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MECHANISMS FOR SPACECRAFT OPTICAL INSTRUMENTATION

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SUMMARY

Several mechanisms which were developed specifically for the airglow optical experiment on the Polar Orbiting Geophysical Observatory (POGO) spacecraft are readily applicable to other spacecraft instruments or applications. Described in detail are the design and operation of a 2-1/4 inch diameter aperture shutter, a system for rapidly indexing mirrors, and a solenoid initiated protective lid for shielding viewing ports during launch. Special problems such as lubrication of an optical device for continuous operation in space are discussed.

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INTRODUCTION

A unique experiment for studying the airglow and other visible atmospheric phenomena will be flown on the first two Polar Orbiting Geophysical Observatories (POGO), in an orbit with a perigee of 160 miles and an apogee of 560 miles. The spacecraft attitude is controlled so that one side is always facing the earth. The experiment makes maximum use of this orientation with two viewing ports, one looking directly at the earth and the other away from it. Figure 1 illustrates how the instrument is mounted in the spacecraft, and its viewing directions.

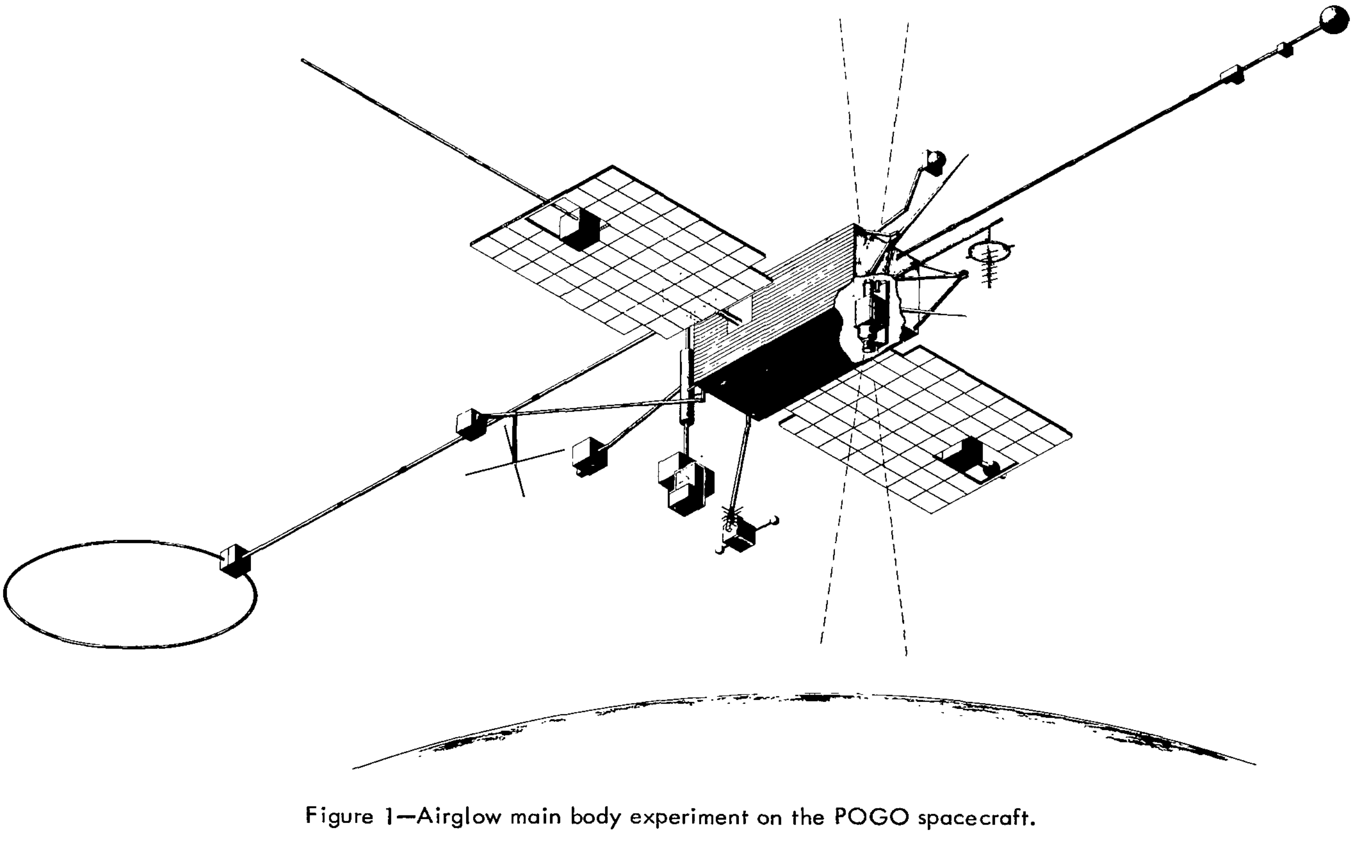

Figure 1—Airglow main body experiment on the POGO spacecraft.

