VERIFICATION TEST FOR ULTRA-LIGHT DEPLOYMENT MECHANISM FOR SECTIONED DEPLOYABLE ANTENNA REFLECTORS

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ABSTRACT

The ultra-light deployment mechanism (UDM) is based on three carbon fibre reinforced plastics (CFRP) curved tape springs made of carbon fibre / cyanate ester prepregs.
In the frame of the activity its space application suitability for the deployment of solid reflector antenna sections was investigated. A projected diameter of the full reflector of 4 m to 7 m and specific mass in the order of magnitude of 2.6 kg/m^2 was focused for requirement derivation.
Extensive verification tests including health checks, environmental and functional tests were carried out with an engineering model to enable representative characterizing of the UDM unit.
This paper presents the design and a technical description of the UDM as well as a summary of achieved development status with respect to test results and possible design improvements.

1. INTRODUCTION

The available launcher fairing dimensions limit the maximum size of solid antenna reflectors, typically below 4 m aperture diameter. In order to increase the usable reflector diameter and to reduce the stowed envelope, a cut of solid antenna reflectors into smaller sections has been proposed [1].
Deployable structures can bring a convenient solution. However, deployment systems bring complexity and risks of mechanism failure or loss of profile stability. The profile stability is particularly critical as the reflector is subject to in-orbit environmental constraints as thermo-elastic deformation.
The architecture of ultra-light reflectors allows cutting the reflector in sections to fold the edges. The development to obtain a stable deployable solid reflector would be limited to light and low shock mechanisms to deploy the wing segments. The configuration depicted in Fig. 1 comprises two side wings, which can be folded on the back of the main reflector.

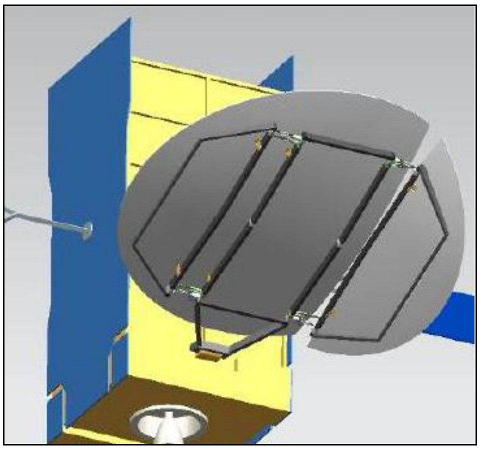

Figure 1. Reflector antenna with sections

In the scope of an ESA ARTES-5 research project HTS GmbH and RUAG Space have developed the UDM, a CFRP based deployment mechanism, representing the next stage following the ULMAAS [2, 3] activity where a hinge design with high stiffness and stability demands was studied and tested.

2. DESIGN AND HARDWARE

2.1. Key Requirements

Some design driving key requirements, such as stiffness, positioning accuracy and temperature range are summarized in the following table [4].

Table 1. Key requirements

Properties	**Unit**	**Required**
Rotational stiffness	Nm/rad	> 4'000
Linear stiffness	N/m	> 10'000
Positioning accuracies Normal to reflector surface Parallel to folding line around folding line	 mm mm °	 ± 0.050 ± 0.100 ± 0.010
Thermal distortion Normal to reflector surface Parallel to folding line around folding line	 mm mm °	 ± 0.050 ± 0.100 ± 0.010
Temperature range	°C	– 150 to + 110
Deployment temperature	°C	0 to + 80
Deployment torque	Nm	> 0.1

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2.2. Hinge Design

Single curved shaped elements which are used as springs are the basis for the ultra light deployment mechanism. They provide the motorisation and the latching function of the mechanism. These elements have been studied in principle behaviour and as deployment unit in [5].
Each UDM unit consist of three tape spring elements; an X-configuration accomplished by a straight connector (see. Fig. 2). The carbon fibre blades are fixed in specifically designed brackets by a gluing/clamping combination. To reduce stress concentrations and allow for large bending angle the brackets are shaped.

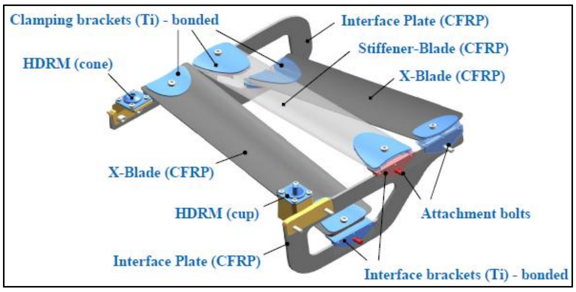

Figure 2. UDM design

Although the tape spring elements are mounted on an interface plate on both ends the load path is led as directly as possible into the structures to be connected. The main function of the interface plate lays in handling and positioning the spring arrangement. A cup/cone interface is accommodated on the interfaces plate as well. This is intended as a hold down and release mechanism (HDRM) point close to the deployment mechanism in order to bear launch loads and minimise vibration amplitudes for the UDM.
The UDM tape springs are made of high tension carbon fibre / high temperature cyanate ester resin prepregs. This combination provides high temperature stability in order to limit relaxation effects leading to loss of deployment motorization and low moisture absorption in order to reduce degradation effects at low temperature (micro cracking). In addition the CFRP design ensures thermo-elastic compatibility to the antenna reflector materials as well as the low weight. Including titanium alloy brackets and mounting hardware the UDM design accounts 0.56 kg per unit

