DEVELOPMENT OF A DIMENSIONALLY STABLE LIGHTWEIGHT STRUCTURE FOR THE LISA PATHFINDER SCIENCE MODULE

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OVERVIEW

The Science Module Structure of LISA Pathfinder - the precursor for ESA's ambitious LISA mission to detect gravitational waves - is designed to fulfil extremely stringent thermo-elastic distortion requirements. It provides the stable reference frame required for the successful operation of both the high precision laser interferometer and the drag-free electric micro-propulsion system. In addition to dimensional stability, the Science Module (SCM) structure offers high stiffness and strength with a reduced mass. The complete structure is manufactured using co-cured CFRP skinned aluminium honeycomb sandwich panels connected to each other by filament wound CFRP cleats. The emphasis of the present paper is placed on the development approach and verification of the stability requirements. It includes aspects such as material selection and characterisation at specimen level, together with characterisation of individual sandwich panels up to the stability verification of the fully assembled SCM structure. The thermo-elastic performance is demonstrated in a dedicated distortion test. The assembled structure, kinematically supported is placed in a climatic chamber and subjected to a temperature variation of 30°C. Structure deformations are measured by a combination of laser metrology for the inner compartment accommodating the LISA Technology Package and by videogrammetry to determine the distorted shape of the external structure. Recorded deflections are finally compared with the analytical predictions obtained from a detailed 3D structure FEM. A conclusion is drawn about the advantages, limitations and performance that can be achieved using traditional CFRP skinned honeycomb sandwich to design dimensionally stable structures.

1. SCIENCE MODULE STRUCTURE DESIGN

The Science Module (SCM) structure is an eight sided prism with an overall height of ~850mm and an overall diameter of ~1800mm built around a central cylinder of ~820mm diameter (see FIG 1). The design ensures compatibility with the candidate launch vehicle envelopes (Rockot and Dnepr) when mounted on top of the Propulsion Module (PRM). At the upper face the SCM structure interfaces with the solar panel which is supported on the eight shear webs. The scientific payload, referred to as the LISA Technology Package or LISA Core Assembly (LCA) is mounted to a dedicated support structure which is accommodated within the central cylinder.

The main components of the SCM structure are the:

- Primary structure, comprising of the central cylinder with the aluminium SCM/PRM interface ring bonded to its bottom edge and eight shear walls
- External structure, comprising of eight panels connected to the shear walls
- LCA support structure, comprising of a circular base plate which is mounted within the central cylinder on eight support brackets, two cylinder segments with flat areas to accommodate the LCA instrument and a circular top cover
- Secondary structure, comprising of the upper and lower closure panels
- Various bracketry used to support gyros, startrackers, medium gain and low gain antennae, purge lines and umbilical/electrical connectors

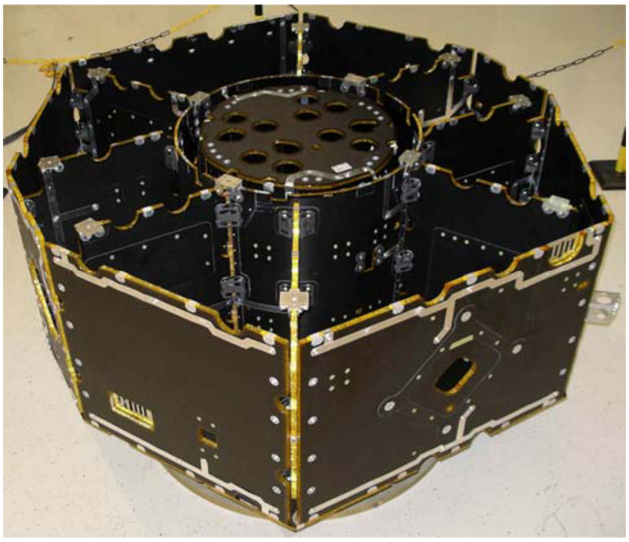

FIG 1. SCM Structure (upper closure panels removed)

The LCA support structure (see FIG 2) provides mechanical support for the LCA and minimises the thermal and mechanical interaction between the instrument and the SCM structure in order to reduce thermo-elastic distortions at the LCA mounting interfaces.

All primary structure panels are connected to each other with D-shaped CFRP cleats combining high stiffness and low thermal expansion.

FIG 2. LCA support structure (top cover removed)

The SCM structure design is driven by the following key requirements:

- very high thermo-elastic stability
- low mass
- high stiffness and strength
- short development time

A trade-off study performed at system level revealed that a structure assembled from CFRP skinned sandwich panels is the preferred concept to simultaneously meet the above set of requirements.

The material selected for the panel skins is the cyanate ester prepreg system Bryte M55J/EX1515 which provides superior mechanical properties, high radiation resistance and low moisture absorption/low outgassing. The EX1515 cyanate ester resin system excels in its ability to resist microcracking, even when subjected to severe thermal cycling and high levels of radiation exposure. The M55J fibre provides an excellent stiffness to weight ratio which is required to achieve a mass optimised design.

A quasi-isotropic lay-up was defined for all laminates in order to obtain an in-plane coefficient of thermal expansion which is nominally zero. Primary and external structure panels were designed with 0.6mm skins (8 plies), secondary structure panels with 0.3mm skins (4 plies). Thicker skins were only used locally to reinforce the structure in highly loaded areas and for the LCA support structure at the instrument interfaces.

To design the sandwich core, a variety of materials including aluminium, carbon, glass or aramid fibre reinforced plastics, or foam can potentially be used. For the SCM structure, a standard hexagonal aluminium honeycomb core was selected for the following reasons:

- extensive heritage in terms of processing, large database
- good availability in different densities / strength classes
- moisture pick-up negligible

The only disadvantage which is inherent to the aluminium core is the significant transverse expansion of the sandwich panels caused by the CTE of the aluminium. This effect can not be avoided. However, the impact on the distortion of critical interfaces can partly be compensated by careful local design of the attachment areas.

2. STABILITY REQUIREMENTS

Coefficients of thermal expansion less than 0.9ppm/K were specified for all primary and external structure sandwich panels. The stability of the LCA support structure was defined in terms of interface distortions which were equivalent to a sandwich CTE of 0.3ppm/K. The thermo-elastic behaviour had to be demonstrated with a distortion test where the assembled structure had to be exposed to a uniform temperature variation from +10°C to +40°C.