The function of the experiment is to measure the intensity of six wavelengths of light from 2500Å to 6300Å in the direction of the earth, and light in the 6300Å range in the direction away from the earth. By means of a unique mechanical-optical device, a single photomultiplier tube is utilized to make these measurements.

Light entering the optics cage through the earth-facing port (Figure 2) is directed by mirrors through a filter and into the photomultiplier tube. Similarly, light from the anti-earth-facing side reaches the photomultiplier tube after being filtered and reflected through part of the optics cage. The key device in this operation is a specially designed rotating mirror.

Other mechanisms developed for this experiment are protective lids for the viewing ports and shutters from controlling light entering the optics cage.

This report documents the design and operation of these mechanisms.

SHUTTER ASSEMBLY

Operational Requirements

Two shutters with a 2.25 inch diameter aperture are required by the airglow experiment to protect the photomultiplier tube from excess light, and to darken the optics cage for calibration.

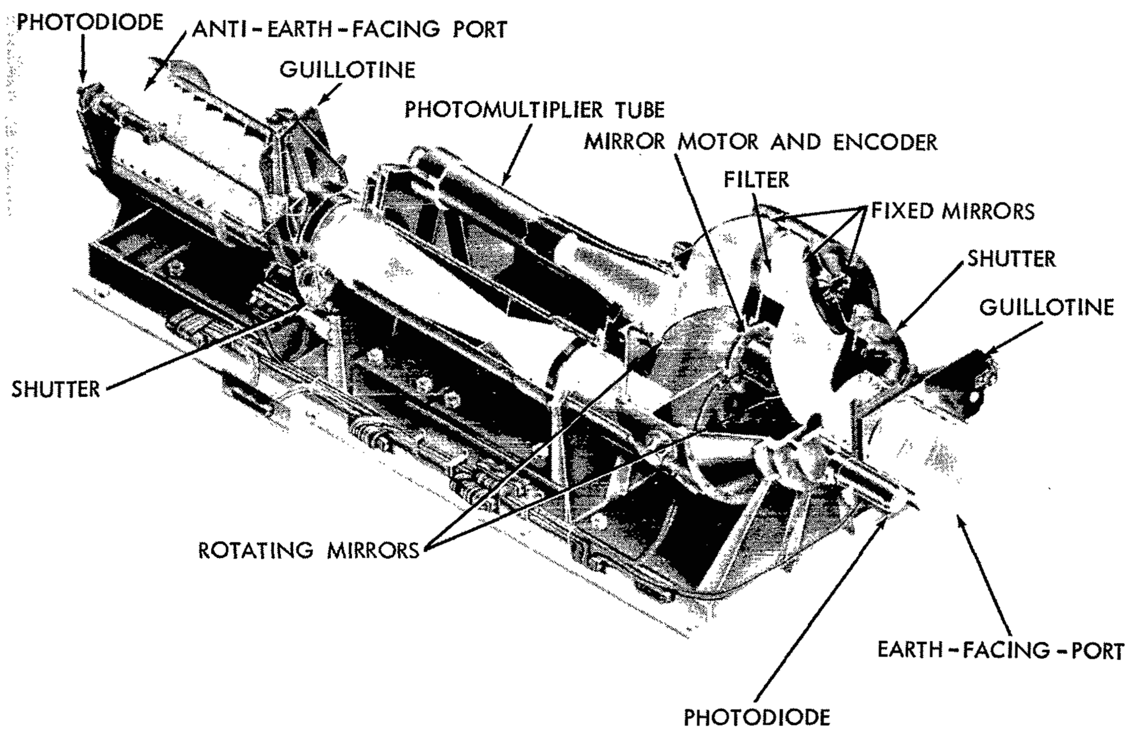

Figure 2—Airglow experiment.

One shutter is on the earth-facing side of the spacecraft (Figure 2), and the light passing through it is routed through six filters by the rotating mirror. The other shutter is on the telescope that is looking away from the earth.

