N84 25083

DESIGN AND TEST OF A LOW-TEMPERATURE LINEAR DRIVER/RATE CONTROLLER

Charles H. Lowry

ABSTRACT

This paper describes the design and testing of a force/rate control device used to deploy an Earth shield on an orbiting satellite/sensor. Test experience, failure modes, and applications are emphasized.

INTRODUCTION

The Teal Ruby Experiment (TRE) involves an Earth-orbiting infrared sensor. The TRE program, which is being carried out by Rockwell International Corporation, Space Transportation and Systems Group, is sponsored by the Defense Advanced Research Projects Agency and managed by the Department of the Air Force, Space Division Headquarters. The P80-1 spacecraft provides a stable orbiting platform for the TRE sensor.

The objectives of the TRE are: (1) to demonstrate that cooperative aircraft can be detected from space with an infrared-type sensor, (2) to establish a global database in several infrared spectral bands that will be useful in defining future space surveillance systems, and (3) to demonstrate mosaic infrared sensor technology in space.

The TRE sensor mosaic focal plane detects infrared energy radiated to space from the Earth in discrete spectral bands. The focal plane and interior optics of the telescope are cooled to cryogenic temperatures by a solid cryogen system that is integral to the sensor assembly. Three electronic boxes mounted on the P80-1 spacecraft functionally support the sensor assembly. Figure 1 shows the TRE mounted on the P80-1 spacecraft.

Figure 1 also shows the Earth shield, which is used to intercept infrared energy and reflected solar radiation from the Earth's surface and to protect the sensor from this heat load. The Earth shield is stowed during launch and until final orbit is achieved. Then, on command from the Earth, a pyro device releases latches and permits the Earth shield to pivot into its deployed position (Figure 1).

This paper describes the mechanical system designed and provided for deployment of the relatively large, lightweight TRE Earth shield; and discusses the advantages of this design and how it could be profitably used in other applications.

ORIGINAL PAGE IS
OF POOR QUALITY

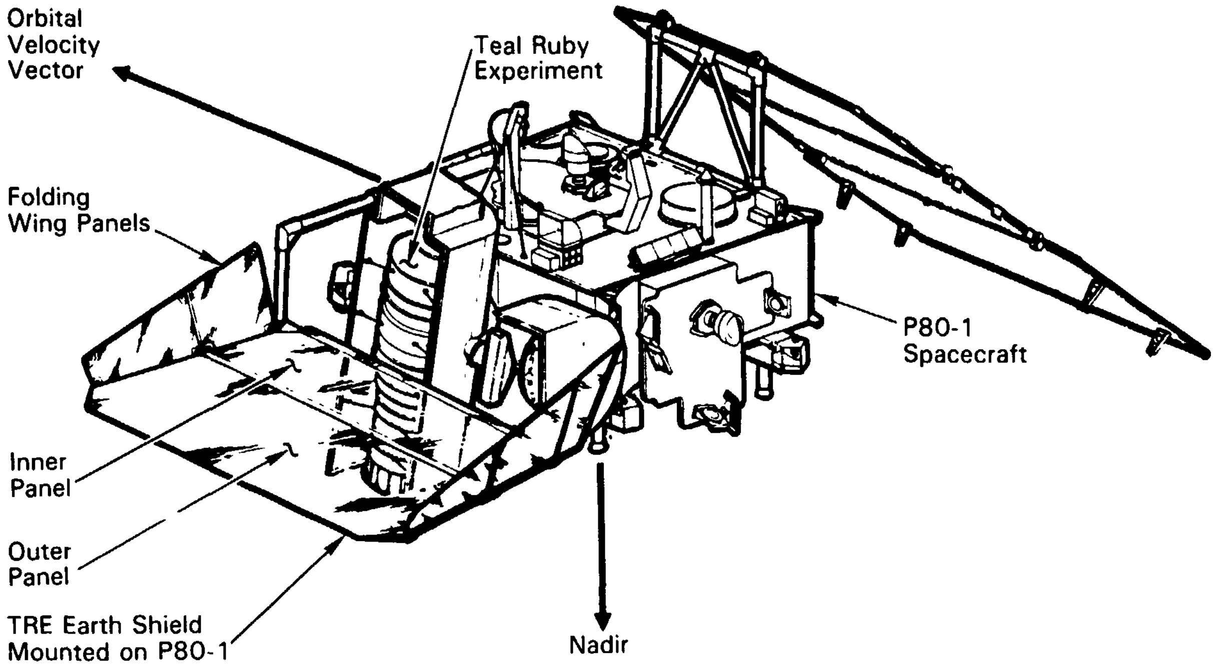

Figure 1. Teal Ruby Experiment with Earth Shield

Single (one-shot) deployment of mechanical and structural devices/members in space often requires a one-way drive mechanism coupled with a rate control device to move deployables into operating position while simultaneously controlling dynamic loads. The drive mechanism must be simple, reliable, and capable of providing the required force with an adequate margin throughout a prescribed temperature range. The rate controller must operate effectively and reliably throughout this temperature range while it limits velocities and loads in the system. Gases or fluids must not leak out, because the device would become ineffective and could contaminate surrounding hardware.

