N87-16015

ADVANCED COMPOSITES FOR LARGE NAVY SPACECRAFT

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First NASA/DOD CSI Technology Conference
Norfolk, Virginia
November 18-21, 1986

CONTRACT SUMMARY

Future spacecraft will be an essential part of the US defense system and ensuring survivability is critical to the spacecraft design. Potential threats to the spacecraft include space-based laser, ground-based laser, and direct ascent nuclear and KEW (pellet) weapon systems. Many of these systems will be large in comparison to conventional spacecraft and the requirements for precision static and dynamic dimensional control are very severe. Payloads such as IR sensors, RF antennas, etc. must be pointed very accurately, which requires dimensionally stable support structures that also have inherent passive damping thus resulting in precise alignment under static, dynamic and thermal disturbances.

This paper is an overview of work conducted on contract for the Naval Sea Systems Command. The objective of this contract was to provide direction for the development of high modulus graphite reinforced metal matrix composites. These advanced materials can have a significant effect on the performance of a spacecraft before, during and after an evasive maneuver.

The information contained in this paper is based on a paper entitled "Spacecraft Survivability by Maneuvering-KEW Environment" (Reference 1) and the contract final report "Effects of Materials and Structures on Spacecraft Controls", N00024-83-C-5353 (Reference 2).

TITLE:	**EFFECTS OF MATERIALS ON SPACECRAFT CONTROL AND MANEUVERABILITY**
OBJECTIVE:	**ASSESS THE IMPACT OF MMC ON SPACECRAFT MANEUVERING**
CONTRACT MONITOR:	**MARLIN KINNA**
PERIOD OF CONTRACT:	**SEPTEMBER 1983–MARCH 1985**

Figure 1

SUMMARY OF PROGRAM TASKS

The work conducted on this program was organized into seven technical tasks; Figure 2 provides an overview of the program. Task 1 was development of a generic Navy spacecraft model. Finite element models of candidate structural designs were developed. In Task 2, the finite-element model(s) of the structure were used to conduct analytical assessments involving conventional materials, resin matrix composites and metal matrix composites. In Task 3 and 4, MMC material design, fabrication and evaluation was conducted. This consisted of generating material designs and developing a data base for a broad range of graphite reinforced MMC materials. All material was procured according to specifications which set material quality and material property standards. In Task 5, a set of evasive maneuvering requirements were derived and used in Task 6 to conduct analytical simulations. These analytical simulations used current SOA material properties and projected material properties to provide an indication of key payoffs for material development. In Task 7, a set of material development recommendations was generated.

CONTRACT OVERVIEW

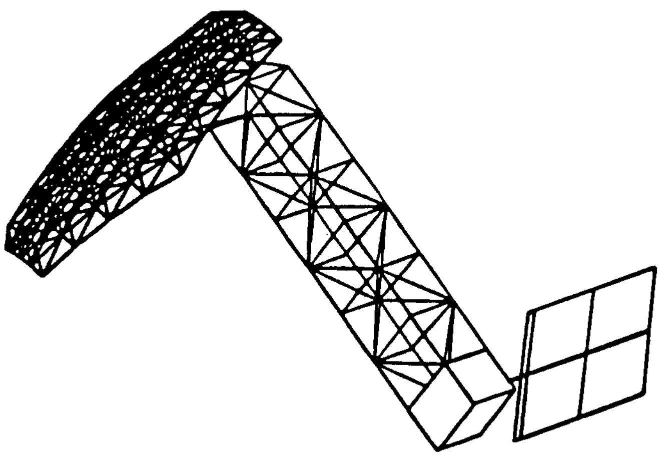
- **DEFINE GENERIC ITSS SPACECRAFT MODEL**
- **ANALYTICAL ASSESSMENT TO IDENTIFY KEY MATERIAL VARIABLES AND INITIAL PROPERTY GOALS**
- **DESIGN, PROCURE, TEST AND EVALUATE STATE-OF-THE-ART METAL MATRIX COMPOSITE MATERIALS**
- **DETERMINE THE EFFECT OF MATERIAL VARIABLES ON MANEUVERING SPACECRAFT PERFORMANCE**
- **RECOMMEND DEVELOPMENT PROGRAMS TO OPTIMIZE MANEUVERING SPACECRAFT DESIGN**
- **MAJOR PROGRAM ACHIEVEMENTS**

