Flatness Adjustment in the Design and Integration of a 35-m^2 Space Deployable Synthetic Aperture Radar Antenna.

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Abstract

This paper presents the process carried out to achieve the flatness requirement requested in orbit for the Synthetic Aperture Radar (SAR) antennas of the Satélite Argentino de Observación Con Microondas (SAOCOM) mission. It describes the main design characteristics, integration and test processes in line with the mission requirements and the possibility to verify it on ground due to the test constraints. The results of the Structural Qualification Model integration process and flatness measurements are described, showing the improvements and modifications that were implemented in the measurement strategy in order to guarantee the success of the flight models, mainly in the measurement strategy.

The results of the tests performed on the Flight Models showed that the flatness requirement was met with margin and confirmed the design robustness.

Introduction

The SAOCOM Mission is defined, managed and operated by CONAE (Comisión Nacional de Actividades Espaciales), Argentine Space Agency. It is composed of a twin satellite constellation, SAOCOM 1A and SAOCOM 1B, carrying each one a polarimetric L-band SAR instrument. The main driver of the mission is to operatively generate soil moisture maps. Both satellites were launched in 2018 and 2020 respectively and now are in full operating mode in a polar sun synchronous frozen orbit at 619 km with a 98° mean inclination.

The SAR Antenna structure and its mechanisms were designed and manufactured by the Comisión Nacional de Energía Atómica (CNEA), while the assembly, integration and tests were conducted together with CONAE.

The SAR Antenna consists of seven panels whose structure is made of a sandwich structure with an aluminum honeycomb core and carbon fiber facings, where all units are mounted (mechanisms, the electronic boxes and RF front end). In the short sides of the panels, two reinforcements are bonded, forming a “U-shape”. With all these hardware mounted, each panel weights approximately 200 kg; the smaller panels are 1.5 meters long and 4.0 meters wide. The whole SAR Antenna has a radiant surface of 35 m^2 with a 10 meters long by 4.0 meters high envelope. The SAR Antenna has a structural configuration with one central panel fixed to the Service Platform (SP) and two symmetrical wings with three panels each that unfold in a spiral way from center to extremes. The central panel is fixed to the SP by means of a tube-reticulated assembly, composed of 16 carbon fiber cylindrical cross section tubes with aluminum end fittings. This interface structure (IS) is fixed to the SP on 6 points connecting the cylindrical trusses by means of titanium fittings and allows the differential thermal displacements between the aluminum SP and the carbon fiber antenna minimizing the distortion of the radiant surface.

During launch, each wing is folded and retained with a dedicated mechanism, once in space each wing is released and deployed by stepper motors in a controlled way by ground commands, reaching its final

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position after six deployment steps. Figure 1 shows general views of the SAR Antenna in folded and deployed configurations.

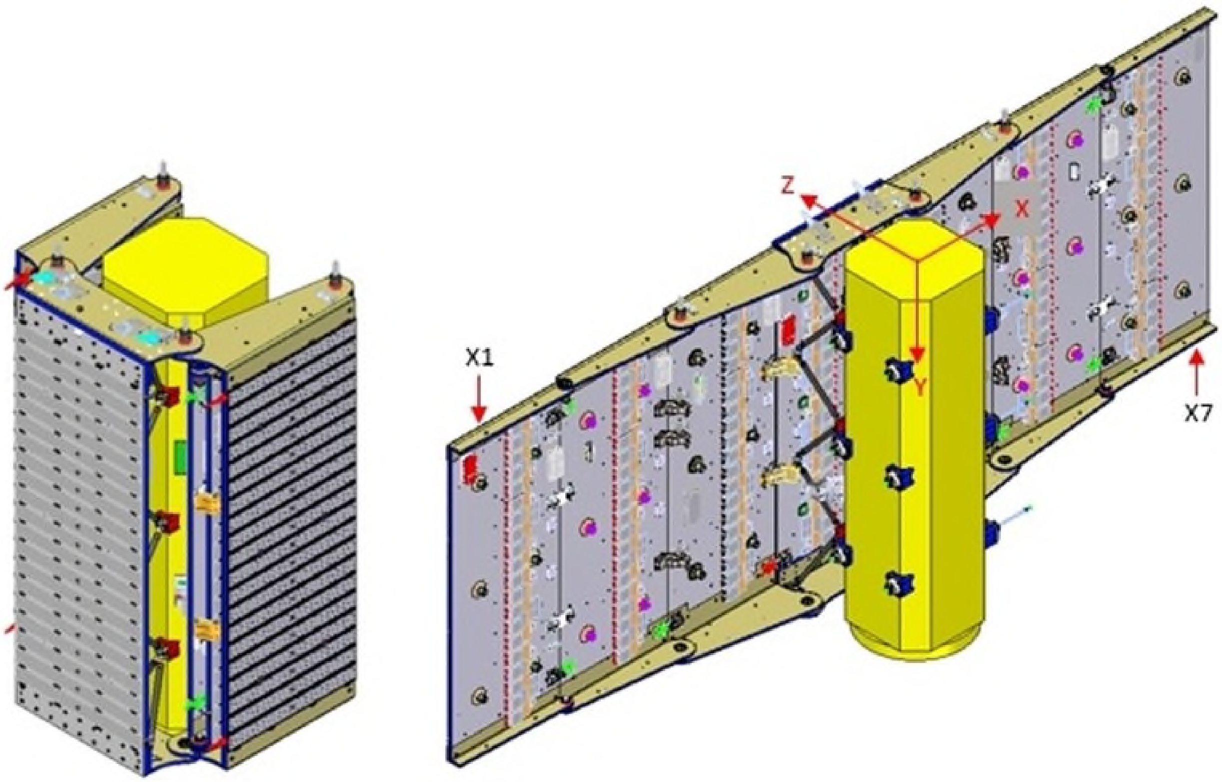

Figure 1. Launch and Flight Configuration of the SAR Antenna.

To assure the operational performance of the instrument, the flatness of the radiant surface must be controlled. The analysis of the flatness of the radiating surface of the deployed SAR Antenna in space should include several error sources such as geometric error sources known and characterized on ground (antenna panels mechanical flatness deviations, mechanism misalignment, stiffening truss errors) and unknown error sources in space (thermo-elastic deformations induced by sun-eclipse cycles, spacecraft maneuvers and instrument OFF-ON transition, dynamic coupling, induced deformation by attitude control perturbations, other movable mechanisms dynamics and the 1G to 0G unloading deformations).

