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PAYLOAD HOLDDOWN AND RELEASE MECHANISM

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ABSTRACT

A payload holddown and release mechanism, designated the Model 1172, was designed and built at G&H Technology during the winter of 1992/1993. The mechanism is able to restrain and release a 45-pound payload with minimal tipoff. The payload is held in place by a stainless steel band and released using electrically triggered non-explosive actuators. These actuators provide reliable operation with negligible shock and no special handling requirements. The performance of the mechanism was demonstrated in two flight tests. Data showed pitch and yaw tipoff rates of less than 0.07 radian (4 degree) per second. The Model 1172 design is an efficient replacement for conventional payload deployment devices, especially where low transmitted shock is required.

INTRODUCTION AND BACKGROUND

Common methods of payload retention and release, including pyrotechnic joints and V-bands and Marmon clamps held by explosive release devices, present definite risks when used on critical missions. Release of non-symmetrical retention can impart perturbations and undesirable motion to the payload. Pyrotechnic device shock can affect sensitive on-board equipment. The Model 1172 holddown and release mechanism was designed to alleviate these problems.

The mechanism design evolved from the separation and retention methods used on a series of electrically actuated umbilical disconnect devices developed for use on the Minuteman III reentry vehicle, the Peacekeeper, Small ICBM and Space Shuttle Programs. These devices had non-explosive actuators integrated into their design. Electro-mechanical actuators locked the spring-loaded connector plug and receptacle together until separation was required. An electrical signal triggered the actuators, releasing the connector halves so that spring energy can drive them apart.

The design elements that provided successful connector retention and release were viewed as possible solutions to the similar requirements of space payload holddown and release. A mechanism integrating spring loading and non-explosive actuators could cushion and capture a payload during flight and release it on command. A preliminary design for a payload holddown mechanism of this type was initiated for the kinetic energy weapon program known as SABIR in 1989.

A new design, using a simplified version of these principles of holddown and release, was developed for Rockwell for use on the LEAP program. The design parameters and performance goals for the device are presented below:

- Retention and separation for a 20.25 kg (45 pound) payload
- 102 ±25.4 cm/sec (40± 10 inch/second) payload separation velocity
- 20 year storage life
- <0.122 radian (7°) per second payload tipoff rate
- 5 kilogram (11 pounds) weight

The Model 1172 is shown in Figure 1.

MECHANISM DESCRIPTION

The main elements of the Model 1172 holddown and release mechanism are:

- A spring-loaded deployment plate, a ring of 14 collet fingers with Belleville spring washers for preload clamping
- A 27.9 centimeter (11 inch) diameter housing that steps down to a 22.9 centimeter (9 inch) diameter for payload interface.
- A steel retention band for collet retention, and
- A pair of non-explosive actuators.

The 22.9 centimeter (9-inch) diameter deployment plate mounts inside the housing. The housing is hard-mounted on the booster. The deployment plate is attached to a shaft that floats within a linear bearing positioned on the housing centerline. The spring-loaded collet fingers, actuators, and steel band retain an asymmetrical payload until separation is required. An overall view of the holddown and release mechanism is provided in Figure 2.

The payload mounts directly on the deployment plate which is shaped to match the countours of the payload's aft end. The hub of the deployment plate is preloaded by a compression spring. Payload retention is accomplished by fourteen collet fingers spaced along the circumference of the housing. The upper edge of each finger is notched to fit and grasp a flange on the payload. The collet fingers are preloaded by a stack of Belleville spring washers mounted in the housing. The washers are concentric with the fingers.

A stainless steel band is wrapped around the outside of the collet fingers and tightened to lock the collet fingers onto the payload flange. The band has small wedge-shaped steel pieces welded to each of its ends. The angular surfaces on these pieces form ramps that are held against matching bosses on the collet housing. Pins from a pair of non-explosive actuators lock the steel band ends against the housing. This is shown in Figure 3.

Upon receipt of an electrical signal, the non-explosive actuators are triggered. This pulls the pins, unlocks the steel band, and releases the payload. The spring load on the deployment plate pushes the payload away at the design velocity, with minimal rotation and tipoff. A linear bearing and shaft system controls the deployment plate motion, restricting it to travel along the housing's vertical axis and providing a stop. A shroud around the mechanism covers it and retains the steel band after payload deployment.

The total mechanism weight is 5 kilograms (11 pounds) and includes the deployment plate, housing, and hardware. All of the materials used in the mechanism, including lubricants used on the aligning shafts, are rated for exposure to the space environment.

OPERATION - HOLDDOWN

The Model 1172 must securely restrain the payload during launch and flight. This is accomplished by a steel band retainer and the system of peripheral collet fingers.

The aluminum deployment plate is shaped and sized to accept the contours of the payload and acts as a cradle for it prior to release. The deployment plate assembly mounts inside the collet flight housing, a circular unit that, using fasteners, attaches directly to the booster. The housing is also made from aluminum alloy. Holddown is illustrated in Figure 4.

The deployment plate assembly is centered on a spring-loaded ball bushing linear bearing. The weight of the payload and plate assembly compresses the deployment spring that is concentric with the linear bearing. The linear bearing shaft extends through the collet flight housing as the spring is compressed. Shaft extension is completed when the deployment plate is completely recessed within the housing.

