N95- 18976

1994

NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

MARSHALL SPACE FLIGHT CENTER
THE UNIVERSITY OF ALABAMA

S9-18
30899
P. 6

COMPOSITE STRUCTURES FOR MAGNETOSPHERE IMAGER SPACECRAFT

Prepared By: Tsuchin Chu, Ph.D.

Academic Rank: Assistant Professor

Institution and Department: Southern Illinois University at Carbondale
Department of Mechanical Engineering and Energy Processes

NASA/MSFC:

Directorate: Program Development
Office: Advanced Spacecraft & Payload Systems
Office: Space Science & Applications

MSFC Colleagues: Les Johnson/PS02
Susan Spencer/PD22

INTRODUCTION

For the past thirty years, scientists were only able to obtain incomplete spacecraft *in situ* measurements of the magnetospheric fields and particles. In order to obtain simultaneous measurements at different wavelengths and with energetic neutral atoms to provide a global view of the magnetosphere, NASA initiated a Science Definition Team (SDT) to define the rationale and scope of the Inner Magnetosphere Imager (IMI, now called MI) mission. Marshall Space Flight Center (MSFC) was given the responsibility to define the mission and to conduct the conceptual and preliminary design studies [1].

The spacecraft will be a spin-stabilized one with an orbit of 4800 km perigee by 7 Re apogee. Due to the constraint of the cost ceiling, only three core instruments will be installed on the MI spacecraft. These instruments include hot plasma imager, plasmasphere imager (He^{+}304), and FUV imager. The baseline launch vehicle is Taurus S which is capable of boosting 330 kg of payload to the designated orbit.

The MI mission is now a part of the Sun/Earth Connection Program. To qualify for this category, new technology and innovative methods to reduce the cost and size have to be considered. The assessment from the preliminary study results in several new technology options for MI. These include using gallium-arsenide solar cells and adopting solid state data recorders. To further reduce the weight and cost of the structure and fully utilize the new material technology, carbon fiber reinforced composites has been considered for replacing aluminum structures.

A study has been conducted to address the issues and benefit in using composites for MI spacecraft design. The results of the composite option trade study are presented in the following sections.

WHAT IS COMPOSITE?

A composite is a combination of a reinforcement material in a matrix or binder material. Composites are light weight, high strength, and high stiffness materials. Low coefficient of thermal expansion (CTE), as well as directional strength and stiffness, can be tailored into composites to meet special spacecraft design requirements. Additionally, with innovative manufacturing processes, the composite materials can be used to provide cost savings and reduced part count.

Reinforcements for composites can be fibers, particles, or whiskers. Fibers are the most common reinforcements in composites. Matrix materials include polymer, ceramic, and metal. The matrix is usually served as a binder to hold the reinforcements together. It provides load transfer between reinforcements, creates formability of the structure, protects the reinforcements from environmental effects, and lend desirable physical characteristics to the composites.

Fiber Reinforced Plastics (FRP) is the largest subgroup of composites. The matrix of FRP is either a polymer or plastics and the reinforcement is a fiber. Epoxy resin is the most common matrix material for FRP. Fibers can be glass, organic (aramid or Kevlar by trade), carbon, or graphite. Advanced composite materials generally refer to composites with high modulus fibers (elastic modulus E>200,000 MPa) and no less than 50% reinforcement fibers in volume.

Advantages and Disadvantages of Composites

The major advantage of using composites to replace metals in aerospace industry is their high strength and high stiffness to weight ratio. In addition, composites offer new design flexibilities, improved corrosion and wear resistance, increased fatigue life, and low coefficient of thermal expansion (CTE). Some specific benefits in using composites over metals are:

- Specific tensile strength (ratio of tensile strength to density) of composites is four to six times greater than that of steel or aluminum.
- Specific modulus of composites is three to five times greater than steel or aluminum. Some newly developed ultra high modulus fibers can provide even higher specific modulus.
- Composites have higher fatigue endurance limits.
- Composites can be tailored to low or zero CTE in a desired direction.
- Some ultra high modulus carbon fibers have higher thermal conductivity than that of metals.
- Composites have high directional strength and modulus.
- Use flexible and innovative manufacturing processes on composites can reduce the cost.

The general disadvantages of composites are their high cost, lack of well-defined design rules, lack of automated manufacturing processes, and susceptible to environmental effects such as moisture and temperature. However, by choosing the proper combination of fibers and matrix materials, many deficiency can be overcome. Additionally, with the development of ultra high modulus graphite fibers and low water absorption resins, more composites are now available for spacecraft design.

