STS PAYLOAD GROUND HANDLING MECHANISM
AT JOHN F. KENNEDY SPACE CENTER

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ABSTRACT

This paper describes the payload ground handling mechanism (PGHM), which lifts payloads out of the payload canister that brings them to the launch pad. The PGHM then loads the payloads into the Orbiter through the wide-open payload-bay doors.

The challenge was to provide this capability in time for Space Transportation System Flight No. 5 (STS-5). Meeting this STS requirement was considerably more challenging than using the stacking method for loading payloads on top of expendable vehicles. This paper describes the new mechanism and its main features.

INTRODUCTION

The STS requires effective payload handling on the ground and specifically at the launch pad in order to carry out its mission. This has been accomplished with the new PGHM, which went on line at Launch Complex 39 Pad A for STS-5.

Expendable vehicles required a relatively simple means of payload loading for vertically stacking the payload on top of the carrier vehicle. One challenge of the STS was to provide an effective means of loading multiple payloads into the payload bay of the Orbiter through the large, open doors while the Orbiter is in a vertical position at the launch pad, which precludes the previous simple stacking approach. The challenge was met by the new PGHM.

Satisfying the numerous operational requirements placed on this mechanism provided no small technical challenge. In addition to the gross X, Y, and Z translations required to position the payload, the lifting hooks themselves required cushioned X and Z vernier adjustment as well as uncushioned Y vernier adjustment capabilities. The cushioning of X and Z is necessary to protect the bearing blocks that support the payloads in the Orbiter payload bay during flight. These bearing blocks have a somewhat limited tolerance to bumping of the trunnions against them during payload insertion. Wind causing small motions of the space vehicle (because of its large sail area) is also a factor.

Generally speaking, friction is a nuisance in a mechanical system that requires accuracy of control and positioning; however, an understanding of coulomb friction and how it functions can be used to advantage. It is this use that is considered a state-of-the-art improvement. There was a significant payoff in obtaining this understanding, as it led to elimination of the need for a complex, electronic, strain-gage, load-measuring system and also led to development of self-compensating means of load assumption. The latter takes advantage of coulomb friction's characteristic of pushing back only as hard as it is pushed upon, up to the point of incipient sliding.

The fitting designs are a state-of-the-art improvement in that, within a limited space, they provide the functions of the necessary X, Y, and Z compliance, including remote control of X and Z vernier adjustment by means of hydraulic power. The necessary cushioning of X and Z is provided by hydraulic accumulators precharged with gaseous nitrogen (GN_2).

OVERVIEW AT LAUNCH COMPLEX 39 PAD A

The Orbiter has about 75 percent of its cargo installed in its payload bay at the launch pad. A series of problems had to be understood and overcome to develop the PGHM, which was designed and installed at the John F. Kennedy Space Center, to do this. To understand the details of the design, some background information is required.

The STS has two solid rocket boosters (SRB's) with an external fuel tank supported between them. The Orbiter is then suspended from the side of the external tank, so the SRB's support the entire vehicle. At the launch pad, this assembly rests on the mobile launcher platform where a rotating service structure (RSS) can be positioned so that the payload changeout room (PCR) inside it encloses, but does not hold, the Orbiter. The payloads are inside the PCR, from which they are installed into the Orbiter (figure 1).

The portion of the Orbiter that carries the cargo is referred to as the payload bay and is a void large enough to contain a cylinder 15 feet in diameter, 60 feet long, and weighing 65,000 pounds (figure 2). While the cylinder represents the maximum space available for payloads, the actual payloads are of various shapes, sizes, and weights. There can be as many as five main elements on each flight, each individual in design but all having a common method of attachment to the Orbiter payload bay along the longeron beam and at a keel point with standard trunnions. The payload longeron trunnions are 3.25 inches in diameter by approximately 8.75 inches long, and the keel trunnion in 3 inches in diameter by approximately 11.5 inches long. They are made of heat-treated steel or titanium with a chrome plating polished to 8 microinch root mean square.

A TYPICAL PAYLOAD

Figure 3 shows two views of a simplified payload: a 90-inch-radius cylinder that has some arbitrary length. The top view shows that the payload trunnion line is offset by 14 inches from the geometric center of the allowable 15-foot-diameter circle. In general, but not always, the center of gravity (cg) of the payload is near the geometric center. From the lower view, it is evident that there is a moment caused by the cg that has to be counteracted by the Orbiter attach points.

PAYLOAD RETENTION IN THE ORBITER

Due to flight flexure of the Orbiter, each attach point has a certain job to perform and is explained using the Orbiter coordinate reference system (figure 3). The X direction runs from nose to tail, the Y direction is from wing tip to wing tip, and the Z direction is from belly to payload-bay doors.

During flight, the Orbiter flexes and twists; and if the payload were firmly fixed to the Orbiter, it also would be caused to flex, twist, and pull. Therefore, to minimize unwanted stresses, the payload is restrained as follows: At the longeron area of the Orbiter there is a primary restraint that reacts the load in the X and Z directions but allows movement in the Y direction. A secondary restraint reacts the loads in the Z direction but allows free movement in the Y and X directions. The keel restraint reacts in the Y direction but allows free movement in the X and Z directions.

Figure 3 shows that force F2 will counteract the weight in the X direction, and the couple F and -F in the Z direction will counteract the moment of the weight W with its 14-inch offset. The keel only reacts side-to-side Y loads and thus mainly reacts flight loads.

