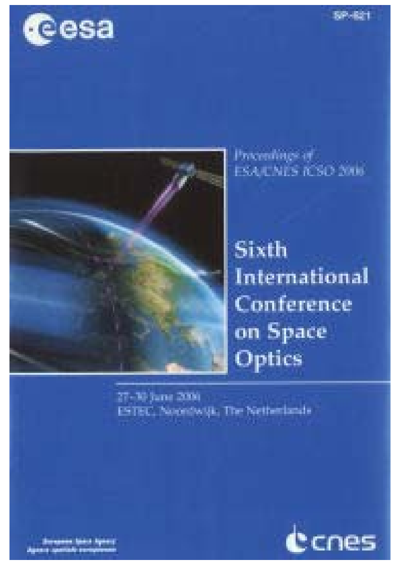
International Conference on Space Optics—ICSO 2006

Noordwijk, Netherlands

27–30 June 2006

Edited by Errico Armandillo, Josiane Costeraste, and Nikos Karafolas



Development and verification of a high-performance CFRP structure for the space-borne lidar instrument ALADIN

Clemens Kaiser, Christoph Widani, Klaus Härtel, Peter Haberler, et al.

International Conference on Space Optics — ICSO 2006, edited by Errico Armandillo, Josiane Costeraste,
Nikos Karafolas, Proc. of SPIE Vol. 10567, 105673D · © 2006 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2308121

DEVELOPMENT AND VERIFICATION OF A HIGH-PERFORMANCE CFRP STRUCTURE FOR THE SPACE-BORNE LIDAR INSTRUMENT ALADIN

Clemens Kaiser(1), Christoph Widani(2), Klaus Härtel(3), Peter Haberler(4), Olivier Lecrenier(5), Daniel Buvat(6), Gilles Labruyere(7)

(1)Kayser-Threde GmbH, Wolfratshauser Str. 48, 81379 Munich, Germany, Email: Clemens.Kaiser@kayser-threde.com
(2)Kayser-Threde GmbH, Email: Christoph.Widani@kayser-threde.com
(3)Kayser-Threde GmbH, Email: Klaus.Haertel@kayser-threde.com
(4)Kayser-Threde GmbH, Email: Peter.Haberler@kayser-threde.com
(5)EADS Astrium SAS, 31 avenue des Cosmonautes, 31402 Toulouse Cedex, France, Email: Olivier.Lecrenier@astrium.eads.net
(6)EADS Astrium SAS, Email: Daniel.Buvat@astrium.eads.net
(7)ESTEC, Keplerlaan 1, 2200 Noordwjik, The Netherlands, Email: Gilles.Labruyere@esa.int

ABSTRACT

The paper gives an overview of the development of a high-performance space structure achieving an optimum combination of mass, stiffness and stability to cope with the very stringent performance requirements of ALADIN instrument, the space-borne LIDAR built for ADM-AEOLUS ESA’s Earth Explorer Mission. Kayser-Threde has been contracted in 2003 by EADS Astrium Toulouse, ALADIN instrument Prime Contractor, for the Phase C/D of ALADIN Structure PFM. The contract with ASF comprised the detailed design, development, verification, PMP qualification, and MAIV program including ALADIN Structure qualification using a complete and fully representative STM.

Fig. 1 ADM-AEOLUS spacecraft (by courtesy of ESA)

1. ALADIN STRUCTURE OVERVIEW

1.1 Background

Kayser-Threde GmbH has been contracted by EADS Astrium Toulouse for ALADIN Structure. The project has been realized between July 2003 and December 2005. Subcontractors of Kayser-Threde were Brühlmeier Modellbau AG, Switzerland for honeycomb structures manufacturing and Invent GmbH, Germany for CFRP struts manufacturing

1.2 Overall Design Concept

ALADIN Structure is the CFRP Primary and Secondary Structure for the spaceborne Lidar instrument ALADIN on ESA’s Earth Explorer Mission ADM-AEOLUS [1] with the goal to analyze the Earth atmospheric dynamics by using an active optic system. A laser beam of dedicated wavelength is send to Earth atmosphere which reflects the signals in the order of 10^{15} lower intensity resulting in a Doppler-effect which can be analyzed providing the required information.

