DEVELOPMENT SUMMARY AND TEST RESULTS OF A 3 METER UNFURLABLE CFRP SKIN ANTENNA REFLECTOR

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Structure and Mechanism Section

1. ABSTRACT

By end of 2001 the development of an Unfurlable CFRP Skin Antenna Reflector was started at Astrium GmbH. Major development steps are now finished, a 3 m Engineering Model of the Reflector was built and the Functional and Contour Performance Verification at ambient conditions was completed. The paper summarises the development approach, verification test results and experiences gained with the realised design.

2. INTRODUCTION

The design concept comprises a number of unfurlable reflector petals, stowed around a central dish during launch. The basic design aims at X-Band application, however also higher frequencies are defined as an application goal.

In order to achieve a minimum stowed envelope at maximum deployed diameter, a thin sheet reflector concept (CFRP skin) is followed. This concept does not only allow storage of the CFRP petals in a geometrically optimised way, but also to deflect the individual petals during storage. This feature enables to accommodate large reflectors of good contour shape in small launcher envelopes and conical fairings.

A growing number of applications is expected in the future for accurate antenna reflectors in the 3 to 6 m class (e.g. for SAR applications or for X-Band / Ku-Band communication). Such reflectors could close the gap between small fixed reflectors and the large and very large mesh reflectors mainly dedicated to low frequency applications.
In a next development step not only central feed arrangements but also offset configurations are being considered.

The major goal of the development phase was to verify the mechanical performance of the chosen reflector concept by test. The following major verification steps were performed:

- o Function
- o Deployed Contour Accuracy
- o Deployment Reproducibility
- o Handling
- o Vibration (still under work)

The electrical Surface Reflectivity is at present verified on sample level, full size electrical testing and thermal (vacuum) testing is foreseen in a later development stage, the thermal deflections and their influence on the reflector contour are presently covered by analysis.

3. TECHNICAL SPECIFICATION

The following key requirements form the development basis:

- Frequency
  X Band or higher
- Surface Reflectivity
  > 97 % of Aluminium
- Reflector Type
  Central Feed
- Contour Shape:
  Symmetric Parabolic $Z= (X^2 + Y^2) /4400$
- Main reflector focal length
  1100 mm
- Minimum Required Accuracy (rms)
  <0.75mm (required for X-Band)
- Main reflector diameter deployed
  3m (growth capability up to 6m)
- Base diameter of stowed Reflector package
  1 m
- Total Mass
  ≤ 15.5 kg
- Eigenfrequency stowed
  >25 Hz
- Eigenfrequency deployed
  >5 Hz

4. DESIGN CONEPT AND FEATURES

The Reflector design is driven by the requirement for minimum mass and stowed volume at maximum achievable deployed diameter and contour accuracy. In addition the reflector performance with regard to the in-orbit thermal environment, as well as functional robustness and the possibility for easy on ground adjustment and testing is of high importance.

The above generic requirements are satisfied best by the described Skin Concept (thin sheet concept) which makes use of flexible CFRP sheets of parabolic shape. The rotation axes of the deploying panels are not arranged tangentially w.r.t. the Central Support Structure, but at a slight inclination such minimising the envelope in the stowed configuration. (see Fig. 1).

Additional advantage is taken from the minimised sheet thickness which allows the CFRP panels to deflect in the stowed condition. The CFRP sheets achieve their nominal well defined parabolic contour after deployment. Each thin sheet panel is supported by a hollow CFRP rib interfacing the circular Central Support Structure.

Fig. 1 shows the stowed reflector. The individual panels are mounted to the Central Support Structure providing a structural interface to the satellite and to the Tripod/ Feed assembly as well. The Central Support Structure is designed as a stiff, hollow CFRP ring comprising the end stops for the individual panel segments as well as the interfaces for the panel deployment axes. The Central Dish itself is manufactured as a CFRP membrane and is glued along its outer rim to the Central Support Structure.

At the top of each panel rib, a Launch Locking Bracket is mounted. All brackets together form a closed ring in the stowed configuration (Fig.2). The resulting form locking structural ring is preloaded by a circumferential release wire compressing all ring segments in order to achieve a stiff top ring structure, taking moments and forces.

The launch loads are guided through the panel ribs down to the Central Support Structure. The Feed Structure (Tripod) is independent from the reflector panels and not used to provide support to the stowed reflector during launch. This feature provides design flexibility and defines a clear interface only between Tripod base and Reflector Central Ring.