Figure 2

GENERIC ITSS SPACECRAFT

ITSS was selected for developing a generic spacecraft model for analytical assessments. A finite-element model of a generic spacecraft and performance requirements that incorporate characteristics of the ITSS spacecraft concepts were defined. The ITSS will be a combination of IR and RF payloads assembled on one spacecraft. The RF system will be relatively large and flexible and the IR system will be comparatively rigid. The combined spacecraft was modeled as an RF antenna with slewing, pointing, and maneuvering requirements and the IR payload was assumed to be a rigid mass lumped at the spacecraft bus. Specific numerical performance requirements and distrubances for the spacecraft were defined in this task.

Figure 3 illustrates the generic spacecraft model. The primary components which impact its dynamic behavior are the antenna dish, the antenna feed, the feed boom, and the spacecraft bus. The rigid IR payload must meet stringent pointing requirements while mounted to these flexible components. The generic model was defined around the flexible part of the spacecraft, i.e., the RF antenna. Based on the results of previous space-based surveillance studies, an RF dish diameter (antenna aperture) of 30 meters and an operational wavelength of 3 cm were chosen. The IR payload is treated as a rigid mass and part of the spacecraft bus. A polar orbit with an altitude of 5600 nautical miles was also specified. The nominal generic spacecraft weighs approximately 4000 kg.



REQUIRED OPERATIONS

- **EVASIVE MANEUVER — 150 NMI, 25 MINUTES**
- **SCANNING — 22°, 33 SEC**
- **STEP-STARE — 45°, 15 SEC**

- **30 METER DISH DIAMETER**
- **30 METER FEED MAST LENGTH**
- **≅4000 KG MASS**

Figure 3

MATERIAL EVALUATION

Material design and fabrication development tasks were conducted wherein a broad range of MMC material variables were used to develop specimen designs using graphite fibers in aluminum and magnesium matrices. The materials evaluated in this program are shown in Figure 4. Two sets of material designs were evaluated in this program. The initial set of materials were designed based on data developed in previous work. Material test data developed in Task 4, was used to design the second set of materials. Materials were procured in flat plate and tube form and specifications were imposed for all of the fabrication activities. Batch acceptance tests were performed on the precursor wire material prior to proceeding with fabrication processes. Diffusion bonding, pultrusion and Rapipress processes were used to fabricate the material designs evaluated in this program. A comprehensive fabrication quality assessment task was conducted where all parts were tested by ultrasonic inspection methods (C-scan) and photomicrographs were taken.

SUMMARY OF FABRICATED PANELS

Material	Foil	Layup	Size	Manufacturer
Round 1				
P100/6061	Al	$(0)_2$	8 in. × 8 in.	DWA
P55/6061	Al	$(0)_2$	8 in. × 8 in.	DWA
P55/6061	Al	$(0)_4$	8 in. × 8 in.	DWA
P55/6061	Al	$(\pm 16)_S$	8 in. × 8 in.	DWA
P100/AZ91C	Ti	$(0)_2$	8 in. × 8 in.	DWA
P100/AZ91C	Mg	$(0)_2$	8 in. × 8 in.	DWA
P55/AZ91C	Mg	$(0)_2$	8 in. × 8 in.	DWA
P55/6061	Al	$(0)_2$	16 in. × 6 in.	MCI
P55/6061	Al	$(0)_4$	16 in. × 6 in.	MCI
P100/6061	Al	$(0)_2$	16 in. × 6 in.	MCI
P100/6061	Al	$(0)_2$	16 in. × 6 in.	MCI
P55/6061	Al	$(\pm 16)_S$	16 in. × 6 in.	MCI
Round 2				
P120/6061	Al	$(0)_2$	8 in. × 8 in.	DWA
P120/AZ91C	Mg	$(0)_2$	8 in. × 8 in.	DWA
P120/AZ91C	Ti	$(0)_2$	8 in. × 8 in.	DWA