In early phases of the project, an alignment budget was established in order to design the structure, the mechanisms, and the integration process according to this budget. This requirement was so demanding that in order to achieve it, complex integration processes had to be developed and verified.

Key Requirements

Many requirements were derived from SAR System to SAR Antenna in order to achieve the desired performance. In addition to these performance requirements, manufacturing, assembly, integration, test and transportation requirements were added, making it difficult to reach a balance between them.

For alignment purposes, an ideal plane was defined by the external faces of the Radiating Modules in Flight Configuration (SAR Antenna Deployed): Overall Antenna Radiating Plane (OARP). The Geometric Center of OARP was located at the intersection of the two ideal diagonals of the OARP, as shown in Figure 2.

The analysis of the deployed SAR Antenna distortions in space, related to the OARP and containing all error sources should be less than 24 mm or λ/10 (where λ is the wavelength of the instrument) and should have 20% positive margin. This value shall be evaluated between two points located anywhere over the radiating area.

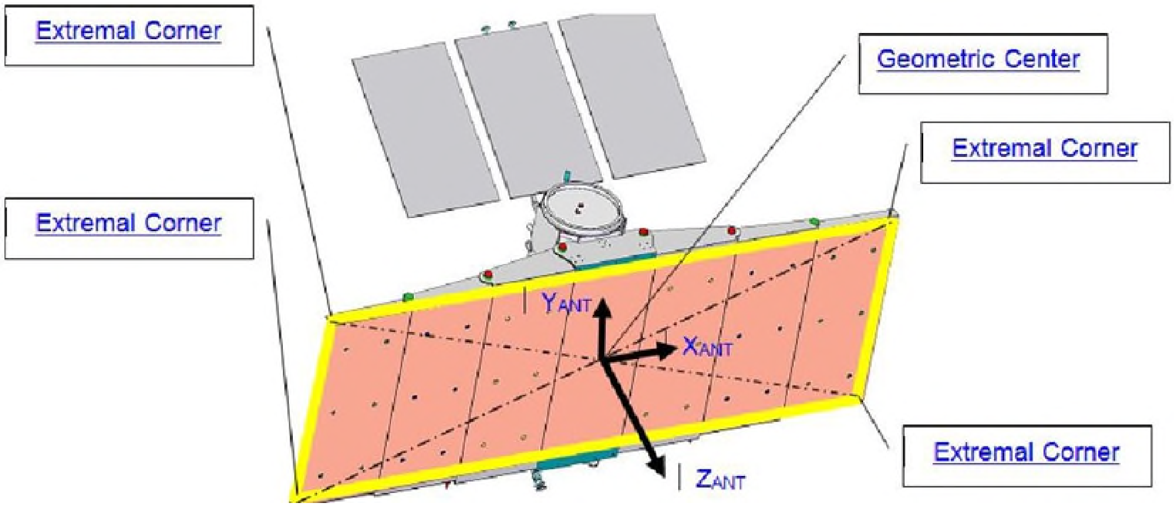

Figure 2. SAR Antenna OARP and coordinate system.

As it was said before, in order to reach final flatness requirements, a budget that considered all the possible geometric error sources that affected the flatness and could be characterized on ground was established in order to control it during the manufacturing and integration processes, the in-orbit flatness requirement was extrapolated to ground and additional security margin was applied to the result. The evaluation resulted in a requirement of a maximum of 12.7 mm RMS value for the flatness of the entire radiant surface when measured on the ground.

A detailed alignment strategy had to be determined in order to align of the SAR Antenna Panels during their integration to minimize the misalignments of the whole SAR Antenna. Considering that the requirement was given on the radiating surface of the antenna, and that it is a sensitive surface, since it is completely coated with white paint, a non-contacting measurement methodology had to be determined.

In addition to flatness requirements, SAR Antenna mechanisms were not designed to support the complete antenna weight on ground, so all the integration had to be supported by a zero-gravity offload device that was designed and used for the integration and deployment on ground and which had to compensate at least 85% of the SAR Antenna deployable panels weight.

In addition to the rigorous design requirements, the integration policies adopted by CONAE added critical constraints to the assembly and integration and test strategy, consequently, the SAR Antenna had to be assembled in vertical position, in a clean room without crane on a dedicated support structure, functionally tested and characterized and then had to be transported to the main contractor facilities, where the SAR Antenna had to be integrated to the spacecraft SP in folded configuration, maintaining the shape and flatness when deployed, with a mounting residual antenna pointing error that should not exceed 0.014 degrees in both azimuth and elevation.

Mechanisms Development

The following mechanisms were designed to accomplish the requirements of keeping the antenna safe during transportation and launch, release it once in orbit, allow the deployment and keep it in that configuration until end of life:

- Restrain-Release (RR)
- Hinges
- Latches

Mechanisms Description and Main Features

Restrain-Release mechanism (RR):

The main function of the RR is to give support to the Antenna while it is in folded configuration for transport and launch and to release it once the satellite is in orbit. To accomplish this task a total of 12 RR are distributed, 6 to each wing of 3 panels. Each RR mechanism consists of the following sub-assemblies: three tubes attached to inserts potted to the sandwich panels; a flange fastened to the SP through four4 calibrated stem bolts and a rod which provides the preload to hold the tubes tightened, as shown in Figure 3.

The six RR mechanisms have the capacity to compensate the misalignments between panels' inserts that arise from the integration process described above, as well as the alignment of the entire wing with respect to the fixing points of the SP or mounting structure.

