BI-AXIAL SOLAR ARRAY DRIVE MECHANISM: DESIGN, BUILD AND ENVIRONMENTAL TESTING

Nigel Phillips [(1)], Mark Ferris [(2)], Noemy Scheidegger [(3)]

[(1)] *Surrey Satellite Technology Ltd, Tycho House, 20 Stephenson Road, Surrey Research Park, Guildford, GU2 7YE, UK, Email:N.Phillips@sstl.co.uk*

[(2)] *Surrey Satellite Technology Ltd, Tycho House, 20 Stephenson Road, Surrey Research Park, Guildford, GU2 7YE, UK, Email: M.Ferris@sstl.co.uk*

[(3)] *Surrey Satellite Technology Ltd, Tycho House, 20 Stephenson Road, Surrey Research Park, Guildford, GU2 7YE, UK,*

ABSTRACT

The development of the Bi-Axial Solar Array Drive Mechanism (BSADM) presented in this paper is a demonstration of SSTL's innovation and pragmatic approach to spacecraft systems engineering and rapid development duration. The BSADM (Fig. 1) is designed to orient a solar array wing towards the sun, using its first rotation axis to track the sun, and its second rotation axis to compensate for the satellite orbit and attitude changes needed for a successful payload operation. The BSADM design approach – based on the use of heritage components where possible and focusing resource on key design requirements – led to the rapid design, manufacture and test of the new mechanism with a qualification model (flight representative proof mechanism), followed by the manufacture and test of a number of flight model BSADMs, all completed and delivered within 18 months to service the need of current and future SSTL missions. A job not only well done, but done efficiently – the SSTL way.

Figure 1. Two BSADM Modules

INTRODUCTION

Surrey Satellite Technology Ltd (SSTL) is a key supplier of small satellites based near London (United Kingdom) providing complete in-house design, manufacture, launch and operation of small satellites. The use of successful proven (heritage) designs, commercial off-the-shelf technology, combined with a common sense and pragmatic approach to manufacture and low cost operations enable SSTL to ensure that program economics are kept as low as realistically possible.

The first step for any new development at SSTL is to perform a make-buy trade to review what is available within SSTL and externally within the market place. The make-buy trade considers the prominent issues: such as development costs; recurring costs and technical compliance to requirements specification; but also includes schedule, technical and programmatic risks assessments too. This trade identified that there was no product on the market or able to be developed externally that could compete with an SSTL developed product for the mix of technical and programmatic criteria. Once SSTL had committed to develop the BSADM itself, is then to identify modules and components that we have already developed, and which have earned invaluable heritage in-orbit on our previous missions.

The SSTL development approach focuses on the experience gained from previous missions. Extensive portions of new projects are evolved from flight-proven design, enabling SSTL to provide custom-designed solutions with high confidence founded on in-orbit performance. Satellite capabilities improve in line with technology developments, allowing the SSTL satellites to fulfill ever-challenging mission objectives. SSTL has an experienced mechanisms skillset; proven by the mechanisms successfully operating in orbit including reaction wheels (with both dry- and wet-lubrication), Antenna Pointing Mechanisms (APM), imager focusing mechanisms, solar array hold down and release systems (including hinges) and a variety of optical scanning

Proc. '16th European Space Mechanisms and Tribology Symposium 2015', Bilbao, Spain, 23–25 September 2015 (ESA SP-737, September 2015)

mechanisms. SSTL has now extended its mechanism's product range and developed a Bi-Axial Solar Array Drive Mechanism (BSADM) for advanced Low Earth Orbit (LEO) missions.

HERITAGE

The first solar array drive mechanism engineering model developed by SSTL - the SADM-Twist (Fig. 3)- is based on the APM's azimuth axis (Fig. 2), and mainly consists of a stepper motor with integrated planetary gearbox driving a spur gear transmission assembly to rotate the central shaft which is supported by a duplex bearing. Magnetic encoders are used for position feedback. Like the APM, the SADM-Twist has a flexible printed circuit board (flexi-PCB) which is coiled up inside the large diameter bearings and allows transmitting power and telemetry across the rotation axis. The APM's baseline flexi-PCB was scaled up for the SADM-Twist, to include 20 power lines (rated at 1.5A), 6 signal lines (rated at 0.5A) and 5 sections. This allowed the SADM-Twist to transfer 300W from its rotating part to its stationary part. While the flexi-PCB provides a cost-effective solution, it does have limited rotation range and power handling capabilities – the latter influenced by track sizing and associated stiffness/bending effects over life. SSTL qualified the low-power SADM-Twist over a 350° movement range to 88,000 cycles, at which point the flexi-PCB tracks started to degrade. Whilst this proven life was far superior to the requirement of 36,000 orbit cycles, it did highlight a limitation to the power-transfer capability of the flexi-PCB technology.

