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DRAWER DRIVE FOR SPACE SHUTTLE VACUUM CANISTER[1]

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SUMMARY

A sliding drawer type canister was designed to contain LDEF experiments which require vacuum storage before and after space exposure. The elastomeric seals require high closing loads which are generated thru camming levers and transmitted thru a spring loaded pressure plate. Lubrication was provided by various dry surface coatings. Higher than expected friction required some redesign after which the assembly functioned well and provided good sealing.

INTRODUCTION

A conceptual study for a Vacuum Exposure Control Canister (VECC) for NASA's Space Shuttle Long Duration Exposure Facility (LDEF) resulted in the sliding drawer concept depicted in figure 1. The experiment is carried in a tray or drawer which upon closing, slides into the Vacuum chamber and the "drawer-front" seals against the face of the chamber. The entire assembly is designed to occupy one third of an LDEF experiment frame and to a 15.2-cm (6-in.) depth. The assembly measures 83.8 x 41.3 x 15.2 cm; the chamber is 37.5 x 37.6 x 9.5 cm; while the experiment drawer measures 35.6 x 34.0 x 4.8 cm deep. The application requires that the drawer may be opened and closed several times in the preparation, exposure, and evaluation of an experiment. This requirement eliminated the use of metallic or ceramic sealing elements in favor of elastomeric sealing elements, despite the knowledge that such seals could not maintain a hard space vacuum in the chamber. It was also decided that the prototype design phase would include a full scale evaluation of three candidate "Gasko-Seal" designs as manufactured by Parker Seal.

SPECIAL DESIGN REQUIREMENTS

In addition to the usual aerospace design constraints the following requirements were special to the LDEF and VECC usages.

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General Requirements

The unit must meet the Space Shuttle environment which was found to be typical of aerospace flight. The most significant single requirement is that the mechanism must function at ambient conditions, in a hard vacuum at 1 g, and after long periods in a hard vacuum at zero g. This means that all sliding members must be provided with lubrication that will be sustained for long periods in space vacuum. The other general requirement impacting the design is that nonmagnetic materials be used in the mechanism and structure.

Specific Requirements

Space

The total volume for the VECC sounds large; however the upper 9.5 cm of the total height of 15.2 cm is occupied by the vacuum chamber or is swept out by the drawer motion. The mechanism must operate in the lower 5.7 cm. The space under the chamber must house the motor with gearing and the mechanism in the closed position along with all electrical connectors and wiring, the programmer, support structure and an experiment data wire trough.

Seals and Loads

The candidate seals are shown in figure 2 along with the face plate configuration. The seals, variants of Parker Seal's "Gasko Seal" design, all are embedded directly into the seal plate, rather than being fabricated into a separate carrier piece as is often practiced. The integral design approach eliminates an extra leak path. The single and double seals were carried thru to tests, while the double lipped single seal was dropped on the recommendation that this seal offered no sealing advantage and sometimes is troubled by gases trapped between the lips. All the seal configurations were to use Parker V720-75 compound, which is a variant of DuPont "Viton" fluorocarbon and is considered to provide the best vacuum sealing.

The required force to close the seal is a function of seal geometry and the seal material characteristics. The gasko seal design requires that the seal is compressed so that it occupies a very high percentage of the volume available in the seal groove. The Viton is a very tough material which resists being compressed into a confined groove. Whereas the preliminary design of the drawer drive was based on a more typical closing load of 6130 N/m (35 lb/in) of seal, the Viton gasko-seal combination requires a load of 20,315 N/m (116 lb/inch). This significant increase of design load required a re-thinking of the drive design. Although a low power drive targeted at 25 watts was desirable, this requirement was not hard. A firmer limitation was the space available for the motor. This condition is somewhat alleviated by a loose requirement for closing and opening time. Initially the design was targeted toward the 3-4 minute range, but any time within half an hour was acceptable. Energy was more critical than time.

