A DEPLOYMENT MECHANISM FOR THE DOUBLE ROLL-OUT FLEXIBLE SOLAR ARRAY ON THE SPACE TELESCOPE

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ABSTRACT

British Aerospace (BAe), as prime contractor to the European Space Agency (ESA), has developed a Roll-Out Flexible Array which provides more than 4 kW of power for the NASA/ESA Space Telescope (ST). The Array is configured as two wings. The Deployment Mechanism for each wing is based on the flight-proven Hughes Aircraft Company (HAC) FRUSA design. However, modifications have been incorporated to accommodate an increase in size and the ST mission requirements. The assembly and operation of the Deployment Mechanism are described together with environmental and functional tests results.

INTRODUCTION

A double roll-out configuration met all the ESA requirements for the proposed mission. Reliability, cost and flight-proven history were critical factors in the choice of the baseline design. The HAC FRUSA design had completed design, development and test phases and successfully flown on the STP 71/72 mission (Reference 1). It was therefore advantageous to supplement existing European technology with this experience, through a consultancy agreement with HAC, and base the BAe design on this proven mechanism.

An overall view of the ST is illustrated (Figure 1). One Secondary Deployment Mechanism (SDM), which incorporates all those elements for the support, deployment and retraction of two solar cell blankets, is required for each wing.

The SDM with partially deployed solar cell blankets is shown (Figure 2). The two blankets are rolled onto a single Storage Drum with an interleaf of embossed KAPTON film cushion to protect the solar cells (Section BB, Figure 3). The outer edge of each blanket is attached to a Spreader Bar which is connected to and between two BI-STEM booms. As the booms are deployed the blankets are pulled from the Stowage Drum via the Spreader Bar. The cushion rolls onto the spring-driven Cushion Roller and Spring Motors act against drum rotation to ensure tension in each blanket.

REQUIREMENT

Apart from an increase in size (x 1.2 on deployed length and x 1.4 on width) additions and modifications have been incorporated into the FRUSA design to comply with the following major ST mission requirements.

- **5 years' operational life before replacement of components**
- 5 launch/return cycles with only minor refurbishment possible between launches

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- Exposure to 27250 eclipse thermal cycles (-70°C to +70°C)
- The STS (Space Shuttle) launch environment
- Pyrotechnic actuators were prohibited.
- The overall design had to be astronaut compatible (Reference 2).
- Provision of an astronaut over-ride mechanism for manual deployment/retraction
- Redundancy of all critical components. Where this was not possible, analysis and tests had to be carried out for loads and durations much greater than expected to ensure compliance with the reliability requirements.

DESIGN DESCRIPTION

The Stowage Drum is a one-piece aluminium alloy (Al.Al) tube (203.2-mm O/D, 2-mm wall). It rotates about the static central tube via duplex bearing units in each titanium alloy (Ti.Al) end support (Figure 3). The inner race of the inboard bearing pair is locked to the central tube's Ti.Al seat but the outboard bearing is free to slide axially to accommodate differential expansion between drum and tube. The outboard bearing seat is hard anodised Al.Al coated with a resin-bonded MoS_2. The thin section bearings which are ABEC7 and 440C stainless steel (St.St) have ion-plated lead on the races and a lead bronze cage. They are mounted face to face under a spring pre-load of 22.25 to 40.00 N. The free rotation of the stowage drum is essential for the successful operation of the SDM. To ensure that axial bearing overload does not occur if the sliding interface seizes, the outboard bearing unit is also housed in a diaphragm mount. This diaphragm is 0.5 mm thick with an axial stiffness of 200 N/mm. It is manufactured from a Ti.Al forging with radial gain flow to reduce the possibility of circumferential cracking when deflected. The electrical interface with each blanket is through soldered connections at the drum surface and the mechanical interface is a glass-fibre-reinforced KAPTON strip bonded to the drum with epoxy adhesive. The drum also contains flat flexible harnesses which provide the electrical interface between the rotating drum and static control tube. These harnesses are 1524 mm long and manufactured from a base laminate of 0.068-mm (2-oz) rolled copper foil on 0.051-mm (2-mil) KAPTON film with an overcoat of 0.051-mm KAPTON film bonded with an acrylic adhesive. Each power harness is 311 mm wide and has 20 7A-rated conductors. The data harnesses are 155 mm wide, each with 30 conductors. These harnesses (Figure 3) unwind as a spiral for half the solar blanket's deployed length and then rewind to the completion of deployment to attain a similar wound configuration in the fully deployed state as in the blankets-stowed condition.