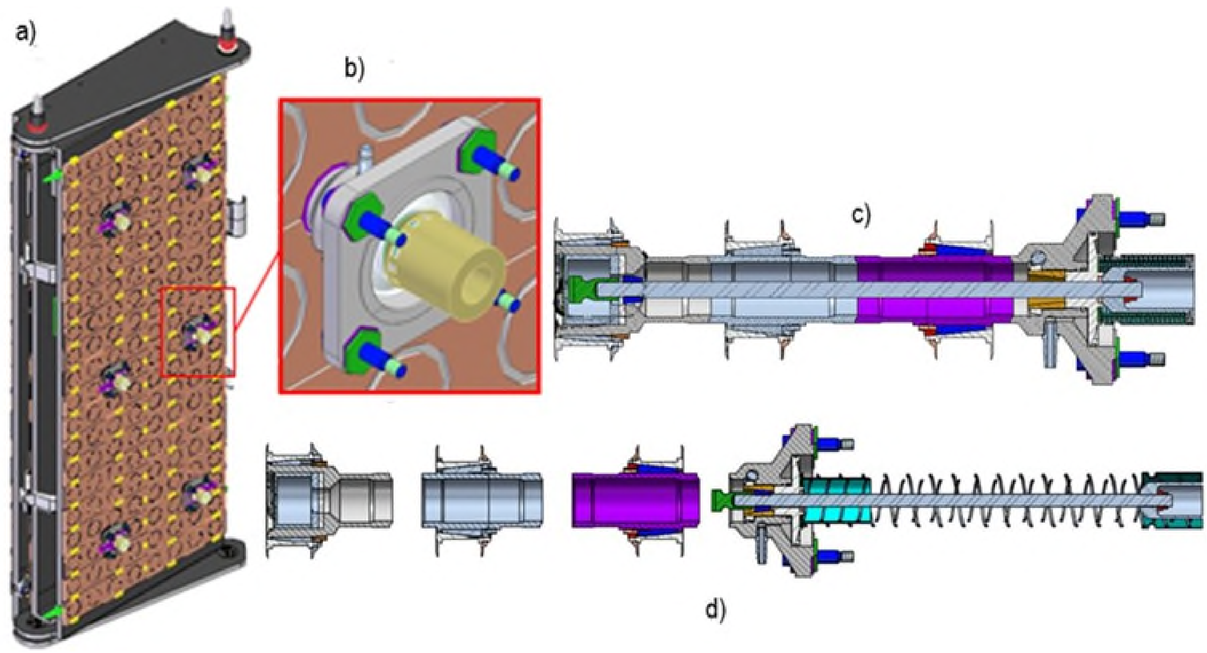

Figure 3. Restrain-Release mechanism a) Distribution in the -X wing b) Flange details c) Mechanism in preloaded configuration d) Mechanism in released configuration.

Hinge mechanism:

The hinges link two adjacent panels, forming the joint axis between them. Furthermore, they provide the active torque needed for deployment by means of a stepper motor installed in one of the two hinges which form each joint; the other hinge is not motorized and features a potentiometer to provide telemetry of the position of the panel. The hinges have the capability to move the rotation shaft in two directions perpendicular to the shaft (flatness adjusting device); the axial position can be adjusted by means of calibrated shims in the motorized hinges. The angular displacements can also be regulated by differential adjustment between opposite hinges. To avoid over constraints and distortion in the panels, the non-motorized hinges allow the shaft to slide axially. INVAR 36 was selected for most of the parts in hinges to minimize thermal-induced distortion propagating to the antenna, see Figure 4.

A total of 12 hinge mechanisms are installed to form the 6 rotational joints of the antenna.

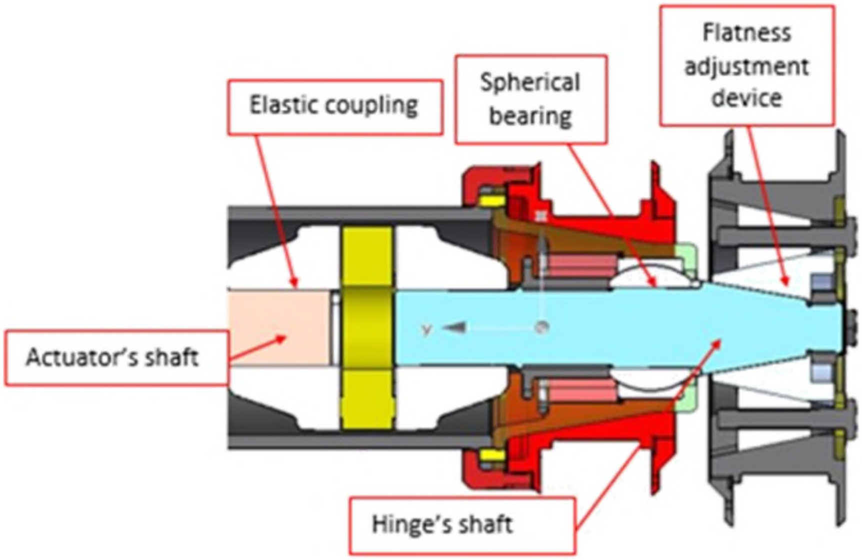

Figure 4. Motorized hinge cross section

Latch mechanism:

Latch mechanism is composed of the base and the pawl sub-assemblies. Positive latching is achieved with a lock bolt that slides down a notch in the pawl that prohibits the pawl retraction. Once deployed, the latches constitute two contact points with no movement and no gap, and along with the regulation capabilities of the hinges, allow the longitudinal, transversal and warping adjustment of each panel, therefore modifying the flatness of the antenna. INVAR 36 was selected for base and pawl to minimize thermal-induced distortion propagating through the antenna, as shown in Figure 5.