SUMMARY OF FABRICATED TUBES

Length	Material	Foil	Layup	Size Dia. × Wall Thick.	Manufacturer
42 in.	P100/Al	Al	$(0)_2$	1.071 in. × 0.048 in.	MCI
42 in.	P100/Mg	Mg	$(0)_2$	1.067 in. × 0.048 in.	MCI
42 in.	P120/Al	Al	$(0)_2$	1.068 in. × 0.046 in.	MCI
42 in.	P120/Mg	Mg	$(0)_2$	1.071 in. × 0.047 in.	MCI
18 in.	P100/Al	Ti	$(0)_2$	1.501 in. × 0.047 in.	DWA

Figure 4

SUMMARY OF MATERIAL PROPERTY TEST DATA

A test matrix was designed to satisfy two objectives. The first objective was to obtain the necessary data for conducting analytical performance assessments using the generic spacecraft. These tests include longitudinal tensile modulus, shear modulus, coefficient of thermal expansion and material density. The second objective was to enhance the material design data base by obtaining relevant properties essential to conducting a complete structural design. These properties include longitudinal tensile, transverse tensile and shear properties. A summary of the longitudinal tensile testing is summarized in Figure 5.

P100 COMPOSITE MATERIAL PROPERTIES SUMMARY

MATERIAL PROPERTY	MEASURED PROPERTIES							
	P100/AZ91C Ti FOIL		P100/AZ91C Mg FOIL		P100/6061 Al FOIL		P100/6061 GROUND WIRE Al FOIL	
	CALC.	MEASURED	CALC.	MEASURED	CALC.	MEASURED	CALC.	MEASURED
LONGITUDINAL MODULUS (MSI)	48.4	53.8	47.2	52.2	49.6	47.5	50.4	48.6
LONGITUDINAL STRENGTH (KSI)	155.8	103.8	154.6	116.8	147.5	119.9	150.3	120.2
CTE (IN/IN-°F)	+0.207	TBD	+0.254	TBD	+0.624	TBD	+0.575	TBD
V_F%	—	43.9	—	43.6	—	44.0	—	44.9
DENSITY (PCI)	0.0807	0.0783	0.0706	0.0719	0.0892	0.0901	0.0890	0.0889

Figure 5

ANTENNA PAYOFFS FOR
SPACECRAFT MANEUVERING

Development of high specific modulus and high inherent damping materials can have a significant effect on the performance of a spacecraft before, during and after an evasive maneuver. The major effects are illustrated in Figure 6. High specific modulus reduces the peak amplitude dynamic distortions and also minimizes total static deformation. High damping properties result in faster settling time for structural vibrations. In both cases, the time required to reach operational capability after a maneuvering disturbance is imposed will be minimized by increasing these material parameters. As part of this contract, the effects of high specific modulus and damping loss factor on maneuvering capability were assessed.