Figure 2. APM

Figure 3. SADM-Twist

The higher power requirement for the new SADM development and the need for continual rotation forced the replacement of the flexi-PCB with a more conventional slip-ring. In addition to that, the SADM had to be equipped with a second rotation axis to cope with regular satellite orbit and attitude changes. These considerations were the main drivers for the enhancement of the SADM-Twist design leading to the Bi-Axial Solar Array Drive Mechanism (BSADM) development presented in this paper. The modular nature of SSTL's mechanisms allowed using qualified components for most of the BSADM design to retain heritage and reduce risk:

- The track / trim axis bearings are from the same family as the APMs bearings (the trim bearings also being used on a reaction wheel product type)
- The track / trim axis stepper motor and gearbox are from the same family as used within the APMs and the Imager Focus Mechanisms
- The spur gear transmission is based on the design used within the APMs and the Imager Focus Mechanisms
- The BSADM is commanded by a Bi-Axial Solar Array Drive Electronics (BSADE), which is based on the APM drive electronics.

REQUIREMENTS

The BSADM key requirements are detailed in Tab. 1. The BSADM has furthermore to provide full internal electrical redundancy, position feedback and the capability to sustain a solar array deployment moment of 50 Nm. In addition, the BSADM had to be modular in design such that the tracking axis can exist as an entity in its own right (without trim axis) for use as a conventional tracking SADM.

Table 1. BSADA Requirements Specification

Parameter	**Track Axis**	**Trim Axis**
Motion Range	Unlimited continuous rotation	±60°
Rotation Speed	< 2°/s	< 2°/s
Position Accuracy	Absolute: ±3° Relative: < 0.01°	Absolute: ±3° Relative: < 0.01°
In-Orbit Duty	30,800 revs (360°)	675 sweeps of ±60°
Qualification Cycles	64,000 revs (360°)	3160 sweeps of ±60°
Physical Properties	**BSADM**	
BSADM Mass	<6kg	
Volume	Diameter 150 x 150mm	
Power/Signal Transfer		
Number of Circuits	60 @ 1.6A max	
Voltage	Nom. 32 V	
Operation Characteristics		
Mission Life	5.5 years	
Temperature Range	Operational: -30 to +60°C Non-Operational: -40 to +80°C	

DESIGN

The Bi-Axial Solar Array Drive Mechanism includes two rotation axis assemblies as illustrated in Fig. 4: The lower axis (“Track”) assembly consists of a traditional SADM and is responsible for continual tracking of the sun. The upper axis (“Trim”) is responsible for the array trimming to compensate the satellite orbit and attitude changes needed for a correct payload operation. Both rotation axis assemblies are characterized by:

- A stepper motor generating the torque needed for the axis rotation
- A planetary gear box and a spur gear which transmit and amplify the motor torque
- Angular contact bearings to support the rotation axis, lubricated with Maplub pf101A
- A redundant potentiometer which generates an analogue signal between 0V to 5V, proportional to the absolute angular position of the rotation axis.

