# DURABILITY OF SPACECRAFT MATERIALS

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## INTRODUCTION

Composite materials will be used for future space missions such as communication antennae, solar reflectors, satellite power systems, and a space operations center because of their unique combination of high specific stiffness and low coefficient of thermal expansion. (See fig. 1.) For long-life space missions (10-20 years), the durability of these materials in the hostile space environment has been identified as a key materials technology need.

This paper reviews NASA Langley's research efforts on the space durability of materials, including radiation effects on polymer matrix composites and films, dimensional stability of polymer matrix composites and tension-stabilized cables, and thermal control coatings. Research to date has concentrated on establishing a fundamental understanding of space environmental effects on current graphite-reinforced composites and polymer systems, and development of analytical models to explain observed changes in mechanical, physical, and optical properties. As a result of these research efforts, new experimental facilities have been developed to simulate the space environment and measure the observed property changes. Chemical and microstructural analyses have also been performed to establish damage mechanisms and the limits for accelerated testing. The implications of these results on material selection and system performance are discussed and additional research needs and opportunities in the area of tougher resin/matrix and metal/matrix composites are identified.

**FOCAL MISSIONS FOR ADVANCED TECHNOLOGY DEVELOPMENTS**

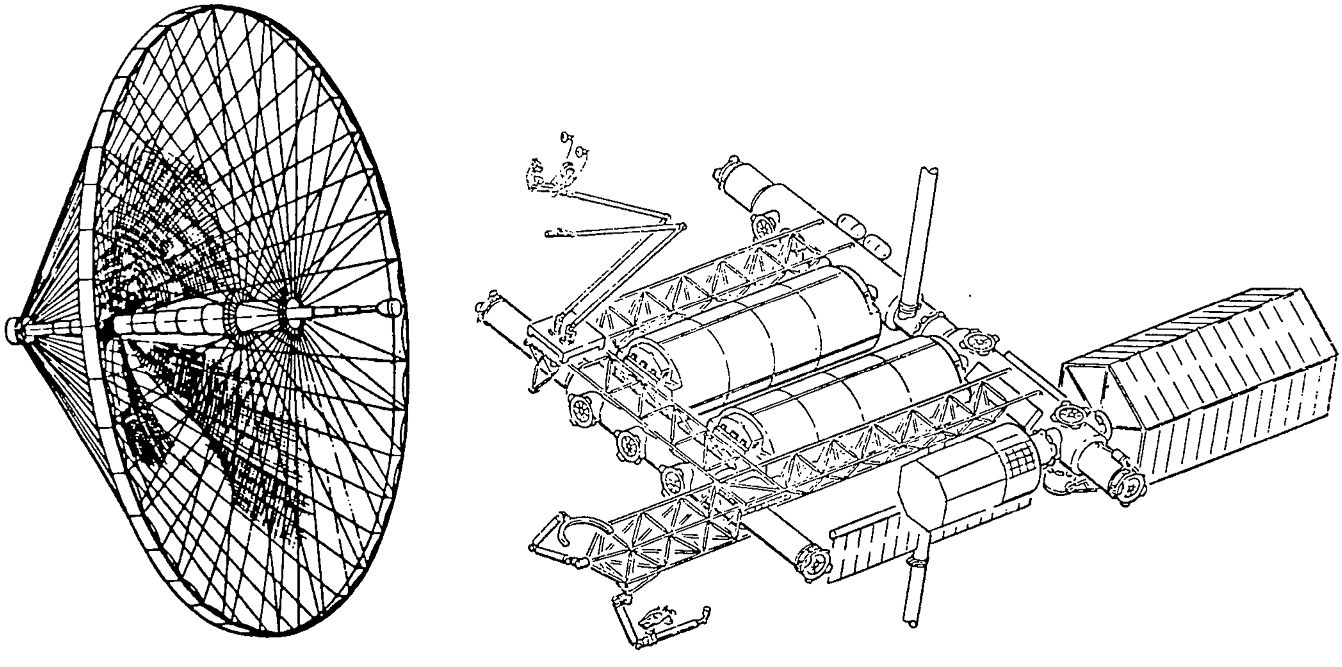


Figure 1

## HIGH-STIFFNESS LOW-THERMAL-EXPANSION SPACE MATERIALS

Structural requirements generally focus on light weight, high stiffness, and dimensional stability. Conventional aerospace materials such as aluminum and titanium do not provide these characteristics, whereas advanced graphite reinforced composites do. The coefficient of thermal expansion (CTE) values and specific stiffnesses of graphite composites and selected other low-expansion materials are compared in figure 2. Quartz and ULE (titanium silicate glass) fall within the preferred range of CTE values but do not provide the needed stiffness. A range of values is shown for both the graphite/resin and graphite/metal composites, indicating the flexibility that these composites offer for tailoring properties by varying the fiber type and ply orientation. Graphite/resin and graphite/metal composites both provide the needed CTE values and can be selected for a particular application depending on the stiffness requirements. Graphite/glass has a very low CTE and high stiffness but its low thermal conductivity may make it undesirable in applications where large thermal gradients could cause warping of the structure.

Metal matrix composites (graphite/aluminum and graphite/magnesium) research for space structures is being conducted in several Department of Defense programs. Resin matrix composites (graphite/epoxy, graphite/polyimide, and graphite/advanced resins) research is the primary focus of the NASA program. Each of the composite materials has potential advantages for large space structures. Continued research on both classes of composite materials is warranted to assure their technology readiness and to provide the designer with material options for optimum structural design.

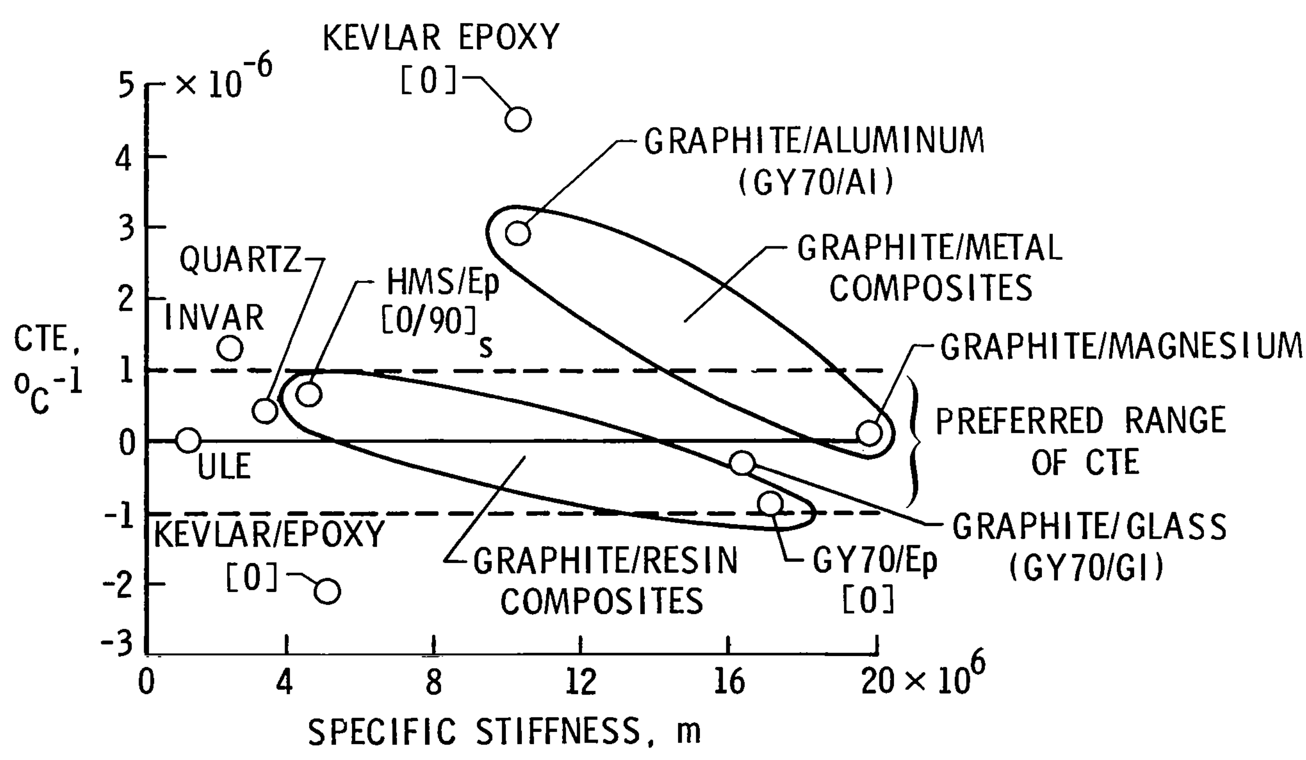



Figure 2

## DURABLE SPACE MATERIALS

Space-durable materials are a necessary requirement to achieving long-life space structures. (See fig. 3.) As previously noted, materials of construction will include advanced metal and polymer matrix composites, coatings for thermal control, polymer films, and adhesives. In low Earth orbit (LEO), materials will be subjected to repeated thermal cycles from approximately +200°F to -200°F, to UV radiation, and to ultra-high vacuum. Micrometeoroids and space debris are also considered as hazards in LEO. For higher orbits, such as goesynchronous Earth orbit (GEO), the materials will also be subjected to large doses of high-energy electrons and protons. The primary concerns for resin matrix composites are radiation-induced changes in mechanical and physical properties and dimensional stability, as well as microcracking due to residual stresses produced during thermal cycling. Similarly, the residual strains produced by the thermal expansion mismatch between the fibers and the matrix in metal matrix composites are likely to affect the dimensional stability of these materials.

Long-life coatings are required to keep the spacecraft system within design temperature limits. Degradation of the optical properties of these coatings by UV and particulate radiation and by contamination appears to be a significant problem that must be solved to achieve long-life systems (10 to 20 years).

The ability to predict the long-term performance of all classes of materials in space must be a central part of any durability program and may require flight experiments for verification of ground exposure data and analytical predictions.