3. MATERIAL CHARACTERISATION

The LISA Pathfinder mission not only requires a dimensionally stable science module structure but also the precise knowledge of the thermo-elastic behaviour in order to allow accurate predictions of the gravitational field and its variation. The material characterisation programme commenced with coupon tests covering the quasi-isotropic laminate used for the panel skins and the two main sandwich types used in the structure design.

3.1. Coupon Tests

The coupon tests were performed at the National Physical Laboratory in London with test specimens of 40mm x 40mm [1]. The length change of the test specimen was continuously measured with a Linseis type dilatometer for a temperature range from -80°C to +90°C.

The test set-up comprised of a silica apparatus with a flat platform upon which the test specimens were placed in vertical orientation. On the upper side of the sandwich test specimen, a thin silica plate was used to bridge the two face sheets. This provided a central contact point for the silica push-rod which transmitted the changes in length to a linear displacement transducer. The overall uncertainty of the measurement was approximately ±0.2ppm/K.

The test coupons were first cooled down from ambient to -80°C and then heated up to +90°C. Bedding-in effects and/or moisture loss (identified by a loss in mass) occurred during the first heating cycle. In subsequent thermal cycles (typically 3-4), the specimen performance was repeatable (see FIG 3 to FIG 5).

The coefficients of thermal expansion were calculated from the measured fractional length change ignoring the first temperature cycle. The evaluation of the CTE was made for a reduced temperature range from +10°C to +40°C which was of specific interest for the verification of the assembled SCM structure in the full scale distortion test.

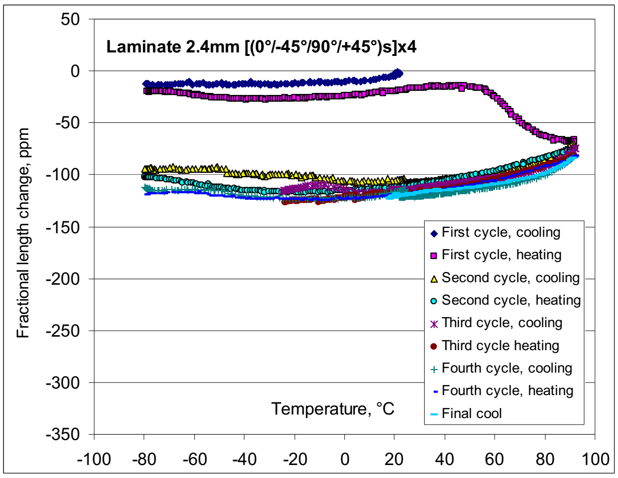

FIG 3. Fractional length change over temperature of EX1515-M55J laminate

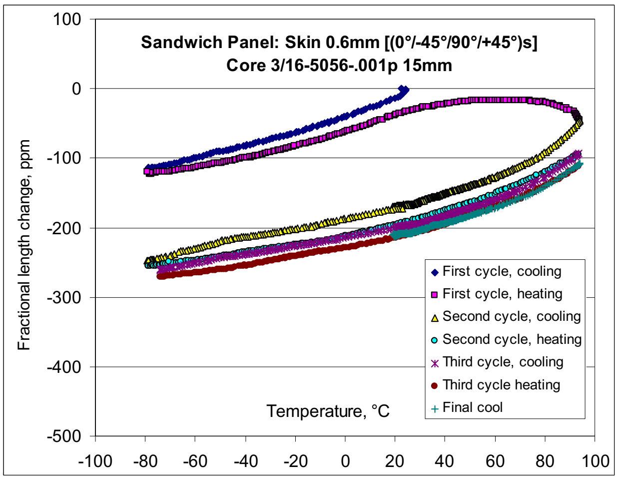

FIG 4. Fractional length change over temperature of primary structure sandwich panels

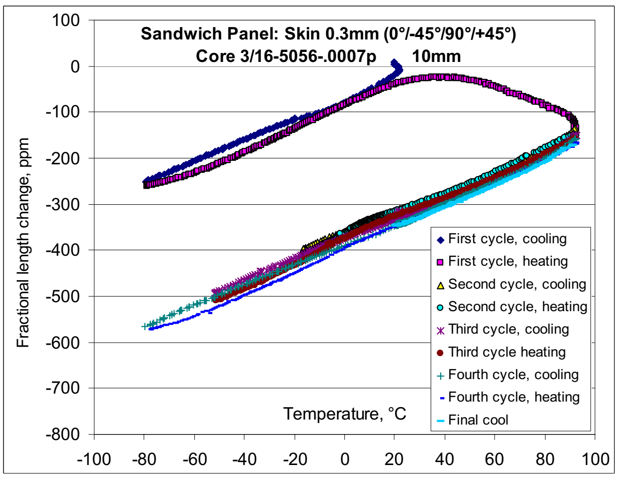

FIG 5. Fractional length change over temperature of secondary structure sandwich panels

As highlighted from FIG 3, the quasi-isotropic laminate remains stable over the complete temperature range and shows a minimum rate of fractional length change around 0°C. Typical expansion curves for the primary and secondary structure panels are presented in FIG 4 and FIG 5 respectively. The coefficients of thermal expansion for laminates and blank panels are summarised in TAB 1. For the sandwich panels, the quoted CTE is the one measured in ribbon (L) direction of the honeycomb core.

Laminate			
thickness			CTE [ppm/K]
2.4 mm			0.16
2.4 mm			0.20
2.4 mm			-0.03
2.4 mm			-0.08
Sandwich Specimen 40mm x 40mm			
Skin thickness	Core height	Core type	CTE [ppm/K] L-direction
0.6 mm	15 mm	3/16-5056-.001p	0.58
0.6 mm	15 mm	3/16-5056-.001p	0.57
0.6 mm	15 mm	1/8-5056-.001p	0.72
0.6 mm	15 mm	1/8-5056-.001p	0.88
0.3 mm	10 mm	3/16-5056-.0007p	2.41
0.3 mm	10 mm	3/16-5056-.0007p	2.07

TAB 1. Coefficients of thermal expansion evaluated for the temperature range from 10°C to 40°C (measurement accuracy: ±0.2ppm/K)

With a quasi-isotropic layup of the EX1515-M55J prepreg, a CTE of nominally zero is reached. However, when the laminate is used as face skin on sandwich panels, the overall panel CTE is significantly higher than the CTE of the panel skin itself. Although the stiffness of the aluminium honeycomb core and of the film adhesive used to bond the panel skins is small compared to the stiffness of the face skins, their contribution to the overall panel expansion can not be neglected. As seen in TAB 1, the panel CTE increases with core density and reduced skin thickness. Coefficients of thermal expansion less than 0.9ppm/K can be achieved for typical primary structure panels.

