QUALIFICATION OF GAIA DEPLOYABLE SUNSHIELD

Iñaki Pinto, Eduardo Urgoiti, Iker Gabiola, Victor Balmaseda, Julian Ramirez [1]

[1] SENER-Structures & Mechanisms Section, Av. Zugazarte 56, 48930 Las Arenas (Vizcaya) Spain
Tel: 34944817878 Fax: 34944817600 Email: inaki.pinto@sener.es eduardo.urgoiti@sener.es iker.gabiola@sener.es, victor.balmaseda@sener.es julian.ramirez@sener.es

ABSTRACT

This paper goes through the qualification process focused in the mechanical performances of the Gaia Deployable Sunshield and its associated mechanisms providing the final achieved performances.

The design evolution required from the initial developed solution to the final qualified one, the design challenges faced during the test campaign and the process of characterization of driving parameters of the deployment will also be part of the present paper.

The paper deals with the difficulties encountered in the verification of large size deployable structures, the required combination of analytical and empirical data for the full qualification and the outcomes and lessons learnt.

1. INTRODUCTION

The GAIA Deployment Sunshield Assembly (DSA) is part of the SVM of the GAIA S/C providing a stable and continuous shadow environment to the SVM and PLM of the satellite.

The DSA is composed by 12 rectangular petals joined by 12 triangular sectors to form an almost circular plane around the base of the spacecraft.

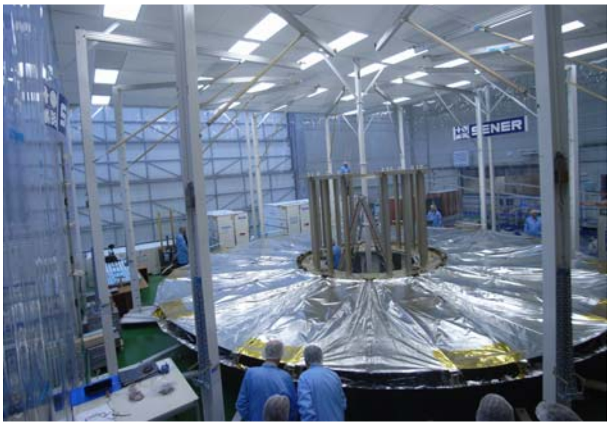

Fig. 1 Gaia Sunshield Deployed

In working configuration the DSA is a flat circle of about 10,2m diameter that due to the geometrical constrains of the rocket fairing, the sunshield is folded into a dodecagonal prism configuration around the thermal tent for launch purposes, to fit into the fairing diameter of 3,8 m.

Fig. 2 Gaia Sunshield Deploying

The problematic to keep the DSA in the stowed configuration without any performance degradation during launch, and once in orbit deploy with the sufficient torque margins, have determined the qualification of the system.

The difficulties to define a totally representative test qualification approach on ground, with such large structures that are highly influenced by gravity and the unknowledged behaviour of the MLI in stowed configuration, have increased the difficulty of the GAIA DSA qualification.

The planarity requirement verification, also influenced by the action of gravity, has been solved by the implementation of specifically designed Zero G assemblies, with specific functions for each step of the verification, but with the inevitable disturbance in the measurements.

2. DSA INITIAL DESIGN OVERVIEW

The DSA comprised initially twelve identical sections, each of which is mainly formed by a structural frame (X shaped) composed by CFRP tubes joined by metallic fittings bonded to the tubes.

In the centre of the X shape transversal tube the fitting through which the frame is fixed to the thermal tent in stowed configuration can be found. This fitting holds a

'14th European Space Mechanisms & Tribology Symposium – ESMATS 2011'
Constance, Germany, 28–30 September 2011

separation nut to keep the frames structurally attached to a flexible part bolted to the thermal tent.

The thermal function of the DSA is achieved by two layers of thermal foils: sun side foil and shadow side foil designed to meet the thermal requirements.