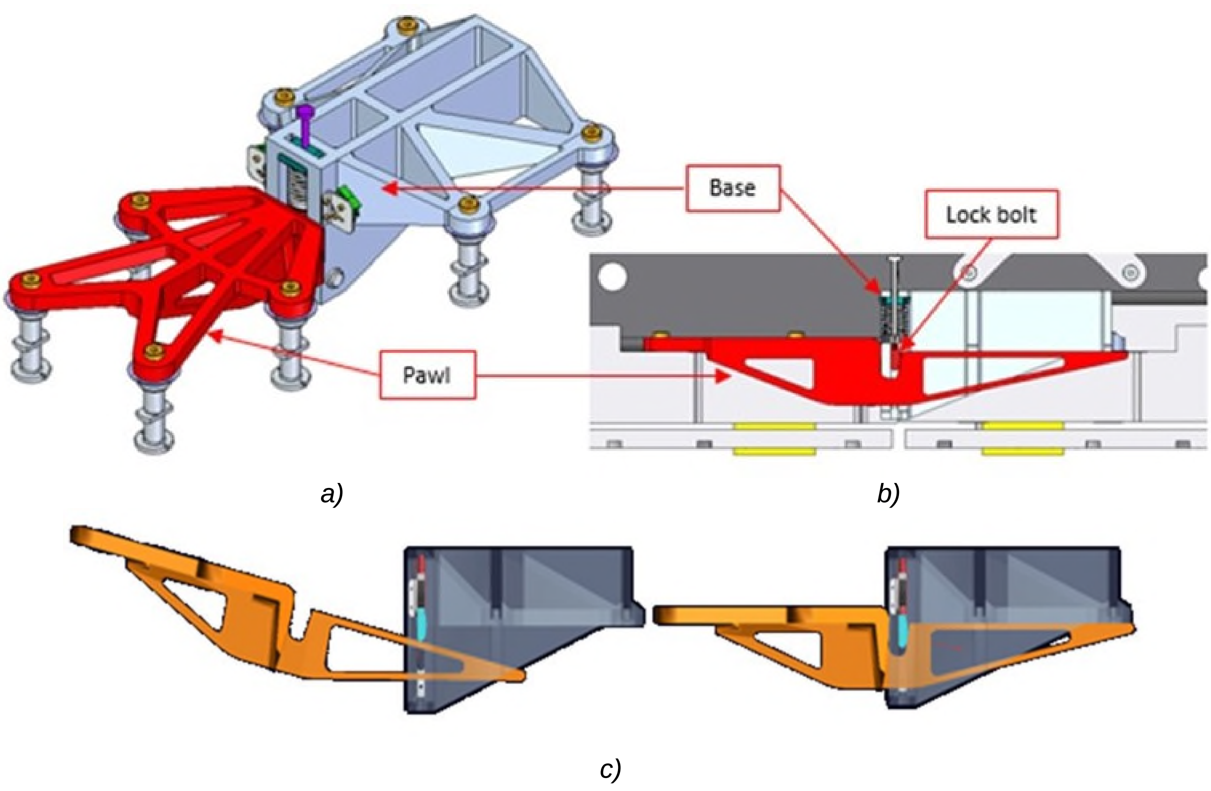

Figure 5. Latch mechanism a) Isometric view b) Cross section c) Latching kinematics

Structural Model Campaign

The models adopted by the SAOCOM mission to verify deployment, flatness and alignment requirements were a structural qualification model (SQM), a proto-flight model (SAOCOM 1A) and a flight model (SAOCOM 1B).

The SQM is a full-scale model composed of the SP fully representative and the SAR Antenna composed of the central panel X4 with the IS, a structural flight-like wing (panels X5, X6 and X7) and dummy wing simulating panels X3, X2 and X1; this dummy wing did not have deployment capabilities.

In order to decouple SAR Antenna assembly from SP integration, a dedicate Mechanical Ground Support Equipment (MGSE), called Mounting Structure which simulated the SP was developed. This MGSE has the same interfaces as the SP.

<u>The SAR Antenna structural model integration</u>
The IS was mounted on central panel X4, and both were integrated to the mounting structure standing in vertical position. This integration was done using a dedicated MGSE which hangs the panels from the RR inserts, allowing slow motion movements, in order to reach the mounting structure interface. This assembly was placed with minimum position restrictions, since the integration criteria were height, level and perpendicularity with respect to the mounting structure, which were achieved taking advantage of the articulated and adjustable ends fittings of the IS.

Once the central panel was positioned and fixed, the next adjacent panel (X5) was assembled and handled via the RR inserts with the same integration device mentioned above. The integration objectives were the hinges inserts were aligned; the hinges could be assembled without introducing any loads to the structure (no panel deformation); and the correct actuation of the latch mechanisms. Once these objectives were met, the 0-g device was integrated; the hinges were assembled with calibrated shims when necessary; and the integration device was released.

After reaching the final position of the panel, the partial flatness is measured without contact using a laser theodolite. Corrections can be made using the regulation capabilities of the hinges until this partial value is accepted. Same steps were performed to achieve the integration of the other two panels, X6 and X7.

All measurements made with position regulation purposes were performed with a laser theodolite and several dial indicator gauges.

After the Antenna wing was assembled, the 6 Restrain-Release mechanisms were integrated. No measurement methodology was considered necessary, so their regulation was achieved through an iterative process of folding one panel on the following, measuring the alignment of the tubes, unfolding, regulating and all over again.

The integration of the dummy wing was performed with the same MGSE in a simpler way since it did not require RR integration and regulation, no flatness nor deployment requirements were applicable, no latch mechanisms were present, the only restriction was that all dummy wing hinges needed to be integrated.

In order to complete the SQM integration process, the antenna SQM needed to be transferred to the main contractor facility, where it had to be re-assembled and joined with the SP SQM instead of the mounting structure. For the transportation, the SAR Antenna was separated in 3 main sub-assemblies: central panel (X4), +X wing (panels X5, X6 & X7) and dummy wing. Before disassembling the antenna, some key parameters were measured, in order to try to reproduce the integration condition on the SP. These measurements were relative positions between interface flanges, latch components and hinges.

Once in the integration facilities, the Antenna and the SP were meant to be integrated all together conforming the whole satellite structural model. In this opportunity, due to the level of integration in the wings and the advantage of having a crane bridge, the procedure was different:

The first step was the integration of the central panel X4 with IS to the SP, which was placed in horizontal position. The central panel was hoisted and lifted onto the SP by means of a bridge crane; once positioned the IS was fastened and secured to the platform. In a similar way, the measurements required for regulating the position were initiated with dial indicator gauges and adding the assistance of a 3-D coordinate measurement arm. The central panel final position was established with the relative positions taken when it was vertical, which means that the latch base was in the same relative position with respect to the RR flange interface of the SP.

The second stage consisted of rotating the SP, leaving the central panel pointing sideways and a lateral face upwards. The 3-panel assembly, or +X wing, was hoisted onto the SP with the crane, after measurements and position regulation, was fastened in place through the Restrain-Release flanges. In this stage, the desired position was one that could meet integration requirements, meaning the hinges should be aligned and the 24 calibrated stem bolts (shear bolts) of the RR flange should be able to be placed using the allowable regulation systems (hinge alignment mechanisms and adjustable shear pins concentric with the bolts). After several interactions, the desired position could not be reached so some of the shear calibrated bolts were replaced by standard bolts. Finally, when all bolts were placed, both hinge mechanisms in the joint between the central panel and X5 panel were re-assembled and regulated.

Finally, the SP was rotated 180° and a similar procedure was executed to integrate the dummy wing. In this case, no RR mechanisms were present but hinges between the central panel and the dummy were. At this moment we noticed that central panel was tilted so it was not possible to integrate the dummy wing as planned because the hinges axis could not be aligned. This was solved by doing some modification of the dummy hinge, but this method was not acceptable for flight.