Deployed blanket tension (22.25 N) is provided by redundant constant torque springs (Figure 3). The spring storage pulleys are attached to the inboard support brackets which also incorporate an SDM lifting point and a Grapple Fixture interface to enable possible use of the Orbiter's Remote Manipulator System (RMS). The springs are St.St coated with bonded MoS_2. The carbon-fibre-reinforced plastic (CFRP) cushion roller is also driven by constant torque springs which impart a cushion tension of 5.5 N. The cushion roller has St.St. end fittings which rotate in bearing units which comprise a spherical bearing with two small flanged ball bearings fitted into its inner diameter. This arrangement accommodates misalignment, provides redundancy and off-loads the small low friction bearings during launch.

The Boom Actuator comprises two cassette assemblies. Each assembly contains two deployable and retractable BI-STEM Booms (23-mm O/D, 5.85 m long). The cassette assemblies are dry-lubricated, gears are lubricated by a bonded solid lubricant, and the boom element guides are a polymide/MoS_2 composite. The power unit in each two-boom cassette assembly is a size 13PM DC-brushed motor driving through a three-stage epicyclic gearhead (113:1). The gearhead is lubricated with BRAYCOTE 3L-38-RP grease, and the phenolic retainers of the output shaft bearings are vacuum impregnated with BRAYCO 815Z oil. An external molecular seal surrounds the output shaft, and a lip seal is fitted at the motor/gearhead interface to protect the dry-lubricated motor. The spring-loaded radial composite brushes run on a 7-bar commutator of zirconium copper with mica insulators. Anticreep film is used within the gearhead and motor to prevent internal oil migration and leakage from the unit. The two geared motors are connected by a Torque Tube to provide an electrically redundant drive.

The outer edge of each solar cell blanket is attached to a CFRP Spreader Bar (50.8 mm, 2-mm wall) which is located between and attached to the outer tips of each pair of booms via fixed extension rails. The Spreader Bar houses a spring mechanism which compensates for mismatch in boom extension rates and final boom deployed length to maintain a uniform tension across the blankets. The compensator mechanism is connected to the extension rails by St.St tapes and includes a linear potentiometer which senses spring extension, from which the blanket tension is determined. The potentiometer movement is limited to 25.4 mm; and to provide a read-out over full extension rail length, 127 mm, the potentiometer is enclosed by a secondary spring in series with the primary spring such that the load which results in 228.6-mm extension of the primary spring causes the secondary spring to extend 25.4 mm (Figure 6).

The Manual Over-ride gearbox has a ratio of 0.711:1 and is in constant mesh with an output gear on the Torque Tube. The Drum Lock mechanism (Figure 4) also interfaces with the Torque Tube and the design is such that in the locked position the load on the release cam passes through the axis of its carrier shaft which results in a very low torque transfer to the release quandrant.

The overall mass of the SDM is 54.72 kg. However, approximately 10 kg of this is for instrumentation and astronaut EVA interfaces. Apart from thermostatically controlled heaters on the motor units the thermal design is passive with most of the exposed external surfaces covered with self-adhesive aluminised KAPTON film and some internal surfaces black anodised.

OPERATION

A tension of 111.25 N is applied to the solar cell blankets to prevent slippage during launch. This tension is maintained by the Drum Lock mechanism. After primary deployment the SDM is activated and during the initial revolution of the Torque Tube the Drum Lock releases. This is possible because the first revolution of the boom-stowage cassettes is used to open out the elements from their tightly wound condition prior to their exit from the cassette housing. The booms are driven out and the blankets are pulled from the Stowage Drum via the Spreader Bar. The cushion rolls onto the Cushion Roller and the main Spring Motors act against drum rotation to ensure tension in each blanket. At the completion of deployment, or in any interim position, the booms remain locked by virtue of the high gearing within the Actuator Unit. For full deployment the Stowage Drum rotates approximately 8 revolutions and the Cushion Roller 32 revolutions.

For normal deployment and retraction both motors are driven together to deploy or retract one wing at a time. However, if electrical failure occurs in one motor, each motor is capable of driving both boom cassette assemblies and backdriving the failed motor. The drive electronics also has the capability to drive one motor in each SDM to simultaneously deploy or retract both wings. The drive motors are switched off at the completion of deployment or retraction by pre-set microswitches within each cassette assembly. Normal two-motor-drive deployment time is approximately 5 minutes and the manual input torque required for blanket deployment is <5 Nm.

