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1. INTRODUCTION

1.1. Purpose

This document defines the requirements for the mechanical structure of the calorimeter modules of the Gamma-Ray Large Area Telescope.

1.2. Applicable documents

GE-00010	'GLAST LAT Performance Specification', August 2000
GLAST00110	'Mission Assurance Requirements (MAR) for Gamma-Ray Large Area Telescope (GLAST) Large Area Telescope (LAT)' , NASA Goddard Space Flight Center, Current Draft Sept 20, 2000
GEVS-SE Rev A	'General Environmental Verification Specification for STS and ELV Payloads, Subsystems and Components', revised June 1996.
MSFC-SPEC-522	'Design Criteria for Controlling Stress Corrosion Cracking', revised 1 July 1987
MIL-HDBK-5H	'Metallic Materials and Elements for Aerospace Vehicle Structures', revised 1 December 1998.
LAT-SS-00018-D4	'LAT CAL Subsystem Specification - Level III Specification', 20 March 2001
LAT-DS-00095-03	'LAT Calorimeter CsI Crystal Specification', 5 April 2001
LAT-SS-00107-1 D2	'LAT Mechanical Parts Plan', 19 March 2001
LAT-MN-000928-D1	'LAT Mechanical Performance Specification'

1.3. Acronyms

GLAST	Gamma-Ray Large Area Telescope
LAT	Large Area Telescope
CAL	the Calorimeter subsystem of the LAT
MPS	Mechanical Performance Specification for the mission
PEM	Pre-electronics Module
CDE	Crystal Detector Element
LV	Launch vehicle
AFEE	Analog Front End Electronics
RMS	Root Mean Square
TBD	To be Defined
TBR	To be refined
CAD	Computer Aided Design
CTE	Coefficient of Thermal Expansion
CsI	Cesium Iodide
MECO	Main Engine Cut-off

1.4. Definitions

m	meter
s	second
mm	millimeter

g	gravity acceleration 9.81 m/s²
W	Watt
dB	Decibel
Ω	ohm

2. GENERAL DESCRIPTION

The Calorimeter of the GLAST Large Area Telescope is configured in 16 identical modules, in a 4x4 array. Each module contains 96 CsI logs with photodiodes glued at both ends. A front end electronic boards that processes the signals of the photodiodes is attached to each side of the Calorimeter modules.

The mechanical structure of the calorimeter modules consists of carbon composite structure that provides support for the 96 CsI Detector Elements (CDE), an Aluminum base plate which presents the structural interface to the LAT Grid structure, Al top plate, Al cell closeout plates and EMI shields on the four sides.

The composite structure consists of an array of 96 carbon fiber epoxy resin composite cells, arranged into 8 layers of 12 cells. Each layer is rotated by 90° in the relation to the neighbors, to define an X – Y orientation for the CsI logs.

All the aluminum parts are attached to inserts, manufactured inside the composite structure.

