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GLAST Standard Tracker Tray Facesheet Material Selection

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Abstract

One of the main structural members to the GLAST standard tracker tray is the tray facesheets. The facesheets serve three purposes for the GLAST tracker tray. First, they provide in- plane compressive strength, tensile strength, and out-of-plane bending stiffness against both static and dynamic loads. Second, the facesheets serve as the interface plane for bonding of the GLAST detector payload to each tracker tray. Lastly, the facesheets encapsulate the honeycomb core in the tray closeout frame to provide a complete structural unit from which the GLAST tracker towers can be built. It is because of this reason that material selection is a critical part of the GLAST tracker tray structural design.

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1. Definitions

CTE:	Coefficient of Thermal Expansion.
GLAST:	Gamma-ray Large Area Space Telescope.
GFRP:	Graphite Fiber Reinforced Plastic: any polymeric matrix composite materials reinforced with high performance graphite fibers.
SSD:	Silicon Strip Detectors.
SI-SC IRD:	Science Instrument-Spacecraft Interface Control Document.
RL:	Radiation Length.
Tow:	Continuous filaments per fiber bundle (K=1000).
Unbalanced:	Term used with ply fiber orientation through the thickness of the laminate. Unbalanced laminates do not have the same ply fiber orientation spaced symmetrically around the neutral bend axis of the laminate.
Unipreg:	Unidirectional fiber strand bundles impregnated with resin and uncured.

2. Introduction

The tracker tray facesheets along with the tray core provide the majority of the tray structural stiffness. Originally, both aluminum and GFRP materials were considered as possible candidates for the facesheet materials. However, GFRP materials were selected because of the distinct advantages they have over aluminum. GFRP is naturally longer in RL properties than aluminum making it more transparent to high-energy particles. In addition, the similar CTE property for both the carbon closeout frame and GFRP materials made GFRP facesheets a better material choice. This design decision is due to a CTE mismatch problem between aluminum and carbon materials causing large stresses in the adhesive bond line between the facesheets and the closeout frame as the tracker tray sees thermal cycling during normal operation.

This document compares various GFRP fiber materials for cost, weight, and laminate properties to the requirements set forth in the NASA Proposal. Other considerations such as material availability, flight history, and facesheet development costs are discussed in section five of this report.

3. Material Requirements

In selecting the facesheet material from the dozens of different fiber and resin combinations available, the following requirements were used to assess the performance of each facesheet material selected. These requirements are similar to those used in the selection of the core material due to the coupled interaction of both needed to determine static and dynamic tray response.

- Mass: the NASA proposal, issued November 1999, assumed the mass for two facesheets to be 120 grams.
- Radiation Length: a radiation length of 0.1% was assumed for each facesheet in the NASA proposal simulations. (0.1% RL translates into ~188μm thick GFRP facesheet)
- Tray Stiffness: a fundamental frequency of 500 Hz (Q = 40), as supported in the tower assembly, was used as the minimum design value to avoid collision between adjacent trays during qualification level random vibration excitation. Stiffness contributions from the payload are ignored, as further definition of the interface configuration is required to accurately predict the mechanical coupling.
- Mechanical Loading: two combinations of pseudo-static launch load factor cases were considered, as defined in the GLAST SI-SC IRD,
    1. 4.00 gy and 3.35 gz (liftoff & transonic)
    2. 0.10 gy and 6.60 gz (MECO)
- Cost: the NASA proposal assumed $50/facesheet and was later adjusted to a cost of $250/facesheet for the flight hardware budgetary estimates.

4. Face Sheet Material Options

Because there are many different families of fibers to choose from to form GFRP facesheets, down selecting from the entire database of possible fibers was based upon cost, availability, and strength requirements. From the database, six of the selected materials were unipregs and three of them were fabric weaves. The following six composite unipregs were selected: P75/RS-11, M55J/954-3, XN50/RS-3, XN80/RS-3, YSH50/RS-3, and YS90A/RS-3. The following three composite fabrics were selected: XN50/0^{o}-90^{o} fabric, YSH50/4SH fabric, and YS90A/4SH fabric.

The P75 fiber has been replaced by YSH50 for commercial use and is only available as a special order. YSH50 fibers have similar mechanical and thermal properties to P75. Most of the fibers chosen were selected because of their flight history like M55J or because their high tensile modulus like XN80 and YS90A. The fabrics were also selected because of their high bending stiffness and basic in-plane quasi-isotropic properties. One draw back to considering fabrics is that the minimum ply thickness that most fabrics are supplied in is 4 to 5 times thicker than the minimum ply thickness for unipregs; therefore, limiting the number of plies that can be used to form a laminate.