The contract with ASF contained the complete design, development, verification, parts, materials and processes (PMP) qualification, manufacturing, assembly, integration, testing (MAIT) including qualification using a STM and final MAIT of the PFM.

ALADIN structures are constituted of two main sets. The first set is called the primary structures supporting all large and sensitive equipments: The main structure, the satellite interface structure and the star tracker support structure. They are all made out of sandwich panels with low CTE and CME CFRP face-sheets and aluminium honeycomb cores. The satellite interface structure provides the interfaces to the bus platform by four stainless steel satellite interface mounts.

The second set, namely the secondary structures, are including a large external baffle, three thermal heat shields and a thermal hood for the optical bench assembly. The external baffle is a framework made out of CFRP struts and aluminium ring profiles and brackets. The thermal heat screens and the thermal hood are used for thermal control purposes respectively for the Telescope primary mirror and the optical bench.

Proc. ‘6th Internat. Conf. on Space Optics’, ESTEC, Noordwijk, The Netherlands, 27-30 June 2006 (ESA SP-621, June 2006)

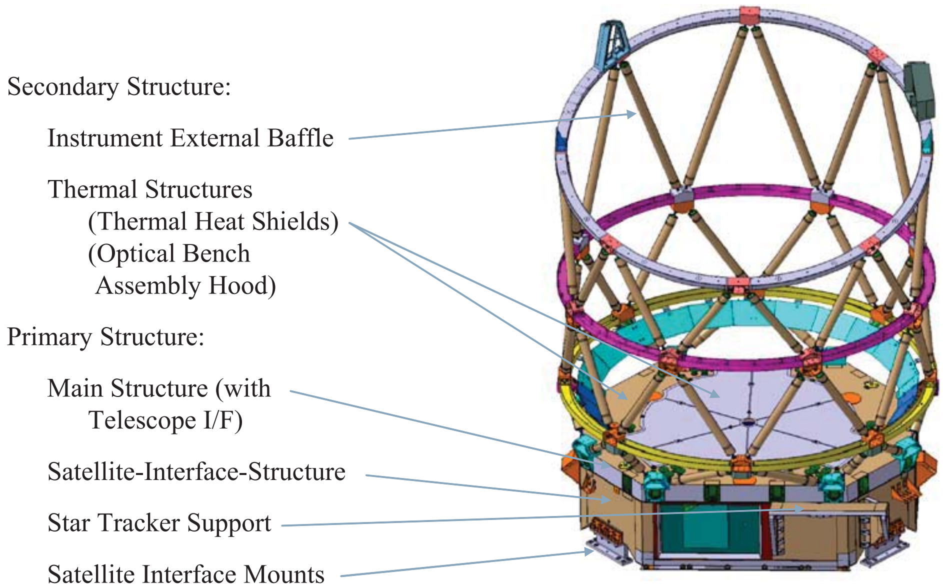


Fig. 2. ALADIN Structure Design Concept

Fig. 3. ALADIN Structure PFM

They are all made out of aluminium sheets equipped with a high coverage of thermal hardware for thermal control purposes.

The sizes of ALADIN Structure are: overall height 2.6m, baffle diameter 1.6m, main structure and satellite interface structure of octagonal shape with overall 1.1m x 1.5m.

1.3 Primary Structure

For the primary structures three main design drivers have been taken into account: First, they have to withstand very high loads. These are caused on the one hand by the attached heavy equipments (mainly laser heads, optical bench and telescope) and further infrastructure equipments (laser cooling system, harness, connector brackets, star trackers etc.) summing up to 250 kg and on the other hand by the dynamics of the external baffle due to the very high excitation levels of up to 22.5g in axial and 10g in lateral directions specified at the instrument basis.

