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PAYLOAD RETENTION FITTINGS FOR SPACE SHUTTLE PAYLOAD GROUND HANDLING MECHANISM

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ABSTRACT

New ground fittings for Space Shuttle payload handling were designed, built, and tested by Government and contractor personnel at the NASA John F. Kennedy Space Center (KSC), Florida, from May 1981 through November 1982. Design evolution of the Space Shuttle Orbiter payload retention fittings, which contained a load-sensitive split bushing in a pillow-block housing, created an incompatibility between the interfacing ground and airborne equipment. New fittings were designed and successfully used beginning with the fifth Space Shuttle flight, STS-5. An active hydraulic spring system containing a gas accumulator in the hydraulic system provided the load relief required to protect the Orbiter bushing from damage.

INTRODUCTION

The NASA KSC Design Engineering Directorate, in conjunction with the Planning Research Corporation, began design of new payload retention fittings in May 1981. Several other contractors and NASA Centers, including Rockwell International Corporation, The Aerospace Corporation, Martin Marietta Corporation, and Lyndon B. Johnson Space Center, also contributed through participation in design reviews. The new fittings were designed and tested, and production units were installed and successfully used for payload installation on STS-5 on November 11, 1982.

The Space Transportation System (figure 1) consists of two solid rocket boosters with an external fuel tank supported between them and an Orbiter cantilevered from the side of the external tank. Thus, the solid rockets support the entire Space Shuttle vehicle. At the launch pad, this entire assembly rests on the mobile launcher platform. The rotating service structure (RSS) can be moved so that the payload changeout room (PCR) encloses, but does not hold, the Orbiter to allow installation of payloads at the launch pad.

Payloads are held by the Orbiter at the longeron beam and keel points using standard payload trunnions. The longeron trunnions are 8.26 cm (3.25 in) in diameter and approximately 22.23 cm (8.75 in) long, and the keel trunnion is 7.62 cm (3 in) in diameter and approximately 29.21 cm (11.5 in) long. All have a chrome plating polished to 8 root-mean-square.

On the longeron beam of the Orbiter, there is a primary trunnion restraint that reacts the loads in the X and Z directions but allows movement in the Y direction. The longeron beam also has a secondary restraint that reacts the trunnion loads in the Z direction but allows free movement in the X and Y

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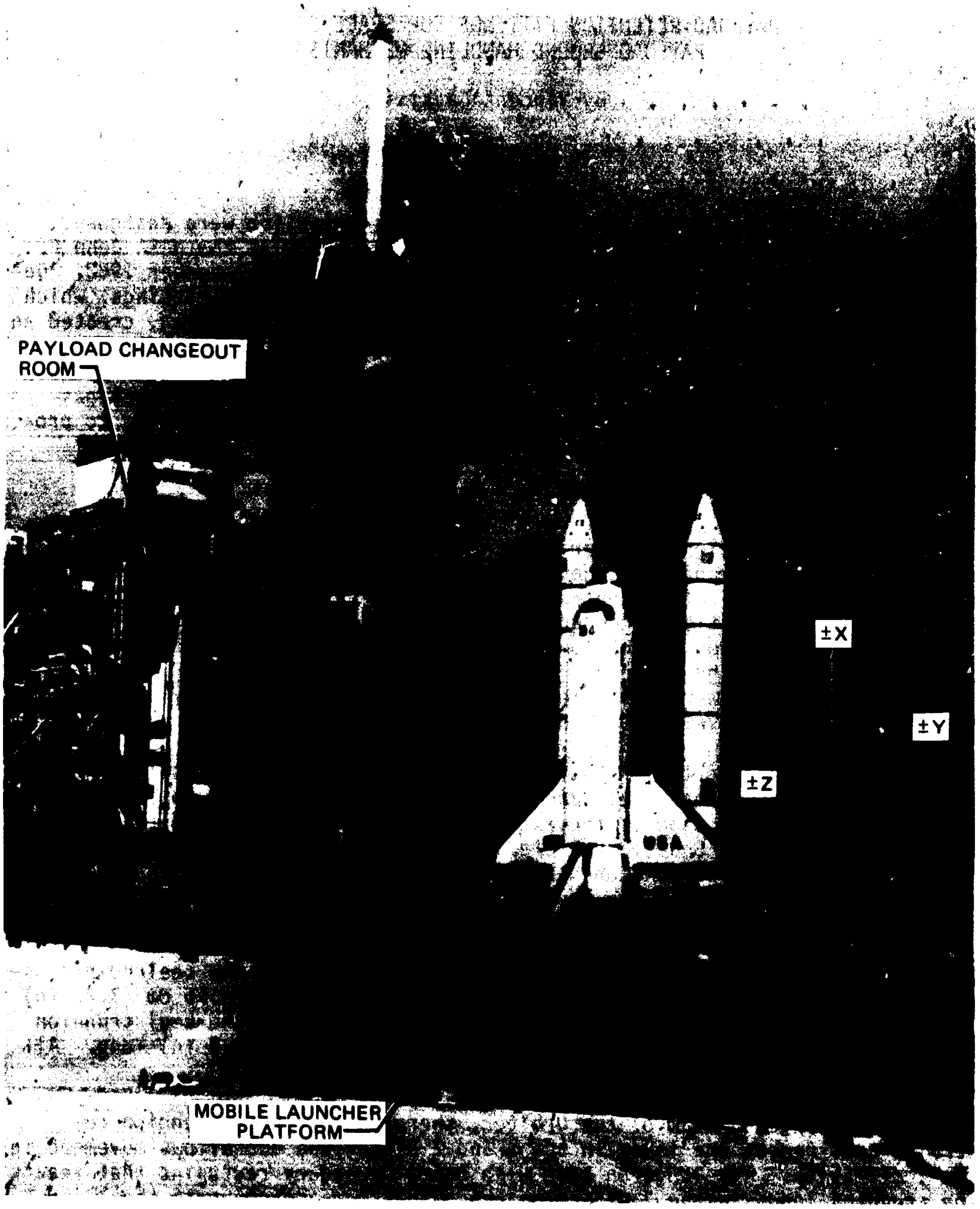

Figure 1. View of Launch Pad

directions. The keel restraint reacts trunnion loads in the Y direction but allows free movement in the X and Z directions.

The primary Orbiter fitting is firmly attached to the longeron beam, while the secondary fitting is allowed to slide in the X direction only. The trunnion interface with the Orbiter longeron fittings is a split spherical bearing to allow slight angular misalignment of the trunnion due to deflection, etc. This split bearing is prevented from rotating out of its housing by a small pin that will shear with a 13,344-N (3,000-lb_f) load. The bore surface of the bearing has a Teflon coating to reduce friction from sliding motion and to protect the polished trunnion, which has a diametrical clearance of 0.003 to 0.010 cm (0.001 to 0.004 in).