The first deployment of the antenna was not successful, since the latch mechanisms of the joint between the central panel and the X5 panel did not make it to the final position. A lack of alignment and a shift in position were confirmed through a number of measurements. A procedure to adjust the +X wing (without de-integrating it) was developed and performed; the issue was solved, and the antenna did perform all the following deployments correctly. Nevertheless, the integration measurements and instruments had been proven inaccurate to guarantee the success criteria of the deployment.

Flatness was measured after 3 deployments, 2 before the mechanical tests campaign and 1 after it. The instrument used was the laser theodolite and a 40 dots matrix. As it was a partial antenna (4 panels), the flatness requirement budget established a peak-to-peak value equal or less than 10.7 mm. Table 1 shows these results.

Table 1. Flatness results in SAR Antenna SQM for 3 different deployments

	Deployment #1	**Deployment #2**	**Deployment #3**
Flatness, peak-to-peak (mm)	7.83 ±2	7.43 ±2	7.11 ±2
Pass criteria (mm)	≤ 10.70	≤ 10.70	≤ 10.70

Due to the limited accuracy in the relative position of the sub-assemblies of the SQM (platform, central panel, +X wing and dummy wing), some deviations to the design needed to be included:

- Not all the bolts in the RR flanges could be of calibrated stem. Some had to be replaced for reduced stem ones, increasing the clearance with the bore.

- The dummy hinge mechanisms between the central panel and the dummy wing had to be modified to make their integration possible. A modification to enlarge the regulation capabilities was chosen as a time-saving solution.

Adopting a standard policy regarding alignment measurement, it had been requested that the central panel of the antenna should have two alignment cubes, so that it could be referenced to the SP. These cubes were placed in the lateral beam of the panel, and were not used throughout the integration process, but they were used to determine if there were variations in their relative position after environmental qualification campaign, giving satisfactory results. However, these cubes did not give information regarding the SAR Antenna radiating plane position and it was determined that their alignment was very sensitive to truss tensioning and hinge loading. This last condition occurred every time we preload the RR mechanisms.

This integration process was done with high confidence in mechanisms and structure design criteria, without taking into account integration process restrictions that could arise (technical and programmatic). This led to a difficult and long integration.

Design Changes to Improve Results

After the qualification campaign some changes were implemented in the hardware and in the integration procedures, with the aim to improve and facilitate the integration of the flight models and to reduce the time required for the task (limit the iterative operations). These changes are summarized as follow:

Modifications to the hardware:

- The size and tolerances of the Platform bores were incremented, to slightly increase the clearances. These bores were finished with reamer to improve roughness and verified with go/no go gauges, as well.

- The use of a number of bolts with reduced stem were allowed. The nominal diameter of the stem was between 15.842 mm (max) and 15.799 mm (min) and was reduced by 0.2 mm.

- The pieces used to regulate and adjust the position of the bolts in the RR flanges (named “eccentrics”) were modified to avoid blind spots in the regulation.

- Calibrated shims were added to fill gaps between flanges and platform and avoid distortions in the panels.

- 8 inserts with calibrated bore were potted in each one of the 7 panels of the antenna (near corners, 4 in the radiating face and 4 in the back). These inserts allowed an accurate and repetitive positioning (and quick removal) of measuring devices for the photogrammetry and laser tracker equipment.

Modifications in procedures and MGSE:

- New measuring equipment that facilitated control during both integrations, vertical and horizontal were acquired. This equipment was composed of a real-time 3D coordinate measurement system composed of a FARO Vantage laser tracker [1] and a photogrammetry V-STARS D System configured with two high-speed DynaMo D12 cameras [2]. These systems are complementary to each other, since the first one allows direct measurement of the desired surface, measuring one point at a time with high precision, while the second requires placing magnetic or adhesive targets on the desired surface, allowing the entire cloud of points to be measured in the same acquisition. This measurement equipment showed its results in a 3D model of the antenna and its MGSE, which identify the points measured in the real model, indicating their deviations from the desired position.

- During the antenna integration in vertical position, the regulation of the RR was changed, adding more measurement and characterization and reducing the iterative trial-and-error process.

- A complete mechanical characterization of all assemblies was performed before starting the integration (central panel, wings and platform were measured with laser tracker and photogrammetry equipment). Results were gathered and analyzed with a software tool. Based on this, the most convenient position (target position) for each assembly was defined.

- Related to the previous bullet, for the integration of each main assembly, two bolt holes were selected as most convenient and guidance pins were installed to facilitate reaching the target position.

- The order of integration of the 3 main assemblies of the antenna to the SP was altered: from central panel, then +X wing, finally dummy wing in the SQM to +X wing, then -X wing, finally central panel in both Flight Models.

- The integration of the IS was modified. For the flight models the integration to the central panel was partial: 12 out of 16 tubes were integrated when the central panel was hoisted on the SP. The remaining 4 were integrated after the central panel was already positioned and fixed.

All these modifications were verified with the SQM before being implemented in the flight models. After the structural qualification campaign was complete, the antenna was removed from the SP and re-integrated.

To verify the integration, flatness and repeatability, 9 deployments were performed, yielding the results shown in Table 2. The instrument used was the photogrammetry equipment, with a PRO-SPOT [3] which allows a grid of 5600 light dots in each projection. In addition to substantially increasing the amounts of dots, a great improvement in precision was also achieved.

Table 2. Flatness results in deployments after the SQM was re-integrated implementing the proposed changes.

	Deployment #								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Flatness, peak-to-peak (mm)	7.3 ±0.3	7.4 ±0.3	6.7 ±0.3	7.5 ±0.3	7.2 ±0.3	7.2 ±0.3	8.0 ±0.3	8.0 ±0.3	6.9 ±0.3
Pass criterion for one wing (mm)	≤ 10.70								

Flight SAR Antenna Integration in Vertical Position

The first step of the integration was to characterize the mounting structure using the laser tracker and photogrammetry measurement systems in order to know the position of the actual fixation points, and the more relevant parts. This characterization will then be used across the whole assembly process, because it was the reference for alignment and folding as it will be explained later.

In parallel to this characterization, the central panel without the IS was characterized using both measurement systems. This characterization includes the four structure calibrated reference points located at the corners of the panel, the position of the latch mechanisms, which was needed for reference for next panels integration, and the hinges axis position, as is shown in Figure 6.

