SPACE SHUTTLE PAYLOAD HANDLING

ON THE LAUNCH PAD

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ABSTRACT

The NASA space shuttle launch facility must provide access to a payload in the orbiter payload bay and be capable of installing or removing a payload. To comply with this requirement, launch facility designers conceived of a payload change-out room. The payload change-out room (PCR) will provide a controlled environment and the structural platform for a payload ground handling mechanism (PGHM), which will perform the actual installation or removal of the payload.

Design efforts to develop a PGHM compatible with the free-standing launch vehicle and the payload change-out room housing have had to overcome problems uncommon to the design of material-handling equipment for other uses. The PGHM must compensate for structural deflections resulting from wind forces and the transfer of the payload weight and provide protection for the payload, the orbiter, and the PGHM itself against damaging impacts that could occur during such deflections.

SPACE SHUTTLE LAUNCH FACILITY

The space shuttle launch pad now under construction at the Kennedy Space Center must provide access to the orbiter and its payload from the time the orbiter is emplaced until moments before launch.

Immediate access to the orbiter payload bay or to the payload will be through a payload change-out room (PCR) which will seal the payload bay section of the fuselage and the payload bay doors. Use of airlock systems will continuously maintain the environment in the payload change-out room at clean-room standards to prevent contamination of the orbiter payload bay when the payload bay doors are opened.

The payload change-out room (Figure 1) will house the machinery which will be the access platform to the 60-foot-long payload bay in the orbiter. The machinery will also serve as the payload ground handling mechanism (PGHM) which will emplace the payload within or retrieve the payload from the orbiter.

The PGHM will handle payloads weighing up to 65,000 pounds, measuring up to 15 feet wide by 60 feet long and typically consisting of one to five structurally independent modules.

PGHM PERFORMANCE REQUIREMENT

The launch vehicle, consisting of the orbiter, the external fuel tank, and two solid rocket boosters, is a free-standing structure, which during launch will be supported by a modified Saturn mobile launch pad. Like any free-standing structure, the launch vehicle will deflect under a load, and, if exposed to gusty winds, will oscillate or sway. The swaying motion will occur at a rate equal to the natural frequency of the free-standing structure. The amplitude of the motion will depend on the strength and direction of the prevailing winds. Unfortunately, the orbiter is most flexible in the direction for the payload transfer operations.

The natural frequency of the free-standing launch vehicle is calculated as approximately 30 cycles per minute. Under hurricane conditions, the free-standing launch vehicle will sway 6 to 7 inches from its static position. Payload transfer operations between the orbiter and the PCR, however, will be limited to conditions in which vehicle displacements are 3 inches or less as measured at the top of the payload bay.

The payload change-out room housing the PGHM will similarly respond to wind forces; however, relative to the orbiter displacements the PCR deflections will be negligible. The occurrence of the orbiter displacements dictate the following performance specifications:

- When a payload is to be placed in or retrived from the orbiter on the launch pad, the PGHM supported by the PCR structure, must perform the load transfer operation without exposing the payload or the orbiter to critical impact forces resulting from a collision of the relatively stationary PCR with the swaying orbiter.

- During the load transfer process, the PGHM must yield space for the orbiter deflections to prevent any structural interference between the orbiter and the payload change-out room which could cause undesired strain buildup in either of the structures as the weight of the payload is shifted from the PCR to the orbiter payload bay.

The payloads will be fastened in the orbiter payload bay (see Figure 2) through special payload retention fittings attached to the longerons on both sides of the fuselage. The payload retention fittings resemble conventional journal-bearing pillow blocks. The payloads will mate with the fittings through the 3.25-inch-diameter trunnions which are integral parts of the payload cradle structures. During a load transfer, the payload trunnions must be accurately positioned in line with the payload retention fittings. Bumping or forcing of the payload trunnions against the retention fittings could result in damage to the payload or to the launch vehicle.

The PGHM must provide continuous position control between the payload and the orbiter during all phases of the load transfer.