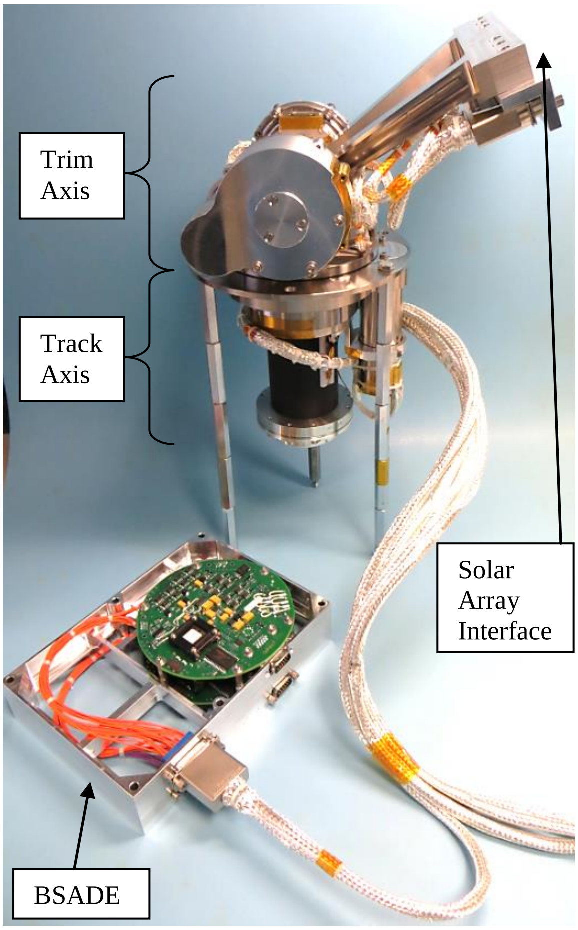


Figure 4. BSADA (BSADM and BSADE)

The drive electronics shown in Fig. 4 are from the APM housed in a standard module tray vastly reducing the cost of non-recurring engineering. In addition to these ‘standard’ mechanism features, there are some particularities in the BSADM design as presented hereafter.

Fig. 5 demonstrates the BSADM design’s modularity: the bottom (track) axis can exist independently from the top (trim) axis, and thus a more conventional Sun-tracking only mechanism is formed.

Figure 5. BSADM Track Axis Modularity

Angular Range Lock

During launch, the solar array will be folded and the BSADM hinge oriented perpendicular to the satellite surface panel as shown in Fig. 6. Once the solar array has been deployed, the hinge will be rotated towards its nominal operation range which is between +60°/-70°. An angular range lock has been implemented on the hinge rotation axis to prevent the hinge (and the solar array) to exceed this operation range. This is particularly important as the solar array might collide with other satellite instruments if the track axis was rotated while the hinge is positioned outside this range.

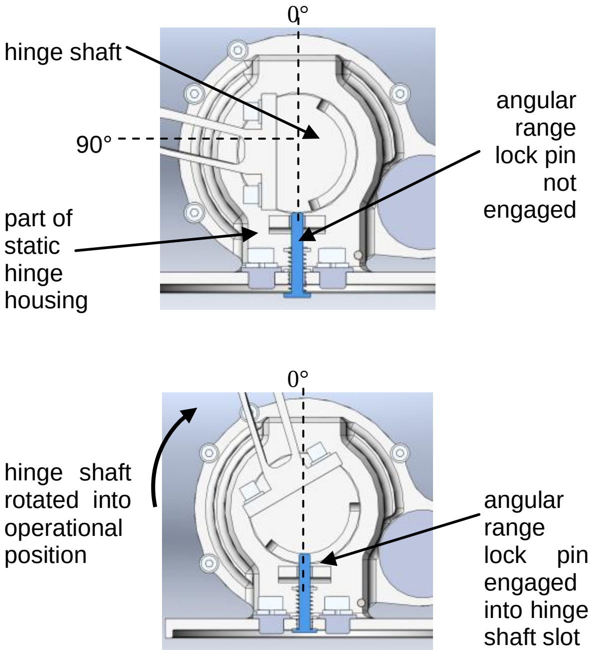


Figure 6. Angular Range Lock

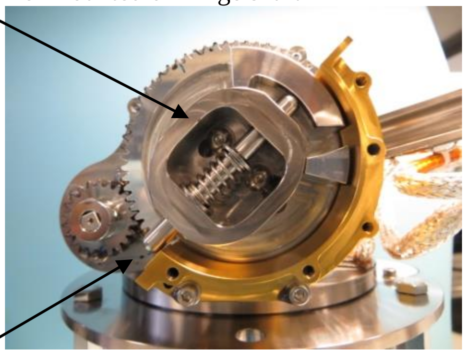
Deployment Lock

Under conventional circumstances, without damping, the solar array wing used for the SSTL satellite would bounce back after deployment, and come to a rest at an unknown position. A back-driving torque of 50Nm is needed during the deployment to reasonably limit this solar array wing back-bouncing. In order to accommodate this requirement within a compact and lightweight product, an additional locking mechanism has been incorporated into the hinge assembly. The solar array deployment lock operation method is illustrated in Fig. 7 and includes the following operation steps:

a. During the solar array deployment, the hinge rotation is blocked through a pin which is in contact with an end-stop on the hinge static housing. The translational displacement of this pin is prevented through an add-on feature of the gear, which forces the pin to remain in its position. The pin-carrier is mounted to the hinge shaft, onto which the solar array bracket is also attached. The rotation of the solar array is thus prohibited, and the required high back-driving torque resistance is provided through this locked pin.
b. Once the solar array has been deployed and settled, the hinge motor is actuated and the gear begins to rotate. Since at this point the hinge shaft and the gear are still disengaged, the gear rotates, whilst the pin's position remains static until it reaches the gear opening allowing the pin to push through.
c. The pin pushes through into a cavity in the gear add-on feature, forming thus a rigid connection between the gear and the hinge shaft (on which the solar array is attached). The hinge drive is now engaged; the rotation of the gear is transmitted through the pin to the shaft and the solar array. Nominal operation can be started.