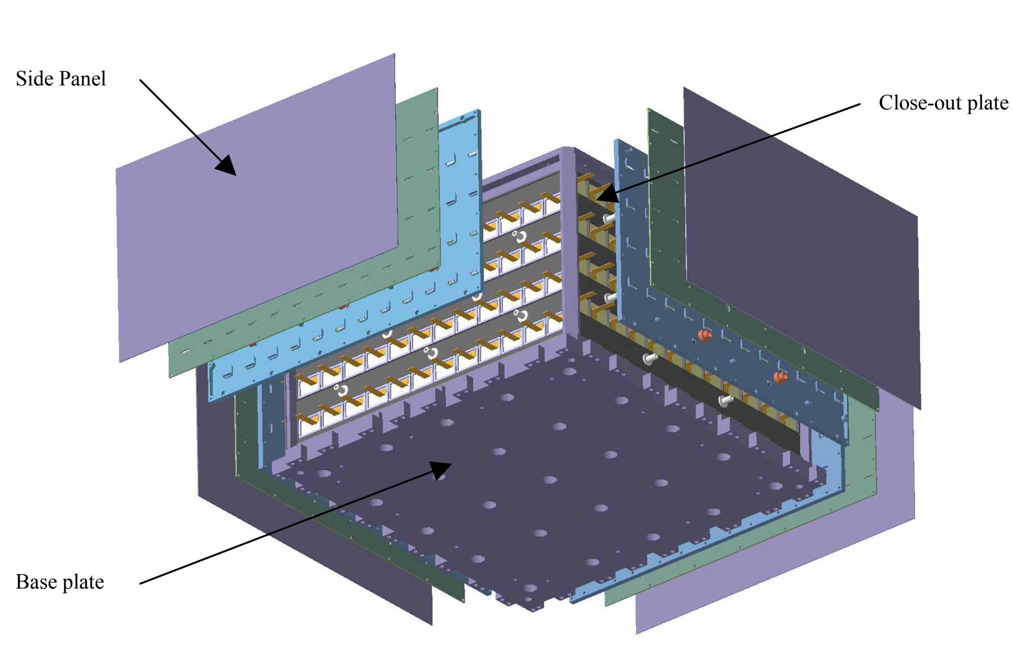

Figure 1: Exploded view of a calorimeter module

3. MISSION

3.1. Lifetime

The materials, processes and structural assemblies used to build the mechanical structure of the CAL modules shall able to withstand the environmental loads they exposed to during the service life of the instrument. The service life include 10 years of in orbit operation plus all the ground operations (assembly, testing, storage…), which could last up to 2 years for the first modules.

3.2. Load events

The environmental load events that will be experienced by the calorimeter modules during the lifetime of the instrument are listed below, classified according to their nature. The thermal loads are presented separately.

3.2.1. Ground and test loads

3.2.1.1.Assembly and integration loads

No load event is applied on the mechanical structure during the assembly of the PEMs. Integration procedures of the CAL modules are still to be defined but no particular load events are expected during this operation, except the ones resulting from the handling of the modules.

3.2.1.2.Handling

The CAL modules are lifted from the top when moved between assembly or test areas. The modules can be integrated in any orientation as defined in the LAT Mechanical Performance Specification, paragraph 6.4.2. The load event is given by the weight of a fully assembled module, i.e. a 1g acceleration applied along any orientation.

3.2.1.3.Test loads

During science performance tests, muons test or beam test, the load applied on the mechanical structure is a 1g acceleration along any orientation (weight of a module). In case of a test in a beam, the modules are move and oriented in the beam line. Expected dynamic loads are negligible since motion is slow.
Structural test loads are defined according to launch loads and are therefore specified in the corresponding paragraphs, for both qualification and acceptance.

3.2.1.4.Transportation

Road and air transportation are used to ship the CAL modules between the different assembly and test areas. During this operations, the mechanical structure undergoes random vibration and thermal load events during several hours. The shipping containers shall be designed to guarantee that the load levels remain below acceptance levels.

3.2.1.5.Thermo-elastic loads

During ground operations and transportation, the temperature range to which the CAL module can be submitted is 0 to 40°C (LAT MPS table 6.2-2). The mechanical structure shall be able to withstand the loads due to a 20°C temperature increase or decrease, assuming the assembly is made at 20°C. The thermo-elastic loads result from different coefficients of thermal expansion between the composite structure, the aluminum alloy parts and the printed circuit boards. The stress levels in the mechanical part shall remain below yield loads, with a safety factor of 1.25 (TBR). The parts shall be able to withstand the loads for several hours (TBD) without creep effect.

3.2.2. Launch loads

3.2.2.1.Static loads

Quasi-static loads for the GLAST mission are defined in the LAT MPS document, in paragraph 6.1.1. The values are derived from DELTA II launch vehicle Payload Planner Guide. The levels for the primary structures are given in table 3.7. The levels are given in g unit, with 1 g = 9.81 m/s².

