The Solar X-ray Imager Vacuum Door Assembly

Donald H. McQueen, Jr.*

Abstract

This paper discusses the design and development of the Solar X-ray Imager (SXI) vacuum door assembly (VDA). Rationale for the type of mechanism, seal, and prime mover is covered. An overview of the testing performed is included.

Introduction and Background

The SXI is a satellite-based x-ray telescope. SXI will monitor solar activities so that resultant magnetic disturbances can be forecast for earth sooner and more accurately. SXI is launched on an Atlas II vehicle and is mounted on the solar array boom of the Geostationary Operational Environmental Satellite - M (GOES-M). GOES-M is an existing design, so SXI must perform within GOES-M resources. This limits SXI severely in redundancy, size, and mass. These are dominant factors in the design of the vacuum door assembly.

SXI is a class C instrument. NASA applies class C requirements to a payload that is generally of medium priority, and does not involve any possibility of human injury if the payload should not function as designed. Class C requirements leave much to engineering judgment, including level of testing and type of testing. As a class C instrument SXI is designated a protoflight instrument, which means the project has no dedicated qualification unit. All qualification and acceptance testing are done on the flight (or protoflight) system.

SXI requires a vacuum door because of a sensitive camera component (a micro channel plate, or MCP). This component can only be operated safely at a pressure of $1.33 \cdot 10^{-7}$ kPa (10^{-6} torr) or less. The vacuum door contains a window used in ground testing of the camera. In this ground testing, ultraviolet light illuminates the camera to determine the charge coupled device health before launch. The door remains closed during ground operations to preserve a protective environment for the camera MCP. A ground command opens the vacuum door on orbit after sufficient time for instrument and satellite outgassing.

The operational requirement of the vacuum door is a one time actuation on orbit. The door's purpose is to protect the camera from the ground environment and from on-orbit outgassing of the instrument. The only requirement for reset exists for ground testing. The mechanism is low profile to fit within the space envelope available. The envelope is approximately 50 x 13 x 178 mm (2 x 0.5 x 7 inches). The mass requirement is 0.454 kg (1 lb). Maximum power available is 10 watts. The window must transmit ultra violet light. The door must seal so that ground support equipment can pump down the camera housing to 1.33×10^{-7} kPa (10^{-6} torr). The design outlined below was chosen

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* George C. Marshall Space Flight Center, Huntsville, AL

to provide the most simple and lowest cost mechanism that would perform the task reliably within the requirements stated above.

The limitations of the available GOES-M resources and the designation of SXI as a class C instrument dictated the design philosophy taken for this mechanism. This mechanism is a simple, rugged, relatively low cost design. No redundancy was incorporated other than the redundant heater elements of the paraffin actuator. Care is taken to use proven and already qualified elements wherever possible. The mechanism is tested thoroughly at the component level before system integration.

Basic Design

The mechanism can be divided into three different areas: the prime mover, the latch, and the carriage. Each interacts with the other to successfully open the door. The prime mover applies force to the latch. The latch restrains the carriage system when the door is closed, and applies opening force to the carriage system when the prime mover is energized. The carriage system for the door/window assembly of the mechanism is a slider-crank mechanism. Figure 1 shows an exploded view of the device.

The prime mover applies the opening force to the latch, which applies force to the carriage assembly. The prime mover selected for this application is a paraffin actuator. A power supply applies voltage to the actuator heaters. The paraffin goes through a change of state (solid to liquid). The paraffin applies hydrostatic pressure to an output pin. This particular paraffin actuator (or linear motor) outputs 222 N (50 lb) nominally, requires 10 watts, and is approximately 56.7 g (0.125 lb) in mass.

The latch of this design performs two functions. A cut out in the latch captures a pin in the carriage assembly. The latch restrains the door in the closed position. The latch also transfers the opening force of the prime mover to the carriage assembly (see Figure 2). An extension spring provides reset force for the actuator and latch.

The slider- crank mechanism was chosen for the carriage system. The profile of movement for this mechanism is low and fits in the required envelope (see Figure 3). The initial movement of the door is normal to the sealing surface; thus the seal loading reacts through the carriage system. A torsion spring actuates the carriage after de-latch. The torsion spring attaches to ground bracket and the input link. The design has liberal clearances so that no thermal expansion problems are encountered.