The DSA STI covers the 12 rectangular petals by different fixed blankets and the triangular space between the petals at the deployed configuration. These triangular blankets are kept rolled between the frames and unrolled during deployment to their flat deployed configuration.

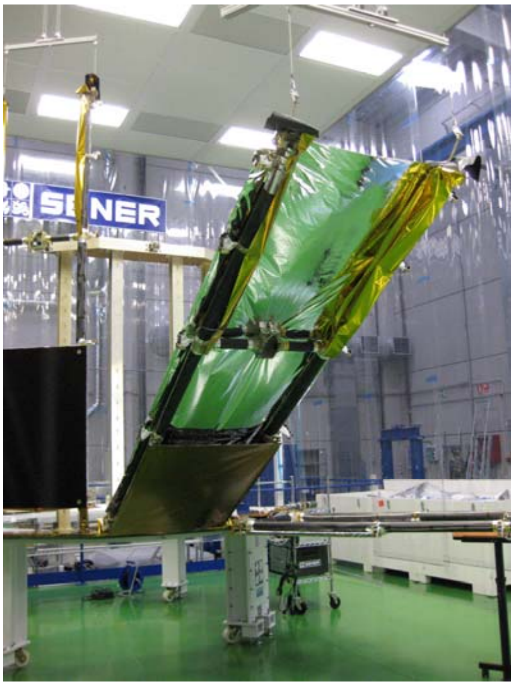

Fig. 3 Gaia Sunshield Frame

These foils are kept in place by special tensioning devices which maintain the thermal insulation in a controlled manner once the item is deployed.

Eight frames implement solar panels at the base near the S/C to supply the S/C electrically to S/C in a symmetric lay-up.

The structural frames are hinged at the base -two hinges per frame- attached to a ring assembled over the base of the SVM. The hinges perform the deployment function by means of loaded springs. Each hinge is equipped by 2 flat springs.

The 12 frames are joined at the hinges axis via flexible couplings, composing a single shaft loop in order to achieve a synchronous deployment when the deployment is triggered.

The deployment is controlled actively by one DSA regulator. This regulator is an electrically controlled device that brakes the deployment providing a constant deployment speed for a constant electrical power input.

3. DSA QUALIFICATION APPROACH

The DSA qualification approach has been based on the following parameters at component level:

- Qualification of Structure frames in terms of thermo-mechanical behaviour.
- Qualification of Sunshield Thermal Isolator (STI) material (thermo-optical and mechanical properties) and used fixation technologies.
- Qualification at component level for each mechanism subassembly: Deployment Hinge Mechanisms (DHM), Hold-Down and Release Mechanisms (HDRM), Synchronization, Deployment Regulator and STI Attachments.

Once the component level qualification has been completed, all the mechanisms that form the GAIA DSA are joined in a single loop and harness assembly included to test the mechanism overall assembly. This subassembly is functional, mechanical vibration and thermal vacuum tested.

The full DSA assembly qualification model is based on a DSA Quarter composed by three sections of the twelve that form the full DSA. This Qualification Model (QM) is subjected to functional, vibration and TV/TB tests that will assess the compliance to the functional, mechanical and thermal requirements specified to the GAIA Sunshield.

Prior to these phases, a scaled breadmodel to simulate and assess the suitability of the STI Blanket stowing concept and designed tensioning elements was constructed and mechanically tested. The presentation of the tests follows the qualification sequence in time.

4. STI BREADMODEL

As an outcome of an extensive trade off performed by STI suppliers (RUAG Austria), the rolling concept to store the blankets within the stowed configuration was selected. This selected option based on the fact that no folding line in the blankets was recommended making the material be a continuous layer without discontinuities and higher thermal performances.

The selection of this storing concept, in addition to parallel trade off performed by the frame supplier (RUAG Switzerland) led to the adoption of the H shaped structure as baseline design for the DSA. This H shaped frames allowed the installation of a set of stowage brackets at the longitudinal tubes, which kept the STI blankets rolled in the stowed configuration without going out from the dedicated STI envelope between frames.