Second, they have to provide maximum stiffness to have ALADIN dynamically fully de-coupled from the AEOLUS bus. And third, the primary structures have to provide very high stability primarily between star tracker and telescope axis in the range of some 10µrad to ensure instrument’s full operation in short, medium and long term taking into account the inhomogeneous thermal mapping all over the structures. All secondary structures have been designed in such a way that they withstand the loads caused by the dynamic excitation of their own masses. This was critical mainly for the large external baffle truss work, where antennas and earth and sun sensors located on the top rim see maximum accelerations of up to 80g RSS. On top of all a stringent mass requirement, very challenging envelope and various and numerous complex interface requirements have to be fulfilled for the overall ALADIN Structure configuration.

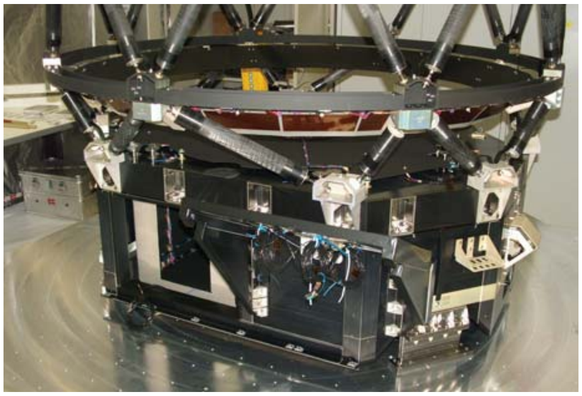


Fig. 4. ALADIN Primary Structure PFM

To fulfil these challenging requirements for all primary structure honeycomb sandwich face sheets with a prepreg system having very low CTE and CME properties have been used. The main structure has a thickness of 100 mm and is equipped with nearly 100 aluminium inserts of different kind providing all the required interfaces. For telescope mounting 30 mm above the top of the main structure special titanium inserts have been used going through the complete main structure and connecting the upper with the lower face sheet of the main structure also for thermal stability reason. The 18 load transfer points between main structure and satellite interface structure are realized by titanium brackets bonded into the honeycomb edges. The star tracker support is repositionable by close tolerance pins due to the necessity of several mounting and dismounting activities and keeping the tight dimensional tolerances between star tracker interface plane and telescope axis.

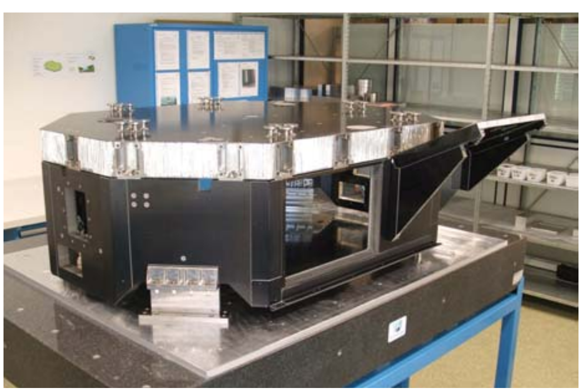


Fig. 5. Primary Structure (honeycomb structure only)

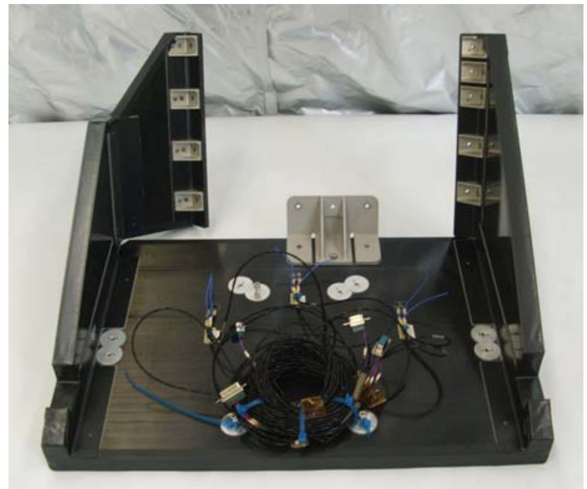


Fig. 6. ALADIN Star Tracker Support (including attached thermal hardware)

