OF FIVE SPECIMENS

(2) PLY ORIENTATION:

MULTI: $(0, +45, 0\ -45, \bar{0})_s$, TESTED IN 90°

BI: $(0/90)_9$ TESTED IN 90°

(3) MICRO-UNITS

0385-016D

TABLE 4. TEST MATRIX FOR ORGANIC-MATRIX FILAMENTARY MATERIALS PROGRAM (NADC)

TEST CONFIGURATION	STATIC		FATIGUE					
			CONSTANT AMPLITUDE				SPECTRUM	
			R = 0.05		R = -1			
	RT DRY	350°F WET	RT DRY	350°F WET	RT DRY	350°F WET	RT DRY	350°F WET
TENSION								
UNNOTCHED	10[1]	10[1]	6	6				
CENTER NOTCHED	10	10	6	6			2	2
POST LOW VELOCITY IMPACT DAMAGE	3		3					
COMPRESSION								
UNNOTCHED	10[2]	10			6	6		
CENTER NOTCHED	10	10			6	6	2	2
POST LOW VELOCITY IMPACT DAMAGE		3				3		
HORIZONTAL SHEAR	10	10						
SHEAR PANEL	1[3]	1			1[3]	1	1[3]	1

1 UNNOTCHED STATIC TENSION TESTS EMPLOYED CONVENTIONAL EXTENSOMETRY

2 THREE OF THE TEN R.T. UNNOTCHED STATIC COMPRESSION SPECIMENS WERE INSTRUMENTED WITH 2 AXIAL GAGES

3 R.T. SHEAR PANELS EACH USED TWO BACKED-UP, 2-ELEMENT ROSETTES PLUS 6 AXIAL GAGES

0385-017D

- Static and constant-amplitude fatigue testing of impacted coupons
- Static, constant-amplitude, and spectrum fatigue testing of hat-stiffened shear panels representative of a V/STOL aft-fuselage panel.

In addition, the temperature-dependent absorption characteristics of Gr/BMI were quantified in an early phase of the effort to permit accurate prediction of the expected in-service moisture contents and to enable adequate definition of the requisite conditioning and testing procedures for reliable simulation of these in-service conditions. The rate at which this material system absorbed moisture as a function of temperature (diffusivity) and the equilibrium moisture content as a function of relative humidity were established. The moisture desorption and reabsorption characteristics were also determined. Test panel configurations are shown in table 5. These parameters, together with environmental and aircraft mission scenarios, were inputted to a Grumman-developed semi-empirical computer model based on a Fickian diffusion process to estimate the total amount of moisture absorbed by Gr/BMI structures during the service life of future aircraft. (See figs. 7 through 10.) The effects of a range of impact energy levels on graphite/BMI were also determined visually and ultrasonically in order to determine the level that causes barely visible impact damage for subsequent tests as a "worst case" condition of subvisual damage. Grumman investigated the F-178 resin matrix in this program while Northrop evaluated the V-378A resin matrix in a parallel effort.

TABLE 5. CONFIGURATIONS OF T-300/F-178 GRAPHITE/POLYIMIDE MOISTURE CONDITIONING TEST PANELS

PANEL NO.	LAYUP SEQUENCE	THICKNESS, IN.	FIBER VOLUME, %	VOID CONTENT, %
X1	+45/–45/+45/–45/–45/+45/–45/+45 (MULTIDIRECTIONAL)	0.071	59.42	0.67
H2	$[0]_{16}$ (UNIDIRECTIONAL)	0.080	61.54	0.56
T8	+45/0/+45/0/–45/0/90/90/0/–45/0/+45/0/∓45 (MULTIDIRECTIONAL)	0.087	60.16	1.20
SPECIFIC GRAVITY: RESIN – 1.2964 FIBER – 1.7600				

0385-018D

Bismaleimide Composite Fuselage Structures for High-Temperature Applications (NADC)

The objective of this on-going Bismaleimide Composite Fuselage Structures (BCFS) Program is to design and develop an advanced composite fuselage structure which can satisfy the load and environmental requirements of a Fighter/Attack (F/A) V/STOL aircraft. In so doing, this program will develop design criteria and data, and demonstrate manufacturing techniques for generic high-temperature composite fuselage structure designed to operate in the 177°C to 204°C (350°F to 400°F) temperature range. The component selected is a 3.7 x 1.2 m (12 x 4 ft) section of V/STOL aft fuselage. The specific design is a hat-stiffened post-buckled skin with J-section longerons and frames (fig. 11). The potential advantages of this structure are:

- Weight savings of 28% over an equivalent metallic baseline
- Damage-tolerance for both low- and high-energy impact
- Structural integrity, reliability, and maintainability
- Affordable production costs (10% less than metallic baseline).