The purpose of this breadmodel was to study the adequacy of the rolling concept, the stowage bracket design, the number of fixation points and the STI fixation design, for both fixed and deployable blankets, by means of flexible elements called STI attachments.

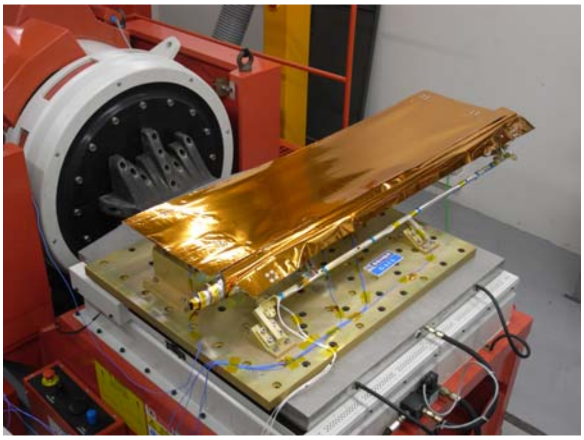

Fig. 4 STI Breadboard

The scaled breadmodel was vibrated and the following outcomes were derived:

- The STI attachment design was totally suitable for the fixation of the STI providing a flexible attachment to cope with thermal deformation of the blanket and enough sustaining capability to fixed and deployable blankets.
- The STI material if kept rolled was not damaged and the fixed blankets survived to the imposed displacements and loads when assembled to the frames.
- The number of stowage brackets was required to be increased from the initially defined 3 to 4. The main reason was the local buckling of the rolls due to the excessive distance between stowing points.
- The initial simple shape of the stowage brackets was improved since the rolls were not able to be kept inside their allocated space during vibration. The new design provided flexible elements to cope with the high elastic displacements on the tubes. These deformations -especially at the tips- were responsible of the unexpected unrolling during shaking. Besides, two dedicated cavities for the new rolling concept, based in rolling the blanket in two semi rolls were implemented making the stowed configuration totally symmetric.

The compromise between the capability of the stowage brackets to keep the rolls stowed and the provided restriction to let the rolls come out from the stowing cavity, drove the qualification of the Sunshield and the subsequent delta qualification required to characterize the STI.

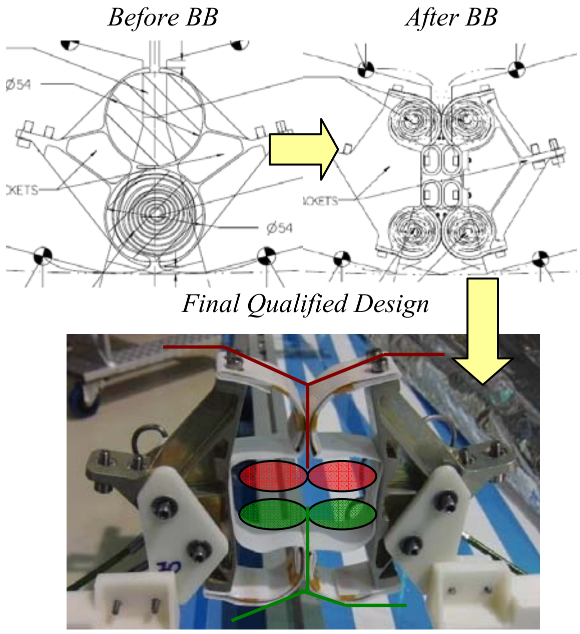

Fig. 5 STI Rolling Concept Evolution

5. MECHANISM SUBASSEMBLY LEVEL QUALIFICATION

Measurements at Mechanisms subassembly level

Once the mechanisms at component level were characterized, each set of mechanisms is assembled to simulate a Quarter DSA formed only with mechanisms. The test sequence was as follows: functional, vibration including sine and random exposure, Thermal Vacuum test and final functional test.

