# Tracker Tray Core Material Selection

**Erik Swensen, Steve Ney, Mike Steinzig**
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| | Name: | Phone: | Signature: |
|---|---|---|---|
| Main Author: | Erik Swensen | (505) 661-4021 | Erik Swensen |
| Approved: | Erik Swensen | (505) 661-4021 | Erik Swensen |

## Abstract

The tracker tray sandwich support structure will be used to support the silicon payload and must survive the launch environment. The sandwich tray structure is made from three key components: the closeout frame, face sheets and honeycomb core. This document summarizes the core material considerations and presents the options, which best fit the needs of the GLAST program. The requirements, material options, and key issues are addressed and summarized. Core selection recommendations are made based on the discussion presented herein.

DESIGN ENGINEERING
ADVANCED COMPOSITE APPLICATIONS
ULTRA-STABLE PLATFORMS

110 EASTGATE DR.
LOS ALAMOS, NM 87544

PHONE 505 661•3000
FAX 505 662•5179
WWW.HYTECINC.COM

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# 1. Definitions

| | |
|---|---|
| CTE: | Coefficient of Linear Thermal Expansion. |
| E/M: | Engineering Model. |
| GFRP: | Graphite Fiber Reinforced Plastic; any polymeric matrix composite materials reinforced with high performance graphite fibers. |
| GLAST: | Gamma-ray Large Area Space Telescope |
| MECO: | Main Engine Cut Off. |
| SI-SC IRD: | Science Instrument – Spacecraft Interface Requirements Document. |
| RL: | Radiation Length. |
| RMS: | Root-Mean-Square. |

# 2. Introduction

The tray sandwich structure is constructed of several key components. These include the closeout frame, face sheets, and core. The structural trays are designed to support the tracker payload (silicon, bias-circuit and converter layers) during launch and maintain critical alignment during operation. The core and face sheets provide almost all of the structural stiffness and strength, neglecting contributions from the silicon payload.

Core selection is critical to ensure adequate load sharing between face sheets, which results in an acceptable tray stiffness that meets the requirements of the GLAST program. The remainder of this document outlines the requirements, material options and addresses key issues so that a proper core selection can be made.

# 3. Material Requirements

In selecting the core material and geometry, the following requirements were used to assess the core performance.

- Mass: the NASA proposal, issued November 1999, assumed a core mass of ~123 grams.
- Radiation Length: a radiation length of 0.2% was used in the Monte Carlo simulations for the NASA proposal.
- 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,
    - 4.00 $g_y$ and 3.35$g_z$ (liftoff & transonic)
    - 0.10 $g_y$ and 6.60 $g_z$ (MECO)
- Thermal Requirements: the thermal environment is generally mild, with temperature ranges of –20 to +40°C. The CTE mismatch between the aluminum cores and GFRP face sheets have been neglected; similar tray configurations have been prototyped and tested to greater extremes without evidence of damage. The CTE mismatch effects to the payload are also neglected because in-plane stiffness of the core has almost no effect on the thermal stresses induced in the silicon payload.
- Cost: the NASA proposal used a value of $800/core for the budgetary estimates for fabrication of the flight hardware.
- Venting: the core must be properly vented to allow trapped air to escape during launch.

## 4. Material Options

Core material options that were considered include GFRP, aluminum and Kevlar. GFRP was selected as the primary option because of its high stiffness to weight ratio and long radiation length. Aluminum was selected as an alternative because of its flight history and acceptable mechanical properties, which should meet performance requirements. Kevlar was selected as a low cost backup to GFRP, but was not selected for reasons described below.

Several GFRP honeycomb core materials were considered, which included several off the shelf products as well as one new product currently under development. YLA Cellular has been developing an ultra-lightweight carbon fiber honeycomb core for a customer in Europe. The application of this new core is also space-based, as with GLAST. Because the core is currently being developed, there is limited data available. A number of tests have been performed to estimate the mechanical properties and investigate the handling of this product. Two alternative off-the-shelf GFRP cores were also considered; UCF-51, which uses an XN50 fiber, and UCF-126, which uses a less expensive fiber, YSH50.

Several aluminum and Kevlar cores were considered as alternatives to the more expensive GFRP cores. Several variations of each were investigated to determine the performance penalties to the tray, if used. Hexcel produces a number of aluminum cores, of which 3/8-5056-.0007 and 3/8-5056-.002 were investigated. These core identifiers can be interpreted to have a 3/8” cell size, uses 5056 aluminum, and a wall thickness of 0.0007” or 0.002”. Aluminum alloy 5052 was initially considered, however 5056 aluminum has a higher shear stiffness-to-weight ratio, which improves tray performance. The Kevlar core is indicated by the identifier HRH-10-3/8-3.0, which refers to a 3/8” cell size and density of 3.0 lb/ft$^3$.