There are three separate control circuits for each of the two shutters. The primary control is a photodiode which senses the light intensity outside the field of view of the photomultiplier tube and closes the shutter before the photomultiplier can be damaged by an increasing light level. The photodiode opens it again when the light level has decreased. Since the shutters are facing in opposite directions, each has a photodiode so that the experiment can look through one when the other is closed.

During the normal operation of the experiment, the shutter is programed to close once every 200 seconds for a period of 10 seconds while the experiment is calibrated.

The third control mode is a fail-safe feature that closes the shutters in the event of a power failure. The reason for this feature is to protect the photomultiplier tube from excess light during this period so the experiment will still be operative if power is again restored. Capacitors supply the energy to the shutters for this operation.

Design

Several methods were considered for performing the shutter function. The first was simply to move a disc in and out of the light path. However, this required more room than was originally available. Another system utilized a flexible tape with a hole in it. This tape would be supported between two reels and drawn between them as roll film is in a camera.

An iris type shutter appeared to be the best solution, especially if a standard camera shutter could be adapted for this application. Two series 5 camera shutters were then selected for evaluation. The basic shutter parts were removed, and modified to be driven by a stepper motor. Both commercial units were vibration-tested at OGO prototype levels and survived without any damage. One shutter was selected for further development because it was mechanically better suited for conversion to the motor drive, and had a smaller outside diameter.

Figure 3 shows the components of the shutter mechanism. The motor pad assembly consists of a 90° stepper motor and two miniature snap switches mounted on a plate. These switches monitor the shutter position and are actuated by a cam on the motor shaft. A bronze pin extends from this cam; it operates the shutter drive ring which is located on the other side of the shutter bottom plate. A steel cam, attached to the drive ring, protrudes through the bottom plate and engages the bronze pin. This pin rides in a slot in the steel cam.

The hole in each shutter blade fits over a bushing on the bottom plate, and the slot is for a drive pin on the actuating ring. Five blades are needed to close the aperture, and each overlaps