Grumman used its polyimide design/manufacturing experience to aid in the developing the BMI resin matrix (Hercules 4001) used in this program.

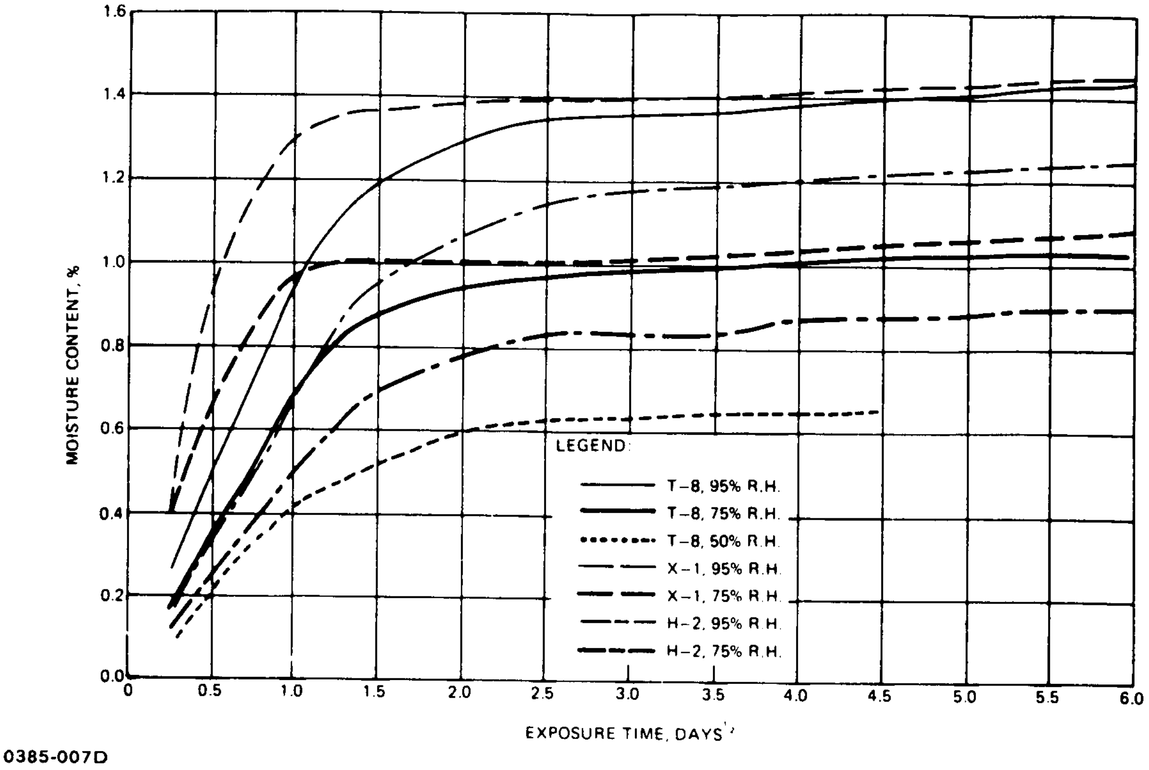


Figure 7. Effect of relative humidity on moisture content of 16-ply, T-300/F-178 graphite/polyimide panels at 77°C (170°F)