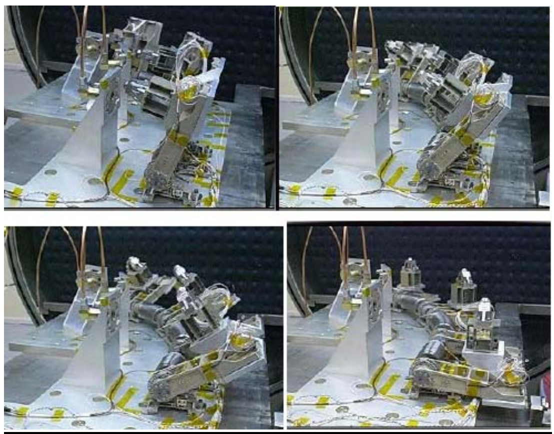

Fig. 6 DSA Mechanisms Functional Deployment

No unexpected issue was encountered during this successful qualification.

Fig. 7 DSA Mechanisms Vibration Test

6. DSA QM QUALIFICATION CAMPAIGN

The qualification campaign was based in the full qualification of the master quarter of the DSA. This master Quarter comprised the installation of the deployment regulator that brakes the deployment actuated by springs. The following test sequence was performed:

- Functional Quarter Model Deployment
- Sine environment exposure
- Functional Test
- Thermal Vacuum / Thermal Balance Test
- Life test
- Functional Test

Functional Test

The main objective of the functional test is to derive the torque loss of the unrolling of the deployable blankets in ambient after the measurement of each of the mechanism contribution.

The full sequence of the qualification is focused on checking that the initial performances do not present any degradation after the exposure to the required environments (vibrations, vacuum and thermal balance) and thus the functional and performance tests are repeated and checked after the exposure to these environments.

With the aim of counteracting the action of the gravity, a dedicated Zero G is built. The Zero G structure design is based on a rolling surface and a trolley that provides all through the deployment a vertical load that counteracts the gravity action. The pulling point to the DSA is the tip of the frames at 3400mm from the rotation axis due to the full coverage of the sunside blankets and the requirement of total light tightness.

Two different configurations are tested, deployment from vertical to horizontal with S/C axis in vertical and deployment from horizontal to vertical with the S/C axis horizontal.

Fig. 8 QM DSA Vertical Deployment Test

The functional test is performed with and without deployable blankets to derive the contribution of the deployable blankets and to measure the unbalancing of the Zero G.

The typical measurement at ambient conditions to unroll the blankets in this initial configuration was around 2Nm per frame leading to a maximum of 24Nm for the full DSA. The installed actuating spring torque warranted positive torque margin for the deployment.

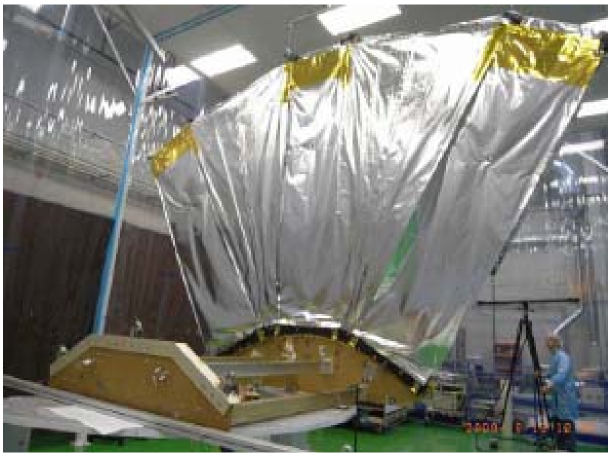

Fig. 9 QM DSA Horizontal Deployment Test

Vibration Test

The Quarter model was sine shaked in the axial and two lateral axes to the following levels:

Frequency Band Hz	LOW LEVEL QM g-level [g]	INTERM LEVEL QM g-level [g]		HIGH LEVEL QM g-level [g]	
		axial	lateral	axial	lateral
"5-30"	0.5	8.5	5	17	10,5
30-60	0.5	3	1.5	6	3
60-100	0.5	1,5	0.75	3	1.5
100-140	0.2 (continue until 2000Hz)	0,75	0.5	1,5	0.75

The Deployable blankets kept inside the dedicated cavities during the entire vibration test and did not suffer any damage during the shaking. The expected displacements at the tip were confirmed to be more than 30mm and the CuBe flexible spring based design of the stowage brackets provided expected flexibility to cope with the tube-to-tube displacements.