2.3. Configuration on Reflector Hardware

The UDM is foreseen to be integrated on a reinforced antenna reflector backing structure. For the launch and deployment of one reflector wing segment at least two UDM units and three HDRM are necessary. The cup/cone interfaces with Frangibolt® release mechanisms carries the launch loads and enable the in-orbit deployment process of the wing segment. One HDRM is located at each UDM unit, because the bended and therefore flexible CFRP tape springs are not able to bear launch loads. The third HDRM is located in the middle of the backing structure. The deployment of a reflector wing segment will be initiated by releasing the two UDM HDRMs first.

2.4. Engineering Model

After successful breadboard (BB) tests and critical design review followed by manufacturing readiness review two mirror-symmetrical UDM engineering models (EM) with the dimension of about 260 mm x 260 mm x 120 mm were manufactured in combination with required ground support equipment (GSE). The UDM EM unit is a cost-efficient precursor of a UDM FM unit. It has the same geometry. Cost saving material alternatives and fabrication methods are used where main performance is not affected, e.g. steel instead of titanium and partially simplified geometrical shapes for machined parts. As mentioned the basic arrangement consists of a truss frame like grid structure of tape springs, called 'X-Configuration'. Each UDM EM unit consists of CFRP stiffener blade, CFRP X-blade, CFRP interface plate, mounting parts, cup-cone parts and standard parts. To demonstrate the manufacturing quality of the UDM EM units various pre-functional tests, such as stiffness measurement, first folding and cup-cone interconnection were performed before test readiness review.

Figure 3. Front view of one UDM EM

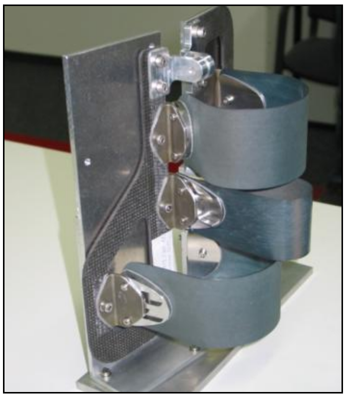

Figure 4. First folding of UDM EM unit

3. VERIFICATION TESTS

3.1. Test Program

After an intensive development phase and manufacturing, the two UDM EM units were subjected to a comprehensive test program. Between main test blocks the integrity and performance of each UDM unit was checked several times (Fig. 5)

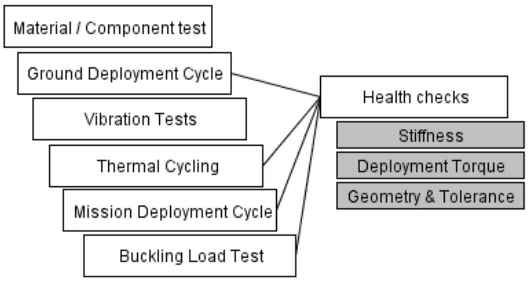

Figure 5. Test program overview

3.2. Ground Deployment Test

Ground deployment tests were performed in a controlled (guided) motion. Main objective was to execute the required number of more than 30 full range deployments and latching cycles at this stage. The hinge was not subjected to loads from buckling or overshooting and acted as expected.
Basis for the tests were developments of a mass dummy for an antenna reflector wing segment and an offloading setup. The assembled test stand is shown in Fig. 6. The wing dummy is suspended adjustable at its CoG with a spring. Rotation of the wing dummy is enabled by a low friction lever on top of the arrangement. The ground deployment tests conducted during this activity provided technical expertise on the dynamic behaviour of the deployment of a wing segment.

