N85-33534

SIX MECHANISMS USED ON THE SSM/I RADIOMETER

Howard R. Ludwig*

ABSTRACT

Future USAF Block 5D Defense Meteorological Satellites will carry a scanning microwave radiometer sensor known as SSM/I. SSM.I senses the emission of microwave energy and returns to earth data used to determine weather conditions, such as rainfall rates, soil moisture, and oceanic wind speed.

The overall design of the SSM/I radiometer was largely influenced by the mechanisms. The radiometer was designed to be stowed in a cavity on the existing spacecraft. The deployment of the sensor is complex due to the constraint of this cavity and the need for precision in the deployment. The radiometer will continuously rotate, instead of oscillate, creating the need for a bearing and power transfer assembly (BAPTA) and a momentum compensation device. The six mechanisms developed for this program are described in this paper.

1. INTRODUCTION

Future spacecraft of the USAF Defense Meteorological Satellite Program (DMSP) will carry a passive microwave radiometric system known as the special sensor microwave/imager (SSM/I). It is a seven channel, four frequency, linearly polarized, passive system. The SSM/I measures ocean, atmospheric, and land surface brightness temperatures. The Air Force Air Weather Service and the Naval Oceanography Command will process these data to obtain precipitation maps, oceanic wind speed, sea ice morphology, and soil moisture percentage. Figure 1 illustrates the SSM/I integrated into the DMSP satellite.

2. SSM/I OVERALL MECHANICAL DESIGN

The existing DMSP Block 5 spacecraft had only two possible locations to stow the sensor. Potential designs were made to use these locations. For each of these designs, mechanisms were selected. The final selection was based on an efficient, low-risk system. Figure 2 illustrates the selected sensor in stowed and deployed configurations. The mechanisms had a major influence in the overall design of the sensor. These account for approximately 30 percent of the weight of the SSM/I. The stowed volume is approximately 20 percent of the deployed on-orbit swept volume.

One of the major decisions was in the manner of scanning. It was decided to continuously rotate the sensor at 31.6 rpm to provide 103° of uninterrupted earth scan. As the sensor rotates beyond this range, the sensor passes a hot load and a cold space reflector that calibrate the sensor. This method is more efficient and accurate than a back and forth or oscillating reflector. Continuous rotation of the sensor adds uncompensated momentum to the

* Hughes Aircraft Company, El Segundo, California

spacecraft. Previous studies (Ref. 1) suggested use of gear or belt driven counterrotating masses to compensate for sensor momentum. A trade-off study for providing compensating momentum determined that an existing momentum wheel would be more reliable and efficient than the previously proposed devices. Developing a geared or belted system for a 3-4 year life was felt to be too risky. The momentum wheel could be located in a separate compartment of the spacecraft to help its balance and not take up volume in the location chosen for the sensor.

Deployment of the SSM/I is unique. First, the whole sensor is deployed from the spacecraft. The reflector is then released and rotated 170° by the reflector deployment mechanism. At that point a four-bar linkage is engaged which translates the reflector into its final location (Figure 3). This sequence does not interfere with the view of the DMSP's other sensors. Six mechanisms are used on the SSM/I: bearing and power transfer assembly, momentum wheel, three deployment mechanisms, and pyrotechnic devices.

3. MECHANISMS

3.1 Tribological Design

In the design of mechanisms there are two general philosophies (usually unstated) on the tribological aspects. One is to perform the electrical and mechanical designs and to then add the lubrication method. The other approach, and the one used on the SSM/I mechanisms, is to consider the tribological aspects of the design from inception. The general type of lubrication is chosen early in the design, and compatible materials are selected. The final lubricant is based on requirements such as temperature, load, and speed.

3.2 Bearing and Power Transfer Assembly

Continuous rotation of the SSM/I sensor is provided by the BAPTA (Figure 4). The BAPTA developed for this program has some unique features, but it was based on existing technologies. The BAPTA provides rotating mechanical and electrical interfaces between the spinning and stationary sections of the sensor. The physical characteristics are shown in Table 1.

The tribological design of the SSM/I BAPTA uses state of the art technology. A pair of CEVM 440C angular contact bearings with patented nitrileacrylic copolymer retainers (Refs. 2-3), in an open cell configuration, are used. Stainless steel sideplates provide the required mechanical stiffness and strength. The copolymer material has a large capacity for oil storage (Figure 5).