DESIGN SOLUTION

Two solutions to the problems caused by the uncontrolled relative motions of the orbiter and the payload change-out room were considered:

- Rigidly clamp the orbiter to the payload change-out room, eliminating any uncontrolled relative motion during load transfer

- By a suitable means, synchronize the movement of payload with the motion of orbiter, thereby preventing any uncontrolled relative motion.

Because early evaluation of the first solution revealed a high potential for damage to the orbiter, the second suggested solution was selected as the basis for the PGHM concept.

The PGHM (Figure 3) will essentially consist of the bridge and stem assemblies, which will position and support the payload, and the load transfer equipment, which will install or retrieve the payload. Coupling devices will fix the load transfer equipment to the stem, to hold the payload in a fixed position, or to the orbiter, so that the payload will move with the orbiter while the weight of the payload is supported by the orbiter and/or the PGHM.

In transferring a load from the PGHM to orbiter, the PGHM, carrying the payload, will move from the rear of the PCR to the front by rolling on support rails with the load transfer equipment coupled to the stem. By completion of this move, the payload will be partially inserted into the swaying orbiter payload bay, a safe distance from the retention fittings on the orbiter.

At this point, four connecting links will be manually attached to the orbiter, and the respective locking mechanisms will couple the load transfer equipment (with the payload) to the orbiter and decouple it from the stem. Thus coupled to the orbiter, the load transfer equipment and the payload will follow the motion of the orbiter, eliminating any significant relative displacement between the payload retention fittings on the orbiter and the trunnions on the payload which remain supported by the PGHM load transfer equipment. Lateral and vertical linear actuators on the PGHM load transfer equipment will then position the payload trunnions coaxial with the payload retention fittings on the orbiter. After the retention fittings are secured, the weight of the payload will be released onto the orbiter.

The PGHM concept thus compensates for relative displacements between the orbiter and the PCR at the PGHM stem and load transfer equipment interface, and eliminates potential impacts between the payload trunnions, the support fittings on the PGHM, and/or the retention fittings on the orbiter.

PGHM LOAD TRANSFER EQUIPMENT

A payload positioned on the PGHM will be supported by support fittings (see Figure 3) which in turn will be supported by two payload support beams, one on either side of the PGHM.

Vertical and horizontal positions of the support beams will be controlled by the top and bottom floating beams. The floating beams will be supported in the vertical position through their housings by two sets of jackscrews. One set will locate the housings relative to the strongback beams supporting the housings; the other set will locate the strongback beams relative to the PGHM stem.

The horizontal or lateral position of the floating beams (Figure 4) will be controlled by linear actuators and the lateral position of the common connecting beam on each side of the PGHM. The floating beams will be connected to the common connecting beams by means of linear actuators. The lateral position of the support fittings relative to the common connecting beams will be adjustable by extending or retracting the actuators. The floating beams will move the support beam, which in turn will change the position of the support fittings.

The common connecting beams will have two modes of operation. In the first mode, they will be locked in a fixed position to the strongback beams through locking mechanisms located at each end (Figure 5). In the second mode, they will be locked to a slide mechanism on each end of the strongback beams.

In the first mode, the lateral position of a payload held by the PGHM will depend on the movement of the stem; in the second mode, it will depend on the motion of the slide mechanisms on the strongback beams. Using a set of connecting links installed between the orbiter and the slide mechanisms, the payload will follow the lateral motion of the orbiter without any significant uncontrolled relative displacement between the orbiter and the payload. Load transfer will thus be smooth and dynamically undisturbed.

COMMON CONNECTING BEAM LOCKING MECHANISM

As described above, the lateral motion of the payload will depend on the freedom of motion of the common connecting beams. The position of the locking mechanisms (Figure 5) will control the motion of the common connecting beams and the dynamic loads imposed on the payload and the orbiter through the orbiter connecting links.