Fig. 10 QM DSA Z Axis Vibration Configuration

TVTB Test

The thermal performance of the full DSA was tested by solar simulation under cold vacuum conditions. Besides, a deployment in cold vacuum conditions was performed to demonstrate the DSA capability to deploy under these conditions.

A test motor was introduced in the QM TB/TV test set up to measure the required torque to deploy and guarantee that the deployment at cold vacuum conditions was completed in case of contingency.

The temperature defined to initiate the deployment was set at -106 ºC in the deployable blankets with the mechanisms at the minimum qualification limit. At that point, the pyro sequence was fired and successfully released.

The expected nominal deployment sequence was to heat up the deployment regulator melting the fusible alloy allowing the springs to deploy. During this phase, it was perceived that the installed actuating torque was not enough to deploy.

In order to complete the TB phase, the deployment was aided by the test motor. The installed torquimeter showed a sharp torque peak and a sudden release of the sunshield which was deployed at a high speed.

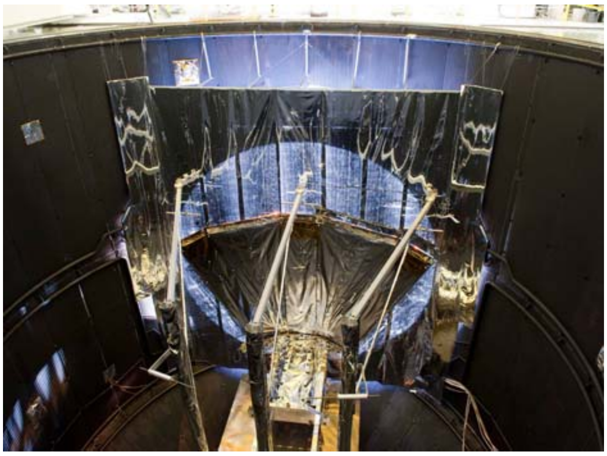

Fig. 11 QM DSA in LSS Solar Simulation

The solar simulation test phase showed that the DSA provided even better thermal performances than what analytically expected. The two layer configuration separated 120mm with the sunside made of 2mil Kapton/Nomex-VDA and the shadowside of VDA/0.5mil Kapton/Nomex-VDA were confirmed as sufficiently compliant to the challenging thermal requirements of the GAIA mission.

The solar simulation equilibrium was reached with four different solar power densities: 600W/m2, 1000W/m2, 1400W/m2 and a BBQ case of 1700 W/m2 which permitted the measurement of the heat flux at these four different conditions. During each stable condition, videogrammetry measurements were performed to assess the planarity and thermoelastic distortion of the DSA that shall drive the thermal stability of the sunshield and the GAIA S/C.

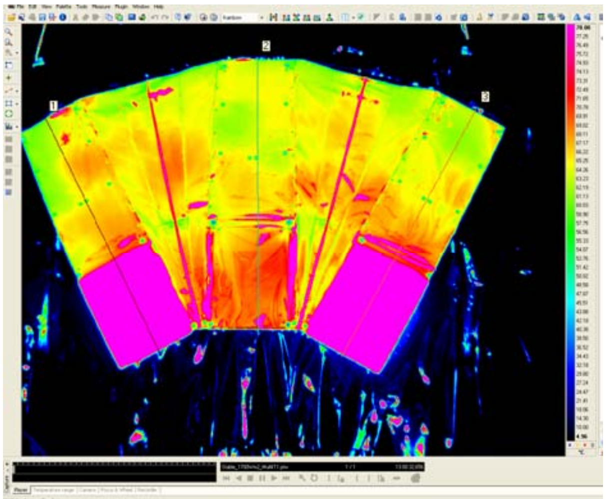

Fig. 12 QM DSA IR Measurement 1700W/m2

Several targets were located at the shadowside layer and test set up, measuring each location during the test completion. The sunshield was concluded to be compliant to the stringent requirement in terms of planarity and stability.