As the United States Space Program moves toward large space platforms, more requirements that involve deployment of basic structural members, antennas, and solar arrays will appear. Therefore, more attention will be focused on driver/rate controller devices. Standardization of concepts, if not standardization of specific designs, could result. To distribute loads and make deployment systems more failure tolerant, several of these devices may be used in parallel in a typical application.

The device described in this paper is a low-temperature, linear driver/rate controller (LDRC) that has been tested and proven effective in controlled deployment applications. The LDRC employs a compression spring for storing energy and a unique welded bellows system to prevent leakage of the low-pressure gas used in the orifice system. Through use of metal bellows and welds in all pressurized joints, it provides a hermetically sealed container that is without the conventional static or dynamic seals that can become potential leak paths. Further, positive pressurization of the device is verifiable up to the time of launch through use of an external mechanical indicator.

Specific design features in the device, methods of simulating zero-g testing, test results, problems encountered, problem resolutions, and performance data are all topics that are discussed in this paper.

DESIGN REQUIREMENTS

The LDRC was designed to deploy a specific Earth shield from its stowed position to its fully deployed position within a prescribed time period and without inducing excessive loads. Specific design requirements that influenced the chosen concept included the following:

- For redundancy two independent but identical LDRC's will be used.
- The initial deployment force in the stowed position will be 18 kg (40 lb) maximum. Upon release, the LDRC will linearly stroke 11.7 cm (4.62 in.). The final force at the end of a stroke must be at least 3.7 kg (8.2 lb).
- Stroke time will be 3.0 sec minimum and 15 sec maximum. If one LDRC loses its damping capability, the other one will ensure proper system performance.
- Positive prevention of leaks will be emphasized in the design.
- The prescribed volume envelope will be met, and weight will be minimized.
- Dynamic performance will be in accordance with Figure 2.
- A pressure indicator will be provided to verify that no leakage of damping fluid has occurred just before launch.
- A tracer fluid will be used for leak testing on the ground.
- The operating temperature range will be from 380^{o}K to 172^{o}K.
- The device will meet these requirements after exposure to boost dynamics and acoustics.

DESIGN

The design concept chosen involved a basic spring thruster and viscous damping. A gaseous fluid was chosen because of its relative insensitivity to temperature and because of the system elasticity it provides.

ORIGINAL PAGE IS
OF POOR QUALITY

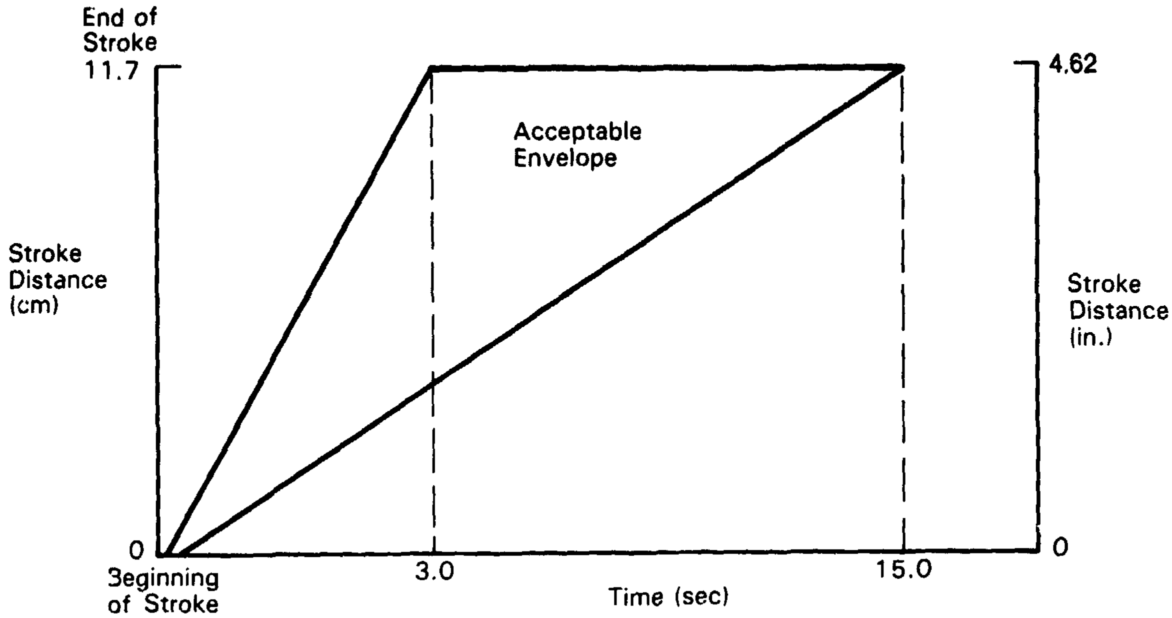

Figure 2. Acceptable LDRC Operating Dynamic Envelope

Leakage of this fluid was a major concern because of possible contamination and also because of changeout and retesting of the actuator, if carried out during critical system environmental testing or late in the sensor checkout and prelaunch phase, would cause schedule delay. Therefore, a totally enclosed, low-pressure gas system, hermetically sealed by welds, was chosen. Conventional static or dynamic seals were not required to maintain the gas in the device. Metal bellows were employed to contain the damping fluid while they allowed the actuator to stroke. The spring thrust system that was chosen is unique because it uses the metal bellows to supplement the force produced by the main thrust compression spring to produce a resultant force versus stroke curve ideal for this application (i.e., high force at the beginning of a stroke, tapering down to the prescribed holding force at the end of a stroke.)