Carbon/Graphite Fibers

The demand of high strength and high modulus reinforcements for composites has led to the development of carbon or graphite fibers. Although the graphite fiber has higher carbon contents and is stronger than carbon fiber, the terms have been used interchangeably. Carbon fibers can be manufactured by using polyacrylonitrile (PAN), rayon, and petroleum pitch. Rayon based carbon fibers are mainly used for making nozzles. Pitch-based fibers have a higher degree of graphite structure than to PAN-based fibers. Pitch fibers have high elastic moduli (480-830 GPa) but reduced tensile strength (up to 2.4 GPa). However, for small spacecraft, such as MI, the stiffness (elastic modulus) is more important than the strength of the material. Additionally, high modulus fibers are also high thermal conductors. The excess heat generated by electronic equipments and batteries can be dissipated to heat sink or radiator through these fibers in the composites. Amoco has developed some high modulus graphite fibers such as P75, P100, and P120, which have thermal conductivities comparable to those of metals. Table 1 shows some of the thermal conductivities of these materials [2,3].

Fiber or Metal	Supplier	Thermal Conductivity (W/m-K)
P75	Amoco	185
P100	Amoco	520
P120	Amoco	640
T300	Amoco	10
Copper		450
Aluminum		200

Table 1. Comparison of Thermal Conductivity of Some Carbon Fibers

STRUCTURAL DESIGN FOR MI

Three major factors have been considered for the Magnetosphere Imager (MI) spacecraft structural design, namely the stiffness, excess heat dissipation, and ease of manufacturing and assembly. The baseline design, as shown in Figure 1, includes twelve side panels and the top and bottom decks mounted on a frame structure. The spacecraft is 1.3 m high and 1.3 m in diameter. All panels and decks are made of aluminum honeycomb sandwiches. Electronic boxes and instruments are mounted directly around the center of the panels for efficient dissipation of excess heat generated from electronic instruments and batteries to the radiator. Power for the spacecraft will be supplied by the gallium-arsenide solar cells mounted on the panels and decks.

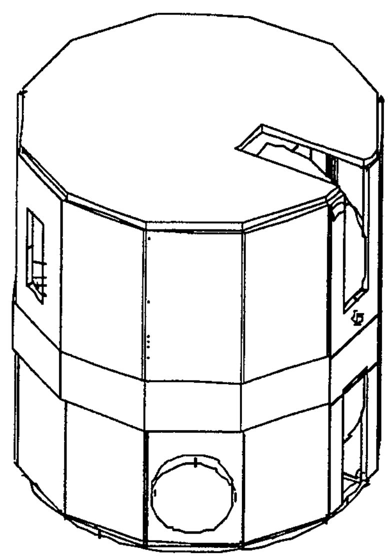

Figure 1. MI Spacecraft Conceptual Design [4]

Composite Design Configuration

Composite materials in general are more expensive than aluminum alloy. However, the high stiffness and high strength to weight ratio of composites along with innovative manufacturing methods can dramatically reduce the overall cost of using composite structures for spacecraft design. The composite design configuration includes replacing the aluminum face sheets of the honeycomb sandwich panels with graphite/cyanate composites as well as using composite longerons and brackets. Another option utilizes the light weight and high stiffness composite isogrid panels for the two decks.

Replacing the aluminum face sheets (skins) in the baseline design by composites can reduce the skin weight by approximately 30% to 40%. The aluminum honeycomb core should be used for heat conduction through the thickness of the sandwich panel. Various options and design guidelines can be considered for MI spacecraft design using composite sandwich panels and composite isogrid panels:

- Co-cure all panels to form the body of the spacecraft. Upper and lower decks can be attached to the body with potted insert fasteners. They can also be fastened to the co-bonded brackets at the ends of the panels. This design eliminates all logerons and the fasteners required to attach the panels, thus reduces the weight and the assembly cost.

The only disadvantage is that difficulties may arise for installing and uninstalling the instruments and cables.

- Co-cure two to three panels to form sections. Longerons can be co-bonded and co-cured to the edges of each section of two to three panels. Deck attachment is the same as above mentioned design. This option can reduce one half to two-thirds of the longerons and fasteners. However, since the body is formed by four to six sections, installing and uninstalling the instruments will no longer be a problem.