	Event	
Axis	Liftoff / Transonic	MECO
Thrust	+3.25 / -0.8	+6.0 ± 0.6
Lateral	+/- 4.0	+/- 0.1

(+) Indicates compression and (-) tension in the thrust axis Acceleration levels are specified in g

Table 3.7-1: Delta II Static launch load levels

The CAL modules are defined in the LAT MPS document as secondary structures, paragraph 6.1.1. The corresponding static limit load levels are +/- 12 g applied independently to X, Y or Z axis.

3.2.2.2.Random vibration

The random vibration levels for the systems and subsystems are specified in paragraph 6.1.2 of the LAT MPS document. The envelop of the input ASD is used to specify both acceptance and qualification levels. The levels are corrected for mass above 22.7 kg, according to the table 3.7-2.

	ASD in g^2/Hz	Comments
dB Reduction	= 10 log (W/22.7)	
ASD (50 – 800 Hz)	= 0.16 (22.7 / W)	For protoflight
ASD (50 – 800 Hz)	= 0.08 (22.7/ W)	For acceptance
W indicates component weight The slopes shall be maintained at + and – 6 dB/oct for components weighting up to 59 kg. Above that weight, the slopes shall be adjusted to maintain and ASD level of 0.01 g^2/Hz at 20 and 2000 Hz.		

Table 3.7-2: Delta II random vibration load levels

With a conservative rounded value of 90 kg per fully assembled CAL module, the corrected ASD levels that shall be withstand by the mechanical structure are given in the table 3.7-3, for qualification and acceptance.

Frequency in Hz	ASD level in g^2/Hz	
	Qualification	Acceptance
20	0.01	0.01
20 - 50	+4.55 dB/oct	+2.28 dB/oct
50 - 800	0.04	0.02
800 - 2000	-4.55 dB/oct	-2.28 dB/oct
2000	0.01	0.01
Overall acceleration level	7.63 gRMS	5.65 gRMS

Table 3.7-3: CAL modules random vibration load levels

The PEM mechanical structure shall be able to preserve the safety of the CAL modules under random vibration levels that meet the qualification levels, applied along each axis independently, for a duration up to 2 minutes (TBR).

3.2.2.3.Acoustic noise

The CAL modules are dense, compact elements, buried inside the bays of the grid. Therefore, acoustic noise is a negligible load event for the mechanical structure. Acoustic testing is not performed at CAL modules level but at the instrument level. The CAL modules shall be capable of normally operating after application of the acoustic loads defined in table 6.1-5 of the LAT MPS document.

3.2.2.4.Shock loads

The shock loads levels to which the CAL mechanical structure shall be qualified are limited to piroshock loads, produced by explosive nuts during the launch vehicle separations. The mechanical structure shall protect efficiently the CAL modules under the shock load levels defined in 6.1-6 of the LAT MPS document.

3.2.2.5.Depressurization

The depressurization curves for the mission are given in figure 6.1-7 of the LAT MPS document, derived from DELTA II LV Payload Planner's Guide. The CAL modules shall be able to withstand the corresponding time rate of change of pressure. No air shall be trapped inside the composite cells. Sufficient venting path shall be preserved between the side panels and the bottom plate to allow the release of all the volume of gazes that can fit inside a CAL module. The air shall path shall be minimized between the side panels and the top frame to prevent the air from filling the volume between the top of the CAL modules and the bottom of the tracker towers.

3.2.2.6.Thermo-elastic loads

The CAL mechanical structure shall be able to withstand the thermo-elastic loads due to variations of temperature between 0 and 30°C. The loads can be applied in combination with the static loads previously defined or dynamic loads, independently.

3.2.3. In orbit loads

3.2.3.1.Operational pressure

The CAL mechanical structure materials, parts and assemblies shall preserve the full functionality of the CAL modules at the operating pressure of 10-5 Torr, as defined in the LAT MSP document, paragraph 6.1-5.

3.2.3.2.Thermo-elastic loads

During in orbit operation, the CAL structure shall be able to withstand the thermo-elastic loads due temperature cycling within the survival range –30°C to +50°C, resulting from CTE mismatch between the composite and the aluminum parts (including effects due to the grid). The stress levels in the mechanical part shall remain below yield loads, with a safety factor of 1.1 (TBR).