Fig. 1. Stowed Configuration

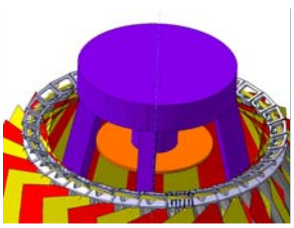


Fig.2. Launch Lock Device Ring Span

To release the reflector, the release wire (tension wire) is opened and the deployment is initiated by means of the leg springs integrated in each individual panel hinge, mounted to the central dish rim. This design avoids heavy and bulky deployment mechanisms to be arranged underneath the Central Dish and leaves the space free for Waveguides and RF electronics.

During deployment the motion is controlled by means of a small friction damping device. A thin string (unloaded during launch) is guided through all launch lock brackets and is pulled off a small cable drum attached to the top of one panel rib by means of the deploying panels, so that the release velocity of the reflector is controlled.

Synchronisation of the deploying petals is achieved inherently by their overlap during deployment (Fig.3). Only in the final deployed end position are all panels located one besides the other. (Fig. 4)

Fig. 3: Partially deployed

Fig. 4: Fully Deployed Reflector

After complete deployment about the spring loaded panel rotation axes, the deployed end position is defined by means of adjustable end stop elements attached to the Central Support Structure. This interface mates with the root of the panel rib carrying an adequate Aluminium End-stop fitting. The residual spring torque still acting about the deployment axis after deployment, suppresses potential residual backlash in the deployment hinge and helps to achieve good deployment reproducibility.

All the 30 individual deploying panels are independent from each other after deployment. This feature guarantees a parabolic contour shape insensitive to any cross coupling effects (manufacturing tolerances, adjustment, thermal effects) between the adjacent panels. Each individual panel provides a well-defined parabolic contour and can be independently fine-tuned by rotation about its deployment axis in order to achieve an optimised global contour either for 1 g (on ground testing) or for 0 g (on-orbit) configuration.

By this concept it is easily possible to exchange one panel segment for maintenance or repair activities without disturbing the global contour adjustment. Due to the high stiffness of the panel rib and the low overall panel mass (about 180 g), local deflections of the panel

sheet due to 1 g effects can be neglected during initial reflector adjustment in the vicinity of the rib.
The design requires small gaps (of about 0.5 mm) between the adjacent petals and between the panels and the central dish and is therefore advantageous in view of PIMP effects relevant to communication applications.
The CFRP material used has to fulfil the following requirements:

- good stiffness and strength
- low mass
- low CTE
- low Creeping (at deflection during storage)
- low residual stresses after curing
- good temperature stability
- good electrical reflectivity for all polarisation directions
- ATOX Protection

In order to optimise for these requirements, a sample manufacturing / test program was carried out at the beginning of the development phase. The outcome was to use a high modulus Carbon fibre together with a hot curing resin system so that orbit temperatures up to about 130 deg C are allowable. As an ATOX protection a PVD SiO_2 coating is used, its good adherence to the CFRP surface was checked by pull-off tests.

5. MAJOR SUB- UNITS

5.1 Central Dish

The Central Dish Structure provides the stiff reflector core interfacing the satellite and accommodates the Tripod Structure.
The Central Dish is formed by a ring structure fully manufactured in CFRP, stiffened by shear walls and framework bars. The Ring Structure carries all Hinge Brackets used to mount the individual reflector panels and the end-stops defining the deployed panel position. To the rim of the ring structure the central dish reflector is glued. The central dish reflector is manufactured, as the deploying panels are, from a 0.4 mm thick CFRP sheet.

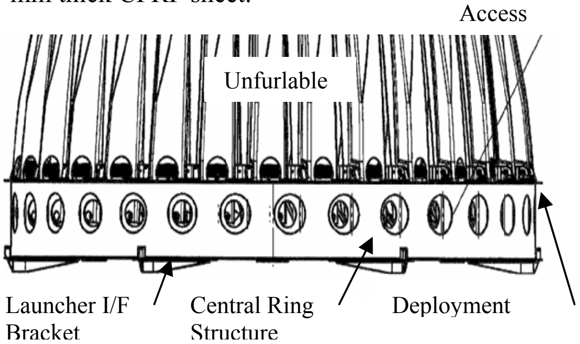


Fig. 5:Central Ring Structure

5.2 Unfurlable Panels

Each individual panel is manufactured and cured on a dedicated mold. Each individual rib is manufactured and cured on a separate mold. Both parts are brought together in a third working step to form the complete panel. To the panel root the deployment hinge axis (Deployment Mechanism) and Panel Endstop Device are mounted in a further working step prior to integration into the Central Dish.