The Orbiter keel fitting is attached to the bottom of the Orbiter payload bay. When open, it presents about a 22.86-cm (9-in) diameter hole. Closing draws two V-shaped halves together linearly in the X direction until at the closed position only a 7.62-cm (3-in) hole remains. The clearance is also 0.003 to 0.010 cm (0.001 to 0.004 in). A damage load limit is in effect to prevent Brinelling the trunnion and receptacle during centering. Finally, the payload keel has to be mated with the Orbiter fitting without the operator's being able to see either one, since there is no means of access or remote sensing.

Located in the PCR is the payload ground handling mechanism (PGHM) (figure 2), which is used to install and remove payloads from the Orbiter. It consists of a bridge, a vertical stem section hanging from the bridge, and adjustment devices attached to the front of the stem. Various mechanisms provide gross X and Z direction adjustments. Two payload fitting support beams on the front provide attach points for payload support fittings that are the support points for the payload trunnions before and during the transfer to the Orbiter fittings. The old fittings were rigid and not adjustable once the trunnions were placed on them.

The Space Shuttle vehicle is on the mobile launcher platform (an entirely separate structure from the RSS containing the PCR/PGHM with the payload) at the time of payload insertion or removal. With any winds, the two structures oscillate at different frequencies: the Orbiter at 0.56 Hz and the RSS at approximately 3 Hz. At the elevation of the payloads in the PCR, the relative motion at 180.04-m/s (35-kn) winds amounts to approximately ±0.318 cm (±0.125 in) in the X direction and 0.635 cm (0.250 in) in the Z direction. This motion far exceeds the 0.003- to 0.010-cm (0.001- to 0.004-in) clearances available. This clearly indicated the need for a completely different ground fitting.

DESIGN DETAILS

The decision to create a new generation of ground fittings to prevent damage to the Orbiter and trunnions carried an additional list of restraints and requirements that had to be met. The new fittings had to be capable of being attached as close as 70 cm (27.56 in) apart vertically anywhere along the 16.154-m (53-ft) long support beams in 10-cm (3.94-in) increments. The

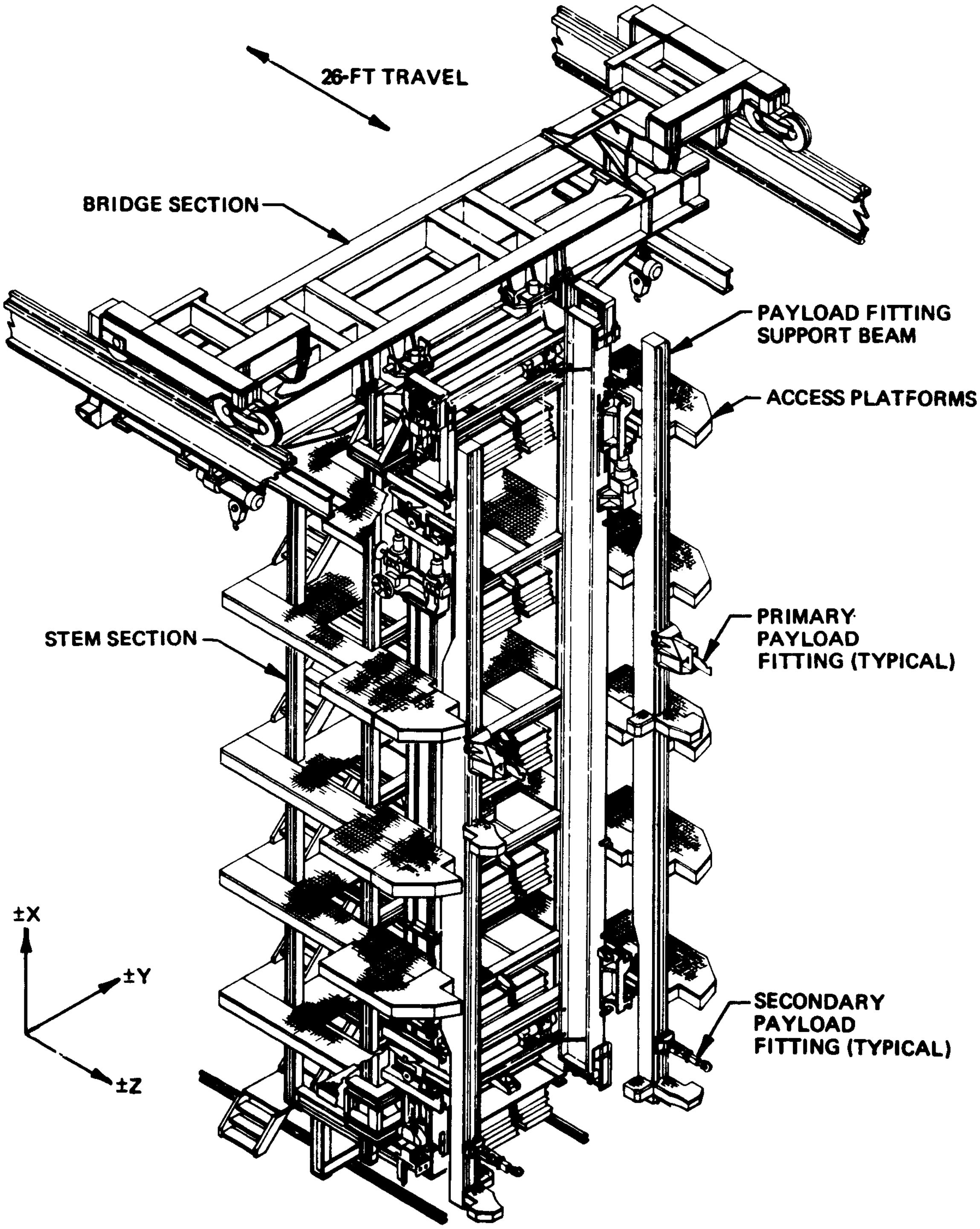

Figure 2. Payload Ground Handling Mechanism Assembled

maximum static load requirement per primary fitting was 173,472 N (39,000 lb_f) in the X direction concurrent with ±71,168 N (±16,000 lb_f) in the Z direction. The secondary position only had the ±71,168-N (±16,000-lb_f) requirement in the Z direction.

The new fittings had to preclude damage to the polished finish of the trunnion. Such damage would change the coefficient of friction and cause higher Y-Y loads during flight.

Since we are dealing with class 100,000 clean rooms, the fittings could not cause contamination. Since some payloads also contained solid rocket propellant and liquid oxidizers, the fittings had to meet restrictive hazardous-area requirements.

Design safety margins for strength had to be 3 to 1 on yield. Further restrictions decreed no possible attachment to the Orbiter in any manner except the insertion of the trunnion. Clearances had to be maintained between the ground equipment and Orbiter equipment including the robot arm (remote manipulator system), hinges, cables, etc. on the Orbiter.

