Apr 22nd, 2:00 PM

Paper Session II-A - Dimensional Stability of the Attitude Reference Assembly on Space Station Freedom

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Abstract
This paper addresses the dimensional stability of a Nav Base for the Space Station Attitude Determination System. Specifically, the methods of evaluating and controlling the thermally induced internal and external forces are discussed.

Space Station Freedom must "know" its orientation at all times if it is to accurately point sensors and telescopes. Knowledge of orientation is initially acquired through the Star Trackers (ST), then maintained with redundant combinations of the three Inertial Sensor Assemblies (ISA) and two Star Trackers. Only one ISA and one ST are required to determine attitude, but multiple units are used for redundancy and fault tolerance. The ISAs are built by Honeywell and each contains three ring laser gyros to sense rotation in inertial space. Three ISAs and two STs are mounted on a navigation base and shielded with a Whipple type micrometeoroid and orbital debris shield (MMOD).

The Nav Base is a large flat plate designed to support these five instruments and function like an optical bench. The purpose of this analysis is to assure that the warping of the Nav Base does not change the alignment of the Star Trackers or ISAs more than one arc minute with respect to the Nav Base reference cube.

Introduction
Temperature gradients through the thickness of the Nav Base is a primary source of misalignment of a ISA or ST. The Nav Base is maintained near a constant temperature with a virtual zero gradient through the plate thickness by striving for an adiabatic environment for the Nav Base. This adiabatic environment is obtained by:

1) Designing a three point mount using insulating springs to support the Nav Base on the Integrated Truss Assembly.
2) Designing three point mounts using insulating springs for each of the instruments mounted on the Nav Base.
3) Covering all exposed Nav Base surfaces with Multi-layer insulation (MLI) or low IR emissivity surface finish.

The magnitude and colinearity of the expansion/contraction forces are controlled by the spring rate of all Nav Base mounts and the mount to Nav Base fastening techniques.

Because the instrument heat can not be conducted to the Nav Base (i.e., adiabatic design), the ISAs and STs must radiate their heat energy to the inside walls of the shields (MMOD). The MMOD must re-radiate this heat along with the solar load and earth albedo to deep space.

This navigation equipment and the MMOD shield is located inside the truss assembly, hence it has a limited view of the ultimate heat sink – deep space. We coordinate the
modeling of the heat transfer to deep space with our customer McDonnell Douglas Space Systems Corporation. The temperature distribution from our radiation model(s) (TRASYS), our thermal model (SINDA), and associated design changes will be discussed. We shall briefly address force colinearity and dynamic mode shapes.

**Details**

Figure 1 shows the outline of the Nav Base with the three Inertial Sensor Assemblies (ISAs) on the left and the two Star Trackers (STs) facing aft. The Star Trackers' function is to correct for ring laser gyro drift in the ISAs. Kalman filtering can not detect and hence, cannot compensate for changes in the bore sight axis of the Star Trackers. One of the major contributors to bore sight axis stability is the stability of the mounting surface on the Nav Base.

The writers perceive that expensive composite structures are often used in space applications where dimensional stability over significant temperature ranges are required. Select composites and composite design can yield low thermal conductivity and a low structure coefficient of thermal expansion in the critical directions.

We are taking a different tack that will reduce cost without compromising function. Hence, a cost effective improvement. Our approach is to create an adiabatic environment with a near zero moment support mechanism for this relatively large aluminum plate.

There are three methods to create bending over the entire surface of a plate. The first is to create a temperature gradient through the thickness of the plate as the result of heat flow (i.e., non-adiabatic boundary). The second method is to impart a moment perpendicular to the plane of the plate. And the third is to generate a mode shape as a result of support boundary conditions (a dynamic environment).