Sandwich Specimen 40mm x 40mm			
Skin thickness	Core height	Core type	CTE [ppm/K] L-direction
0.3 mm	10 mm	3/16-5056-.0007p	2.41
0.3 mm	10 mm	3/16-5056-.0007p	2.07
		average	2.24
Skin thickness	Core height	Core type	CTE [ppm/K] W-direction
0.3 mm	10 mm	3/16-5056-.0007p	0.92
0.3 mm	10 mm	3/16-5056-.0007p	1.00
		average	0.96

TAB 2. Effect of core ribbon direction on sandwich panel CTE

Due to the orthotropic nature of the honeycomb core, the panel CTE is direction dependent which is observed also for quasi-isotropic panel skins. For typical primary structure panels (0.6mm skin / 15mm core) the difference of CTE in L-direction and W-direction is relatively small and close to the measurement accuracy of ±0.2ppm/K. However, the effect is more pronounced for thin skinned panels as shown in TAB 2. For closure panels with 0.3mm skin thickness, the coefficient of thermal expansion in L-direction differs by a factor of two from the one in W-direction. For stable structures made of CFRP skinned aluminium honeycomb panels, the stability requirement rather than stiffness or strength may drive the minimum required skin thickness.

The advantage of the specimen test as discussed above is that the coefficient of thermal expansion of laminates and panels can be determined with reasonable effort over a wide temperature range. However, due to the limited sample size (40mm x 40mm), boundary effects may not be ignored. The position of the core cell cut and the alignment of the core with respect to the specimen orientation could result in an undesirable source of variation. To overcome the disadvantage associated with small samples, additional measurements with full scale sandwich panels were performed.

3.2. Sandwich Panel Tests

The coefficients of thermal expansion were re-measured on sandwich panel level at the Federal Office of Metrology (METAS) in Bern [2]. The measurements were performed at ambient pressure and 50±15% relative humidity. The temperature variation was limited to the +10°C to +40°C in accordance with the requirement for the distortion test.

The measurement equipment included a laser head (HP5518A) with indicating instrument (HP5508A) and a differential plane mirror interferometer (HP10715A). It performs differential measurements between a reference mirror and a measurement plane mirror. This measurement arrangement minimises the thermal drift.

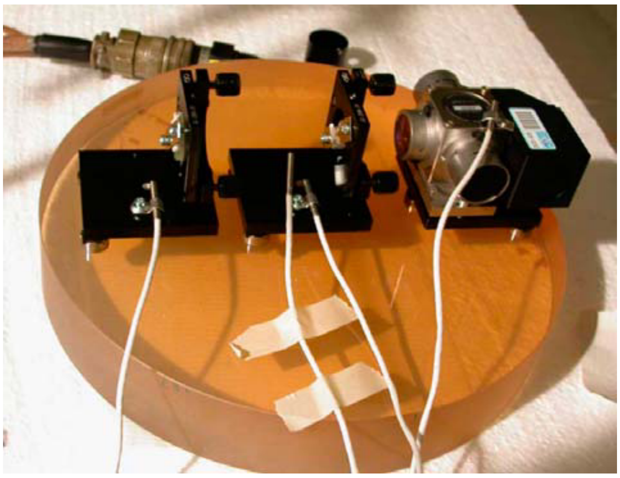

FIG 6. Differential interferometer with reference and measurement mirrors kinematically supported on a zerodur plate

The thermal stability of the measurement system as determined on a zerodur plate was ±0.2µm between +10°C and +40°C. The interferometer and mirrors were kinematically supported on three steel cylinders with the cone, v-groove and flat support principle. Both mirror holders are identical and cancel out their own expansion.

The temperature of the test article was monitored with several PT100 temperature sensors with calibration uncertainty of 0.01°C. The refractive index change on the optical path was calculated taking into account air temperature, pressure and humidity. The overall uncertainty of the laser measurement is ±0.15ppm/K (k=2) and includes contributions from the measurement standard, the calibration method, the environmental conditions and the test article.

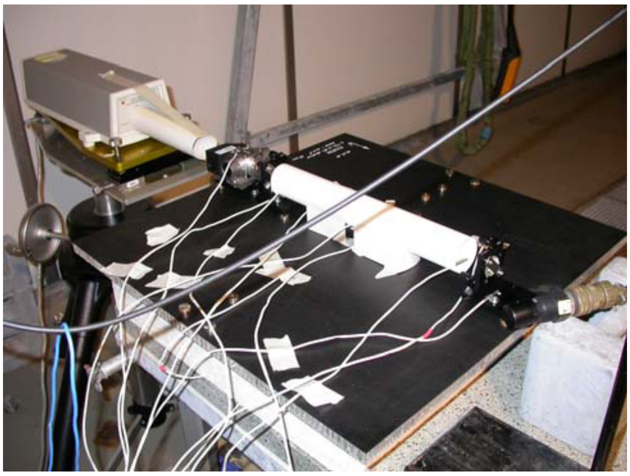

FIG 7. CTE measurement of blank sandwich panel (size: 600mm x 600mm)

In order to back-up the data measured with small sandwich coupons, the CTE measurement was repeated on larger scale for typical primary and secondary structure panels. The size of the test panels was 600mm x 600mm with a distance of 400mm between the reference and the measurement mirror. A comparison between panel and coupon test results is shown in TAB 3.

Variation of Sandwich Sample Size			
Skin thickness 0.3 mm	Core height 10 mm	Core type 3/16-5056-.0007p	CTE [ppm/K]
L-direction	Coupon	40mm x 40mm	2.24
	Panel	600mm x 600mm	1.81
W-direction	Coupon	40mm x 40mm	0.96
	Panel	600mm x 600mm	1.32

TAB 3. Effect of sample size on CTE

The directionality of the coefficients of thermal expansion seems to be less pronounced for the large panel. Taking into account the accuracy of both the dilatometer method and the laser interferometric method the CTE values of both measurements match reasonably well.

