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ARA MK4 SOLAR ARRAY DEVELOPMENT

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ABSTRACT

The ARA (Advanced Rigid Array) Mk4 solar array development program is conducted under an ESA-Artes contract.
In order to enter new markets with recurring potential such as the market for small to medium range Comsats and moreover to remain competitive with its Solar Arrays on existing markets, Airbus DS Netherlands needed to evolve its current product line of ARA Mk3 and FRED to a new generation Solar Array, the ARA Mk4. The main goals of the ARA Mk4 development program are solar array cost and risk reduction, robustness, performance increase and readiness for growth capability.
The requirements for the ARA Mk4 solar array are enveloping the needs for a number of intended applications such as EDRS-C, GMP-T, MetOp-SG and Geostar-3. Furthermore the requirements are based on launch with today's launchers. The EDRS-C program has been the first customer for the ARA Mk4 solar array.
The ARA Mk4 solar array has been divided into a number of units such as PVA, Panel Substrates, Yoke, Holddown and Deployment mechanisms and Inter-Panel Harness. These units are developed and qualified before verification at wing assembly level. Wing level tests, including sine vibration and acoustic noise testing, has been performed successfully.
In addition to hardware development also the analysis tools, integration approach, qualification status control and documentation generation for recurring projects have been upgraded.
The outline of the ARA Mk4 development program, the obtained results and the achieved status with regard to the set goals are presented in this paper.

1. DEVELOPMENT PROGRAM DEFINITION

As a first step an inventory is made for all potential improvements and lessons learned from the previous solar array programs. These improvements have been categorized and trade-offs have been performed to set the goals for the ARA Mk4 development. The potential applications for ARA Mk4 have been used to determine an enveloping key requirements baseline. The potential solar array applications include EDRS-C, GMP-T, MetOp-SG and Geostar-3.
The ARA Mk4 solar array has been divided into a number of units such as PVA (Photo Voltaic Assembly), Panel Substrates, Yoke, Holddown and Release System, Deployment Mechanisms and Interpanel Harness. For production and GSE (Ground Support Equipment) development the maximum panel dimensions are set at 2.5 m by 3.5 m.
The ARA Mk4 solar array range has been set from 2 panel configurations being the low end, and to 5 panel configurations being the high end of the range.
The low and high end configurations have been used to derive the requirements for the individual units. The units have been designed against the so derived unit level requirements.

A breadboard program has enabled establishing the ultimate properties by testing flight representative test samples. The ultimate performance limits have been used to determine the qualification levels. For thermal qualification a robustness margin of 5°C is selected on top of the qualification margin of 10°C and an uncertainty of 10°C to minimize the risk of thermal delta qualification needs in future programs.

2. DEVELOPMENT GOALS

The ARA Mk4 Solar Array development goals are:

Cost reduction of 25%, by:

- Upgrade of solar array subsystem design
- Selection of cost effective materials
- Selection of cost effective processes
- Selection of competitive suppliers
- Thorough manufacturing engineering
- Increased efficiency of Engineering and AIT (Assembly Integration & Test) processes
- Reduction of the throughput time
- Standardization and streamlining of documentation
- Improvement of tools (design & managerial)

Risk reduction of 50%, by:

- Higher margins (thermal, mechanical, electrical), both for the production process and for in-orbit operation

- Double sourcing through suppliers and materials/processes selection (obsolescence risk)
- Increased robustness of production processes

Performance increase:
- Lower mass (target is 6%)
- Higher (local) stiffness (target is an increase of the deployed wing frequency by 5%)
- Adjustable electrical interface for SA (Solar Array) Release Mechanisms

Readiness for growth capability:
- PEF implementation capability
- Implementation of thin film high efficiency solar cell technology

3. UNIT DEVELOPMENT

3.1 Panel substrates

Until ARA Mk4 Airbus DS NL always subcontracted the production of panel substrates Built-to-Print. For ARA Mk4 it has been decided to define besides the dimensions and interface positions, only the design influencing parameters such as facesheet skin ply orientation, carbon fibres, honeycomb core type and height. The selection of all other materials (e.g. resin for the facesheet skin, adhesives) and processes is the responsibility of the supplier. The advantage is that the supplier can determine the most cost effective approach for manufacturing.

Airbus DS NL has selected three suppliers for the ARA Mk4 panel substrates: two European suppliers (Airborne Aerospace and Airbus DS Spain) to have redundant suppliers also for ESA programs and one US supplier (ATK) for US solar array opportunities.

First the general panel substrate baseline has been defined in terms of materials, processes and production sequence. After that breadboard samples have been made to verify the approach, followed by engineering samples (including 1 full size panel by each supplier) and qualification samples. Testing included structural, thermal and electrical tests. The achieved thermal qualification range is -188°C to +162°C.