3.2.3.3.Hygroscopic load

The composite structure shall be able to withstand the hygroscopic loads due to variations in moisture content. The change in the mechanical properties of the material shall not influence the structural functionality of the CAL mechanical structure. The change in the dimensions of the composite structure due to change in moisture content shall not influence the functionality of the CAL modules.

3.3. Thermal loads

Thermal loads are split into 2 categories: environmental thermal loads and heat power dissipated by the electronics, attached to the mechanical structure. In this category, two different sources shall be taken into account, the AFEE boards attached to the close-out plates and the TEM boxes and power supplies attached on the bottom plate.

3.3.1. Environmental thermal loads

The materials, parts and assemblies of the CAL mechanical structure shall be able to keep their full functionality inside the temperature ranges, defined for the entire instrument. The temperature ranges are presented in table 3.7-8, classified according to the different phases of the service life.

	Environmental thermal loads					
	Assembly Integration	Storage Transport	On LV	Launch	Operational	Survival
T_{max} qualif. Test (1)					35 °C	50 °C
T_{max} design accept	25 °C	40 °C	26.7 °C	30 °C	25 °C	40 °C
T_{min} design accept	20 °C	0 °C	12.8 °C	0 °C	-10 °C	-20 °C
T_{min} qualif. Test (1)					-20 °C	-30 °C
Nbr of cycles					120	120
dT/dt_{max} (2)					5 °C/hr	5 °C/hr

(1) Test temperature set at 10 °C higher than maximum design temperature and 10 °C lower than minimum design temperature, per GEVS-SE rev A
(2) Maximum time rate of change of temperature

Table 3.8-1: Mission environmental thermal loads

The mechanical structure shall be qualified for up to 120 thermal cycling within the survival temperature range, with a 5 °C per hour time rate of change of temperature. The main constraint for the structure is the thermo-elastic loads, which have been detailed in paragraph 1.7.

3.3.2. On orbit heat flux

The CAL modules are protected by the thermally controlled walls of the grid. They are not exposed to Earth or Sun heat flux.

3.3.3. Heat power from electronics

The power dissipated by the AFEE boards or TEM and SIU boxes are not direct thermal loads for the mechanical structure but must considered in the functionality requirements because it's the mechanical structure that transfer the heat dissipated by the components to the thermally controlled grid.

3.4. Loads factors

Load factor shall be used to define the relevant loads for the design, the test and the qualification of the mechanical structure. This factors shall be applied to the limit loads defined in paragraph 1.7. The values for the different factors are given in table 3.9-1.

Load factors	
Design load KD	1.3
Qualification factor KQ	1.25
Acceptance factor KA	1.1

Table 3.9-1: Summary of load factors

For Gaussian distributed random loads, with zero mean value, the standard deviation multiplied by 3 shall be used as the limit load contribution.

4. FUNCTIONALITY

4.1. Mass and inertia properties

The mass of mechanical structure shall be minimized. It shall not exceed 10.5 Kg (TBR). The shape of the mechanical parts shall be optimized to get the required functionalities with the minimum amount of material.

The mass of all the mechanical parts shall be known with a precision of 5%.

The position of the center of gravity of the mechanical structure shall be known with a precision of 5 mm.

The first moment of inertia about 3 axis of the mechanical structure shall be known with a precision of 10%.

4.2. Strength

The mechanical structure shall be able to withstand the different load events without yielding, failing or exhibiting deformations that can influence the performance of the CAL modules or any other system or sub-system.

Any point of the mechanical structure shall not displace by more than 0.5mm under a +/-12 g static load, applied along X or Y axis independently, to avoid interaction with the grid walls.

Any point of the top of the mechanical structure shall not displace by more than 0.5 mm under a +/-12 g static load applied along Z axis.