**Adiabatic Boundary**

The adiabatic boundary needed at the top and bottom of the aluminum plate can be created with a blanket of multi-layer insulation if necessary. In the vacuum of space, although MLI and attachment points for other hardware do not create a perfect adiabatic boundary, it is very adequate for engineering purposes. That is, the residual heat which enters either through the blanket or along the titanium mounting brackets is readily conducted across the thickness of the plate without creating a significant gradient. But what is a significant gradient? Our design goal is to maintain the three mounting brackets for each ISA and ST to within one arc minute. Equations 1 thru 3 yield a $\Delta T$ across a 0.20 inch plate of 0.59°F.

\[
R = \frac{t}{\Delta T_{\infty}} \quad \text{Eq. 1}
\]
\[
X = R (1 - \cos \Theta) \quad \text{Eq. 2}
\]
\[
R \Theta = L \quad \text{Eq. 3}
\]

where
- $R$ = radius of curvature
- $t$ = plate thickness
- $\Delta T$ = temperature gradient
- $\infty$ = coefficient of thermal expansion
- $X$ = vertical displacement of one mounting foot
- $L$ = stance between mounting feet
With a nominal conductivity of 80 BTU FT/HR FT°F for alloyed aluminum, a significant amount of heat can be moved across this plate without exceeding our design limit.

The Nav Base with its inertial instruments and Star Trackers are housed inside a double walled Whipple type orbital debris shield. Hence, it is not exposed to either deep space or direct solar impingement. The orbital environment is defined by our customer in terms of arrays of solar and earth albedo flux and effective heat sink temperatures. The array for each node of the outer shield consists of 17 flux values and sink temperatures. The orbit is divided into 12 positions. Two more positions are defined at each terminator and a seventeenth closes on the first position. These environments are calculated by a combination of TRASYS (Thermal Radiation Analyzer System) and SINDA (Systems Improved Numerical Differencing Analyzer) models of the MB2 segment of the Space Station where our equipment is resident. Honeywell uses TRASYS to determine the 5933 radiation heat transfer paths between the ISAs, STs, Nav Base, and shields. The Star Tracker Sun Shades penetrate the shield and offer a unique view of the space environment which we must incorporate into our models. We used the SINDA code to determine node temperatures in the dynamic orbital environment.

**Perpendicular Moments**

There are various sources for generation of moments on the plate. For example, any acceleration of the Nav Base creates cross products of the mass at the center of gravity and the distance to the neutral plane of the plate. But in the benign dynamic environment on orbit, only the moments generated by thermal expansion or contraction are expected to be significant. The Nav Base plate will be attached to the vehicle by three and only three supports. Consider that a simple support offers no moment loading and the spring rate is only one fourth the magnitude of a "guided" support. If a simple support can be designed that will carry the Nav Base through the qualification vibration and shock test, it will be the best design on orbit. Why? Because the simple support will not generate any moments perpendicular to the plate. This assumes that the plate is attached at the "in-plane" neutral axis. To minimize plate distortion near the Star Trackers, the Nav Base to vehicle mounts should be located so that the load path does not pass under the Star Tracker mounts.

**Mode Shapes**

Finally, to obtain a dynamically stable mounting configuration that results in minimum swaying during the launch vibration environment, the mounts must be placed at an "optimum" location between the center of the plate and the edge of the plate. They should be equally spaced and the plate reinforced to avoid a low resonance as is shown in Figure 2. In Figure 2, we have the simulated mounts on our NASTRAN structural model at 135/90/135 degrees of arc rather than equally space at 120 degrees. An additional factor is that the mounts are at the perimeter of the plate. Inboard mounting and careful stiffening should increase this resonance by a factor of two. Any increase in resonance will decrease the sway space by the square of that ratio. A pinned joint (Figure 3C) on a re-inforcing beam as shown in Figure 3A would offer the simple support for expansion perpendicular to the rib and offer moment support to increase the rotational stiffness. Increased rotational stiffness will increase the resonant frequency. The hexagonal design shown in Figure 3B will provide the rib support structure at the mounting location. Ribs perpendicular to the support ribs at the point of support should tie the other three ribs into the supports.
Conclusions

The aluminum Nav Base has shown less than 10 arc seconds of deflection at the Star Tracker mounts for the preliminary thermal environment encountered when using the TRASYS and SINDA codes. At this writing, we are resolving the potential sway space problem created by the 10.2 Hz rotational mode of the Nav Base (Figure 2). We have every expectation of meeting and exceeding our 60 arc second goal using the aluminum plate with MLI and thermal isolation mounts.

Figure 1. Nav Base Loaded with Three ISAs and Two STs.
FREQUENCY = 10.2 Hz.

DASHED LINE = UNDEFORMED; SOLID LINE = DEFORMED

Figure 2. Rocking Mode with 135/90/135 Mount.
Figure 3. Design to Minimize Thermal Distortion and Increase Resonance Frequency for Plate Rotation and “Oil Conning.”