Proc. of SPIE Vol. 1303, Advances in Optical Structure Systems, ed. J Breakwell, V L Genberg, G C Krumweide (Oct 1990) Copyright SPIE

The Application of Composite Materials to Spaceborne Radiometer Instrument Design

Robert A. Hookman and George E. Zurmehly

ITT Aerospace/Communications Division
Fort Wayne, Indiana

ABSTRACT

The stability and coregistration requirements for future radiometric instrument designs spawn the need for a totally integrated instrument structure and thermal control scheme. To meet the requirements of the future Geostationary meteorological missions an Ultra Stable Instrument Structure (USIS) will be needed. An instrument structure of lightweight construction is described that takes advantage of composite materials that combine high stiffness, low density along with low Coefficient of Thermal Expansion(CTE). In addition, this paper will outline the mission objectives, the operating environment and stability requirements needed for future spaceborne radiometer structures. A conceptual design of a composite instrument structure along with its thermal control system will be outlined, and various design trade-offs will be presented.

1. INTRODUCTION

ITT is a leader in the development and manufacture of spaceborne meteorological radiometers, having flown instruments in both low earth orbit (LEO) and geosynchronous orbit (GEO). The instruments produced by ITT are used for making global and local weather predictions. The instruments scan the earth and detect various wavelengths of visible and infrared radiation being emitted by the earth. Some applications include viewing cloud coverage, storm tracking, producing vegetation indexes for crop predictions, determining the moisture content at various elevations in the atmosphere, measuring sea surface temperatures and jet stream tracking. The information collected from ITT instruments has became a part of every day life. In the future ITT is committed to developing more reliable, predictable and versatile instruments.

As stability and coregistration requirements of the instruments become more demanding, the need for an ultra stable instrument structure is essential to meeting system requirements. The geosynchronous orbital mission has a more demanding thermal environment and has greater sensitivity to angular distortions. In a geosynchronous orbit the instrument is 23,500 miles from earth. The earth subtends approximately a 17.4° angle, and a typical minimum resolution of 1 km, corresponds to only 28 μradian (approximately 5 arcseconds). To insure that the registration between sets of imagery does not drift or show erroneous trends the pointing stability of the instrument must be maintained. A goal for the pointing stability of the total instrument system will be 75 μradians.

To achieve the required pointing stability, the instrument must have either a very precise temperature control system or the materials utilized will have to be insensitive to temperature changes. The optimum solution is a combination of the two, a primary structure constructed from graphite epoxy and a totally integrated thermal control system. The graphite epoxy material offers an extremely low coefficient of thermal expansion (CTE) along with a high stiffness to weight ratio.

2. OPERATIONAL REQUIREMENTS AND ENVIRONMENTS

The instrument structure must provide support for the optical subsystems through the launch and transfer orbit phases of a mission and it must provide positional stability for these subsystems during the operational phases of a mission. The highest stresses are placed upon the structure during launch when the instrument must survive the launch vehicle vibration environment. This environment generally drives the structural stiffness needs of the instrument and it is relatively independent of the orbit (LEO or GEO) in which the instrument will be placed, being driven by the launch vehicle selected. The major concern for an instrument structural design during the operational phase of a mission is temperature stability.

Solar energy entering the instrument will always cause a temperature change which will in turn cause some change in the spacial and angular relationships between the optical components comprising the instrument. Generally, in a LEO environment the fraction of orbit spent in sunlight is small or a sunshade can be installed to prevent sunlight from entering the optical port of the instrument so misalignments caused by thermal effects are minimal. In a GEO orbit the sun sweeps slowly through the field of view once a day and there is no way of arranging an optical port sunshade to prevent sunlight from entering the instrument. To compound this problem the length of time that the sun can enter the instrument is on the order of hours (compared to minutes for a LEO instrument) so the total temperature change and the resulting alignment errors can be quite large. Because of the need for alignment stability and the increased magnitude and duration of temperature changes the GEO instrument will benefit most from the use of composite materials in the structural design of the instrument.

3. INSTRUMENT STABILITY REQUIREMENTS

The design of the USIS is dependent upon the thermal environment that the components of the instrument are exposed to. Since the angular stability requirement of 75 μradian has been given as the goal, a corresponding stability budget was defined for the instrument components. The maximum gradient and uniform temperatures are the result of the budget and will be utilized in defining the parameters for the thermal control system. The pointing stability budget for the ultra stable instrument structure is detailed in Table 1.