The VDA uses a gask-o-seal design for the primary seal. The material is viton (fluorocarbon). The crown height is 0.38 to 0.51 mm (0.015 to 0.020 in). The VDA utilizes the gask-o-seal design for several reasons. The door would have to be reset on the ground, and if this operation were to be remote the seal would have to be reusable (i.e., elastomer). The gask-o-seal is molded in place and can be formed in various shapes. The high contact stress generated when the gask-o-seal is compressed reduces overall permeability of the seal material. NASA has a long history of use and a high confidence level in the gask-o-seal design.

Development Testing

A development model was fabricated in December of 1993 (see Figure 4). This model was fabricated to test the basic design and to test seal material compatibility. The development unit underwent functional, vibration, and thermal vacuum tests. The functional tests were performed at room temperature and ambient pressure. The device operated a total of 40 cycles. The device was checked for leakage regularly to determine the effect of seal or mechanism wear. No significant changes in ultimate leak rate were recorded during these tests. A random vibration test was performed at the expected flight levels. Functional tests and leak checks were performed before and after. No anomalies occurred.

The VDA experienced trouble in the thermal vacuum test that resulted in design changes. The actuator and heater arrangement for the development model proved to be inadequate for this application. The actuator was low cost, low mass, and had high output force. However, the heater arrangement (externally mounted) was inefficient and the paraffin seals (shaft seals) were inadequate for cleanliness requirements. The design also lacked adequate instrumentation to signal the open position. The lack of these features resulted in long actuation times at cold temperature, contamination of the device through paraffin leakage, and damage to the device because of actuator "overstroke."

In addition to the problems discussed above, the lack of a remote control for door reset proved to be troublesome. The lack of a reset system lengthened the down time on thermal vacuum testing. The test chamber had to return to ambient temperature and pressure to reset the door by hand. This changed the time between cycles from a few minutes to a few hours.

Seal testing was an important part of development testing. Seal testing included outgassing/ contamination tests, ultimate leak rate tests (comparative), and compression effect on ultimate leak rate. Two different seal materials were tested for contamination per MSFC-SPEC-1443. MSFC-SPEC-1443 outlines testing procedures to determine material compatibility with optical systems. The two materials of study were a butyl rubber compound and a viton (fluorocarbon) compound. The viton was chosen because the leak rate was very similar to the butyl and the viton was much more compatible with optical systems. A test was conducted to find the effects of seal compression on ultimate leak rate. The results showed a considerable effect for the first 0.20 to 0.25 mm (0.008 to 0.010 in) of compression, but not much effect for the last 0.13 to 0.18 mm (0.005 to 0.007 in). From this series of tests come the determination of seal material and nominal compression of the seal for minimal loads reacted through the assembly.

Engineering Model

The next VDA to be designed and fabricated was the engineering model (EM). The EM design incorporated changes to alleviate some of the problems described in the last section. A new paraffin actuator that fit the design requirements more closely was

selected and procured. A sensor was added to the VDA to signal door actuation. A remote reset feature was incorporated for ground operations and testing.

The paraffin actuator chosen for the EM showed three improvements from the development model actuator. The EM actuator heaters are internal to the actuator and are in direct contact with the paraffin. The cavity in which the paraffin resides is hermetically sealed using a boot seal. The EM actuator has a shear disk arrangement that limits the output force to approximately two times the nominally rated output. Figure 5 shows the EM actuator installed on the developmental vacuum door.

The sensor added to the EM vacuum door assembly was a military standard sub-miniature switch. The switch is hermetically sealed. Exposed surfaces are stainless steel. The sensor is used on orbit to determine when to discontinue power to the actuator.

The remote reset feature was added to aid in ground testing. The return arm of the mechanism attaches to the input link of the carrier system. A flexible shaft actuates the return arm. The flexible shaft penetrates the optical bench of the telescope assembly and connects to a rotational feed through in the test chamber wall.

Engineering Model Testing

Some of the same testing was conducted on the development model and EM vacuum door assemblies, but with different objectives. As an engineering model, this unit was meant to unofficially qualify the design of the VDA. In the development program, changes are expected; and the results influence fundamental design decisions.