a. Hinge Locked

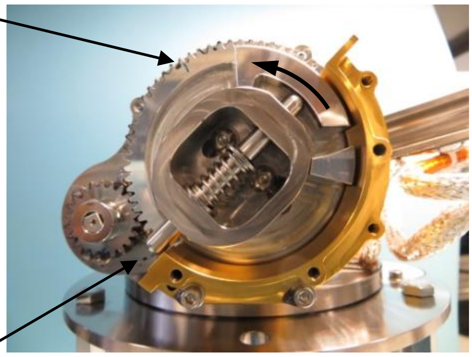
pin-carrier mounted on hinge shaft



pin against stop on static housing

b. Unlocking Operations

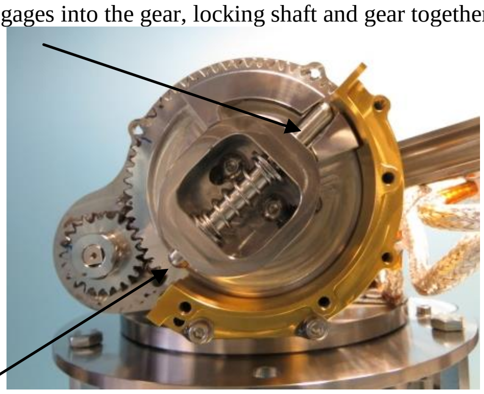
gear rotates



pin constrained against housing

c. Drive Engaged

pin engages into the gear, locking shaft and gear together



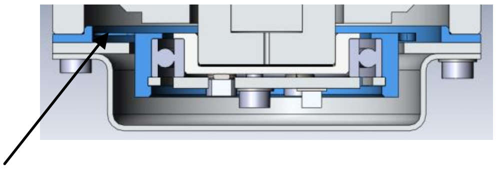
pin is no longer constrained by housing, hinge shaft is free to rotate

Figure 7. Deployment Lock

Thrust Axis Rear Bearing and Membrane

The track axis shaft is mainly supported by its front duplex bearing. These bearings will take most of the axial and radial loads during launch. An additional single row bearing has been implemented at the rear end of the slip ring to further restrict radial displacements and guarantee that the shaft (especially the slip ring shaft) remains properly aligned with respect to its stationary counterpart.

The rear bearing is supported by a flexible membrane which allows translation along the rotation axis. This membrane compensates thus for shaft elongation/retractions due to temperature gradients between the shaft and the housing, and hence prevents significant variations of the bearing load, as per Fig. 8.



Bearing membrane allowing for axial translation of rear bearing

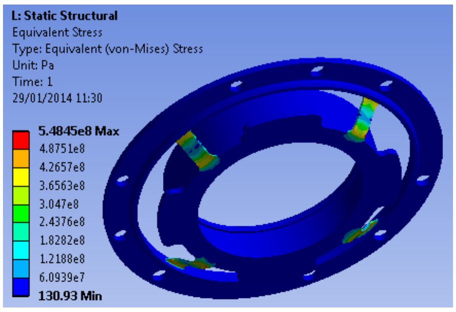


Figure 8. Track Axis Rear Bearing Membrane

Slip Ring

The slip ring allows the transmission of power and electrical signals from the stationary to rotating structure of the track axis. Its core consists of 60 current transfer rings made from gold plated brass, each of them having the capability to transfer 1.6A. The moulding of the rings within a space qualified epoxy provides a very high electrical insulation between the tracks. The counter parts for these rings are gold brushes, wiping over the gold rings and thus providing electrical connection between the rotating and the stationary part of the track axis. Due to the criticality of the gold-on-gold contact between the brushes and the gold rings, the slip ring was bought-in in order to benefit from existing heritage of such a sophisticated element and experience gained on a previous SSTL mission (Fig. 15). The slip ring will none the less be completely re-qualified within the BSADM as its performance significantly depend on the method how it's supported.