TEST RESULTS

The tests programme is summarized (Figure 7). Structural tests confirmed reserve factors >2 on the maximum predicted loading conditions. The Narrow Blanket Model, using two full-length, 150-mm-wide blankets with a combination of real and dummy solar cells was used to check roll-up geometry and general blanket interface. It was subjected to vibration, acoustic and linear acceleration tests. No solar cell damage occurred. The diaphragm housing successfully completed 45,000 oscillations of +/- 2-mm amplitude without any evidence of cracking. The Sliding Bearing interface also completed 45,000 oscillations of +/- 2 mm in thermal vacuum conditions with 20°C temperature differential between drum bearing housing and central tube. The sliding force was < 10 N, both at high- and low-temperature conditions, and inspection of the bonded MoS_2 film after the tests showed that it was barely worn and thus had more than adequate life. Similarly, the Spring Motor Assembly completed 45,000 drum oscillations of +/- 5° in the fully deployed position and 50 full deploy/retract operations. The Flexible Harnesses completed the same tests in thermal vaccum and while in the deployed configuration a current of 3.7 A was passed through each of the 40 power conductors to simulate the heating effect. The total flexible harness resistance torque (2 power, 2 data) over 9.5 revolutions of the drum at temperatures of +/- 40°C was 0.56 Nm to 0.90 Nm. No de-lamination was observed and continuity was satisfactory during and after tests.

During thermal vacuum testing of the Boom Actuator Unit at -35°C and maximum loading conditions, a problem occurred in the redundant one-motor-drive mode. The detent torque of the back-driven motor increased from its normal 0.42 Nm to about 1.41 Nm (Figure 5). This increase in detent torque, attributed to a reduction in gearhead clearances (backlash) and possibly some increase in lubricant viscosity, was deemed to be a major factor in a drive motor stall condition occurring before retraction was complete.

As a result of this test failure a decision was taken to fit heaters to the gearhead and increase the gear ratio between the gearhead output and cassette drive from 1.943 to 3.579:1 to further reduce the load on the drive motor.

Blanket deployment over water is shown (Figure 9). There was no humidity problem. Provided the water was always colder than the room temperature the relative humidity fell to the general room level (40%) from about 100 mm above the water level. One minor problem with this method of testing is that the stowage drum torque is absorbed in lifting the blankets from the polystyrene floats onto the drum and as a result little or no boom compressive tip load is induced to assist retraction. Therefore, motor currents were higher than expected. Although this test demonstrates the correct function of the SDM/Solar Cell Blanket interface, representative motor performance is best obtained using a zero blanket mass simulation. The blankets were replaced by terylene cords between the Spreader Bars and Drum, resulting in a good prediction of in-orbit motor and Boom Length Compensator performance.

The SDM integrated with mass-and-stiffness-representative PDM and SAD successfully completed Vibration testing including vertical vibration (Figure 11). In all cases blanket slippage was minimal and did not affect subsequent deployment and retraction. The overall first resonant frequency of the stowed wing was 39 Hz (Requirement 25 Hz). Temperatures recorded during the Thermal Balance tests were generally within 5° to 10°C of predicted values and the Thermal Vacuum Function and Accelerated Life test were completely successful. Solar Cell blanket tensions from these tests are summarised (Figure 8).

CONCLUSION

The adoption of an existing design, coupled with direct access to supporting data, has reduced design and development time. It enabled major effort to be concentrated on design modifications and additions, with the knowledge that the concept was proven. An initial concern was the 5-year life with exposure to approximately 30,000 eclipse thermal cycles. However, the results of the thermal vacuum testing, particularly with regard to the lubrication aspects, have instilled a high degree of confidence in the design and laid the foundation for the future development of this and other mechanisms which have to comply with similar requirements. The mechanism has proven its ability to stow, protect and deploy the solar cell blankets. The final inspection of the blankets after completion of the Qualification programme showed that the cover glass on 28 real cells and 22 dummy cells out of a total of 24,370 cells had been cracked as a result of handling and testing.

ACKNOWLEDGEMENT

The author wishes to thank the Hughes Aircraft Company personnel and, in particular, Mr. G. Wolff, who provided FRUSA data and technical support during the initial design phase.

REFERENCES

1) G. Wolff and A. Withmann, "The Flight of the FRUSA," presented at the AIAA 9th Electrical Propulsion Conference, 1972.

2) NASA. MSFC-STD-512A, "Standard Man/Systems Design Criteria."