Each bearing is lubricated with HMS 20-1727 oil, which is a highly refined, low vapor pressure, mineral oil with a 5 percent lead naphthanate extreme pressure additive. The nitrile-acrylic copolymer with this oil is now at the 9 year mark in a continuing life test and has been successfully flown on the Pioneer Venus, GMS II, and GOES programs.

The electrical power and signal transfers are through slip rings made of silver and brushes of a self-lubricating material made of 85 percent silver, 3 percent graphite, and 12 percent molybdenum disulfide. Based on the wear rate from a 10 year life test, these brushes will last more than 100 years.

3.3 Deployment Mechanisms

3.3.1 General Design Philosophy. There are two general approaches to the design of spring-driven deployment mechanisms for delicate appendages or devices that have to point precisely. One method is to use a deployment spring that is only slightly stronger than the resistive torque. This is done to avoid shock damage at the end of stroke. A great deal of testing and adjustments are usually associated with this approach. The second approach is to employ very large torque margins and to rate-limit the deployment. This is accomplished by viscous or eddy current damping. The bottom line of the trade-off study indicates that the high torque margin rate limited method is more reliable and easier to test at the expense of weight. Although the simple spring mechanism is less costly as a unit, the overall cost is usually higher due to the complexity of testing and need for exotic offloaders for system level testing.

The use of the high torque margin was chose for SSM/I so that there would be no risk of a failure to deploy. Additionally, all tests were performed in 1G without offloaders. This was accomplished by mounting the sensor with the deployment hinge in line with the gravity vector for each deployment.

3.3.2 Viscous Damping. The deployment mechanisms for SSM/I are multispeed. There was a system requirement that all deployments be made in a 10 minute period and also a self-imposed rate requirement to keep the precision and repeatability. The two were not compatible with a single speed device. In order to make the mechanism multispeed, the damping gap is varied. The radiometer deployment mechanism (RDM) has two speeds and the antenna deployment mechanism (ADM) has four speeds (two fast and two slow) to meet the time requirement at cold condition.

The two main deployment mechanisms for SSM/I are rotary viscous damped. These devices combined the features of the pivot hinge and bearings, deployment springs, viscous damper, and hard stops into one unit. The mechanisms are powered by redundant laminated spring sets. They feature redundant spring-loaded tapered latch pins to provide a positive lock at latch-up and adjustable hard stops to ensure positioning accuracy. These actuator designs have evolved from the basic JPL concept originally developed for Mariner '71 and Viking Orbiter to their current compact third generation design (Ref. 4).

The actuator mechanism consists of a housing, two end plates containing O-ring seals, and a stator shaft with integral damping paddles. These are all made of aluminum. A take-up reel is provided for the deployment springs. The dimethyl silicone fluid of 0.1 m^2/s kinematic viscosity provides damping. A reservoir compensates for the change of fluid volume with temperature. Figure 6 is a cutaway view of an actuator.

Double paddle wheels are used for deployment angles less than 130° and a single paddle is used for angles greater than 130°. The nousing rotates about the slator shaft. Torque is supplied by the constant torque deployment springs. Damping is provided by flow of the damper fluid from the high pressure side of each paddle, through the gaps between each paddle and the housing, into the low pressure side. The majority of the damping comes from the flow of fluid through these orifices (the gap between each paddle and the housing), while the remainder is due to viscous shear.

The main pivot ball bearings are selected to provide proper stiffness and strength. Lubrication of the deployment devices is a combination of wet and dry. The main bearings are in the silicone fluid. The laminated springs, take-up reel bearings, and latch pins are lubricated with sputtered MoS_2 (Ref. 5). The tips of the latch pins are made of a self-lubricating plastic material.

3.3.3 Radiometer Deployment Mechanism. Deployment of the SSM/I radiometer from the stowed position is accomplished by the RDM. The pyrotechnic devices at the base plate are fired, releasing the radiometer. The RDM rotates the sensor 90° about the deployment axis, bringing the BAPTA spin axis parallel to the local vertical. Tapered latch pins drop into place to brace the radiometer in the deployed position. Completion of the deployment is indicated by a normally closed microswitch which opens as the latch pin drops into place. Adjustable hard stops control the deployment angle and repeatability of the deployment angle. Figure 7 shows the RDM. As can be seen, the mounting base for the radiometer was made integral with the RDM. Table 2 provides test results for the engineering, qualification, and the first flight models. Figure 8 shows a typical deployment angle versus time plot for the RDM. As can be seen, the first (70°) is at a rate of 0.4 rad/s and the last (20°) at a rate of 0.04 rad/s.