The EM vacuum door underwent four tests at the subsystem level: random vibration, thermal vacuum, thermal cycle, and life cycle tests. The random vibration test was conducted to the levels shown in Table 1. A functional test before and after (and leak checks) were the pass/fail criteria for the test. A twenty-four cycle thermal test was conducted in conjunction with a thermal vacuum test. These tests proved survivability and functionality at the expected flight temperatures. The criteria for these tests are shown in Table 2. The test program included life cycle testing to prove the ruggedness and durability of the design. The EM vacuum door operated approximately four times the expected duty cycle of the flight unit. The life cycle test had a duration of sixty cycles. The life cycle count included operations required for other tests.

The test program for the EM VDA was very successful. However, EM testing found one deficiency. During the thermal vacuum test, the operator left power engaged to the paraffin actuator longer than design parameters specified. This error resulted in the fail safe of an actuator and damage to the vacuum door. There are two reasons for the incident described above. The system level (i.e., the control circuit or operator) should have shut the device down before any damage was done to the mechanism. In the event of a system failure, the paraffin actuator should not have had enough output to damage the latch mechanism. One positive result of this incident is that the actuator did not release contamination even after being pushed well beyond design limits. Two changes will be implemented: 1) an automatic cut-off in the control logic of the SXI

system, and 2) the de-rating of the paraffin actuator to a 111 N (25 lb) nominal output instead of the original 222 N (50 lb) nominal output. Even if the control circuit fails, the actuator will fail safe before any harm. This is less important on orbit, since the door operates only one time. However, if a failure of this type occurs during testing it is necessary only to replace or refurbish an actuator rather than replace and re-qualify the whole VDA mechanism again. There is also less risk to the camera since the door could be closed again to protect the camera while actuator change out is accomplished.

Conclusion

The Solar X-ray Imager vacuum door assembly is a simple, low cost, reliable mechanism. The basic design is three very familiar mechanisms integrated to one device; a four-bar mechanism, an inclined plane, and a hydraulic actuator. Even during a "failure" in testing, the door has never failed to meet the overall objective - to open when commanded and provide a high vacuum seal when closed. The test anomalies experienced were partially due to deficient test set-ups and procedures. However, some valuable insight resulted from those failures. Because of this insight, design changes resulted in a more reliable unit.