It was also desired to have the fittings designed for use on either side of the payload (not left or right hand only). The load exerted on the trunnion had to be known in addition to the trunnion position and amount of movement. Motion had to be linear, allowing fine adjustment in any direction without any unintentional movement in the other two axes. The new fittings were also required to be compatible with the remaining existing PGHM. The new 100.33-cm (39.5-in) cantilever from the face of the payload fitting support beam was greater than for the old fittings [was 45.72 cm (18 in)] but had to be kept reasonable to minimize the higher moments and the reinforcing required. Finally, the new design had to be completed; the prototype unit had to be built and tested; and the 20 production fittings had to be fabricated, tested, and delivered to meet the launch schedule while staying within the budget.

The ground fittings were separated into two designs according to function (figures 3 through 6): a primary fitting that had to support a 173,472-N (39,000-lb_f) vertical load combined with a ±71,168-N (±16,000-lb_f) horizontal load, and a secondary fitting that had to support a ±71,168-N (±16,000-lb_f) horizontal load. The primary fitting required precisely controlled linear motion capability in all three perpendicular axes for alignment under load. A cantilevered horizontal trunnion support beam was supported on rollers and adjusted horizontally against the load with a double-acting hydraulic cylinder. This system was enclosed in a housing that was allowed to move only vertically by a second single-acting hydraulic cylinder. This housing was located within another structure that contained both the lateral movement mechanism and the means of attachment at various vertical locations as needed. The secondary fitting contained a horizontally positioned double-acting hydraulic cylinder that held and precisely moved the payload in the Z (in-out) direction but allowed free movement vertically and laterally through use of universal and wrist joints. Limiting loads to the sensitive Orbiter elements was achieved by use of a gas accumulator in the hydraulic system (figure 7).