SEAL EVALUATION

The program plan was to evaluate the seals at the earliest possible date while the design and fabrication of the remainder of the unit were in progress. Accordingly the chamber, face plate, and pressure plate assemblies were designed first. Face plates as shown in figure 2 were fabricated with blank faces and shipped to the seal manufacturer where the grooves were cut and seals molded. The chamber was designed and fabricated with a thick bottom which could be later modified to mount and accommodate the drawer drive elements. The pressure plate assembly including the stacks of Belleville washer springs were designed. Individual springs were loaded to a recommended 67% of deflection to the flat state. The washers were stacked in parallel to provide the necessary load and these stacks were used in series to provide a deflection judged necessary for good load distribution. The total seal load for the single seal is 18,237 N (4100 lbs) and for the double seal 36,474 N (8200 lbs). Nominal location for the three spring stacks had been established in the early design release. An examination of deflections in the face plate revealed that the ends deflected well in excess of the allowable .008 cm (.003 inch) flatness to assure good sealing. Side stacks of springs were introduced to closely match the distribution of the applied spring load with the seal loading. A breadboard pressure plate was made up for seal evaluation testing. Figure 3 shows the spring stack arrangements used and the tie bolted test setup. The belleville springs were lubricated with dry film MoS_2 to avoid binding between individual washers. The tie bolts were tightened to provide the computed spring deflections. The face plates - chamber face gap was measured before loading and was found to conform to the seal height tolerance .061 to .066 cm (.024 to .026 in). When loaded, the design fully satisfied the seal manufacturer's recommendations that the seal plate faces shall be closed within .008 cm (.003 in).

Helium leak rate testing is shown in figure 4. Six tests were run using two single seal face plates and one double seal plate. Leak rates were obtained as follows:

Run No.	Seal Plate S/N	Leak Rate SCC/Sec (He) Single Seal	Leak Rate SCC/Sec (He) Double Seal
51	2	4.28×10^{-5}	
52	2	5.38×10^{-5}	
53	1	5.17×10^{-5}	
54	1	4.13×10^{-5}	
D1	1		3.56×10^{-5}
D2	1		5.74×10^{-5}

Although the double seal tests took up to 50 minutes to arrive at steady state while it took up to 17 minutes for the single seals, the steady state leak rates show no significant difference. In the application, the steady state leak rate is the significant criterion. Accordingly, all subsequent work was with the single seal which required a 18,237 N (4100 lb) rather than a

36,474 N (8200 lb) closing load. These tests validated the pressure plate and spring stack design and demonstrated seal leak rates compatible with predictions.

MECHANISM DESIGN

The design approach was driven by the duty cycle. The drawer must traverse its full length, 33.3 cm (13.1 inches), at a very nominal loading, overcoming only friction and in the final .439 cm (.173 inches), the load increases to the final value of 18,237 N (4100 lb). This suggests a drive of modest load capability to traverse the distance and which then operates a load multiplying mechanism to develop the high terminal load. The basic drive consists of a gear motor driving an Acme lead screw engaging a trunnion nut. The nut drives the tray thru a pair of actuating arms as shown in Figure 5. These arms are held in disengaged position by latches. As the drawer approaches the closed position the operating arms pass thru an opening in a reaction plate, and then are unlatched so that further movement of the trunnion nut rotates the actuator arms. The trunnion nut and slide blocks slide in the arms, and a cam surface on each actuating arm bears against a reaction surface on the reaction plate. The actuator arms are mounted to the pressure plate by support fittings which pull the pressure plate home. Trade offs include gear ratio, lead screw pitch and diameter, Acme nut vs. ball nut, and lever ratio. A ball nut was rejected as being too bulky and unnecessary. Low friction coatings promised high efficiency of the drive. A load limited 7/16-12 Acme lead screw was used after analysis of shaft resonance frequencies showed that heavier shafts still resonated within the 60-300 Hz vibration requirement. A 218.4:1 commercial gear motor with a nominal 13 RPM no load speed and a stall torque of .71 N•m (100 oz•in.) was chosen to match the loads and provide a closing or opening time of approximately 12 minutes. The chosen motor performance was characterized by test and found to closely match catalog data. It was found that this motor offered good performance while the cost of purchasing it and modifying it for space operation was much less than for purchasing an aerospace motor.