VERIFICATION

The BSADM qualification test campaign aims at proving the mechanism design's performances during a mechanisms life (ground, launch, in-orbit), by conducting extensive testing on a flight-representative Qualification Model (QM). It includes

- A bench test to characterize both rotation axis and to verify the mechanism's functional performances prior to its submission to mechanical and thermal loading
- Vibration tests to demonstrate that the mechanism is able to sustain launch loads
- Post-vibration tests to prove that the mechanism performance has not deteriorated from vibration alone
- A deployment test to show that the deployment torque generated by the solar array wring will not damage the mechanism (and in particular the deployment lock pin)
- A thermal test to verify the mechanism's robustness to temperature changes and its capability to provide the required performance over the whole operational temperature range
- A life test performed with temperature changes in vacuum, to prove that the targeted mechanism performances are provided during the whole orbital lifetime
- Post-life tests to prove that the initial functional performance characteristics of the mechanism have not deteriorated through the envisaged life.

Functional tests are performed regularly throughout the entire qualification test campaign to closely analyze and monitor the evolution of the mechanism's performances under the various circumstances/operation scenarios.

Bench Test

The bench test focuses on the verification of the BSADM key functions, consisting of the measurement of the operation accuracy (relative & absolute angular position accuracy), the torque margin and the deployment lock release capability.

Vibration Test

The vibration tests are started with a resonance search (low-level sine sweep) followed by a high-level sine vibration conducted to confirm the structural integrity of the BSADM. An intermediate level random vibration test is then performed at -6dB to assess the mechanisms responses before it is finally submitted to the full-level random vibrations that simulate flight-launch representative loading. The random vibration spectrum is unique for each test axis. Fig. 9 shows the Z-Axis test setup and Fig. 10 shows the test full levels and the mechanism's response as example. The resonance searches done before and after the high-level sine and the full-level random vibration did not show significant Eigenfrequency changes, especially for the critical mechanism elements. The visual inspection and the performance tests done after the vibration tests did not reveal any damages neither and reinforce the confidence that the mechanism is able to sustain the predicted launch loads.

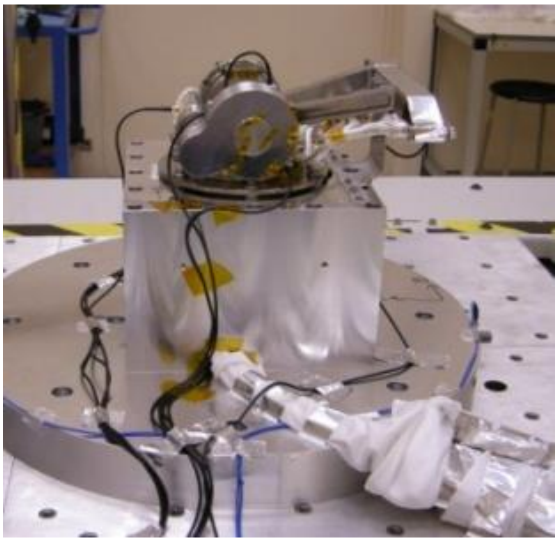


Figure 9. BSADM Vibration Test Setup

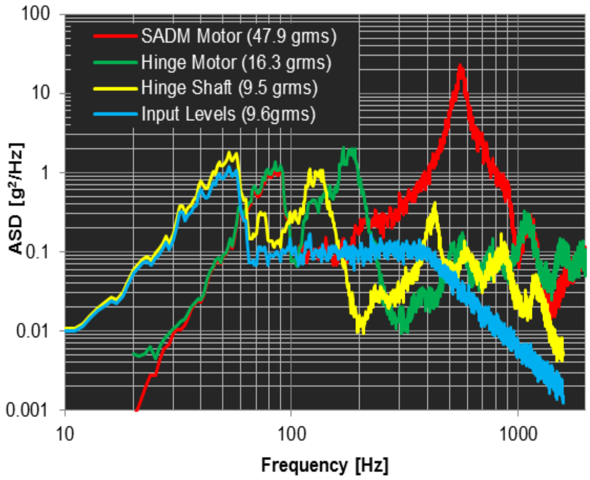


Figure 10. BSADM Z-Random Vibration Response

Deployment Test

A static torque of 60Nm is applied on the solar array bracket to demonstrate that the deployment lock pin will not be damaged through the loads generated by the solar array deployment. A smooth and controlled release of the deployment lock after this test confirms that the deployment lock pin is robust enough to sustain the solar array deployment torque.