The basic function of the common connecting beam locking mechanisms will be to move the payload and part of the load transfer equipment from a standstill into a harmonic oscillation (or vice versa). In either movement, coupling or decoupling forces will necessarily be applied gradually to minimize dynamic amplification and to maintain the inertia loads on the payload and on the orbiter connecting links below a predetermined limit.

The common connecting beam locking mechanism concept is based on the gradual application of a spring force to couple the end of a common connecting beam to a slide mechanism moving with the orbiter. The locking mechanism will consist of an actuator rod mounted on the common connecting beam through linear bearings and positioned by a linear actuator, also mounted on the common connecting beam. When locked to the strongback beam, the common connecting beam will be restrained in the lateral direction by the engagement of the actuator rod in a slotted cam plate attached to the strongback beam.

When locked to the slide mechanism, the actuator rod will disengage from the slotted cam plate. A pair of cam followers will be pressed by the actuator rod against a V-shaped cam on the slide mechanism through a stack of disk springs. As the force on the springs is increased, proportionately higher lateral forces will move the slide mechanism relative to the common connecting beam. The length of the slotted cam plate will be adjustable so that the common connecting beam will become free of the strongback beam when sufficient force is developed through the spring stack to hold the common connecting beam in static equilibrium by the orbiter connecting link connected to the slide mechanism. As the spring stack force increases, the common connecting beam will move with the slide mechanism and gradually follow the motion of the orbiter. At fully rated spring stack force, there will be no slippage between the common connecting beam and the slide mechanism; therefore, the payload will track the motion of the orbiter.

A common connecting beam locking mechanism will be placed on each end of the two common connecting beams, with each slide mechanism coupled to the orbiter through a separate orbiter connecting link attached to the orbiter near the the forward and aft payload bay bulkheads. Assuming rigid body conditions for both the orbiter payload bay and the PGHM load transfer equipment, a payload supported by the PGHM will have no displacement relative to the retention fittings.

STRAIN-RELEASE MECHANISM

The bottom of the PGHM stem will deflect horizontally as loads increase on the PGHM floors and platforms. This deflection will be accumulative to the relative displacements between the orbiter and the PCR and in some cases could be binding. The PGHM will therefore be clamped to the PCR structure (Figure 3) both at the top support rails and at the PCR floor.

Using the clamps, a change-of-load condition on the PGHM will not cause significant relative displacements when the payload fittings are critically close to the orbiter; however, a locked-in strain condition will be generated which could cause lurching of the PGHM if the clamps are subsequently released without control. The strain-release mechanism will prevent this sudden motion.

The rail clamp will be positioned relative to the bottom of the PGHM stem by means of a jackscrew assembly. To release a locked-in strain, the jackscrew will be actuated in the direction which allows the stem to relax. After the strain between the stem and the rail clamp is eliminated, the rail clamp can be opened without the threat of sudden lurching of the structure.