The unit level tests have demonstrated a significant strength and stiffness improvement for the panel hinge connections.

For the ARA Mk4 qualification wing Airborne Aerospace has provided the panel substrates since Airborne Aerospace is the supplier for the first application program, EDRS-C.

Figure 1. Solar panel substrate.

3.2 Yoke

The yoke connects the solar panels to the spacecraft and ensures that the solar panels are positioned out of the S/C shadow. The yoke design is in general different for every solar array application due to mission requirements and S/C designs. The non-recurring effort to come to a new yoke design has always been quite extensive and the ARA Mk4 goal has been to develop a simple and straightforward approach for project specific yoke designs.

A trade-off on several yoke design concepts including yoke panel, Y-shaped yoke, I-shaped yoke and V-shaped yoke has resulted in the V-shaped yoke as the ARA Mk4 baseline. Main reasons were S/C radiator field of view, yoke mass and yoke stiffness.

The ARA Mk4 V-shaped yoke design comprises an ARA Mk4 root hinge with a standard interface to a root bracket creating the required V-angle, square CFRP (Carbon Fibre Reinforced Plastic) yoke tubes, tip brackets and a flexprint panel. The flexprint panel is a CFRP sandwich panel, based on the panel substrate technology above and serves to collect the electrical harness from the solar panels and to route this harness towards the yoke tubes.

For a project specific yoke design only the yoke tube length and the bracket angles need to be adapted. The root - and tip brackets are made of Titanium using ALM (Additive Layer Manufacturing); this manufacturing method enables a quick and low cost switch for project specific parts.

Yoke samples have been tested to verify the structural and thermal properties of the bracket to tube and bracket to flexprint panel connections. At yoke level proofloading, stiffness measurements and thermal vacuum cycling tests have been performed.

The achieved yoke deployed out-of-plane stiffness is 8380 Nm/rad which is a factor of 1.5 above the previous

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ARA design. The achieved thermal qualification range is -100°C to +120°C.

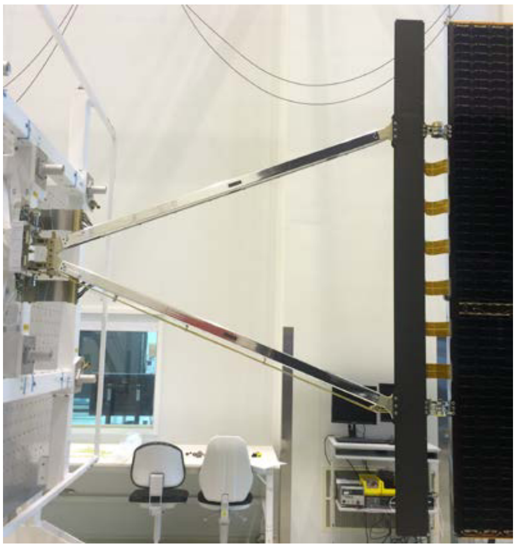

Figure 2. Yoke Assembly.

3.3 Hold Down and Release Mechanism

In a parallel program a multi-functional holddown and release mechanism called NELS (Non Explosive Low Shock) is under development. This NELS concept is compatible with the ARA Mk4 solar array design.

The NELS holddown and release system will provide an increased pretension capability for ARA Mk4 solar arrays of 15 kN which is more than a factor 2 higher than for the previous ARA design, while the release shock has been reduced to a level below 10g.

Another improvement of the NELS holddown and release system is that the operational voltage for the release mechanism can be tuned within a range of 20-50V to one of the available interface voltages of the S/C.

The details of the NELS holddown and release mechanism have been presented in [1].

Figure 3. NELS HDRS.

3.4 Deployment Mechanisms

The deployment mechanisms for ARA Mk4 solar arrays include a root hinge, panel hinges, a partial deployment mechanism, a deployment damper and the synchronisation system. Several improvements have been implemented for the deployment mechanisms, the most important ones are listed below.

The electrical wiring transfer at the root hinge has been changed into a flat cable loom design. This concept enables a simple and effective design that complies to the latest ECSS derating requirements. The root hinge has a standard interface to the yoke structure; the root hinge design can be used for the complete ARA Mk4 range.

The latch and stop-bolt configuration of the panel hinge has been optimised, which results in an improved deployed stiffness and a higher strength allowable compared to the previous ARA baseline.

A new partial deployment mechanism concept has been introduced that allows partial deployment of the outer panel also for 2 panel wings such as EDRS-C. The partial deployment mechanism is derived from the Eurostar 3000 partial deployment mechanism design [2] with ARA Mk4 interface adaptations.

Figure 4. Partial Deployment Hinge.