3.3. Component Tests

The objective of the material characterisation programme is to provide the basis for a reliable prediction of the thermo-elastic behaviour of the complete LISA Pathfinder Science Module Structure. For this reason, the emphasis of the development programme has been shifted after completion of coupon and blank panel testing towards testing of components and fully assembled flight panels.

This was deemed necessary since the results obtained from sandwich coupon and blank panel testing can not be directly applied to panels equipped with a large number of inserts. Both the aluminium inserts and the surrounding potting compound considerably affect the thermo-elastic behaviour of the sandwich panels.

The subassembly of prime interest is the LCA support structure with its baseplate and cylindrical segments. For these items, the design and dimensions are considerably different from the standard primary and secondary structure panels. Both the LCA baseplate and cylinder segments feature several large cut-outs and contain face-to-face inserts.

FIG 8. CTE measurement of LCA baseplate

FIG 9. CTE measurement of LCA support cylinder segment

Compared with the primary structure panels, the thickness of the LCA support panel skins was increased from 0.6mm to 1.2mm to strike a balance between high dimensional stability and low structure mass. As shown in TAB 4, the coefficients of thermal expansion measured for the LCA support structure panels were in the order of 1ppm/K. Although this value is significantly above the required 0.3ppm/K, the design was found to be acceptable on the basis of a system level instrument performance analysis. As evident from FIG 3 the required CTE could have been reached by further increasing the skin thickness or by changing from the sandwich design to a monolithic CFRP structure. However, both options would have led to a considerable mass impact and since mass has been very critical throughout the entire LISA Pathfinder programme, the presented LCA support structure design was finally kept.

LCA Support Structure Component Test			
LCA Baseplate			
Skin thickness	Core height	Core type	CTE [ppm/K]
1.2 mm	68 mm	3/16-5056-.001p	0.95
1.2 mm	68 mm	3/16-5056-.001p	0.85
		average	0.90
LCA Cylinder Segment			
Skin thickness	Core height	Core type	CTE [ppm/K]
1.2 mm	10 mm	1/8-5056-.001p	0.91
1.2 mm	10 mm	1/8-5056-.001p	1.09
		average	1.00

TAB 4. Coefficients of thermal expansion for the LCA support structure components

The knowledge of the thermo-elastic behaviour of the individual components is a vital prerequisite to understanding the behaviour of the assembled structure. In addition, the contribution of the connecting members must not be disregarded in the stability considerations. The panels of the LISA Pathfinder Science Module structure are connected to each other with filament wound CFRP cleats. Even though the in-plane CTE of the cleats is low and comparable to the CTE of a pure laminate, the distortion caused by the complete panel-to-panel joint can not be neglected. The method chosen to determine the contribution of the cleated joint was to measure the total thermal distortion across a panel joint and to substract the contribution from the expansion of the panel itself (see FIG 10).

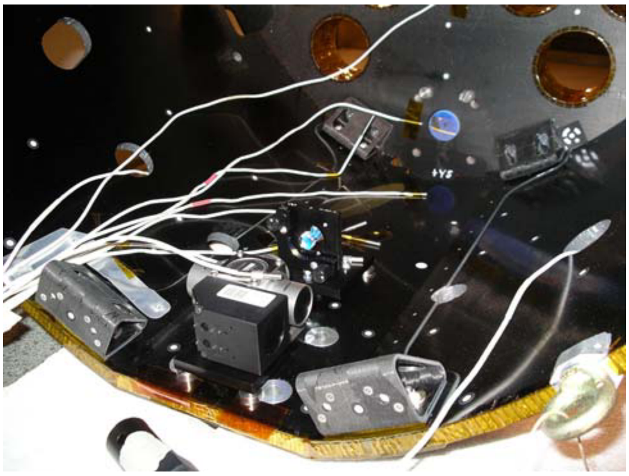

FIG 10. Set-up to measure the effect of cleated joints

The displacement caused by the cleated joint was found to be 0.36μm/K. This number includes the contributions from the cleat itself, from the insert flanges, the titanium fasteners, washers and the involved adhesive and potting compound. To simplify the analysis, it was considered practical to use the leg of the cleat as a reference length and derive an “equivalent” or “apparent” CTE for the complete joint. An apparent coefficient of thermal expansion of 11.9ppm/K was calculated for the joint which is considerably higher than expected and accentuates the need for proper consideration of connecting elements in the stability analysis of spacecraft structures. However, the most elaborate way to determine the thermo-elastic behaviour of a satellite structure is to execute a full-scale thermal distortion test.

4. FULL SCALE THERMAL DISTORTION TEST

For the final verification of the dimensional stability a thermal distortion test was performed with the fully assembled LISA PF SCM structure. The test was performed in the climatic chamber of METAS in Bern under normal atmospheric conditions apart from the temperature which was varied between +10°C and +40°C. In order to generate well defined mechanical boundary conditions, the structure was kinematically supported on the bottom face of the LCA baseplate.

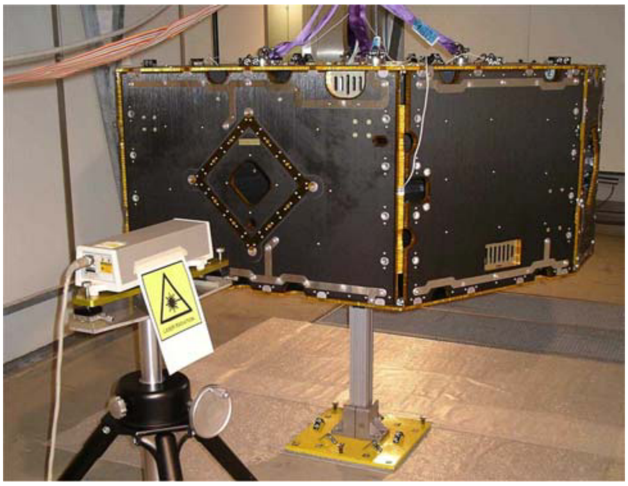

FIG 11. LISA PF SCM structure on kinematic support in METAS climatic chamber

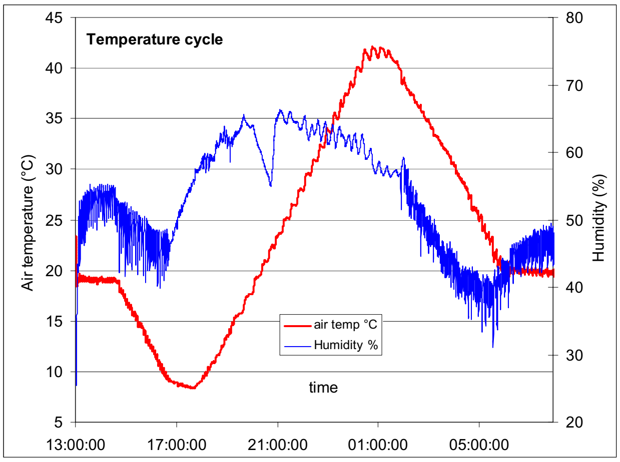

FIG 12. Temperature cycle from +10°C to +40°C (relative humidity: 50±15%)