Once the initial characterization was done, the points of each component measured from the real model were fitted to the 3D model using a best-fit criterion that minimized the dispersion of the points. Once the measured points were related to the ideal locations, the central panel 3D model was placed in the best position with respect to the mounting structure 3D model. The SAR Antenna alignment with respect to the SP was very sensitive to the central panel position, but not SAR Antenna flatness, which could be corrected with the mechanisms provided for the integration of the panels. The resulting 3D model positions defined where the reference points should be (nominal position), and in order to reach that position, how the IS had to be assembled in order to fit the panel to the mounting structure.

Then the IS was assembled and aligned to the desired position with a dedicated auxiliary frame, in order to enable mounting of the central panel to the mounting structure. The IS together with the frame ware stiff enough to guarantee that the central panel position would be maintained. Then, central panel together with the IS was hoisted vertically, using the dedicated MGSE described above, in order to reach mounting structure interface. Once the IS reached the final position, screws were adjusted and all MGSE was removed. A new characterization was done using the system, where the final position of the panel was compared with the desired one, in order to reach a position which met alignment and flatness requirements, antenna panels' integration, and subsequent folding. In the event that small corrections were necessary, they could be accomplished by tensioning the IS, guided in real time with the photogrammetry system. Otherwise, the central panel would have had to be removed, restarting the entire process. Fortunately, this did not happen. The resulting position was measured and taken as a baseline for SAR Antenna Integration. The most critical points were final hinge axis and latch mechanisms positions as shown in figure 7.

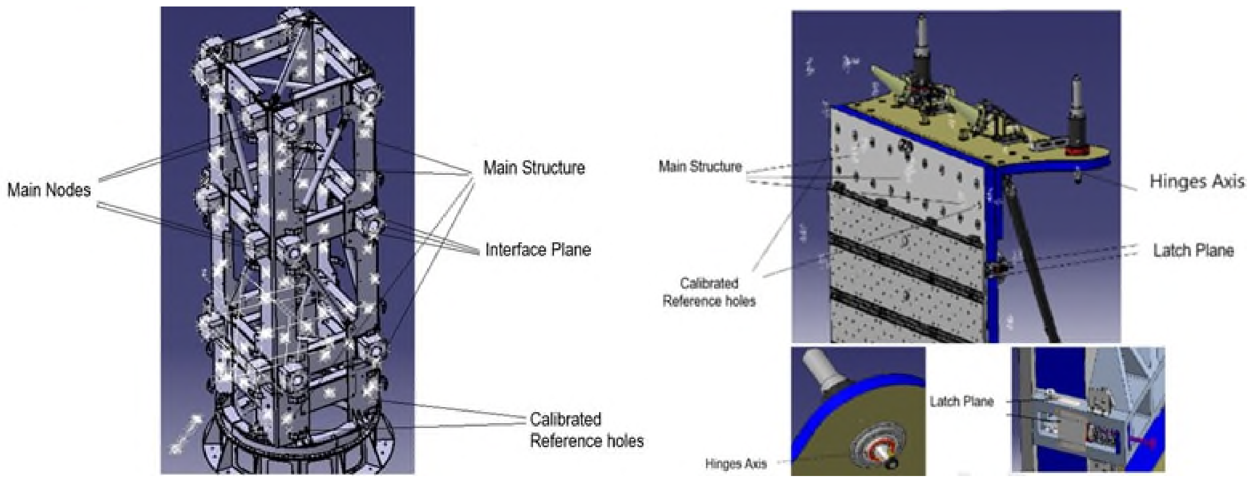

Figure 6: Mounting structure characterization - Central Panel Characterization

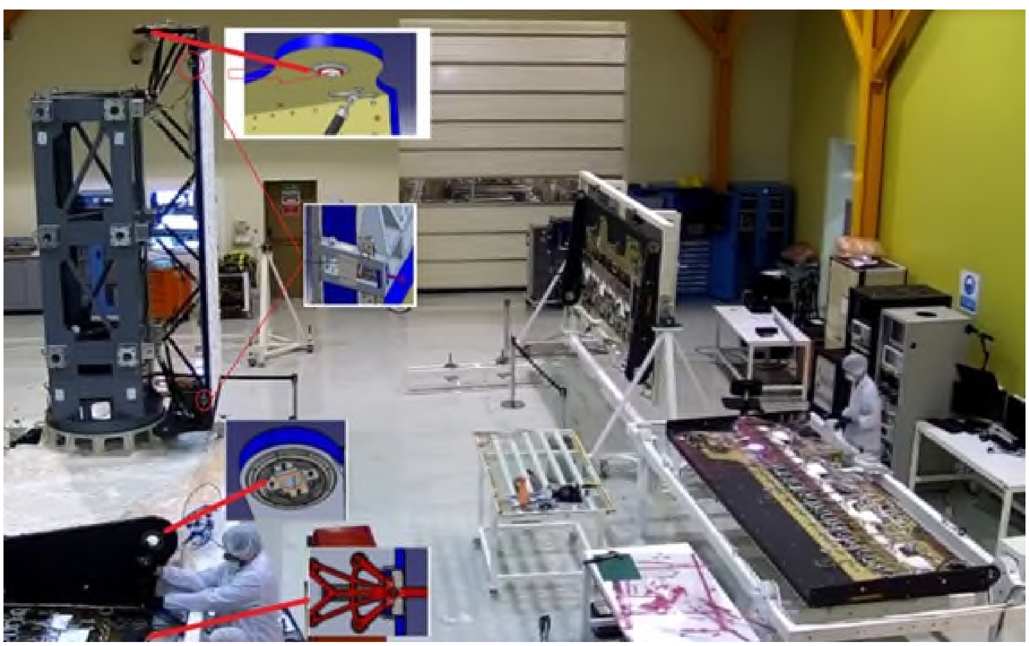

Figure 7. Hinges and latches characterization in central panel and in X5 panel.

Once the central panel was placed and characterized, the next step was to start with the integration of the adjacent panel. The procedure was similar for all panels. Before mounting, each panel was characterized using a laser tracker and the photogrammetry system as described above, and the measurement included the same critical points, similar to the central panel.

Once the panel to be mounted was characterized, the best fit to the 3D model was established and was virtually integrated in the position necessary to meet the flatness and alignment requirements. This desired position normally required some calibrated shims installed on the hinge shaft to align the panel on Y axis. This position was called the nominal position, being the position that would achieve a perfect plane. This nominal position established the desired positions of the four structure reference points of each panel to achieve an acceptable accuracy.