However, a new field for qualification was opened due to the unexpected increase of torque at cold vacuum conditions that had to be investigated. Several different contributors were analysed as possible root causes:

- Stacking or increase of retaining torque provoked by the Zero G assembly, specially coming from the high number of pulleys and rolling trolley solution.
- Increase of detent torque coming from the unrolling of the deployable blankets and/or sticking effects between rolls at vacuum conditions.
- Icing effects that could derive in sticking between blankets
- Loss of actuating torque of the deployment mechanism
- Malfunctioning of the HDRM (failure in retraction of holding bolt) due to imposed thermoelastic distortions and/or gravity loads for the horizontal to vertical deployment configuration.

Some of them were discarded after LSS opening and the visual inspection of the hardware such as HDRM contribution or actuating torque decrease.

After the TVTB test, the life assessment of the sunshield was completed by deploying all assembly 21 times which covered the required number of cycles.

TV deployment Test

With the aim of investigating the remaining contributors, a new test in vertical to horizontal deployment configuration (with Zero G acting nominally within the full deployment range) was considered necessary to identify the root cause of the failure. Besides, an extra deployment test without deployable blankets was performed to observe the contribution of the deployable blankets to the experienced increased detent torque.

The DSA design was able to accommodate springs with increased actuating torque replacing the previously used ones with impact in neither schedule nor design. The set up was enhanced removing any part that could affect the deployment. After refining and correlating of the thermal mathematical model at spacecraft level, an improved temperature limit was defined at -80ºC for any of the thermocouples installed on the deployable blankets.

The test motor was removed for this test as well as a torquimeter and a potentiometer included between the DSA deployment hinge mechanism and the regulator that recorded the relevant data of the deployment at regulator level.

At the set temperature conditions, the release sequence was successfully performed and the regulator warmed up till melting up of the regulator but the actuating spring torque was again not sufficient to start the unrolling of the blankets. At this stage, it was decided to warm up the chamber but maintaining the vacuum and proceed to a new attempt of deployment. At these environmental conditions, the deployment was successfully completed and the measured retaining torque was comparable to that measured in ambient.

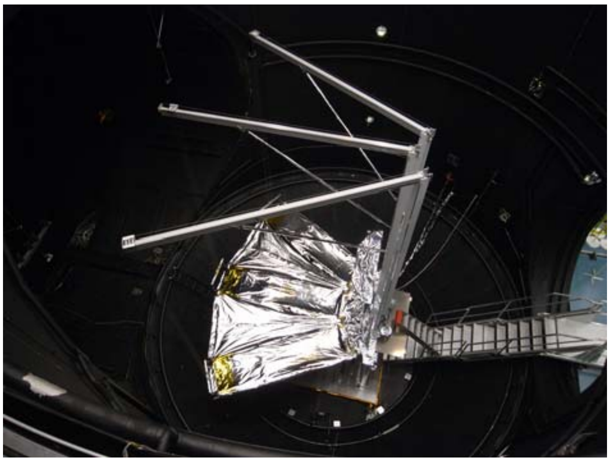

Fig. 13 QM DSA Deployed in LSS Solar Simulation

With this test only two root causes were still considered as responsible of the deployment failures: The Zero G influence in cold conditions and the unrolling of the blankets. The following deployment in cold vacuum conditions without deployable blankets demonstrated that both had influence in the previous experienced failures.

