N88-10093

STRUCTURES AND MATERIALS WORKING GROUP REPORT

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The Structures and Materials working group addressed a variety of issues relative to the Spacecraft 2000 concept. The objective was to determine key technology areas which the group considered critical to the efficient development of spacecraft of the 21st century.

Based upon the experience of the members of the group and the information presented in the plenary sessions, a brainstorming session brought numerous issues to the attention of the group. These were divided into structures issues and materials issues as presented below:

Structures Issues

- Test bed requirements -- ground and flight
- Weight -- increase payload mass fraction
- Analytical methods -- large flexible structures
- Damping -- active and passive
- Joints
- Broad temperature range of operation
- Stringent thermal deformation requirements (low / 0 CTE)
- Test -- Large structures -- flight and ground (1g)
- Integrated design
- Modularity
- Self adjusting structures
- Cost
- Risk minimization
- Effects of launch loads
- SAMS (Space Assembly, Maintenance and Servicing)

Materials Issues

- Requirements for advanced materials
    - metal matrix, carbon/carbon, and ceramic matrix composites
- Environmental factors -- atomic oxygen, radiation, UV
- Contamination
- Analytical capability for material property/performance prediction
- Design data base for advanced materials
- Material standards
- Coatings
- 30 year life
- Extreme thermal cycling

Due to the time constraints of the workshop it was important to limit the issues discussed to a manageable number. Towards that end, the group set some ground rules for selection of key issues. These ground rules are shown in Fig. 1. Although SDI hardware will place exceedingly demanding requirements on structures and materials performance, the SDI specific drivers were not emphasized for the purpose of this workshop. In the materials area, the group focussed primarily on structure, recognizing that all subsystems have materials requirements. For completeness in this discussion, some of these issues are presented below:

- o Cryogenic storage -- thermal insulation
- o Power conversion (800F - 1500F)
- o Propulsion (cryogenic - 4000F+)
- o Working fluids
- o High temperature / high voltage insulation
- o Optical materials
- o Coatings
- o Tribology

The readiness dates referred to in Figure 1 and referenced in following discussions refer to dates when the technology can be available for application to spacecraft. This translates to launch dates approximately five to eight years later.

Fig. 2 lists the technology drivers which were considered to be of prime importance to the evaluation of the current structures and materials state-of-the-art. These drivers reflect structural, environmental, system and cost considerations and resulted in the selection of the four key technology issues which the group then proceeded to further define and evaluate. These issues, presented in Fig. 3 are:

- o Advanced materials development
- o Analysis / design methods development
- o Test of large flexible structures
- o Development of diverse structural concepts

Each of the key issues were discussed in detail with the results summarized in Figs. 4 through 7.

<u>Advanced Materials Development</u> (Figs. 4a & 4b)

The basic premise is that 21st Century spacecraft demands will exceed the capabilities of materials currently available and in use. In addition to mechanical and thermomechanical requirements, stringent contamination and environmental resistance requirements will have to be satisfied over a spacecraft lifetime (up to thirty years).

Many of these advanced materials are now being fabricated only in laboratory quantities or for prototype hardware. For these materials to be accepted for S/C 2000 usage, reliable fabrication methods must be developed and implemented.

These will include fabrication on earth and, very possibly, on orbit in some cases.

Materials' properties data bases and standards will be necessary for efficient utilization of advanced materials. This will permit the development of material design allowables with realistic properties, not penalized for lack of data.

The readiness dates presented in Fig. 4b refer to readiness for incorporation into the design phase for S/C 2000. Actual use in flight could be five to eight years later.

Analysis/Design Methods (Figs. 5a & 5b)

A key area of technology concern relates to analysis and design methods for large flexible structures with their complex system interactions. The dynamics and control requirements will necessitate the employment of sophisticated analytical methods to develop these extemely flexible structures. These structures will exhibit non-linear behavior (geometrical, material, joints) which require detailed analysis models for performance predictions. The passive damping characteristics of the structure will have significant impact on its performance and a predictive capability is needed. This includes both material damping and the employment of passive damping mechanisms. The complex interactions with propulsion, thermal control, and other systems will add to the difficulties of the analysis tasks.

In general, joints make up a significant portion of the structural weight of a spacecraft. This can become critical in the case of large structures where the absolute joint weights can become prohibitive. In addition, the joints can have a profound effect on the overall structural stiffness, CTE, and overall dynamics. These complex interactions require new and improved analysis capabilities and design approaches to minimize any negative impacts.

Another area which would benefit advanced spacecraft structures is the design accomodation of material and process variability. By this we mean acceptance of the fact that each part will vary slightly from previous ones and, in order to meet some of the extremely tight overall structural/dimensional/thermomechanical requirements, the designer must learn how to accomodate these variations.