INSTRUMENT STABILITY BUDGET
TABLE 1

INSTRUMENT COMPONENT	BUDGETED POINTING ERROR (μrad)	MAX TEMP EXCURSION (°C)	GRADIENT OR UNIFORM
PRIMARY STRUCTURE	20	20	GRADIENT
	25	10	UNIFORM
SCANNING SYSTEM			
MIRROR SUPPORTS	20	5	GRADIENT
	5	20	UNIFORM
SCAN SUPPORT STRUCT	20	0.5	GRADIENT
	2	10	UNIFORM
SERVO ERROR	20	-	OTHER
TELESCOPE SYSTEM			
MIRROR SUPPORTS	20	5	GRADIENT
	10	5	UNIFORM
TEL SUPPORT STRUCT	10	2	GRADIENT
	2	10	UNIFORM
RELAY OPTICS SYSTEM			
OPTICS STRUCT	2	1	GRADIENT
	10	5	UNIFORM
MOUNTING STRUCTURE	2	1	GRADIENT
	5	5	UNIFORM
RADIANT COOLER SYSTEM			
COOLER INTERNAL	5	2	GRADIENT
	5	10	UNIFORM
MOUNTING STRUCTURE	10	5	GRADIENT
	5	10	UNIFORM
KINEMATIC MOUNTING SYSTEM	10	5	GRADIENT
	20	15	UNIFORM
POINTING CALIBRATION SYS	10	-	OTHER

RSS TOTAL POINTING ERROR = 61 μradian

ADDITIVE FOR INDIVIDUAL COMPONENTS AND RSS = 72 μradian

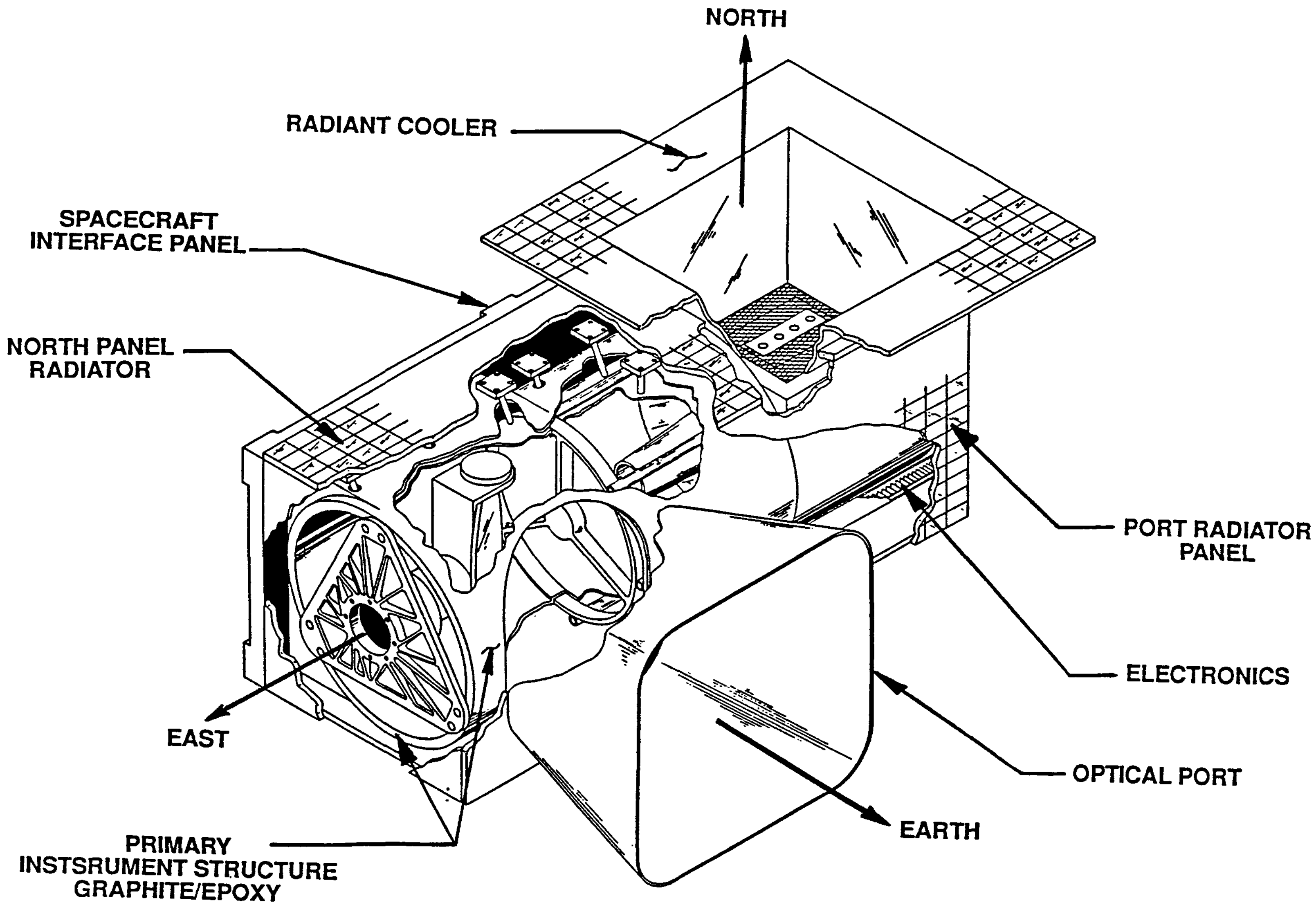
From Table 1 it can be seen that the primary structure's allowable temperature induced distortion is 20 μradians for a maximum gradient of 20°C and 25 μradians for uniform or bulk temperature changes. Nonuniform material properties over the entire structure are the cause of pointing errors due to bulk temperature changes. The allowable distortions for the major subassemblies are also identified and the thermal control system or the design of the subsystem must insure the stability will be met. Included in the budget is a pointing calibration system contribution, this is not an instrument component and will be supplied from the spacecraft's navigation control system.The spacecraft platform will tend to have an angular drift during its operation (as much as 4 mrad), the scan system will be corrected (via the pointing calibration system) to maintain absolute pointing accuracy.