3.3.4 Antenna Deployment Mechanism. After the radiometer has been deployed from the spacecraft, the antenna is released by firing another set of pyrotechnic devices. The antenna is then driven 170° about the first antenna deployment axis by the deployment springs. As the antenna reaches this fully extended position, a four-bar linkage is engaged. The antenna is then translated into the operating position. Again, tapered latch pins are engaged and microswitches are closed to indicate latch-up (Figure 3). The deployment scheme is a result of a customer imposed requirement that other sensors on the spacecraft not have their fields of view obscured by SSM/I during its deployment. Table 3 summarizes the test results.

3.3.5 Bias Momentum Wheel Assembly. The specification for the SSM/I radiometer required no unbiased momentum from the radiometer system. The choice of using a continuously rotating antenna, together with the unbiased momentum specification, led to incorporating a bias momentum wheel into the design.

The momentum compensation system, an independent open loom momentum wheel and a continuously rotating radiometer, was compared with mechanically coupled momentum wheels through gear or belt drives. These alternatives were eliminated as a result of radiometer jitter caused by the coupling system, dry lubricant life limitations, and volume constraints. Gear or belt drive linking the radiometer to the compensation wheel would feed back any jitter to the radiometer spin control loop inducing rate errors. It would also result in an excessive weight penalty (for gear ratios near unity) or excessive number of revolutions of the compensation wheel (for gear ratios of 50 or more). Dry film gear lubricant is not compatible with a 3-4 year life requirement. Wet lubrication could be employed, but would require an additional sealed housing, adding complexity and weight. Other self-lubricating gear materials would require extensive development and life testing. Belt drives similar to those used on JPL designed radiometers were considered, but again additional development/life testing would be necessary to meet reliability requirements. Discussions with other aerospace company personnel have indicated the critical nature of belt drive details to reliability. It was unlikely that a belt drive system development program could be satisfactorily accomplished during the 14 month SSM/I development period.

The momentum required to compensate for the SSM/I in nominally 3.0 N · m. There were several commercial momentum wheels in this size range. The final momentum specified can be adjusted over the range of 2.75 to 4.25 N · m in 205 increments by final adjustment of the drive electronics. The desired speed of the momentum wheel is programmed by using 10 jumpers on a programming connector plug. This system allows final selection and momentum adjustments to match the momentum of the radiometer as the two are integrated. Table 4 delineates the characteristics of the momentum wheel, and Figure 9 shows the momentum wheel with its drive electronics.

3.4 Simple Deployments

When precision pointing or end of stroke shock are not important, simple undamped deployments are ample. The fact that a deployment is without rate control does not mean that the details of design and lubrication are not important. The materials should be selected with lubrication in mind and the drive springs should be redundant. In the case of SSM/I, there are two such deployments.

3.4.1 Lubrication Aspects. The general lubrication technique used on simple deployment mechanisms is to choose shaft and bushing or pivot materials that will not gall. For example, a hard stainless steel pin and a hard anodized aluminum bearing have to be used on most of the SSM/I pivot joints. All rubbing surfaces and springs are then sputtered with MOS_2 to give a low coefficient of friction. This combination of materials and lubricants has been reliable and trouble-free throughout the development and hardware programs.

3.4.2 Launch Support Bracket Deployment. The SSM/I antenna is held in the stowed position with a pyrotechnic device. The launch support bracket is a swing-away structural member. The loads from the antenna are passed through this bracket into the radiometer structure. Upon firing the pin pullers, the launch support bracket pivots 135° and is held in place by the redundant deployment springs. The springs and part of the bracket can be seen in Figure 10.