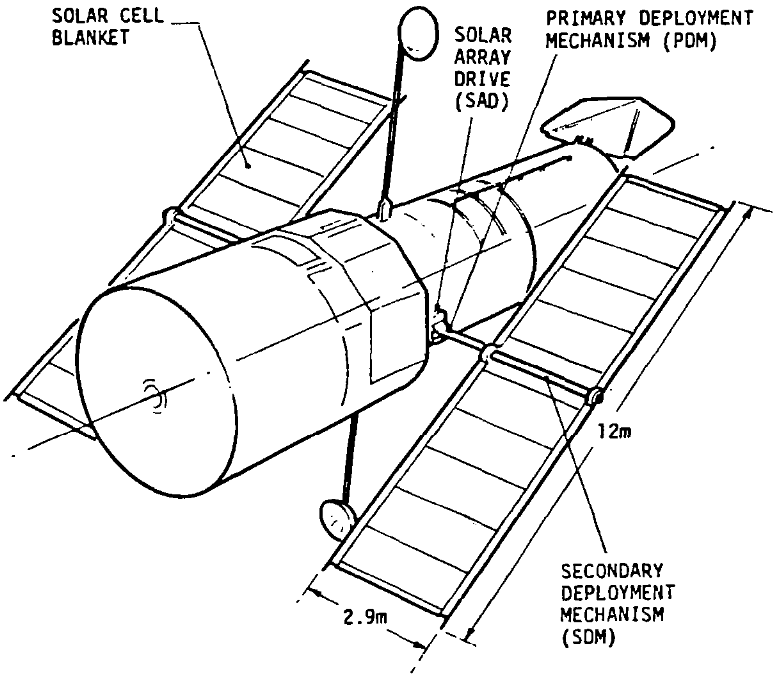


Fig.1. DEPLOYED SOLAR ARRAY

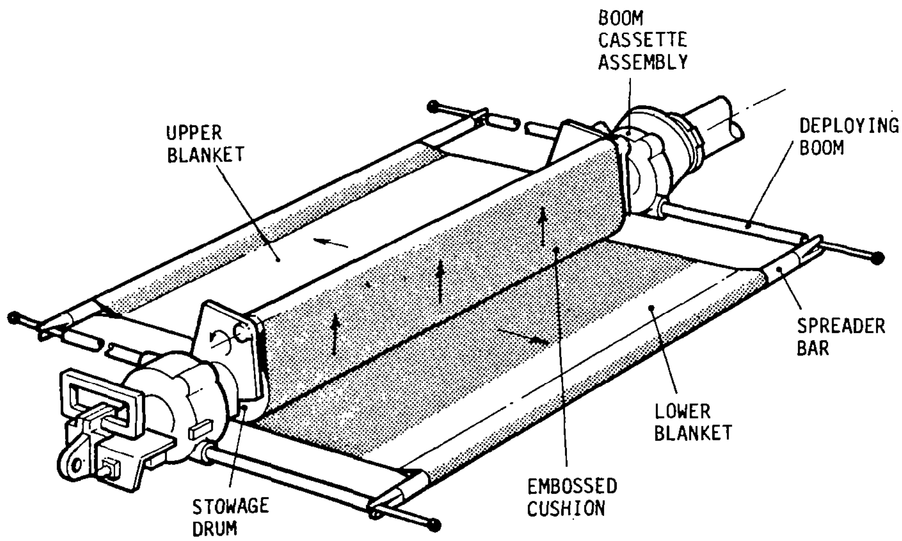


Fig.2. SDM DEPLOYMENT OF SOLAR CELL BLANKETS