4. INSTRUMENT DESIGN UTILIZING COMPOSITE MATERIALS

The primary instrument structure design concept is shown in Figure 1. The structural concept for this design is to separate the assemblies which need to maintain constant spacial relationships from the structural loads imposed by support subsystems which do not require a high degree of dimensional stability. This design also provides an efficient structure (the tube) to maintain spacial relationships between the optical components. This design concept requires that a thermal control subsystem be used to manage the solar and electronics heat loads on the structure.

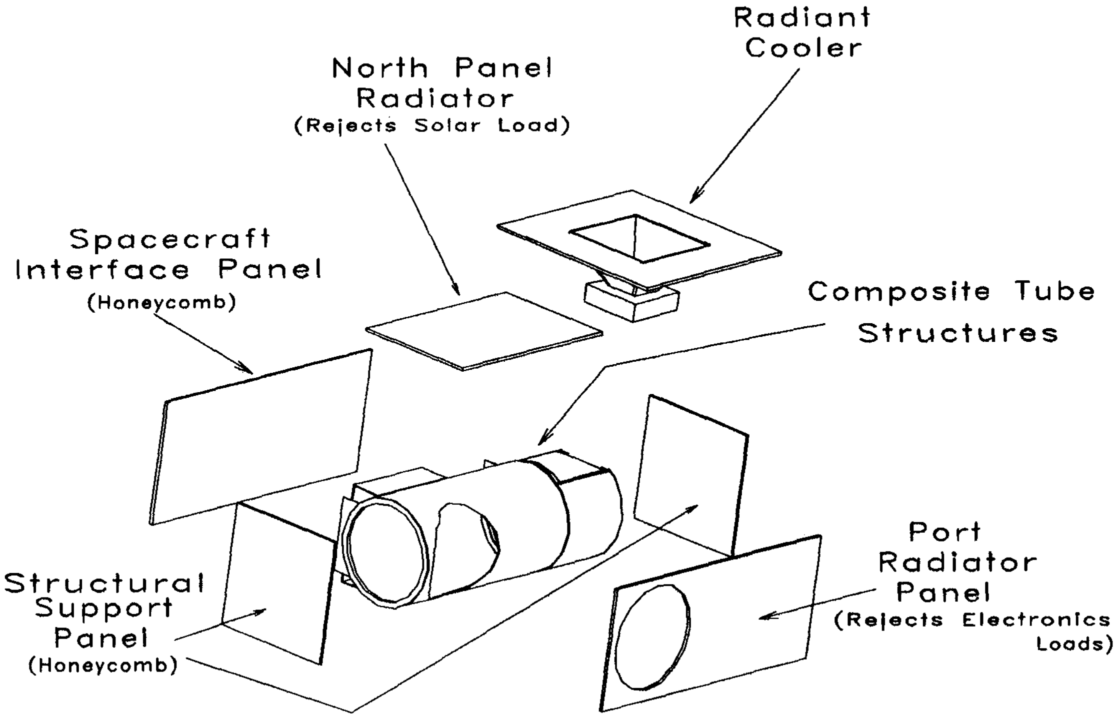
The instrument structure design concept uses a tube as the primary structural member for the scan system, telescope, optical assemblies and the radiant cooler. The scan system, telescope and aft optics assembly are each attached to the structural support tube at three points to produce connections which are mechanically determinant (not over constrained). The radiant cooler is attached to a second structure which, in turn, attaches to the primary structure. The structural support tube is kinematically mounted to the spacecraft interface panel which is constructed from a honeycomb panel. The spacecraft interface panel is the primary structural component for the aperture port sunshade, the thermal control surfaces and any electronics components required in the sensor module assembly. Figure 1 shows a cut-away view of the instrument and the major instrument subassemblies.