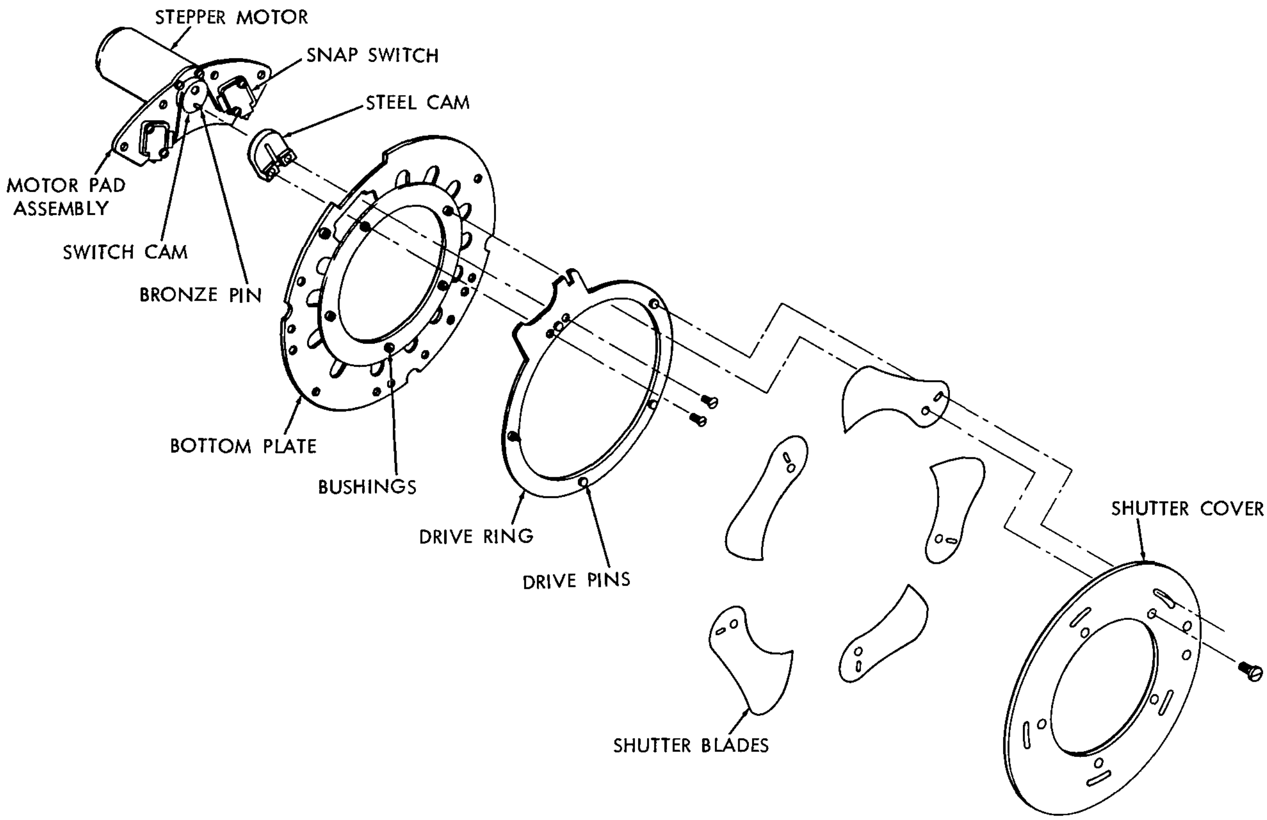

Figure 3—Shutter mechanism components.

the blade behind it. A sixth blade is used to complete the overlap, and is placed on top the first after the other blades are in position. The shutter cover prevents the blades from slipping off the pins. It is mounted flush to the bushings on the bottom plate and provides slots for the pins of the drive ring to protrude through.

As the development of the shutter design progressed, revisions to standard parts were made so that now the drive ring and bottom plate are the only parts used from the original commercial shutter. The blades are identical in shape to the commercial part, except that they are made from beryllium copper for its nonmagnetic properties.

Shutter actuation is initiated by a 150-millisecond, 18-volt pulse which rotates the motor 90 degrees. The pin and slotted cam linkage causes the drive ring to rotate 12 degrees. The pin on the drive ring working in the blade slot rotates the blade about its pivot bushing, opening the shutter. Another pulse that reverses the motor 90 degrees closes the shutter. The actual time required for the blades to open or close is 3 milliseconds. Figure 4 shows the closed shutter mounted in the housing, and the calibration light attached to the shutter cover.

Housing

The shutter is housed in a hermetically sealed case as protection for the large sliding surface areas which otherwise would present a lubrication problem in the high vacuum in which the experiment will operate.

There are five basic parts to this housing. The first is the main structure to which the shutter mechanisms are attached. The front cover, motor cover and quartz window are sealed to this structure with O-rings. A plano-convex lens is sealed in the front cover with O-rings. All O-rings are made of Viton, a material suitable for use in a vacuum. The quartz window is on the side always exposed to light, and the lens is on the optics cage side.

As seen in Figure 5, the shutter housing is a fairly complex, machined part. It is fabricated from ZK60A magnesium for minimum weight, and treated with a black galvanic oxide coating. A copper flash was applied to the aluminum motor cover for soldering the hermetically sealed connector in place.

A fill valve is incorporated in the housing to facilitate leak checking and purging. The maximum acceptable leak rate is 10^{-7} cc/sec. After the leak test, the housing is backfilled with dry nitrogen to a gage pressure of 5 psi.

Both shutters are identical except that the lens in the earth-facing shutter has a longer focal length than that in the telescope, and the calibration lights have different characteristics. Each shutter assembly weighs 0.98 pound, and is attached to the optics cage with eight screws passing through both the main structure and the front cover.

Lubrication

Even though the shutter operates in a hermetically sealed housing, special attention was given to the lubrication in the event the seal was broken. Lubricants that outgas are prohibited because of the proximity of lenses, mirrors and filters. The motor bearings

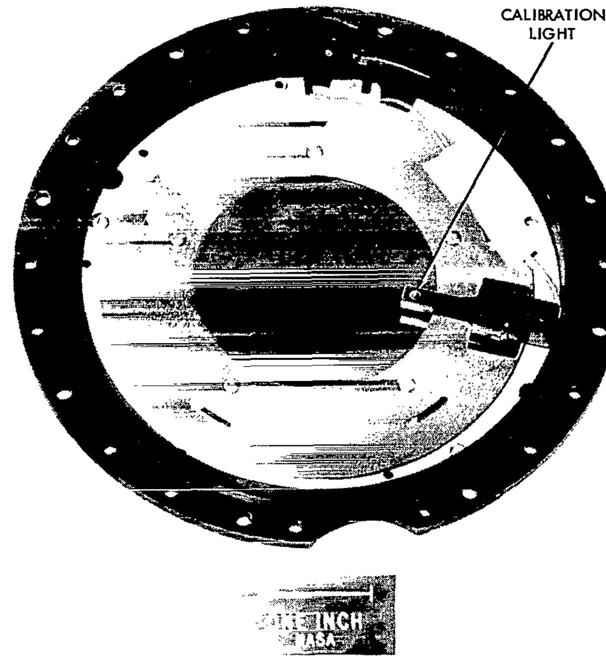

Figure 4—Shutter mechanism assembled in housing.