Figure 3 shows the designed of the LDRC device for this application in its relaxed or deployed position. For installation in the stowed Earth shield, the main thrust spring is compressed when the retraction rod is pulled to the left. A latch device is not provided, because the LDRC is held in this position by the stowed Earth shield. A separate pin-puller latch system is provided elsewhere on the Earth shield to initiate deployment and allow the LDRC to stroke.

The LDRC is made up of the following principal parts and constituents:

- Main thrust spring
- Bellows

ORIGINAL PAGE IS
OF POOR QUALITY

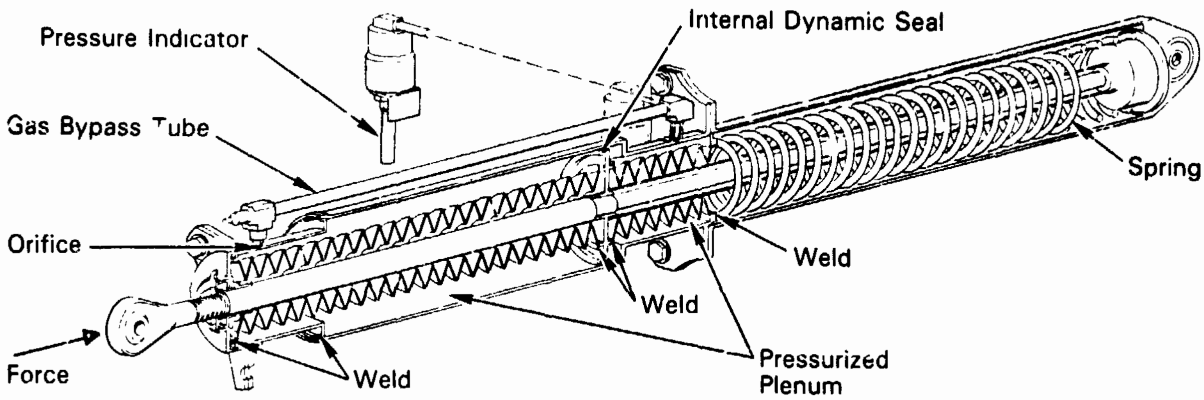

Figure 3. Linear Driver/Rate Controller

- Orifice
- Piston
- Gas
- Pressure indicator
- Housing
- Retraction rod

The main thrust spring is contained in a separate, removable part of the housing to facilitate assembly and to provide access to the spring. This feature allows changeout to a stronger or weaker spring to be carried out as requirements change. Provisions were also made to accommodate dual, nested coil-springs, should they be needed. Tests of the system verified the adequacy of the present spring, whose performance is shown in Figure 4.

The bellows, which were the most challenging aspect of the LDRC design, were the only area in which failures were experienced. The bellows supplier's analytical methods indicated that the critical parameter in this application would be bellows tension loads, and a configuration was established. The bellows were initially amde from AMS 350 stainless steel. After several failures, more convolutions were added to both bellows, the heat-treated length was modified, and the material was changed to Inconel 718. These measures were aimed at reducing stress. The heat-treated "free" length is important to the establishment of desired spring force characteristics and to the control of tensile stress in the bellows. The primary failure mode in the bellows involved excessive tension, which is further discussed in a later section.

Installation of the bellows in the LDRC is shown in Figure 3. Each attachment of the bellows is done through tungsten inert gas (TIG) welding.