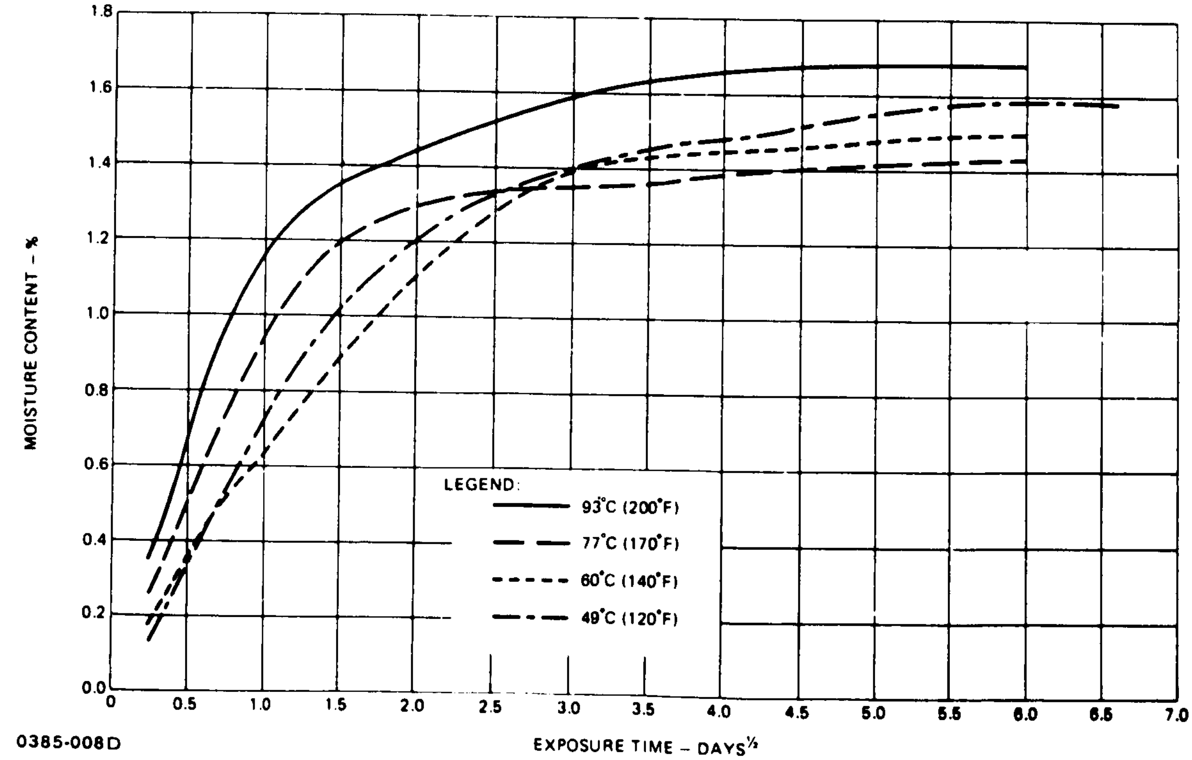
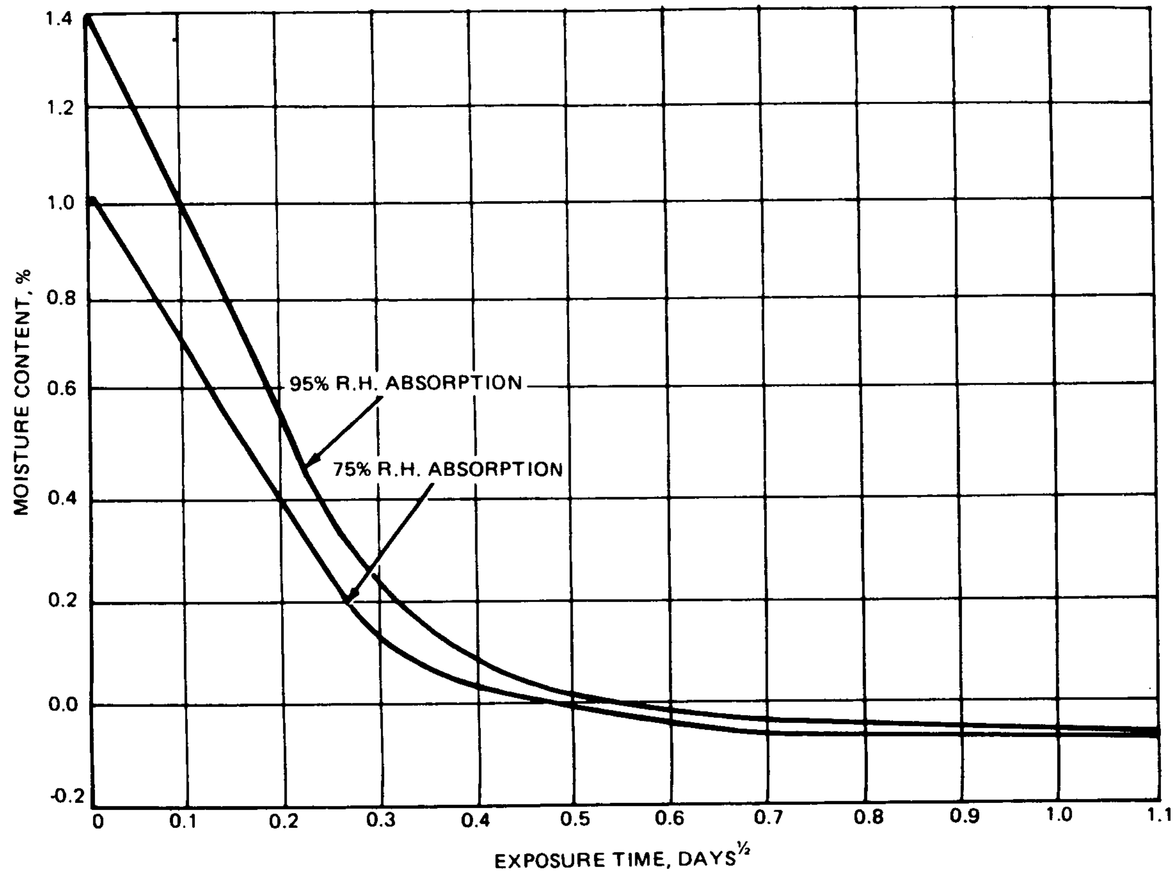
