N93-10587

PROPOSED TEST PROGRAM AND DATA BASE FOR LDEF POLYMER MATRIX COMPOSITES

R. C. Tennyson
University of Toronto Institute for Aerospace Studies

P. George
Boeing Defense and Space Group

G. Steckel
The Aerospace Corporation

D. G. Zimcik
Canadian Space Agency

INTRODUCTION

The purpose of this report is to present a survey of the polymer matrix composite materials that were flown on LDEF with particular attention to the effect of circumferential location (α) on the measured degradation and property changes. Specifically, it is known that atomic oxygen fluence (AO), VUV radiation dose and number of impacts by micrometeoroids/debris vary with α. Thus it is possible to assess material degradation and property changes with α for those materials that are common to three or more locations. Once the α-dependence functions have been defined, other material samples will provide data that can readily be used to predict damage and property changes as a function of α as well.

Another objective of this report is to summarize what data can be realistically obtained from these materials, how this data can be obtained and the scientific/design value of the data to the user community. Finally, a proposed test plan is presented with recommended characterization methodologies that should be employed by all investigators to ensure consistency in the data base that will result from this exercise.

LDEF POLYMER MATRIX COMPOSITES — TYPES AND LOCATION

Table 1 summarizes the extensive number of polymer matrix composites that were distributed over nine different circumferential locations around LDEF. Also shown is the variation in atomic oxygen fluence (atoms/cm^2) and the total VUV radiation exposure at each location, measured in "equivalent sun hours" (ESH). For reference purposes, each experiment is defined by its NASA LDEF code and the experimenters identified.

Of particular interest are those materials which are common to three or more locations. From Table 2 it can be seen that 5 different materials meet this criterion and thus it is expected that any angular dependence of degradation mechanisms or property changes can be determined. Once the angular dependence functions are known, one can then utilize material data obtained from any of the LDEF samples to assess "worst case" scenarios regardless of the sample location on LDEF. For example, mass loss due to AO erosion can be calculated for the "ram" direction based on measurements made on samples located at any α, providing $0 \leq |\alpha| \leq 90°$.

Another example relates to the damage done to composite laminates due to impacts by micrometeoroids/debris. It is known that the number of "hits" is indeed a function of 'α' (and time in orbit). Consequently, if one knew the correlation between "surface damage area" as a function of micrometeoroid/debris impact, one could then calculate "total damage area" for a given location on a satellite.

DATA BASE REQUIREMENTS

The usefulness of a data base is often determined by the presentation format employed. Processing of the raw data can take different forms, ranging from a fully catalogued "library," thus enabling full access to the raw data, to a condensed and "interpreted" handbook form which enables a user to apply the information directly. The need and usefulness of each of these forms will depend on the specific user community.

In the case of LDEF data, it is possible to identify a spectrum of likely users, ranging from researchers and scientists who are interested in the raw data necessary to further the science in this area, to the design engineer interested mainly in the direct application of the data to a specific problem. While being careful not to oversimplify this at either extreme, the needs of each community are quite distinct and different. In addition, the data base generated from LDEF must ensure completeness, integrity and traceability to enable future scientists to explore those "peculiar" results of today that will invariably find explanation or interpretation in future work. The complete LDEF data base must be multi-dimensional.

In creating a data base from LDEF data it is therefore imperative that the user community for which it is targeted be clearly identified and consulted (or at least considered) in its generation. The first requirement for such a data base must be to establish the user's needs in order to define the format of the presentation.

Technical requirements of a data base are determined by two factors:

- particular space environment effect on material damage or specific property,
- importance of specific material property on structural/component design and performance.

Table 3 summarizes the characteristics of materials that are deemed important in terms of their applications to spacecraft systems and components. The "degree of importance" can be assessed by the "value of the data" for design purposes, which is also described in Table 3. In addition, the "scientific value" is also noted. It should also be stressed that any of the property data obtained from flight samples is always useful for validating ground-based simulation tests and for providing a comparative basis on material performance for long term space applications.