ORIGINAL PAGE IS
OF POOR QUALITY

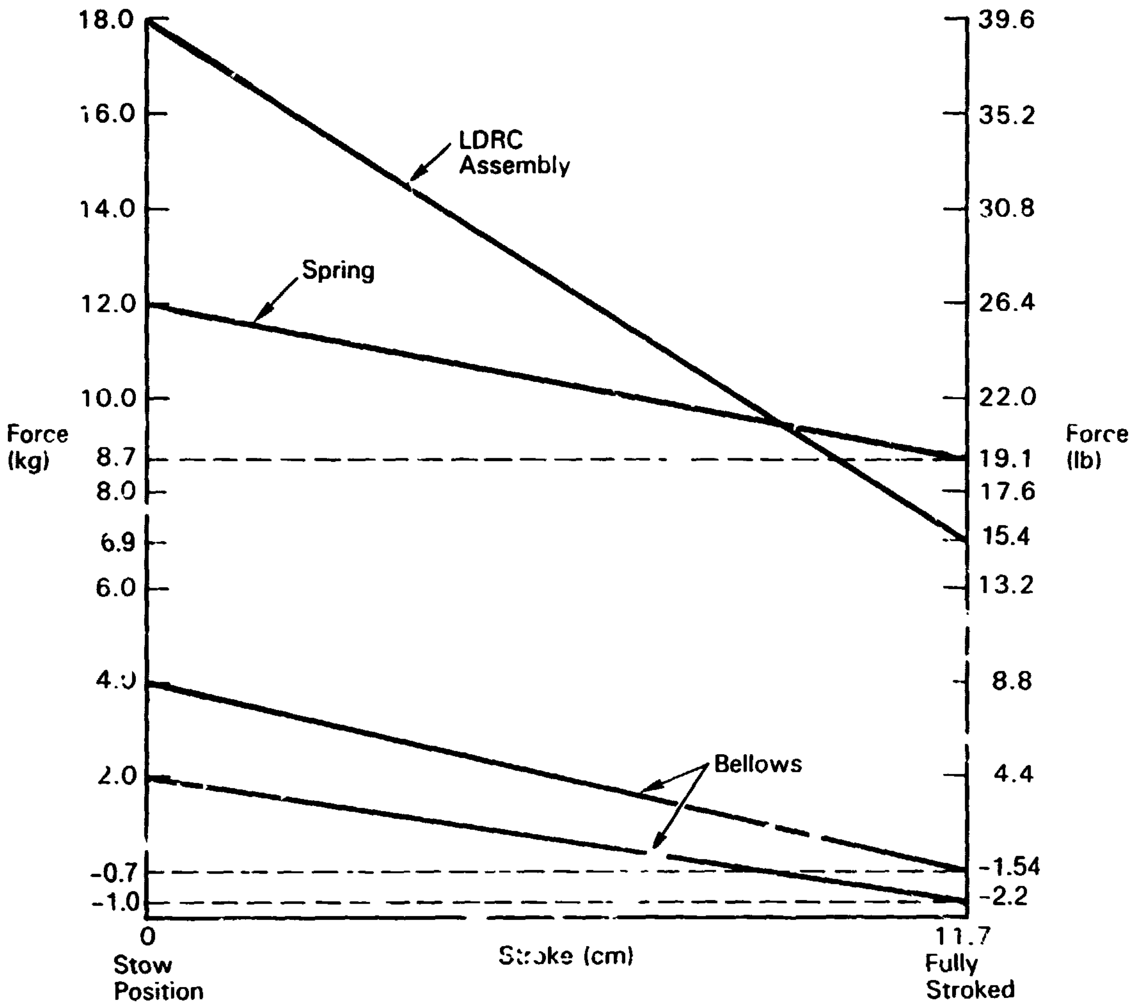

Figure 4. Force Versus Stroke Envelope

All weld joints are identical, so that weld schedules are uniform. Welds are verified by pressure leak testing at subassembly level. No leaks were experienced in this testing by any of the units fabricated.

The thrust contribution of the bellows is shown in Figure 4. Although one of the bellows is compressed and the other bellows are extended through actuation of the LDRC, both have similar force/stroke curves. Both provide opposing forces to the spring system near the end of a stroke. This is governed by the position in which the bellows are held during heat treating, which establishes the "free" length of the bellows.

The size of the orifice controls the damping force. (The orifice is a simple drilled hole in an orifice plate.) Dual orifices could have been provided for redundancy, but this design was not adopted because it would have resulted in extremely small orifices. The location of the orifice in this application was selected because it was necessary to have changeout capability in the event that performance requirements changed. Thus the orifice is located in an exterior porting system, as shown in Figure 3. Installation of the orifice directly into the piston is desirable because it minimizes the vulnerability of the exterior porting system.

The piston shown in Figure 3 is rather inert; it contains only an omniseal for sealing between bellows chambers that are internal to the hermetically sealed system. Any leakage that occurs at this seal during actuation is considered repeatable and accounted for in performance testing of the LDRC. In other applications, as indicated previously, it may be advantageous to incorporate the orifice in the piston.

The damping gas chosen was 95 percent dry nitrogen and 5 percent helium. Nitrogen was chosen because it is relatively dense, inert, and inexpensive. The helium is used in postmanufacturing checkout and leak check. The system is pressurized at a 2-atmosphere gage reading, which provides a gas density sufficient for efficient damping but at a pressure low enough to avoid stressed joint problems.

A pressure indicator such as that shown in Figure 3 was provided for long-term monitoring. This device is essentially another bellows that can be monitored periodically against a fixed, go/no-go scale just before launch.

The housing is primarily made up of simple, turned parts. Aluminum is used in the spring thruster housing, but steel is used in those areas where welding is necessary.

The retraction rod and the mounting interface on the other end of the LDRC are equipped with spherical bearings to facilitate alignment during actuation.

ANALYSIS

The design and performance capability of the LDRC was largely verifie by analysis. In addition to the usual static stress analyses, a versatile dynamic model was constructed to demonstrate the kinematics of the Earth shield panels, the force history of the LDRC, and the time history of deployment. This model can accommodate a family of orifice diameters, spring rates, initial gas pressures, and piston diameters.

From a loads standpoint, the key parameter is the panel deployment velocity at the end of a stroke, which produces impact loads as the panels drive into their stops. By variation of the orifice and spring parameters, a final design configuration was established. The only uncertainty was the precise orifice diameter, and finalization of this parameter was relegated to development testing of the LDRC in a system simulator.

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 5 shows a deployment history of the two main panels of the Earth shield. It can be seen that the outer panel has a major influence on the behavior of the inner panel and the LDRC. The outer panel is released from its stowed position, which allows the LDRC to begin its stroke. The outer panel pivots around the top of the inner panel, driven by spring-driven hinges. As the inner panel is deployed by direct force from the LDRC, the outer panel completes its excursion to its hinge-stop position. This maneuver kicks energy back into the inner panel and thus into the LDRC, driving them temporarily in a reverse direction. This can be seen in Figure 6, which shows the inner panel stroke history. This analysis was useful in varying parameters to ensure that all such perturbations were damped out before the system approached its stops, enabling the system to avoid high-impact loads and rebounds. The LDRC displacement and force history curves shown in Figure 7 reflect this action. As the LDRC is driven backward, damping becomes effective in that direction, also.