A thermal cycle starting from ambient temperature down to +10°C, up to +40°C and back to ambient was performed. The control system of the climatic chamber was programmed to generate a temperature change of five degrees per hours which was sufficiently low to minimise temperature gradients within the test article. The homogeneity of the temperature field achieved for the structure was better than ±1°C for the complete test sequence.

During the full scale distortion test two different measurement methods were applied:

- laserinterferometric measurements, as used for the CTE measurements on component level
- digital photogrammetry (videogrammetry) which was adopted as a complementary measurement method to determine the global distortion of the external structure.

4.1. Laserinterferometric Measurements

The laser interferometric measurement method discussed before and used for the characterisation of individual panels was successfully applied to the assembled structure. The distortions of the LCA support structure and of the primary structure were measured (see FIG 13). Numerous cut-outs were implemented into the structure to obtain an unobstructed line-of-sight for the laser beam.

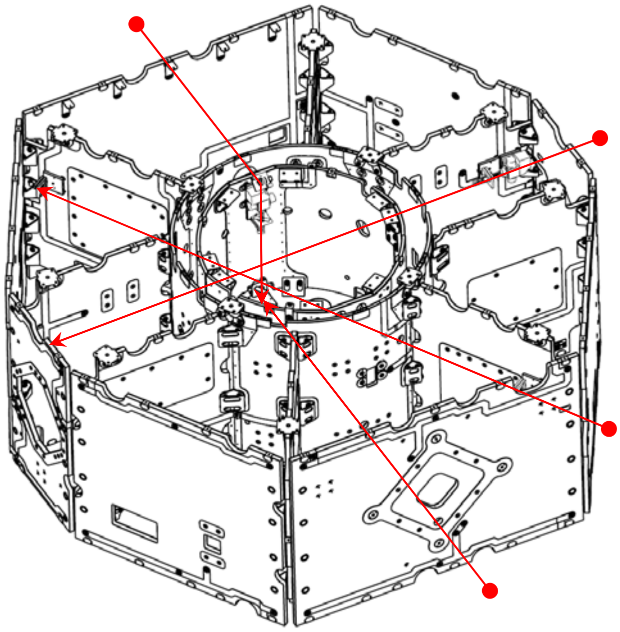

FIG 13. Illustration of different courses of the laser beam

As only one differential interferometer was available for the distortion test, the laser had to be repositioned and adjusted for every measurement. During the test campaign a total of sixteen temperature cycles as per FIG 12 have been performed. The data obtained from the measurement was the change in distance between measurement and reference mirrors. The raw data was first corrected for the variation of the refractive index during the test and then linearised.

As shown in FIG 14, the LCA baseplate expands by approximately 11µm when exposed to a uniform temperature increase of 30°C. The expansion of the primary structure is approximately 100µm measured along the parallel shear walls and 140µm along the radial shear walls as shown in FIG 15 and FIG 16 respectively. Since for geometrical reasons the mirrors could not be mounted at the panel edges but only with a certain distance from the edge, the real edge-to-edge expansion is about 15% higher than the above values.

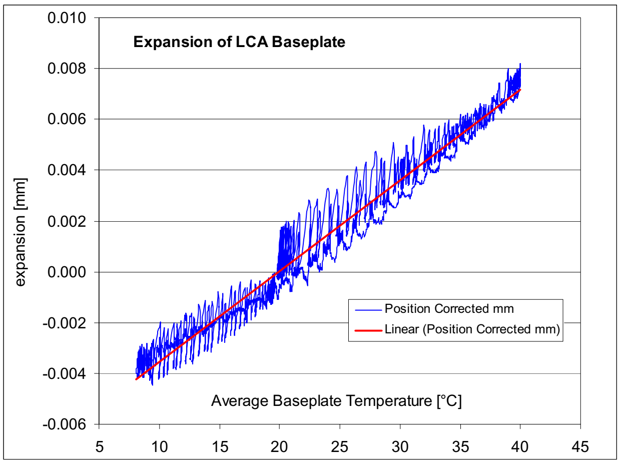

FIG 14. Expansion of LCA baseplate as a function of temperature

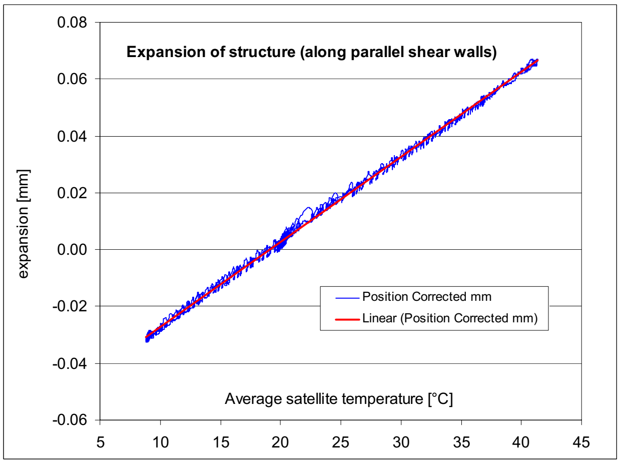

FIG 15. Expansion of SCM primary structure along parallel shear walls as a function of temperature

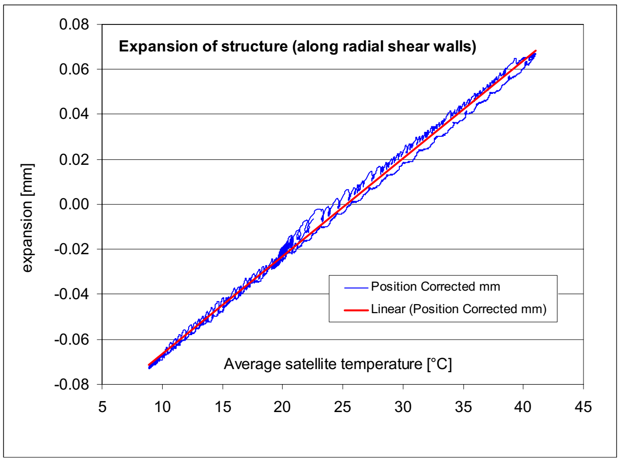

FIG 16. Expansion of SCM primary structure along radial shear walls as a function of temperature

Although laser metrology is considered to be the most accurate method to measure distortions of one micrometer or smaller, it is not a practical method to determine the distorted shape of a complete structure as only the change of one dimension with temperature can be measured. In addition, the method requires mounting provisions for the interferometer and mirrors and even mass compensation devices when the optical elements are to be fixed on vertical panels.