3.4.3 Cold Sky Reflector Deployment. The SSM/I radiometer is calibrated each revolution. An ambient hot load and reflected cold space are viewed by the sensor each revolution. The cold sky reflector can be seen in Figure 10. It is the small reflector on the top surface of the sensor body. During launch it is stowed under the larger antenna. It is kept from deploying by a strip of self-lubricating plastic material attached to the back of the main reflector. As the main reflector deploys approximately 45°, the cold sky reflector is no longer restrained and rapidly rotates to its deployed position.

3.5 Pyrotechnic Release Devices

The selection of pyrotechnic release device types is dictated by locations and mass properties of the items to be released and the amount of preloading required. For SSM/I an additional requirement of pyrotechnic redundance was specified.

The SSM/I is secured to its base plate by two independent redundant pyro lock systems, and is preloaded against four posts attached to the spacecraft interface mounting plate (Figure 11). Launch locking in this fashion provides two distinct advantages. First, pulling down the spinning portion of the sensor against the base provides rigid nesting without carrying undue loads through the radiometer deployment mechanism bearings of the BAPTA bearings. Second, the launch loads, spread over a large area of the spacecraft panel, place no local moment loading on this panel.

The two pyro systems with redundancy provisions have been fully qualified and flown on the NASA Pioneer Venus program. The same hardware was used. Redundant pint pullers tie down a "whiffle tree" fitting so that retraction of either pin will release the load. The pins are in double shear. With this dual system, retraction of either pin in each of the two circuits will deploy the radiometer.

The antenna lock system uses the same hardware as the bas lock system, except that two whiffle trees are in the double shear clevis to effect a dual element release. The antenna support arm is locked to the support arm as shown in Figure 10. Both of these elements are independently preloaded to achieve an overall rigid system.

There were two structural failures during development test in the launch restraint devices. The whiffle tree pivots failed structurally under the 454 kg load. The whiffle tree material was then changed from aluminum to stainless steel. The second failure occurred when the bracket holding the pin pullers on the antenna support arm broke off as the pin pullers were fired. It was theorized that the shock load caused by the pistons in the pin pullers pulled the bonded-on bracket loose. This bracket was redesigned to be a bolted-on bracket. After these two redesigns were made, no further failures occurred.

4. CONCLUSION

Six mechanisms were successfully designed, developed, and qualified for the SSM/I radiometer. The major accomplishment was in the successful development of high precision, repeatable, multispeed deployment mechanisms.

5. REFERENCES

1. NASA-CR-144853, "Scanning Mechanism Study for Multi-Frequency Microwave Radiometers," General Electric Company.
2. Christy, R. I., "Evaluation of a Nitrile Acrylic Copolymer As A Ball Bearing Retainer," ASLE preprint 74 AM5A-1, 1974.
3. U.S. Patent 4,226,484 (1980), Bearing Retainer.
4. JPL Drawing Package, Deploy/Damper/Latch Assembly Solar Panel 10040060, Rev D, 1972.
5. Christy, R.I. and Ludwig, H.R., "RF Sputtered MoS_2 Parameter Effect on Wear Life" Thin Solid Films, 64 (1979) 223-229.

Table 1. BAPTA Characteristics

Weight	9.1 kg
Dimensions	19.4 cm max OD x 27.5 cm length
Bearings	
Type	Angular contact
Size	60 mm bore
Class	ABEC Class 9
Material	CRES type 440C CEVM
Lubricant	HMS 20-1727
Retainer	Nitrile-acrylic copolymer
Slip Rings	
Power rings	4 ea
Power circuits	2 ea
Circuit capacity	1.5 A
Brushes per power ring	4 ea
Current density	700 A/m^2 (2 brush contact)
Signal rings	36 ea
Brushes per signal ring	2 ea
Ring material	Silver
Brush material	85% Ag, 3% C, 12% MoS_2
Lubricant	MoS_2 in brushes
Pulse Generators	
Master	1 pulse per revolution
Encoder	45 pulses per revolution
Motor	
Type	Brushless dc resolver commutated
Torque constant	0.1100 Mkg/A
Winding resistance	15Ω
Back EMF	0.983 V/rad/sec

Table 2. RDM Test Results

Parameter	Requirement	Model		
		Engineering	Qualification	Flight
Repeatability, °	±0.05	+0.0003 -0.00015	+0.001 -0.000	+0.003 -0.000
Spring torque, N · m	11 to 12	11.08	11.0	11.8
Torque margin, %	400	433	636	585
Deployment time, s	4 to 80			
22°C -34°C 71°C		15.7 50.0 7.1	9.2 42 4.1	8.0 17.0 at -11°C 5.6 at 41°C