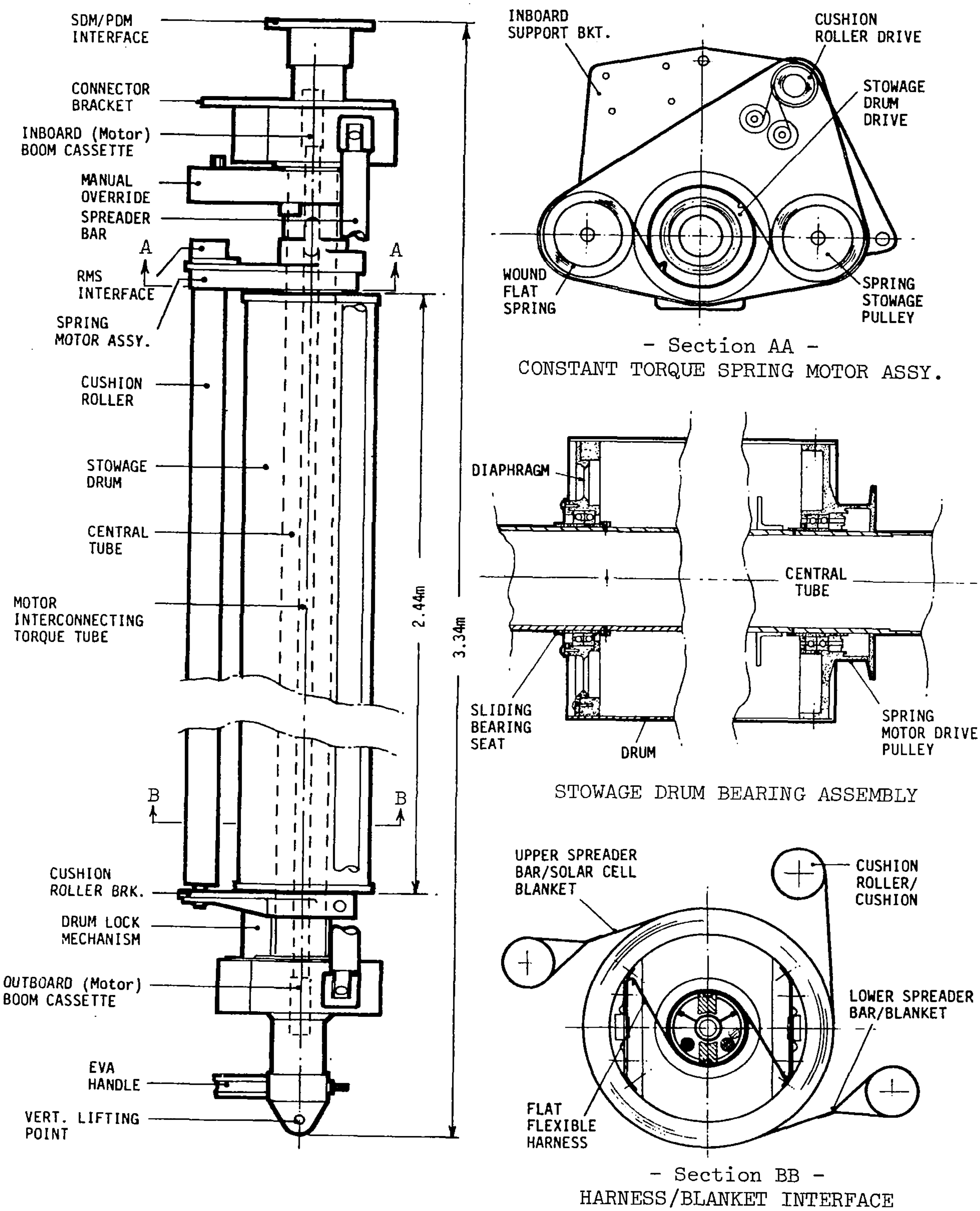


Fig.3: SDM MAJOR COMPONENTS

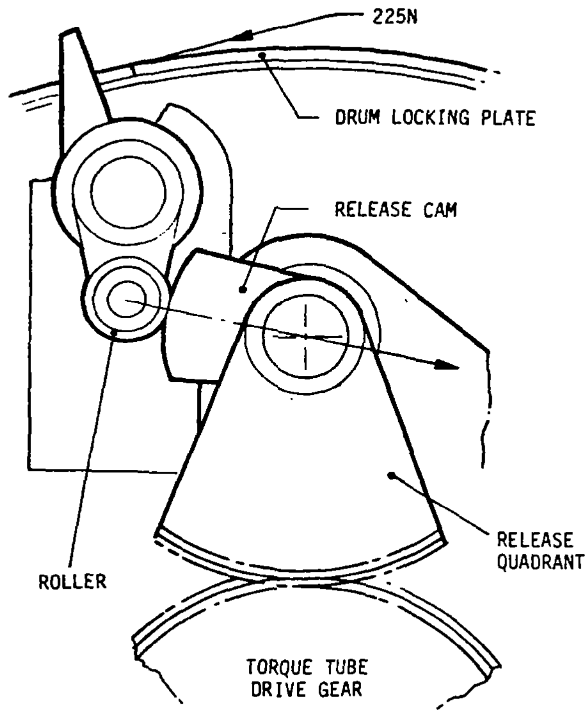


Fig.4. RELEASE MECHANISM LAYOUT