ACKNOWLEDGEMENT
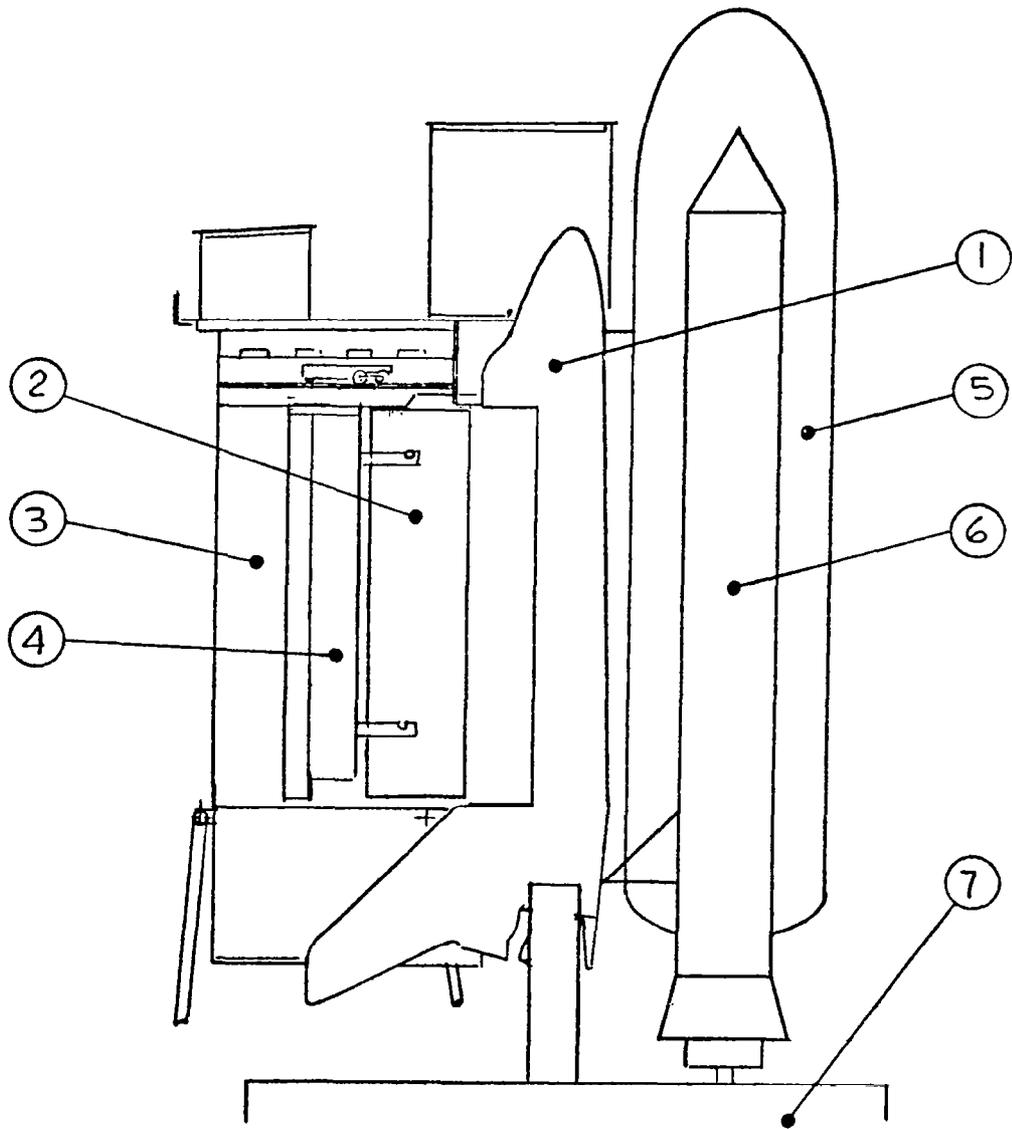
1. ORBITER
2. PAYLOAD
3. PAYLOAD CHANGE-OUT
   ROOM (PCR)