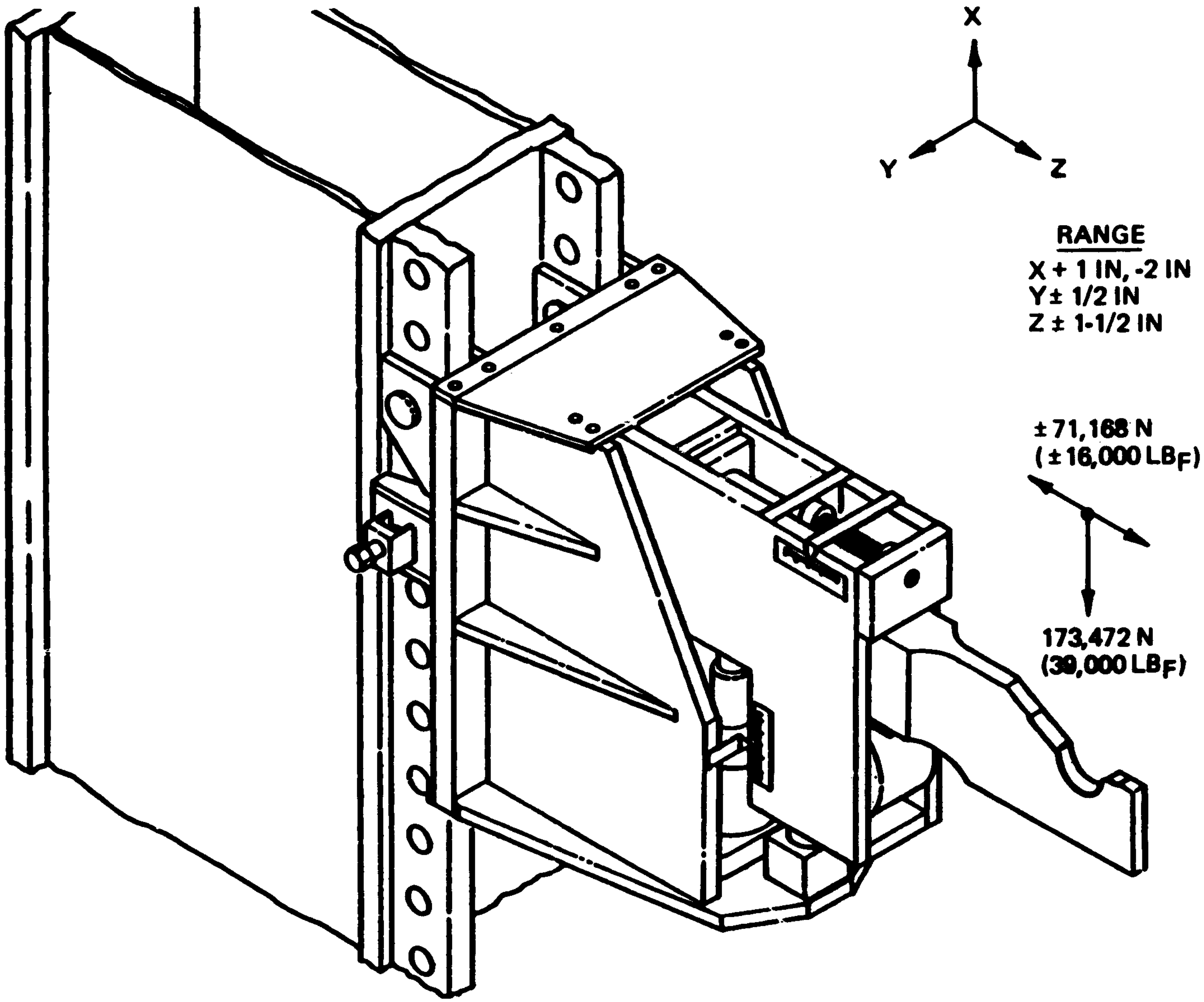

Figure 3. Primary Payload Support Fitting Mounted to Support Beam

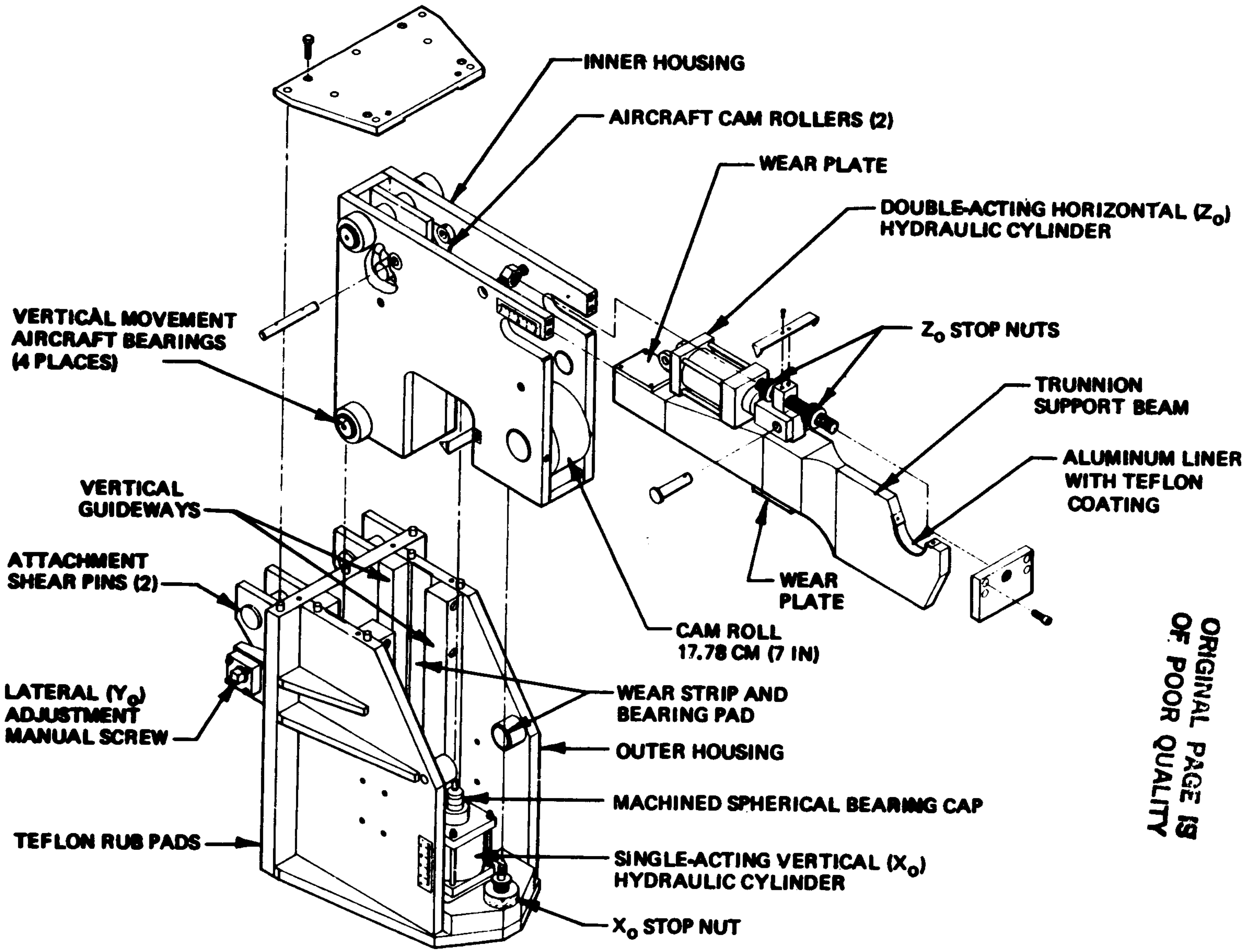

Figure 4. Primary Payload Support Fitting – Exploded View

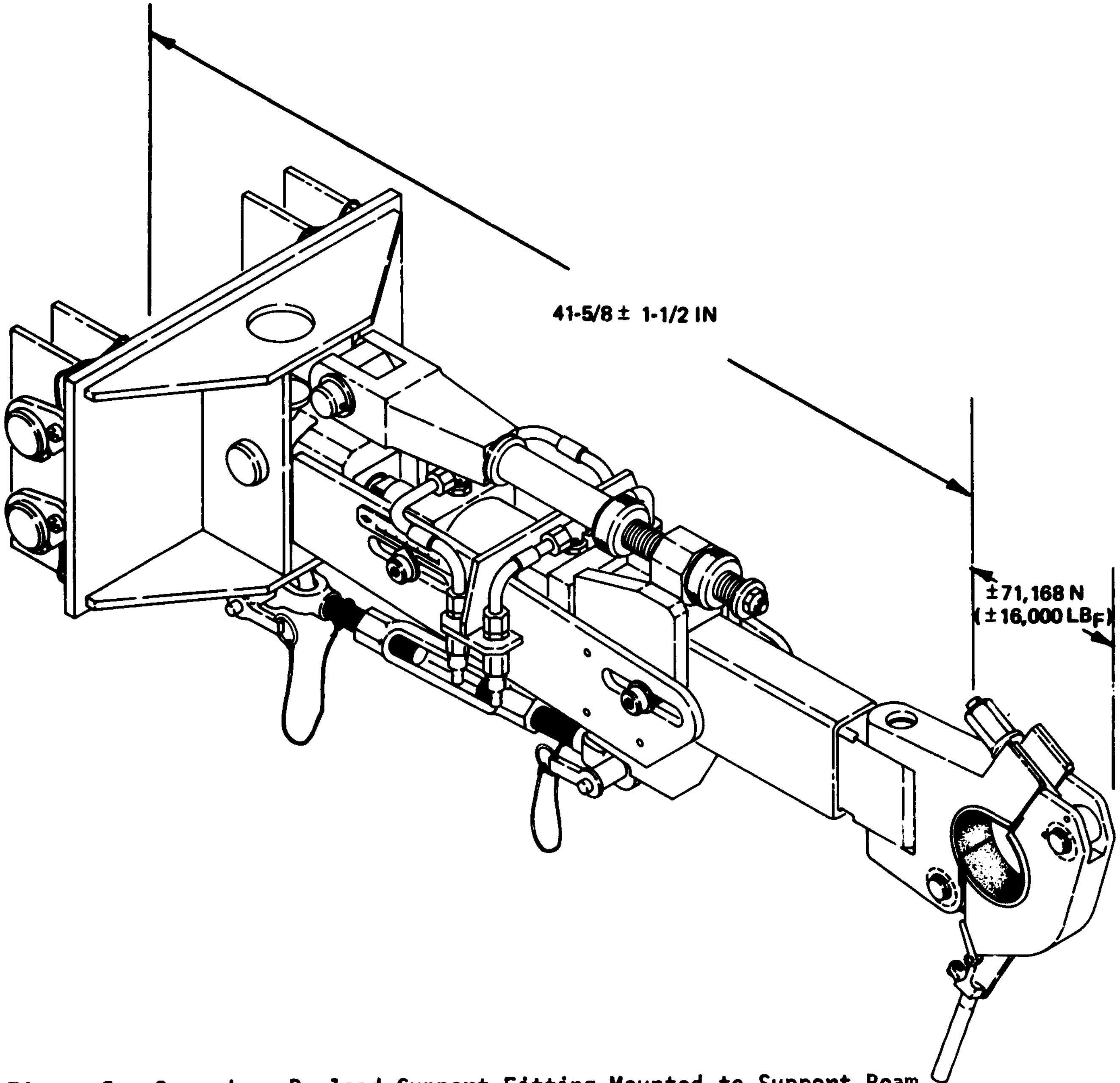

Figure 5. Secondary Payload Support Fitting Mounted to Support Beam

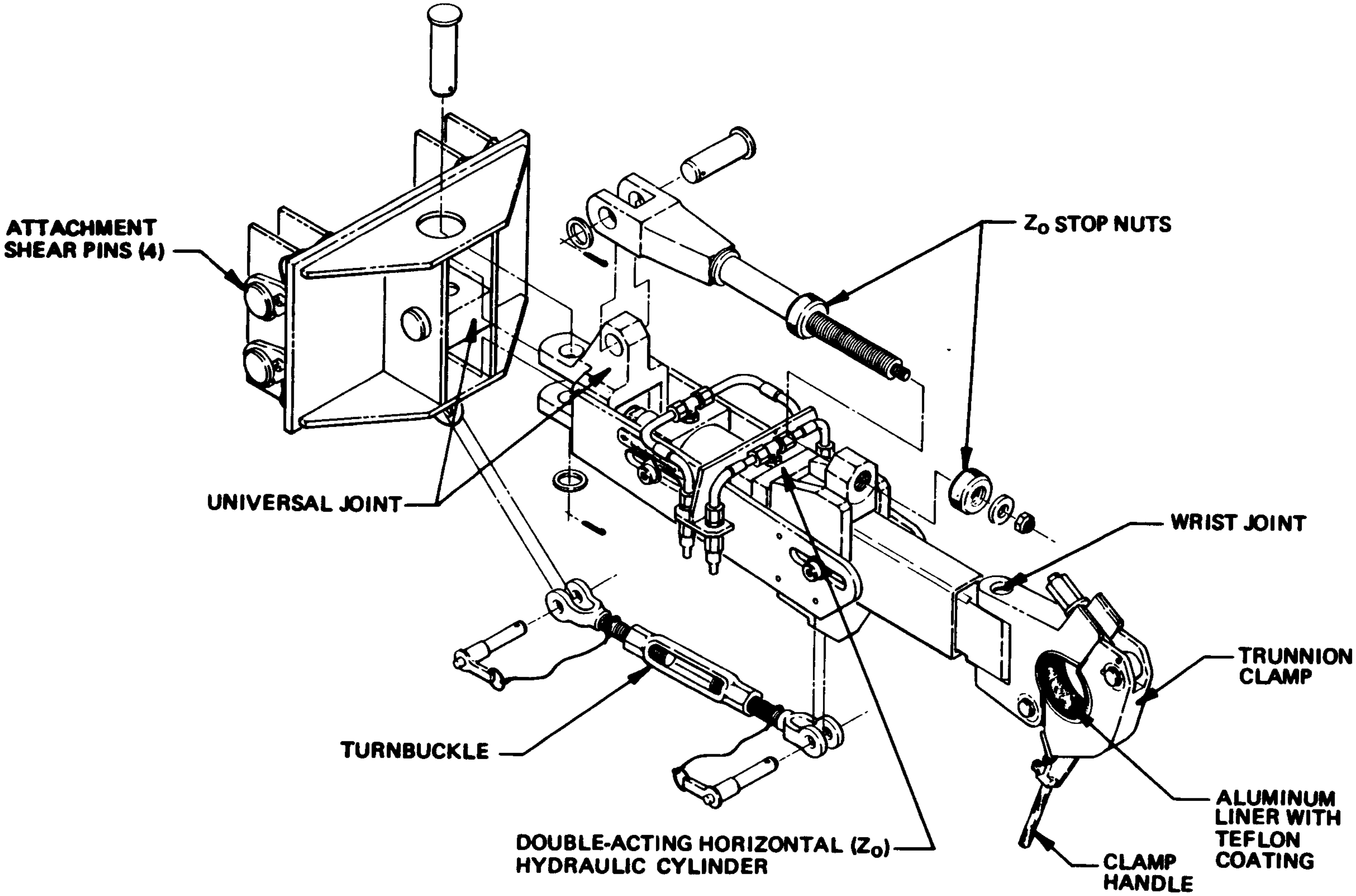