4.2. Videogrammetry

A well proven method to measure 3D geometry and distortions is by digital photogrammetry, also known as videogrammetry. Videogrammetry is a measurement technology based on optical triangulation in which the three-dimensional coordinates of points (targets) on an object are determined by measurements made in two or more images taken from different angles. These can be obtained from successive images captured by the same camera with a view of the object.

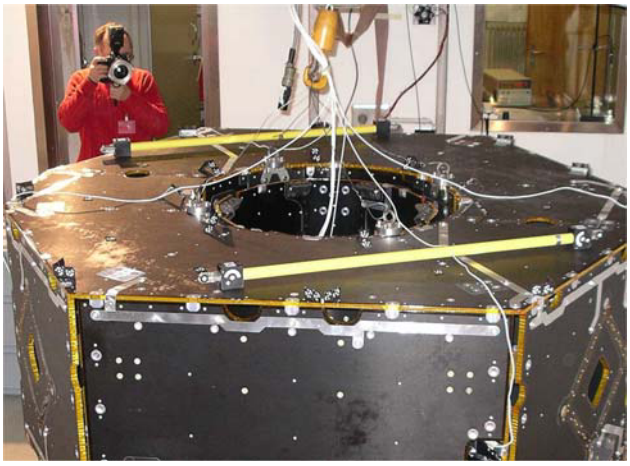

FIG 17. Videogrammetry measurement

The videogrammetry measurements on the assembled LISA PF SCM structure were performed by the company GOM International using a Nikon D2X 12MPixel digital camera and their data processing software TRITOP®.

The external structure was equipped with a large number of self-adhesive optical targets. Calibrated invar reference scales (yellow bars in FIG 17) were positioned close to the test article to provide absolute dimensions.

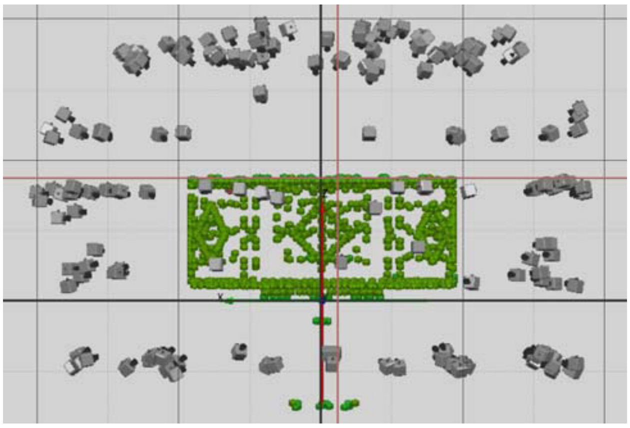

FIG 18. Overview of the camera positions used to generate the images of the test article

It is evident that videogrammetry requires full visibility of the test article and that best results are achieved when the targets are seen from many different angles. To obtain the best possible coverage, approximately 250 pictures were taken at +10°C and at +40°C (see FIG 18). The accuracy of the videogrammetry is typically 10-15µm for objects of the size of the LISA PF SCM structure. Although the accuracy of the videogrammetry is at least on order of magnitude less than the accuracy of the laser metrology, it still provides useful information on the global behaviour.

The distortion of the external structure caused by a uniform temperature increase of approximately 30°C is illustrated in FIG 19.

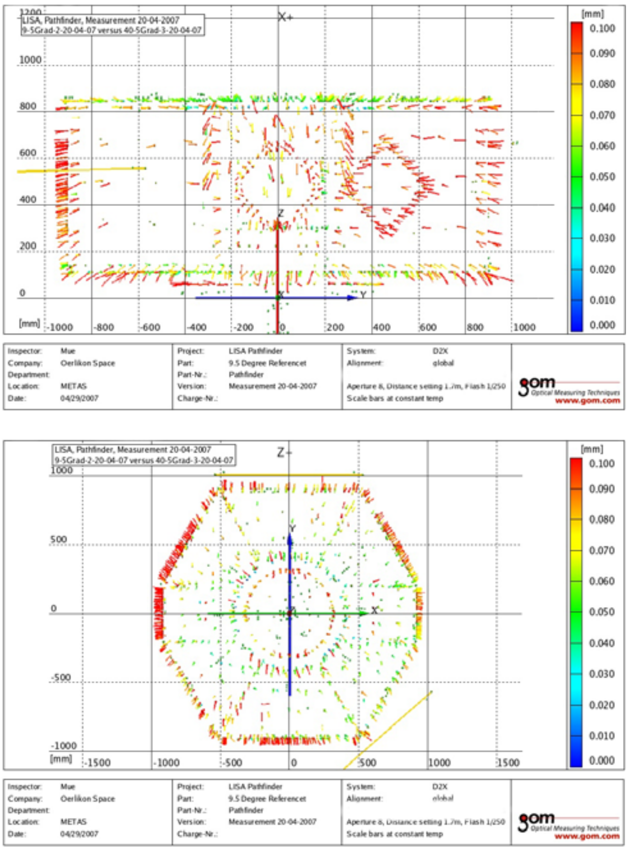

FIG 19. Displacement of targets mounted on external structure for a temperature variation from +9.5°C (reference temperature) to +40.5°C

The structure expands homogeneously and the maximum displacements which were measured on the outer surface of the external structure are in the order of 100µm.

A cross check was performed to confirm that the videogrammetry data is consistent with the results obtained by laser metrology. For this purpose the expansion of the primary structure measured with the laser interferometer was compared with the expansion of the external structure measured by videogrammetry taking into account the transverse (through the thickness) expansion of the external panels and the contribution from the cleated joints between shear walls and external panels.