Furthermore, the assembly, integration and test aspects have been improved for the deployment mechanisms which have resulted in shorter integration and test durations and less non-conformances.

3.5 Interpanel Harness

The ARA Mk4 interpanel harness design uses flexprint assemblies with 12 tracks of flat copper with a derating equivalent for AWG20 wires. The flat copper tracks are laminated in between 2 Kapton® foils with a thickness of 25 micron. The connection to the panel level power and signal harness wires is done inside a PES (Poly Ether Sulfone) connector that is mounted on the edge of the solar panel.

Compared to the old ARA baseline, double insulation

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has been implemented to increase the robustness against ESD (Electro Static Discharge) type phenomena in orbit. Furthermore, the supply chain and production aspects have been improved.

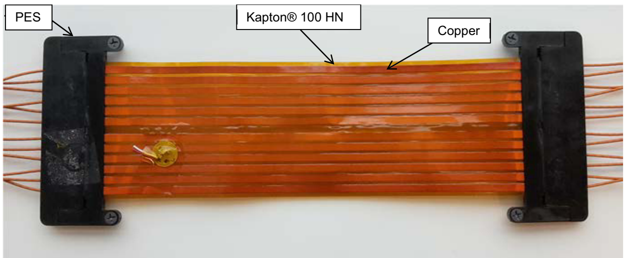

Figure 5. Flexprint Assembly.

3.6 PVA

The objective has been to demonstrate compatibility of the ARA Mk4 panel substrate design with state-of-the-art PVA. For this purpose a number of DVT (Design Verification Test) coupons have been made. The following PVA/solar cell technologies have been tested:

- AZUR 3G30C advanced with integral diode (8x4 cm^2) and 100 micron coverglass CMX 100 AR applied by Airbus DS Ottobrunn
- AZUR 3G30C advanced with integral diode (6x12 cm^2) and 100 micron coverglass CMX 100 AR applied by Airbus DS Ottobrunn
- XTJ (triple junction GaAs 73.52cm^2 net cell area) with an P3 external shunt diode and 100 micron coverglass CMG 100 AR applied by Spectrolab
- ZTJ (triple junction GaAs) 85x85mm^2 (65cm^2 net cell area) with an external shunt diode and 100 micron coverglass CMX 100 AR applied by SolAero

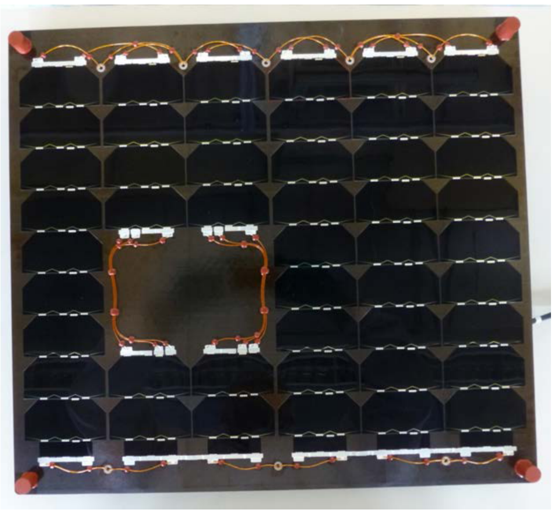

Figure 6. 3G30C 8x4 DVT coupon.

4. WING LEVEL VERIFICATION

After successful unit level development completion, a qualification wing has been built and tested to verify the wing level performance.

The ARA Mk4 qualification wing design is identical to the EDRS-C flight solar array and consists of a yoke plus 2 panels and has partial deployment capability for the outboard solar panel.

The wing level analyses included structural analysis with NASTRAN, ACTRAN for fatigue analysis, ADAMS for deployment analysis, ESATAN for thermal analysis and the Airbus DS Ottobrunn in-house electrical power calculation tool.

The wing level performance tests included wing mass, thermal knife released deployment (partial and full), alignment, stiffness, ELM for solar cell inspection (Electro Luminescence Method) and electrical power measurements. These tests have been performed at the Airbus DS Leiden facilities. The deployed wing stiffness test confirmed the unit level achieved stiffness improvements; the ARA Mk4 QM wing deployed frequency is 0.35 Hz.

At IABG Munich the stowed wing has been subjected to a 3-axis sine vibration test and an acoustic noise test. With a minimum out-of-plane notch of 3.7g the ARA Mk4 target of >2g has been met with ample margin. The acoustic noise spectrum envelopes the levels of Ariane 5 and Falcon 9.

The wing finite element model (FEM) has been correlated with the results of the sine vibration test. The correlated FEM provides a sound basis for structural analysis on follow-on ARA Mk4 solar array applications.