Figure 6. Secondary Payload Support Fitting Exploded View

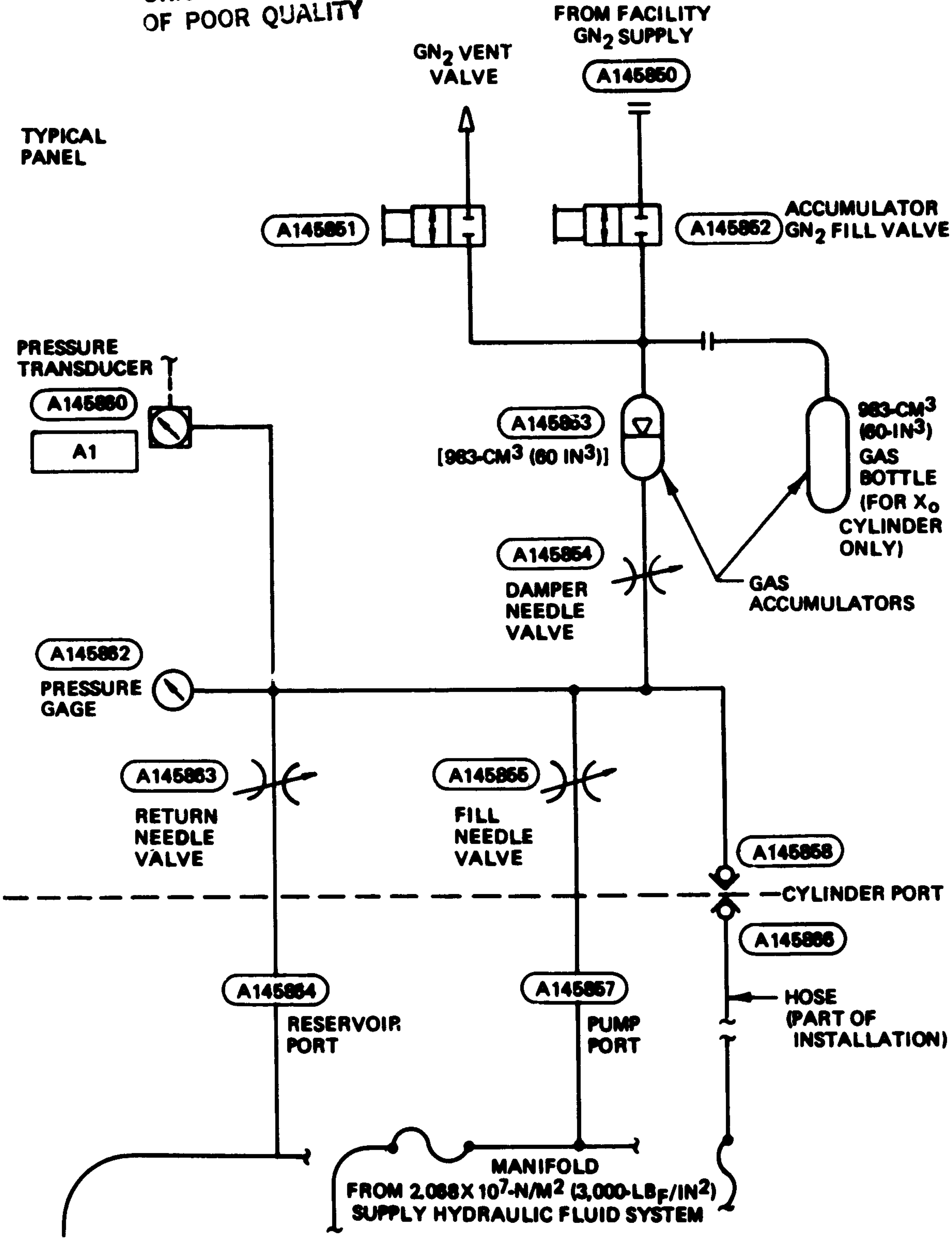

Figure 7. Typical Hydraulic Control Panel (Duplicated for Each Direction of Motion of Each Cylinder)

The cylinders could exert the required holding forces and needle valve positioning but still be soft and yielding to limit these loads during Orbiter motions and/or mismatch during installation.