Finally, increased analysis and design capability should lead to cost and time savings (eliminating several iterations in the build-test cycle) and should lead to stuctures with reduced weight and risk.

Testing of Large Flexible Structures (Figs. 6a & 6b)

The third key technology issue addressed by the working group was the requirement to be able to test large flexible structures. We describe these structures as being somewhat like a "wet noodle" in flexibility. They are not self supporting on earth and the 1g environment could be a design load criterion which is inappropriate for the actual structure. The large structures which are envisioned exceed the current facility sizes making new test facilities a requirement on earth and, more importantly, the availability of a space test bed in the near future an important asset to be developed. Testing these structures in space is necessary to verify the analytical techniques used to design them. Vibration modes, damping, load distributions and deformed shapes are all affected by gravity. These and the effects of joint non-linearities should be confirmed through an in-space test capability.

Structural Concepts (Figs. 7a & 7b)

Spacecraft of the 21st Century will employ highly integrated / multi-functional structures. Various logistics drivers such as modularity, standardization, deployability and erectability will impact the design. The concept of space assembly, maintenance and servicing (SAMS) will affect the ultimate structural design. Some of these (integrated / multi-functional) will enhance the structural efficiency of the design while some (modularity, standardization, serviceability) may reduce the structural efficiency while minimizing initial and/or life cycle costs. The key here is to recognize that structures and materials requirements for Spacecraft 2000 will be affected by many new concept drivers which will have to be incorporated into the system.

Summary and Conclusion

As an evaluation of the appropriateness of the selection of these four issues, Fig. 8 presents a cross-check of the issues and their relationship to the technology drivers. As shown in that figure, although all of the issues addressed numerous drivers, the advanced materials development issue impacts six out of the seven drivers and is considered to be the most critical.

Fig. 9 presents a summary of the findings of the Structures and Materials Working Group. The advanced materials technology development and the advanced design/analysis methods development were determined to be enabling technologies with the testing issues and development of new structural concepts considered to be of great importance, although not enabling technologies.

In addition, and of more general interest and criticality, the group established the need for a Government/Industry commitment which does not, at this time, exist. This commitment would call for the establishment of the required infrastructure to facilitate the development of the capabilities highlighted above through the availability of resources and testbed facilities, including a national testbed in space to be in place within ten years.

GROUND RULES

- O SDI CONSIDERED, BUT NOT A PRIME DRIVER
- O MATERIALS - PRIME EMPHASIS ON STRUCTURE
  - RECOGNIZE ALL SUBSYSTEMS HAVE REQUIREMENTS
- O READINESS DATES
  - CURRENT FUNDING
  - SIGNIFICANT FUNDING (ENVIRONMENT OF 1960'S)

Figure 1

TECHNOLOGY DRIVERS

- O LIGHT WEIGHT
- O DIMENSIONAL STABILITY
- O PRECISION CONFIGURATION & CONTROL
- O LONG LIFE/ENVIRONMENTAL RESISTANCE
- O CONTAMINATION CONTROL
- O WIDE TEMPERATURE RANGE
- O MODULARITY/SAMS

Figure 2

KEY TECHNOLOGY ISSUES

- O ADVANCED MATERIALS DEVELOPMENT--
  S/C DEMANDS EXCEED CURRENT
  MATERIALS' CAPABILITIES
- O ANALYSIS/DESIGN METHODS--
  LARGE/FLEXIBLE STRUCTURES WITH
  SYSTEM INTERACTION
- O TEST OF LARGE FLEXIBLE STRUCTURES--
  NOT SELF-SUPPORTING IN 1G/TEST METHODS
  NON-EXISTENT
- O STRUCTURAL CONCEPTS--
  LOGISTICS & LIFE CYCLE COSTS

Figure 3

ADVANCED MATERIALS DEVELOPMENT

S/C DEMANDS EXCEED CURRENT MATERIALS CAPABILITIES

MATERIALS PROPERTIES

- O SPECIFIC STIFFNESS, STRENGTH, THERMAL/DIMENSIONAL,
  LONG-LIFE, NON-CONTAMINATING
- O METAL MATRIX (MMC), CERAMIC MATRIX (CMC), CARBON-CARBON (C/C)

RELIABLE MANUFACTURING PROCESSES

- O EARTH
- O IN-ORBIT

DATA BASE & STANDARDS (STATISTICAL DESIGN ALLOWABLES)

SUPPLIER INFRASTRUCTURE

Figure 4a

ADVANCED MATERIALS DEVELOPMENT (CONT'D)