4. PAYLOAD GROUND HANDLING
   MECHANISM (PGHM)
5. EXTERNAL FUEL TANK
6. SOLID ROCKET BOOSTER
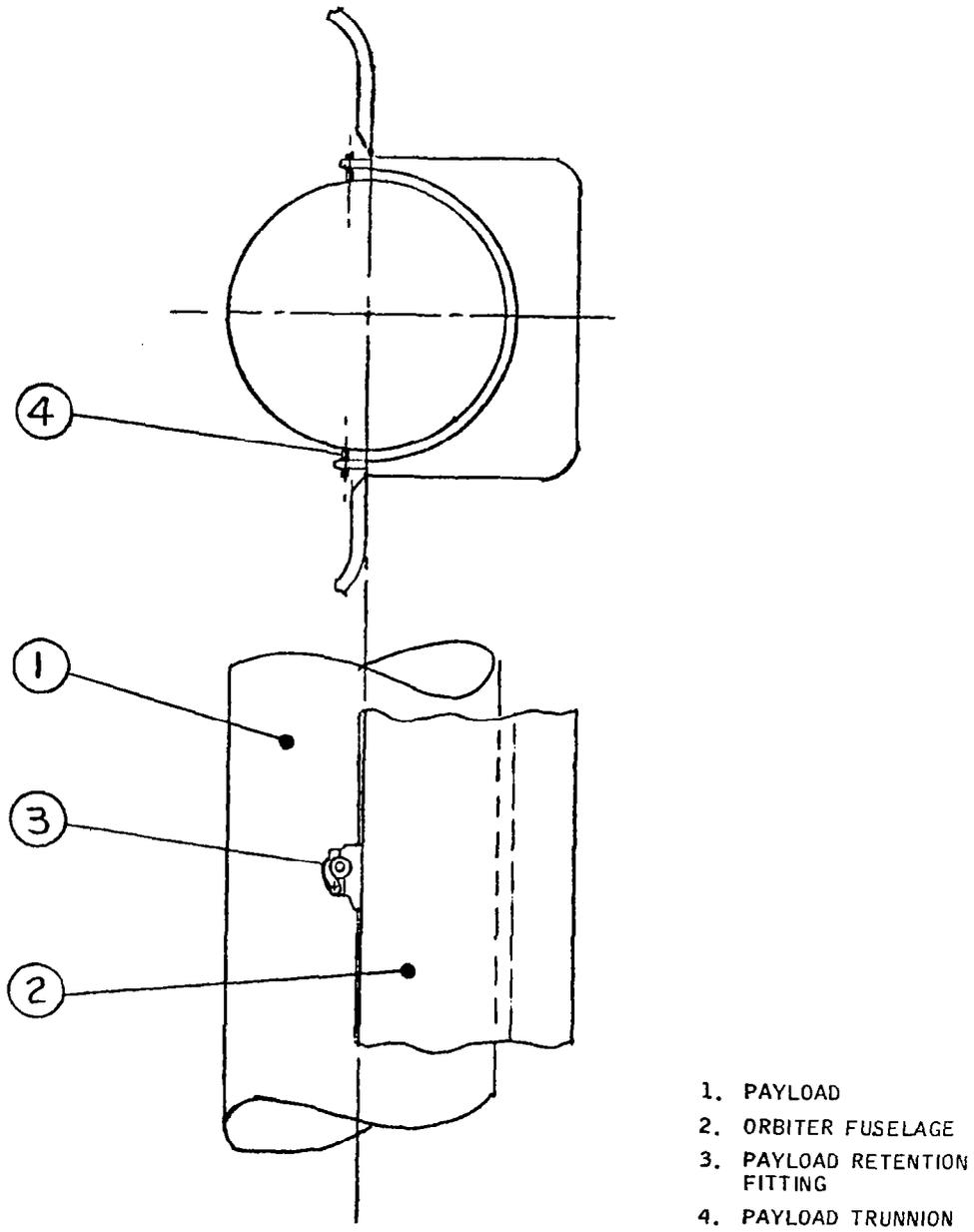