Three additional deployment alignment shafts are attached to the deployment plate. These also extend through the flight housing and prevent rotational motion of the deployment plate about the mechanism's centerline.

Fourteen collet fingers are located along the 22.9 centimeter (9 inch) periphery of the flight housing. Each finger has a small notch which is positioned to slip over and retain a flange on the payload. The bases of the aluminum alloy fingers have a conical shape and are centered in cavities spaced around the housing. Each of the collet fingers is uniformly preloaded through forces exerted by Belleville spring washers stacked at their bases.

A stainless steel retention band wrapped around the exterior of the flight housing collet fingers holds them in position so they grip and retain the payload flange. The band is sized, with an ample safety factor, to withstand the collet finger radial loading imparted by force from the Belleville washers. Each end of the band has a wedge-shaped locking ramp that is attached by TIG welding. As this welding process causes partial annealing in localized areas of the band, the band design is based on working stresses well below the yield strength of heat treated 17-7 stainless steel.

Pins from a pair of non-explosive actuators trap the 5.24 radian (30°) locking ramps on the band ends against bosses on the collet housing. The actuator pins restrain the band, keeping the deployment plate and payload in place on the housing. For the 20 kg (45 pound) payload, the collet finger Belleville spring system payload preload is 34,500 newtons (7,700 pounds). This results in the collet fingers imposing a 4,000 newton (900 pound) preload on the band.

Statically indeterminate methods were used to determine the collet retention forces needed to secure the payload during flight. The maximum loading on the collet fingers, the stress on the retention band, and the side loading on the actuator retention pins were calculated. Representative free body diagrams of the critical elements are shown in Figure 5.

Assembly of the mechanism requires special tools to preload the Belleville washers so the collet fingers can engage the payload flange. The retention band is brought over the collet fingers and properly positioned using an engagement tool. The tool prevents over-stressing of the retention band as it is tightened against the individual collet fingers. Another tool holds the deployment plate in place, seated against its spring, as the band is positioned and locked. A safety plate is used to prevent danger from the spring-loaded collet fingers if the band assembly is accidentally released during assembly.

During preflight ground handling, launch, and flight the collet fingers and Belleville washers resist any forces that might cause unwanted payload separation. The non-explosive actuator pin puller assemblies are not affected by flight vibration and shock and can not be triggered by stray electrical signals. The mechanism reliably holds the payload in full contact with the deployment plate and collet flight housing until separation from the booster is desired.

The Model 1172 separation mechanism has a pair of D-sub connectors mounted in the deployment plate. These serve as quick disconnect umbilical connectors, allowing the transfer of data and power between the booster and payload while it is restrained. They are symmetrically arranged to minimize their effect on tipoff rate when separation occurs.

OPERATION - SEPARATION

Separation is initiated by an electrical trigger signal. The signal, usually 4.5 amperes at 5 Vdc, causes the non-explosive actuators to pull their pins away from each end of the stainless steel band. The actuators are sized so that they have sufficient force to overcome the side loading from the band and withdraw the pins. Without the pins retaining them, the band ends slip off the bosses on the collet housing and the band springs loose.

The unrestrained band can no longer hold the collet fingers. The force exerted by the Belleville spring washers bottoms the 14 collet fingers in their cavities. This movement strips the gripping notches on the collet fingers away from the payload flange. The collet fingers move simultaneously, insuring a uniform release of the load so that the payload tipoff rate is kept to a minimum. This release initiates deployment.

Figure 6 illustrates the holddown and release mechanism at the moment when the actuator has pulled the pin and freed the retainer band.

The design is redundant, using two non-explosive actuators as pin pullers. The band is released if either pin is pulled by its actuator or if both pins are pulled at the same time. The addition of the second, redundant pin puller increases the mechanism's predicted reliability to .99998. A single actuator design would have a reliability of .9998.

With the retainer band removed, the energy stored in the deployment spring is released. This pushes the deployment plate and accelerates the payload forward, away from the booster. The quick disconnect connectors come apart as the deployment plate begins to move away from its recessed position in the housing.

The movement of the deployment plate and payload is controlled by an alignment shaft and linear bearing on the plate centerline and three other alignment shafts. The alignment shaft and low friction ball bushing linear bearing maintain precision centering of the payload on the booster as the deployment plate and payload gain velocity. The other alignment shafts are equi-spaced around a common diameter of the deployment plate. They prevent rotational and angular motion.

This design maintains close alignment and minimizes the tipoff rate upon separation.

Movement of the deployment plate is halted when a mechanical stop on the bearing washer comes into contact with the flight housing. The payload continues its movement with the velocity imparted at separation by the deployment spring. The Model 1172 is sized to deploy a 20 kilogram (45 pound) payload at 76 to 127 centimeters per second (30 to 50 inches per second).

Figure 7 illustrates the holddown and release mechanism as the payload is deployed.

A shroud surrounds the collet housing and captures the steel retention band after it is released. The pin pullers, deployment plate, springs, and other parts of the mechanism stay with the booster after release. Separation occurs without gas release, debris, or other pollution.