Any point of the bottom plate of the mechanical structure shall not displace by more than 0.5mm under a +/- 12 g static load applied along Z axis to minimize mechanical loads on the TEM boxes, attached below the CAL modules.

4.3. Stiffness

The mechanical structure shall provide a minimum fundamental frequency greater than 100 Hz to a CAL module, isolated from other systems. The influence of the boundary conditions, attached on the grid, shall be evaluated.

4.4. Dynamic behavior

The mechanical structure shall be stiff enough in the X and Y directions to keep the difference between the RMS displacements between any two points of the side panels below 0.25 mm, under random vibration with qualification levels.

The mechanical structure shall be stiff enough in the Z direction to keep the difference between the RMS displacements between any two points of the top of the structure below 0.5 mm, under random vibration with qualification levels.

The mechanical structure shall be stiff enough in the Z direction to keep the difference between the RMS displacements between any two points of the bottom plate below 0.25 mm, under random vibration with qualification levels.

The levels for random vibration are defined in table 3.7-3.

4.5. Thermal

4.5.1. Thermal control of AFEE boards

The AFFE boards are attached to the close-out plates on the four sides of the CAL modules. The components of each boards dissipates a total power of 1 W (TBR). This power needs to be transferred by the mechanical structure to the grid, whose temperature is regulated.

The total thermal resistance of the mechanical structure, from the attachment tabs to the interface with the circuit boards, shall be low enough to keep below 10 °C the difference between the temperature of the contact surface with the grid walls and any point of the boards.

The thermal resistance of contact between the close-out plates and the printed circuit boards shall be low enough to keep the temperature gradient of the boards below 5 °C. The assumption is made that

the in plane thermal conductivity of the boards is greater than 100 W/m°C and the transverse conductivity grater than 0.8 W/m°C.
The mechanical structure shall provide an efficient vertical heat flow so that the variations of temperature remain below 5 °C in 3 of the boards, if the power dissipated by the fourth goes to 0 or 1W.

4.5.2. Thermal control of PIN photodiodes

The mechanical structure shall guarantee that the photodiodes are sufficiently isolated from the power dissipated by the AFEE boards. Their temperature shall not change by more than TBD °C per hour.

4.5.3. Thermal control of the TEM, SIU and power supplies

A TEM box is attached below each CAL module on the bottom plate. On 4 of the modules, in addition, a power supply and SIU box are mounted on the TEM box. The power total dissipated by these elements is in the worst case 50 W (TEM + SIU + power supply). The heat need to be transferred to the grid walls through the bottom plate of the CAL mechanical structure.
The thermal resistance of the bottom plate shall be low enough to keep below 5 °C the gradient of temperature between the interface plane with the TEM boxes and the top of the tabs of the bottom plate.
The thermal path provided by the structure from the TEM boxes to the grid shall guarantee that the temperature distribution in the AFEE boards does not change by more than 3°C when the power dissipated in the TEM + SIU + power supplies is raised from 0°C to its nominal value.

4.6. Tolerances and alignment

4.6.1. Outer dimensions

The design of the mechanical structure and the associated system of tolerances shall guarantee the conformance to the geometrical interface requirements presented in the Interface Control Document between the CAL module and the other systems and sub-systems.
The parts shall be built and assembled with enough precision to guarantee that the outer transverse dimensions of the CAL modules remain below 363x363 mm² (tabs not included).
The parts shall be built and assembled with enough precision to guarantee that the height of the structure from the top of the tabs to the top of the frame attached to the composite structure remains below 209 mm.

4.6.2. Alignment of parts

The alignment between the top frame, the composite structure and the bottom plate shall be better than 0.15 mm.

4.6.3. Planarity of sides

The end surface of the inserts attached to each side of the composite structure shall remain between two planes, distant by less than 0.2 mm.

4.6.4. Attachment of close-out plates

The surfaces of the side inserts, top frame and bottom plate in contact with the close-out plates shall remain between two planes, distant by less than 0.2 mm.
The distance between +X, respectively +Y, close-out plate and –X, respectively –Y, close-out plate shall be 342 mm, with a tolerance of ±0.1 mm.