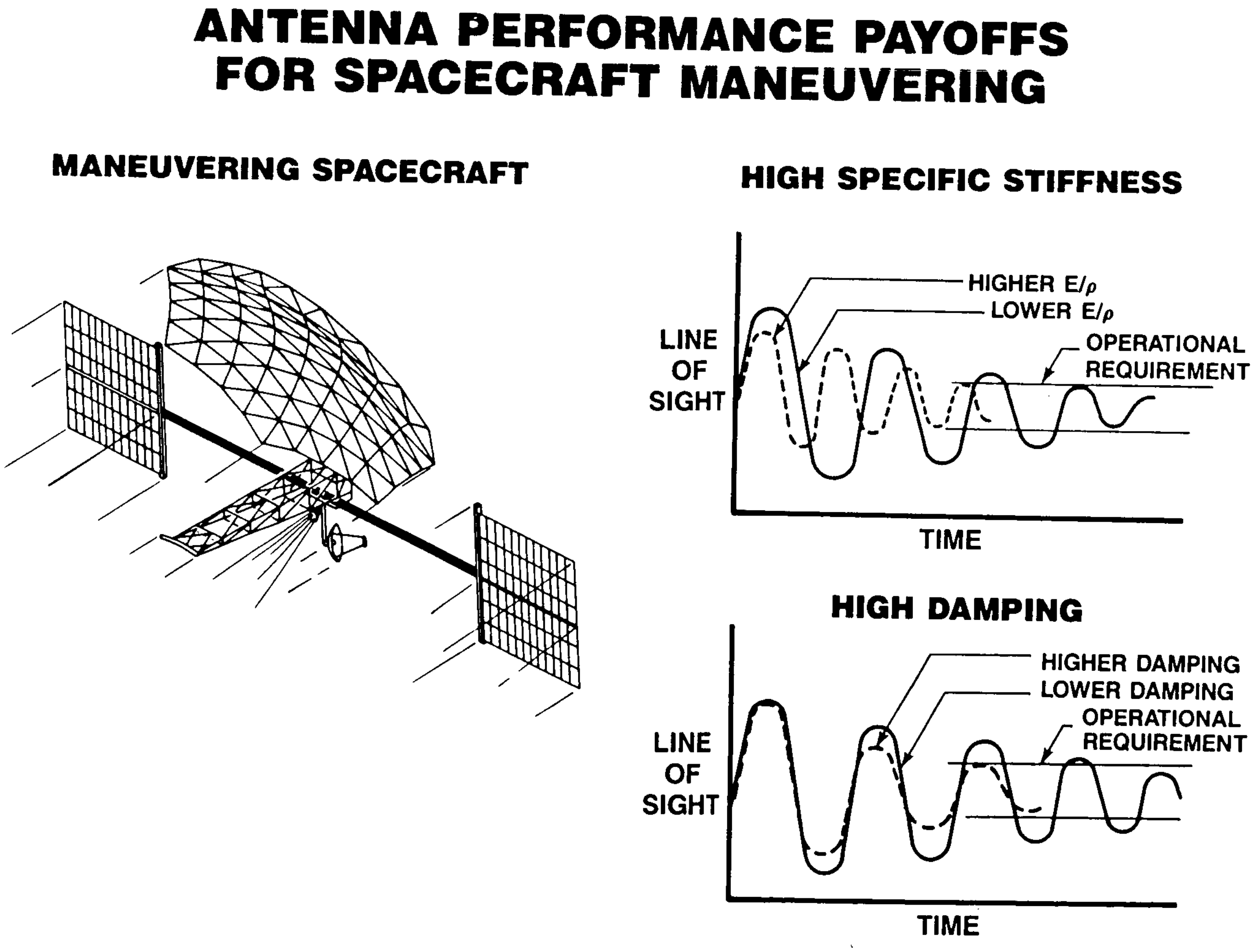


Figure 6

SPACECRAFT STRUCTURAL MASS VS. FIBER MODULUS (EQUIVALENT PERFORMANCE DESIGNS)

Maneuvering simulations were conducted using the generic spacecraft design where a large combination of material designs were evaluated. These simulations are conducted by imposing disturbances on the finite-element model of the generic spacecraft and then analyzing the resulting response.

Figure 7 shows the effects of improving the fiber modulus on reducing the structural mass of the vehicle. P100 Gr/Al with 50% fiber volume (zero CTE) is approximately the state of the art in graphite reinforced metal matrix composites. Developing Gr/Mg capability and increasing the fiber modulus to 100 MSI can significantly improve the structural mass characteristics of the vehicle. This results in reduction in launch weight, added payload capability, reduced mass on-orbit, etc.