The keel installation required a horizontal movement allowance combined with a load limitation. This was accomplished by allowing the closing lateral load on the payload keel (from the Orbiter keel fitting) to deflect the horizontal cylinders. Once the keel was locked, the payload was realigned laterally with the primary fitting lateral adjustment mechanism.

The primary requirements that guided the design were that the fitting be able to move linearly in the X, Y, and Z directions and that the load be transferred to the Orbiter without damaging the spherical bushing shear pins. A hydraulic system was designed that would not only provide the force to support and move the load but, by using a gas accumulator in the system, would also provide a load-relief spring to limit the interface loads and allow self-alignment during installation. This created a soft hydraulic system (rather than a hard, rigid system) that could limit the interface loads and move with the Orbiter motion. Figure 7 shows a schematic of the hydraulic system for moving one hydraulic cylinder in one direction. The accumulator gaseous nitrogen (GN_2) fill valve is used to precharge the gas accumulators to a value that depends on the spring constant required. To assume the load, the fill needle valve is opened, allowing liquid from the $2.068 X 10^7$-N/m^2 (3,000-lb_f/in^2) supply system to enter both the accumulator and cylinder. The pressure increases, compressing the gas and building up force on the face of the cylinder piston until the pressure times the piston area is sufficient to raise the load. At this point, the pressure of the compressed gas is the same as the pressure on the face of the piston. Any additional liquid introduced into the system will only move the piston at constant pressure (theoretically). Any increase or decrease of load on the piston rod will unbalance the force across the piston face. As the piston moves to balance the force, it either compresses or expands the gas slightly until the new pressure times the piston area equals the new force. The change of force divided by the amount of movement it causes is the spring constant. High-point bleeds are used to bleed air out for good spring-rate calibration. Varying the damper needle valve will vary the dynamic response of the system by varying the flow rate between the accumulator and the cylinder. Opening the return needle valve will lower the load by allowing the pressurized liquid to escape to the central reservoir. A pressure gage reads out in lb_f/in^2 gage, and the transducer feeds data to a digital readout that displays values in lb_f. This system is repeated for each of the three powered directions on a primary fitting and each of the two powered directions on a secondary fitting. The central hydraulic system consists of redundant pumps, the central reservoir, and control panel. Haskell air-driven pumps were selected due to their successful industrial record of running on plain deionized water at high pressures. Here, they are used with 5% lubricant in the water and at lower pressure, which should yield high reliability. (Water is used because it is not likely to damage a payload if spilled.)

The primary fitting holds the polished payload primary trunnion on a liner made of 7076-T6 aluminum coated with Lear Siegler Fabroid G2 Teflon bearing material to protect the trunnion from damage by steel parts. The Teflon was added after tests showed galling of the aluminum and transfer of aluminum to the trunnion surface.

The trunnion support beam is 2.54 cm (1 in) wide to fit the area on the trunnion allocated to ground handling. Depth under the trunnion was minimized to avoid interference with Orbiter attachments 19.89 cm (7.83 in) below the trunnion, and this required heat treatment of AISI 4340 steel to meet the 3-to-1 margin on yield. The beam is cantilevered for clearance to the Orbiter fittings and is supported by a 17.78-cm (7-in) cam roll bearing below and two precision aircraft cam rollers at the top rear to support the X load. To meet the overall height limitation, the beam was tapered at the rear.

All rollers bear on wear plates that are shimmed to provide true linear Z motion. The Z load is taken by a double-acting hydraulic cylinder attached to the protrusion on the trunnion support beam over the 17.78-cm (7-in) roller. Pinned ends on the cylinder prevent moments on the cylinder rod that would side load the seals. The trunnion support beam, supporting rollers, and hydraulic cylinder are all structurally supported by the inner housing. This inner housing, which serves to provide the linear X direction motion, is supported on the single- (upward) acting hydraulic cylinder that has a machined spherical bearing cap on the rod end to reduce side loads on the seals. Four more aircraft bearings, two per side, are located to travel in the vertical guideways attached to an outer housing. The cylinder was located as close to the payload as possible in order to reduce the moment carried by the X rollers, which were spaced as far apart as possible to minimize their size and reduce overall height.

Lateral stability is provided by Teflon-coated wear strips and adjustable bearing pads that are located between the trunnion support beam and inner housing and between the inner and outer housings. The outer housing provides the overall enclosure and the means of attachment to the support beam at the desired location by using shear pins through both clevis ears and support beams on each side of the fitting. These pins, high strength for minimum size, are finished to 16 root-mean-square to provide a sliding surface with the Garlock DU Teflon-coated insert bearing sleeves that line the attachment holes on the fitting support beam.

The width between the clevis ears is 2.54 cm (1 in) wider than the lug on the beam, which allows the fitting to be moved in the lateral (Y-Y) direction ±1.27 cm (±0.5 in) by sliding the pin through the bearing sleeves. This is accomplished by using a coarse-thread manual screw that is located directly below the shear pins. This screw can be mounted on either side of the fitting, depending on accessibility, and will push or pull the fitting laterally on the sleeves. One screw is located on each primary trunnion fitting. Thus, to move a payload laterally, the screws to both fittings are operated simultaneously. A 0.64-cm (0.25-in) in-and-out free-sliding travel is designed into each screw. This prevents a screw on one side from binding up the screw on the other if they are erroneously turned at a different rate or in different directions. The lower rear portion of the outer housing also has Teflon rub pads that bear against the front surface of the support beam lugs.

The X adjustment provides a range of movement of up 2.54 cm (1 in) and down 5.08 cm (2 in) from the null position. This allows the fitting to be lowered 5.08 cm (2 in) to clear the half diameter [4.13 cm (1.625 in)] of the trunnion for withdrawal.