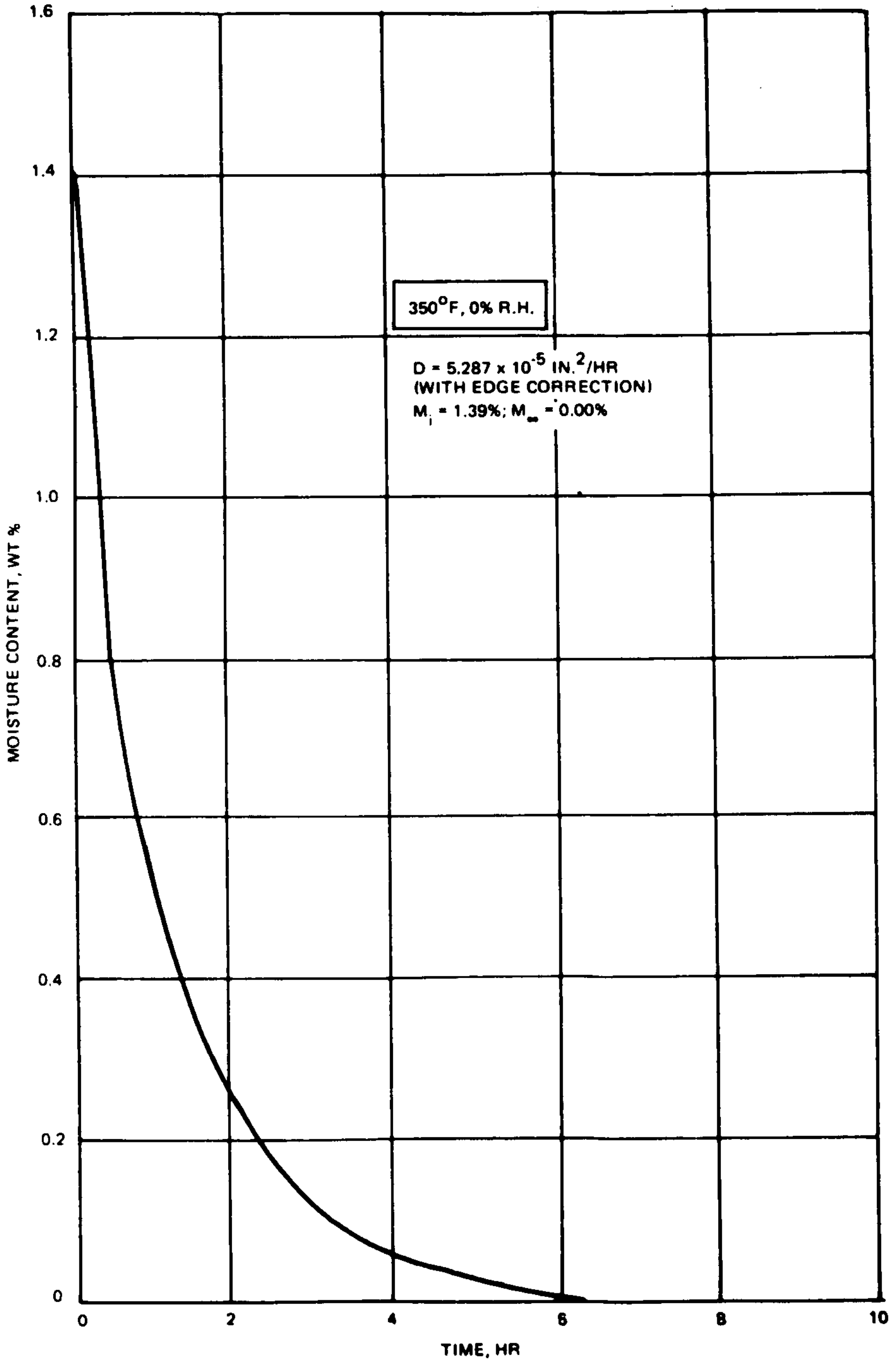