Then the panel was positioned using the same dedicated integration device used for the central panel, which supports the panels from the RR inserts. The position of the panel was monitored in real time with the photogrammetry system, which showed the residual value between the desired and current position of the structure reference points, so the integration conductor could lead the maneuver until these residuals met the integration requirement. Once this objective was met the hinges were assembled with the shims defined before, without forcing the structure, and then the 0-g device was integrated in order to support the panel weight and to release it from the integration device. Then the added panel was folded, the pawls of the latch mechanisms were integrated, and then it was deployed again to evaluate repeatability and final position once latched. In case it was necessary, the panel alignment could be corrected with precision by means of the regulation capabilities of the hinges. If necessary to raise or lower the panel, calibrated shims could be placed on the hinge shafts. After reaching the final position of the panel, the partial flatness was measured without contact using a dense array of high-contrast targets projected [3] onto the radiating surface. If this partial value was accepted, then this new configuration was characterized and same process was repeated for the next panel, see Figure 8.

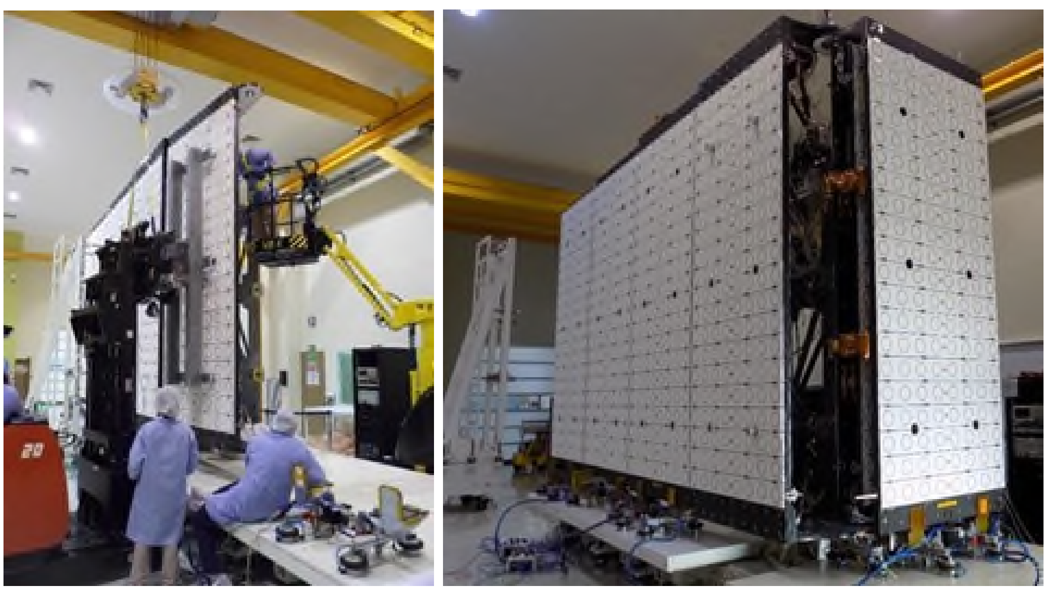

Figure 8. SAR Antenna during integration in vertical position, one panel at the time.

Once one wing was assembled, a complete folding was done in order to evaluate repeatability and start with the restrain release mechanisms integration and alignment in order not to introduce distortions - therefore loads- to the antenna structure. Once the mechanisms were aligned with respect to the panels, their positions were fixed, leaving only the possibility of adjusting the interface in a circle with a 4mm radius, in order to absorb differences when mounted to the SP.

After the SAR Antenna was completely integrated, the flatness and alignment were verified, and the radiation pattern was characterized in an anechoic chamber. Following that, it was disassembled into three main sub-assemblies: central panel with the IS, and the two wings. These sub-assemblies were sent to the main contractor where they were integrated again in a folded configuration, together with the hinges that were removed during the partial disassembly process.

SAR Antenna Assembly in Horizontal Position

As described during the SQM integration, the integration of the SAR Antenna to the SP was performed in horizontal position and making use of a bridge crane. The main differences implemented in the integration of flight models were the measurement systems and the sequence of integration.

Before the integration itself, a series of geometric characterizations using laser tracker and photogrammetry were performed. In the SP, the planar contact surface and the 4 holes of each node were characterized (6 nodes for +X wing, 6 nodes for -X wing and 4 nodes for IS). Likewise, similar characterizations were made in the antenna sub-assemblies, the planar contact surfaces and bolt holes of the RR flanges and those of the IS. Also, the hinge axes and selected surfaces of the latches were characterized as well.

The measured components were best fit to their 3D model and the nominal position for each sub-assembly was defined and transformed in the target position to be accomplished during the integration. This position was defined not only taking into account the integrability in the current folded position but the final deployed position, in order to guarantee flatness and alignment requirements. As a result of this analysis, 2 bolt holes were defined as integration reference points and guidance pins were installed in order to facilitate the position of the sub-assemblies.

The first stage of final integration was the +X wing. The SP was installed on the integration trolley with the +X face oriented upwards. The +X wing sub-assembly was hoisted and guided onto the SP. When the wing was in an approximate position, the photogrammetry measuring system was initiated, taking advantage of its real-time and multi-point information, enabling the wing to reach its target position. Once the positioning was completed, achieving the pre-defined tolerances, the shear calibrated bolts were installed (but not torqued) in the RR flanges to assess whether standard-size bolts could be used throughout. A final measurement of predefined points was made with the laser tracker, using its greater accuracy to verify an acceptable integration. Once the position was accepted, the interface bolts were tightened.

Figure 9. SAR Antenna during wing integration (left) and central panel integration (right) in horizontal position.

A similar procedure was followed to integrate the -X wing, adding the actual position of the +X wing to adjust the analysis determining the target positions of the -X wing and central panel.

Finally, the central panel and the IS (partially integrated with 12 out of 16 tubes) was hoisted and positioned onto the SP (Figure 9). The positioning was guided using the guidance pins and the photogrammetry equipment; the final position was verified with the laser tracker. To complete the IS assembly, the interface bolts were tightened; and the 4 hinge mechanisms were assembled without introducing deformation to the panels, confirming the first success criteria of the integration. The second success criterion were flatness and alignment, which were verified in the deployed configuration.