The actuating arms were designed to give the maximum ratio consistent with the geometry constraints, which proved to be 5:1. This trade off involved the Hertz stress at the camming surface. The radius of the surface was kept as large as possible, but at 2.54 cm (1.0 in.), the Hertz stress was 1,275,000 kPa (185,000 psi) for the double seal and 896,000 kPa (130,000 psi) for the single seal. This stress in combination with the requirement for non-magnetic materials posed a problem which was solved by fabricating the arms and the reaction plate of A286 steel.

In the vertical plane the support fittings pull on the pressure plate at a line below the center of the sealing forces, creating a moment of 2083 N•m (18,450 lbf•in). This moment is reacted out thru the pressure plate arms as shown at R_1 and R_2 in figure 6. These arms were originally envisioned as lightweight support and guiding members, but to carry the large moment, they were beefed up and provided with reaction surfaces. The top of the far end of each arm slides on the bottom of the vacuum chamber, and a shelf at the pressure plate end engages a mating shelf on the reaction plate. This engagement occurs just prior to seal closure.

In addition to the drawer drive, trigger type mechanisms were designed and built to operate shades which protect the elastomeric seals from strong solar radiation while the drawer is in the fully open position during space exposure. These appear in Fig. 1.

A programmer was also developed to control the operation of the unit. This component appears in figure 6. Although it required a considerable effort it is not discussed further in this paper.

MATERIALS AND FRICTION COATINGS

The structure used aluminum to a maximum degree. Nuts, cap screws, and various pins, slide blocks and small slippers are of 300 series CRES. The high stress members, i.e., the trunnion nut, drive screw, the actuator arms and the reaction plate are all of A286. This alloy provides the necessary strength in a nonmagnetic material, and it is the least expensive and most readily available material meeting these requirements.

For the VECC to be used conveniently, it is required that all sliding surfaces be self lubricated. The need to operate after extended space exposure further emphasizes the need for relatively permanent lubricated surfaces. Dry film MoS_2 and a number of proprietary surface treatments were used. These were various grades of "Tufram", "Nedox" and "Hi-T-Lube" developed by General Magnaplate Corporation. Tufram is a form of anodize impregnated with Teflon. Nedox is a form of nickel plate impregnated with Teflon, and Hi T - is a dry film lubricant developed for temperatures above 587 K (600°F). The design was reviewed with the intent of choosing finishes so that in each sliding contact a relatively hard surface bears against a relatively soft surface.

A few of the major parts and the finishes used are as follows:

Lubricant Surfaces

Component	Material	Surface	Thickness cm
Drive Worm	A286	Hi-T-LUBE	.0013
Trunnion Nut	A286	NEDOX SF-2	.0018
Slider Blocks	304 CRES	NEDOX SF-2	.0013
Actuator Arms	A286	Hi-T-LUBE	.0013
Reaction Plate	A286	NEDOX SF-2	.0013
Guide Slipper	7075-T651 aluminum	TUFRAM H-2	.0025
Rail	6061-T4 aluminum	TUFRAM L-4	.0038

The drive performance was predicted on the basis of a 70% lead screw efficiency which is approximately equivalent to a coefficient of friction of 0.15. A torque margin of 1.01 was available for the double seal and 3.02 for the single seal.

Adapting the motor for space operation was a separate effort. The manufacturer provided silver graphite brushes and then the gearbox was lubricated with a high vacuum grease containing MoS_2.

SYSTEM TESTS

The complete VECC was assembled and operation of various elements attempted. The seal shades were adjusted to accommodate asymmetric tolerance build up. The drawer suspension slippers and rails appeared to function well.

The first serious trouble developed when trying to unlock the actuator arm latches. They did not unlock; rather when the adjustment screws contacted the reaction plate, the drive motor stalled. After some tinkering with adjustment, it became evident that the trouble was more fundamental. Geometrically, the latch looks good and with the "low" nominal friction expected in all parts it should work very well. Accordingly, it breezed thru all the entire design review gamut without a careful force analysis. In actual operation, the low friction surfaces are effective, but friction is still of a significant value. This fact coupled with the moment arm ratio of the trunnion nut to the latch pin approximating 12:1 made the force on the latch pin so high that the latch could not slide off the pin. The latches were replaced by a single latch arm as shown in figure 7, which operates satisfactorily.