NON EXPLOSIVE ACTUATOR PIN PULLERS

The operation of the payload holddown/separation mechanism is based on the performance and reliability of the non-explosive actuators used to restrain and release the retention band. The actuators belong to a family of lightweight devices that have been successfully used in numerous sophisticated space systems.

These actuators use a wire-wrapped split spool assembly to control the release of spring energy. The two-piece spool, with insulator assembly, is held together by a wrap of spring-tempered stainless steel wire set at a predetermined tensile load. One end of the steel wire is tied directly to a spool half. The other end is attached to the resistive link wire which is part of the insulator assembly. The resistive wire is also connected to a pair of electrical contacts.

The wrapped spool is used to restrain a moveable shaft under spring tension. In the absence of an electrical signal, the spools remain bound together under the predetermined and precise tensile load. The spool's restraining grip is constant and resistant to outside vibration, temperature extremes, and other shocks. Severe transportation and launch environments will not loosen the winding or impair the spool's ability to restrain or release. This has been demonstrated by developmental and qualification testing for numerous programs.

However, when the mission critical event is required -in this case separation- actuation will be triggered by the arrival of the appropriate signal. This is done by applying electrical or laser power between the contacts tied to the resistive link wire. The power causes the temperature of the wire to rise, bringing with it a loss in tensile strength. When its strength drops below the imposed tensile load, the link wire breaks. This loosens and releases the wire wrapped around the spools. The two spool halves quickly separate and the spring-loaded shaft, which had been restrained, is now free to move.

Figure 8 illustrates the sequence of operation in these actuators.

The actuators will not actuate or "fire" if the current applied to the link wire is 0.6 ampere or less. This prevents operational failures of the devices from stray or induced signals. Actuation at current levels above one ampere is time dependent. Lower current levels must be applied for a longer duration to generate sufficient heat to lower the link wire strength below the tensile loading. High current levels can cause very rapid triggering. The units are rated for operation at 5 volts dc and 5 amperes with separation resulting within 20 milliseconds.

Spool separation releases the stored spring energy to move the shaft, in this case a pin. The actuator springs are sized to overcome the sideload placed on the pins as they restrain the retention band. The released actuator springs drive the pins free of the separation mechanism's steel circumferential band and allow deployment of the payload.

These actuators perform with negligible shock imparted to the adjoining structure. Although they act as "one-shot" devices during a mission, the spools may be fired and replaced, allowing them to be ground-tested with little difficulty. They contain no age-sensitive materials and can be stored for long periods of time with no degradation in performance. Their non-explosive nature eliminates the need for special handling, training, and safety precautions.

TEST/FLIGHT HISTORY

The test history of the Model 1172 separation mechanism consists of development, characterization, and demonstration testing. Development tests were conducted to refine and improve the design, and characterization tests were used to verify the mechanism performance. Use of the separation mechanism was demonstrated by Rockwell in its LEAP kinetic energy weapon program.

Development testing consisted of 30 tests to evaluate the mechanism and its design features. Several improvements were made as a result of this testing and release experience. The steel retainer band was widened to provide an increased margin of safety. Both brazing and spot welding were tried as methods of attaching the ramped ends to the retainer band. These methods proved unreliable and were replaced with TIG welding of the ends, resulting in a strong secure metal joint. Additional improvements were made to the band and band loading. Two extra collet fingers were added to provide more uniform loading of the non-symmetrical payload flange and to prevent the retainer band from making direct contact with the payload housing. The band mounting was also modified to control the collet preloading. This important factor is, in practice, very difficult to establish with precision. This was achieved by micro-adjustments in the lock ramps at the band ends prior to welding the ramps. Lastly, a shroud enclosing the periphery of the mechanism was added as a safety measure to capture the retainer band after payload separation.

Characterization testing of the mechanism included side load tests to verify the clamping force of the mechanism to the payload and drop tests to evaluate the payload tipoff and ejection velocity. Results of the side load testing agreed with predictions. Drop testing provided a means of evaluating the payload ejection tipoff and velocity in a 1 g gravitational field. The mechanism was inverted and interfaced with a simulated payload. The mechanism was then actuated, and the payload was released. Film data of the drops provided the means of determining the ejection tipoff and velocity. The 1 g acceleration was taken into account in determining the ejection velocity. The tipoff data agreed with expectations, and pushoff springs were characterized and selected to provide the required ejection velocities for the LEAP flight tests.

The Model 1172 was used by Rockwell to retain and eject payloads for a hover test and two LEAP flights. For the hover test, the mechanism was incorporated to demonstrate its integration and function with a Rockwell payload by separating an umbilical from the payload. For both of the LEAP flights (flown in June and September 1993), the mechanism was flown in space and ejected payloads of approximately 20 kilograms (45 pounds). Tipoff and ejection velocity data were obtained from the September test and were within expectations. This data is presented below:

Measurement	Planned	Actual
Ejection velocity	101.6 ± 25 cm/sec (40±10 in/sec)	88.4 cm/sec (34.8 in/sec)
Tipoff,		
Pitch	<0.122 radian/sec (<7 degrees/sec)	0.06 radian/sec (3.5 degrees/sec)
Yaw	<0.122 radian/sec (<7 degrees/sec)	0.01 radian/sec (0.6 degree/sec)
Roll	N/A N/A	0.129 radian/sec (7.4 degrees/sec)

SUMMARY

The Model 1172 payload holddown and release mechanism was designed, developed, and flight tested. Using non-explosive actuators, the mechanism was able to restrain a payload through launch and flight and release it upon command. The actuators required no special handling, eliminating assembly, transportation, and range safety problems. They operated without causing pollution or imparting significant shock to the payload.