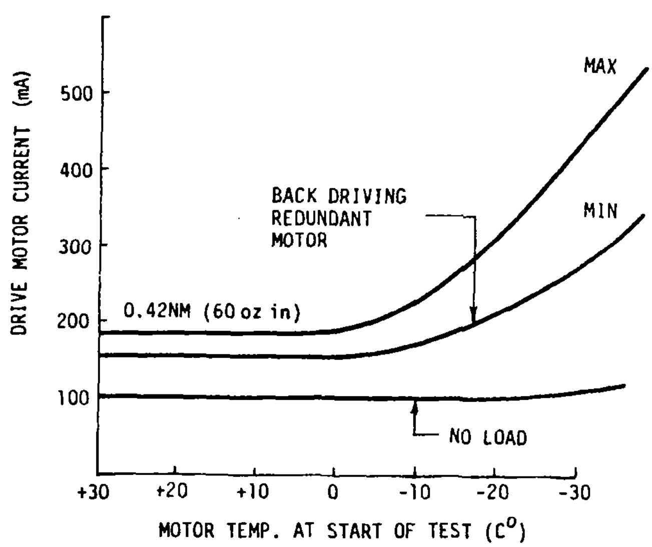


Fig.5. RELATIONSHIP BETWEEN DETENT TORQUE AND TEMPERATURE

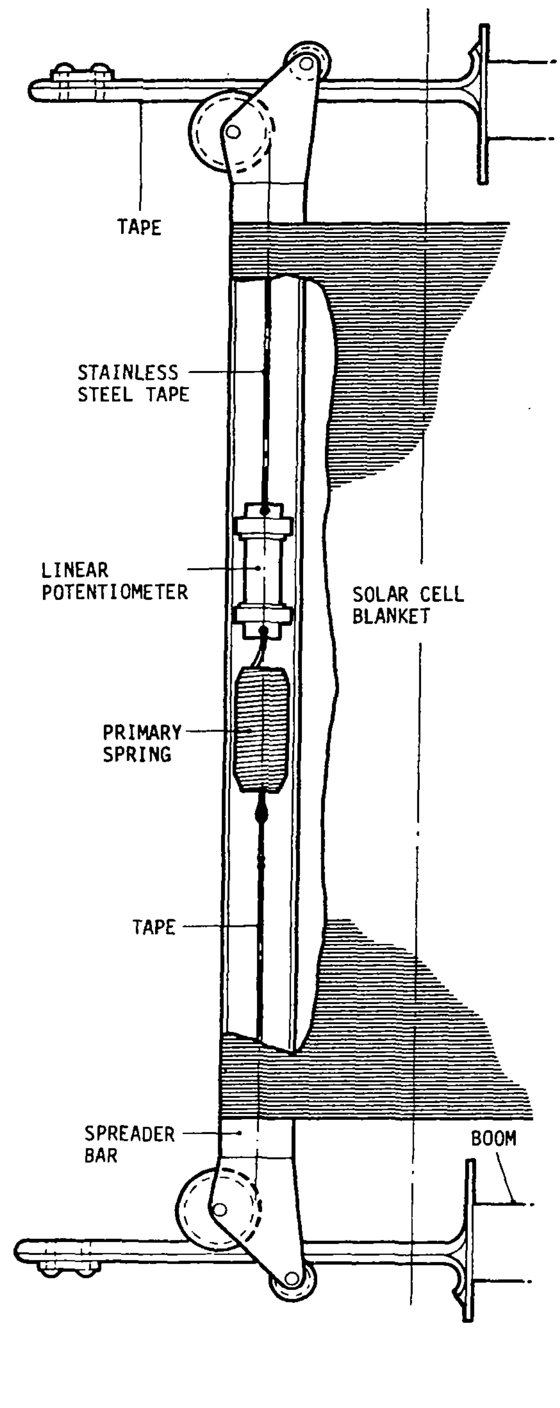
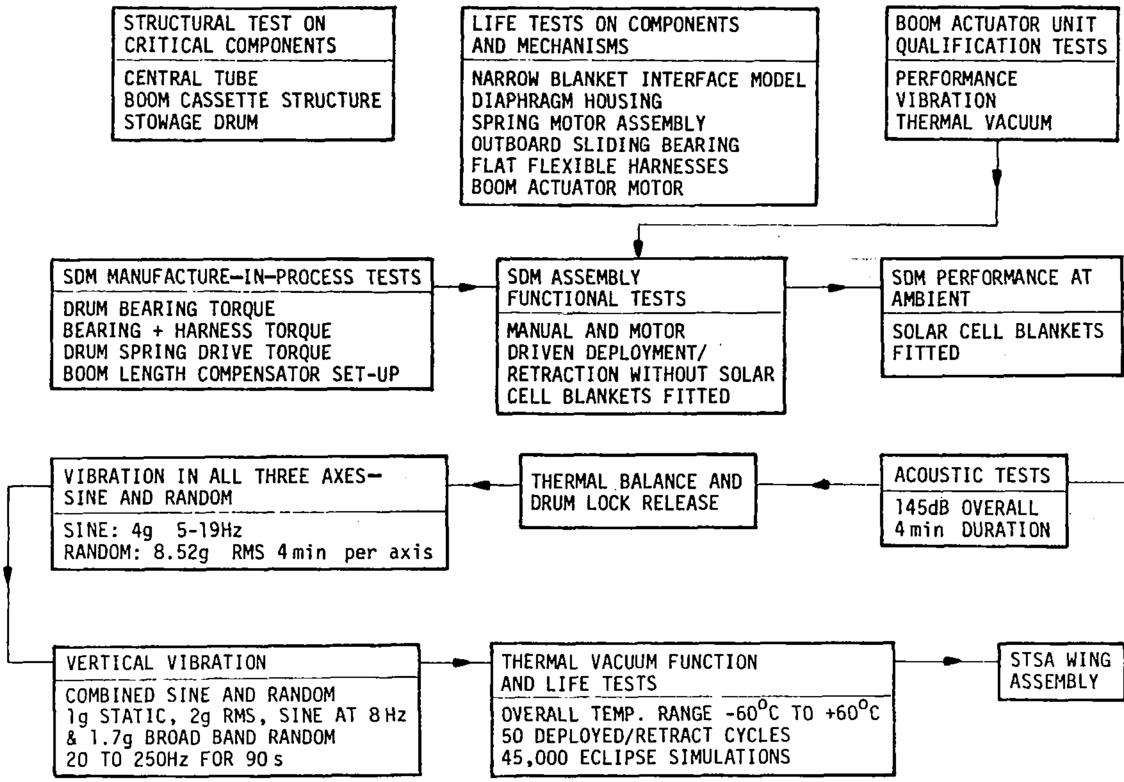