The general level of friction proved higher than predicted including the drive screw friction. In cycling the unit, the drive motor was dragged down to near stall before the actuator arm contacted the shut off switch. This demonstrated that the available motor torque was marginal. Fortunately, a higher torque motor was available, which could easily fit into the design and this was later incorporated.

Leak testing of the chamber when closed by the VECC drawer drive produced leak rates equal to those of the earlier tie bolt tests. The unit was cycled thru more than 50 complete openings and closings, demonstrating the durability of the design and the seals. The unit has since successfully passed environmental testing to Space Shuttle levels, and several units have been built for use on LDEF.

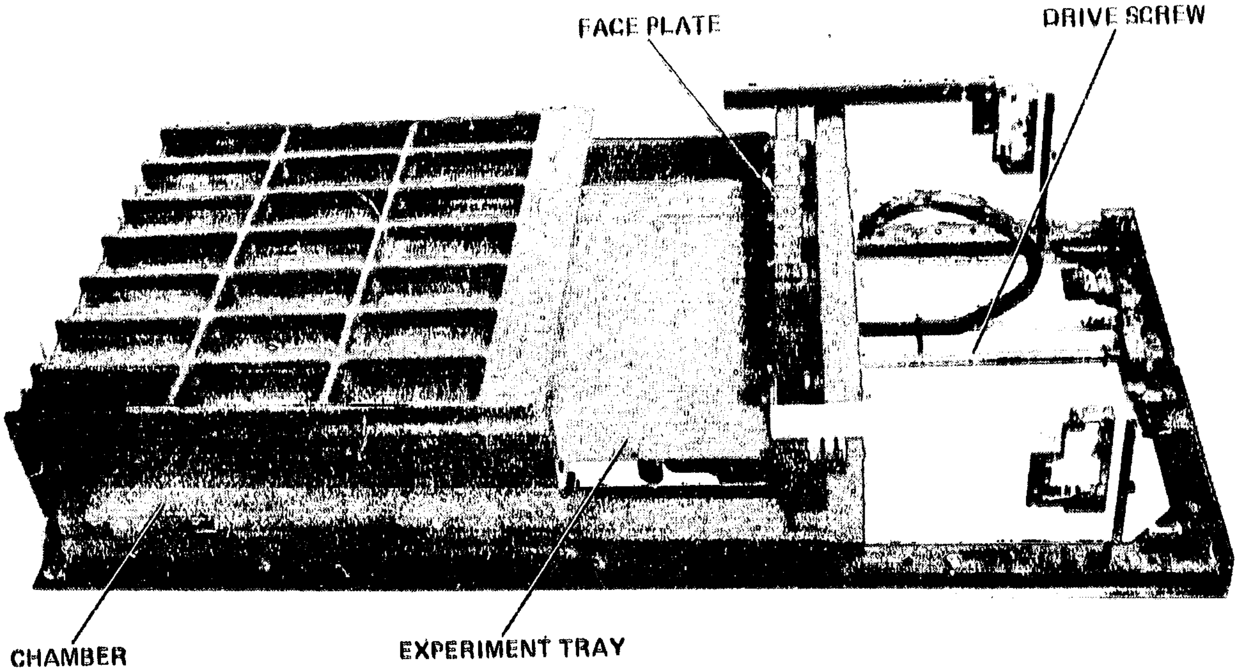

Figure 1.- Sliding tray Vacuum Experiment Control Canister.