5. Face Sheet Performance & Issues

From the nine different graphite fiber panels listed in section 4.0, three of the unipregs were removed either due to high cost or non-production. They are P75/RS-11, XN80/RS-3, and YS90A/RS-3. The three fabrics were eliminated for either high material cost or high development cost. The remaining three unipregs are listed in table 1. They are compared based upon the performance indices listed in section 3.0.

	NASA Proposal (Spec's)	M55J/954-3 (M55J – Toray PAN Fiber)	XN50/RS-3 (XN50 – Nippon Pitch Fiber)			YSH50/RS-3 (YSH50 – Nippon Pitch Fiber)		
Minimum Ply Thickness (mm)	-	63.5 (0.0025 in.)	38.1 (0.0015 in.)		63.5 (0.0025 in.)	38.1 (0.0015 in.)		63.5 (0.0025 in.)
Number of Plies	-	4	4	6	4	4	6	4
Laminate Thickness (mm)	188	254	152	229	254	152	229	254
Mass								
Density (kg/m^3)	-	1623	1760	1760	1760	1750	1750	1750
Est. Mass/Laminate (grams)	60	62	40	60	67	40	60	67
Facesheet Stiffness								
Fiber Volume Fraction (%)		60	60	60	60	60	60	60
Tensile Modulus (GPa)	-	113	108	108	108	109	109	109
Fundamental Frequency[1] (Hz)	500	677	591	636	666	593	637	667
RMS Displacement[1] (µm)	116	74.7	91.3	82.0	76.6	90.9	81.8	76.4
Radiation Length per Laminate	0.1%	0.135%	0.08%	0.12%	0.135%	0.08%	0.12%	0.135%
~Cost Per Laminate	$250	$184	$203	$259	$211	$187	$235	$224
Availability (ARO)	-	4 wks	4-8 wks	4-8 wks	4 wks	4-8 wks	4-8 wks	4 wks
Flight Heritage	-	Extensive	Good	Good	Good	Limited	Limited	Limited
Fabrication/Handlin	-	Fair	Fair	Good	Fair	Fair	Good	Fair

Table 1. Summary table of GLAST Standard Tray Facesheet Performance Characteristics

5.1 Facesheet Ply Lay-up

In choosing the three fibers in table 1, the minimum ply thickness for unipreg materials varied. M55J fiber only comes in a 2k tow[2], which is equivalent to a 0.0025-inch ply thickness. The other two fibers, XN50 and YSH50 are available in both 2k and 1k tow sizes. 1k tow is equivalent to 0.0015-inch ply thickness. To meet the mass and RL budgets set for the facesheets by the NASA proposal, the number of plies to build the laminate was kept to a maximum of six plies. Six plies is the minimum number of plies needed to build a quasi-isotropic, balanced

[1] Based on using Hexcel 3/8-5056-0.0007 (Al) vented core and no payload stiffness in FEA model.
[2] Tow: Continuous filaments per fiber bundle (K=1000).

laminate. A four-ply, unbalanced facesheet lay-up was also considered because of the advantages gained in reduced cost, mass, and RL.

5.2 Mass

The minimization of mass is important for any space program because of the cost required in placing science-based instruments like GLAST in space. As can be seen in table 1, the allocated mass for each facesheet is 60 grams. The 1k tow materials will meet this requirement regardless of fiber selection. A 12 kg savings could be achieved if the 1k-four ply facesheets are chosen. The 2k tow materials exceed the mass budget per facesheet, however, the overall effect (3.4 kg additional mass for all 480 standard tray facesheets)[3] to the entire mass budget for the tracker is minimal for the stiffness that is achieved.

5.3 Facesheet Stiffness

A frequency requirement of 500 Hz is used, which comes from the following assumptions:

- 5% probability that any one peak might exceed the half gap[4] distance during the 60-second qualification level random vibration test.
- Quality factor is less than or equal to 40, which is equivalent to a critical damping ratio of 1.25%.
- The payload is rigidly bonded to the trays.
- Adjacent trays are 180^{o} out-of-phase at the time a tray exceeds collision levels.
- Attenuation from the spacecraft and the rest of the instrument below the tracker trays is neglected.