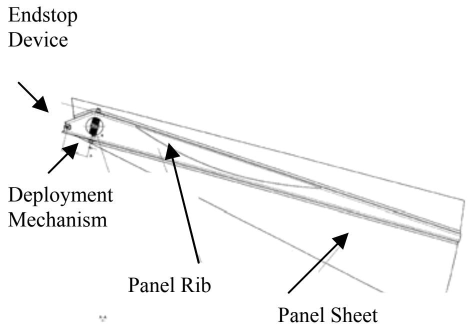


Fig. 6: Unfurlable Panel Segment

The full size panels were submitted to photogrammetric measurement in order to verify the achieved manufacturing accuracy and reproducibility on basis of the chosen manufacturing process. The measurement yielded good results with typical values of about 0.15 mm to 0.3 mm rms for the single panels.
During the development it was found that the panel accuracy is very sensitive against changes in material and manufacturing process. Even the use of a different batch of the identical CFRP material resulted in a different quality of the cured panels. Such effects are occurring due to the low thickness of the CFRP sheets of only 0.4 mm, increasing the sensitivity against built in residual stresses which cannot be counteracted by the design inherent low panel stiffness.
Therefore at the beginning manufacturing process optimisation and creeping tests on different material samples were carried through in order to select the optimum material and process combination under consideration of low manufacturing costs.

5.3 Deployment Mechanisms

Each individual panel (rib) carries at its root an I/F for the Deployment Hinge Axis. Each Hinge Axis is equipped with a set of two (redundant) deployment springs providing the reflector deployment torque for this individual panel. Due to the concept inherent deployment synchronization between the adjacent panels, torque variations in the springs are compensated (i.e. a potentially lower torque of one panel is supported by the higher torque provided by the adjacent one). The deployed position of the panels is individually adjustable about their rotation axis by means of a mechanic end stop device. In addition a (limited) lateral and tilt adjustment possibility is provided in the panel rotation axis.

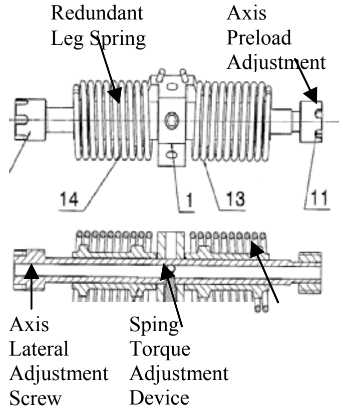


Fig. 7: Panel Deployment Mechanism

5.4 Deployment Damper

To one of the Launch Locking Brackets (the so called Damping Bracket) a small friction damping device is added. The damper consists of a rotating shaft mounted into a housing. By rotation of the shaft two small brass masses are accelerated radially so that friction between the housing and the mass is produced. To one end of the shaft a small cable reel is mounted onto which a thin cord is wound up from two sides.

The two ends of the cord are guided through holes on each side of the Damping Bracket and from there through small guidance openings in each individual Launch Locking Bracket. The ends of the cord are fixed to the Launch Locking Bracket on the opposite side of the Damping Bracket.
If the reflector deployment is initiated, the cord is pulled off the reel, the friction damper is accelerated and a velocity dependent friction force is produced to control the panel deployment. In order to avoid inadvertent rotation of the damping reel during launch, a form locking interface between the reel and the Launch Locking Device tension wire is provided (see Fig.8).

The complete Reflector deployment time using the damper unit, under 0-g conditions but with additional air damping effect, is between 5 and 6 s.