BENEFITS

- O ENABLING TECHNOLOGY
- O INCREASED PAYLOAD FRACTION/PERFORMANCE
- O LIFE/ENVIRONMENT/CONTAMINATION
- O RELIABILITY

READINESS

	CURRENT $	SIGNIFICANT $
MMC	2000	1992
C/C	2005	1997
CMC	2010	1997

Figure 4b

ANALYSIS/DESIGN METHODS

LARGE FLEXIBLE STRUCTURES WITH SYSTEM INTERACTION

- DYNAMICS & CONTROL
  - O LARGE STRUCTURES
  - O DAMPING (ACTIVE, PASSIVE)
  - O NON-LINEARITIES (LARGE MOTIONS, JOINTS, MATERIALS)
  - O THERMODYNAMICS
  - O SYSTEM INTERACTION (PROPULSION, THERMAL CONTROL, ENVIRONMENT, ETC.
- JOINTS
  - O 50% + OF STRUCTURAL WEIGHT
  - O STIFFNESS, CTE VARIATIONS
  - O MANUFACTURING TOLERANCES
- DESIGN ACCOMMODATION OF MATERIAL AND PROCESS VARIABILITY

Figure 5a

ANALYSIS/DESIGN METHODS (CONT'D)

BENEFITS

- O ENABLING TECHNOLOGY FOR LARGE STRUCTURES
- O $ AND TIME SAVINGS (BUILD, TEST ITERATIONS)
- O WEIGHT; INCREASED CONFIDENCE

READINESS*

	CURRENT $	SIGNIFICANT $
DYNAMICS ANALYSIS	1997	1992
JOINTS (GROUND-VALIDATED)	1997	1992

* IF VERIFICATION CAPABILITY FOR LARGE STRUCTURES IN PLACE BY 1990.

Figure 5b

TESTING OF LARGE FLEXIBLE STRUCTURES

GRAVITY EFFECTS

- O NOT SELF-SUPPORTING IN 1G
- O 1G COULD BE DESIGN LOAD CRITERION
- O VIBRATION MODES & DAMPING
- O JOINT NONLINEARITIES
- O DEFORMED SHAPES; INCORRECT LOAD DISTRIBUTIONS

EXCEED FACILITY SIZE

IMPROVED SENSORS

MODULAR ASSEMBLY

Figure 6a

TESTING OF LARGE FLEXIBLE STRUCTURES (CONT'D)

BENEFITS

- O VERIFICATION OF ANALYSIS/DESIGN TECHNIQUES
- O QUALIFICATION/VERIFICATION METHODS FOR FLIGHT

READINESS

	CURRENT $	SIGNIFICANT $
O GROUND TEST BED	2000	1992
O SPACE TEST BED	2000 +	1997

Figure 6b

STRUCTURAL CONCEPTS

LOGISTICS & LIFE CYCLE COSTS

- O HIGHLY INTEGRATED/MULTI-FUNCTIONAL
- O MODULAR/EXPANDABLE/STANDARDIZED
- O DEPLOYABLE/ERECTABLE/FABRICATABLE
- O PRECISION/ADJUSTABLE COMPONENTS
- O JOINTS/FITTINGS
- O ASSEMBLY/MAINTENANCE/SERVICE

Figure 7a

STRUCTURAL CONCEPTS (CONT'D)

BENEFITS

IMPROVED PAYLOAD FRACTION

MISSION ADAPTABILITY

PERFORMANCE ENHANCEMENT

EFFICIENT PACKAGING/DELIVERY/CONSTRUCTION - WEIGHT / $

READINESS

FUNCTION OF PROGRAM /$/ EXTENT

Figure 7b

TECHNOLOGY ISSUES ADDRESS DRIVERS

	Light Weight	Dimens. Stability	Precision Config. & Control	Long Life & Environmental Resistance	Contam. Control	Wide Temp. Range	Modularity -- SAMS
Advanced Materials Development	X	X	X	X	X	X	
Analysis/Design Mehtods	X		X				X
Test Large/ Flexible Structures	X	X	X				X
Structural Concepts	X	X	X				X

Figure 8

SUMMARY

ENABLING TECHNOLOGIES

- O ADVANCED MATERIALS DEVELOPMENT
- O ADVANCED ANALYSIS/DESIGN METHODS

KEY TECHNOLOGIES

- O TEST OF LARGE FLEXIBLE STRUCTURES
- O DEVELOPMENT OF NEW STRUCTURAL CONCEPTS

GOVERNMENT/INDUSTRY COMMITMENT

- O ESTABLISHMENT OF REQUIRED INFRASTRUCTURE TO FACILITATE DEVELOPMENT OF REQUIRED CAPABILITIES THROUGH AVAILABILITY OF RESOURCES AND TEST BEDS.