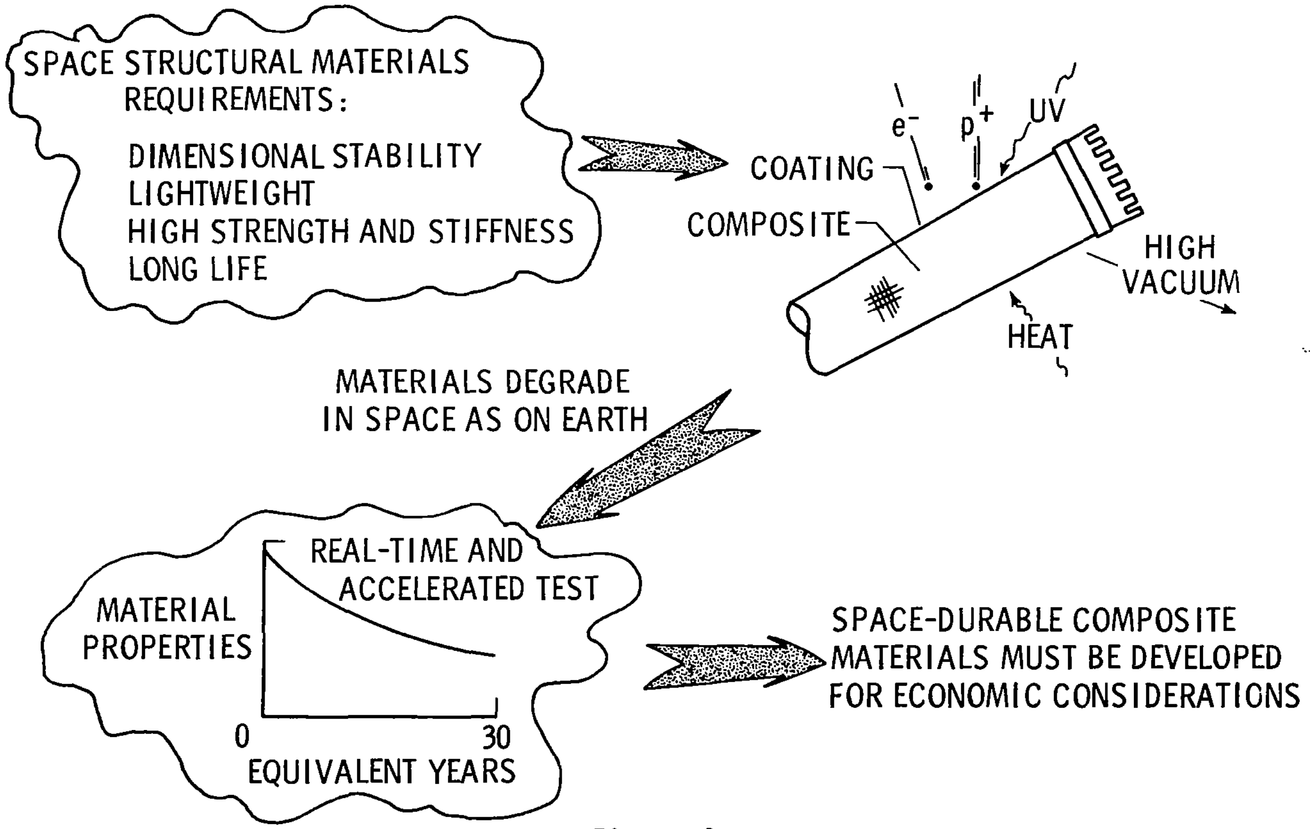



Figure 3

SPACE MATERIALS DURABILITY LABORATORY

Figure 4 shows a schematic of the Space Materials Durability Laboratory at NASA Langley. The laboratory is dedicated to the evaluation of the effects of space radiation on composite materials. This laboratory has a 2.5-MeV proton accelerator, a 1-MeV electron accelerator, and a solar simulator, all focused on a 12-inch-diameter target in a clean ultra-high-vacuum chamber. The accelerators were selected to cover the most prevalent energy range found in space for generation of bulk damage to composite materials.

Two smaller single-parameter exposure chambers are also being developed for in situ chemical characterization studies. In these chambers, polymer films are subjected to low-energy (100 KeV) electrons. Chemical and physical properties such as weight loss, outgassing and condensible products, infrared (IR) absorption, and dynamic moduli are followed during the irradiation. Mechanical properties of the films are obtained after irradiation. These characterizations serve as a sensitive measure of the radiation interaction and provide data for development of mechanistic models of the interaction process.

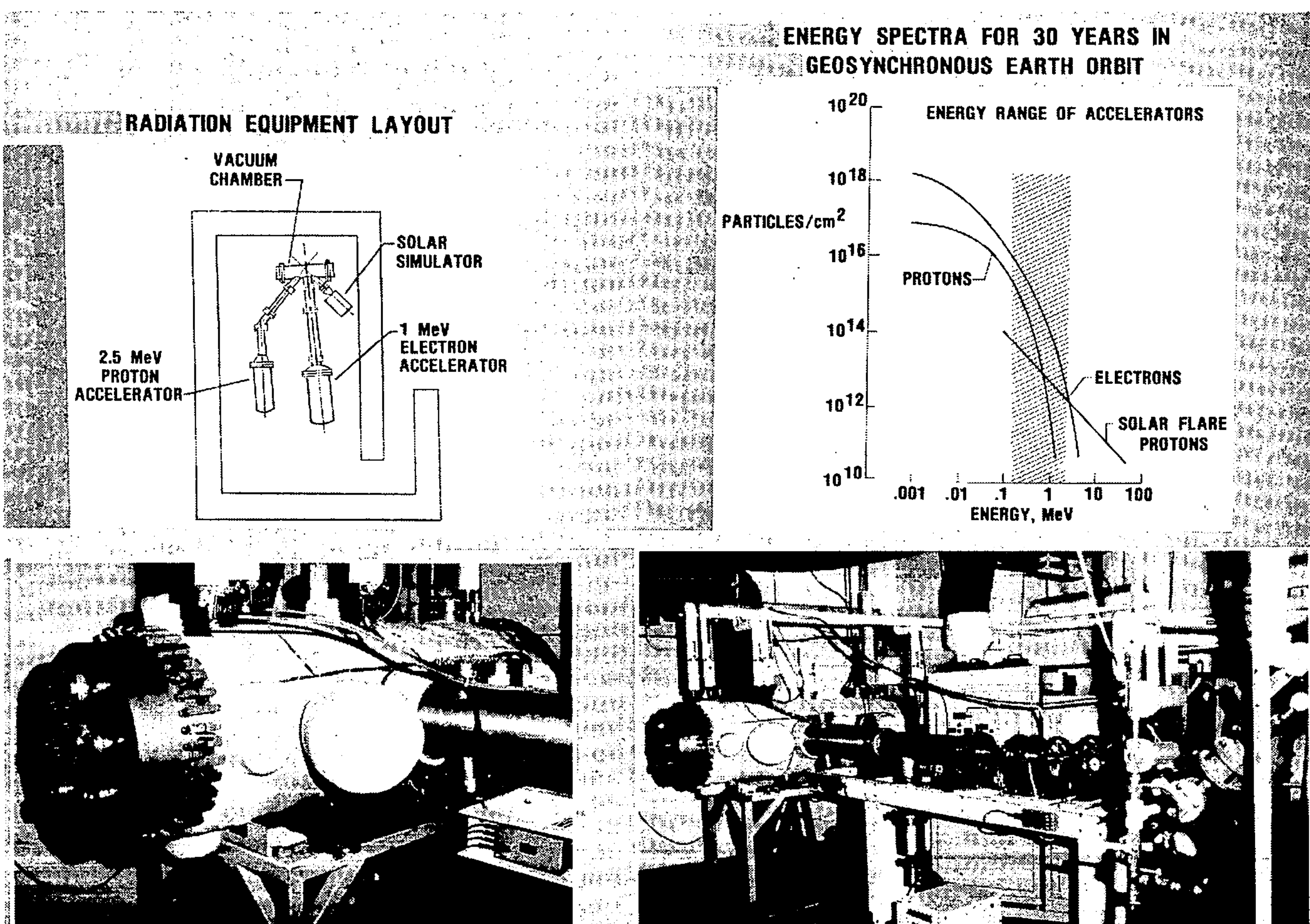



Figure 4

## TEMPERATURE OF POLYSULFONE FILM AND COMPOSITES DURING ELECTRON RADIATION

Because real-time exposures to evaluate space materials are not practical, a test acceleration methodology must be established that can be used to accurately predict long-term performance from short-time data. Test variables such as temperature, particle energy, dose rate, and type of energy must be evaluated to develop this methodology. Figure 5 shows the effect of dose rate (test acceleration rate) on sample temperature for both polysulfone films and a graphite/polysulfone composite (4-ply, unidirectional). Because of the low thermal conductivity of polymers and difficulties in maintaining good contact with the specimen cooling plate, the temperature of the composite specimen was found to increase substantially with dose rate. For polysulfone films, contact with the cooled base plate was easier to achieve and the maximum temperature at $10^8$ rads/hr was about 50°C. This is significantly below its glass transition temperature (190°C) and no major effect due to temperature is anticipated. High specimen temperatures, particularly those near the glass transition temperature, may change the radiation interaction mechanism and therefore produce material changes not representative of changes expected in actual service. For composites, long and thus expensive tests are required.