Table 1   Random Vibration Test Environment

Y AND Z AXIS

FREQUENCY (Hz)	ACCELERATION SPECTRAL DENSITY (G^2/Hz)
20	0.005
100 - 160	0.5
200	0.05
2000	0.00158

OVERALL = 8.05 Grms

X AXIS

FREQUENCY (Hz)	ACCELERATION SPECTRAL DENSITY (G^2/Hz)
20	0.008
80 - 600	0.125
2000	0.00158

OVERALL = 9.77 Grms

Table 2   Thermal Test Environment

TEST	TEMPERATURE (°C)	NO. OF THERMAL CYCLES
THERMAL CYCLE	+36 / -53	24
THERMAL VACUUM	+36 / -53	3

Window Cover

Hinge Pin

Window Frame

*Carrier Link

*Driver Link

*Bracket

*Torsion Spring

Bearing*

Pin, Carrier/Bearing*

Actuator

Cover Plate

Pin, Carriage Assembly*

Latch
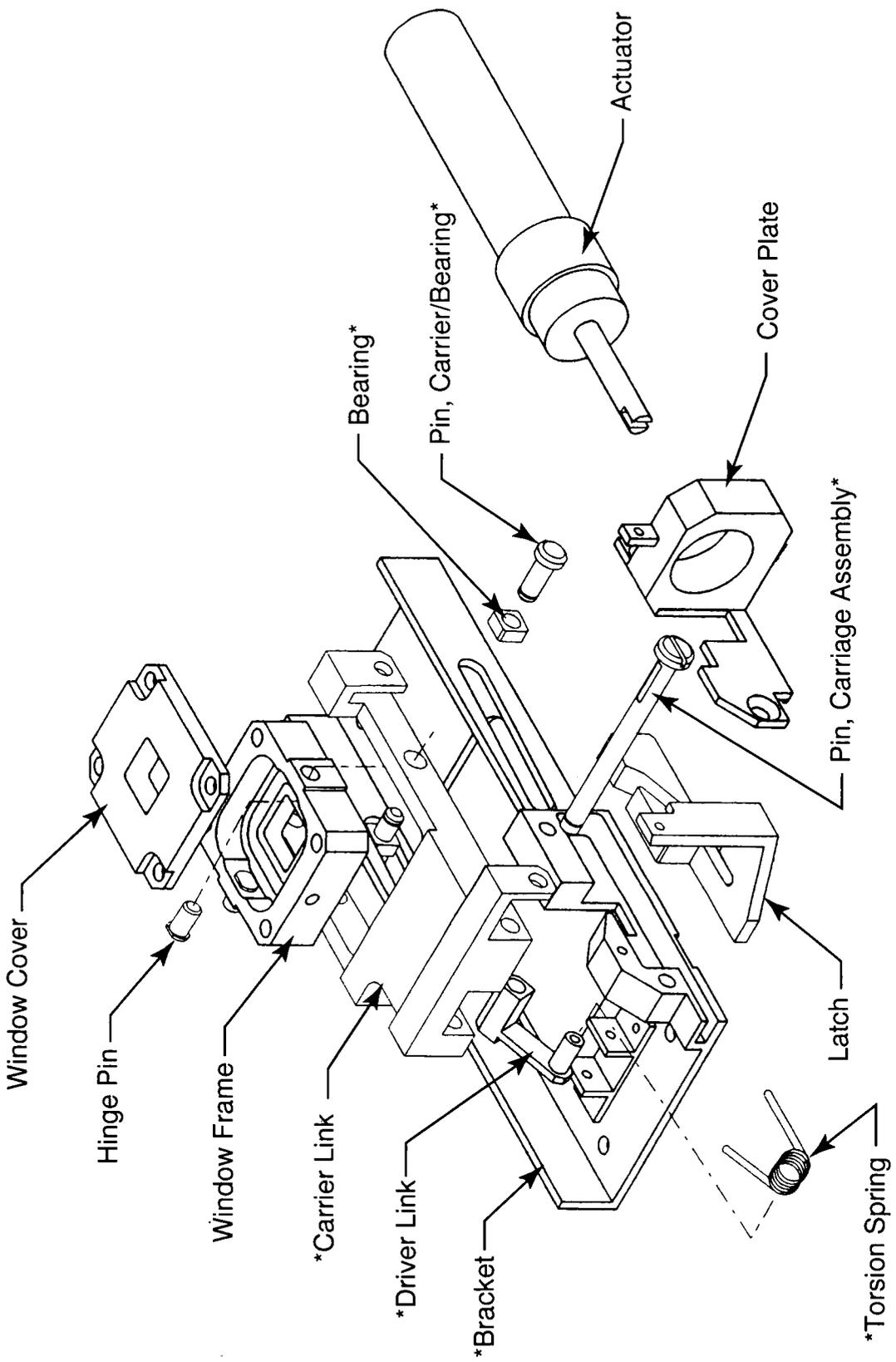
* These Elements Form The Carriage Assembly