Included in Table 3 is a listing of the quantities that would have to be measured to provide the proper characterization of each material.

PROPOSED TEST PLAN

Once the material characteristics have been defined based on their relevance to the user community, Table 3 provides a summary of the quantities that need to be measured. Table 4 can then be employed to define the "methodology" by which each quantity can be measured to determine the specific material characteristic. It is essential in the compilation of a consistent data base that each of the experimenters agree on the methodology.

TABLE 1. LDEF ORGANIC COMPOSITES

Row #	Angle off Ram	AO fluence $x10^{21}$ a/sq.cm.	VUV $ESHx10^3$	Experiment No.	Principal Investigator	Materials
9	8*	8.32	11.1	AO134	Wayne Slemp, NASA Langley Res. C. (804) 864-1334	5208/T300,934/T300,P1700/C6000,P1700/C3000, 930/GY70
				M0003-9	Brian Petrie, Lockheed (408) 742-8244	CE-339/GY70, F263/T50, 934/T50, X904B/T50, E788/T50, 3501-5A/HMS, E788/C6000, 934/HMF176, CE-339/E-Glass, F593/P75, 934/P75
				M0003-8	Pete George, Boeing (206) 234-2679	934/T300, P1700/T300, PMR15/C6000
10	22*	7.78	10.7	A0054	TRW	Epoxy/Fiberglass
8	-38*	6.63	9.4	AO171	Ann Whitaker, NASA-MSFC (205) 544-2510	934/HMS, 934/P75S, P1700/HMF, Epoxy/S-Glass
				M0003-10**	Brian Petrie, Lockheed (408) 742-8244	X904B/GY70, 3501-5A/HMS, X904B/E-glass
				M0003-10**	Thomas Cookson, General Dynamics (619) 547-5081	X-30/GY70*, CE-339/GY70, CE-339/P75S, 934/P75S, 934/GY70, P1700/W722*, V378A/T300
				M0003-10**	Charles Smith, McDonnell Douglas (714) 896-5580	5208/T300*, P1700/T300*, PES/T300*, Polyimide/C6000*
				M0003-10**	Pete George, Boeing (206) 234-2679	934/T300, 3501-6/AS, P1700/T300, PMR15/C6000, LARC 160/Graphite
7	-68*	3.16	7.2	AO175	Dick Vyhnal, Rockwell (918) 835-3111, Ext. 2252	F178/T300, PMR15/C6000
12	82*	1.2	6.9	AO180	Rod Tennyson, U. of Toronto (416) 667-7710	934/T300, 5208/T300, SP288T300, SP328 Kevlar/Epoxy, SP290 Boron/Epoxy
				AOO19	David Felbeck, U. of Michigan (313) 994-6662	5208/T300 interleafed w. Kapton
1	112*	0.06	7.5	AO175	Dick Vyhnal, Rockwell (918) 835-3111 Ext. 2252	934/T300, LARC 160/C6000
5	-128*	0	8.2	P0005	Dean Lester, Morton Thiokol (801) 863-6809	Carbon/Carbon, Epoxy/Graphite, Epoxy/Kevlar, Epoxy/Glass (all mounted internally)
4	-158*	0	10.4	AOO54	TRW	Epoxy/Fiberglass
3	172*	0	11.1	M0003-10 M0003-9 MOOO3-8	(See Row 8 List for M0003-10) (See Row 9 List for M0003-9) (See Row 9 List for M0003-8)	
				AO138	Heinrich Jabs Matra Espace, France (33)-1-61-39-72-73	934/GY70, V-108/Kevlar, V108/T300, V108/GY70, V108/G837