Figure 8. Effect of temperature on moisture diffusivity in 16-ply, T-300/F-178 graphite/polyimide panel No. T8 at 95% relative humidity



0385-009D

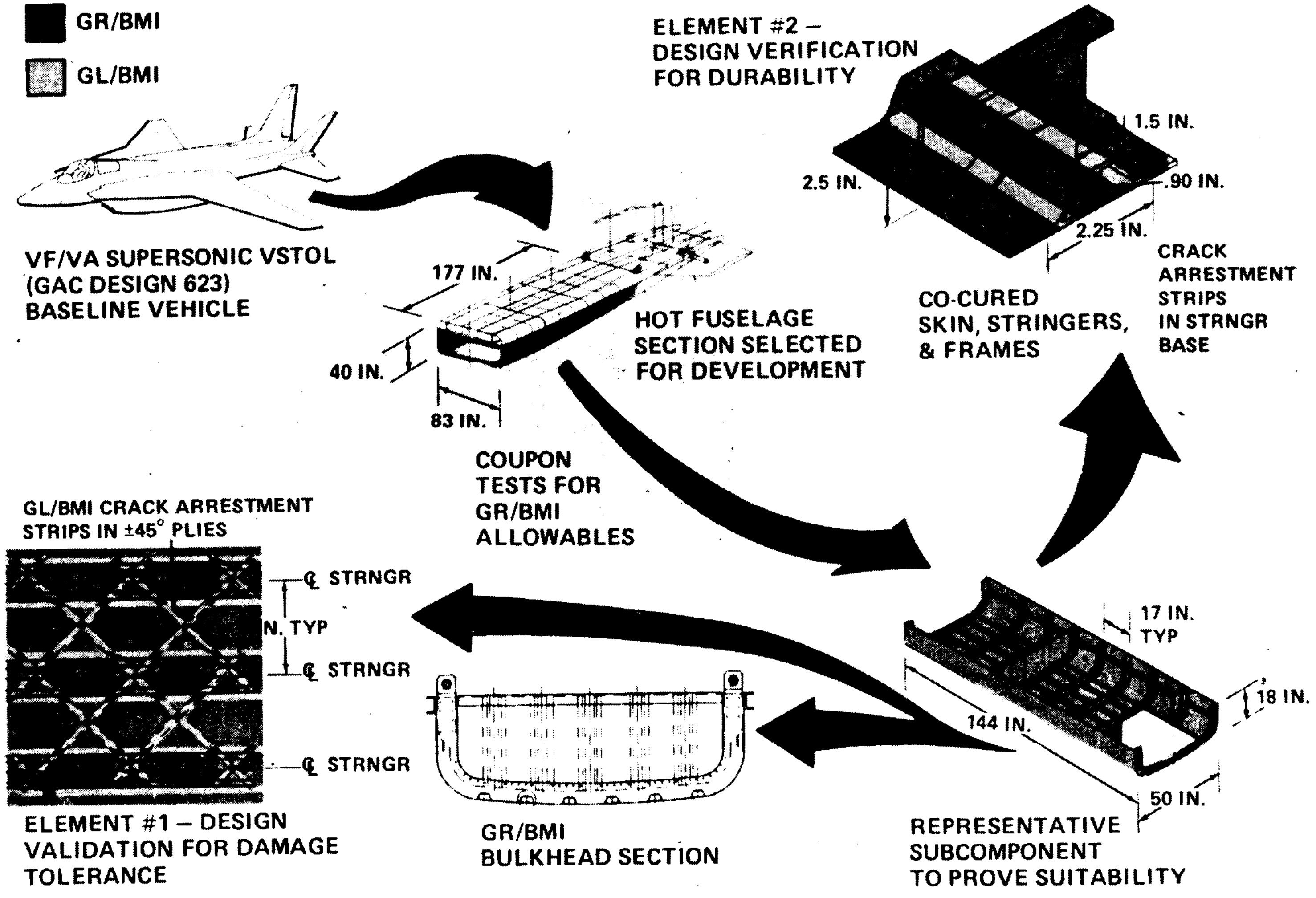
Figure 9. Moisture desorption at 177°C (350°F) from T-300/F-178 graphite/polyimide specimens



0385-010D

Figure 10. Projected moisture content time history for 16-ply graphite/polyimide specimens (M_i = 1.39%, M_∞ = 0.00%)