## 5. Core Performance & Technical Issues

The performance of the core materials defined in section 4.0 are summarized in Table 1. Here, the performance characteristics of various core materials are compared. The following sections will compare these performance indices against the requirements presented in section 3.0. The performance indices used to select an adequate core material include:

- Mass
- Stiffness
- Radiation Length
- Cost
- Availability
- Flight Heritage
- Fabrication/Handling
- CTE Mismatch
- Venting
- Galvanic Corrosion

**Table 1. Summary table of the standard tray key performance characteristics for various cores.**

| | NASA Proposal (Spec's) | YLA Cellular | | | Hexcel | | |
|---|---|---|---|---|---|---|---|
| | | UCF-146 (YSH-70 Fiber) | UCF-126 (YSH-50 Fabric) | UCF-51 (XN-50 Fabric) | 3/8-5056-.0007 (Al) | 3/8-5056-.002 (Al) | HRH-10-3/8-3.0 (Kevlar) |
| **Mass** | | | | | | | |
| Density (kg/m$^3$) | - | 12.04 | 32.1 | 32.1 | 16.05 | 48.16 | 48.16 |
| Est. Mass/Core (grams) | 123 | 43 | 113 | 113 | 57 | 170 | 170 |
| **Stiffness** | | | | | | | |
| Shear Modulus (ksi) | - | 14-20 | 62 | 60 | 15 | 43 | 6.5 |
| Compressive Modulus (ksi) | - | 2 | 25 | 34 | 15 | 92 | 17 |
| Fundamental Frequency (Hz) | 500 | 615[1] | 648 | 672 | 610 | 632 | 480 |
| RMS Displacement (μm) | 116 | 86.7 | 78.9 | 75 | 87.0 | 81.8 | 125.4 |
| **Radiation Length** | 0.20% | 0.077% | 0.21% | 0.21% | 0.18% | 0.54% | NI* |
| **Cost Per Core[2]**<br>**(Top – E/M $, Bottom – Flight $)** | $800<br>$800 | $697<br>$618 | $1,339<br>$1,237 | $1,766<br>$1,541 | $80<br>$50 | $100<br>$62 | NI* |
| **Availability (ARO)** | - | 6-12 wks | 6-12 wks | 3-6 wks | 7 wks | 7 wks | NI* |
| **Flight Heritage** | - | None | Limited | Yes | Yes | Yes | NI* |
| **Fabrication/Handling** | - | Acceptable | Good | Good | Concern | Good | NI* |
| **CTE Mismatch** | - | Ok | Ok | Ok | Ok | Ok | NI* |
| **Venting** | Yes | Yes | Yes | Yes | Available | Available | NI* |
| **Galvanic Corrosion** | - | None | None | None | Concern | Concern | NI* |

* NI – Not Investigated

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[1] Assuming 14 ksi shear modulus.

[2] The aluminum Hexcel cores include the cost for materials, venting and machining tolerances to ±0.001 through the thickness. Quotes were used for material and venting, whereas machining costs were estimated to be 25% greater than the material costs.

## 5.1 Mass

Minimizing the structural mass is always of interest with a space program. The NASA proposal allocated 191 kg (+67 kg of contingency) for all of the tracker subsystem mechanical structures. Of this total, early mass budgets estimated the core to weigh ~123 grams for each standard tray, or a density of 32 kg/m$^3$. This gives a total of 30 kg for all 240 standard trays[3]. Comparison of the trays presented in Table 1 show that all GFRP cores and the 0.0007" aluminum core meet the mass requirement. A savings of 15 kg can be achieved using the thin walled aluminum core and even greater using the lightweight GFRP. The heavier aluminum and Kevlar cores exceed the mass budget by 38%.

## 5.2 Stiffness

The tray structural stiffness plays an important role in surviving the random vibration environment during launch. To avoid collision between adjacent trays during launch, the fundamental frequency of each tray must exceed 500 Hz. This frequency requirement was derived using the following assumptions:

- that there is a 5% probability that any one peak might exceed the half gap[4] distance (600 μm) during the 60 second qualification level random vibration test.
- that the quality factor, Q, is less than or equal to 40; this is equivalent to a critical damping ratio of 1.25%.
- that the payload is rigidly bonded to the trays.
- that adjacent trays are 180° out-of-phase at the time a tray exceeds collision levels.
- that attenuation from the spacecraft and instrument below the tracker trays is neglected.