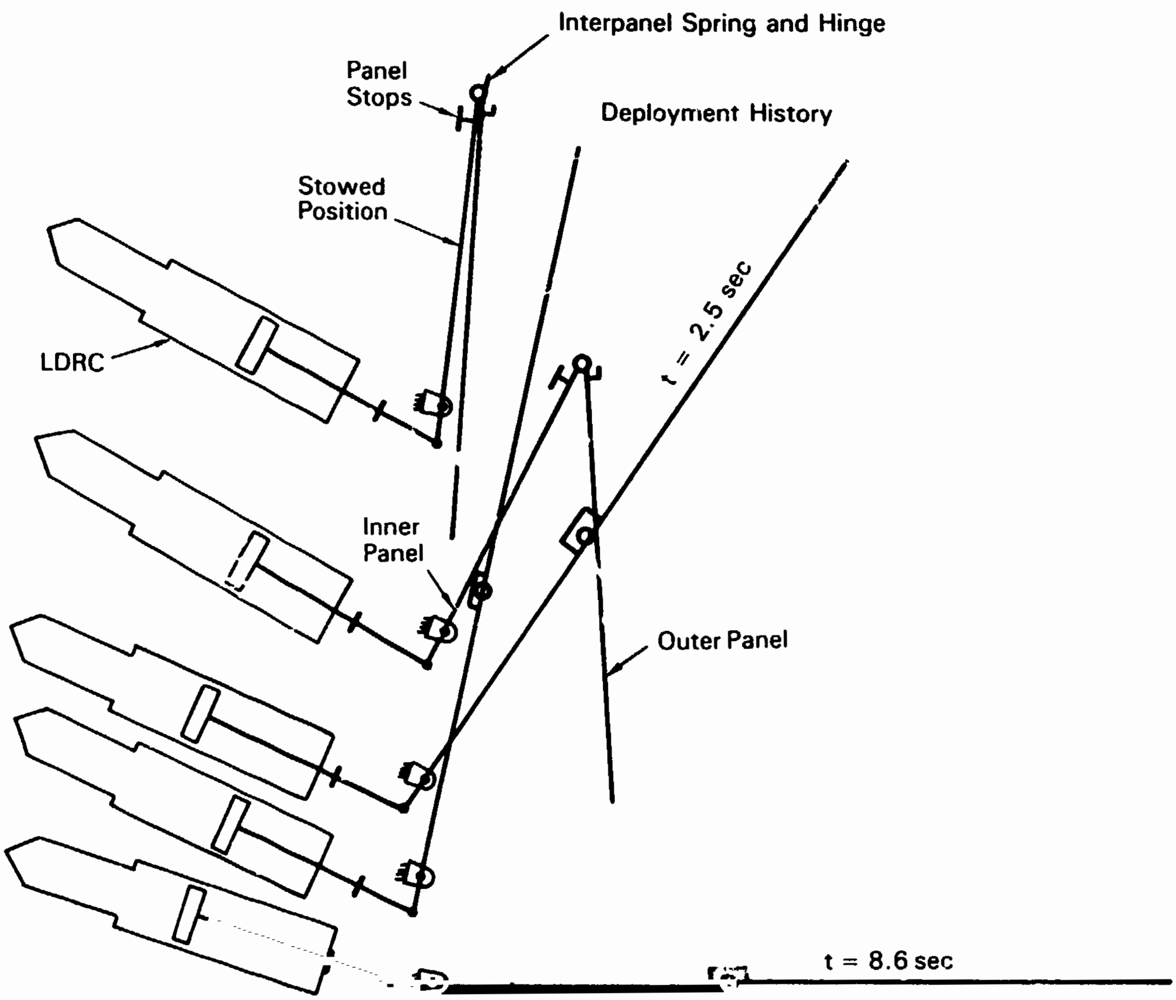

Figure 5. Earth Shield Deployment History

ORIGINAL PAGE IS
OF POOR QUALITY

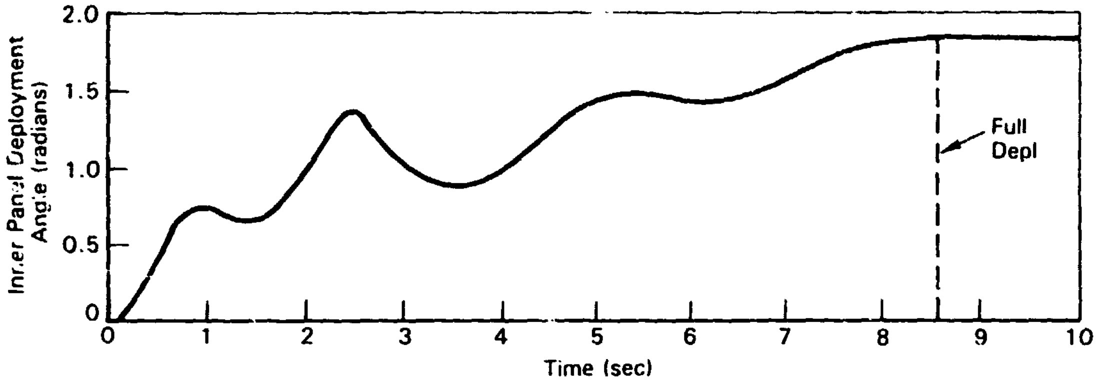

Figure 6. Inner Panel Stroke History

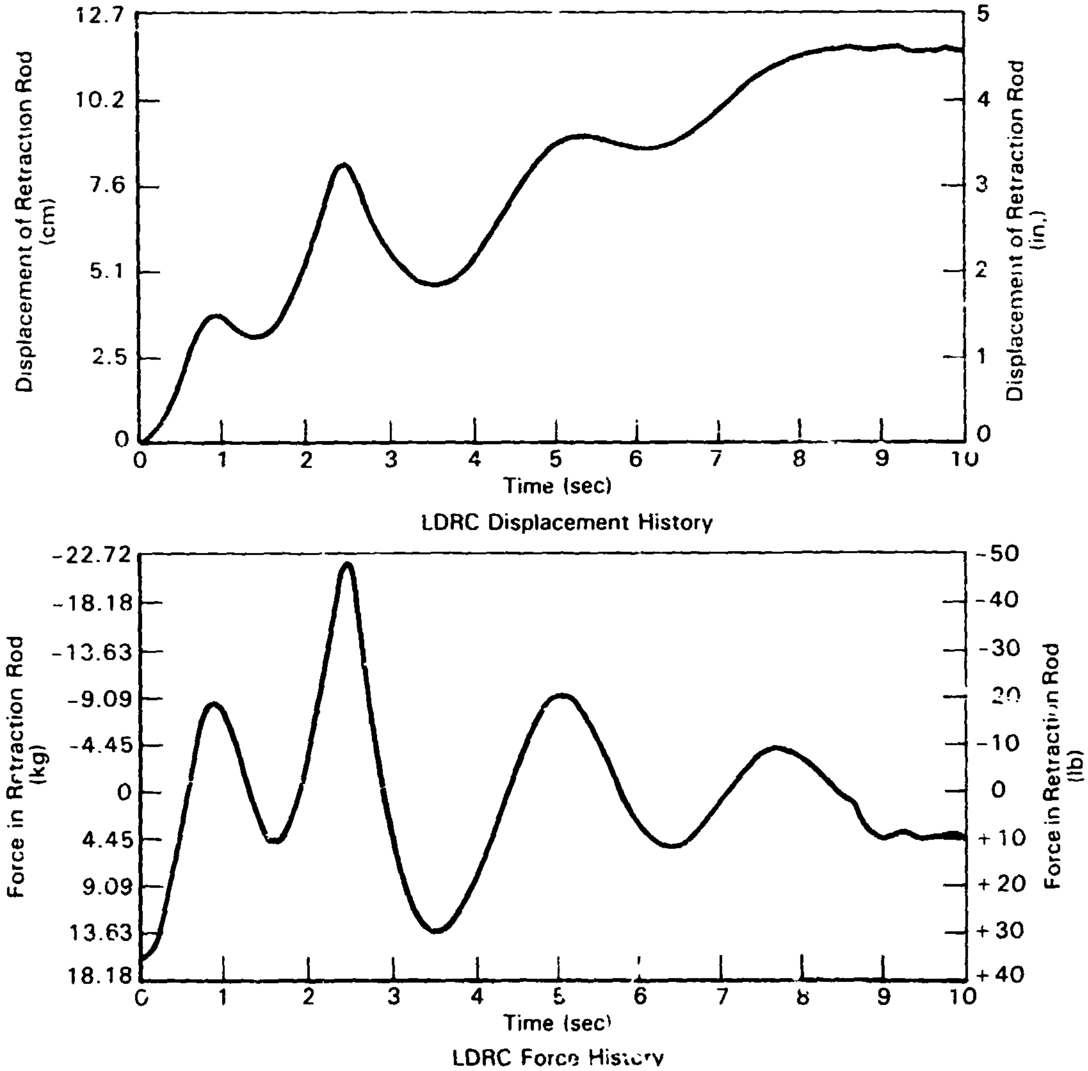

Figure 7. LDRC Displacement and Force History Curves

After system level testing was completed, the analytical model was verified to be representative of actual system behavior. The only variable that changed after the analysis was completed was the orifice diameter.

TESTING

The only development testing carried out involved a series of tests performed with a complete LDRC. No lower level assembly tests were run. The development tests were run with different LDRC orifice diameters at operating temperature extremes. The LDRC was linked to a two-beam panel simulator on an air-bearing table. The beams were mechanized like the main Earth shield panels, with the proper hinges, springs, and stops, and were repreesntative of the mass and moment of inertia of one half of the Earth shield panels. They were supported by the air-bearing table in such a way that they could be deployed in a plane that was parallel to the table top in a relatively frictionless manner. This kind of test was used to minimize the effects of 1-g force. As a result of these tests, the final orifice configuration was established as a 0.5-mm (0.020-inch) diameter drilled hole, and overall LDRC performance with a simulated panel system was verified.