The mechanism design uses a retention band and collet fingers to restrain a spring-loaded deployment plate and payload. The band provides a preload at the attachment points. The system has operational redundancy which, with the simple electro-mechanical nature of the actuators, provides a very high reliability.

The design can be easily adapted to payloads of other sizes and configurations. Adjustment of the size and number of collet fingers, as well as the band, can be made to accommodate smaller and larger payloads, as well as changes in launch loading. To optimize weight savings, the basic design and collet fingers can also be integrated directly into the missile or booster without the need for a collet housing.

The Model 1172 demonstrated a tipoff rate of 0.06 radian (3.5 degrees) per second on the pitch axis and less than 0.017 radian/second (1 degree) on the yaw axis during flight testing. It provides a new and alternate method of payload holddown and release, especially in situations where imparted shock, safety, and reliability are concerns.

ACKNOWLEDGMENTS

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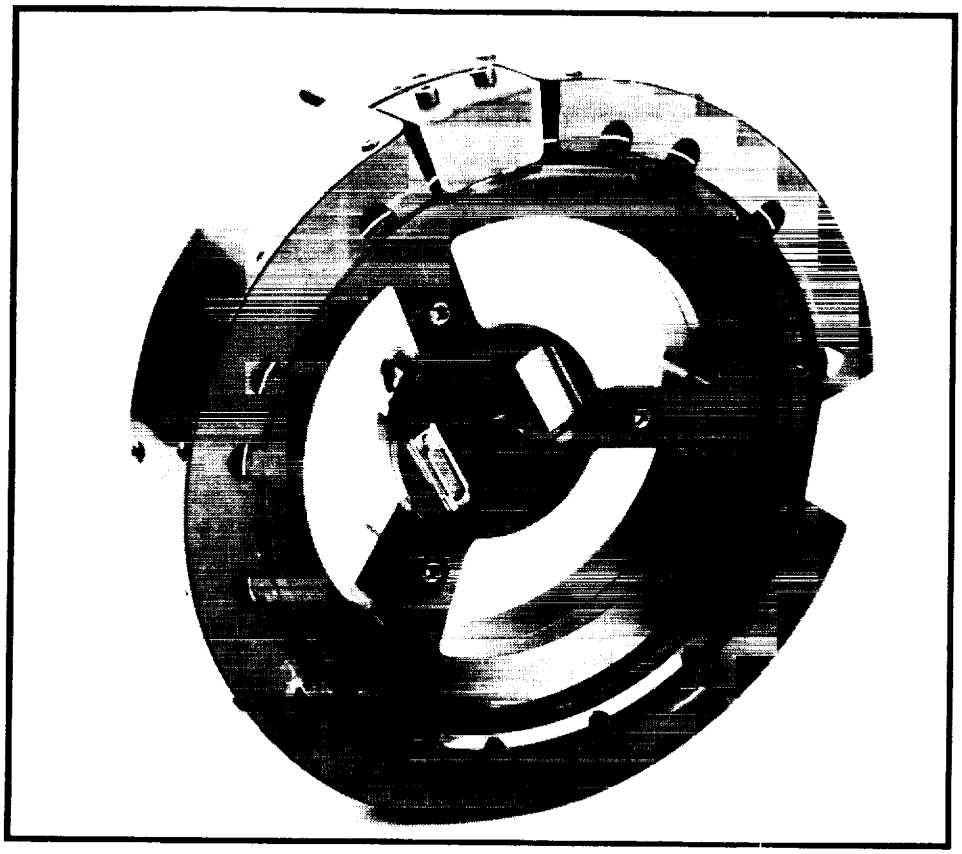