Fig.6: BOOM LENGTH COMPENSATOR POTENTIOMETER INTERFACE



NOTE: Between each environmental test performance tests, mechanical inspection and an electrical check of the solar array was carried out.

Fig.7. TESTS PROGRAMME SUMMARY

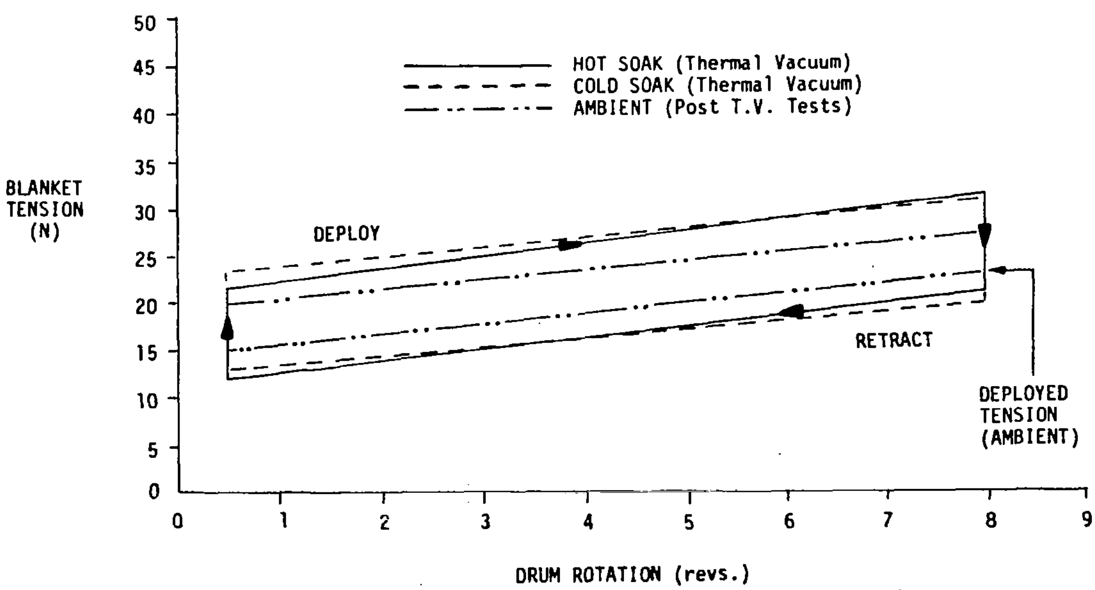


Fig.8. SOLAR CELL BLANKET TENSION OVER DEPLOY/RETRACT CYCLE DERIVED FROM T.V. AND LIFE TESTS DATA

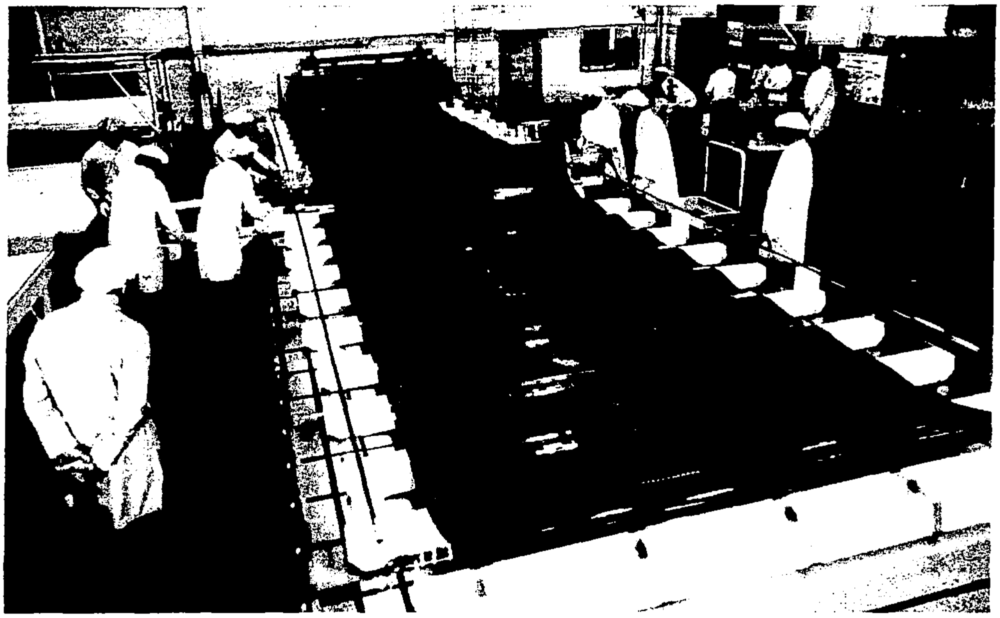


Fig.9. SOLAR CELL BLANKET DEPLOYMENT TEST OVER WATER

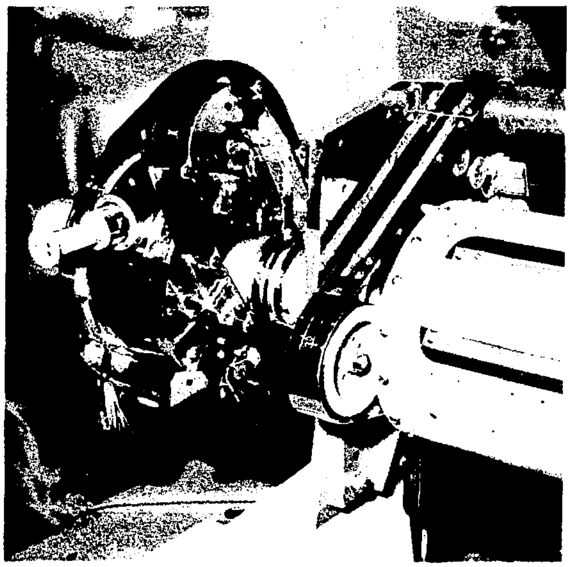


Fig.10. SDM INBOARD BOOM CASSETTE AND CONSTANT TORQUE SPRING MOTOR ASSEMBLY

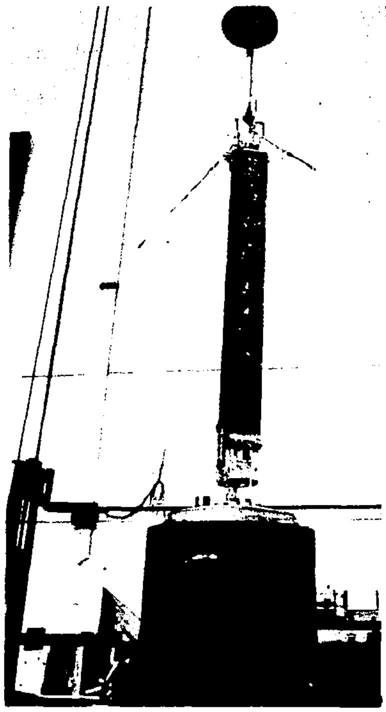


Fig.11. SDM STOWED CONFIGURATION VERTICAL VIBRATION TEST

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Mr. Cawsey has 20 years' experience in mechanism design, initially on guided weapon systems but since 1969 on spacecraft. This includes the design, manufacture, and test of an early roll-up solar array mechanism; pantograph primary deployment mechanism; and the deployable booms, hinges, and release mechanism for the ISEE-B spacecraft that was launched in October 1977 as part of a joint NASA/ESA program. Since 1978, he has been the design engineer responsible for the space telescope solar array secondary deployment mechanism.