1.4 Instrument External Baffle

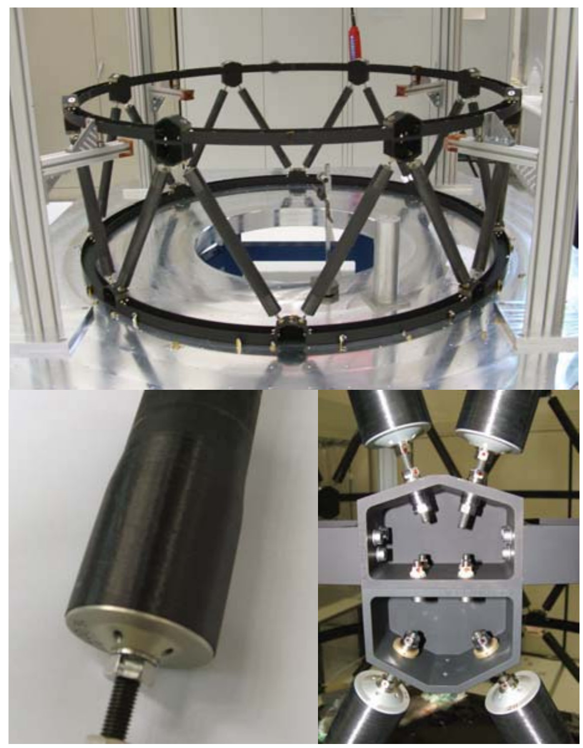


Fig. 7. Baffle middle cylinder (top), CFRP strut end fitting (down left) and typical node (down right)

The external baffle framework configuration - mainly the lower conical part strut arrangement - has been optimized to have maximum baffle stiffness. The single ring elements and framework nodes are made out of aluminium. A specific strut end design has been introduced with the bonding between two CFRP parts to cope with the significant temperature variations of the external baffle (i.e. [-95°C, +50°C]) and to minimize the stresses in the bondings. That for, a dedicated CFRP bushing has been introduced clamped in form and fit between two aluminium parts as the metallic connection being the bonding part to the CFRP struts with either 0.8 (upper part) and 1.2 mm wall thickness.

Fig. 8. Ultralightweighted brackets for X- and S-band antenna on top of external baffle

1.5 Thermal Heat Shields

To allow for thermal control of the primary mirror and the optical bench assembly the dedicated Thermal Structures out of aluminium sheets have been equipped with heaters having large area coverage. In addition thermistors and thermal sensors have been installed all over the structure to provide information about the thermal gradients of the structure during operations.

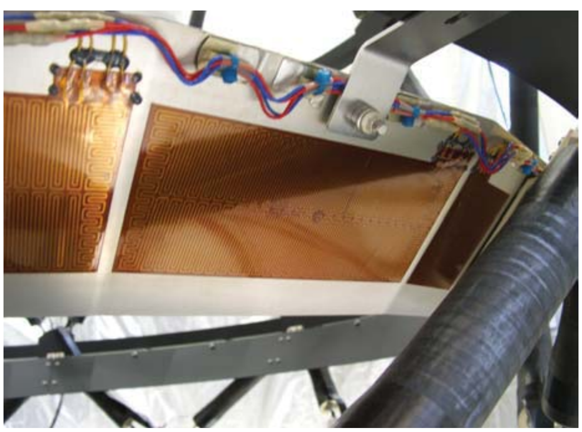


Fig. 9. Detail of Thermal Heat Shield 3 backside

Fig. 10. Thermal Heat Shield 1 backside

1.6 Optical Bench Assembly Thermal Hood

The Optical Bench Assembly is the most sensible part of the ALADIN instrument accommodating the Transmit-Receive-Optics and the Spectrometers. To ensure a constant thermal environment and to protect it from the remaining structure a two-part aluminium housing made out of 2 mm aluminium sheets and riveted together serves as cover. The housing's inner walls were nearly completely covered by thermal hardware for thermal control purposes. After implementation of the thermal hardware the complete inner side has been black painted.