Figure 1: Model 1172 Holddown and Release Mechanism

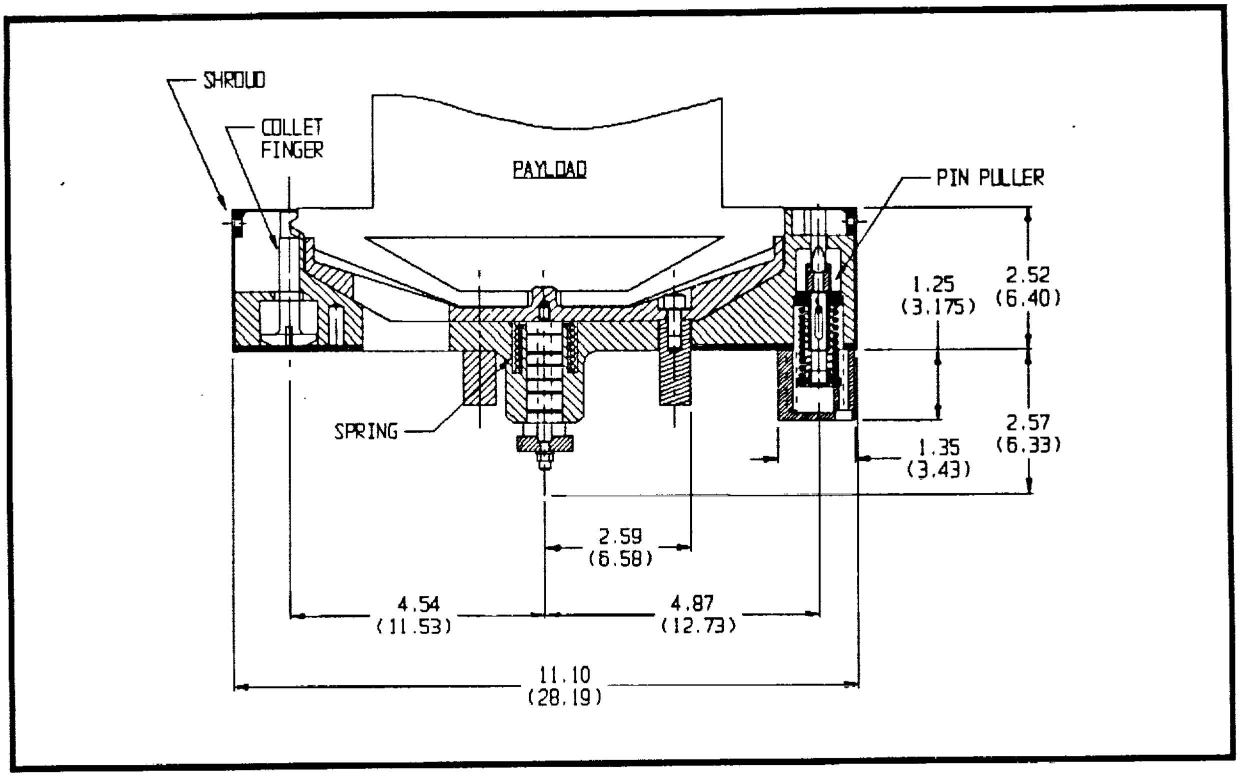

Figure 2: - Holddown and Release Mechanism (HDRM)