All of the fundamental frequencies listed in table 1 exceed the frequency requirement of 500 Hz. The frequencies in table 1 are based upon the 3/8-5056-0.0007-1.0 vented aluminum honeycomb core and the payload in the FEA model only contributing mass, no stiffness to the model solution. The elastic modulus listed for each GFRP composite laminate is a nominal value from manufacturer's literature. A variation of ~10% in actual mechanical properties is common due to fiber volume fraction and matrix selection.

In addition to the fundamental frequency, the RMS displacement at the center of the tray was calculated without the response of the payload. Using the requirements stated above, the allowable RMS displacement must be at or below 116 μm. This value is based upon a frequency of 500 Hz and a 5% probability that one peak exceeds collision levels. All facesheet materials are well below the defined RMS displacement value. Further investigation of facesheet performance will need to be done once the payload attachment is defined.

[3] Note: SuperGLAST trays are neglected here. Pisa is responsible for making the facesheet selection for the SuperGLAST trays. 240 trays are considered for comparison and selection of the standard tray core material.
[4] The half gap distance is defined by taking ½ the separation distance between adjacent trays and subtracting that the wire bond potting height.

5.4 Radiation Length

The Monte Carlo simulations performed for the NASA proposal assume a radiation length of 0.1% for each facesheet. As can be seen in Table 1, only the four ply-1k tow panels for XN50 and YSH50 meet this requirement. The six ply-1k tow panels are slightly over, but the impact on instrument performance of the tracker is minimal. The four ply-2k tow panels are significantly over the radiation length limit. They probably would have a larger impact on the instrument performance, and therefore, they would not be a good choice.

5.5 Cost

The cost estimated in the NASA proposal for each facesheet is $50. This cost estimate was later increased to $250 after further review of quotations from several different composites fabricators. All of the fiber lay-ups in table 1 meet this $250 requirement with the exception of the six ply-1k tow XN50/RS-3. The 1k tow materials are more expensive in unipreg form than the 2k tow. The expense is due to the limited demand for the 1k tow size. Most manufacturers do not stock the 1k tow materials as an off-the-shelf item, so additional cost is incurred due to set-up and mill runs for fabrication of the 1k tow unipreg.

5.6 Availability

The availability of the finished facesheet panels is also based upon whether the material is 1k or 2k. In having the material available in off-the-shelf quantities, the processing time is about four weeks. If however, the material requires a special fabrication run to be done like the 1k tow material, then an additional four weeks is added to the ARO. If the 2k tow material was chosen, the material would probably already be available for facesheet panel lay-up and curing.

5.7 Flight Heritage

M55J fibers have the most extensive flight history of any other graphite composite fiber. XN50 also has an extensive use in NASA programs. YSH50 fibers are still relatively new. They were formulated to replace P75 fibers, and because they are still new, they have a limited flight history.

5.8 Fabrication/Handling

The unbalanced four ply laminates have a unique problem with fabrication and handling. Because the four ply laminates are unbalanced, they tend to curl or scroll up into a cylindrical shape. This is due to the laminate panel not having the same ply fiber orientation spaced symmetrically around its neutral bend axis. Bonding of unbalanced four-ply laminates will pose an issue that the manufacturer of the tracker trays will have to address with possibly special tooling. The difficulty in bonding unbalanced laminates to a tray closeouts or tray core is not considered substantial though because techniques used to build sandwich structures balanced about the sandwich neutral axis are common. Fabrication shops with experience building similar sandwich panels have been contacted to ensure minimal development and ease of fabrication is certain.

6. Summary

Several GFRP facesheet options were compared to the NASA proposal baseline based upon general performance characteristics. From those materials compared, the thicker laminates exceeded the NASA proposal's requirements for thickness, mass, and radiation length. The only laminate, which exceeded the proposed cost budget, is the six-ply XN50 facesheet. The thin four-ply laminates meet most of the requirements listed in the NASA proposal and in table 1. The availability and fabrication/handling issues for both XN50 and YSH50 fiber panels will need to be finalized, but it is believed that both would be adequate solutions for the GLAST standard tray facesheets. Based upon cost, a greater savings could be realized with the use of YSH50 fibers over XN50 fibers. Therefore, the YSH50 1k-unbalanced four-ply lay-up is believed to perform to an acceptable level for the GLAST instrument.

7. References

1. Swensen, E.A., Steinzig, M., and Ney, S.A., "Tracker Tray Core Material Selection", HTN-102050-0026, 9/29/2000.