Figure 9

APPENDIX A - DEVELOPMENT OF MATERIALS FOR FUTURE SPACECRAFT

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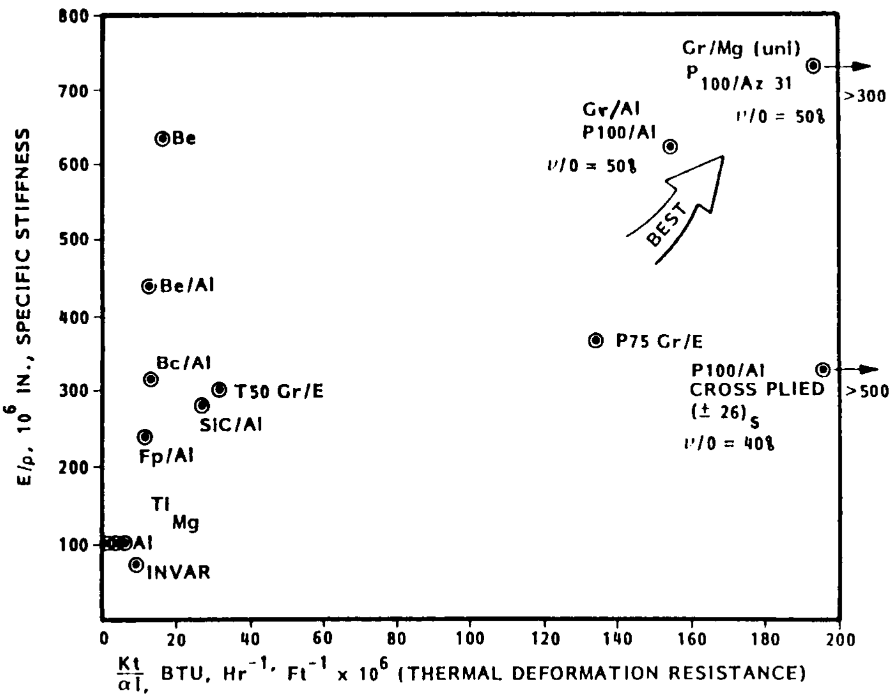
Naval Surface Weapons Center

FIGURE OF MERIT

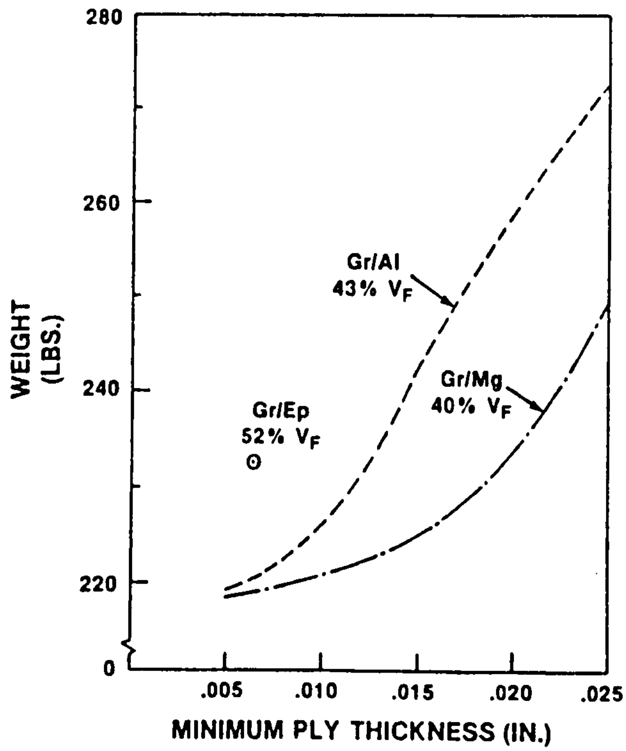
SPECIFIC STIFFNESS VS THERMAL DEFORMATION RESISTANCE



MATERIAL REQUIREMENTS FOR SPACE APPLICATIONS

- LOW DENSITY
- HIGH SPECIFIC STIFFNESS
- ZERO/NEAR ZERO COEFFICIENT OF THERMAL EXPANSION
- DIMENSIONAL STABILITY
- GOOD THERMAL AND ELECTRICAL CONDUCTIVITY
- HIGH TEMPERATURE RESISTANCE
- NO OUTGASSING
- NO MOISTURE ABSORPTION
- RADIATION TOLERANCE
- LASER TOLERANCE