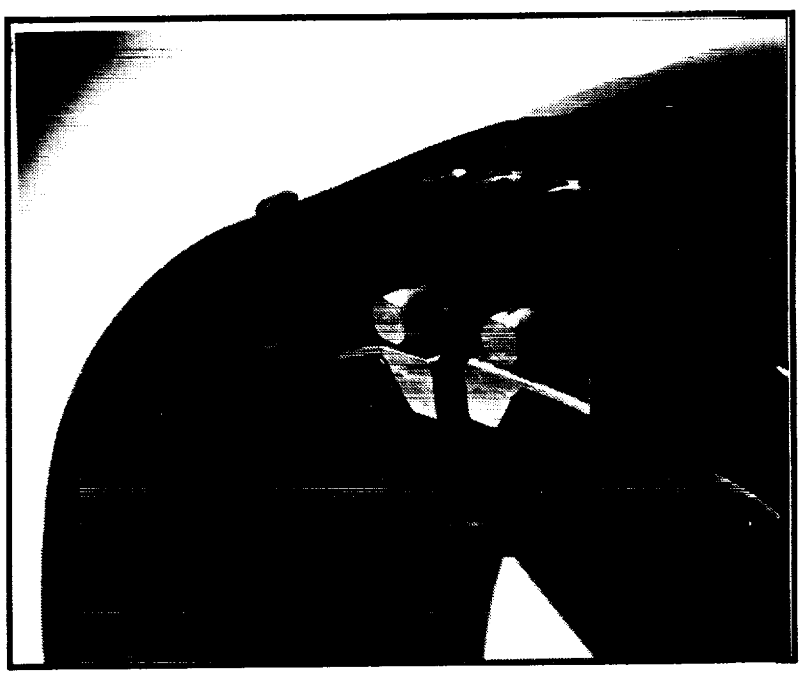

Figure 3: Retainer Locking Mechanism

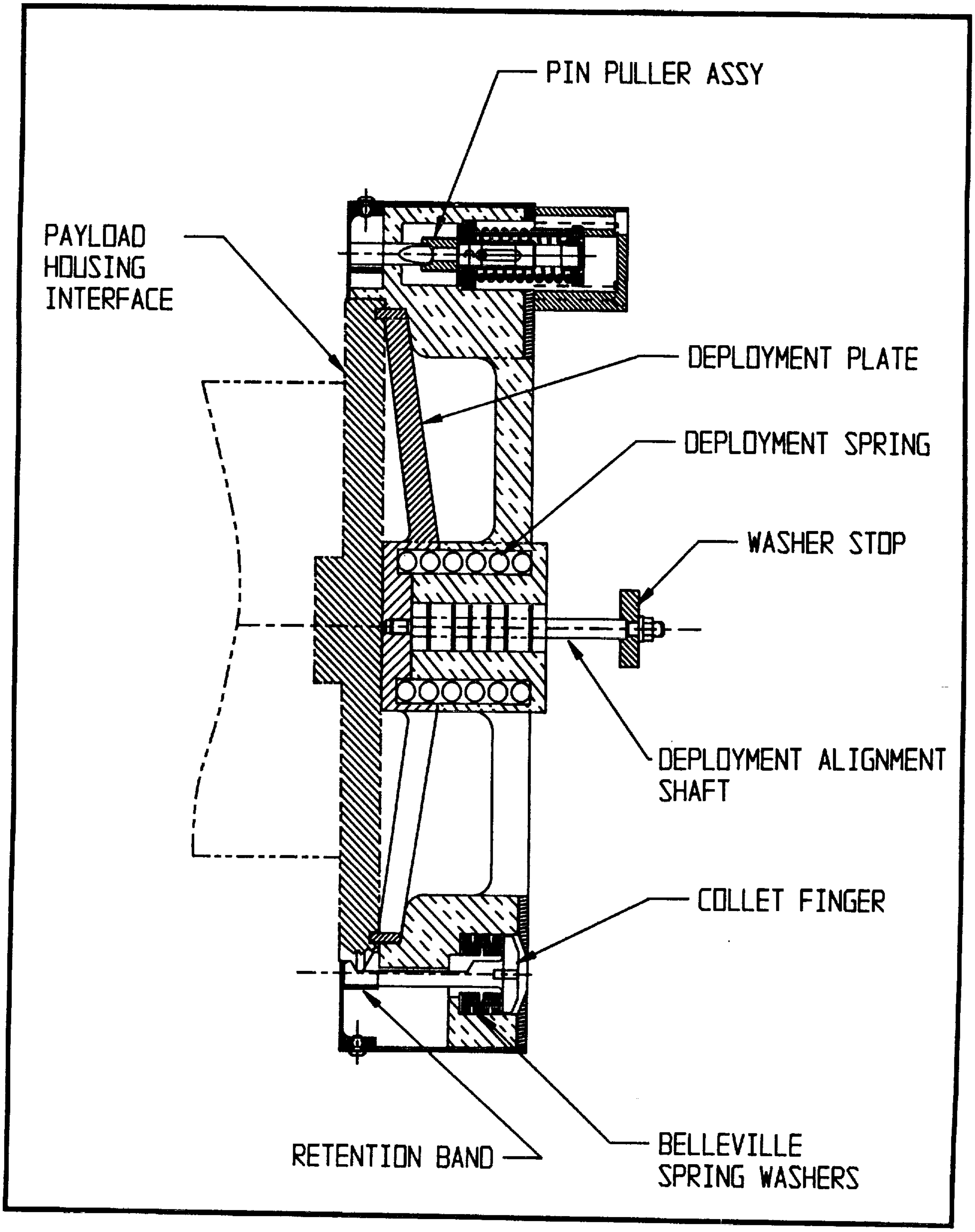

Figure 4: Holddown and Release Mechanism - During Holddown