These assumptions can all be considered conservative with the exception of the third. The type of epoxy or silicon and the bonding pattern used can all have a disastrous affect on the response of the silicon. Earlier analysis showed that the three pad bonding scheme would allow the silicon to respond with excessively high displacements relative to the tray. In addition, compliant epoxies or silicon will allow greater flexibility of the silicon, resulting in higher displacements. These considerations will need to be made when the payload attachment is defined.

The fundamental frequency of the tray is presented in Table 1, using each core option. These frequencies are based on FEA calculations using 4-ply XN50 carbon fiber face sheets. Stiffening effects from the payload are neglected in this calculation, which means only mass considerations are included in the model. All cores presented in Table 1 meet the required fundamental frequency of 500 Hz, with the exception of the Kevlar. At 480 Hz, Kevlar can no longer be considered as an option for the tracker trays. The next lowest frequency is using the thin walled aluminum, at 610 Hz. This is 22% greater than the requirement, and is actually more

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[3] SuperGLAST trays are neglected here. Pisa is responsible for making the core 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 reducing that by the wire bond potting height.

conservative because additional stiffening effects from the payload will increase tray stiffness through mechanical coupling. The remaining cores are all acceptable.

In addition to the fundamental frequency, the RMS displacement at the center of the tray was calculated, again neglecting the relative response of the payload to the tray, but including the payload mass. Using the requirements above, the allowable RMS displacement must be at or below 116 μm. This value assumes that the frequency is 500Hz and the probability that one peak exceeds collision levels is 5%. Using this, all core materials presented in Table 1 meet or exceed the allowable RMS displacement requirement, with the exception of the Kevlar core. The payload will need to be considered in future calculations to ensure that the response of the tray and payload do not exceed required levels.

### 5.3 Radiation Length

RL considerations were a major reason to consider GFRP cores early in the GLAST program. Recent Monte Carlo simulations revealed that lighter aluminum cores would not have the impact on instrument performance that was once thought. As a result, aluminum options became more acceptable.

The NASA proposal assumed a RL of 0.2% for the cores. Using this as a guide, the lightweight GFRP and lightweight aluminum cores meet this performance goal. The heavier GFRP core is slightly higher at 0.21%, and the heavier aluminum is much higher at 0.54%. Both the GFRP and lightweight aluminum cores would meet instrument requirements with acceptable margins. The heavier aluminum cores would have too great an impact on performance. Kevlar cores were not investigated because of poor stiffness results.

### 5.4 Cost

The cost of materials becomes a major driver in ensuring the success of the GLAST program. NASA is carefully scrutinizing budget over-runs, which can be devastating to programs of this magnitude. To ensure success, costs must be minimized when possible so that savings can be reallocated to other areas to maintain cost budgets.

The NASA proposal budgeted $800/core, assuming a GFRP core would be used. Using this as a guide, cost estimates were obtained for those cores presented in Table 1. Two prices are given, which represent the cost when buying in two different quantities. The upper cost is for the E/M prototype, 16 units. The lower cost is for the flight hardware, 285 units[5]. In either case, the cost is much greater than the NASA proposal budgeted.

The lighter GFRP core meets the cost budget coming in at $618/core for flight quantities. Additional development costs may be incurred because this is a relatively new core configuration for YLA, with limited data and history available. The heavier GFRP require little development up front, but does exceed the cost budget by $437/core (UCF-126) in flight quantities. This would produce a cost over-run on the order of $125K to the mechanical structures.

The lightweight aluminum core has exceeded expectations when considering cost. The cost of a finished, vented aluminum core with 0.0007” wall thickness is $50/core. This cost

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[5] SuperGLAST trays are neglected here. Pisa is responsible for making the core selection for the SuperGLAST trays. Here, 16 units for the E/M and 285 units for the flight hardware are considered for comparison and selection of the standard tray core material; this includes 45 cores for spare trays.

includes 25% to finish each core to exact dimensions. The estimated savings, which can be applied to other components, is on the order of $214K, for the 285 standard trays.

### 5.5 Availability

Typically, GFRP honeycomb takes longer to procure than aluminum due to a more extensive fabrication process. The limited availability of certain carbon fiber prepreg[6] materials can add several weeks to the lead-time, if a special run is required to procure the carbon fibers. The lead-time to procure GFRP honeycomb has been estimated to be 6-12 weeks, whereas aluminum honeycomb can be received within 7 weeks.