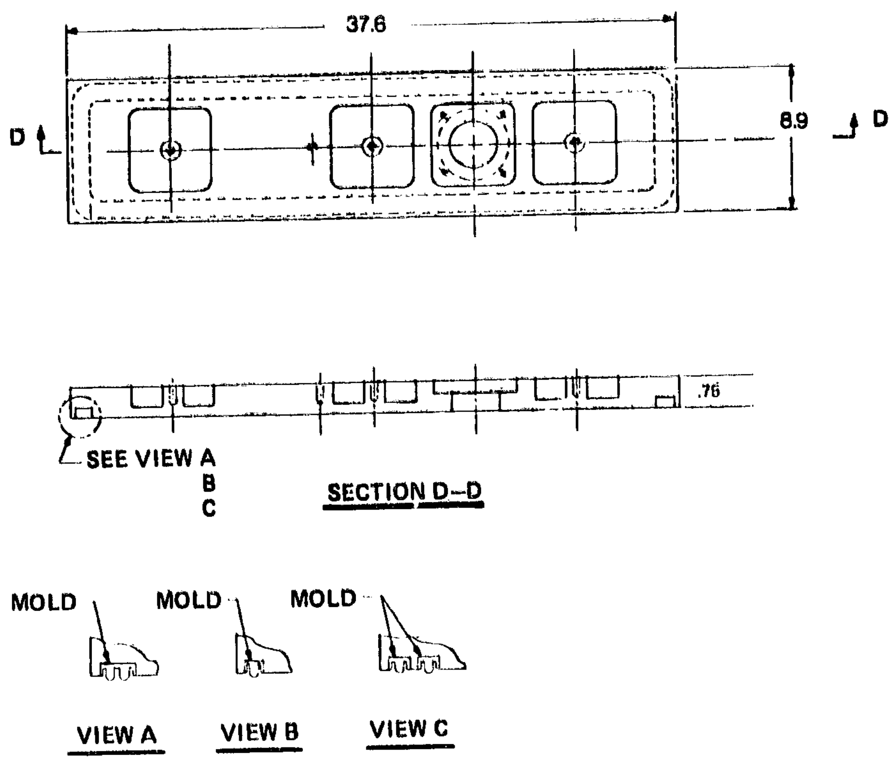

Figure 2.- Face plate. Dimensions are in centimeters.