Other testing that was accomplished included acceptance testing of each unit built and qualification testing of two units. Test environments were characterized by random vibration and thermal cycling. Life cycling and extensive leak testing were also carried out.

The only test failure encountered occurred during thermal vacuum testing, when a crack in one of the bellows allowed leakage of the damping gas. A failure analysis was performed, which led to the conclusion that the bellows were structurally inadequate, and the failure mode was low-cycle fatigue. (This failure mode results from continuously cycling the bellows under loads in which the local elastic limit is exceeded.) A crack that starts during this testing will propagate with the number of cycles completed. The bellows tested had undergone approximately 300 cycles.

The bellows, which consist of a series of stamped-out disks with holes in the center, have outside and inside diameter (ID) surfaces that are welded as shown in Figure 8. As the bellows are extended, a load is produced at the weld that tends to pry the weld bead apart or to fail the disk in bending at the edge of the weld. The level of stress produced depends on the materials and the deflection from the heat-treated position. As shown in Figure 8, the pressure on the outside of the bellows aggravates the load condition at the (ID) welds.

The leaking bellows were sectioned and examined. Cracks were observed in numerous locations along the heat-affected zones in the disks. See Figure 9 for a view of the interior of the bellows, where the leak area is identified. Figure 10 shows a view of the heat-affected zone, and multiple cracks that have not yet become leaks are visible there. Figure 11 shows a cross section of the weld area where a crack is located that has progressed through approximately 20 percent of one of the disks.

ORIGINAL PAGE IS
OF POOR QUALITY

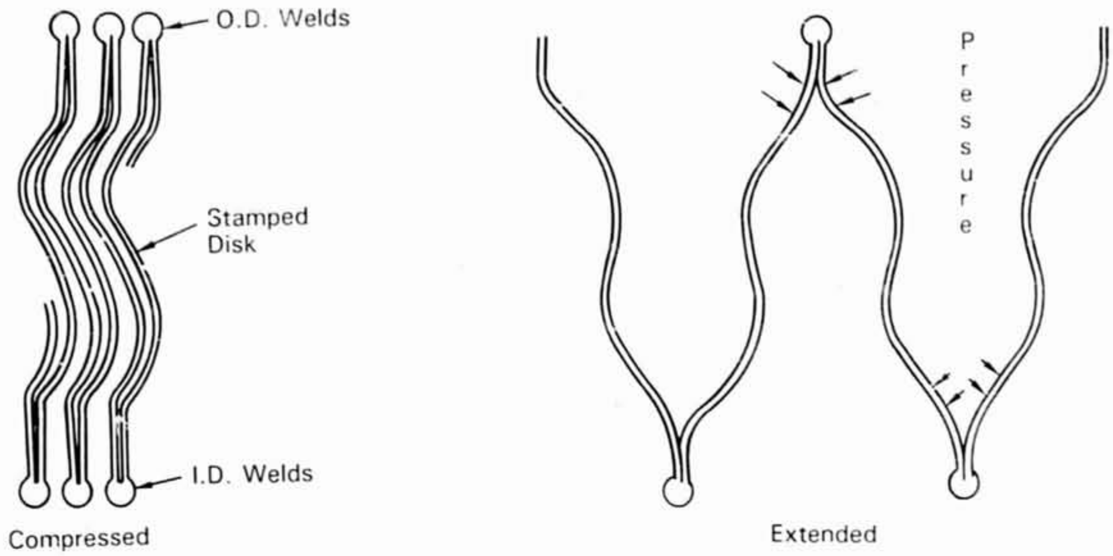

Figure 8. Bellows Cross Section (Not to Sc le)

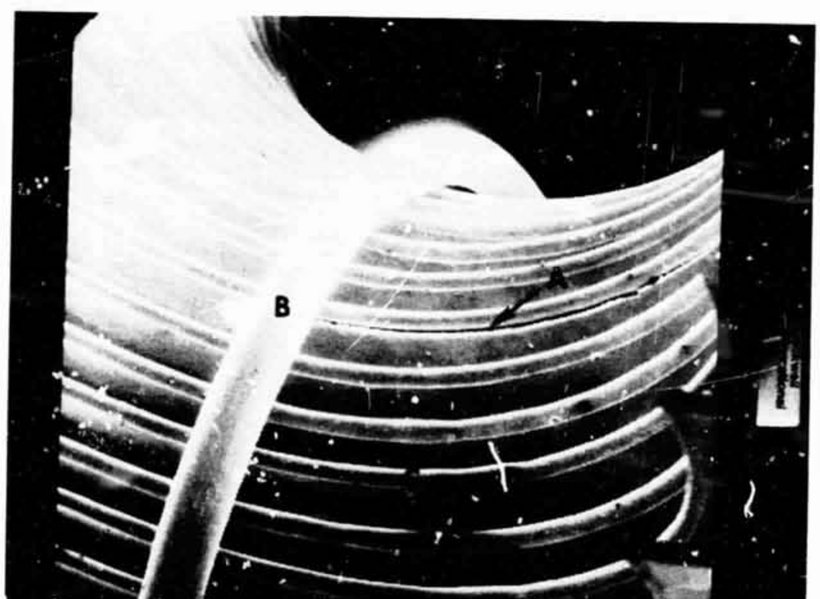

Figure 9. SEM Photomacrograph Showing: A) The Main Leak, B) A Wire Used Only to Hold the Bellows in Place, C) An Artifact