- Use rib stiffened composite panels (isogrid) for upper and lower decks. The composite ribs are arranged in an isogrid configuration and are secondary bonded to the composite skin to replace the honeycomb core in a panel. This composite isogrid panel can further reduce the weight of the panels [5].

- Brackets for installing instruments and batteries can be co-cured and co-bonded to the skin of the panels.

- Local doublers can be incorporated in high shear and high stress concentration areas to maintain overall panel stiffness and local skin strength. These doublers can be imbedded within the panel skins or bonded to the exterior of the panel skins.

- The exterior of the spacecraft will be covered by solar cells except for the middle of the body which will be covered be the radiator. Since the graphite fibers are good electrical conductors along the fiber direction, the skin of the panels should be insulated from the solar cells by nonconductive films. These films can be co-cured with or secondary boned to the composite panel skin.

These options can dramatically reduce the number of parts to be assembled, reduce the number of fasteners, and reduce the weight. With less human touch and automated manufacturing process, the cost can also be reduced.

Material Selection

For small spacecraft design using composite materials, such as MI, high or ultra high modulus graphite fibers should be used for reinforcements to make high stiffness composite structures or components. Some of the newly developed ultra high modulus graphite fibers are also very good heat conductors. Some of these fibers have thermal conductivity values comparable or even higher than that of pure coppers (450 W/m-K). Since the thermal conductivity of polymeric resin is very low, the overall thermal conductivity of a composite laminate is linearly proportional to the fiber volume content. Nysten and Issi have conducted some measurements on the thermal conductivity of carbon fiber reinforced composites [6]. The best composite measured (45% P120 fibers) showed a thermal conductivity value of 245 W/m-K which is higher than that of pure aluminum (200 W/m-K).

The space environment effects, such as radiation, outgassing, and atomic oxygen exposure, should also be carefully considered in choosing the proper type of matrix materials. The polycyanate resin is a specially developed matrix material for spacecraft applications due to its low water absorption and desorption, low dielectric properties, improved resistance to microcracking and resistance to UV radiation. ICI Fiberites, Hexcel, YLA, Dow Chemical, Ciba Geigy, and Bryte Technologies are the major sources of the polycyanate resins.

Analysis of Composite Structures

The above mentioned composite sandwich panels are plates with stiff, thin face sheets supported by soft, thick honeycomb cores. The Kirchoff assumptions for analyzing solid plates are made across the thickness of the sandwich plate. However, the soft honeycomb cores are flexible in shear. Thus the transverse shear effects should be included in the sandwich plate theory. For symmetrical face sheets, the laminate theory for composites can be greatly simplified. The light-weight soft core has negligible in-plane stiffness. The total stiffness is simply the sum of the face sheet stiffness. The forces acting on the sandwich plates are controlled by the in-plane stress resultants acting on the face sheets. The total in-plane and flexural loads can be defined from these resultants. The simplified theory is very useful in design. The error introduced by this approach is small provided that the face sheets are thin [7].

There are many micromechanics theories for composite analysis. None of them are entirely correct. However, the micromechanics fomulas are still useful in predicting the material property variations in conjunction with the empirical data. Composite analysis using the elasticity theory often result in boundary value problems or optimization of functions. For practical spacecraft design, numerical approximations are necessary for finding the solutions. Numerical tools such as finite difference method and finite element analysis (FEA) are some of the useful tools. Commercial packages for finite element analysis, such as NASTRAN, ANSYS, and PAL/2 are available for composites structures.

REFERENCES

1. Johnson, C.L., and Herrmann, M., "Inner Magnetosphere Imager Mission: A New Window on the Plasma Universe," *Optical Engineering,* Vol. 33, No. 2, pp. 329-334, Feb. 1994.

2. Supplier's Data from Amoco Performance Products, Inc.

3. TRW, "Composite Spacecraft Design Guide," Preliminary Draft of NASA Contractor's Report, April 25, 1994.

4. Drawing prepared by S. Hincle.

5. Kim, T.D., et al, "Continuous Fiber Composite Isogrid For Launch Vehicle Applications," *Composite Properties and Application,* Proceedings of ICCM/9, Vol. VI, pp. 101-107, July, 1993.

6. Nysten, B. and Issi, J-P, "Composites Based on Thermally Hyperconductive Carbon Fibers," *Composites,* Vol. 21, No. 4, pp. 339-343, July 1990.

7. Tsai, S.W., *Theory of Composite Design,* Think Composites, 1992.