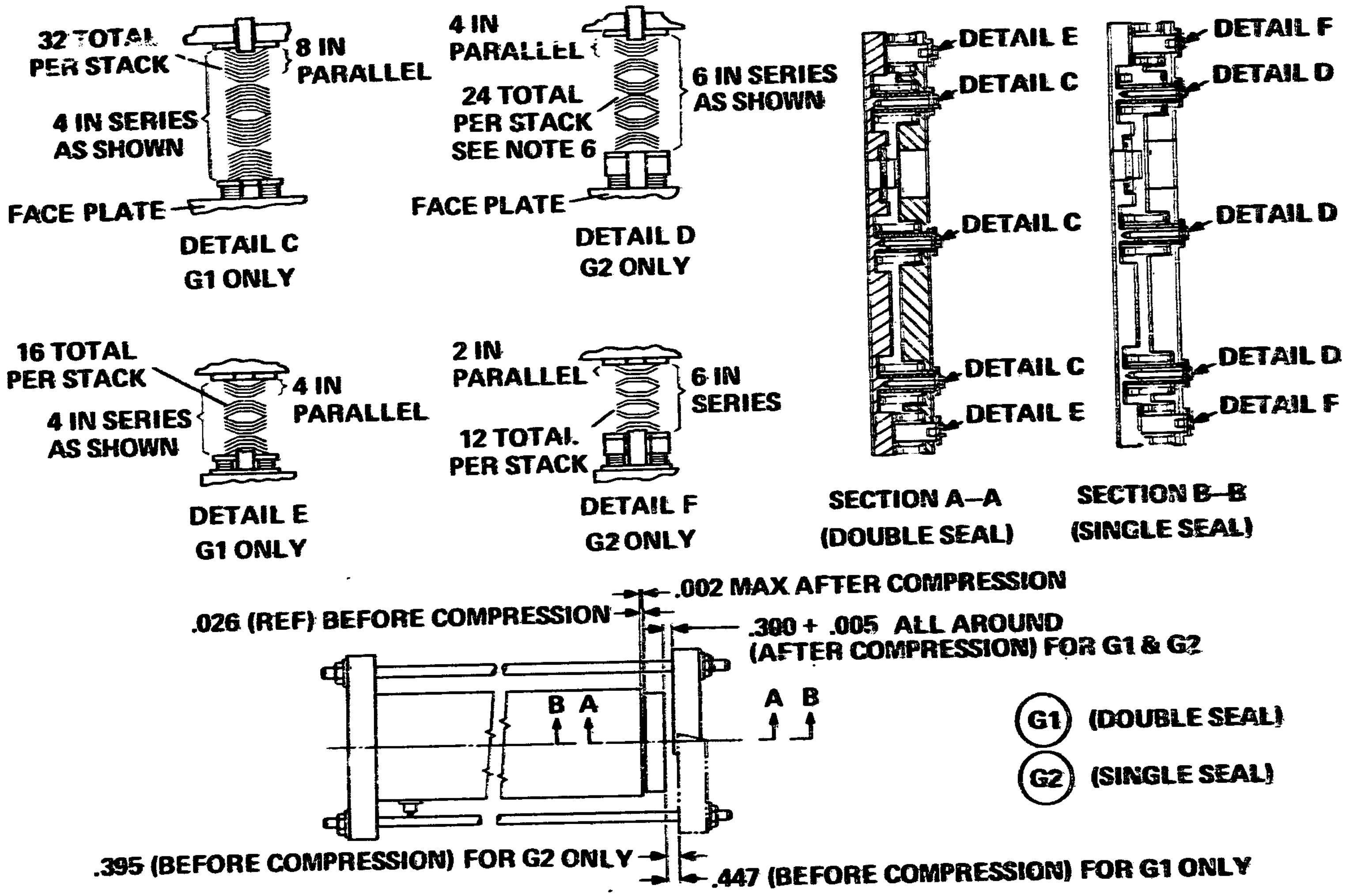

Figure 3.- Spring stacks and test setup.

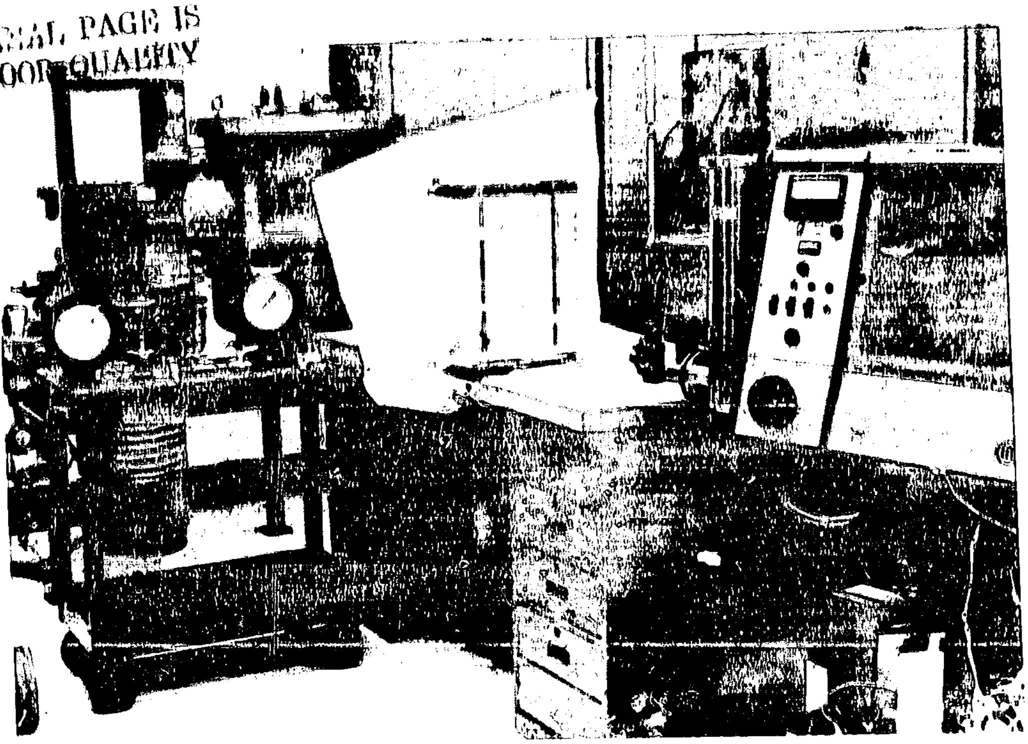

Figure 4.- VECC leak rate test configuration (cannister enclosed for helium fill).