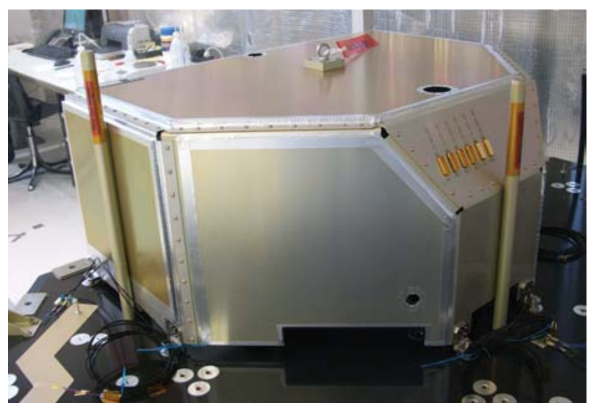


Fig. 11. Optical Bench Thermal Hood mounted on Main Structure backside

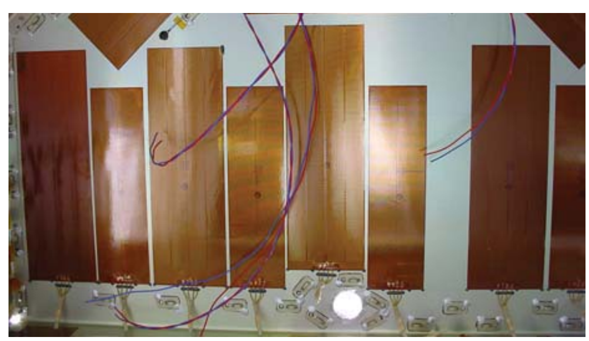


Fig. 12. Optical Bench Thermal Hood inside view before black painting

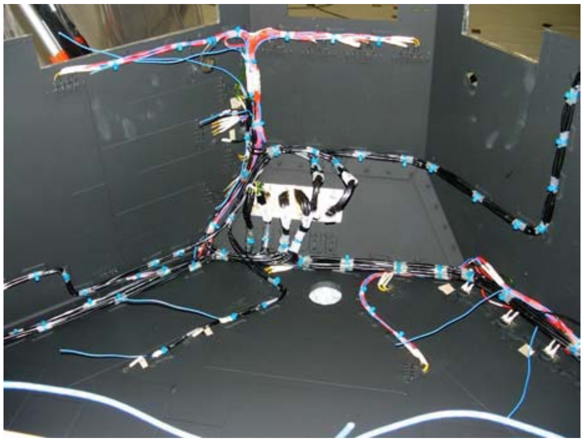


Fig. 13. Inside view of final black painted Optical Bench Thermal Hood

2. Materials & Processes

For the primary structures facesheets a prepreg system M55J/LTM123 from supplier ACG has been used. The matrix system is a Cyanat Esther leading to low CTE and CME values in the laminate. For the CFRP struts also M55J fibres have been used, but here in combination with the epoxy matrix system LY556/HY906/DY from Vantico due to the relaxed constraints on CTE and CME effects in the struts. Two different adhesive systems have been used: Araldite AV138/HV998 for all inserts and strut fittings bonding and Hysol EA9394 for all facesheet to core and brackets into sandwich panel bondings.

All face sheets have been manufactured using autoclave moulding technique. All further bondings (core to face sheets, bracket and insert integration) have been made using a bonding procedure under room temperature. The CFRP struts used are made by filament winding technique. In contrast to the CFRP parts all metallic parts have been manufactured at Kayser-Threde. The assembly and integration of all Thermal Structures (Thermal Hardware integration) has been performed at Kayser-Threde’s electric manufacturing facilities. The complete integration of ALADIN Structure has been performed in Kayser-Threde’s large cleanliness room (class 100.000).

3. Verification Programme

A complete set of verification analyses have been conducted, especially for strength and stability. For the structural analysis a dynamic load analysis has been performed due to the fact, that e.g. the loads at Satellite I/F and local stresses on the external baffle are higher for the dynamic than for the quasistatic load case under the given boundary conditions. Especially for the secondary structures the dimensioning load cases are derived out of the dynamic load analysis.