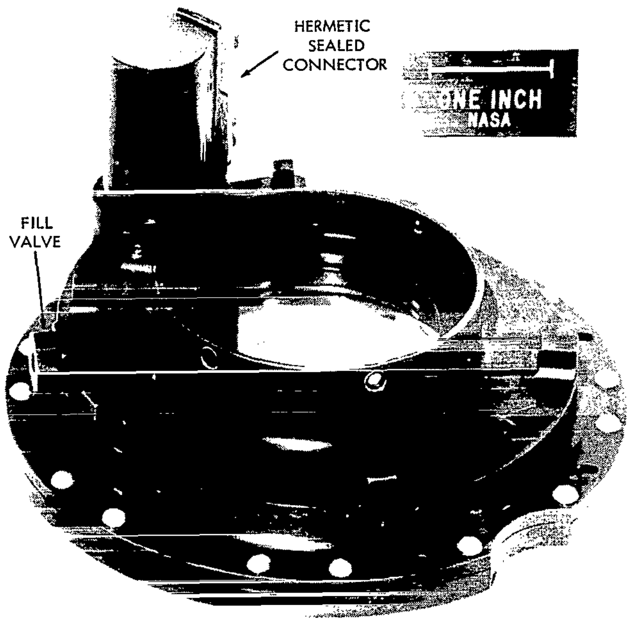

Figure 5—Shutter housing.

incorporate a machined duroid retainer which provides lubrication for the balls. Duroid is a combination of teflon and fiberglass impregnated with molybdenum disulfide (MoS_2).

Spray teflon is applied to the chrome plated drive ring and bottom plate, and to the hardcoated aluminum shutter cover. This works very well in both air and vacuum. Vacuum tests have indicated that a lubricant is not required on the bronze pin that rides on the steel cam.

ROTATING MIRROR ASSEMBLY

Function

Operation of the airglow experiment requires that light of seven wavelengths be sampled at rapid intervals. Since weight limitations prohibited use of individual sensors, a system was devised where one sensor could be used to read the light intensity of each of the desired wavelengths. This is accomplished by sequentially directing the incoming light through a series of filters to a single photomultiplier tube. Indexing of the light is performed by two mirrors mounted 45° to and rotating on the axis of the earth-facing shutter and the photomultiplier tube. This is illustrated in Figure 2.

These mirrors are rotated 45° once a second, with 0.7 second allowed for recording data. It takes less than 0.3 second for the mirrors to be moved and stopped.

Mirror Stepper Motor

The mirrors are mounted on the ends of a common shaft extending out both sides of a size 11 stepper motor (Figure 6). At 20 volts, the motor produces a torque of 1.4 inch-ounces and requires 2.25 watts. It has two phases and is stepped by alternately reversing the polarity of each phase.

Although the motor steps quickly and accurately, it takes about a second to dampen the oscillations because of the relatively large inertia of the two mirrors. To correct this, a ratchet, shown in Figure 7, is used to stop the shaft on the return portion of the first excursion past the magnetic detent point. The motor continuously tries to pull into position, providing a holding force on the ratchet mechanism. When the motor steps, the ratchet tooth is simply pulled away from the pawl, lifting the pawl and permitting it to drop into its next position on the ratchet wheel. Therefore, the accuracy for positioning the mirror is dependent upon the manufacturing tolerance of the ratchet assembly and is expected to be within 5 minutes of true position. A bronze pin is used to stop the ratchet pawl in the same position each time.

The ratchet pawl and wheel are fabricated from 7075-T6 aluminum alloy, and are hardcoated. The ratchet pawl pivots on a gold-plated ball bearing for smooth and accurate operation. The ratchet wheel is pinned to the motor shaft to prevent slipping, and the motor case itself is pinned to its support structure.