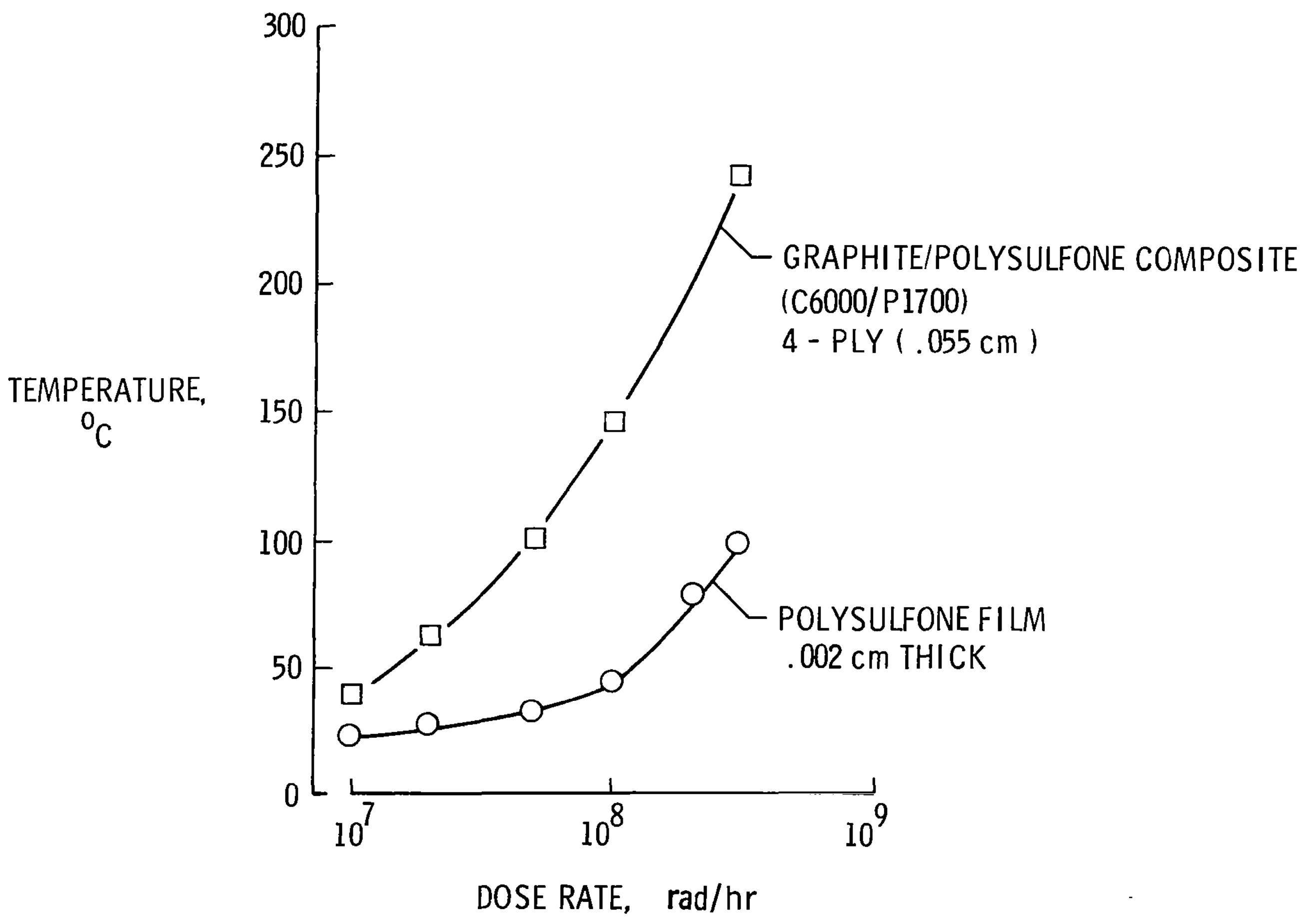



Figure 5

RADIATION EFFECTS ON FLEXURAL PROPERTIES OF A GRAPHITE/EPOXY COMPOSITE

The effect of radiation on composite mechanical properties has not been fully explored. However, limited data have shown that radiation does not significantly affect mechanical properties. An example of the limited data available is shown in figure 6. The flexural strength of small (1.2 x 2.5 cm) unidirectional specimens of T300/5208 graphite/epoxy composite after exposure to electron radiation is plotted as a function of absorbed dose in rads. These miniature specimens were used because of the small diameter of the electron beam. Exposures in vacuum for doses up to and including 8 x $10^9$ rads are shown. The fiber direction was in the direction of specimen length (longitudinal), so the flexural properties were fiber dominated. The flexural strength appears to increase slightly with dose - approximately 4 percent at 8 x $10^9$ rads. However, the size of the confidence band is large and could mask small changes in flexural properties. This scatter is typical of composite specimens and is a major problem in conducting environmental effects studies on composites.

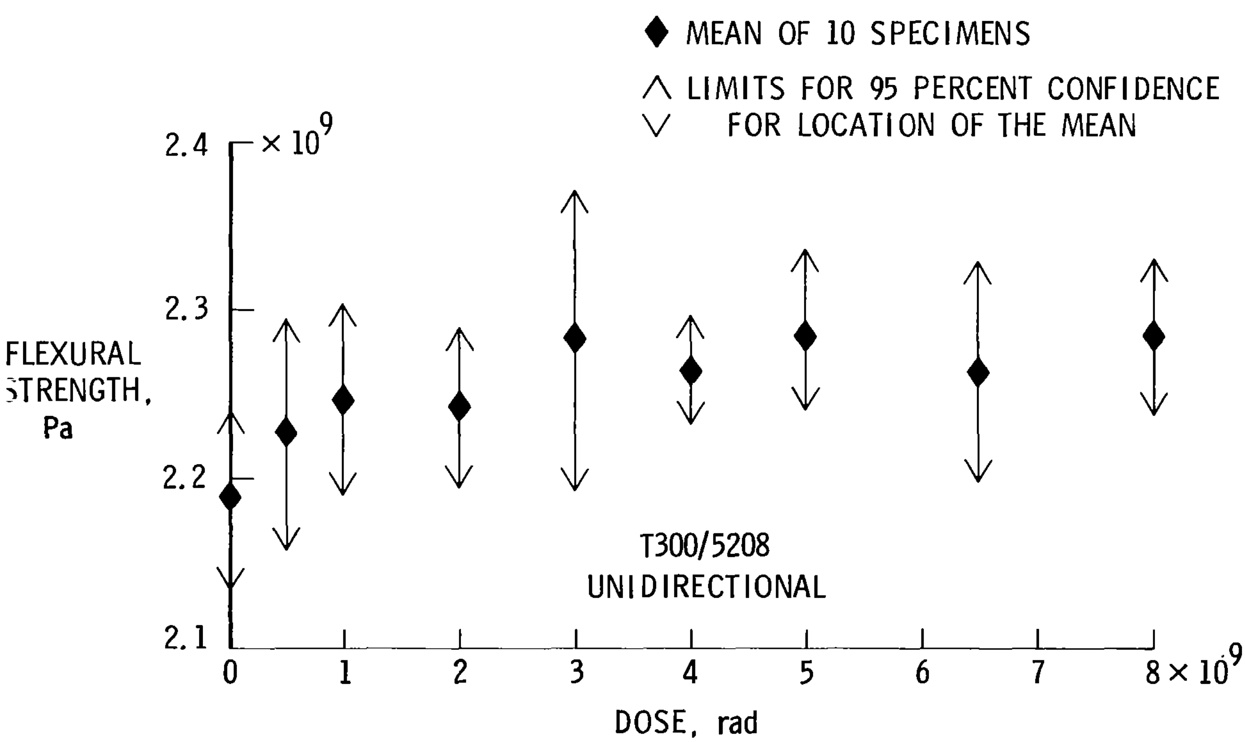



Figure 6

## EFFECT OF ELECTRON RADIATION ON THE MODULUS OF POLYSULFONES

Thermoplastics with improved properties are being actively considered for structural applications. One class that has received considerable attention for space and aircraft application is polysulfones. To assess long-term durability of these materials in space, a series of four materials, each with a different chemical structure, was exposed to either an electron or a proton environment using several different dose rates and particle energy sufficient to give a unifom dose through the polymer film. The absorbed dose was varied between $10^8$ and $10^{10}$ rads. Film samples of all materials were used because chemical characterization of films is much easier than for composites and provides a more sensitive measure of radiation damage.

The effect of total electron dose on the observed modulus of the four polysulfone films is shown in figure 7. Modulus values were obtained using an automated Rheovibron Dynamic Viscoelastometer with all data obtained at a frequency of 3.5 Hz. When determining modulus, the film sample was inserted, removed, and reinserted several times to eliminate sample mounting effects. All reported values are the average of at least three measurements.

For all materials, modulus increased as dose increased and the threshold value for a major change in modulus appears to be near $10^9$ rad. The percent increase ranges from about 24 percent for P-1700 to 58 percent for Radel 5000. This increase with dose suggests that crosslinking is occurring in all materials, particularly above $10^9$ rad.