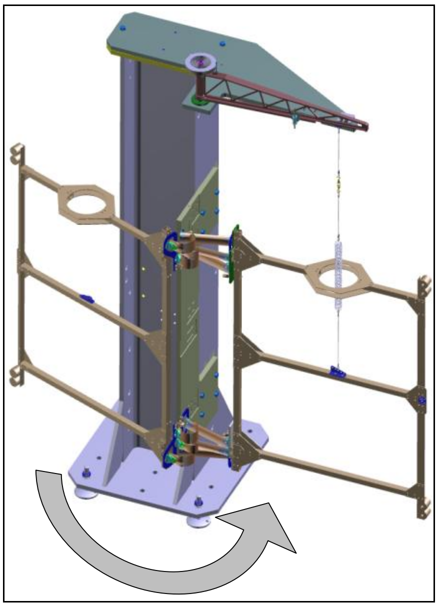

Figure 6. Deployment test stand (start & end position)

3.3. Vibration Test

The UDM integrated on a real antenna reflector wing assembly will be exposed to very small loads related to the mass of the blades. This is true since the main load path for the reflector wing loads is led over the HDRM units. The main interest in conducting the vibration tests is to exclude the possible chafing of the UDM blades at each other which could degrade the UDM assembly during launch.
According to the given requirements the UDM, in stowed configuration with both sides mounted on rigid interfaces, should withstand a sine vibration spectrum in all axes given in Tab. 2. According to the specification the random vibration load cases were not sizing for the UDM. Therefore only the sine vibration test was conducted. Success of the sine vibration tests also demonstrates compliance to the random vibration requirements.

Table 2. Vibration requirements

Axis	**Frequency [Hz]**	**Qualification load**
X, Y, Z	5 – 28.94	22.0 mm (p–p)
	28.94 -70.24	2 m/s system velocity limitation (p-p)
	70.24 - 120	90 g (p-p)
Sweep rate	5 - 120	2 oct / min
		1 sweep-up

Application of sensors on the UDM blades is difficult without modifying significantly the stiffness of the stowed blades and hence the results of the tests. So the sensors used for this test where two triaxial ICP accelerometers, one on top of the UDM mounting jig plate and the other on the upper section at the back side of the rack (see Fig. 7).

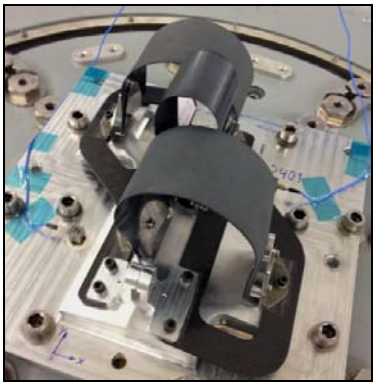

Figure 7. UDM in bent configuration on shaker

Functional and visual checks after test conduction showed no degradation of the UDM units. The highest measured shift of Eigenfrequency was 1.26%, which is below the specified success criterion of maximum 5%. The structural integrity after each high level sine vibration run was checked without finding of negative variations.

3.4. Thermal Test

Thermal cycling is required in order to simulate the degradation effects of the CFRP blades during its lifetime. The major concern is that motorisation decreases due to relaxation effects.

Thermal tests were the follow up step right after vibration test. The temperature range during the eight cycles was -150°C to +110°C. The temperature was measured directly on the CFRP elements which were in 200° bent configuration (see Fig. 8).

The UDM did not show any visible damage after testing. The Degradation of performance was investigated in the continued test sequence.

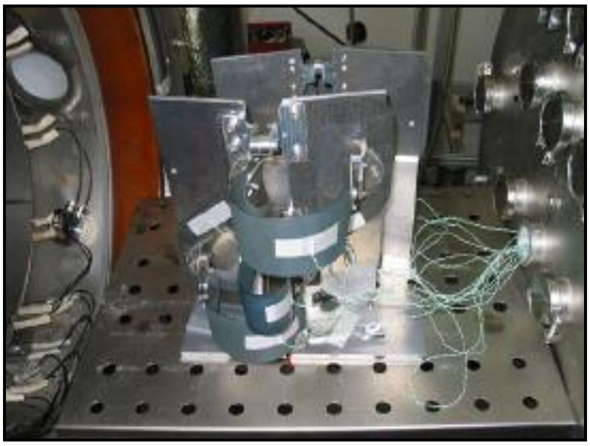

Figure 8. UDM in thermal chamber

3.5. Deployment Torque Measurement

A suitable method for identification of degradation of the UDM structure is the measurement of the torque angle relation. This was done several times for the UDM EM unit as part of the health check activities between test blocks. Measurement was facilitated by a dedicated setup which allows introducing and measuring pure torque (see Fig. 9).