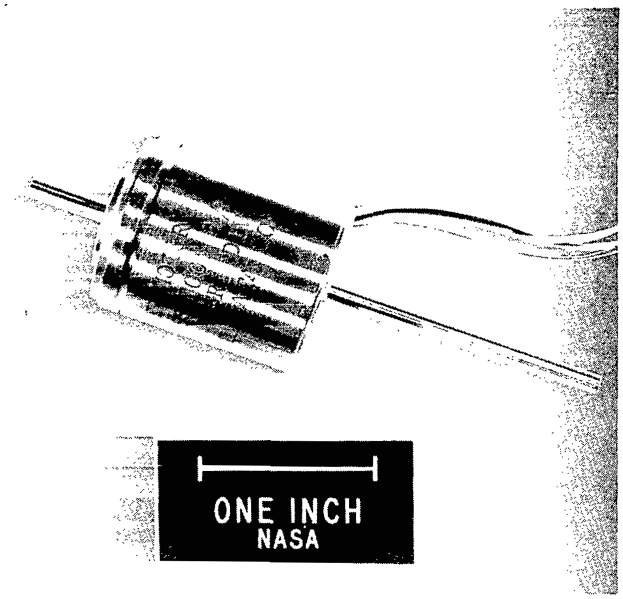

Figure 6—Rotating mirror stepper motor.

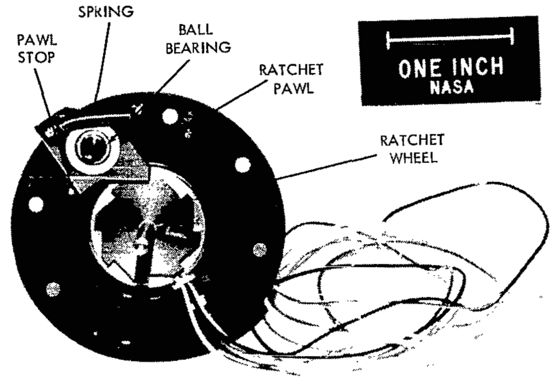

Figure 7—Mirror motor and ratchet subassembly.

Encoder

The position of the rotating mirrors is recorded by a binary shaft encoder and the position information is used three ways. It is telemetered back to earth for coordinating the data; it determines when the shutters are to operate during the calibration sequence; and it is used to locate a specific light path when continuous monitoring of a particular wavelength is commanded from the ground.

Figure 8—Arrangement of motor and encoder on common shaft.

Since the mirrors are on both ends of the shaft, it was desirable to use an encoder with a hollow shaft that could fit onto the motor shaft. This arrangement, illustrated in Figure 8, eliminated the need for a shaft coupling between the motor and encoder and provided optimum alignment by mounting both mirrors directly to the motor shaft. Total weight of the assembly (motor, encoder, ratchet and case) is 0.35 pound.

Vacuum Operation

The assembly is supported by attaching the mounting faces of the motor and encoder to a magnesium case, and this case is mounted on the optics cage filter frame. No seal is provided, so the motor, ratchet and encoder must operate in a hard vacuum continuously for a year. To provide for this, all bearings have gold plated balls and races with silver plated circle "C" retainers with some fine MoS_2 powder added. The contact surfaces of the encoder were gold plated for vacuum operation.

GUILLOTINE

Purpose

Another protective device required by this experiment is a guillotine type shutter. One is attached to each iris shutter to protect the quartz window during the launch phase from contaminants, such as rocket exhaust gasses and outgassing from the shroud when it is heated by aerodynamic friction.

Operation

As shown in Figures 9 and 10, the guillotine is simply an aluminum plate loaded with a negator spring, and is held in place by a solenoid. Even though it is actuated only once, a solenoid was selected over an explosive device because of the inaccessibility for installation of the squib on the launch pad. An added benefit resulting from use of the solenoid was the ability to check the operation of the guillotine after each vibration and environmental test without the problem of