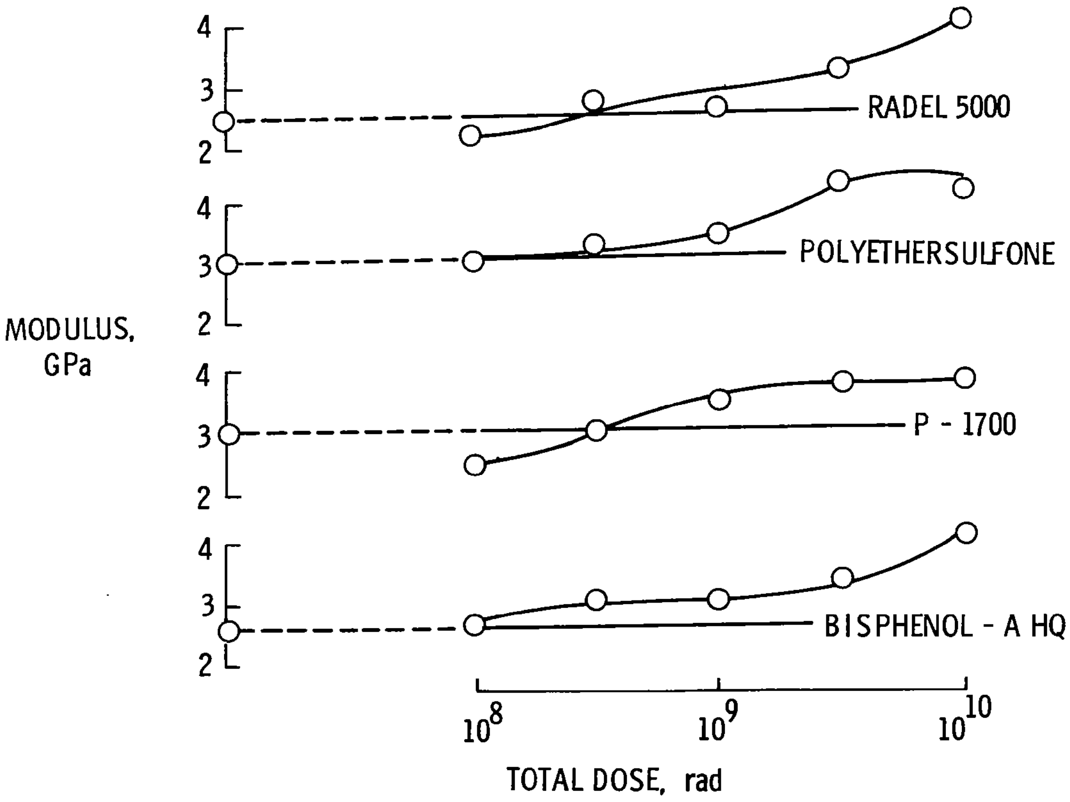



Figure 7

INFRARED SPECTRA OF ELECTRON-IRRADIATED P-1700

Two infrared spectra, each made from a film of P-1700 are shown in figure 8. This polysulfone is representative of the four materials studied. The lower curve represents the portion from 1600 to 600 $cm^{-1}$ frequency of the IR spectrum of nonirradiated polyethersulfone. The upper curve represents that same portion of the spectrum of polyethersulfone irradiated with electrons to $10^{10}$ rads. The $SO_2$ absorption band occurs at approximately 1400 $cm^{-1}$, which can clearly be seen as an absorption peak (an inverted peak) on the nonirradiated curve. However, after irradiation this peak is greatly diminished. Near 1300 and 1150 $cm^{-1}$ are the asymmetric and symmetric $\phi$-$SO_2$-$\phi$ absorption bands, respectively. These bands are present in the lower curve, but they have almost disappeared in the upper curve of the irradiated material. At approximately 1070 $cm^{-1}$, the C-O-C absorption band that appears on the spectrum for the nonirradiated specimen is absent in the spectrum for the irradiated polyethersulfone. The spectra shown here are the two extremes of the data actually obtained. The spectra of those specimens irradiated at lower doses resemble the spectrum of the nonirradiated material, and as the dose was increased, the spectra approached that of the curve at $10^{10}$ rads. All four polysulfones exhibited this same basic trend, with the $SO_2$, $\phi$-$SO_2$-$\phi$, and C-O-C bands being the most significantly affected by the radiation. The proton data, not shown here, also followed this trend, but the magnitude of change is less.

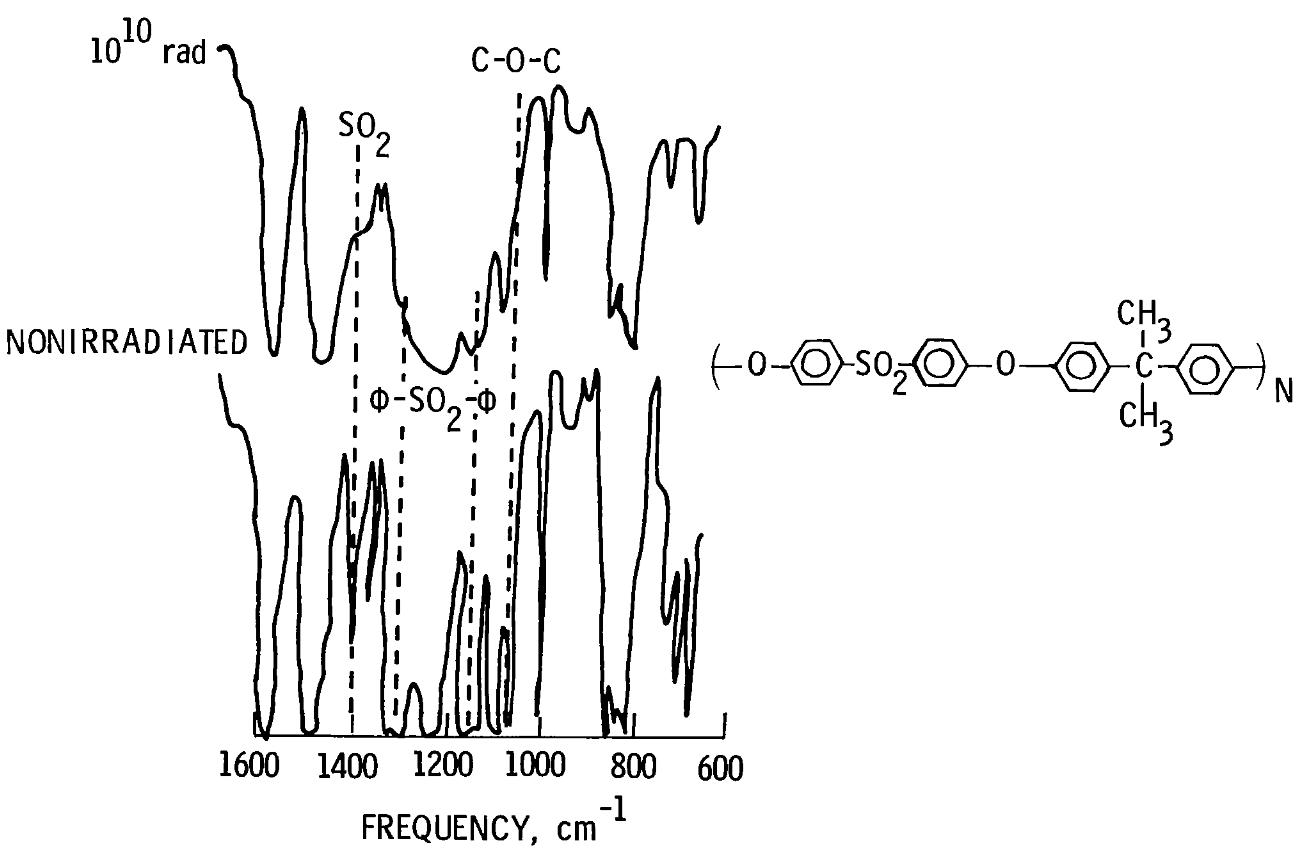



Figure 8

NORMALIZED ELEMENTAL COMPOSITION OF IRRADIATED P-1700

Following irradiation of each polysulfone film, a chemical analysis was performed to determine changes in elemental composition. Figure 9 shows this elemental composition data for one material (P-1700), normalized relative to the chemical analysis of the starting material, as a function of total dose. Similar chemical analysis data were obtained on all polysulfones studied and showed trends as presented in this figure. The analysis showed considerable loss of oxygen and moderate losses of sulfur and hydrogen. The threshold for a major decrease in oxygen occurs near 2 x $10^8$ rads. About 24 percent of the initial oxygen content is lost for P-1700 at $10^{10}$ rads and that loss could establish sites for crosslinks. This apparent loss is supported by the diminished absorption bands associated with oxygen in the IR data. The breaking of an oxygen bond by irradiation and subsequent combination of oxygen atoms to form oxygen molecules, which could then be lost to the surroundings, would explain the decrease in oxygen content and the diminished absorption bands. The loss of oxygen atoms from $-SO_2-$ linkages creates sites for crosslinking to adjacent chains and thus could explain the observed increase in modulus at high radiation doses.

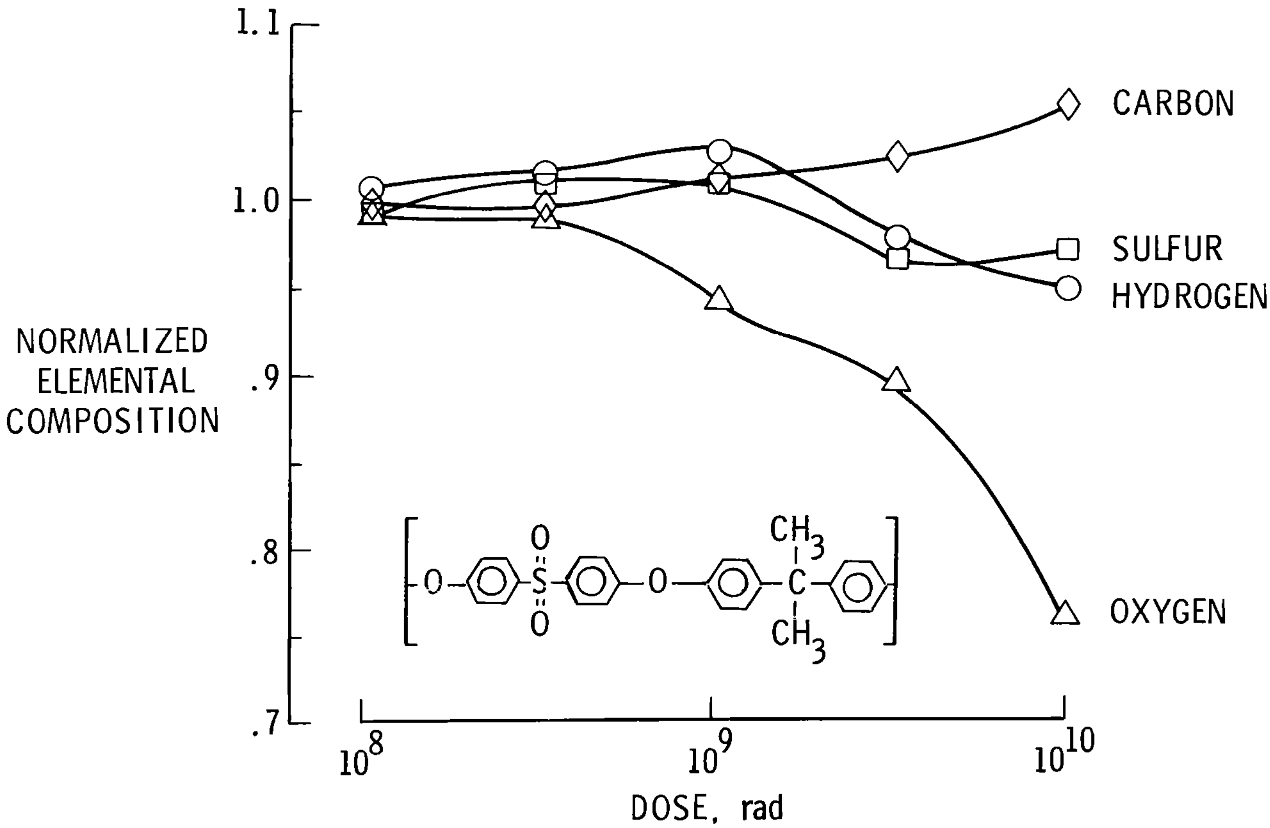



Figure 9

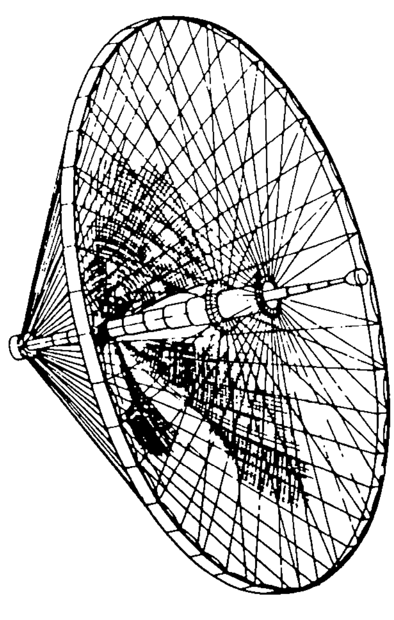
DIMENSIONAL STABILITY OF SPACE STRUCTURES