4.7. Electrical conductivity

The composite structure and all the metallic parts shall be electrically connected, once the mechanical structure is assembled.

The electrical resistance between any two points of the composite structure, including the side, bottom and top inserts, shall be less than 10 Ω (TBR).

The electrical resistance between any two points of the metallic parts shall be less than 0.1 Ω (TBR), once the mechanical structure is assembled.

The surface finishing and surface treatment of the top of the tabs shall guaranty that the electrical resistance between the bottom plate and the grid wall remains below 0.1 Ω (TBR).

4.8. Electromagnetic compatibility

The CAL mechanical structure shall provide effective shielding of the AFEE boards attached on the sides of the modules.

The boards shall be enclosed inside at least 0.5 mm thick aluminum walls. The enclosure is provided by the close-out plates and the side panels.

The only openings allowed are the holes for the cables:

- The slots on the bottom plate to connect the AFEE boards to the TEM boxes and power supplies
- The slots in the close-out plate to connect the PIN photodiodes to the AFEE boards.

The distance from slot edge to slot edge shall be grater than 1.5 times the width of the slot.

5. INTERFACE

5.1. Definitions

The interfaces by which the CAL mechanical structure is concerned can be split in 4 groups.

- Inner interface of the mechanical structure: interfaces between the different mechanical parts.
- Inner PEM interfaces: interface between the mechanical structure and the CDEs.
- Inner CAL interfaces: interface between the PEM mechanical structure and the AFFE boards
- Outer interfaces: interface between the CAL modules and the grid and electronic boxes (TEM, SIU, power supplies)

Only the requirements relative to the CAL modules are presented in this document. The outer interfaces are defined in the Interface Control Document between the CAL modules and other systems and sub-systems (TBD reference document).

5.2. Mechanical structure interface

5.2.1. Surface finishing

The functional faces of the mechanicals parts shall be machined with sharp tools and machining parameters adapted to the material to guaranty an average roughness Ra of 1.6 or better.

5.2.2. Surface treatment

A surface treatment shall be performed on all the aluminum alloy parts to protect them from corrosion. A Chromate conversion treatment ALODINE 1200 shall be used for thermally or electrically conductive parts. A black anodizing shall be used for non conductive parts.

5.3. Interface with CDEs

5.3.1. Description

A CDE is inserted inside each of the cells of the carbon epoxy composite structure. It is positioned and supported inside the cell by four silicone elastomeric cords placed between the corners of the cell and the chamfers of the crystals. The longitudinal displacement of the logs is stopped by 2 elastomeric damper frames, placed around the PIN photodiodes, between the log ends and the close-out plates.

5.3.2. Dimension of cells

A CsI log whose size and shape are within specifications shall inside any of the 96 cells of a composite structure, with 1 mm diameter elastomeric cords placed along the 4 chamfers. The specifications of the CsI logs are defined in LAT-DS-00095-02 document.

5.4. Interface with AFFE boards

5.4.1. Description

Each PEM mechanical structure support one printed circuit board on each of its 4 lateral sides. The boards are mechanically attached to the close-out plates with bolts.
Flex KAPTON cables connect the PIN photodiodes to the boards, through slots machined on the close-out plates. All the flex cables need to be passed through slots on the PCBs at the same time when the board is attached to the close-out plate.
The cables connecting the AFEE boards to TEM boxes or power supplies are routed through slots machined in the bottom plate
Once the boards are mounted and the cables connected, the module is closed with 4 side panels.
The PEM mechanical structure and the AFFE boards share mechanical, thermal and electrical interfaces.

5.4.2. Mechanical interfaces

All the geometrical specifications for the mechanical integration of the AFFE boards are defined in the engineering drawing numbered GLT.XX.03.12 and GLT.XX.03.13 (XX number refers to the model i.e. 05 for VM2). The drawing includes all the dimensions and tolerances to allow the assembly.