5. MATHEMATICAL MODEL CORRELATION

The comprehensive material characterisation programme discussed in section 3 as well as the full scale thermal distortion test contributed to the understanding of the thermo-elastic behaviour of the LISA PF SCM structure. The second objective of the test programme besides the measurement of the distortions was to generate sufficient data to allow the correlation of the finite element model.

Since the precise knowledge of the mass distribution is of utmost importance for the success of the LISA Pathfinder mission, the mathematical model of the SCM structure has been built with a degree of detail which is far above the usual FEM standard for satellite structures [3]. The sandwich panel core was modelled with 3D solid elements to account for transverse expansion effects. The behaviour of the complex panel-to-panel connections has been assessed with detailed local FE models involving solid meshed cleats and contact elements. To limit the degrees of freedom in the overall structure FEM, the cleats were finally represented with shell and beam elements with properties reflecting the correct behaviour.

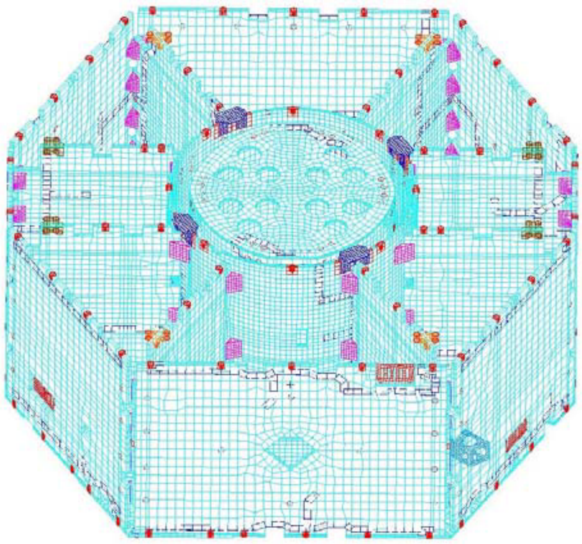

FIG 20. LISA PF SCM structure finite element model

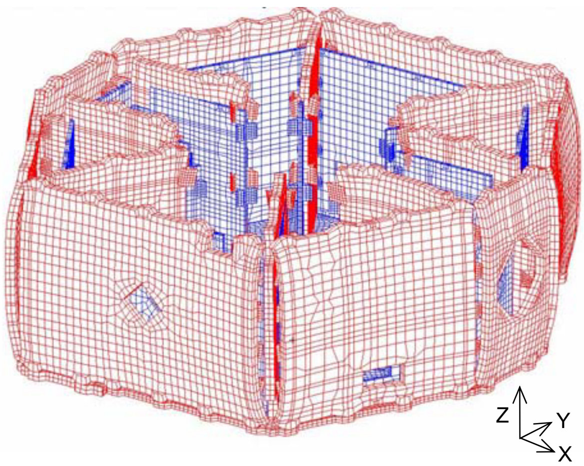

FIG 21. Distortion of shear walls and external structure for ΔT=30°C

Results obtained from coupon and component tests were used for the material property definition in the finite element model. A uniform temperature increase of ΔT=30°C has been applied to the structure FEM and the calcuated distortions were compared with the results from the full size distortion test. A qualitive illustration of the expanded structure is shown in FIG 21. Besides the global expansion, the thickness increase of the sandwich panels and the local effects of individual metallic edge inserts are also well represented. As the structure is not fully symmetric, the expansion of the parallel shear walls is smaller than the expansion of the longer radial shear walls. A comparison between predicted and measured expansion of the external structure is shown in FIG 22.

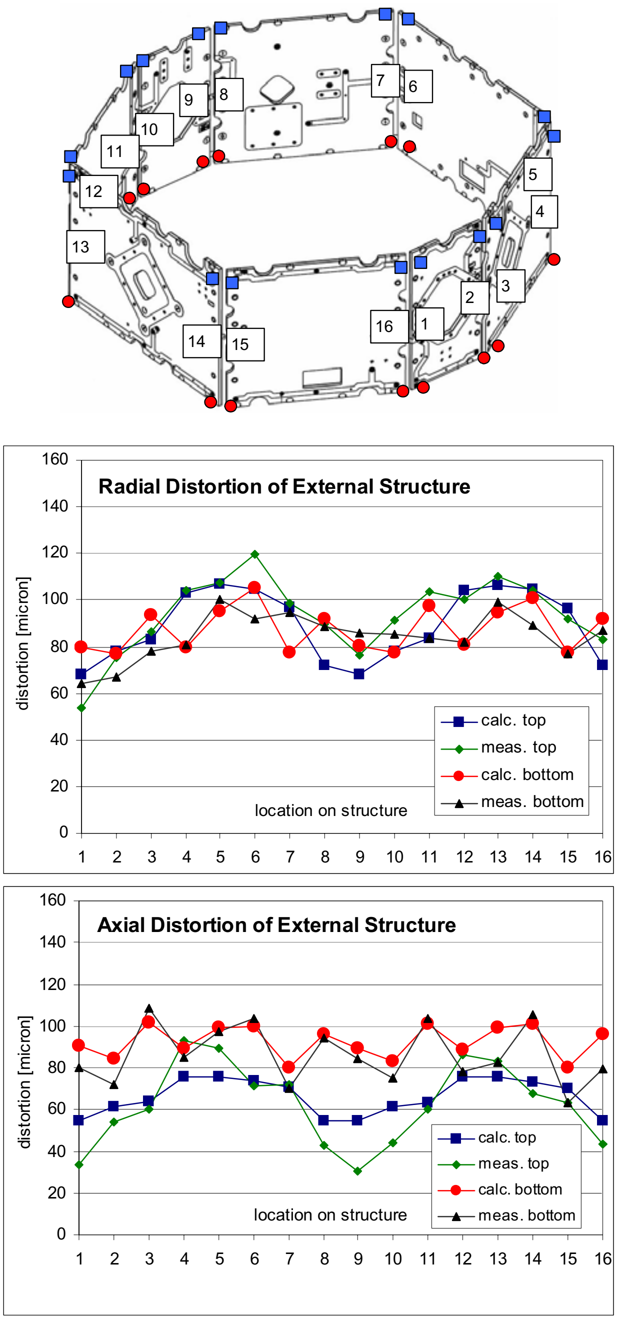

FIG 22. Predicted vs. measured distortion of the external structure for ΔT=30°C

The analytical prediction correlates well with the measurement in both radial and axial directions. Largest deviations are found for the axial displacements at the upper panel edges. The thermo-elastic behaviour of the LCA support structure was correlated in a similar way based on the laser measurements. Axial and in-plane distortions are illustrated in FIG 23.