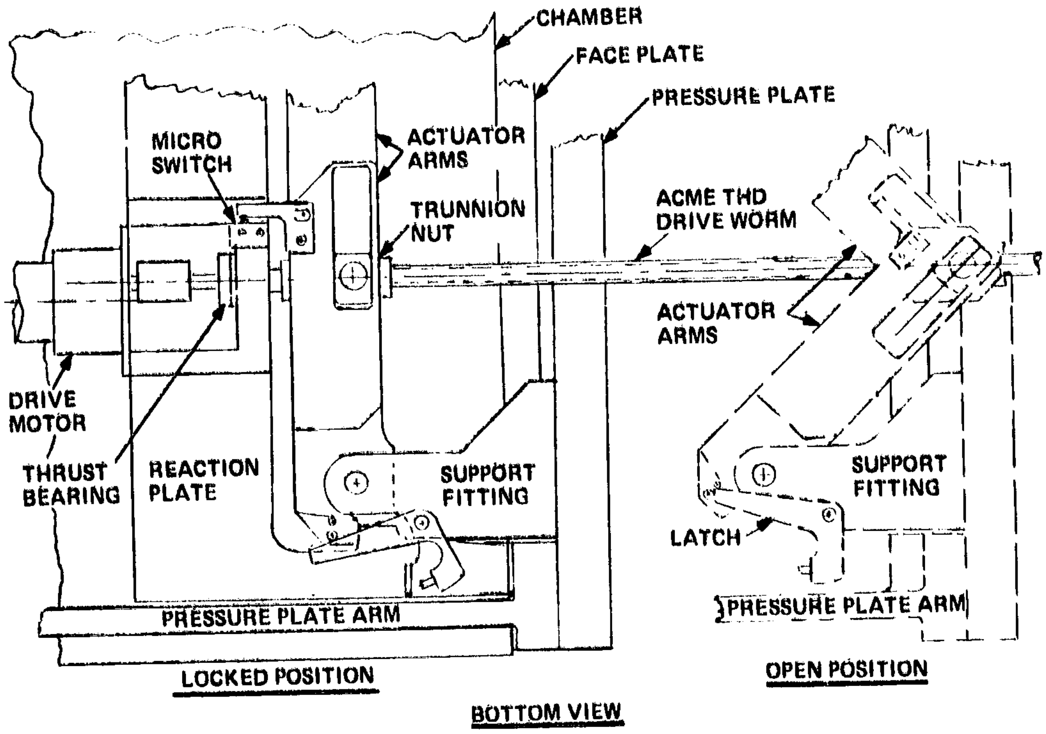

Figure 5.- Tray drive design.