OPTICAL BENCH-TOTAL STRUCTURE WEIGHT VS. MINIMUM PLY THICKNESS



POTENTIAL METHODS FOR FABRICATING THIN-PLY METAL MATRIX COMPOSITES

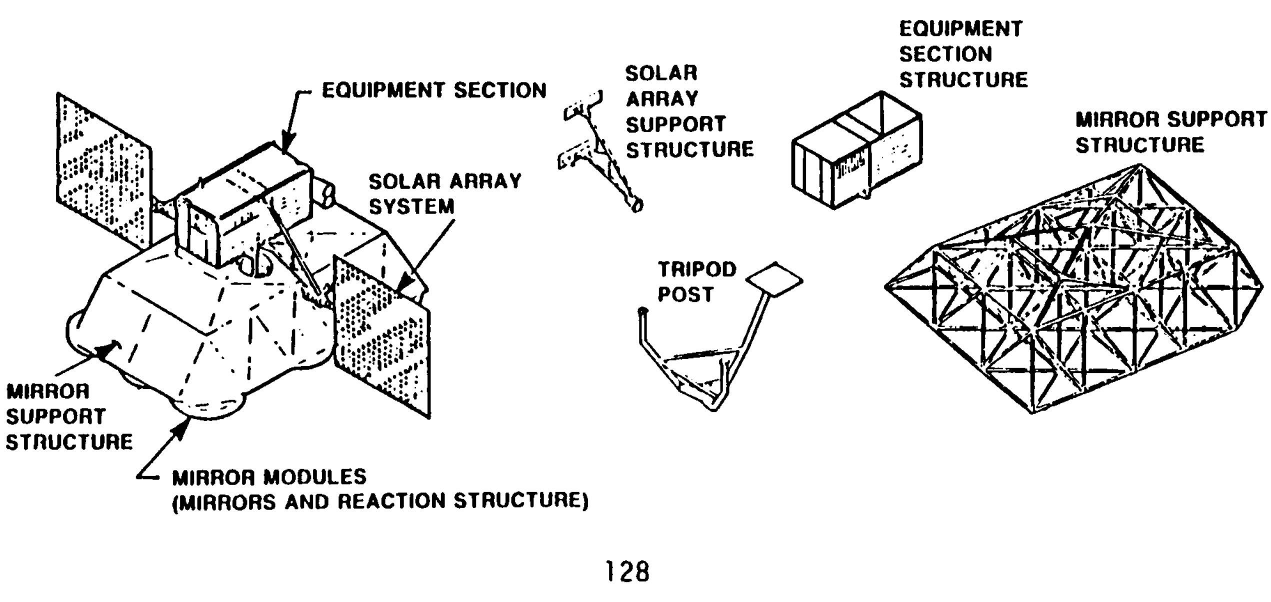
1. THIN WIRE FABRICATION
2. HOT ROLLING OF WIRES
3. SQUEEZE ROLLING AND/OR DIE SIZING OF WIRE
4. ION PLATING
5. TOW-SPREADING
6. INFILTRATION OF PRE-WOVEN GRAPHITE TAPE/CLOTH
7. GROUND AND FLATTENED WIRE

DEVELOPMENT OF METAL MATRIX COMPOSITES FOR UTILIZATION IN SATELLITES

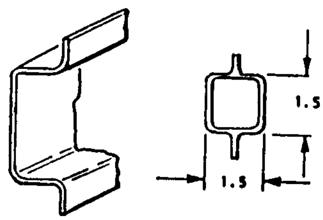
OBJECTIVE: TO DEVELOP METAL MATRIX COMPOSITE ELEMENTS FOR USE IN NAVY SPACE SYSTEMS; AND

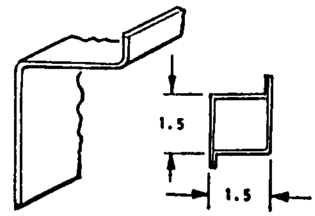
TO EVALUATE THE PERFORMANCE PAYOFFS, COSTS, AND RISKS IN FABRICATING THE SELECTED MMC ELEMENT FOR A COMPONENT DEMONSTRATION.