SPACECRAFT STRUCTURAL MASS VERSUS FIBER MODULUS FOR EQUIVALENT PERFORMANCE

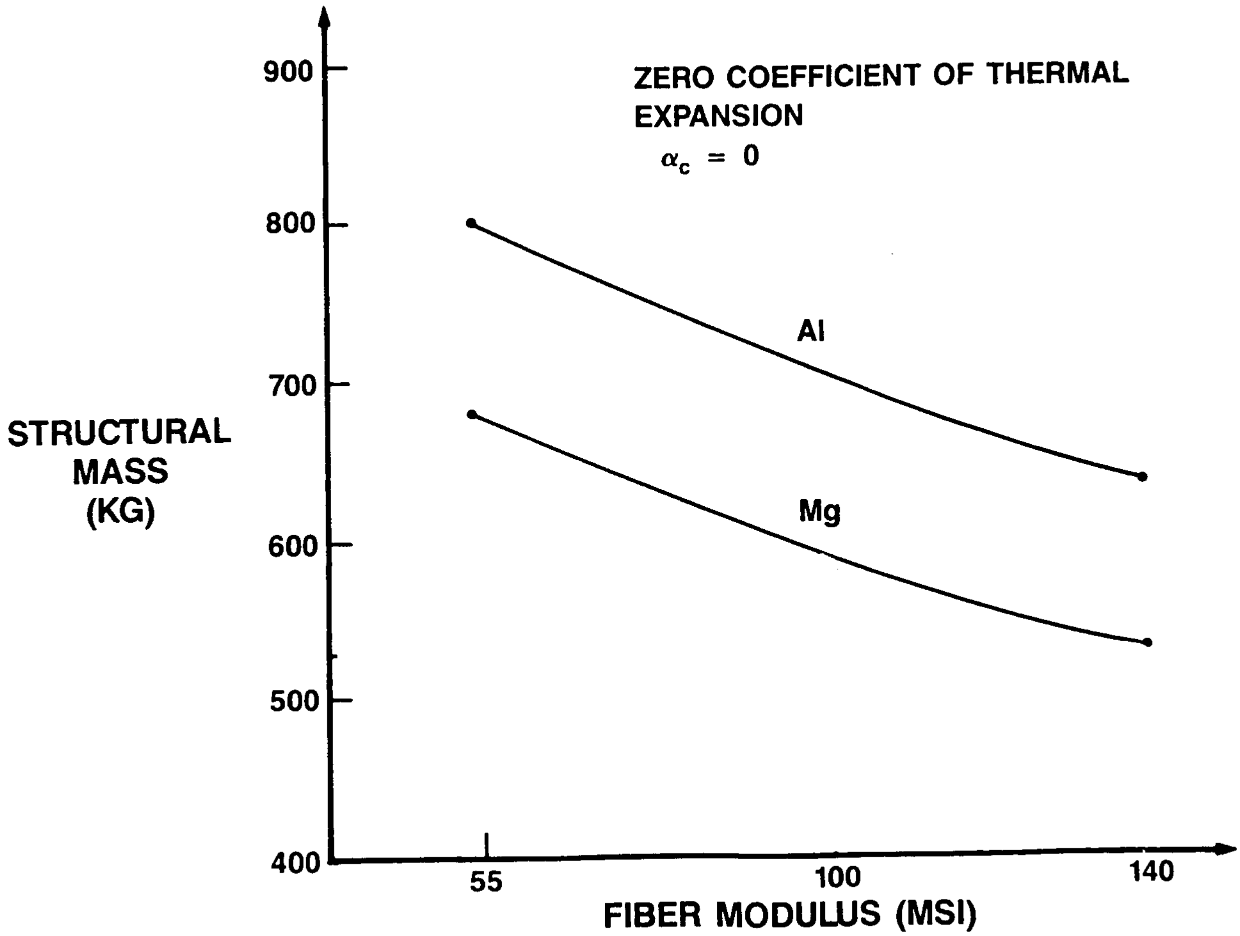


Figure 7

MATERIAL EFFECTS ON SPACECRAFT SCAN TORQUE

Reductions in the structural mass of large area structures results in lower mass moments of inertia. This, in turn, reduces the scan torque requirements for the vehicle. If P55 Gr/Al material were used in this design the scan torque requirements are 6000 N-M which is pushing the state-of-the-art capability in CMG torque capacity. P100 Gr/Mg would require 4700 N-M torque which is well within the capability of todays state-of-the-art actuator torque capacity. This would result in less risk, lower power requirements, higher reliability and reduced ACS weight.