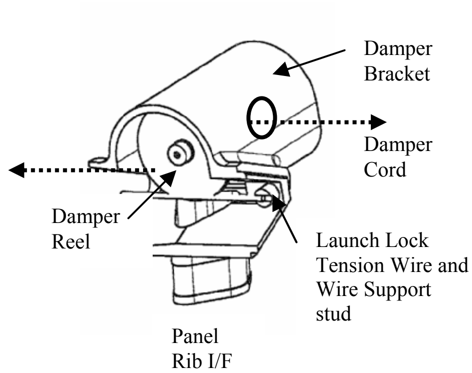


Fig. 8: Deployment Damping Device

5.5 Launch Locking System

In parallel to the damping cord which is not loaded during launch, two steel tension wires each running around half the Launch Lock ring, provide the preload to the locking system in stowed configuration. The tension wires are hooked together and secured by a pin in the Release Bracket that locks them in place. After that, the wire is tensioned by a screw preloading a set of belville washers used to ensure that the tension wires maintain their adjusted force of about 600 N during vibration.
The Launch Locking System as such is fully flight representative, however at present no flight standard release actuator initiating the release process was included. Such an actuator could be a pyrotechnic device, non-explosive actuator or electro-magnetic pin puller. In the present EM only manual release of the Launch Locking Device is foreseen. If a manual release pin is turned, the Launch Locking Device is actuated so that the reflector panels can deploy.
Due to the spring force inherent to the steel locking wire, the two wire segments move back to their initial straight position after reflector release and are positioned behind the deployed reflector surface outside the reflector aperture. This position is assured by an additional spring element, forcing the wire to a defined position after release, so that interfere with the deploying or deployed reflector segments are avoided.

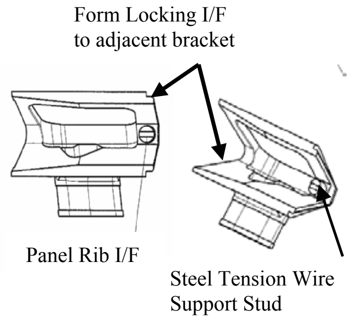


Fig. 9: Launch Locking Brackets (Top Ring Segment)

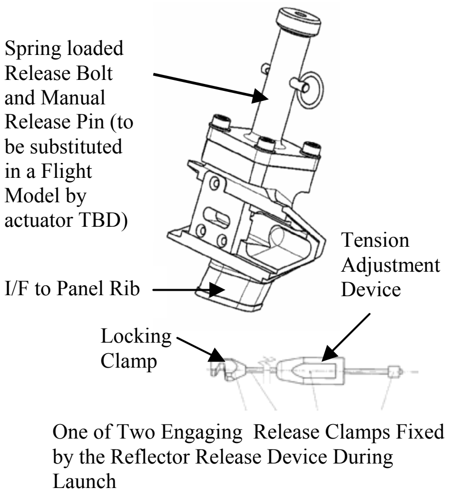


Fig. 10: Reflector Release Device (LLD)

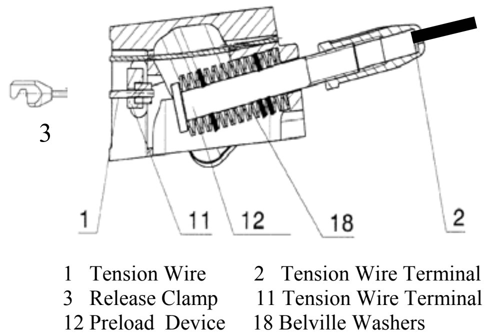


Fig. 11: Launch Lock System Tensioning Device

6. REFLECTOR INTEGRATION AND ALIGNMENT

To ensure full accessibility during the integration, the antenna is assembled on an Integration and Test Rig which can be turned about two axes, namely about the reflector boresight direction and about one horizontal axis. In order to get a satisfying radial run-out during rotation above the bore sight direction, the test rig is mechanically aligned before start of integration.

In a first integration step the Reflector Central Ring Structure is attached via its launcher I/F points to the Integration and Test Rig. In a second step the reflector panels are integrated to the central dish rim turned to a top-down configuration. In a last integration step, the pre-integrated set of launch locking brackets (launch locking ring) is glued in one shot to the top of the panel ribs. After finishing this activity, the closed reflector can be turned with its boresight direction vertical by means of the Integration and Test Rig and the first manual deployment can be performed for visual inspection. Now the deployment springs are loaded and adjusted to the correct torque value.

7. REFLECTOR CONTOUR ADJUSTMENT

Above the integration and test rig carrying the integrated reflector, a zero g- rig equipped with a set of pulleys is positioned by means of a crane in alignment with the (vertical) boresight direction. Over each of the pulleys a string fastened to the top of one reflector panel is guided. The panel weight is counteracted by a small mass at the other end of each string. The only forces acting to the individual panels after deployment are the residual spring forces about the rotation axes.
To adjust and verify the overall surface accuracy and reproducibility three different verification methods are used:

In a first step all individual panel segments are adjusted by means of a mechanical measurement jig formed by a CFRP frame, referenced in the centre of the central dish and on its rim as well. The CFRP frame allows to detect the z- position of each panel rib at a well defined position on the reflector radius by turning the frame about the reflector boresight axis panel by panel.