The performance characteristics of many large space structures are dependent upon their dimensional stability. One example of this is a space communications system, as shown in figure 10, in which small dimensional changes may cause a defocusing of the antenna and a corresponding loss in efficiency. The materials to be used in these structures include graphite cables, organic matrix composites, and metal/matrix composites. The primary factors controlling the dimensional stability of these materials include both thermal and mechanical load cycling, moisture desorption, radiation exposure, and microcracking. These factors may cause permanent changes in the thermoelastic properties, as well as permanent residual strains in the composite materials.

NASA Langley has undertaken a program to determine the dimensional stability of composite materials. This includes studying the effects of thermal cycling, radiation, and processing variability on these composites, both experimentally and analytically. Research to date has focused on the development of precise laser-based measurement systems for measuring small dimensional changes in composites and the effect of microcracking on the dimensional stability. The current effort on commercially available graphite/epoxy composites will be expanded in the future to include advanced composite systems, including hybrids, tougher resin/matrix composites, and advanced metal/matrix composites. The dimensional stability aspects of candidate tension-stabilized cable materials is also being investigated.

FACTORS CONTROLLING DIMENSIONAL STABILITY

- CABLES
  - THERMAL CYCLING
  - MECHANICAL LOADING
- ORGANIC MATRIX COMPOSITES
  - MOISTURE DESORPTION
  - THERMAL CYCLING
  - MECHANICAL LOADING
  - MICROYIELDING (CAUSED BY MATRIX MICROCRACKING)
  - RADIATION
- METAL MATRIX COMPOSITES
  - THERMAL CYCLING
  - MECHANICAL LOADING



HOOP/COLUMN ANTENNA

Figure 10

## TECHNIQUES FOR MEASURING SMALL THERMAL STRAINS

The composite laminates used in structures in which dimensional stability is critical will have CTE's approaching zero. Two laser interferometer systems capable of detecting strains on the order of $1 \times 10^{-6}$ have been developed - a moire interferometer and a Priest interferometer. The moire interferometry technique is similar to conventional methods of moire strain analysis except that a fringe multiplication phenomenon is employed. This allows the use of a relatively coarse grating on the specimen and a much finer grating for the reference. By observing selected diffraction orders, the resolution is dependent upon the frequency of the reference grating and not that of the coarse specimen grating (0.025-inch-thick silicone or epoxy replicated onto the surface). The specimen and reference grating are illuminated with a collimated beam from a 5-mW He-Ne laser and are mounted in an environmental chamber capable of cycling between 422 K (300°F) and 116 K (-250°F). Measurements are made by counting interference fringes between gage marks cast in the specimen grating.

A Priest interferometer measures the displacement of an unknown specimen relative to two parallel rods of a known low-expansion reference material. A schematic of the Priest interferometer developed in this study is shown in figure 11. The interferometer is enclosed in a chamber in which the temperature of circulating air is controlled by a resistance heater and liquid nitrogen. A He-Ne laser illuminates the interferometer through a window in the top of the chamber. The fringe pattern is recorded by a camera. A similar setup is being used in a thermal vacuum chamber to make measurements of specimens being cycled in vacuum.

**SCHEMATIC DIAGRAM OF PRIEST INTERFEROMETER**

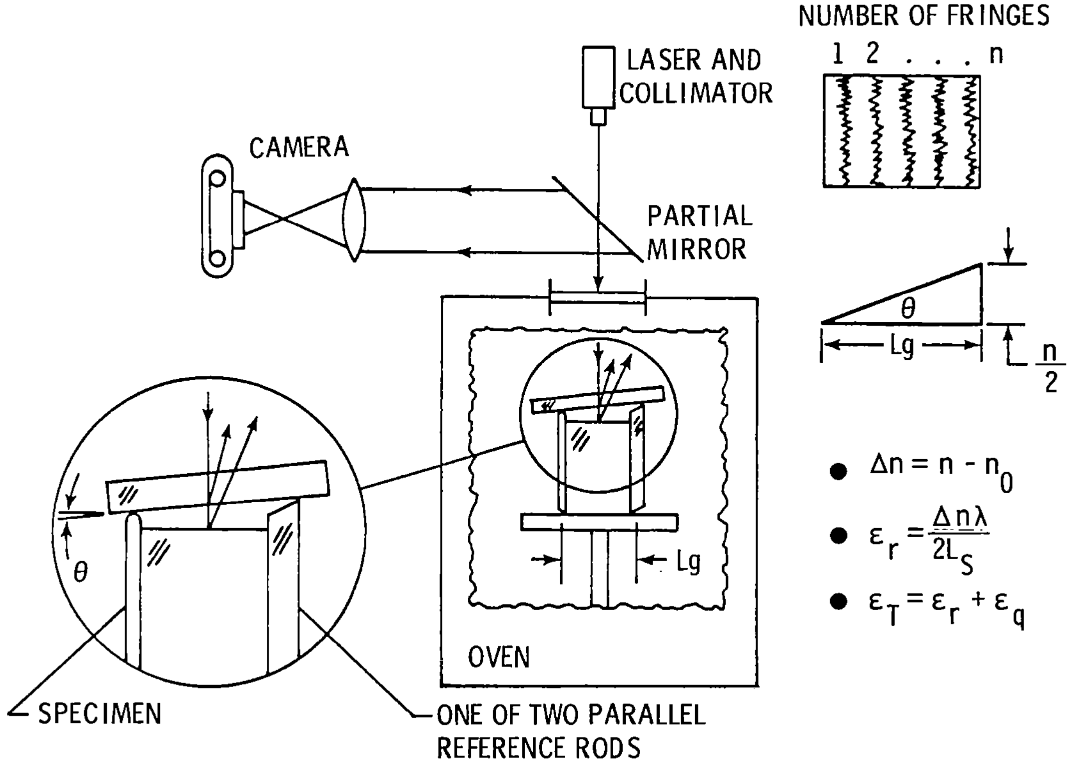



Figure 11

THERMAL EXPANSION OF UNIDIRECTIONAL AND ISOTROPIC T300/5208 Gr/Ep LAMINATES

Typical thermal expansion data collected for unidirectional and quasi-isotropic T300/5208 graphite/epoxy over a temperature range from -150°C to 100°C are shown in figure 12. These data show the large range of CTE values that can be obtained in composites depending on the laminate configuration. As can be seen, unidirectional T300/5208 provides a very small CTE, $-0.13 \times 10^{-6}$ to $0.17 \times 10^{-6}$ per °C, over the entire temperature range. The expansion behavior of these laminates is expected to bound the behavior of the laminates chosen for space structures. These data for different graphite fibers and resins are essential for verification of analyses used for tailoring laminates to achieve required stiffness and low CTE.