The high influence the Zero G Kits introduced to the full system, compared to the relative small internal load/torques of the flight hardware and the precisions required for a proper balancing, made these tests with relevant external contributions not suitable for the verification of the deployment capabilities of big systems. Any small increase of friction or unbalancing in the Zero G for such massive structures, acting at long distances from the rotating axis, can kill any test in cold vacuum conditions.

Based in the perturbed measurements up to that moment, a new approach was defined for the definition of the unrolling detent torque at representative conditions. The selected approach was to measure at component level, with a single set of sunside and shadowside deployable blankets and no interaction of any movable system.

7. STI MATERIAL CHARACTERIZATION

The test campaign was divided in two stages:

- Reduced size test. This test was performed in a small test chamber to assess the effect of temperature on a strip of STI providing a qualitative assessment of the effect of cold conditions in the unrolling of the STI.
- Full scale unrolling test. The specifically designed test set up was used to reproduce the relative displacement of the STI during the DSA deployment. This allows performing full scale testing measuring quantitatively the resistance of the unrolling.

The unrolling test set up simulates the deployment of a pair of deployable triangular blankets (sun and shadow side). The deployment axis has been changed with respect to the DSA hinge axis in order to deploy in a reduced volume chamber and to isolate the unrolling resistance to other resistance elements. The new axis used for this test is the deployment axis of one structure frame with respect to the adjacent, considering that both frames are always at the same deployment angle

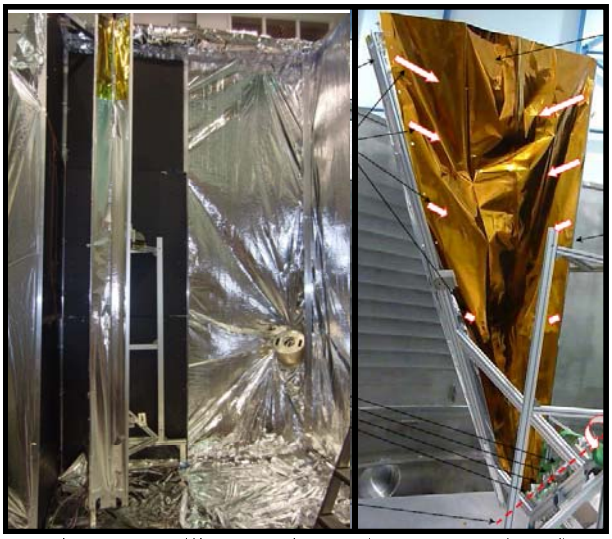

Fig. 14 Unrolling Test in VC (Stow & Deployed)

The unrolling test set up intention is to reproduce the relative movement between two adjacent frames with a one axis rotation set up. The unrolling set up has one degree of freedom, the axis of rotation. The unrolling test set up reproduces a relative movement of the two frames.

Several tests were performed in ambient and cold conditions to assess the effect of the temperature in the unrolling resistance. The outcome of these tests was that the STI had a total different behaviour from ambient to cold conditions. The stiffness of the material increased acting as a spring during the unrolling. For the coldest conditions the roll even recovered the rolled configuration and showed a heavy transition point at -40ºC. The baseline configuration with two cavities for the STI rolls provided retaining torque figures that were not compatible with the overall design of the sunshield, therefore a redesign was required for these components.

Besides, the necessity to install more actuating torque with the limitation of the regulator maximum load capability, and the existing deployment mechanisms, made the team propose an overall design modification introducing two actuators and removing the related single regulator.

8. DSA QM DESIGN IMPROVEMENTS

The different unrolling torque tests showed an initial range of the deployment where the blankets required a higher actuating torque. From 5 to 10 degrees of the deployment, the blankets had to come out from the stowage brackets and initiate the rolling movement to proceed with the total unfolding.

This fact with an initial high required torque and a subsequent lower need led to the inclusion of a four-bar-linkage mechanism between the actuator and the hinge coupling. This four-bar-linkage initial position was selected to be close to the over centre position with a high reduction ratio at the early stages of the deployment. The small available envelope to locate the system discarded the inclusion of commonly used commercial planetary or gear assemblies.