SPACECRAFT SCAN TORQUE versus FIBER MODULUS FOR EQUIVALENT PERFORMANCE

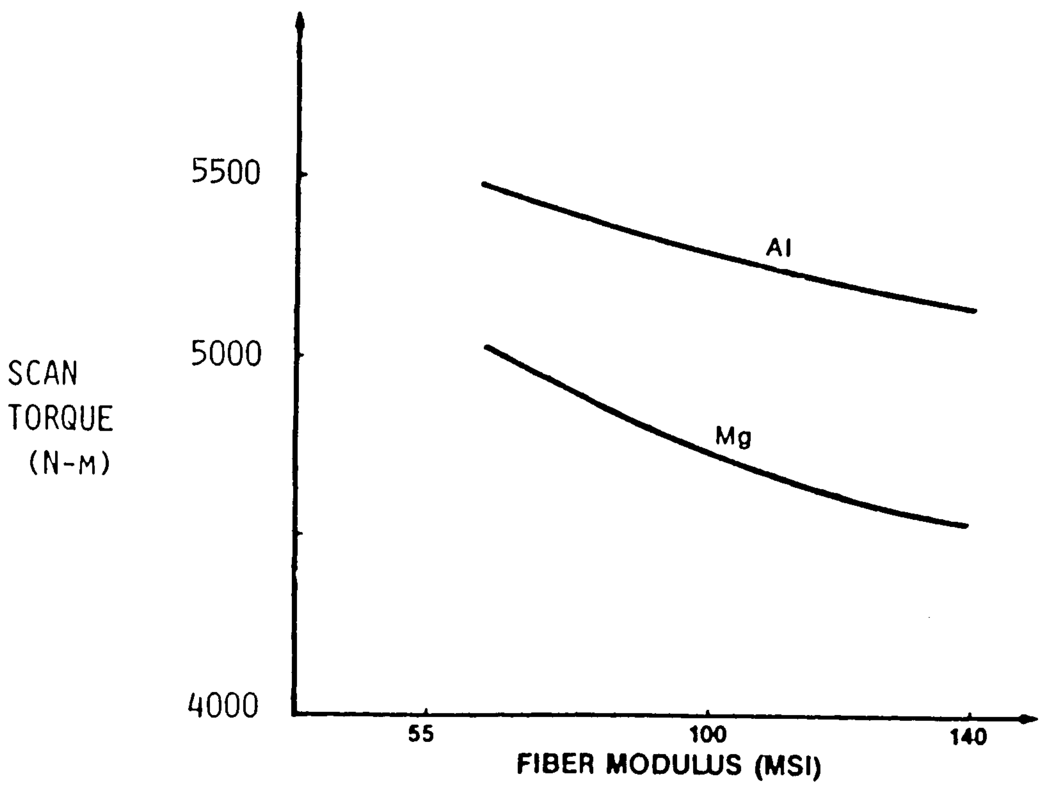


Figure 8

SUMMARY

Unidirectionally reinforced metal matrix composites are ideal for application to large truss structures in space. They are attractive for use when thermal distortions are critical, and in addition, their extremely high stiffness to weight ratio suits them for use in dynamic environments. Structural designs based on the use of very high modulus MMC will be lightweight and may enable operation during an evasive maneuver without the need for structural control systems. The use of metal matrix composites can reduce structural mass and inertia, requiring smaller maneuvering thrusts and scanning torques, and resulting in additional fuel and actuator weight savings.

REFERENCES

1. Davis, William E.; Levin, Richard N.; and Lesieutre, George A.: Spacecraft Survivability by Maneuvering - KEW Environment, Sixth Metal Matrix Composites Technology Conference (Monterey, CA.) May, 1985

2. Effects of Materials and Structures on Spacecraft Controls. HR Textron SED CR 850001 (NSSC Contract No. N00024-83-C-5353), Apr. 1985.