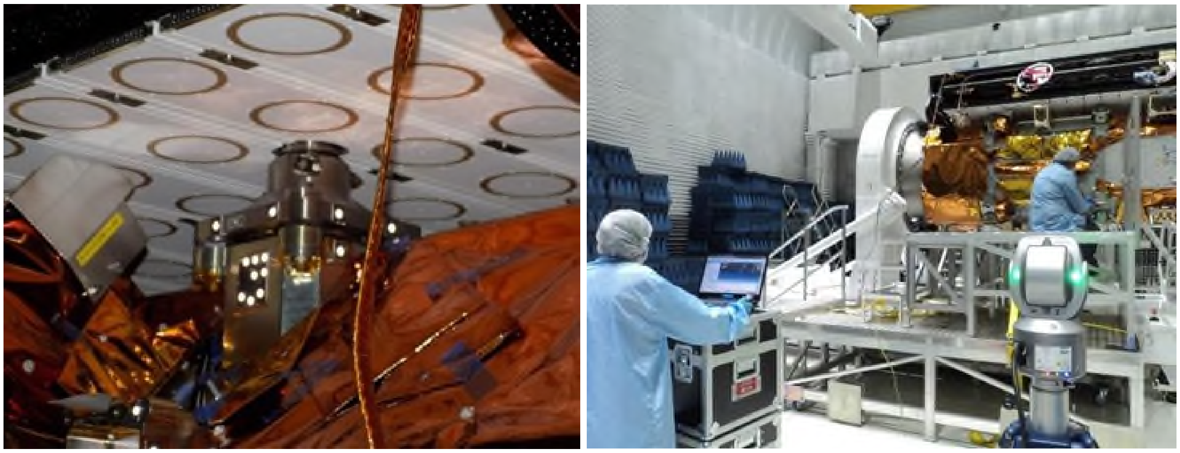

Figure 10. Reflective targets for photogrammetry measurement (left) and measurement with laser tracker during central panel integration (right).

Flatness Measurement

Once the SAR Antenna was completely integrated, a workflow similar to the structural model was followed: the satellite was positioned in vertical position and atop the corresponding trolley; the MGSE for deployment was installed (0-g device and deployment tables), leaving the antenna ready for its first deployment.

Along the AI&T campaign, a total of 3 mandatory deployments were planned, including a system validation test (several extra deployments were performed but for operational convenience and with no requirement-verification purposes). Flatness was measured each time (see Figure 11)

- Deployment #1 after antenna integration was completed
- Deployment #2 prior to the mechanical environment test campaign
- Deployment #3 after the mechanical test campaign

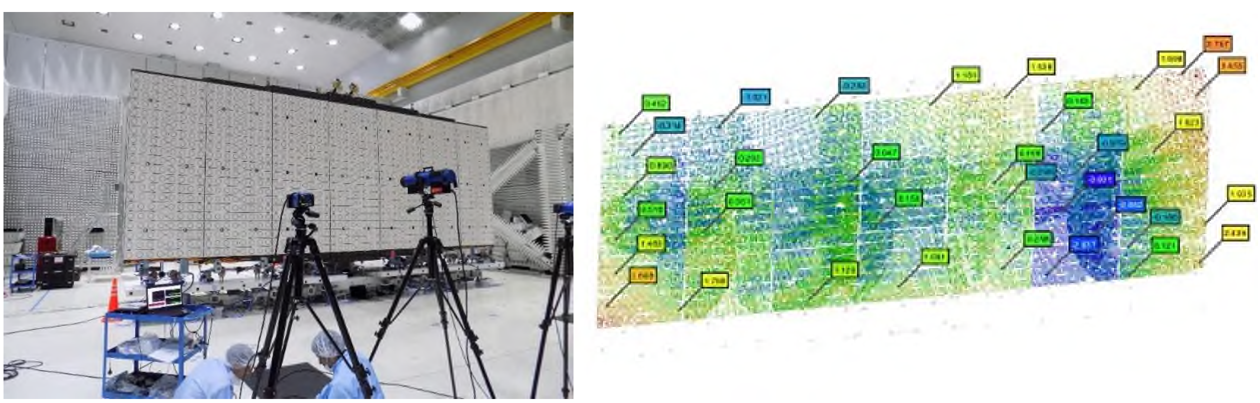

Figure 11. SAR Antenna flatness verification. Measuring set-up (left) and data visualization (right)

The SAOCOM 1A and 1B achieved similar flatness and repeatability values. Table 3 summarizes the flatness measurement results obtained during SAOCOM 1A and 1B AIT campaigns.

Table 3. Flatness results in deployments pre and post dynamic tests campaign, for SAOCOM 1A/B.

	SAOCOM 1A		SAOCOM 1B	
	Pre dyn. test	Post dyn. test	Pre dyn. test	Post dyn. test
Flatness, peak-to-peak (mm)	8.7 ±0.3	8.6 ±0.3	8.0 ±0.3	7.0 ±0.3
Pass criterion (mm)	≤ 12.70			

Conclusions

A short summary of the mechanism's design and its contribution to flatness regulation were introduced. Integration and measurements strategies along the lifecycle of the project were described, including the improvements.

As was indicated, at the very beginning the best way to meet the flatness and alignment requirements from the design and manufacturing point of view were established, without considering the problems that the integration and assembly of the antenna could arise. Trying to use standard alignment criterion (such as the use of cubes) in such complex, flexible and large structures was not possible, and it would not have allowed the radiating plane of the antenna to be measured relative to the satellite reference system. These inconveniences were detected early, thanks to the model philosophy adopted by the project, and the pertinent design modifications that accounted for integration requirements in the design and manufacture of the structure. The reference points calibrated on the structural panels were key to the success of the integration.

The acquisition of modern measurement equipment and great metrology and engineering teams made the integration successful in both satellites, fulfilling the desired requirements with sufficient margin. Also, this methodology allowed not only a significant reduction in the integration time but a minor uncertainty in their predictions, since the iterative, trial-error procedures are by nature uncertain and they were reduced.

It was also a good decision to implement the MGSE mounting structure. This allowed decoupling of the integration of the antenna from the SP, dealing with a great part of the tasks (flatness and RR regulation, for instance) in parallel, thus, optimizing the schedule.

The commissioning of both satellites also showed very good results for the instrument performance, thus confirming that the flatness requirements were also compliant to design requirement after the in-orbit deployment allowing the mission to start its operational phase successfully.

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