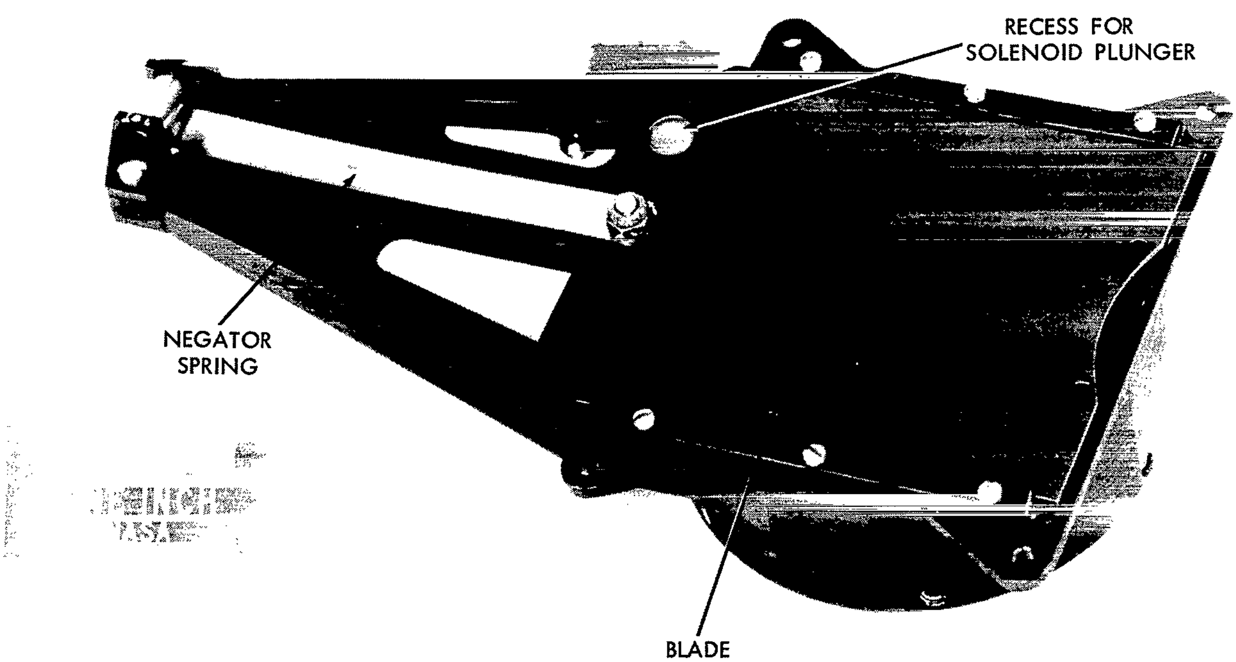

Figure 9—Guillotine shutter with blade closed (viewed from back).

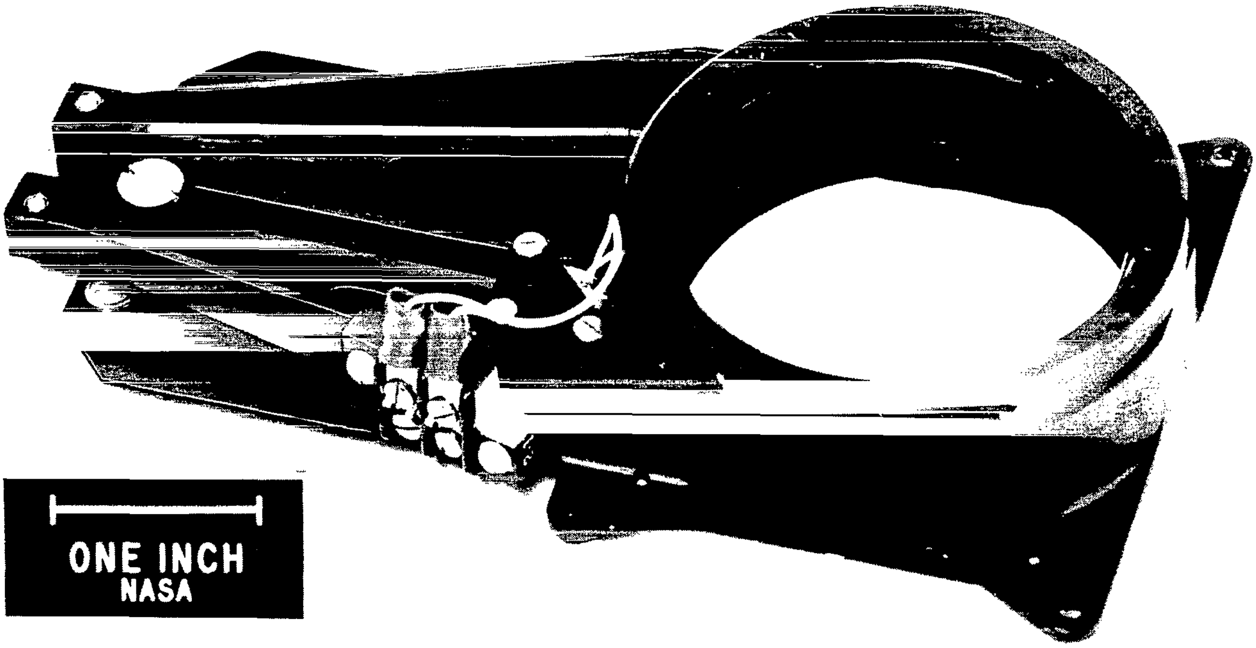

Figure 10—Guillotine shutter open (viewed from front).

replacing squibs. Once actuated, the device is cocked again by simply pushing the blade down until the spring-loaded solenoid snaps into position.