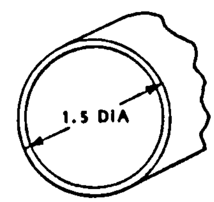
SLCSAT RELAY SATELLITE STRUCTURAL SUBSYSTEM ELEMENTS



STRUCTURAL ELEMENTS FOR TESTING







BASIC ELEMENT: DIFFUSION-BONDED HAT SECTION CREEP FORMED TUBE: TWO HAT SECTIONS ARE WELD-BONDED INTO RECTANGULAR TUBE MATERIAL: Gr/Mg or Gr/Al, 2 PLY, UNIDIRECTIONAL, V_f = 45%, t = .05 in. DEVELOPMENT REQUIRED: • CREEP FORMING PARAMETERS • SMALL BEND RADII • WELD-BONDING PARAMETERS NUMBER 10 x 12 IN. LONG MAKES 5-□-TEST ELEMENTS	BASIC ELEMENT: MODIFIED Z-SECTION DIFFUSION-BONDED IN MATCHED DIES TUBE: TWO Z-SECTIONS ARE WELD-BONDED INTO RECTANGULAR TUBE MATERIAL: Gr/Mg OR Gr/Al 2 PLY, UNIDIRECTIONAL, V_f = 45%, t = .05 in. DEVELOPMENT REQUIRED • LARGE MATCHED DIES • LENGTH TO 60 IN. • Gr/Mg PARAMETERS NUMBER 10Z x 12 IN LONG MAKES 5 □ TEST ELEMENTS	BASIC ELEMENT ROUND TUBE 2 PLY PULTRUDED WITH SURFACE FOILS MATERIAL: Gr/Mg OR Gr/Al UNIDIRECTIONAL t = .05, VF 45% DEVELOPMENT REQUIRED • LENGTH TO 60 In. • Gr/Mg PARAMENTERS • VOLUME FRACTION > 40% • STRAIGHTNESS NUMBER 5 PCS X 10 In. LONG

INERTIAL MEASUREMENT UNIT — STABLE MEMBER

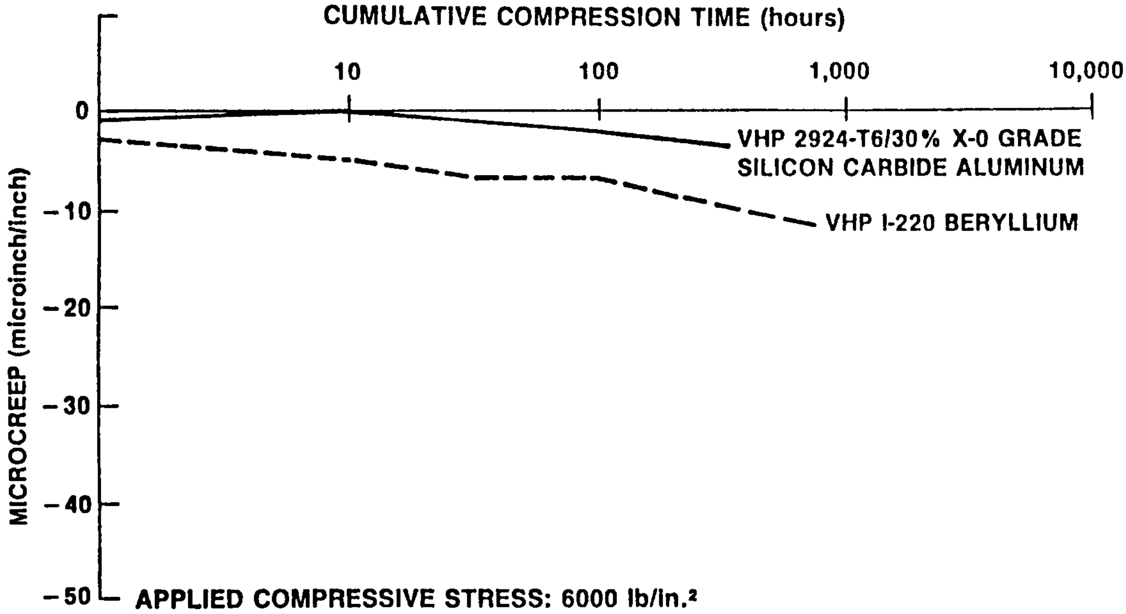
OBJECTIVE: DEVELOP A MATERIAL TO REPLACE BERYLLIUM FOR OPTICAL BENCH APPLICATIONS (SHIPS, TACTICAL MISSILES, STRATEGIC MISSILES)

RATIONALE FOR DEVELOPMENT:

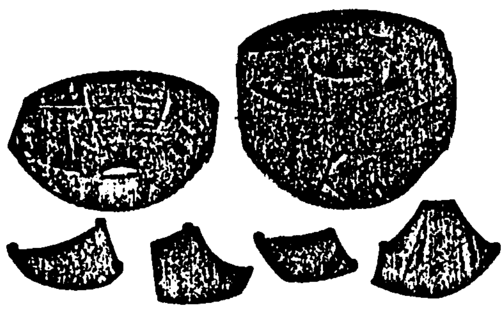
- BERYLLIUM IS A COSTLY CRITICAL MATERIAL, SUPPLIED BY A SOLE SOURCE PRODUCER
- SiC/Al METAL MATRIX COMPOSITE POSSESSES THE NECESSARY PROPERTIES TO REPLACE BERYLLIUM:
  - LIGHTWEIGHT AND DIMENSIONALLY STABLE
  - ISOTROPIC MECHANICAL PROPERTIES
  - THERMAL EXPANSION AND THERMAL CONDUCTIVITY TAILORABLE TO MATCH BERYLLIUM

IMU STABLE MEMBER

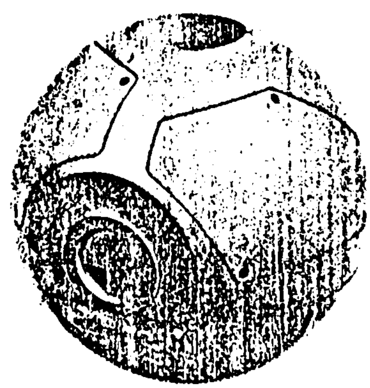
MICROCREEP CHARACTERISTICS UNDER MAXIMUM LOAD



MACHINED MMC GUIDANCE SYSTEM COMPONENTS



ELECTRONICS SHELL, INSTRUMENT COVERS AND STABLE MEMBER



ASSEMBLY OF COMPONENTS

DATA SUMMARY FOR P-2056

40 v/o $B_4C/Mg - 6\ Zn$
(7" DIA X 1-5/8" THICK, AS-PRESSED; FORGED TO 1-5/16" THICK)
AS-PRESSED DENSITY: 100% OF THEORETICAL

CONDITION	TEST NO.	E, msi	UTS, ksi	YS, ksi	PL, ksi	ε_f%
AS-FORGED	7669	18.3	40.3	–	23.0	.266
	7670	17.8	36.3	–	22.3	.231
	7683	17.6	23.4	–	–	.135
	7684	17.8	35.5	–	22.3	.222

E= YOUNG'S MODULUS
UTS= ULTIMATE TENSILE STRENGTH
YS= YIELD STRENGTH, .2% OFFSET
PL= PROPORTIONAL LIMIT
ε_f= STRAIN TO FRACTURE

BORON CARBIDE REINFORCED MAGNESIUM COMPOSITE DEVELOPMENT (IN-HOUSE EFFORT)

OBJECTIVE:

MICROSTRUCTURAL EXAMINATION AND MECHANICAL PROPERTY DETERMINATION OF B_4C/Mg COMPOSITES FOR SPACE APPLICATIONS SUCH AS END FITTINGS, CONNECTORS, BRACKETS, OR SPACERS.

REQUIREMENTS:

LIGHTWEIGHT, HIGH SPECIFIC STIFFNESS, LOW CTE, ISOTROPIC PROPERTIES

APPROACH:

THE EFFECT OF MATRIX (ZK60A, AZ91C), FORM (BILLET, EXTRUSION, FORGING), AND VOLUME PERCENT REINFORCEMENT (40V/0) WILL BE EVALUATED BY MICROSTRUCTURAL EXAMINATION, TENSILE TESTING, CTE DETERMINATION, AND CORROSION TESTING.

BORON CARBIDE REINFORCED MAGNESIUM COMPOSITE DEVELOPMENT
(CONTRACTOR EFFORT)

OBJECTIVE:
TO DEVELOP B_4C/Mg FOR THE GIMBAL APPLICATION IN NEXT GENERATION TRIDENT II INERTIAL MEASUREMENT UNIT COMPONENTS.

REQUIREMENTS:
LOW DENSITY, DIMENSIONAL STABILITY, HIGH SPECIFIC STIFFNESS

APPROACH:
A 35 V/0 $B_4C/ZK60A$ - Mg COMPOSITE WILL BE DEVELOPED AND EVALUATED FOR:

MICROCREEP RATE, MICROYIELD STRENGTH, CTE, THERMAL CONDUCTIVITY, DENSITY, YIELD STRENGTH, ULTIMATE TENSILE STRENGTH, YOUNG'S MODULUS, ELONGATION, MACHINING STUDIES, CORROSION STUDIES