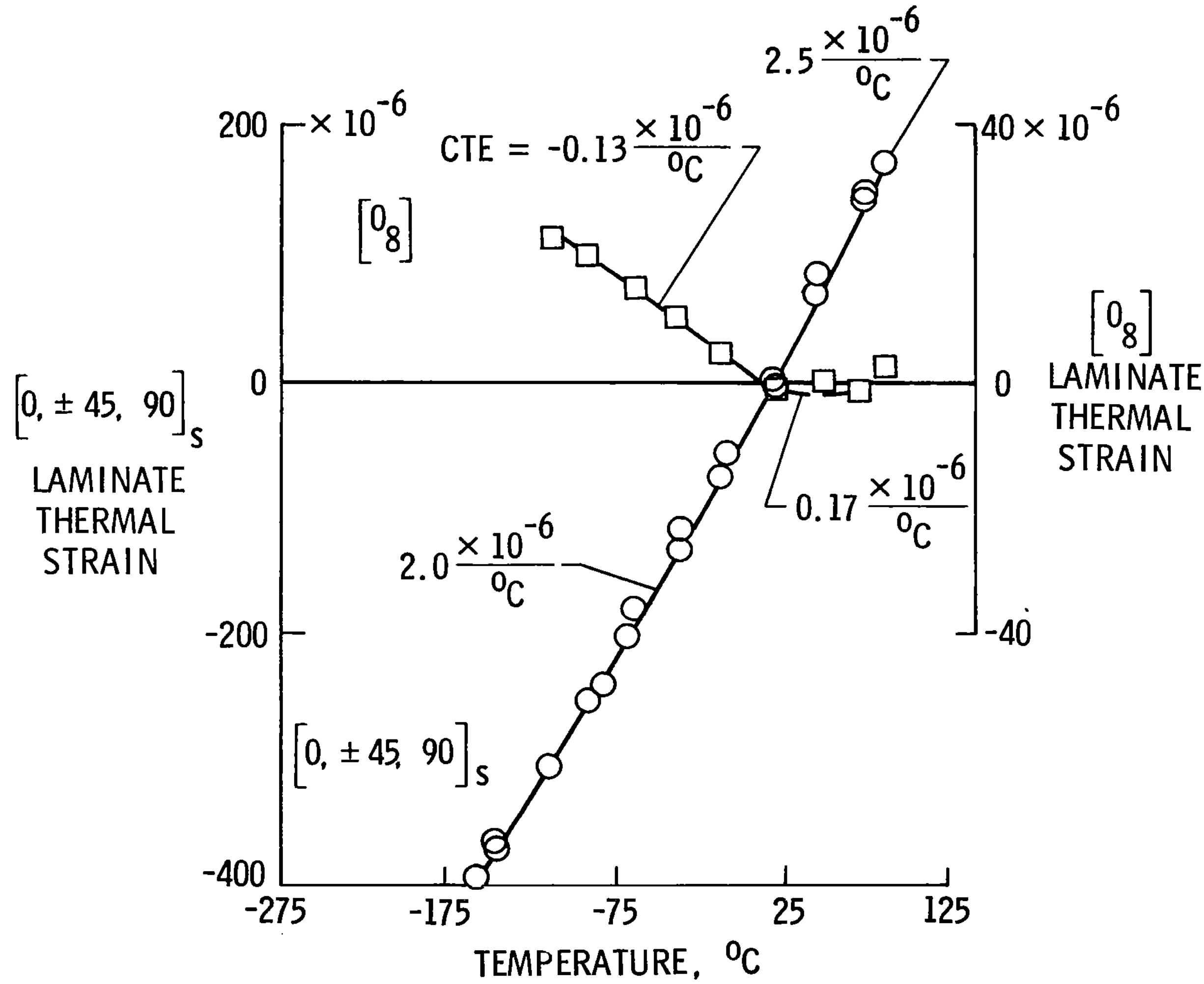



Figure 12

## MICROCRACKING IN COMPOSITES

Microcracks are small cracks in the matrix of organic composites that extend parallel to the fiber direction. They occur when the internal stresses exceed the transverse strength of an individual lamina. The two primary causes of microcracking are mechanical and thermal loads.

A limited amount of research has been conducted concerning the causes and effects of microcracking in composites. Repeated thermal cycling has been shown to cause microcracking in graphite/epoxy laminates, which causes the CTE to approach that of the unidirectional material. A typical example of this thermal microcracking is shown in figure 13. Research has also shown that residual strains due to microcracking of up to 20 $\mu\varepsilon$ may develop in graphite/epoxy during the first cooling cycle to $-143^{o}C$. What was lacking in past research was a quantitative relationship between the amount of microcracking and changes in CTE. This was the main focus of the current research.

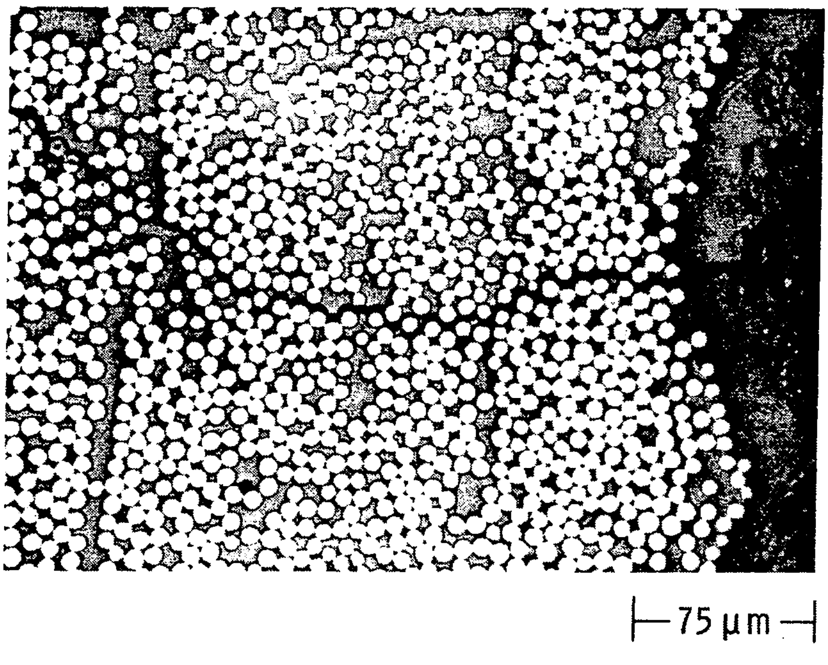



Figure 13

## MODELING THE EFFECT OF MICROCRACKING ON CTE OF COMPOSITES

The effect of microcracks on the CTE was modeled with a finite-element analysis. A generalized plane strain formulation was used with four noded linear general quadrilateral isoparametric elements capable of handling orthotropic material properties.

Numerical results were generated for the $[0_m/90_n]_s$ (m, n = 1, 2, 3) class of laminates using typical material properties for T300/5208. Results are presented in the form of CTE as a function of linear crack density in the 90° plies, which was varied from zero to three cracks per mm. The value of three cracks per mm was found to be an upper limit on the crack density formed in these materials during the experimental phase of this research.

The results for this family of laminates are shown in figure 14. As would be expected, the laminate configuration with the largest percentage of 90° plies experiencd the largest reduction in CTE. The CTE at three cracks per mm for the three laminates, $[0/90_3]_s$, $[0_2/90_2]_s$, and $[0_3/90]_s$, was reduced by approximately 80, 65, and 40 percent, respectively. For all of these laminates the CTE was reduced in a direction towards the value of the CTE for the unidirectional material, $-0.1 \times 10^{-6}$ per °C, and approached a stabilized value after approximately two cracks per mm.

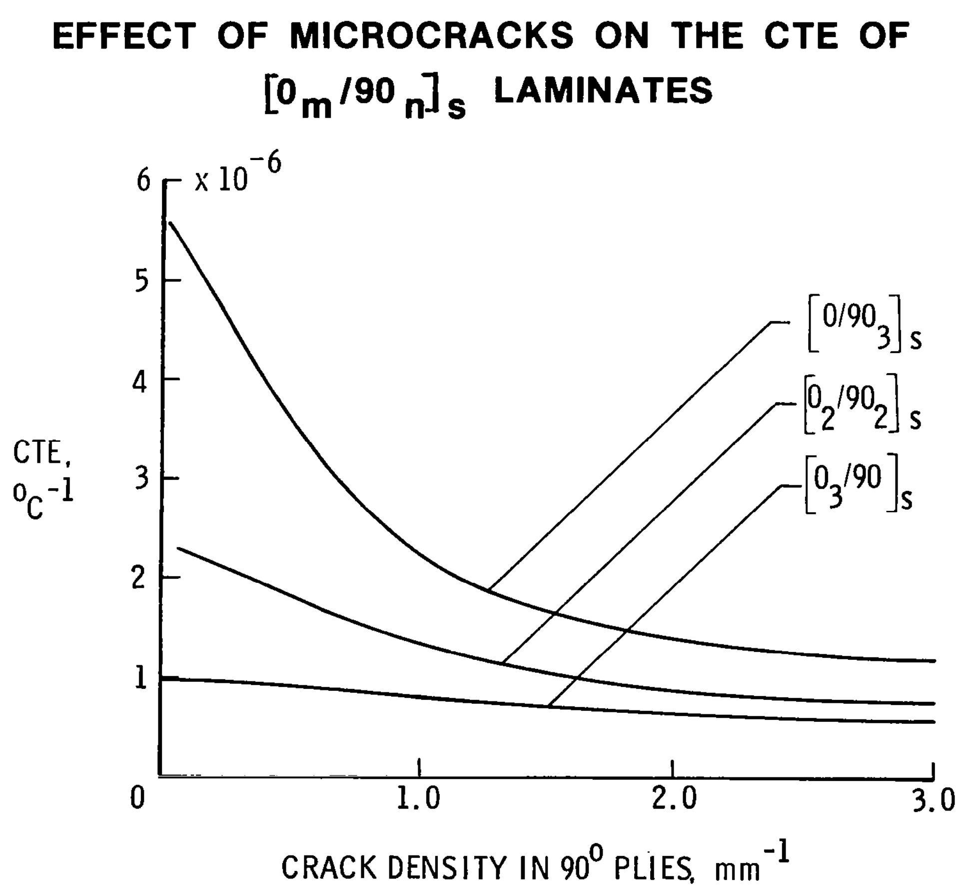



Figure 14

THERMAL CYCLING EFFECTS ON THE CTE OF GRAPHITE/MAGNESIUM COMPOSITES

Graphite-reinforced metal/matrix composites are an emerging new class of composites that have good potential for space applications. These materials can be fabricated with high-modulus (100 msi) pitch fibers to give a very low coefficient of thermal expansion (CTE). In addition, metal/matrix composites have a higher thermal conductivity than polymer/matrix composites and are therefore more resistant to thermal distortions resulting from through-thickness temperature gradients. Also, these composites are very stable in the space environment, are not affected by space radiation, and are very low outgassing materials. However, the thermal cycling response of these materials is one area of concern. Typical data collected on a three-ply graphite/magnesium composite manufactured with 45 volume percent pitch fibers are shown in figure 15. Upon cycling from room temperature to 60°C the CTE was observed to be approximately $0.95 \times 10^{-6}$ $°C^{-1}$. However, when the material was cycled to low temperature, the CTE was observed to change during the first several thermal cycles, as indicated. After approximately six cycles from room temperature to -80°C, the low-temperature CTE approached that observed at higher temperatures. This type of transient behavior is related to the state of residual stress in the composites due to the difference in expansion between the graphite fibers and the magnesium matrix. Considerable effort is being expended to characterize and quantify the thermal cycling response of these materials. To achieve a uniform CTE over a large temperature range, cyclic preconditioning of subelements made with graphite/magnesium may be required for precision space structures.