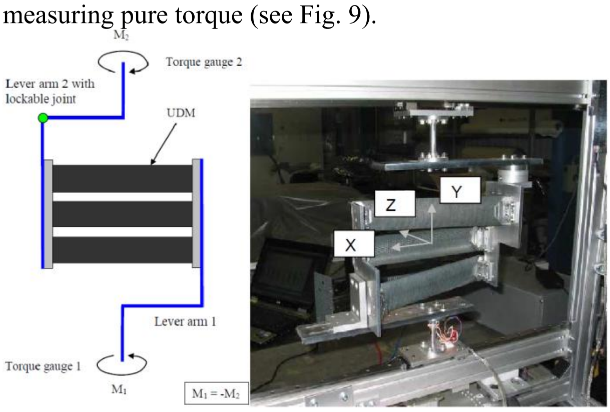

Figure 9. Torque measurement setup

The evaluation of the results showed that no significant changes in motorisation occurred during tests. The graph in Fig. 10 shows a peak of up to 6.5 Nm close to 0° (latching position) and a minimum torque plateau of more than 1.38 Nm. With respect to the UDM torque requirement to provide at minimum 0.1 Nm, both UDM exceed by far the torque needed over the deployment angle. One has to consider that the UDM hinge has no inherent frictional resistances.

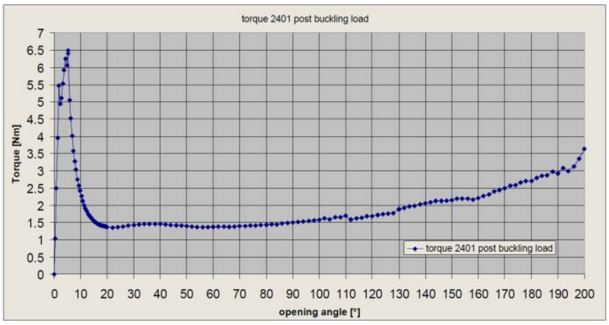

Figure 10. Torque angle relationship of a single UDM

4. RESULTS

All tests were conducted successfully without any damage to the UDM EM units. The test evaluation reveals that the UDM design is currently capable to fulfil all requirements with respect to space environment. On the one hand the survival of extreme environment in stored/bent position without loss of operational reliability was demonstrated. On the other hand launch load requirements, in-orbit accuracy requirements and in-orbit dynamic deployment behaviour were verified.

A summary of general performances achieved within this activity is given in Tab. 3. The comparison shows only one non compliance for the rotational stiffness which is 12.6% too low.

Table 3. General performance

Properties	Required	Actual design
Deployment Torque at each UDM	> 0.1Nm (at any position)	1.38 Nm (lowest measured)
Bending Angle	180° - 200°	200°
Rotational Stiffness (any axis)	≥4'000 Nm/rad	3'497 Nm/rad
Linear Stiffness (any axis)	≥10'000 N/m	229'000 N/m
Temperature Range (survival)	-150°C to +110°C	-163°C to +130°C

A summary of the end position accuracy performance of the UDM EM units is given in the following table.

Table 4. Position accuracy performance

Positioning accuracy	Required	Actual design
Parallel to folding line	+/- 0.1 mm	+/- 0.027 mm
Gap width	+/- 1.0 mm	+/- 0.082 mm
Normal to reflector surface	+/- 0.05 mm	+/- 0.018mm
Rotation around folding line	+/- 0.01°	+/- 0.006°

5. CONCLUSION

The UDM hinge technology based on flexible curved CFRP tape springs for advanced antenna systems comprises adequate motorisation and end stiffness for deploying reflector antenna segments or comparable appendages. The UDM hinge is not intended to carry launch loads while the antenna reflector is in stowed configuration. This is done by the HDRM's. Once the deployment is completed, the UDM shall provide sufficient stiffness to meet the pointing accuracy requirements after deployment and during the lifetime under the operational environment.

The repeatability and accuracy of the UDM hinge is reasonable high. However, application in arrangements with more than one unit has to consider the adequacy of the structures to be connected. Stresses introduced by integration and thermal expansion of the backing structures will influence the overall accuracy and have to be taken into account for the design. To improve the rotational stiffness and prevent the twisting of asymmetrical three blade UDM units, a possible alternative could be to use symmetrical five blade UDM units. The advantage of a symmetrical blade configuration is the elimination of the coupling behaviour between transversal displacement and rotational twisting internally of such an UDM device. With this five blade design the transversal stiffness could be increased up to 240 % and the rotational stiffness up to 400 % compared to three blade UDM design.

The UDM unit was developed as universal device for one-shot deployment of payload in space environment. The test results showed that the stored elastic energy of the CFRP blades has to be reduced during deployment to prevent large overshoot at the end position and possibly resultant damage of deployment unit or payload. Future investigations could focus on a slowdown of the deployment process or a damping device with dissipation of kinetic energy at end of travel (e.g. deformable elements close after latched position, controlled overshooting).

In summary, the UDM show evidence of a very good deployment device with a minimum weight and good end position accuracy and stiffness. Based on the performed tests within this activity it was found, that a damping or deploying movement control device seems to be mandatory.

6. REFERENCES

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