7. MOBILE LAUNCH PAD
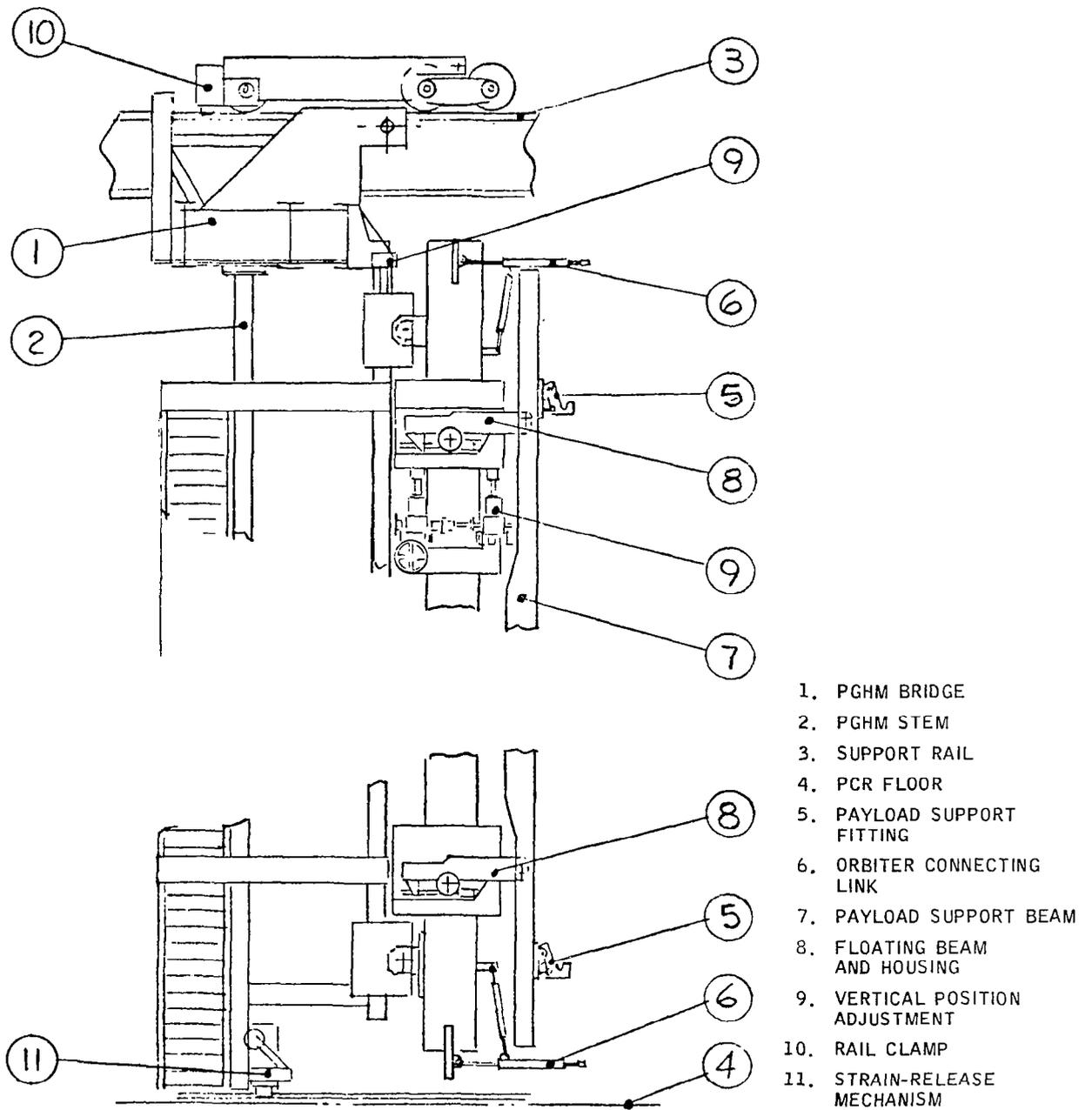
Figure 1. Access to the orbiter