Fig. 15 DSA Actuator and Four-Bar-Linkage

The selected actuator was the SENER developed HDRA actuator with a 1 60 ratio harmonic drive compatible with the required four-bar-linkage and driven by SENER developed electronics for GAIA M2MM. This electronics was especially customized for this application but with the same components and overall electrical specifications to M2M MDE.

A parallel qualification campaign was defined for the hinge plus the four-bar-linkage and actuators to qualify under GAIA requirements. The subassembly was subjected to functional, mechanical (sine + random) and thermal cycling / vacuum tests. The qualification was performed successfully and the deployment mechanisms were qualified according to expected results.

The number of needed actuators was selected according to the enhancements introduced by the stowage brackets. After several trials deploying the set of blankets in the climatic chamber a promising design solution was defined based on a slightly modified cavity of the stowage bracket. See figure 5.

The torque measured in the climatic chamber was reduced to values that were able to be covered by two actuators, and therefore the measurement at cold and vacuum conditions was defined as next step in the qualification.

On the other hand, the vibration/qualification campaign to DSA QM with finally selected configuration was performed showing that there was no mechanical issue or unrolling during shaking.

The TV deployment with a set of blankets was performed at different temperatures, including the final defined one at -40ºC as deployment temperature. The new stowing concept provided two peak values coincident to the initial unrolling of the first roll and the second to the unrolling of the last roll. These peaks were considerably higher than the measured ones in the climatic chamber with exactly the same configuration. This fact confirmed that the combination of the temperature and vacuum conditions made the material behave different providing high friction between STI layers during the unrolling.

The increased torque in the TV chamber made the team look for a new design improvement of the baseline including some rigid wedges in the stowage brackets which made easier the popping out from the stowage bracket cavity. The finally achieved reduction provided values compliant to positive torque margins according to ECSS rules. These independently measured figures provided by addition the overall torque margin calculation of the DSA.

Parallel ESA studies have revealed that the friction of the STI material under cold vacuum conditions is increased by a significant factor especially for the sunside blanket with Kapton material outwards. Besides, bimetallic effect has been also noticed due to the Nomex scrim and related adhesive (Nomex scrim was required for micrometeorite damage avoidance). This study is still on going and will provide the complete understanding of the STI material.

9. LESSONS LEARNT

The defined tests for these big assemblies, with the complete configuration and all contributors installed, have been revealed to be not convenient due mainly to the gravity action and the impossibility to act independently on each individual part. Component by component measurements have been identified to be more efficient from the technical point of view.

Material properties must be part of the development activities (not only on industry shoulders) and can not be investigated at latter stages of the project.

Developments must be clearly defined and financially covered to check all the technical risks of the programs. The definition of the requirements must be set with special attention in order not to impose higher levels than required especially in mechanical and thermal environments –in this case going from -100ºC to final -40ºC- that can lead to discard valid design concepts.

10. CONCLUSIONS

The Gaia Sunshield has been qualified as a system that provides a reliable deployment complying with the performances required for the mission. This has been achieved after a long process of improvements in the area of AIT and design.

The main requirements of the sunshield have been verified as combination of analysis and tests (planarity and deployment capability) as well as direct test (vibration and thermal performances).

The inclusion of qualified actuators, the related four bar linkage and the availability of representative overall detent torque coming from component level measurements, have provided enough reliability in the deployment performances in orbit of the GAIA sunshield.

11. ACKNOWLEDGEMENT

The Authors want to thank all Astrium Friedrichshaffen, Astrium Toulouse and ESA/ESTEC team members for their support and excellent ideas that led to the common successful GAIA DSA qualification.

12. REFERENCES

1. “MECHANISMS FOR GAIA DEPLOYABLE SUNSHIELD”, 11th European Space Mechanisms & Tribology Symposium,