Figure 1

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Carriage Assembly

Latch

Pin

Bracket
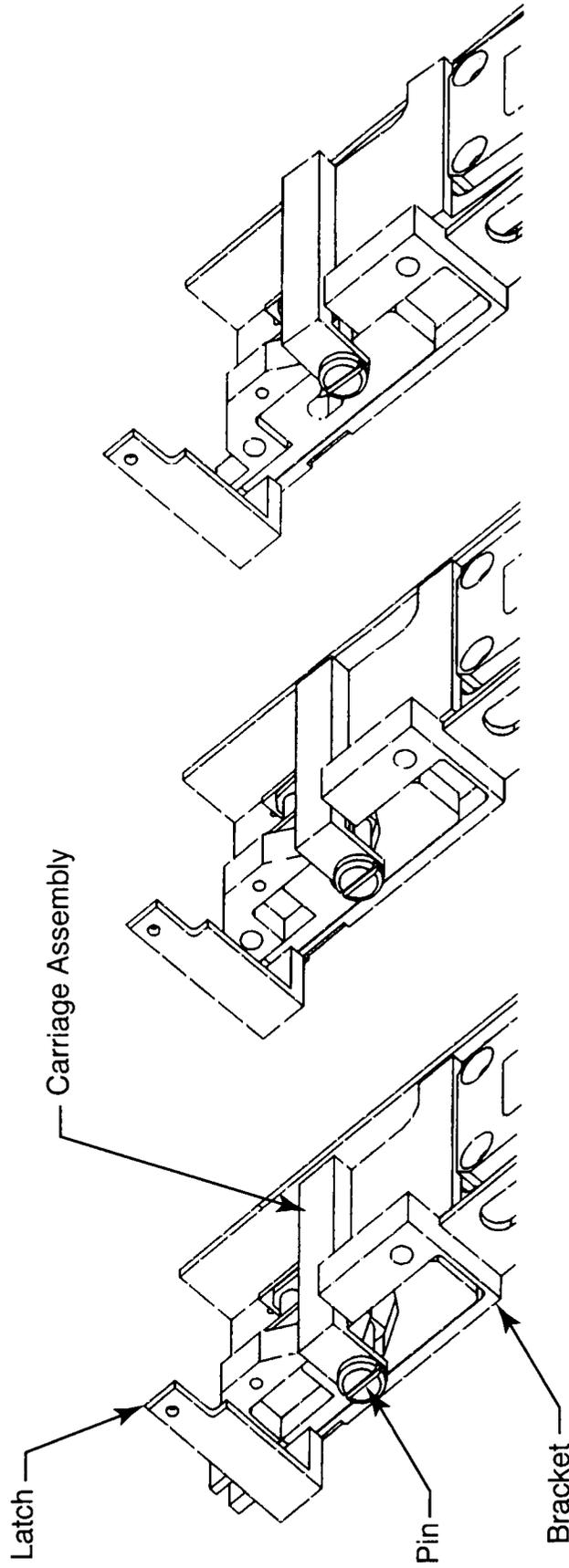
Fully Locked

Unlocked

Figure 2

(For illustration, the actuator and cover plate have been removed)