Table 3. ADM Test Results

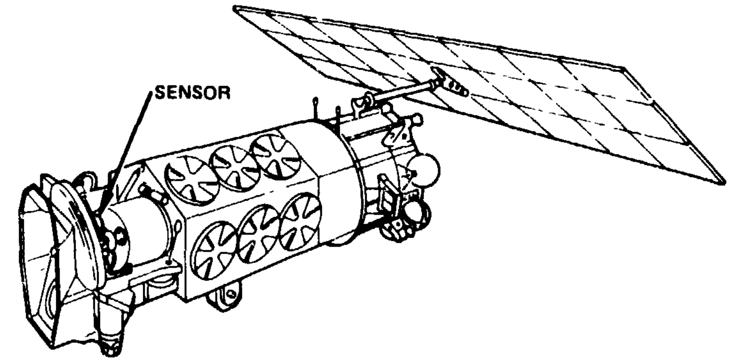
Parameter	Requirement	Model	
		Qualification	Flight
Repeatability, °	±0.04	+0.00 -0.02	+0.00 -0.01
Spring torque, N · m	3	3.6	4.3
Torque margin, %	200	329	215
Deployment time, s	<161		
22°C -32°C 69°C		17.8 89.0 10.0	29.0 118.5 16.8
Deployment rate into stop, °/s	<10	8.3	4.9

Table 4. SSM/I Momentum Wheel Design Data

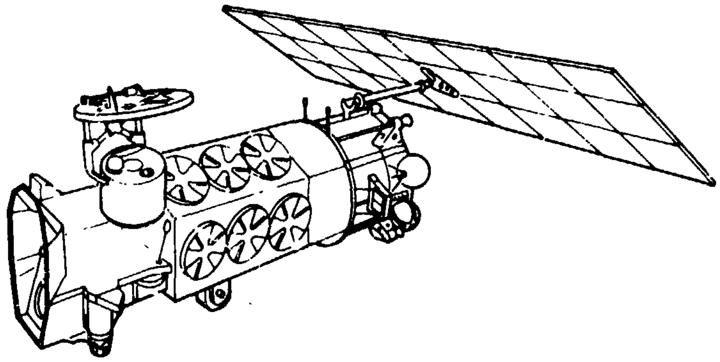
Unit angular momentum	3.0 N · m at 1300 rpm
Unit weight	5.5 kg without electronics
Rotor inertia	0.022 kg · m^2
Rotating weight	3.64 kg
Rotor diameter	18 cm
Envelope dimensions	20 cm dia by 28.5 cm high excluding mounting feet and connector
Spin motor type	AC squirrel cage induction
Synchronous speed	2400 rpm (theoretical) at 400 Hz
Unit internal atmosphere	98% HE, 2% O_2, 50% ATM
Friction and windage torque	58 gm · cm at 1400 rpm
Bearing type	Deep groove R8, double shielded
Lubrication type and quantity	MIL-L-6085A, +5% TCP, 20 to 25 mg
Tachometer type	Permanent magnet pulse Generator - 12 pulses/rev