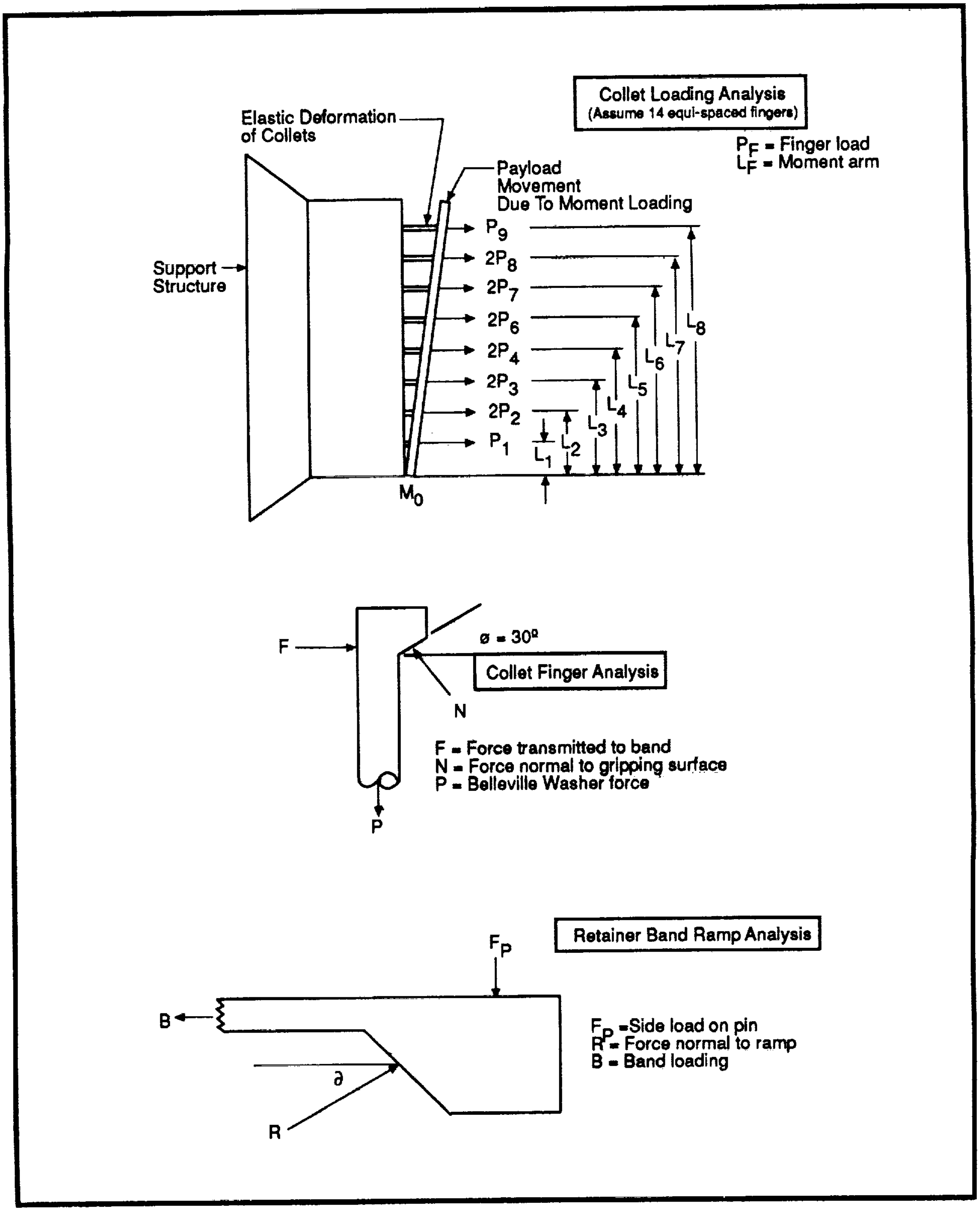

Figure 5: HDRM - Typical Free Body Diagrams

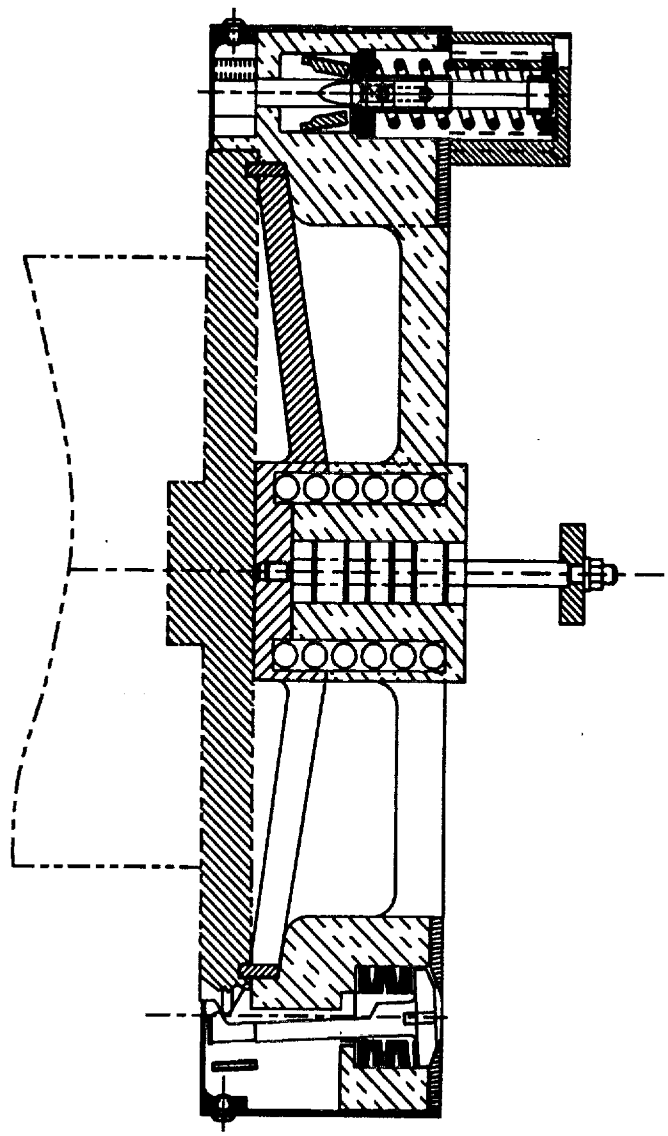

Figure 6: Retainer Band Release