GRAPHITE BISMALEIMIDE (GR/BMI) COMPOSITE FUSELAGE PROGRAM

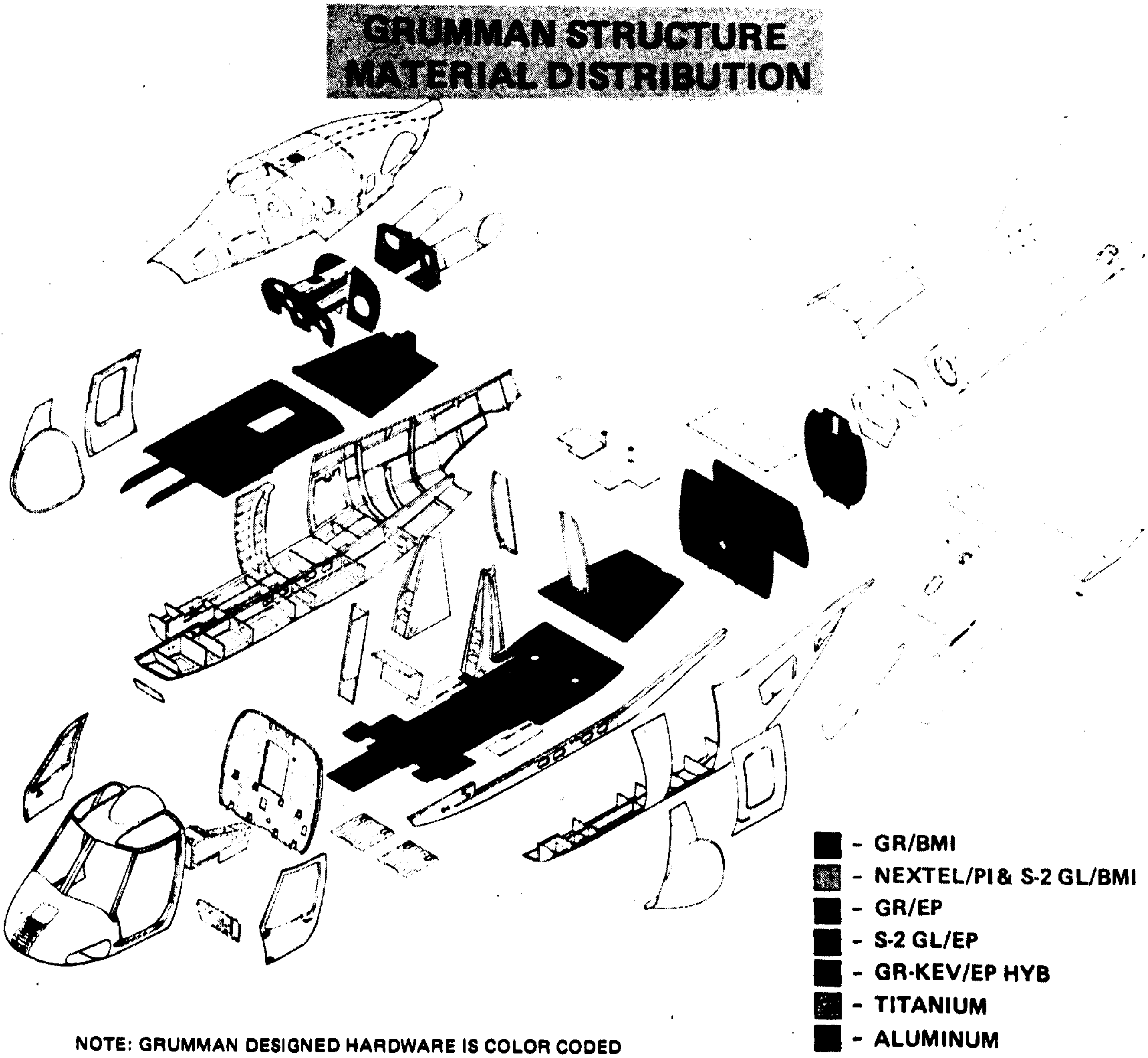


0385-011D

Fig. 11 Program Schematic for NADC - Funded BMI Composite Fuselage Program

Advanced Composite Airframe Program - ACAP (Army)

The objective of this program is to demonstrate how advanced composites, when applied in a helicopter airframe design, can provide weight/cost payoffs for future Army helicopters. Due to the operating service temperature [127°C (260°F)] and the fire-containment requirements of the Bell/Grumman ACAP design, a high-temperature resin system is required. Specifically, the aft roof is composed of two major components — the engine deck and the center beam assemblies. Both of these assemblies are fabricated using graphite/BMI. The engine deck is designed to contain a 1093°C (2000°F) fire for 15 minutes without backside penetration. The construction materials are HRP honeycomb core faced with fiberglass-graphite/BMI laminates. Outside of the fire containment area, the deck design consists of an integrally stiffened graphite/BMI skin with longitudinal hat stiffeners and transverse J-frames. The material distribution for this Grumman-designed structure is shown in fig. 12.



NOTE: GRUMMAN DESIGNED HARDWARE IS COLOR CODED

0385-012D

Fig. 12 Bell/Grumman ACAP Configuration

Composite Matrix Resin System Study for Advanced Aircraft (NADC)

The objective of this new and innovative program is to select the optimal composite matrix system for service to 121°C (250°F) and in the 177°C to 232°C (350°F to 450°F) temperature range. The candidate graphite/resin system will be assessed for structural efficiency and environmental durability plus compatibility with cost-effective, reliable, and reproducible manufacturing processes. As a corollary to this effect, an evaluation of the compatibility of these resins with the new high-strain fibers will be investigated.