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Unlocked

Half Open

Full Open
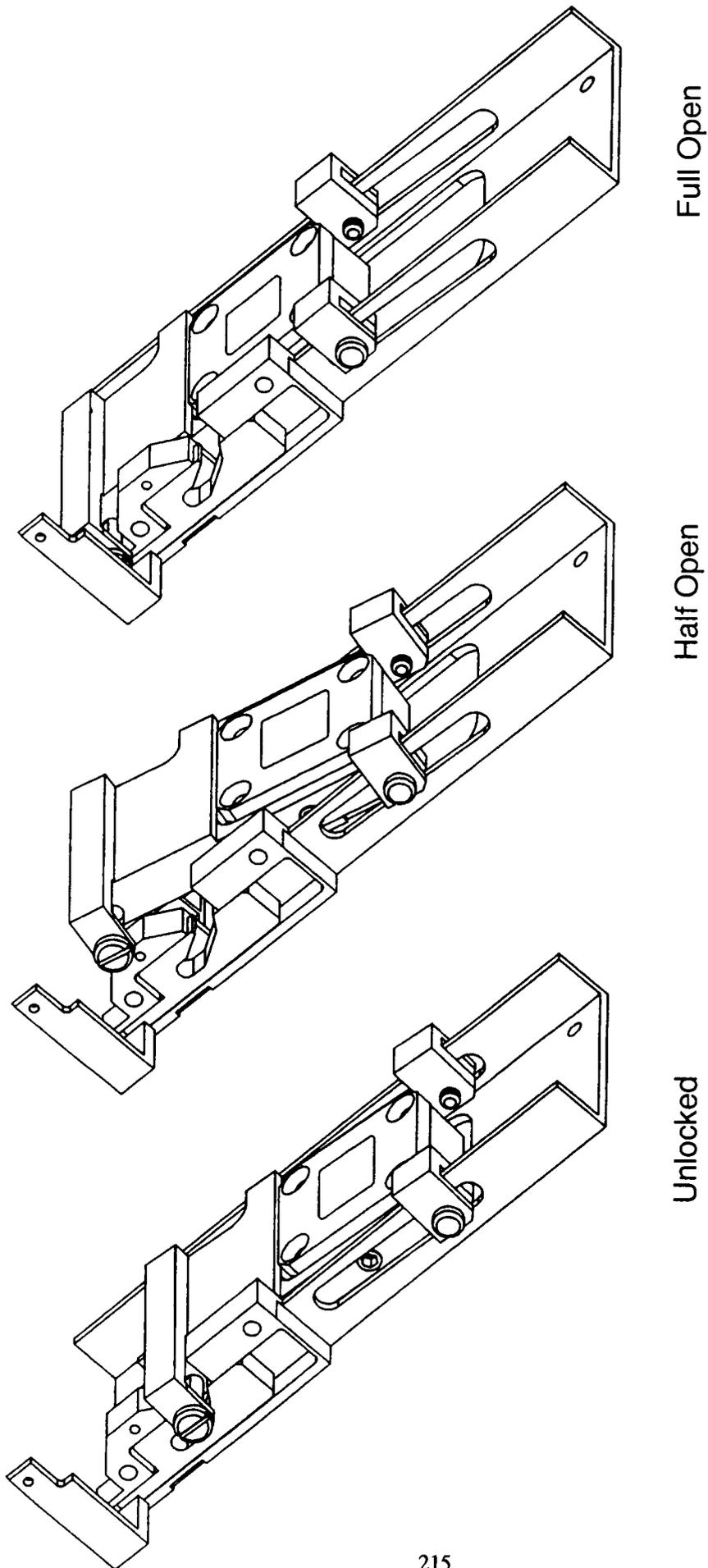
Figure 3

(For illustration, the actuator and cover plate have been removed)

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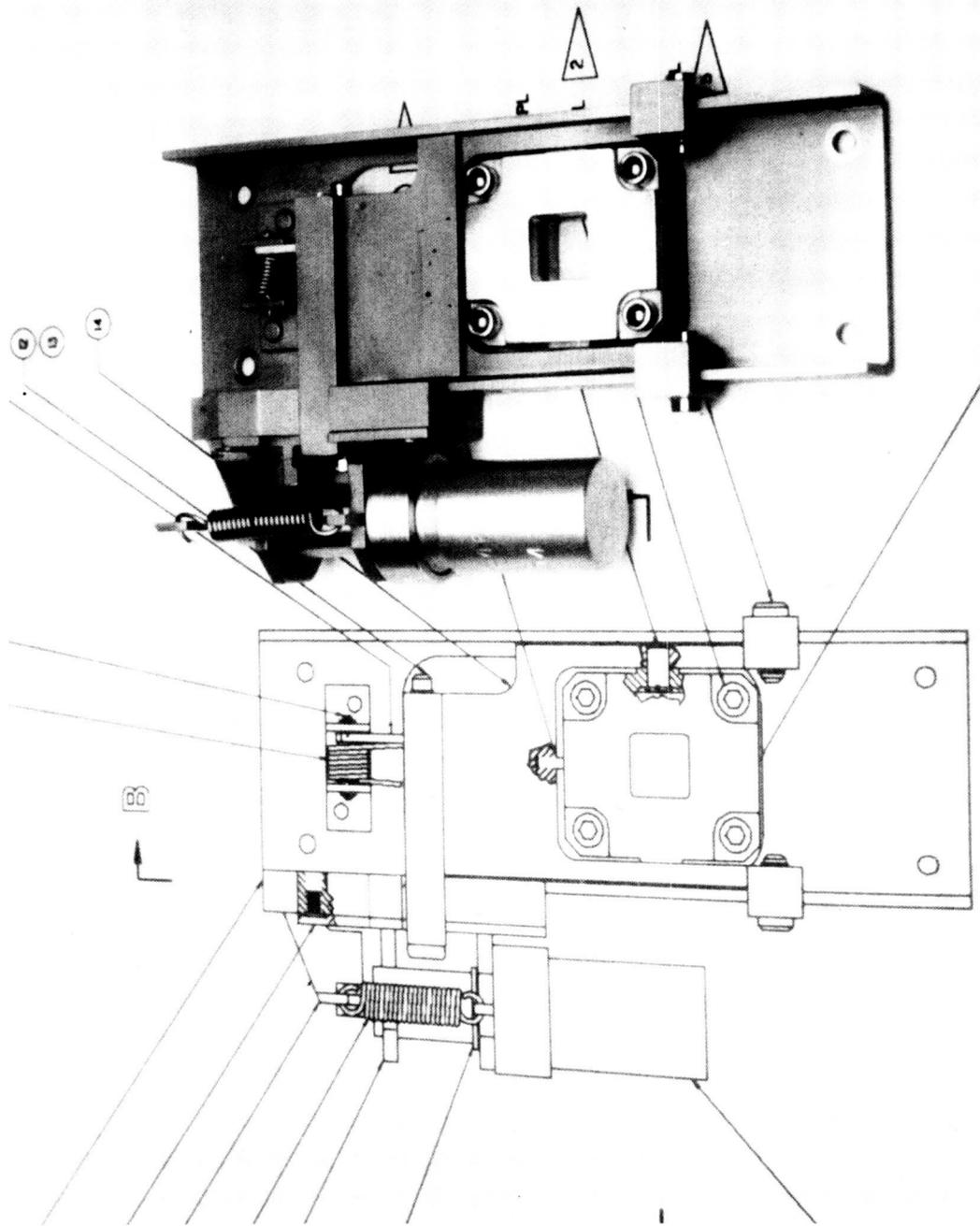
The Vacuum Door Assembly Development Unit