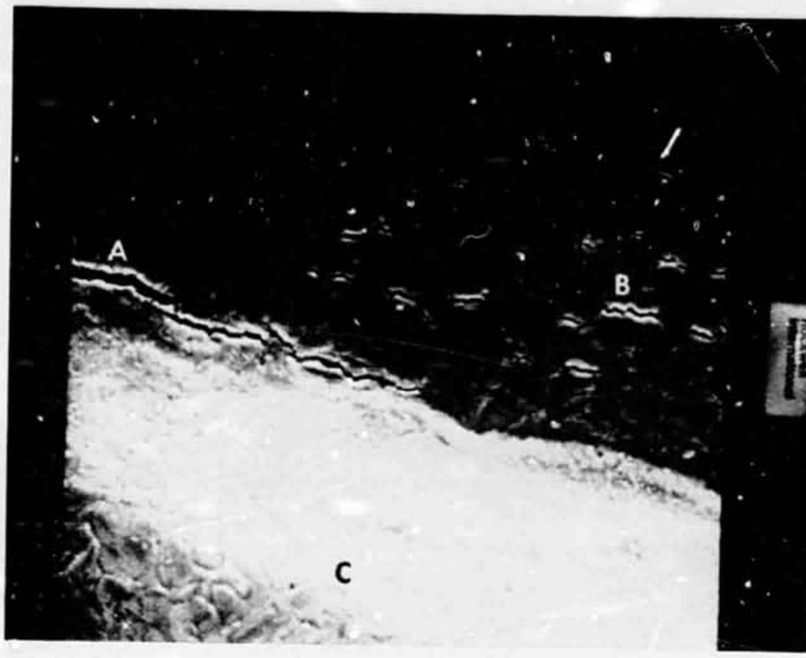

Figure 10. SEM Picture Showing: A) The Main Crack, B) Secondary Cracks, C) The Weld Bead

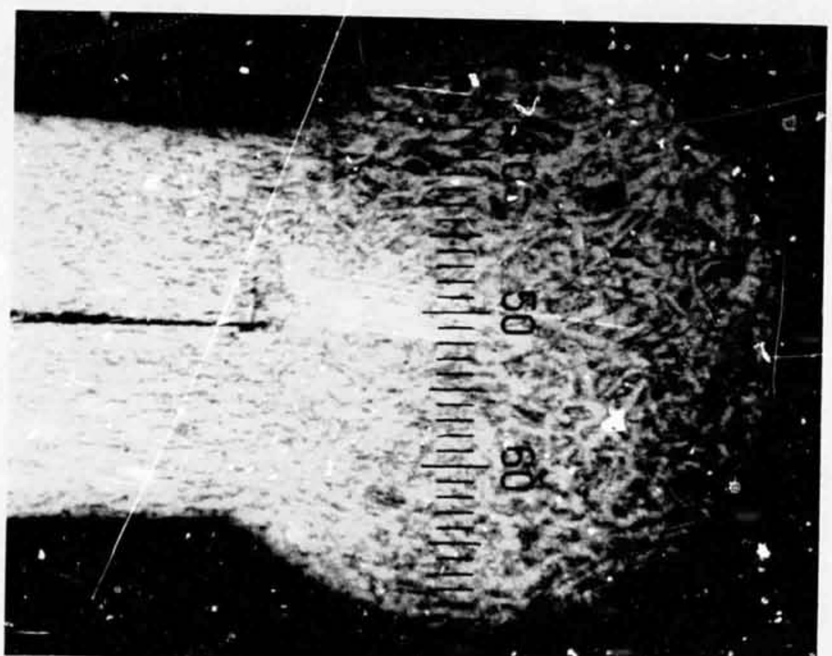

Figure 11. Photomicrograph Showing a Fatigue Crack Starting at the Crotch of the Weld Bead. Note Uniformity in Plate Thickness and Weld Bead (Each Increment Equals 0.00023 Inches)

ORIGINAL PAGE IS
OF POOR QUALITY

As discussed earlier, the solution to this problem involved adding more convolutions to the bellows, heat treating the finished bellows to a prescribed length, and changing the bellows material to Inconel 718. Tests to date have verified this fix.

CONCLUSIONS

The LDRC described in this paper offers a simple solution to a classic mechanical deployment problem. This device, which controls time-to-deployment, end-of-stroke velocities, and end-of-stroke holding force, is relatively insensitive to temperature changes and can function at extremely low or high temperatures. With proper bellows selection, leakage of the damping fluid is not a credible failure mode.

Larger or smaller versions of the LDRC can be used in a number of applications where controlled deployment is a requirement. Through various factors such as gas pressure, orifice size, piston diameter, and springs, the range of application of the basic concept is broadened. In addition, the LDRC design employs components that can be reliably simulated with analytical methods which eliminates the need for extensive and expensive testing, with the possible exception of the bellows. To minimize risks in this area, development tests should be run in which new bellows configurations recycled to verify whether they are working well within their elastic limits.

ACKNOWLEDGMENT

The author wishes to thank the designers of the LDRC, E.M. Altman and A. Holmberg of Rockwell's Shuttle Integration and Satellite Systems Division, for their support in the preparation of this paper.