Longer lead-times for GFRP honeycomb will not impact the schedule during the E/M prototype and flight hardware procurement phases of the GLAST program, because sufficient time has been allocated to procure longer lead-time components, such as silicon. The development phase, FY'01, however, is much tighter, and long lead-times can have a greater impact on schedule during this phase. There is sufficient time in the schedule to procure GFRP honeycomb once, however if changes are made along the way due to unforeseen circumstances, the schedule will be at risk. If GFRP honeycomb is used, a conservative selection must be made up-front to minimize risk to the schedule and program later.

### 5.6 Flight Heritage

The flight heritage of composite materials is always in question with NASA. Using materials which have a flight history are viewed with lesser concerns because they do not bring unknown risk into the program. YLA Cellular's UCF-51 uses an XN50 carbon fabric and has an extensive flight history. YLA UCF-126 honeycomb uses a YSH50 carbon fabric that has a limited flight history, primarily because the YSH fibers are relatively new. YLA UCF-146 is currently in the development stage and has no flight or application history. Aluminum has an extensive flight history as a structural material.

### 5.7 Fabrication/Handling

There have been some concerns discussed regarding potential damage that may occur to thin walled cores, resulting from fabrication and handling. YLA UCF-146 has been handled and fabricated into sandwich structures with some evidence of damage. This damage was primarily due to the inexperience of the fabrication shop used. YLA will need to deliver each core in its finished state to avoid such damage during production.

Thin walled aluminum cores are susceptible to damage during fabrication and handling, however with proper care in handling, damage can be avoided. Previous work on the GLAST program used 0.0007" wall aluminum honeycomb core to fabricate several tray structures. There was no evidence of damage during this process. Taking proper steps to protect the cores and minimize handling will reduce the risk of damage and allow the use of thin walled cores.

### 5.8 CTE Mismatch

The CTE mismatch between the GFRP face sheets and the GFRP core are negligible. The CTE mismatch between the GFRP face sheets and the aluminum cores are much higher,

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[6] Prepreg material refers to the initial process of saturating the carbon fibers with resin materials, also referred to as preimpregnation. Prepreg usually comes in tape form and is used to layup the carbon structure.

however the impact of this is also negligible. The reason for this is because the in-plane modulus of the GFRP face sheets is several orders of magnitude greater than the aluminum honeycomb modulus, in the same direction. This will allow the face sheets to constrain the core from expanding. The thermally induced stresses will be minimal on the face sheet when compared to those produced by the payload.

### 5.9 Venting

Venting is required in the core to allow trapped gasses to escape from each cell during launch. All GFRP cores reported in this document have an adequate amount of venting holes to relieve this pressure. The aluminum, however, can be purchased with or without venting holes. It is obvious that any aluminum core selected for use on the GLAST instrument will have sufficient venting holes. Including these venting holes, however, does come with an associated cost increase and stiffness reduction. The cost to include venting holes increases the cost per core by 8%, and is included in the cost quoted in Table 1.

The stiffness reduction is of greater interest. Hexcel has quoted a 10% reduction to the shear modulus when venting holes are included. A 10% reduction to the shear modulus will reduce the fundamental frequency to 600 Hz, or less than 2%. The RMS displacement will increase to 89.3 μm. These new values still meet the requirements to avoid contact between adjacent trays during launch.

### 5.10 Galvanic Corrosion

Galvanic corrosion has been discussed as an issue of concern when considering using a GFRP face sheet bonded to an aluminum core. Although this issue must be addressed, the concern is not severe. Sandwich structures using GFRP face sheets and aluminum honeycomb cores have an extensive flight history, and the issue of galvanic corrosion has been addressed. The simplest solution is to ensure that an adequate bond layer, using a non-conductive adhesive, separates the two materials and eliminates the conductive path. This procedure has been successful on other satellite programs.

## 6. Summary and Core Material Selection

Several core options have been considered here which meet the requirements of the GLAST program. The Kevlar and heavier aluminum core have been ruled out because of poor performance. All the GFRP cores meet program requirements with the exception to Cost. Both the UCF-51 and UCF-146 cores exceed the NASA proposal budget by more than 50%. The lighter core meets the cost budget, but has little history and will require some development to ensure success. The thin walled aluminum core, 3/8-5056-0.0007, meets the requirements of the GLAST program and will save the program nearly $214K. There are remaining technical issues, such as handling and galvanic corrosion, that have to be addressed, however minimal R&D is required. Assuming there are no unforeseen issues with the thin walled aluminum core, it is believed that this core will perform to an acceptable level for the GLAST instrument.