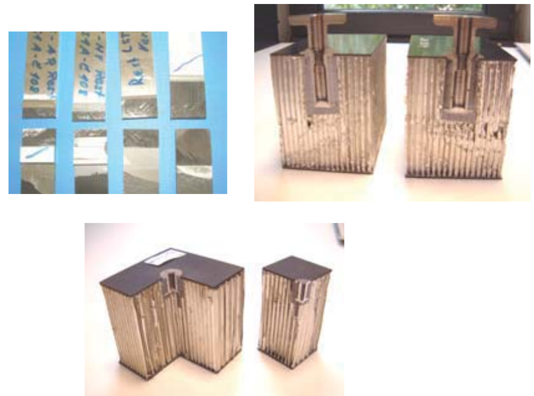


Fig. 14. Test samples for PMP qualification

A full Parts, Materials & Processes qualification programme has been performed to demonstrate respective suitability for the project, which was mainly material and bonding characteristics determination. Specific focus was put on the new strut end fitting design which has led to a complete strut qualification program demonstrating a load capability of up to 30 kN together with compliance with respect to stringent thermoelastic loads due to large temperature excursions. A complete witness test sample program has been realized for full workmanship control. Same has been done for all inserts, which has been tested to limit load. ALADIN Structure has seen a complete qualification test program for the STM (thermal cycling and vibration) and acceptance test program for the PFM (thermal cycling, vibration, depressurization, outgassing).

All CFRP parts have been inspected before and after testing using US inspection. For interface control a 3D measurement device has been used. For dimensional envelope control of the baffle before and after testing a 3D camera system has been used able to detect tolerances in the range less than 0.1 mm.

The complete structure including all mounted secondary structures has been exposed to a thermal cycling and vibration test for full structure qualification using the STM and acceptance testing for the PFM. The vibration input level has been arranged according to the test prediction analyses identifying additional manual notchings besides the specified automatic notchings for the attached hardware like antennas, star trackers etc. All equipment (in total in the range of 270 kg) to be mounted finally onto the structure has been mechanically simulated by using structural dummies. The heavy ones (telescope, laser heads, etc.) have been accommodated using representative isostatic mounts.

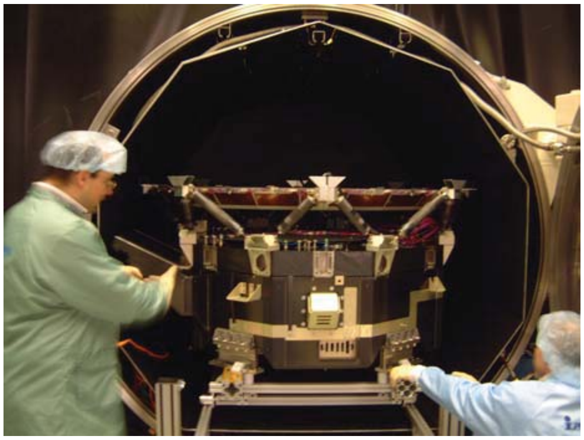


Fig. 15. Primary Structure PFM Thermal Vacuum & Cycling Test

Fig. 16. External Baffle PFM Thermal Cycling Test

Fig. 17. PFM Vibration Test at IABG

Both structures have been delivered to the customer for final instrument integration. The STM program has been finalized in 2005 by a final qualification program on satellite level. The ALADIN PFM is under final integration at Astrium France premises with a delivery for bus integration in 2007.

Fig. 18. ADM-AEOLUS STM vibration test at ESTEC (photo by courtesy of Astrium)

4. SUMMARY

A high performance CFRP structure could be realized for the advanced ADM AEOLUS program able to withstand very high loads and providing required stiffness and stability for the in orbit operation. The design is based on standard principles except a new strut end fitting design. Same is valid for the chosen materials to cope with the stringent parts, materials and processes requirements (mainly outgassing) well known material systems and combinations have been used, already proven in previous hardware projects.

5. REFERENCES

1. ADM-AEOLUS - ESA’s Wind Mission, ESA Brochure BR-236, February 2005.