Industry-wide development efforts with BMI composites are growing, with every large aerospace company either actively evaluating these materials and/or planning their introduction into production. A partial listing of the programs that the author is aware of is shown in table 6.

TABLE 6. OTHER INDUSTRY BMI APPLICATIONS

COMPANY	APPLICATION	MATERIAL
GENERAL DYNAMICS/ FORT WORTH	F-16XL WING COVERS	GRAPHITE/V-378A
LTV	S-3 NACELLE DOOR	GRAPHITE/V-378A
MCDONNELL DOUGLAS/ ST. LOUIS	AV-8B HARRIER STRAKES, VENTRAL ANTENNA COVER & INBOARD TRAILING EDGE	FIBERGLASS/V-378A GRAPHITE/V-378A
ROCKWELL/BRUNSWICK (SUBCONTRACT)	B-1 RADOMES	FIBERGLASS OR QUARTZ/F-178
SNECMA	• ENGINE SHROUD • CFM 56 AIR OIL SEAL	• FIBERGLASS/ KERIMID 601 • KINEL 5504
ROLLS ROYCE	RB-211 TERMINAL BLOCK & STIFFENER RB-162 STATOR VANE & ROTOR BLADE	KINEL 5504

0385-019D

TOKAMAK FUSION REACTION - DIELECTRIC INSULATION

A unique polyimide program of interest at Grumman is the Tokamak Fusion Test Reactor (TFTR) which utilizes high-temperature polyimides. The overall TFTR is the largest project in the long-range program by the U.S. Energy Research and Development Administration (ERDA) to achieve a demonstration fusion power reactor by the late 1990's. The TFTR will be the first magnetic fusion system in the U.S. capable of producing fusion energy in significant quantities; it is being designed and developed at Princeton University's Plasma Physics Laboratory (PPPL). The prime industrial contractor working for PPPL is Ebasco, Inc., and their major subcontractor is Grumman Aerospace. In fabricating the TFTR torus, a doughnut-shaped container (high-temperature dielectric insulation) is used for magnetic confinement of plasma. This insulation prevents the flow of structure eddy currents that would distort the desired magnetic field of the Tokamak. The severe thermal [274°C (525°F)] and electrical (0.75 kV) environment dictated a high-performance polyimide/fiberglass insulation material. Based on previous Grumman experience and the availability of industry data, the Polymeric Monomeric Reactant (PMR-15) polyimide resin system was selected as the matrix construction material. This resin system, originally formulated by NASA-Lewis Research Center, is prepared by combining two ester-acids and a diamine in methanol solvent. The 7781/PMR-15 fiberglass prepreg was available from several industry sources; Ferro's CPI-2237 material was selected.

Grumman generated material procurement and process specifications for the fiberglass/PMR-15 system. Extensive structural and electrical testing was conducted to characterize the material's performance in the unique Tokamak environment. Chemical evaluation of the prepreg consisted of establishing processing parameters and baseline control characteristics. Tests were run to determine the structural performance of the material: room-temperature compression creep; 1000-hour at 295°C (520°F) compression creep and coefficient of static friction; compression test under electric load (table 7); and electrical properties-dielectric strength, insulation resistance, dielectric constant, and dissipation factor (table 8). Following successful completion of the above testing, the required Tokamak dielectric insulation including 50 0.9 x 0.9 m (3 x 3 ft.) panels were fabricated and installed (fig. 13). Ring insulations for the Tokamak torus vacuum vessel outboard support pins were also successfully produced.

TABLE 7. ELECTRIFIED COMPRESSION PROPERTIES OF 7781 FIBERGLASS/PMR-15

TEST TEMP, °C (°F)	APPLIED STRESS, MPa (KSI)	DC VOLTAGE, kV	MAX LEAKAGE CURRENT, μA
127(260)	276(40)	0.75	NIL
127(260)	345(50)	0.75	NIL
271(520)	207(30)	0.75	0.72
271(520)	276(40)	0.75	0.78

0385-020D

TABLE 8. ELECTRICAL PROPERTIES OF 7781 FIBERGLASS/PMR-15

PROPERTY	AVERAGE VALUE
DIELECTRIC STRENGTH, V/MIL	1,023
INSULATION RESISTANCE, 10^{14} OHMS	>5.31
DIELECTRIC CONSTANT	5.17
DISSIPATION FACTOR	0.00810
TESTS PERFORMED AT ETL TESTING LABORATORIES, CORTLAND, N.Y.	