The exterior panels shown in Figure 2 connect the port radiator and the north (space looking) radiator panels to the spacecraft interface panel. The port radiator panel supports the aperture port sunshade and any instrument electronics that need to be placed in the sensor module. Kinematic connections between the spacecraft interface panel and the composite tube stop small deflections of the spacecraft interface panel from stressing the tube or the optical components which it supports. Because small deflections of the outer panels (the spacecraft interface, support and port panels) do



STABLE INSTRUMENT DESIGN
FIGURE 1

not transfer loads to the primary structure, sandwich panels made of lightweight materials such as Kevlar® or Nomex® can be used to make these panels. The separation of the electronics card assembly from the structure supporting the optical components also allows the mechanical and electrical integration tasks to be carried out in a more parallel fashion. This should also produce some cost and schedule savings.



Sensor Module Assembly
for the
Composite Tube Design

FIGURE 2

4.1 Instrument Structural Design Trade-offs

During the investigation into the design of the ultra stable instrument structure various materials and configurations where evaluated. The conventional material utilized for the basic instrument structure has been aluminum and a baseplate has been used as the optical bench for the system. The proposed structure utilizes a tubular structure as the optical bench, which is a more efficient structure with less weight. The materials considered were aluminum, graphite epoxy and invar. The comparison of the same structural design with the different materials is given in Table 2.

MATERIAL COMPARISONS
TABLE 2

MATERIAL EVALUATED	DENSITY (LB/IN^3)	MODULUS OF ELASTICITY (PSI)	CTE (PPM/°C)	INSTRUMENT MASS (LB)
ALUMINUM 6061-T651	.098	10×10^6	23.5	44.1
GRAPHITE/ EPOXY	.065	15×10^6	0.18	19.2
INVAR	.295	21×10^6	1.0	62.4

It can be seen from the table above that the weight of the instrument is far less and the dimensional stability will be much greater for a Graphite/Epoxy primary optical support structure. Other factors which must be considered when evaluating a material are the fabrication techniques available for the manufacture of the structure. For the proposed structure it is most easily fabricated from Graphite/Epoxy. Besides performing design trade-offs on the materials to be utilized the general design geometry was also optimized for function.

The configurations which have been considered are the tubular design, a truss type structure and a baseplate/box type structural enclosure. For the size of the system the tubular type structure offered the greatest stiffness and design adaptability for the mass of the system.

5. THERMAL CONTROL SUBSYSTEM DESIGN

The thermal control concept for the composite tube design is to isolate the instrument structure from the solar heat load and provide separate heat rejection surfaces for the solar heat load and the electronics heat load. By separating the solar heat load from the electronics heat load, daily changes in instrument structure temperature should be reduced. The heat rejection surface for the solar heat load will be the north panel radiator (see Fig. 1). The temperature of the north radiator panel will not be controlled. The electronics heat load and any solar heat load that leaks into the instrument structure will be rejected from the port panel radiator. The temperature of the port radiator panel will be controlled by heaters and thermostats attached to its instrument cavity face.