5.4.3. Volume allocated to the boards

The PEM mechanical structure shall provide room on its 4 sides to integrate 333x194 mm² printed circuit boards. A clearance of at least 0.5 mm between the board and the edges of the close-out plate is required to ensure mounting. The distance between the close-out plates and the side panels shall be greater than 8.5 mm, except above the photodiodes connections. This defines the available volume for the boards.
The PCB shall be centered in the previously defined volume by the mechanical structure.
Leave.
A clearance greater than 0.8 mm shall remain between the close-out plates or side panels and the top of the components that are mounted on boards.

5.4.4. Attachment of the boards

The mechanical structure shall provide attachment points at the 4 corners and along the 4 edges of the PCBs. The mechanical structure shall provide 10 attachment points on the surface of the boards. The planarity of the surface on which the boards are attached to shall be lower than 0.2mm (all fixation points shall remain inside two 0.2 mm apart planes).

5.4.5. Cables

Four slots shall be machined on each side of the CAL bottom plate to connect the cables of the AFFE boards to the TEM boxes. The width of the slots is 20 mm ±0.2mm, imposed by the tabs pattern.
Edges shall be smoothen to avoid damaging the cables during contact against the mechanical parts.
Attachment points for the cables shall be provided by the mechanical structure (TBD).

5.4.6. Thermal interface

The thermal resistance of contact between the AFFE boards and the close-out plates shall be less than (TBD) to ensure an efficient heat transfer by conduction.
The faces of the aluminum close-out plates in contact with the PCBs shall be surface treated to preserve the properties of the thermal contact.
The mechanical structure shall ensure the thermal control of the AFFE boards as described in paragraph 4.4, "thermal control of AFFE boards".

5.4.7. EMI / EMC

Requirements for electrical and electromagnetic interfaces are described in chapter 4.5 and 4.6.

6. DESIGN

6.1. Inspectability

It shall be possible to control the optical performance of the CDEs of a module at any stage of their integration inside the composite structure.

6.2. Interchangeability

All the parts of the mechanical structure shall be identified by an item number. The parts with the same item number shall have the same functionality and be dimensionally interchangeable so that they can be integrated in any of the CAL modules.
The design and the assembly of the mechanical structure shall guaranty that all the CAL modules have the same geometry to allow the integration in any of the 16 bays of the grid.

6.3. Maintainability

Until the AFFE boards are integrated, it shall be possible to access any of the 96 CDEs of a modules without damaging the components of the mechanical structure or the CDEs themselves.

6.4. Design concept

The design concept is described

6.5. Materials

6.5.1. Materials selection

All the materials that are used to build the mechanical structure of the modules shall have been qualified for space application by the ESA or NASA or through a dedicated qualification procedure. The material shall in particular pass out gassing requirements.

6.5.2. Metals

All metallic components shall be built using metals listed in MSFC-522-B Table I documents to avoid stress corrosion cracking.

6.5.3. Composite structure

A process control plan shall be developed to ensure the uniformity of the characteristics of the carbon epoxy composite material. The process used to manufacture the structure shall guaranty that the fiber to resin volume ratio is controlled within 10%.
Test samples shall be processed and cured with each structure and their mechanical properties measured.
Out gassing measurements shall be made on test coupons, cured during the same thermal cycle as the composite structures.

6.5.4. Elastomeric parts

The mechanical and out gassing properties of each batch of elastomeric parts shall be controlled. The mechanical properties measurements shall include durometer and compression set. For the silicone cords, elongation at break and ultimate tensile strength shall be measured in addition.

7. VERIFICATION

The verification plan of the mechanical structure is described in the document named "Mechanical Structure Verification Plan" and numbered LAT-XXXXX.

8. PRODUCTION AND MANUFACTURING

8.1. Procurements

The procurements for the materials and parts of the mechanical structure shall be made according to written specifications. Acceptance requirements shall be clearly identified.

8.2. Manufacturing process

The components of the mechanical structure are standard machined metallic parts except for the composite structure which is produced according to specific techniques. Its manufacturing process is detailed in document named "Composite Structure Design and Manufacturing" and numbered LAT-XXXX. Requirements for quality control are identified in this document.