The guillotines are actuated by the ordinance power source shortly after the spacecraft is inserted into orbit. The shutters are opened and closed immediately before the solenoids are energized to insure their complete closure after launch.

The structure is made from ZK60A magnesium alloy with a black galvanic oxide coating. A Kel-F cup is placed in the blade to receive the solenoid plunger. Each guillotine assembly weighs 0.23 pound.

ENGINEERING TESTS

Life Tests

The design goal for the life of the experiment was one year. To achieve this, a philosophy of continuous testing was followed to uncover flaws and parts susceptible to premature failure.

If the shutter operated continuously for one year on the standard 200 second cycle, it would be actuated about 160,000 times. Even though there will be periods when the experiment will be shut down, such as when the light intensity is too high or when the spacecraft batteries are low, it is assumed for test purposes that this value represents a year's life. Accelerated life tests of the shutter can be run in just a few days, by cycling the shutter once or twice a second. These tests were performed in air, in a nitrogen atmosphere, and in a vacuum of 10^{-9} torr. Because the prototype shutters were assembled, several shutters had been operated for more than a million cycles each under these conditions.

These tests revealed early material problems with the pin and slotted cam linkage, and proved the utility of the spray teflon lubricant. They also demonstrated the necessity of using dimensionally accurate parts.

The first rotating mirror assembly with flight-type components was placed in a vacuum chamber and run at the normal speed of one step per second at a pressure of 10^{-9} torr. At the time the prototype experiment completed qualification tests, this test unit had been operated continuously for ten months. The unit was performing satisfactory after one year in this test, and the monitoring equipment indicated the encoder was still conducting the 1 milliampere current.

Since the guillotine operates only once shortly after injection into orbit, the standard environmental tests performed on the whole experiment were sufficient to qualify it.

Magnetic Problem

Initial environmental testing of the prototype disclosed that the experiment had a permanent magnetic field of about 2000 gammas (0.02 gauss) at 1 foot. When added to the magnetic field of the spacecraft and other experiments, it could affect the operation of a neighboring magnetometer experiment. A program was initiated to reduce the field as much as possible. A check of the individual shutters revealed that each produced a 1400 gamma field at 1 foot when not operating. The 2000 gamma field was the resultant vector sum of all the individual fields of the experiment.

Two steps were taken to reduce the magnetic field of the shutters. The steel shutter blades, which had been purchased from Wollensak, were replaced with identical blades fabricated from beryllium copper. These blades were chemically treated to obtain a dull black finish.

The magnetic field of the stepper motor is perpendicular to the motor shaft and could be attenuated by the addition of several layers of magnetic shielding material. Table 1 shows the effects that different combinations of magnetic shielding material had on the magnetic field of the motor. Two 0.004-inch-thick layers of "Netic" with an outside layer of "Co-Netic" reduced the permanent field of the motor from 189 gammas at 1 foot at about 38 gammas.

After these modifications were made to the prototype shutters, and other shields were placed on the relays in the electronics, the permanent magnetic field of the prototype was reduced to 108 gammas at 1 foot after a 25 gauss deperm (exposure to a 25 gauss demagnetizing field for about a minute).

Table 1

Data From Tests With Magnetic Shields.

Item	Magnetic Field (gammas at 1 foot)
Shutter Stepper Motor*	189
Motor with 1 layer of "Netic"	102
Motor with 1 layer of "Co-Netic"	127
Motor with 1 layer of "Netic" and one outside layer of "Co-Netic"	102
Motor with 2 layers of "Netic"	102
Motor with 2 layers of "Netic" and one outside layer of "Co-Netic"	35
Motor with last shield after 25 gauss perm	38

*The total magnetic field of the mirror motor while operating is 60 gammas at 1 foot, therefore, a shield is not required. The magnetic field of the solenoid is also negligible.

CONCLUSION

Though the mechanisms described were developed for a specific application, they can be utilized in other instruments. For example, the size of the guillotine can be varied to provide launch protection for many types of experiments, or, in addition to protecting an instrument from excessive light, the shutter can also be used in the thermal control of satellites. The shutter blades can be vapor coated with aluminum to prevent heat loss from sensor ports when the experiment is not operating, or when the satellite is passing through the earth's shadow. Extensive testing after the experiment was built indicated that the shutter can work in a vacuum and does not need to be hermetically sealed.

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