0385-021D

ORIGINAL PAGE IS
OF POOR QUALITY

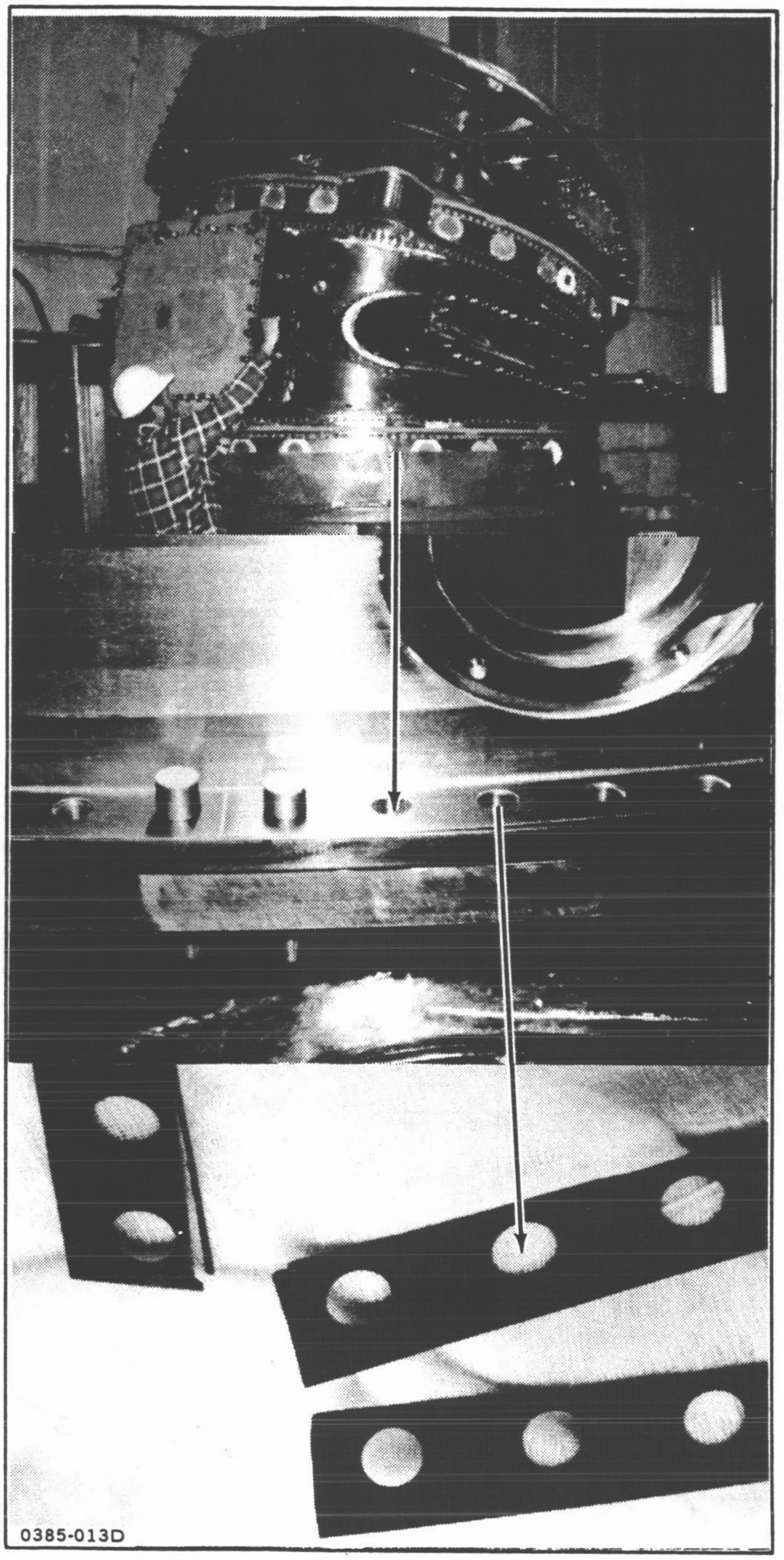


Figure 13. Location of 7781 fiberglass/PMR-15 dielectric insulation in Tokamak vacuum vessel

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions of the following personnel and companies who helped make the programs described herein possible: R. Holden, J. Mahon, P. Palter, P. Pittari, J. Roman, M. Martin, S. DeMay, J. Lundgren, and C. Parente of Grumman; W. Redden and A. Brooks of Ebasco Services; Princeton Plasma Physics Laboratory; Cammacorp, and R. Trabacco, L. Buckley and T. Hess of NADC.

REFERENCES

1. L. Poveromo, "Polyimide Composites - Grumman Application Case Histories", 27th National SAMPE Symposium/Exhibition, May 1982.

2. L. Poveromo, "Polyimide Composites - Aerospace Case Histories", SPE First Technical Conference on Polyimides, November, 1982.