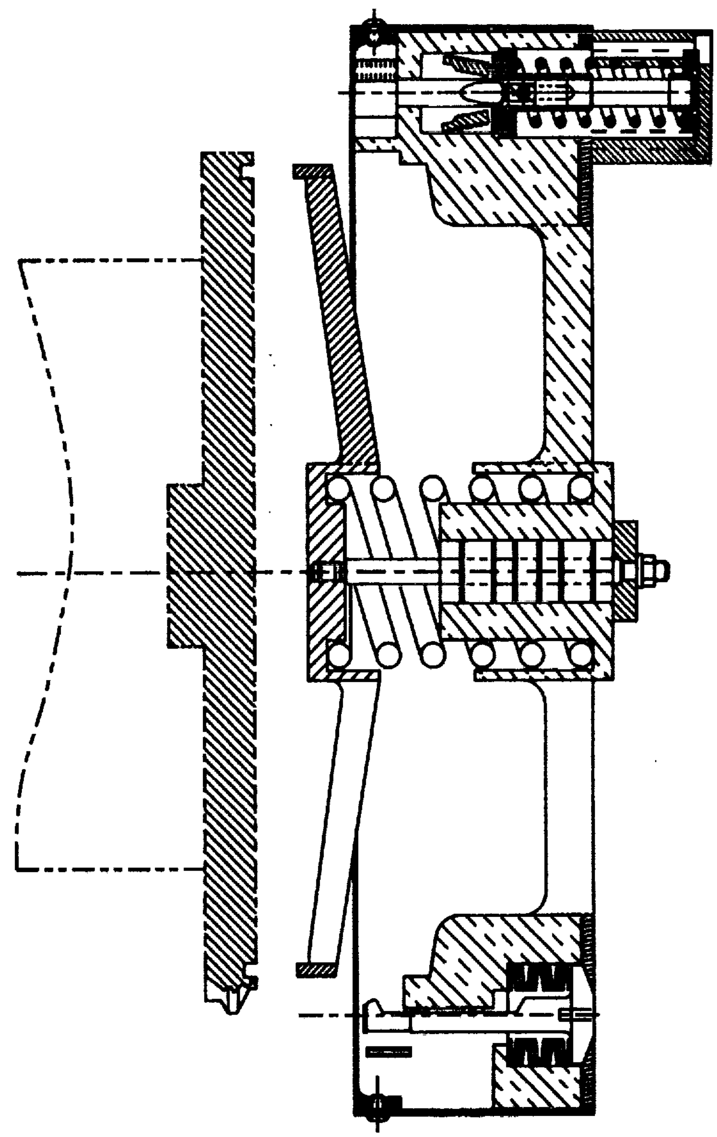

Figure 7: Payload Deployment

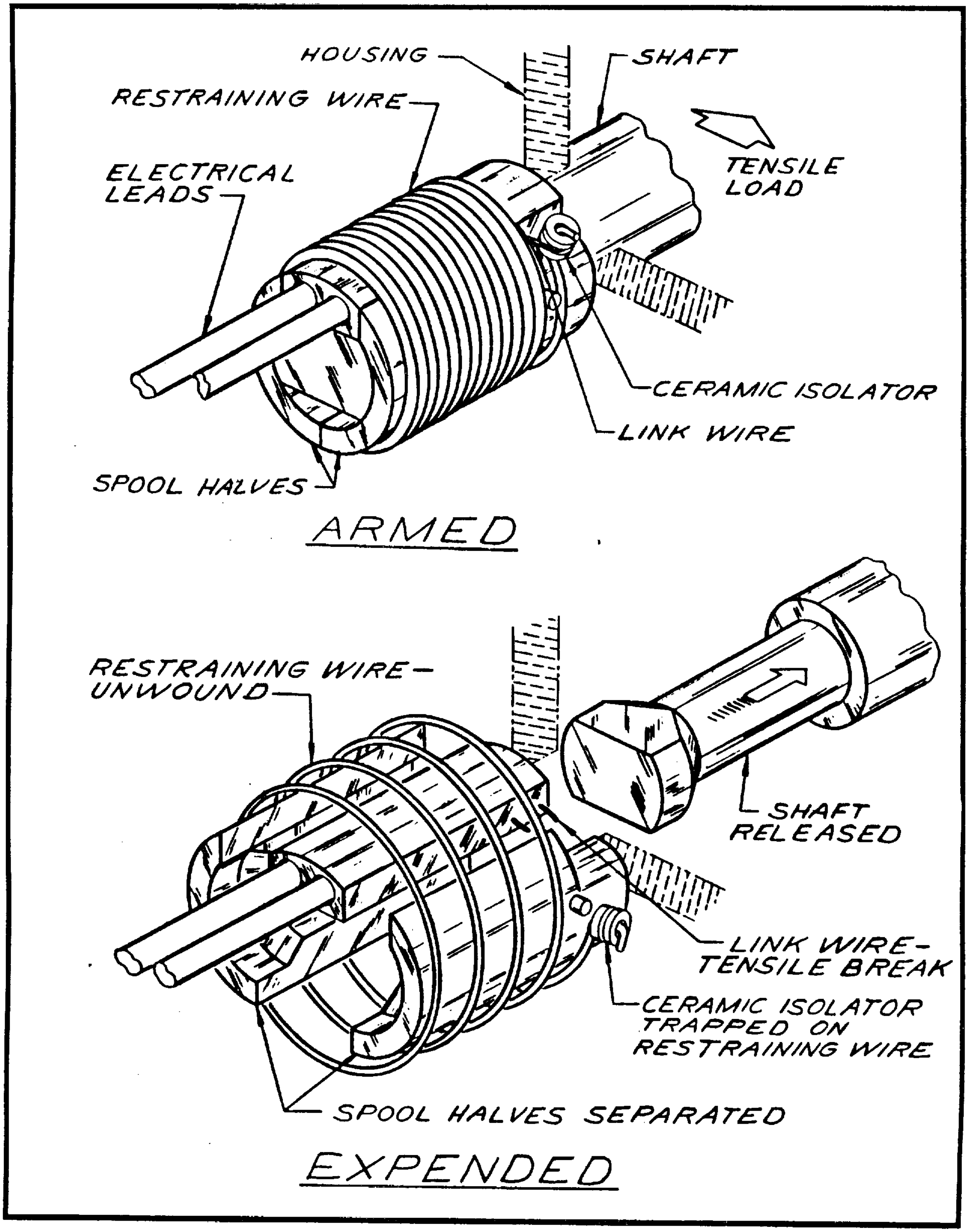

Figure 8: Non-Explosive Actuator Operation