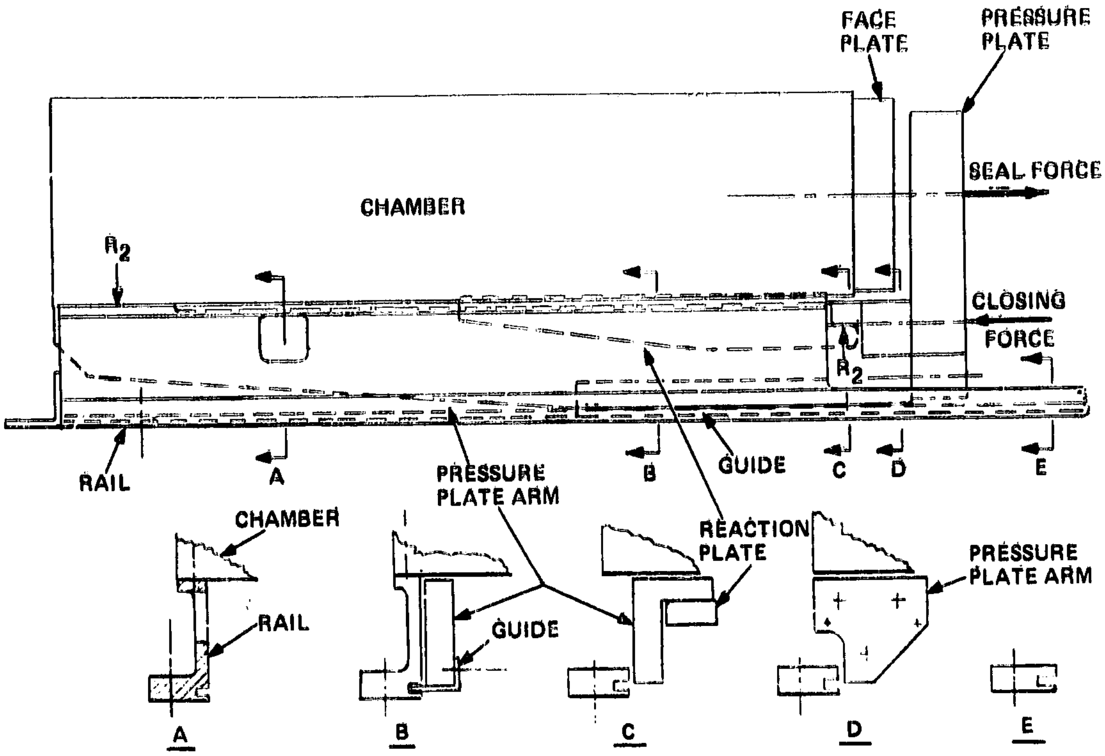

Figure 6.- Tray and chamber support.

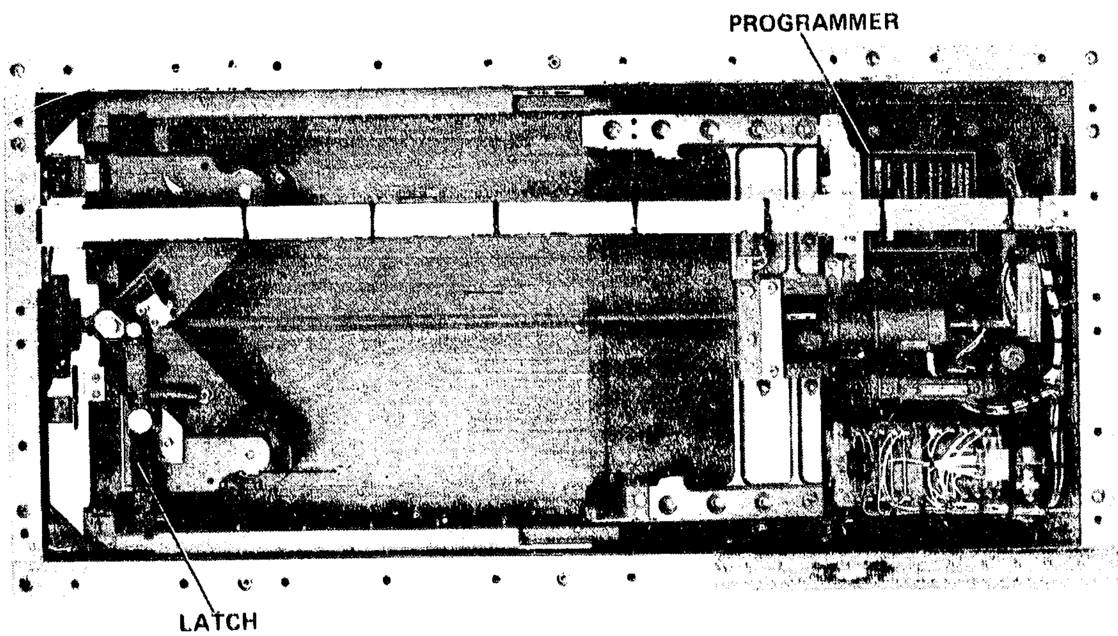

Figure 7.- VECC bottom view.