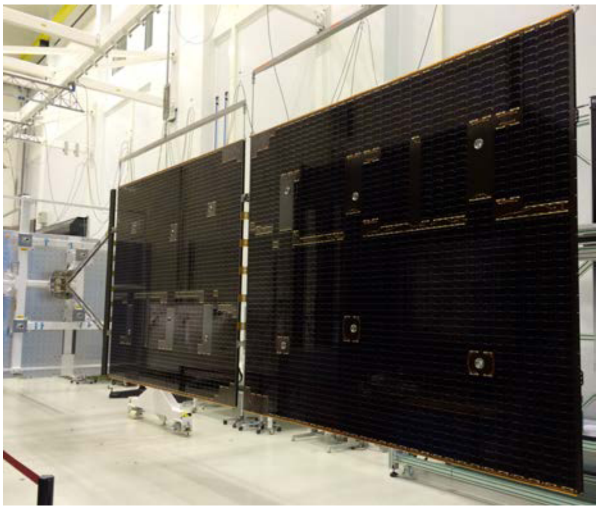

Figure 7. ARA Mk4 QM wing.

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5. REALIZED GOALS

During the course of the ARA Mk4 development program the status with regard to the set goals has been monitored as key performance indicators. In the figures below the evolution during the program is shown.

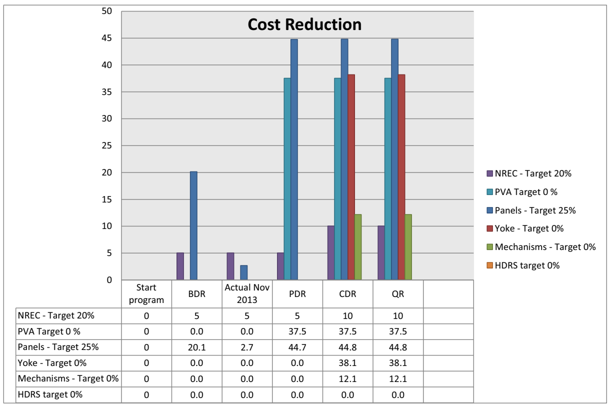

Figure 8. Cost Reduction (goal overall 25%).

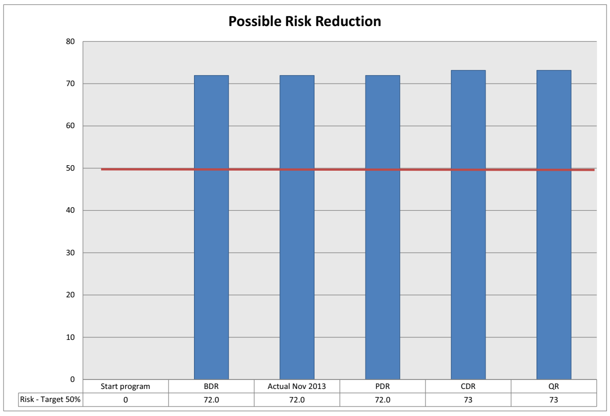

Figure 9. Risk Reduction (goal 50%).

Figure 10. Mass Reduction (goal 6%).

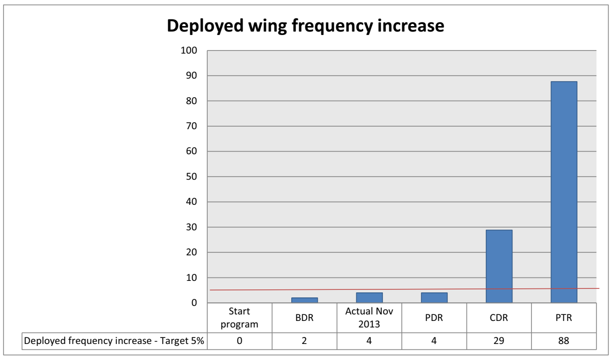

Figure 11. Deployed Wing Frequency Increase (goal 5%).

The figures above show that all development goals have been met with the exception of the mass reduction goal. Several mass reduction options were identified (e.g. thin ply CFRP for the panel substrates) but the majority resulted in increased cost or increased risks. In these cases it has been decided to not introduce the mass reduction option. For the Partial Deployment Mechanism a significant mass reduction of about 300 grams per wing has been realized.

6. NEW ARA MK4 APPLICATIONS

The successful completion of the ARA Mk4 development program has put Airbus DS Netherlands in the position to offer competitive solar array proposals.

After the EDRS-C first application the new ARA Mk4 solar array applications are:

- Exomars
- MetOp-SG
- Quantum
- JUICE

The Exomars, MetOp-SG and JUICE programs have a large number of special solar array features such as for instance increased honeycomb core height for Exomars, skewed solar array deployment angels for MetOp-SG and lateral deployable panels plus a very wide temperature range for JUICE. These features will further extend the ARA Mk4 range.

7. REFERENCES

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