Figure 1. DMSP satellite with SSM/I

**ORIGINAL PAGE IS
OF POOR QUALITY**

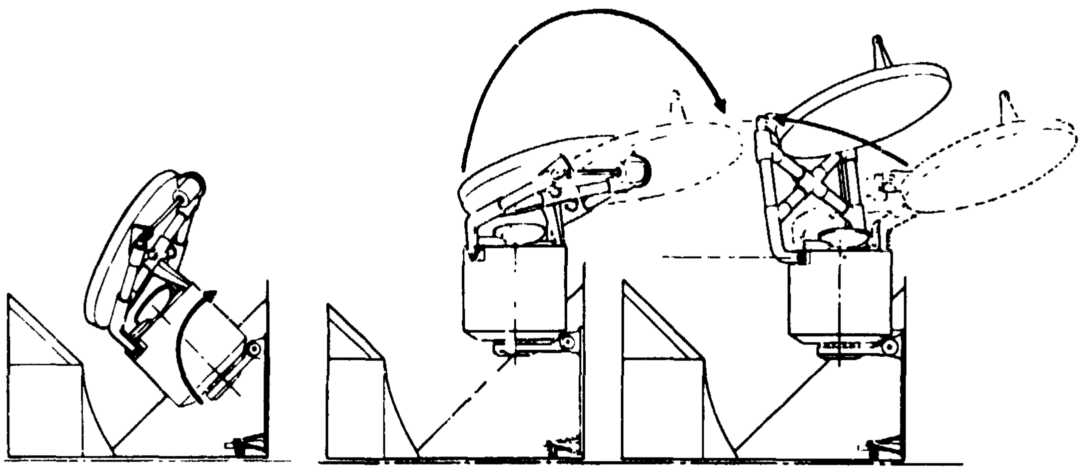


a) Stowed



b) Deployed

Figure 2. Sensor location



a) Instrument pivoting b) Antenna reflector rotation c) Antenna reflector translation

Figure 3. Deployment sequence

ORIGINAL PAGE IS
OF POOR QUALITY

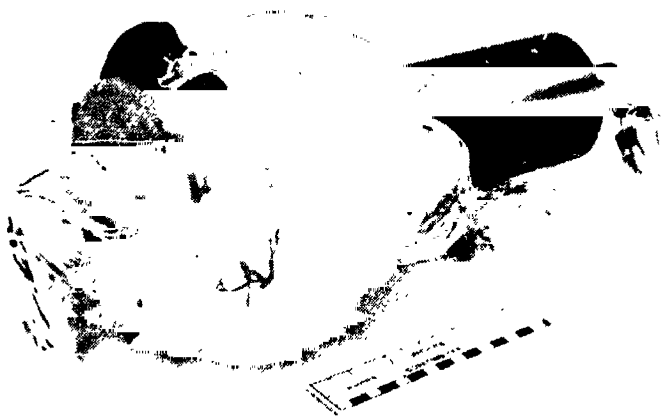
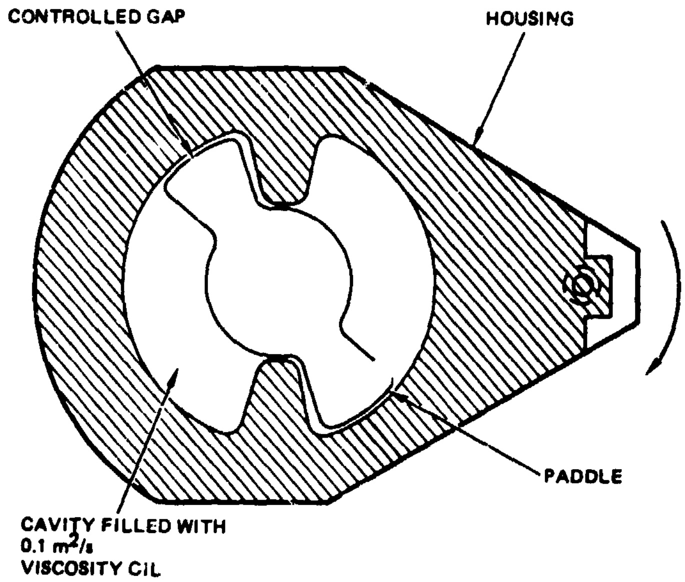


Figure 4. SSM/I BAPTA

Figure 5. Retainer lubricant capacity

ORIGINAL PAGE IS OF POOR QUALITY



- PADDLE IS PINNED TO SUPPORT STRUCTURE
- HOUSING ROTATES WITH RESPECT TO PADDLE
- FLUID IS FORCED THROUGH CONTROLLED GAPS