In order to protect the payload and the Orbiter from colliding with each other in the event of a hydraulic failure, two mechanical stops were devised with manual follow nuts to minimize the free-fall distance. These nuts are positioned approximately 0.95 cm (0.375 in) from engaging to allow float with the Orbiter relative motion but to catch if failure occurs. They also are snugged up to support the loads whenever hydraulics are secured and pressure brought down during nonoperating periods.

Since the secondary fitting had to support ±71,168 N (±16,000 lb_f) in the Z direction but offers no resistance in the X and Y directions, the design evolved into a stiff arm with a universal joint and a wrist. A clamp was devised that would firmly grab the trunnion and was lined with Teflon on aluminum for the same reason as was the primary fitting. A vertical-axis wrist was used to connect the clamp to the body of the fitting with a universal joint allowing unrestricted movement in the X and Y directions. The main body of the fitting consists of the double-acting hydraulic cylinders and the surrounding structure. The cylinder is mounted with the rod end toward the universal joint and the cylinder being pushed/pulled with respect to the rod. This surrounding structure is designed to eliminate bending due to frictional forces acting on the clamped trunnion as the trunnion moves vertically. (Bending the rod and cylinder would cause seal problems.) A turnbuckle supports the fitting prior to attachment to the payload. The secondary fitting also has the same gas accumulators for compliance to loads as does the primary fitting and has the mechanical stop screw with adjustable stop nuts.

CONCLUSION

A primary and a secondary fitting were built for test purposes and showed that the fittings were fully capable of preventing damage to the Orbiter and trunnion. Although early testing caused galling of the aluminum, the Teflon coating added later did provide full protection. The measured friction in the system from rollers, rub guides, seals in the hydraulic system, etc. proved to be somewhat greater than expected and varied with the magnitude of load. This extra damping allowed the full-open use of the damper needle valve. Physically, the fittings met all the size, cleanliness, compatibility, and strength requirements (figures 8 through 11). Ten primary and 10 secondary production fittings were fabricated, with 16 additional pairs destined for KSC Launch Complex 39 Pad B and Vandenberg Air Force Base, California.

STS-5 payloads were installed by the new fittings without problems. Final cost was within the original budget estimate.

Figure 8. Primary Fitting During Development Tests

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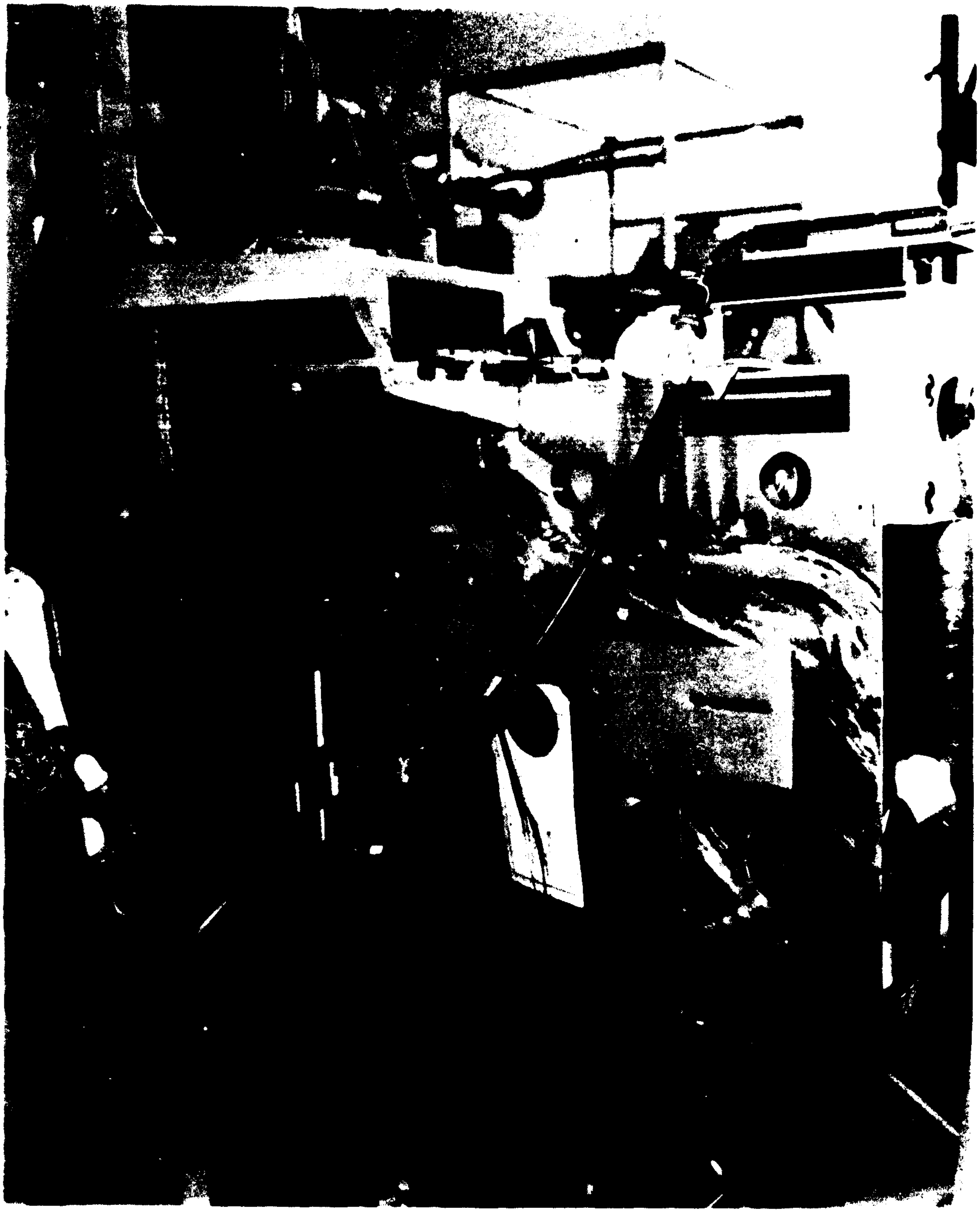