8.3. Tooling

The manufacturing of the composite structures requires a complex, dedicated tooling. The description of the tooling and the associated specifications are defined in the document named "Composite Structure Design and Manufacturing" and numbered LAT-XXXX.

8.4. Assembly

8.4.1. Assembly stages

The CAL mechanical structure is assembled in 3 stages:

- Attachment of the top frame and bottom plate on the composite structure
- Attachment of the close-out plates once the CDEs are mounted inside the cells
- Closing of the module with the side panels once the AFEE boards are mounted

8.4.2. Assembly of the top and bottom plate

The top frame is mounted on the inserts located on the top of the composite structure and the bottom plate on those located on the bottom of the structure.
The 16 M4 screws used to attach the top frame shall be tighten with a TBD torque.
The 25 M5 screws used to attach the bottom plate shall be tighten with a TBD torque.
The top frame and bottom plate shall be aligned to less than 0.1 mm once attached to the composite structure.

The height between the top of the tabs and the top of the structure shall be less than 209 mm.
The parallelism between the top and bottom faces of the structure shall be better than 0.2 mm

8.4.3. Assembly of the close-out plates

The close-out plates are fastened to the bottom plate, top frame, corners and side inserts of the composite structure.
The 20 M3 screws that attach to close-out plates to the bottom plate and top frame shall tighten with a TBD torque.
The 10 M2 screws that attach to close-out plates to the corners shall tighten with a TBD torque.
The 10 spacers that that attach to close-out plates to the side inserts of the composite structure shall be tighten with a TBD torque.
The planarity of the close-out plate, once assembled, shall be better than 0.2 mm.
The distance from close-out plate to close-out plate shall be 342 mm with a tolerance of ±0.1mm.

8.4.4. Assembly of the side panels

The side panels are fastened to the bottom plate, top frame, corners and side inserts of the composite structure.
The 30 M2.5 screw that fasten the side panels to the other mechanical parts shall be tighten with a TBD torque.
The surface of the side panels shall remain inside two 0.25 mm apart planes, perpendicular to the top of tabs of the bottom plate.

8.5. Packaging, handling and transportation

8.5.1. Packaging

The mechanical parts shall be protected inside sealed bags until move to the assembly clean room.

8.5.2. Handling

During assembly, test and integration, handling devices are used to manipulate the 100 Kg of a CAL module. The mechanical structure shall provide attachment points to connect the handling devices to the modules.
It shall be possible to lift the CAL modules from the top so that they can be moved with a crane between assembly areas or transferred inside a container. Four attachment points shall be provided, each one able to support at least a 50 Kg load.
The bottom plate of the calorimeter structure shall have 4 M10 threaded holes to attach steel cylindrical legs so that the modules can be raised for integration of the PEM and power supply boxes.

8.6. Protection

The tabs of the bottom plate shall be protected to avoid any damage in case of a shock against a hard surface.
The top of tabs shall remain protected until the CAL modules are assembled on the grid to preserve the quality of the interface.
The face of the bottom plate on which the TEM boxes are attached shall be protected to prevent any scratch that could increase the thermal contact resistance.

8.7. Cleanliness

All the mechanical parts shall be cleaned according to procedure adapted to the materials they are built of. Mechanical parts shall be stored inside sealed bags or inside a clean room to avoid dust. The composite structure and the elastomeric parts shall be protected from humidity. Airtight sealed bags with dry air shall be used to store them until assembly starts.

9. DATA EXCHANGE

9.1. Design and manufacturing

Data shall be exchanged by mean of manufacturing drawings, documents or CAD files. HPGL format shall be used to exchange engineering drawings.

9.2. Design and structural analysis

If possible, surface or solid geometry shall be exchanged using native CAD format. Otherwise, ISO STEP format shall be used.

10. DELIVERABLES

Deliverables are defined in the PEM Requirements document, numbered LAT-XXXX.