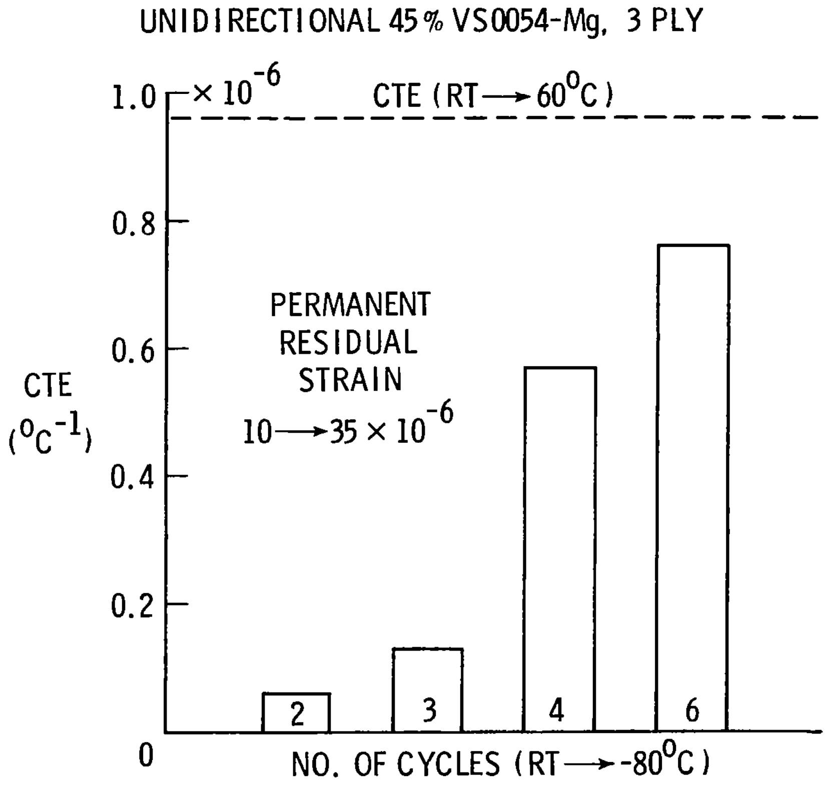



Figure 15

## IMPROVED TENSION-STABILIZED CABLE MATERIALS

Lightweight deployable cables are currently being used in certain antenna designs to shape the mesh reflector surfaces. Current cables are made of quartz fibers because quartz has a low thermal expansion, is inherently stable in the space environment, and can be made in small-diameter fibers. A typical cable, approximately 450 $\mu\varepsilon$ in diameter, is composed of approximately 2000 individual quartz fibers, 9 $\mu\varepsilon$ in diameter, held together by a Teflon cross wrap. One of the problems with this type of construction is the difficulty in aligning the fibers and keeping them aligned during handling and storage of the cables. This results in a small ($60 \times 10^{-6}$) but significant residual strain in the cable when subjected to repeated load or thermal cycles. Also, considerable variability is observed in this residual strain, making it difficult to accurately bias this out during fabrication when the precise length of each cable is determined.

The results of a recent program conducted to develop an improved cable are summarized in figure 16. Two major improvements were made that significantly advanced space cable technology. Unidirectional composites were made by impregnating the bare fibers with Teflon while holding the fibers straight under tension to achieve a better alignment of fibers and minimize the amount of twist in the fiber along the cable. This resulted in a substantial increase in the relative stiffness of the cable and reduction in residual strain after repeated thermal/mechanical cycling. Further improvements were achieved by using graphite fibers in place of the quartz fibers.

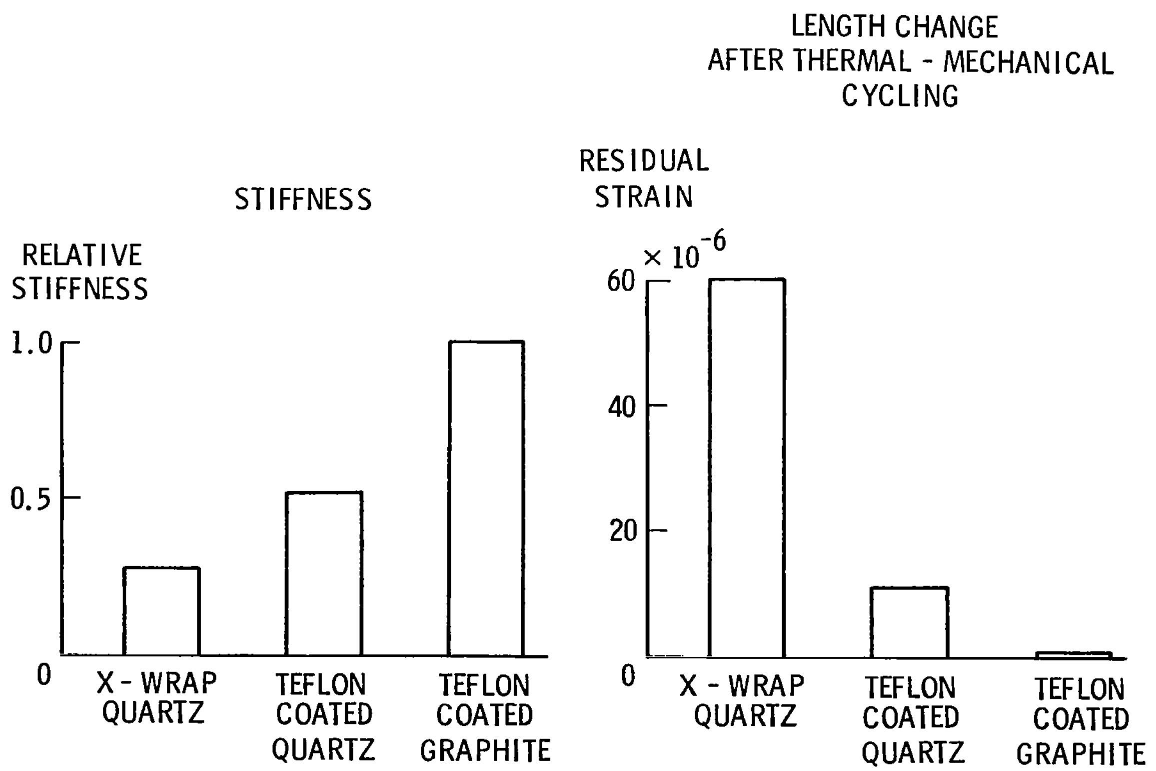



Figure 16

## THERMAL CONTROL COATING REQUIREMENTS FOR SPACE STRUCTURES

The basic requirement for thermal control coatings is to keep spacecraft components within allowable temperature limits. Thermal designers have two major problems. The first occurs when the temperature limit is dictated only by the solar heat input (for example, large-area structures) and the second occurs when both solar and internal heat are thermal inputs (for example, a manned habitat). In each case a coating with a different ratio of solar absorptance to thermal emittance is required. In figure 17 the coating requirements for a composite structure in GEO are compared to the requirements for a manned habitat in LEO. The major differences are: (1) low-emittance coatings are required for the composite structure to reduce the extent of cooldown during a solar occult, (2) coating to be used in GEO must be able to withstand high-energy electrons and protons in addition to UV, and (3) a higher electrical conductivity is required in GEO to eliminate spacecraft charging. Contamination would be a major source of coating performance degradation for the manned habitat because of contaminants from the Shuttle. However, repair or refurbishment of coatings can be considered for this application but not for GEO.

| | COMPOSITE STRUCTURE GEO | MANNED HABITAT LEO |
|---|---|---|
| OPTICAL PROPERTIES | $\alpha/\varepsilon$ - SELECTABLE WITH $\varepsilon \leq 0.3$ | $\alpha/\varepsilon$ - SELECTABLE WITH $\varepsilon \geq 0.8$ |
| TEMPERATURE | $-100^0$ TO $+80^0$C | $-100^0$ TO $+40^0$C |
| ENVIRONMENT | UV, $e^-$, $p^+$, VAC, $\Delta T$ | UV, VAC, $\Delta T$ |
| ELECT. CONDUCTIVITY | $\leq 10^{-8}$ (ohm$^{-1}$-cm$^{-1}$) | $10^{-8}$ - $10^{-17}$ (ohm$^{-1}$ - cm$^{-1}$) |
| LIFETIME | 10 TO 20 YEARS | 10 YEARS |

Figure 17

## LIMITATIONS OF CURRENT THERMAL CONTROL COATINGS

Figure 18 summarizes some of the existing and previously used radiator thermal control coating materials and identifies the major problem with each of these materials. The table also points out that no low-emittance paint-type coatings are available for use on large space structural components. Because of the weight penalty associated with use of this type of coating on small, thin-gage tubular structural elements, organic-matrix white-paint coatings would not likely be considered. New coating concepts that are easily adapted to any structural configuration and have good long-term durability in the radiation (ionized particle and UV) environment must be developed.

RADIATOR COATINGS (LOW ABSORPTANCE, HIGH EMITTANCE)

| COATING | PERFORMANCE |
| --- | --- |
| S-13 GLO (ZnO/RTV-602) | RTV 602 DISCONTINUED, NEW SILICONE BINDER FOR QUALIFICATION |
| ZOT ($Zn_2TiO_4$/SILICATE) | ABSORBS MOISTURE, HARD TO CLEAN |
| Z-93 (ZnO/SILICATE) | ABSORBS MOISTURE, EASILY CONTAMINATED |
| Al OR Ag/TEFLON | LARGE AREA APPLICATION DIFFICULT |

STRUCTURAL COATINGS (LOW ABSORPTANCE, LOW EMITTANCE)

NO QUALIFIED PAINT-TYPE COATINGS AVAILABLE

Figure 18

## DEVELOPMENT OF NEW THERMAL-CONTROL COATINGS

To achieve long-lived (10-15 years) space structures, space-durable coatings are required. Current thermal-control coatings are generally considered to degrade significantly after 5 to 7 years in orbit. NASA has undertaken a program to develop long-life, UV-resistant thermal-control coatings for space systems with tailored optical and electrical properties (fig. 19). In addition, these coatings must be capable of being applied over a large area of coverage. Both metallic- and oxide-vapor-deposited coatings will be evaluated for laminated polymer/matrix composites. The solar absorptance to emittance ratio will be tailored for operation over a -50°C to +100°C temperature range. These coatings will be exposed to electrons, protons, and UV radiation under space flight conditions to evaluate their long-term space durability. Contamination effects will also be evaluated to develop coatings with minimum sensitivity to contamination. A necessary requirement for these coatings is that they be low outgassing and thermally stable.