Figure 9. Primary Fitting

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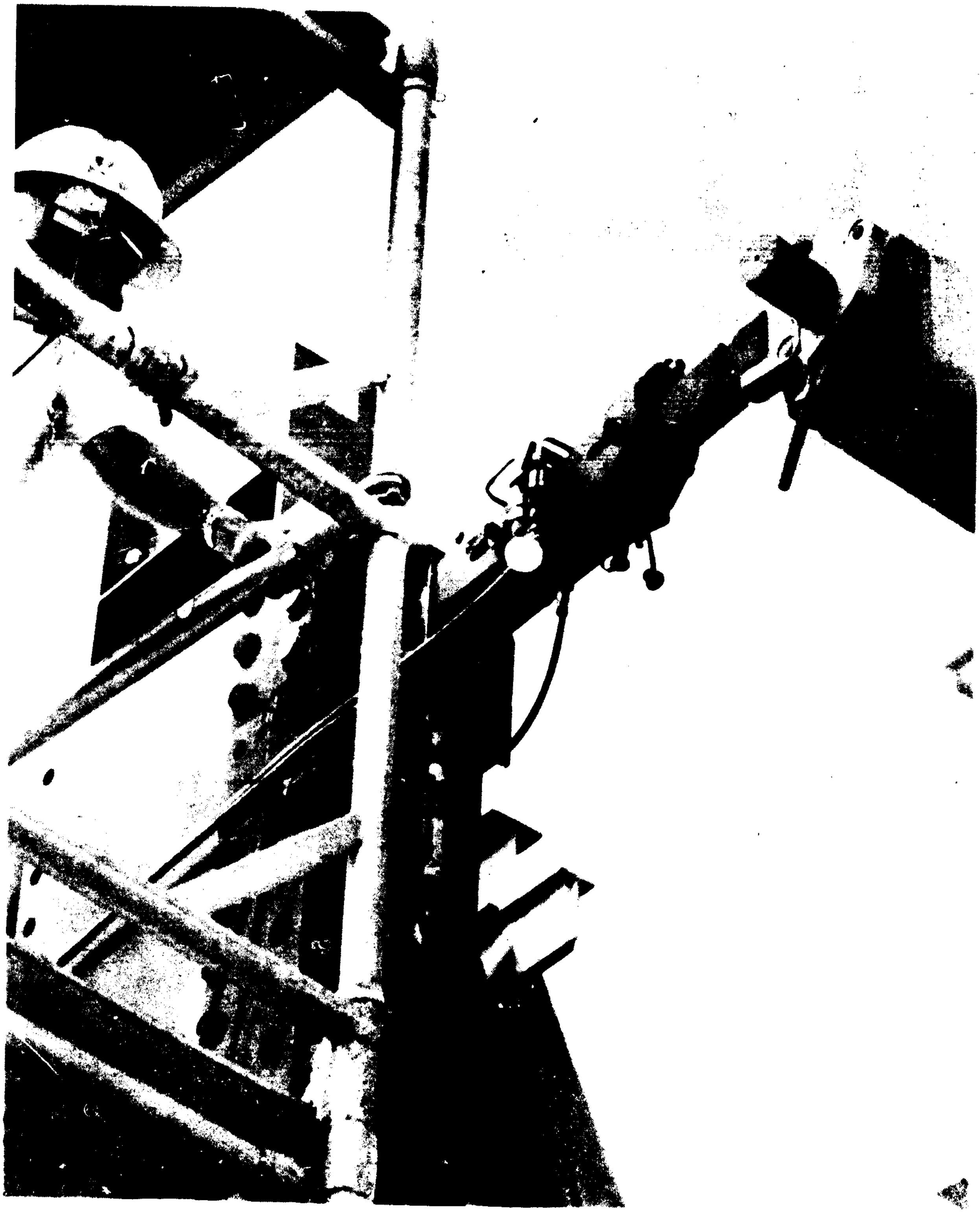

Figure 10. Secondary Fitting During Development Tests

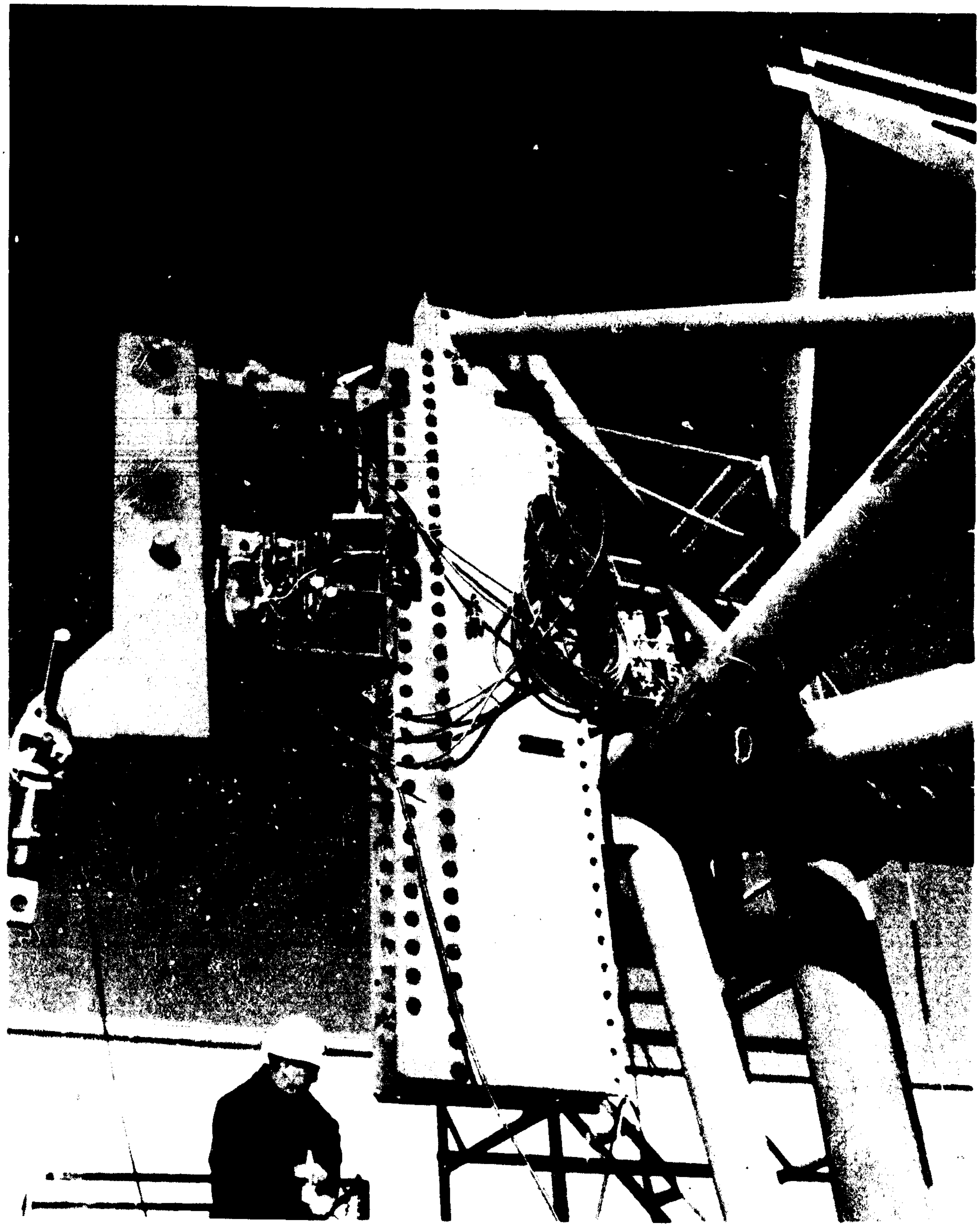

Figure 11. Secondary and Primary Fittings on Test Stand

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