* Some specimens flown with protective coating

** Part of Advanced Composites experiment integrated by Aerospace Corp., Gary Steckel (213) 336-7116

TABLE 2. COMMON MATERIALS

Row No.	Angle off RAM (°)	AO Fluence (10^{21} a/cm^2)	VUV (ESH x 10^3)	Materials				
				934 T300	5208 T300	PMR C6000	CE 339 GY70	934 P75
9	8	8.32	11.1	√	√	√	√	√
8	-38	6.63	9.4	√	√	√	√	√
7	-68	3.16	7.2			√		
12	82	1.2	6.9	√	√			
1	112	.06	7.5	√				
3	172	0	11.1	√	√	√	√	√

Table 3

Polymer-Matrix Composites - Data Base Requirements*

Characterization	**Quantities Measured**	**Value of Data** (Scientific & Design)
Atomic Oxygen (AO) Erosion	• thickness loss • mass loss • surface morphology • surface molecular structure changes • optical property changes	• material selection criteria based on erosion yield(cm^3/atom) • material lifetime predictions • synergistic effects due to VUV & AO • angular dependence effects • shadow effects • changes in structural CTE, strength, stiffness & buckling load • validate theoretical AO erosion models • degradation in system performance • guide for new material formulations & coatings
Coefficient of Thermal Expansion (CTE)	• strain/displacement as function of temperature	• change in CTE with vacuum outgassing • effects of combined VUV & AO on changes in CTE • effect of thermal fatigue & microcracking on CTE • validattion of zero CTE configurations for long term space exposure
Outgassing and Dimensional Changes	• outgassing products • strain/displacement changes with time and temperature • mass loss	• contamination • long term "permanent" dimensional changes (important for zero CTE design) • validation of theoretical desorption models • times to reach equilibrium state
Micrometeoroid/ Debris Impacts & Damage	• number & size distributions • surface damage area • number of penetrations • rear surface spallation	• probability of hits based on size and damage zone • effectiveness of coatings • probable cumulative damage to structural elements • angular dependence

Table 3 (cont'd)

Polymer-Matrix Composites - Data Base Requirements*

Characterization	**Quantities Measured**	**Value of Data** (Scientific & Design)
Mechanical Properties		
- Microcracking	• number and extent of transverse& interlaminar cracks	• damage effects on strength, stiffness of laminates • thermal fatigue data • validation of micromechanics models • design of stiffness/strength critical laminates • change in properties due to combined space environmental effects
- Modulus & Damping	• variation of modulus & damping with frequency and temperature	
- Transverse & Interlaminar Shear Strength	• shear strength & modulus	
- Tensile & Compression Strength	• tensile and compression strength and modulus	
Solar Absorptance & Infrared Emittance	• absorptance & emittance	• thermal property changes due to long term space environmental effects • system thermal design data
Molecular Structure Changes	• surface molecular structure changes	• reaction of resin systems with A0 & VUV radiation • resin long term stability & property retention • validation of theoretical reaction models

* **Note:**
All data useful for:
1. Validating ground-based space simulation systems and tests
2. Comparing relative material performance characteristics for long term space applications

Table 4

Polymer-Matrix Composites Proposed Test Plan

Characterization	Methodology
Atomic Oxygen Erosion	SEM Cross-Section Profilimetry, Gravimetric
Coefficient of Thermal Expansion	Laser interferometer, strain gauges dilatometer (in vacuum)
Outgassing and Dimensional Changes	Laser interferometer, strain gauges dilatometer (in vacuum)
Micrometeoroid/Debris Impacts & Damage	Optical microscope SEM
Mechanical Properties	
• Microcracking	SEM Cross-Section
• Modulus & Damping	DMA test system, various T
• Transverse & Interlaminar Shear Strength	ASTM D1002 ASTM D638, D695
• Tensile & Compression Strength	
Solar Absorptance & Infrared Emittance	ASTM E- 424, A ASTM E- 408, A
Molecular Structure Changes	Diffuse Reflectance • Solid State NMR

Lubricants, Adhesives, Seals, Fasteners, Solar Cells, and Batteries

Co-Chairmen: James Mason and Joel Edelman
Recorder: Harry Dursch