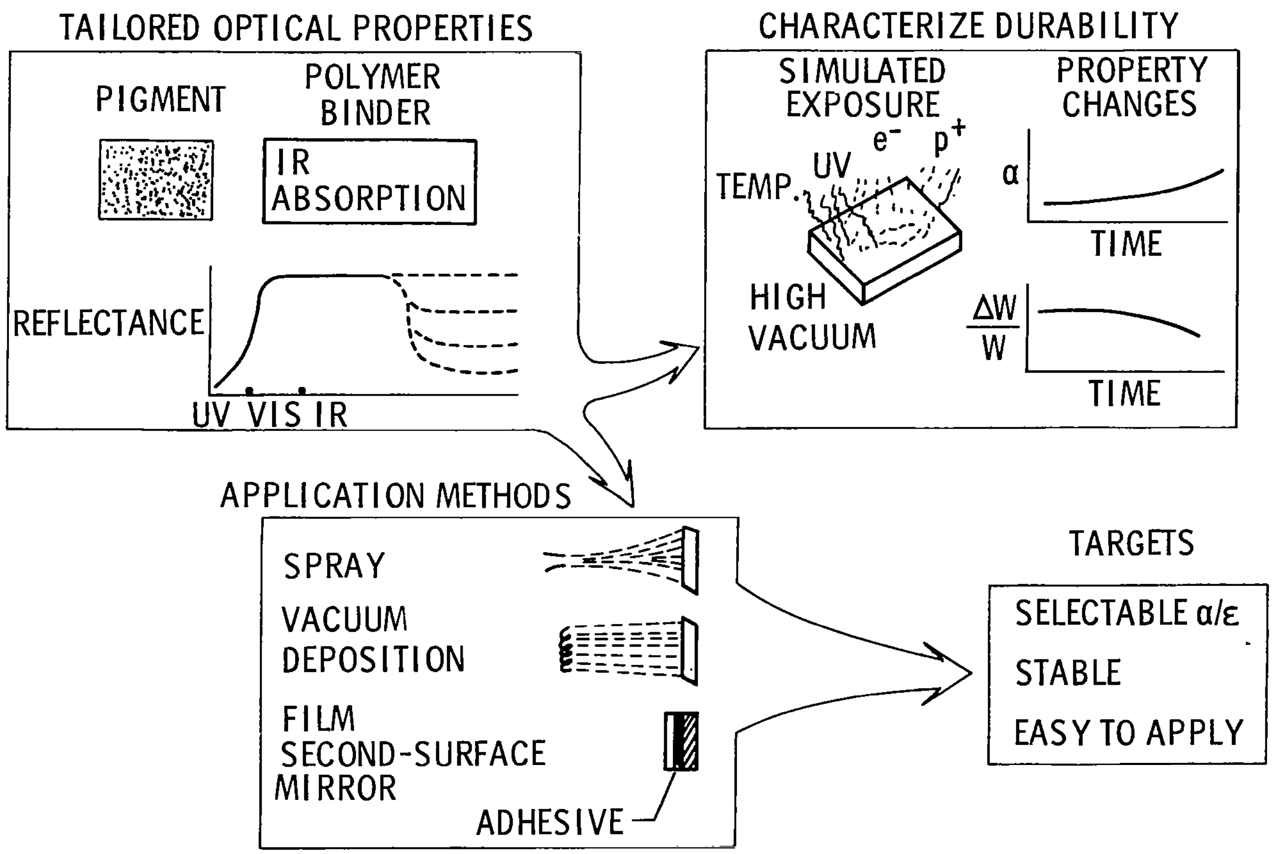



Figure 19

LDEF FLIGHT EXPERIMENT

In addition to development of new coating concepts, Langley has also maintained a continuing role in both ground testing and development of flight tests of coatings. A Langley coatings experiment will be flown on the Long Duration Exposure Flight (LDEF) spacecraft. The objectives of LDEF are to determine the effects of both the Shuttle-induced environment and the space radiation environment on selected sets of spacecraft thermal-control coatings. The experimental approach is to passively expose samples of thermal-control coatings to Shuttle-induced and space radiation environments, return the samples for postflight evaluation and compare with preflight measurements to determine the effects of environmental exposure. Two additional sets of samples will remain in the laboratory and will be analyzed for comparison with the flight data. Optical measurements of the samples will include total normal emittance and spectral reflectance. The experiment will use a 15.2-cm-deep tray and an Experiment Exposure Control Canister (EECC) to provide protection for some of the samples against the launch and reentry environment. The EECC will be programmed to open about 2 weeks after LDEF deployment and close prior to LDEF Shuttle retrieval (fig. 20).

Some samples will not be housed in the EECC and will be exposed to the Shuttle-induced environment during launch and reentry. Comparison of data from these samples with that of samples the EECC will yield information about possible contamination-induced degradation effects.

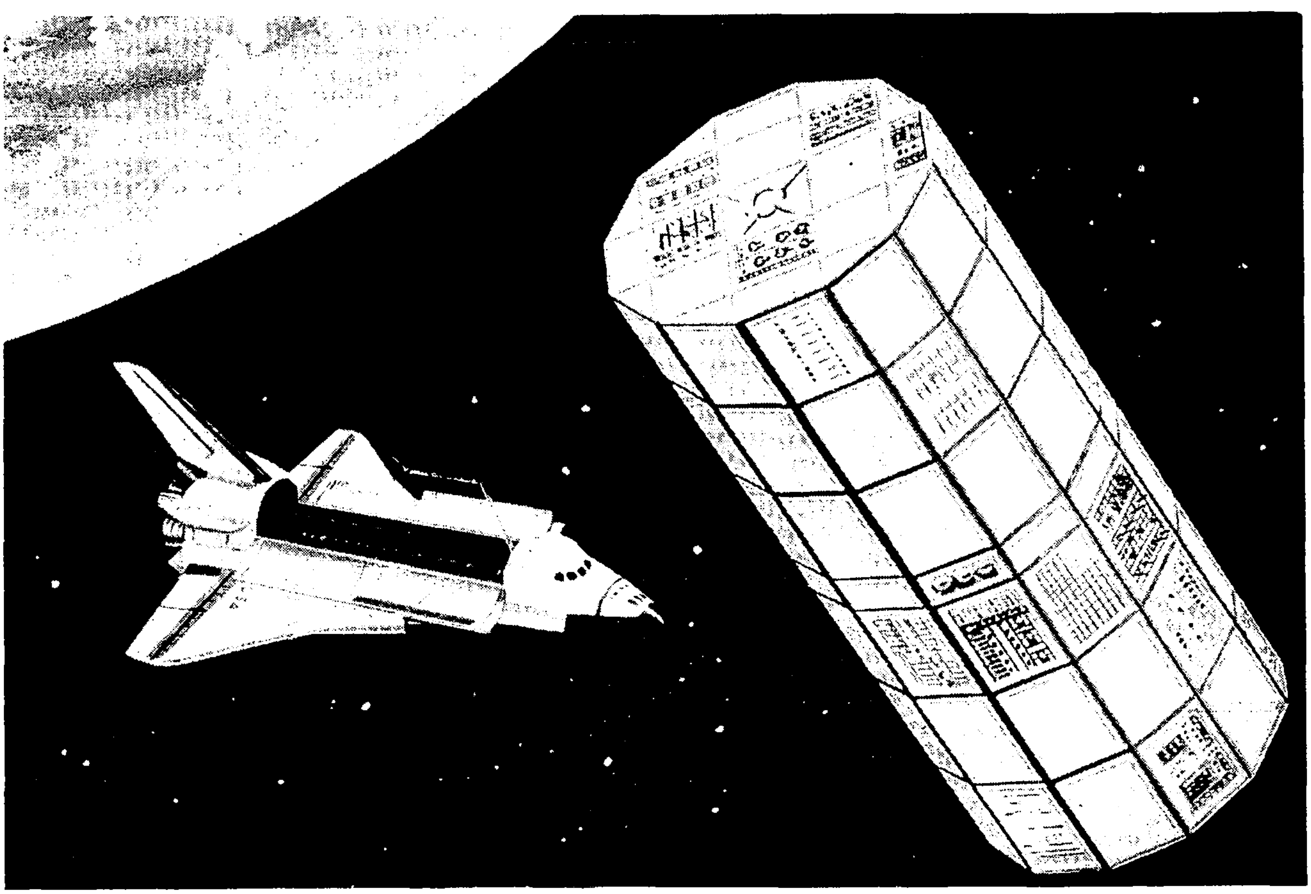


Figure 20

## CONCLUDING REMARKS

Polymer/matrix composite materials will be used for future space structures because of their excellent properties. Test results suggest that currently available composites will not undergo significant mechanical property changes for 20 to 30 years of service in space. No significant degradation has been observed in residual strength of composites upon laboratory exposure to electron radiation doses to $5 \times 10^9$ rads (equivalent to 30 years exposure in GEO). However, results to date are preliminary and were obtained using high dose rates (30 to 60 hours of test to simulate 30 years of exposure). Longer term low-dose-rate tests that are more representative of the conditions expected in space need to be conducted to determine if dose rate effects are significant. These tests are under way.

Extensive chemical characterization of polymer films exposed to radiation doses expected in space have shown that radiation does produce significant chemical changes. Degradation mechanisms have been established for a polysulfone and similar studies are ongoing on a number of other polymers. The point at which mechanical property changes appear has yet to be established. Radiation degradation models currently under development are expected to aid in understanding how radiation damage occurs in polymers and how chemical and mechanical properties are changed.

Thermal expansion measurements of composites are difficult because of the orthotropic nature of composites and because of their low coefficient of thermal expansion. To make precision strain measurements of composites, two laser interferometer techniques were developed. The effect of mechanically induced microcracks on the CTE was determined experimentally and an analysis was formulated to predict the observed changes. Results showed that microcracks reduce the CTE towards the value for the unidirectional material, and the reduction is a function of both the crack density and laminate configuration. Research in the area of improved cable materials has resulted in the development of a Teflon-impregnated graphite cable with a higher stiffness, lower CTE, and greatly reduced residual strain compared to the conventional quartz cable.

An assessment of current coatings indicates that they will not meet the thermal-control requirements for large space structures. Existing white paint coatings are heavy and undergo significant degradation in optical properties in 5 years of space exposure. Langley is working on new advanced coatings concepts including unique particulate and UV-radiation-stable polymer films that may be suitable for thermal-control coatings and blankets. The development of a clear polyimide offers good potential for developing improved coatings. The planned coating experiment on LDEF will provide useful data for evaluating Shuttle contamination of coatings and for verification of ground-based simulation tests.

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