Figure 6. Deployment mechanism cross section

Figure 7. Radiometer deployment mechanism

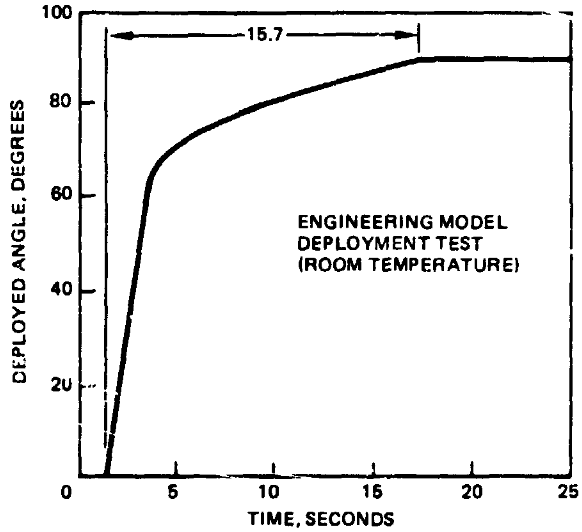


Figure 8. RDM deployment angle versus time

Figure 9. Momemtum wheel assembly and drive electronics

ORIGINAL PAGE IS OF POOR QUALITY

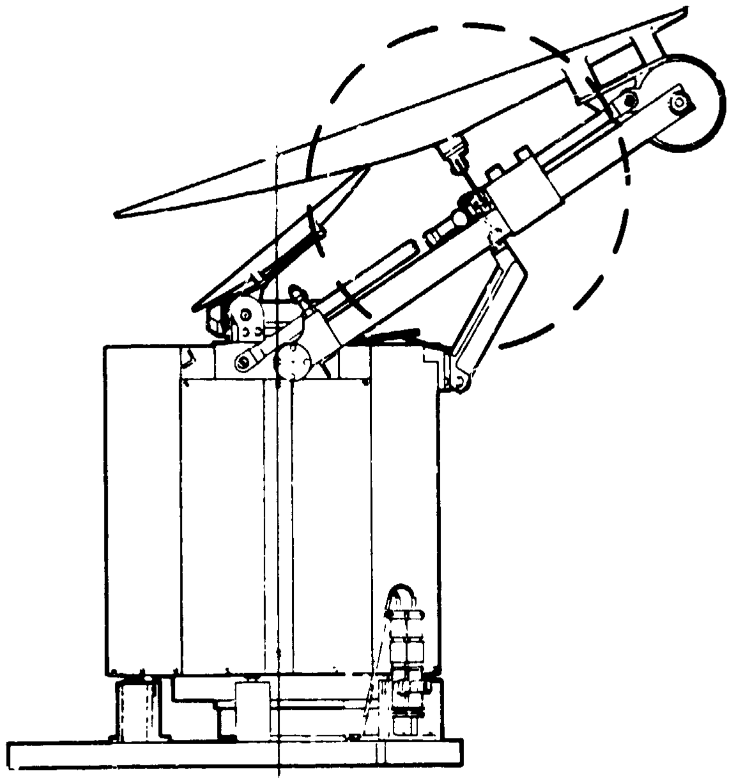


Figure 10. Launch support bracket deployment

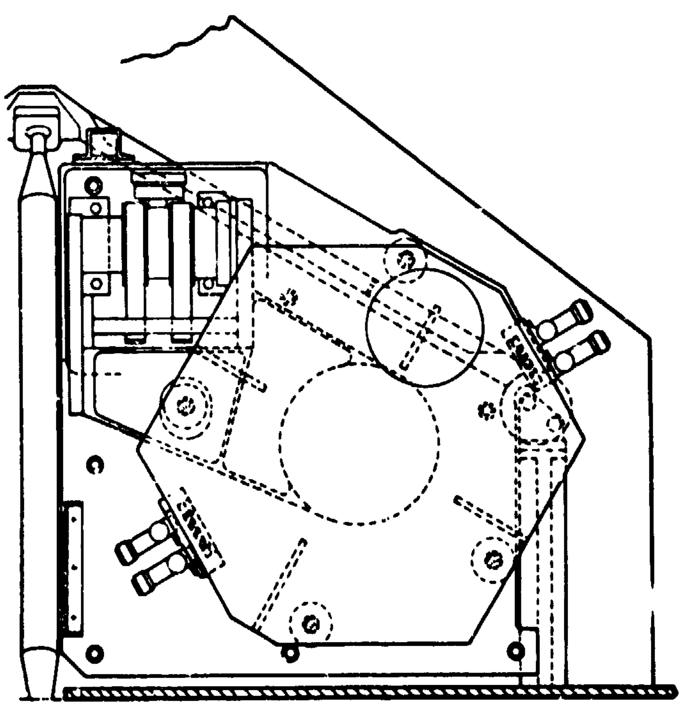


Figure 11. Base launch lock system