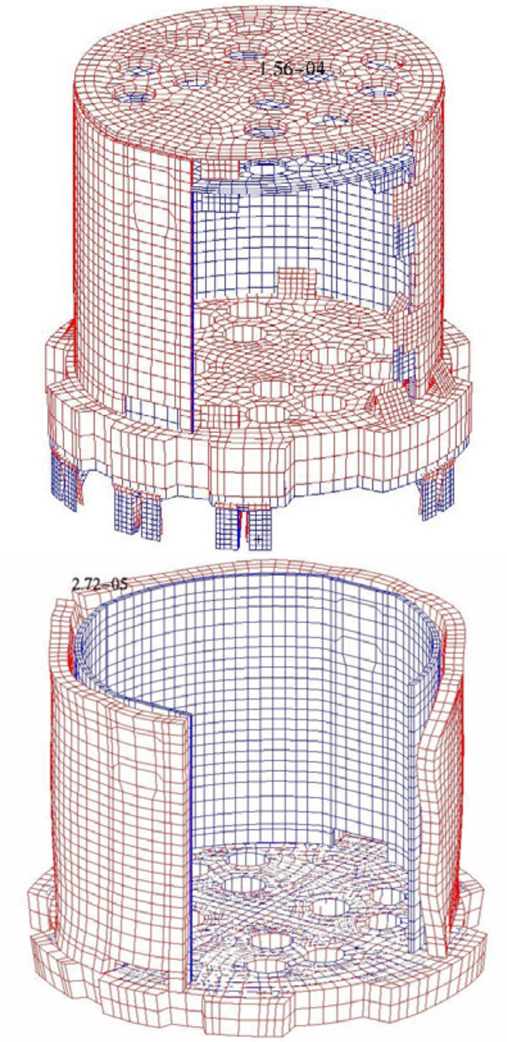

FIG 23. Axial (top) and in-plane (bottom) distortion of the LCA support structure for ΔT=30°C

The axial distortion is dominated by the transverse expansion of the aluminium honeycomb core of the LCA baseplate. For an uniform temperature increase of ΔT=30°C the maximum distortion of the LCA support structure is 156μm in axial direction and 27.2μm in radial direction.

6. DISCUSSION

The selected approach to develop a dimensionally stable structure for the LISA Pathfinder Science Module and to verify its thermo-elastic performance has been successfully demonstrated. In the early project phase, the development was focused on coupon testing in order to determine the coefficients of thermal expansion of the different sandwich configurations and laminates used in the structure design. At a later stage, the data base was complemented with measurements performed on larger test panels and components which helped to improve the quality of the input to the mathematical model and hence the accuracy of the thermo-elastic analyses.

A full-scale distortion test was considered necessary to demonstrate the performance of the assembled structure and to finally correlate the mathematical model. Instead of applying a complex temperature distribution obtained from the mission thermal analysis, the structure was subjected to a uniform temperature change of 30°C. The advantage of this simple thermal test case is that it could be conducted easily in a climatic chamber and showed good repeatable. Well defined mechanical boundary conditions helped to simplify the interpretation of the distortion test results. The kinematic support concept which provided a stable stand but still allowed the structure to expand freely under thermal loads turned out to be very practical. A test with the structure being freely suspended from slings was attempted but led to laser alignment problems due to small movements of the structure caused by circulating air.

The accurate measurement of small distortions requires measurement equipment with exhibits very low thermal drift. The selected differential plane interferometer proved to be suitable to measure the displacements within the LCA support structure with an accuracy of better than ±0.5μm. Supplementary videogrammetry measurements helped in the understanding of the global deformation of the structure.

Although the development of a dimensionally stable sandwich structure appears to be straight forward, the experience gained from the LISA PF SCM structure showed that the influence of all materials and components involved in the design must be carefully assessed. The in-plane CTE of blank sandwich panels can be doubled depending on the number of inserts installed and the quantity of adhesive and potting compound used. The sandwich panels developed for the LISA PF SCM structure use an aluminium honeycomb core which drives the panel expansion in the transverse direction and must be accounted for in the analysis.

7. CONCLUSION

Traditional CFRP skinned aluminium honeycomb sandwich panels are still a good choice for the design of stiff and dimensionally stable lightweight structures. In particular for large structures, the CFRP sandwich offers considerable advantages over design solutions based on glass ceramic or ceramic matrix composite materials. However, accurate predictions of the thermo-elastic behaviour are only possible if the analytical models take into account the properties of the complete sandwich panels. The effect of inserts, adhesive and potting compound is significant and can not be ignored. Attention must be paid as well to connection elements such as cleats and fasteners as they contribute to the structural distortion. For platforms requiring high stability, it is beneficial to increase the thickness of the panel skins, to use lightweight core and to reduce the amount of adhesive as far as practical. Coefficients of thermal expansion below 1ppm/K are feasible and have been achieved for the instrument support structure of the LISA Pathfinder Science Module. In-plane CTE values between 1.5 and 2.5ppm/K were measured for typical equipment support panels and closure panels. Special filament wound CFRP cleats and brackets were developed to minimise the distortion of the assembled structure. The structure developed and built for the LISA PF Science Module combines excellent dimensional stability, high strength and stiffness at reduced mass and may serve as a valuable example for future developments in the field of stable lightweight structures.

8. REFERENCES

[1] Thermal Expansion Measurements on Carbon-Fibre Composite Panel and Sandwich Materials – LISA Project, Report No. E06030005/1, 2006, National Physical Laboratory, Teddington Middlesex UK TW11 0LW

[2] LISA Pathfinder SCM Structure Thermal Distortion Test, Measurement Report No. 111-02055, 2007, Federal Office of Metrology METAS, Lindenweg 50, CH-3003 Bern-Wabern, Switzerland

[3] D.Kaiser and T.Pagano, Development of a 3D Finite Element Model for Distortion and Gravitational Analyses of a Dimensionally Stable Satellite Structure like the LISA Pathfinder Science Module, 1st CEAS European Air and Space Conference, Berlin 2007