To align the correct reflector contour, the deployed panels are adjusted in height via adjustment screws mounted at the panel root underneath the central dish. These screws interface metallic counterparts on the Central Ring Structure.

In a second alignment step aluminium targets (tapes) are attached to the outer rim of each deploying segment so that a contact free capacitive sensor can measure the distance to the Al-target (see Fig. 12). This measurement result is converted into the distance in mm between the sensor and each panel. During measurement the sensor is fixed to the test rig and the reflector is turned about its bore-sight direction panel by panel to measure the distance between sensor and target, so that a quick and easy global Reflector alignment and deployment reproducibility checks can be performed.

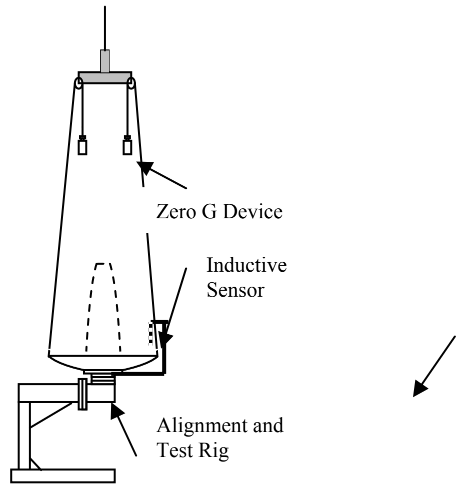


Fig. 12: Deployment Test Configuration

In order to measure the overall reflector (rms) contour accuracy, a third step is performed. This is done by photogrammetric measurement of the complete reflector shape. A high resolution digital camera equipped with a wide angle lens is used to take photos from different working positions. For this activity a set of circular targets is glued onto the Reflector. Reference bars with known target distances are used as a reference. The photos taken from different viewing angles are evaluated by a special software which correlates the measured target points and calculates the overall rms value and best fit parabola.

Photogrammetric measurements are made before and after deployment and after the vibration test in order to ensure the reproducibility of the reflector surface shape under ambient conditions.

The results of the above described three measurement methods are evaluated and based on these results individual segments can be re-adjusted or fine-adjusted as appropriate, in order to optimise for the overall contour accuracy.

8. FUCTION AND PERFORMANCE TEST

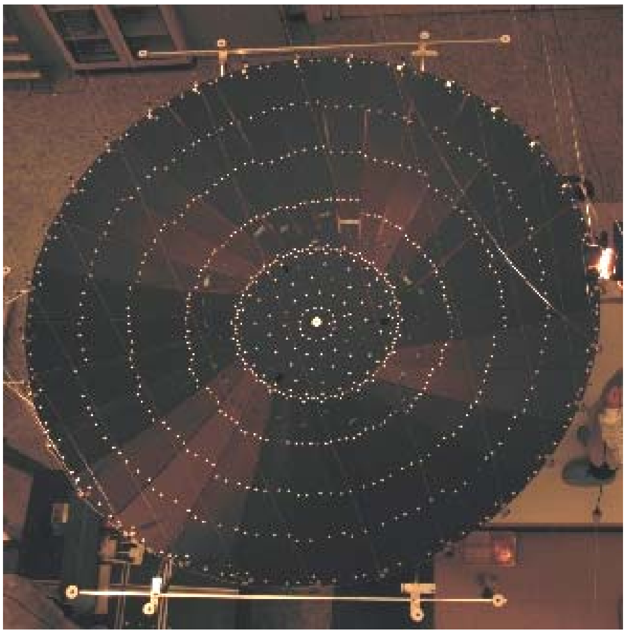


Fig. 13: Deployed Reflector during Contour Measurement.

In Fig. 13 the deployed reflector is shown, equipped with a number of circular target spots on its surface. Reference bars are shown on top and bottom. By means of this arrangement the global contour accuracy and reproducibility was measured by means of a photogrammetric equipment.