Figure 4
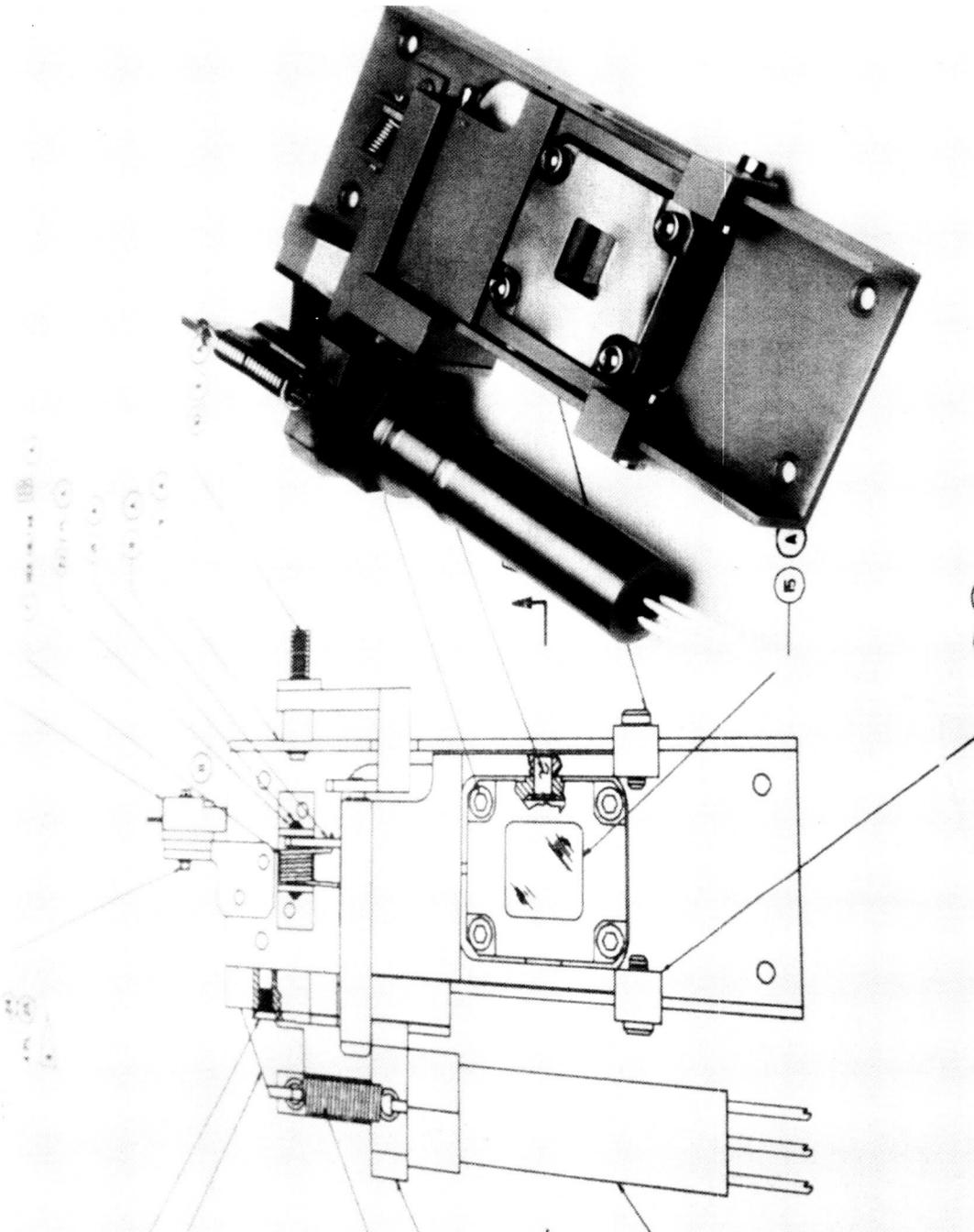
The Vacuum Door Assembly Development Unit With Eng. Model Actuator

Figure 5