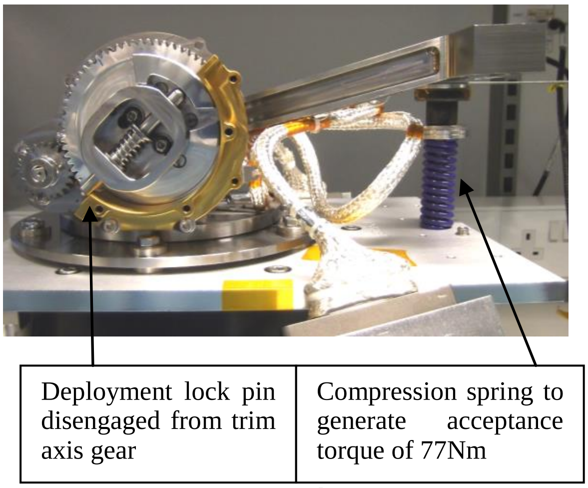


Figure 11. BSADM Deployment Test Setup

Thermal and Thermal Vacuum Life Test

The BSADM is submitted to 4 cycles between +50°C and -20°C during the thermal tests, and to 12 additional cycles in vacuum between +80°C and -30°C during the thermal-vacuum (TVAC) life test. The first cycle of each test sequence is used to verify the structural integrity of the mechanism under thermal loading. A mechanism start-up and functional tests are then done at hot and cold temperature during the second cycle. During the remaining thermal cycles, the mechanism track axis is continuously rotated, while the trim axis performs sweeps of ±60°. The BSADM performs 64000 continuous rotations of 360° with its track axis and 3160 sweeps of ±60° with its trim axis in overall, and will therefore be qualified as per ECSS for the targeted in-orbit life.

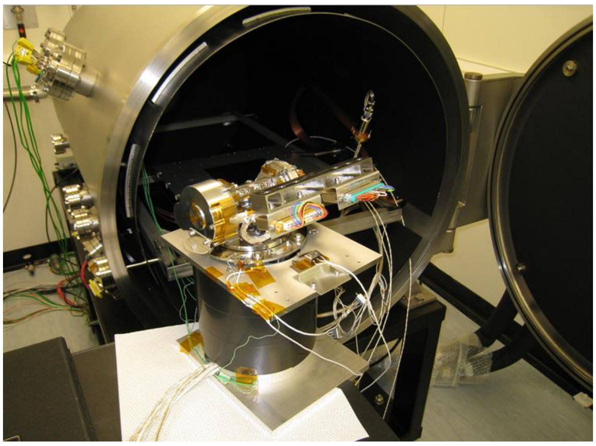


Figure 12. BSADM TVAC Test Setup

FLIGHT MODEL MANUFACTURE

Following successful completion of the qualification campaign on the QM BSADM, then a number of Flight Model (FM) BSADMs were committed to manufacture. In fact, due to the pragmatic engineering approach and use of heritage components, meant that the majority of FM components had been procured in parallel to the QM test campaign, rather than consecutive. This meant that the mission schedule could be achieved in terms of BSADM delivery for spacecraft integration.

Each of the BSADMs underwent extensive module level testing prior to spacecraft integration. Rather than functional performance testing alone, the BSADM modules had to go through acceptance vibration and thermal vacuum environmental testing (EVT). Traditionally at SSTL, modules would experience ambient pressure functional tests at module level, followed by EVT tests as part of the spacecraft testing. However, for the BSADM a multi-array wing is fitted at spacecraft testing which relies on a gravity offload jig, and thus rotational movement of the BSADM with the array fitted is not possible on the ground. Instead the EVT campaign was performed at module level prior to spacecraft integration.

CONCLUSIONS

The BSADM design approach – based on the use of heritage components where possible and focussing resource on key design requirements – led to the rapid design, manufacture and test of the new mechanism with a qualification model (flight representative proof mechanism), followed by the manufacture and test of a number of flight model BSADMs, all completed and delivered to the spacecraft within 18 months. A job not only well done, but done efficiently – the SSTL way.

REFERENCES

1. Scheidegger, N.; Ferris,M. & Phillips,N. (2014). Bi-Axial Solar Array Drive Mechanism: Design Build and Environmental Testing, AMS 2014