CARBON-CARBON

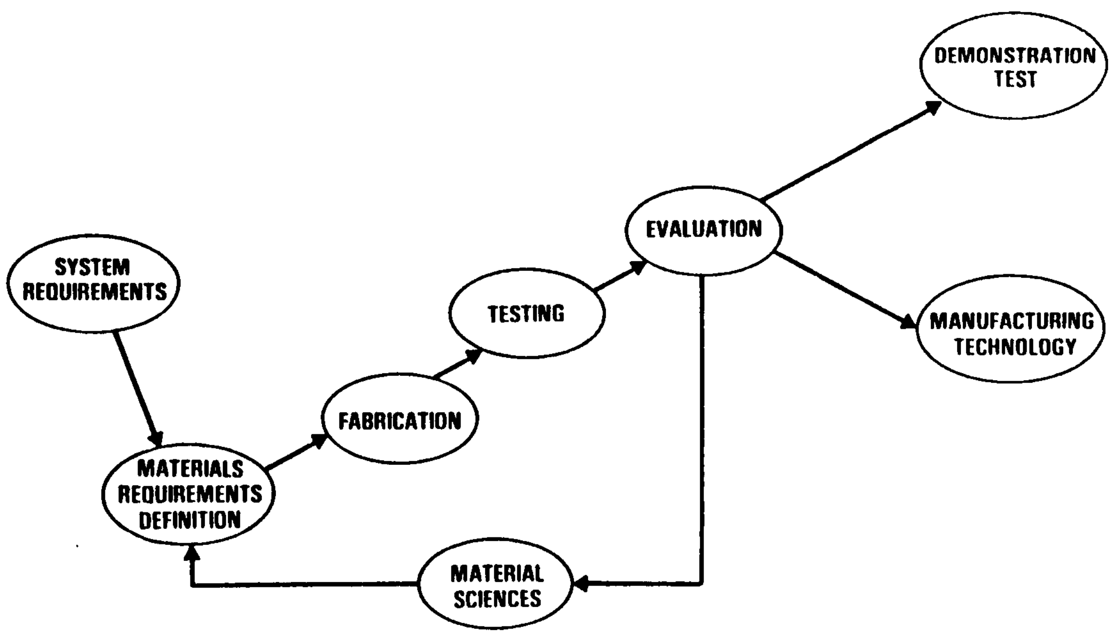
CARBON-CARBON FOR SPACE STRUCTURES

- HIGH CONDUCTIVITY RADIATOR PANELS
- DIMENSIONALLY STABLE STRUCTURES
- HARDENED SPACECRAFT SHELLS
- HEAT PIPES
- PROTECTIVE SHIELDS AND SENSOR COVERS
- THERMAL INSULATION FOR CRITICAL COMPONENTS

MATERIALS TECHNOLOGY NEEDS

- FINE DIAMETER FIBERS
- VERY HIGH MODULUS FIBERS
- THIN PANEL TECHNOLOGY
- THIN-WALLED TUBES
- ATTACHMENT AND JOINING
- TEST METHODS
- DESIGN DATA BASE
- MANUFACTURING TECHNOLOGY

CARBON–CARBON COMPOSITE TECHNOLOGY PROGRAM: TECHNICAL APPROACH



CARBON–CARBON FOR SPACE STRUCTURES

CURRENT AND NEAR TERM PLANS:

MATERIALS REQUIREMENTS DEFINITION - ASSESS NEAR TERM SYSTEMS NEEDS AND IDENTIFY CRITICAL MATERIAL PROPERTIES THAT HAVE TO BE DEVELOPED AND DEMONSTRATED

MATERIAL FABRICATION - DESIGN AND FABRICATION CRITICAL MATERIALS FOR EARLY EVALUATION. CRITICAL MATERIALS TECHNOLOGY IDENTIFIED BRAIDED TUBES (10 TO 15 MILS WALL THICKNESS).

THERMAL/MECHANICAL CHARACTERIZATION - DEFINE TEST MATRICES FOR TESTING OF THIN WALLED CARBON-CARBON COMPOSITES. EMPHASIS IS PLACED ON MEASURING MODULUS, EXPANSION AND CONDUCTIVITY. SPECIAL TEST PROCEDURES WILL BE DEVELOPED.

CONCEPT DEMONSTRATION - FULL SIZE PANELS AND TUBES WILL BE FABRICATED TO DEMONSTRATE MANUFACTURING TECHNOLOGY. THERMAL CYCLE TESTS WILL BE CONDUCTED ALONG WITH CONTINUOUS AND PULSED LASER TESTS.

MATERIALS REQUIREMENTS DEFINITION

- INERT MATERIALS IN VACUUM
- HIGH MODULUS FOR RIGID STRUCTURES
- HIGH TEMPERATURE RESISTANCE
- HIGH SPECIFIC CONDUCTIVITY
- LOW DENSITY
- LOW THERMAL EXPANSION
- LOW SUSCEPTIBILITY TO HOSTILE RADIATION