5.1 Solar Heat Loads

Solar heat is absorbed by all surfaces which receive sun light. The amount of solar energy passing through the optical port varies daily from zero to well over a hundred watts. The amount of solar energy that is received can be reduced by reducing the total area illuminated by the sun or by lowering the solar absorptance of the surfaces which are illuminated. The reduction of area illuminated by sunlight is not very feasible because there is a minimum field of view which an instrument must have in order to perform properly and this field of view cannot be reduced. Reducing the solar absorptance (increasing the reflectance) of the surfaces illuminated by sunlight is not allowed because the resulting increase in reflected energy can cause stray light problems in the instrument. The method of controlling the solar heat loads in the composite tube design is to place sun shields inside the instrument cavity to absorb as much of the solar energy as possible, thermally isolate the instrument structure from these shields and conductively couple the shields to a heat rejection surface.

The sun shields will form a tube surrounding the optical axis of the instrument. These shields will be conductively coupled to a north panel radiator and thermally isolated from all instrument structure. The solar energy absorbed by these shields will conduct through graphite/aluminum conduction rods(heat pipes may be utilized for added weight savings) to a north panel radiator where it will be radiated to space. The north radiator panel will be insulated with a multi-layer insulation (MLI) blanket on its instrument cavity face to reduce heat transfer with the instrument structure. The temperature of the north panel radiator is not controlled so the sun shields will run cold when no solar energy strikes them. The thermal design parameters for the sunshields and the north panel are as follows:

1) The effective emmittance between the shields and the structure: The goal is to minimize the fraction of the solar heat load which will leak into the primary instrument structure. A very low value of effective emmittance is necessary to isolate the primary structure and subsystems. A low effective emmittance will be obtained by use of multiple layer shields.

2) The thickness and conductivity of the material used to fabricate the shield: These parameters determine the maximum

operating temperature of the shields. Low shield temperatures are desireable because high shield temperatures lead to instrument calibration errors (due to reflected energy in the infrared spectrum).

3) The method of connecting the shields to a north panel radiator: This parameter determines the temperature rise between the radiator and the shield. A small thermal resistance is desired, graphite/aluminum conduction rods will be utilized. This connection must also allow for assembly and installation of the shields in the sensor module. The design of the mechanical interfaces along the thermal path are critical to the function of the thermal control sub-system.

4) The size of the north panel radiator: The north panel radiator will be sized to meet the temperature requirements of the internal sun shields. The thermal resistance of the conduction rods between the radiator and the internal shields is also critical to the sizing of the north panel radiator.

5.2 Electronics Heat Loads

The electronics heat loads will be approximately 30 watts in the sensor module and will be nearly constant. Most of the electronic components will be attached to the instrument cavity side of the port radiator panel. This panel will be temperature controlled and will act as a conduction boundary for the electronic components and a radiative boundary for the instrument structural components. The instrument cavity side of this radiator panel will be painted and the space facing side of the panel will be covered with optically selective radiators (OSRs).

6. CONCLUSIONS

To achieve the 75 μrad pointing stability over a geostationary diurnal cycle the Graphite/Epoxy primary support structure is essential. The composite primary structure will provide a stiffer and lighter weight structure to support the optical subsystems of the sensor module, while providing the dimensional stability required for the harsh geostationary environment. The results of ITT's analysis clearly show that the use of graphite/epoxy to construct the primary instrument structure will significantly reduce weight. It is estimated that the instrument structure's weight can be reduced by approximately 35 percent as compared to a conventional aluminum structure.

The use of graphite/epoxy for the primary instrument structure will also decrease the sensitivity of the structure to temperature change. This is due to the fact that the graphite/epoxy has a CTE that is two orders of magnitude smaller than that of aluminum. The composite tube design also has the added benefit of reducing the number of bolted interfaces which results in a more analytically tractable structure and should result in better repeatability in optical pointing. For the composite instrument structure to capitalize on the enhanced stability characteristics, the thermal control system is essential. Since the graphite epoxy composite material has a low thermal conductivity, the heat shielding concept utilized is necessary to prevent large temperature excursions and gradients in the structure. The thermal control system will maintain the temperature of the primary structure to within a 20°C range and with a maximum gradient of 10°C. The thermal control system will also be responsible for maintaining the temperature of other instrument subsystems so that the required pointing stability is met. The primary structure contributes only 45 μrad to the total 75 μrad, and the stability of all subsystems must be considered in the design of a stable instrument.

Overall the use of a graphite epoxy composite structure will out perform the existing structures currently utilized at ITT for weight, stiffness and dimensional stability for this application.

7. ACKNOWLEDGMENTS

This work on the development of an ultra stable instrument structure was funded by ITT under a internal research and development investigation. The authors would like to acknowledge the work of Peter Harter.