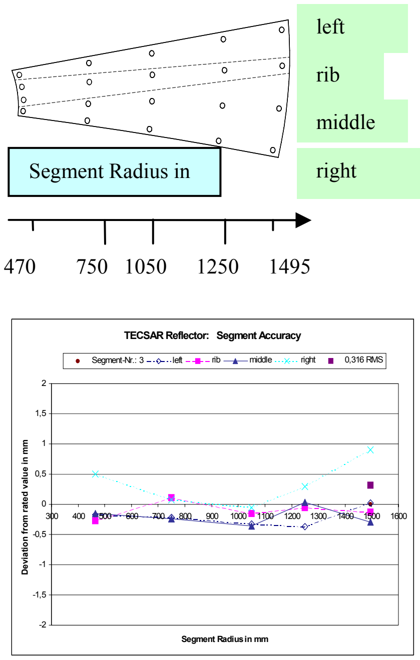
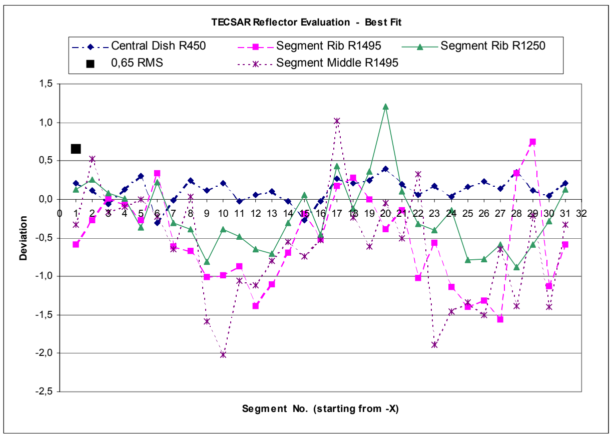


Fig. 14: Target points on each panel

Fig. 14 shows the positions of the target points on each panel (on the left, on the rib, in the panel middle and at the right side of the panel) and along the panel radius. These points are correlated on the bottom part of the diagram with the measured results of a typical panel. One can see that the typical peak to peak deviations on the panel are in the range of 0.6 mm mm, one can also see that the maximum local deflection on the unsupported extreme right panel edge (radius 1500 mm) is at about 0.9 mm.

Fig. 15: Overall Panel by Panel Contour deviation

In Fig. 15 the maximum deviations of each panel (1 to 30) are plotted for some typical points on a large reflector radius (1250 and 1495 mm). The evaluation of all target points of the whole reflector leads to an rms value for the reflector of about 0.65. This value can still be significantly improved by fine tuning of



the reflector panels and for a flight model by panel screening and improvement of the panel adjustment possibility on the hinge axes so that a global rms value of about 0.3 to 0.4 mm is expected.

9. FURTHER VERIFICATION STEPS AND OUTLOOK

At present the Reflector is developed to flight standard. Only minor design adaptations or improvements are still to be included into a flight design (e.g titanium hinge brackets on the central dish instead of Al-brackets, or optimisation of the panel adjustment capability along different DoF for improvement of the integration process). Some items such as the flight standard Launch Locking Actuator have to be selected, other details might be improved on basis of the experience gained during the development phase.

A Vibration test is under preparation. Electrical testing was performed on Material sample level and is still pending for the complete reflector. The same is valid for vacuum testing .

In a further development step, design concepts for central Feed and Offset Configurations in the diameter class of 5 to 6 m are planned to be investigated.

10. LESSONS LEARNT

It was found during the development that the manufacturing process of the thin sheet reflector components is sensitive against changes in material batches and process variations and tolerances. Therefore the material used for manufacturing of the complete reflector has to be procured in one batch and in sufficient quantity in order to allow to produce a sufficient number of additional reflector panels used for selection and performance optimisation purposes.

The Adjustability of deployment axes has to be improved. At present full adjustment capability is provided for each panel about its deployment axis. Only a limited adjustability is provided laterally along the deployment axis and in tilt. This capability has to be improved by modification/optimisation of the deployment mechanism. By this measure a much better global reflector contour can be adjusted than presently possible.

The design of the Deployment Spring torque adjustment allows only to adjust the torque in discrete steps. The zero 0 torque position is different for each panel axis, since the panel axes achieve different rotational positions during panel integration into the central dish. Therefore at present the torque value applied to each deploying panel is not identical and has to be harmonised for a flight configuration. However the effect on the deployment kinematics is quite low due to the concept inherent panel synchronisation during deployment. Only at the end of deployment when the individual panels get independent from each other, the residual torque difference between the panels yields some non-uniformity in the deployment process.

The Damping Unit Detailed Design has to be improved. It was found during deployment testing that the winding process of the damping string onto the reel is critical w.r.t. the deployment function. The string wound from the left and right side simultaneously onto the reel tended to jam on the reel if the winding process was not totally controlled. Therefore the reel was separated into two parts, one taking the string end coming from the left side and one taking the other end coming from the right side to the reel. By this measure both stings are completely separated from each other and a proper winding and unwinding process can be achieved.

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