1. PAYLOAD
2. ORBITER FUSELAGE
3. PAYLOAD RETENTION
   FITTING
4. PAYLOAD TRUNNION

Figure 2.   Payload retention method

1. PGHM BRIDGE
2. PGHM STEM
3. SUPPORT RAIL
4. PCR FLOOR
5. PAYLOAD SUPPORT FITTING
6. ORBITER CONNECTING LINK
7. PAYLOAD SUPPORT BEAM
8. FLOATING BEAM AND HOUSING
9. VERTICAL POSITION ADJUSTMENT
10. RAIL CLAMP
11. STRAIN-RELEASE MECHANISM

Figure 3. Payload ground handling mechanism

1. FLOATING BEAM
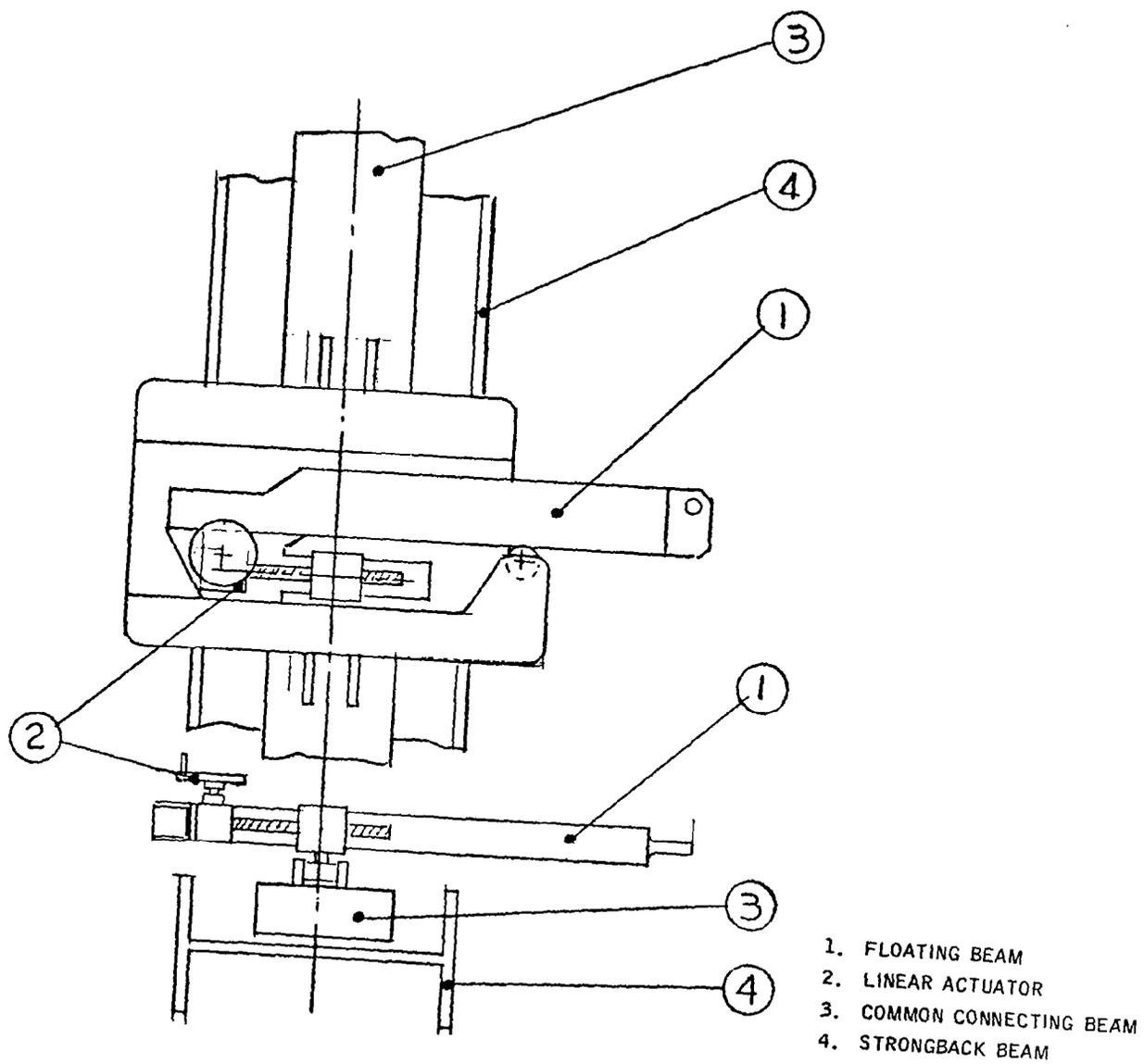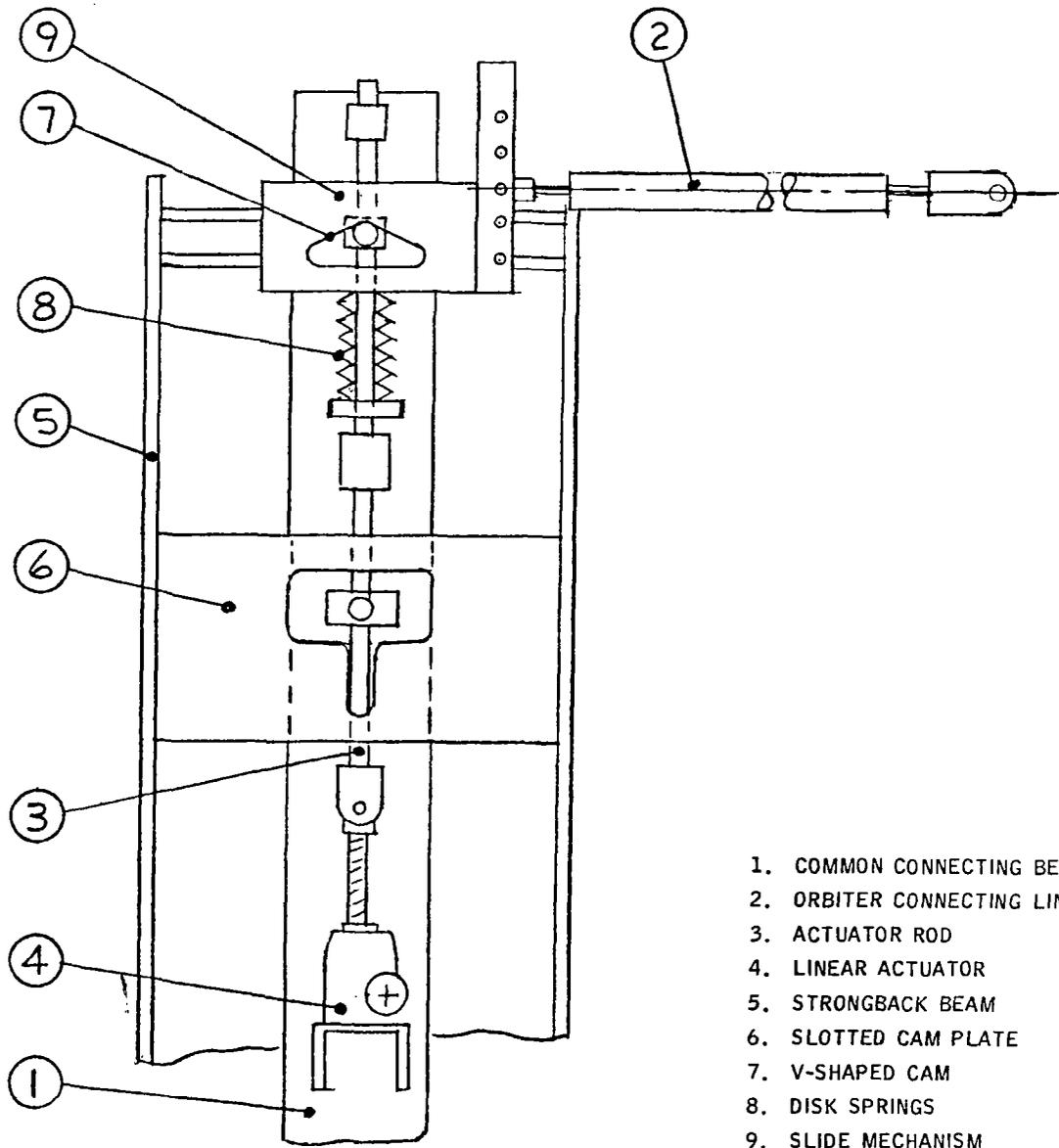2. LINEAR ACTUATOR
3. COMMON CONNECTING BEAM
4. STRONGBACK BEAM

Figure 4.   Floating beam positioning

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1. COMMON CONNECTING BEAM.
2. ORBITER CONNECTING LINK
3. ACTUATOR ROD
4. LINEAR ACTUATOR
5. STRONGBACK BEAM
6. SLOTTED CAM PLATE
7. V-SHAPED CAM
8. DISK SPRINGS
9. SLIDE MECHANISM

Figure 5.   Common connecting beam