The Orbiter has two types of longeron restraints. One, called the passive longeron fitting, is closed and bolted on the ground and stays that way for nondeployable payloads. The other is opened and closed remotely by the astronauts for deploying payloads in orbit and is known as the active longeron fitting. Both are attached to the longeron beam through use of a bridge assembly and both can be used as primary or secondary. In primary use, the fitting is firmly attached to the longeron beam; and in secondary application, it is allowed to slide.

The keel is attached to the bottom of the Orbiter payload bay by use of a bridge assembly and is powered open and closed by the astronauts. When open, it presents about a 9-inch-diameter opening. The closing motion draws both halves together linearly in the X direction until, at the closed position, there is only a 3-inch hole. When locked on the trunnion, motion is allowed by sliding the entire unit along the X direction, but the payload is held rigid in the Y-Y direction. The polished trunnion is allowed to slip longitudinally through the Orbiter fittings at all three attachments. Both the longeron fittings and the keel fitting contain a split bushing that could be damaged during payload installation if a misalignment of the trunnion to fitting causes a bushing force of approximately 3,000-lb shear.

VEHICLE AND PGHM STRUCTURE

The Orbiter is a cantilevered load hanging from the side of the fuel tank, which is a thin structural member that will flex under load. Deflections are produced when the load on the Orbiter is changed either by adding or removing a payload. The fuel tank is also suspended from the SRB's, so

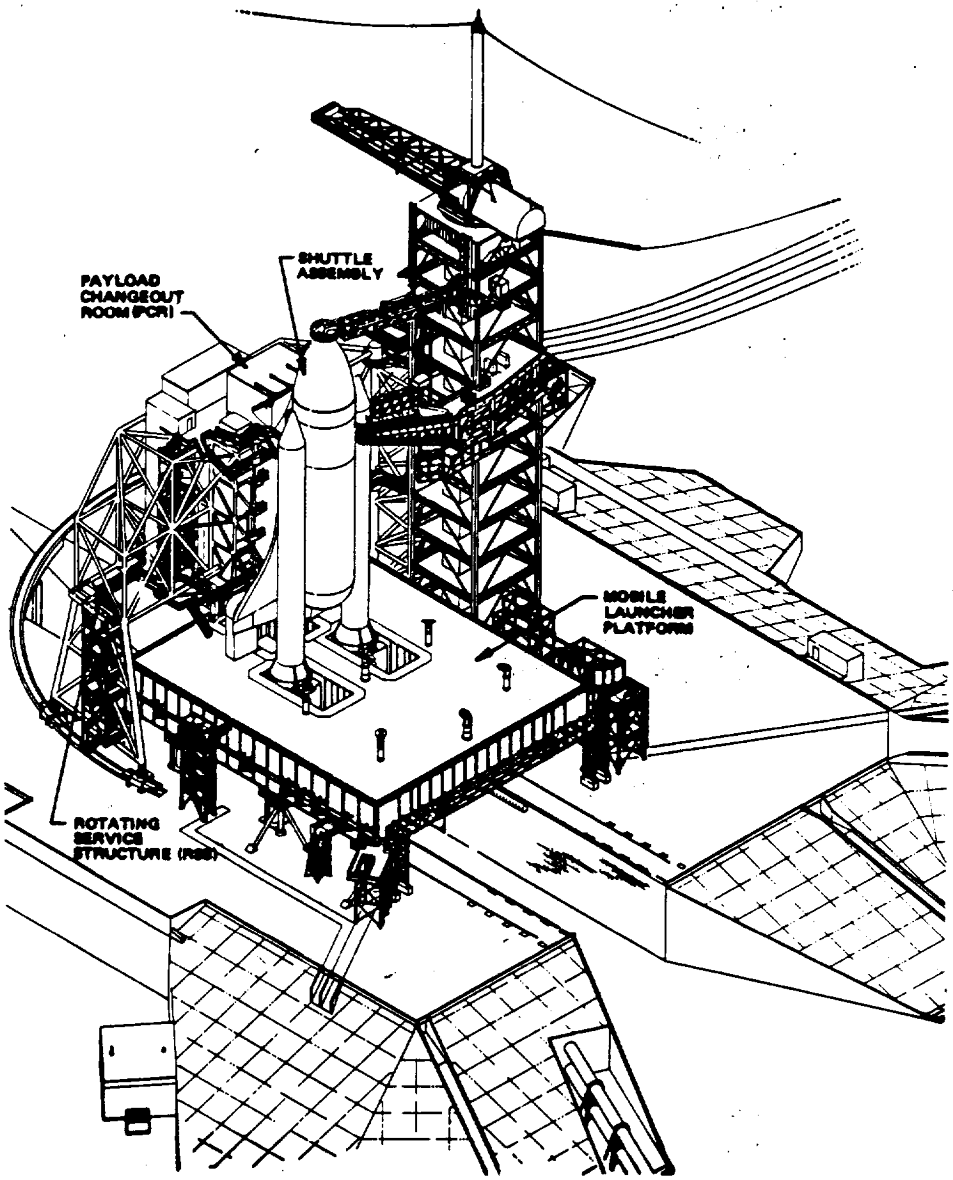


FIGURE 1. PAYLOAD CHANGEOUT ROOM WITH PGHM AND ACCESS STANDS

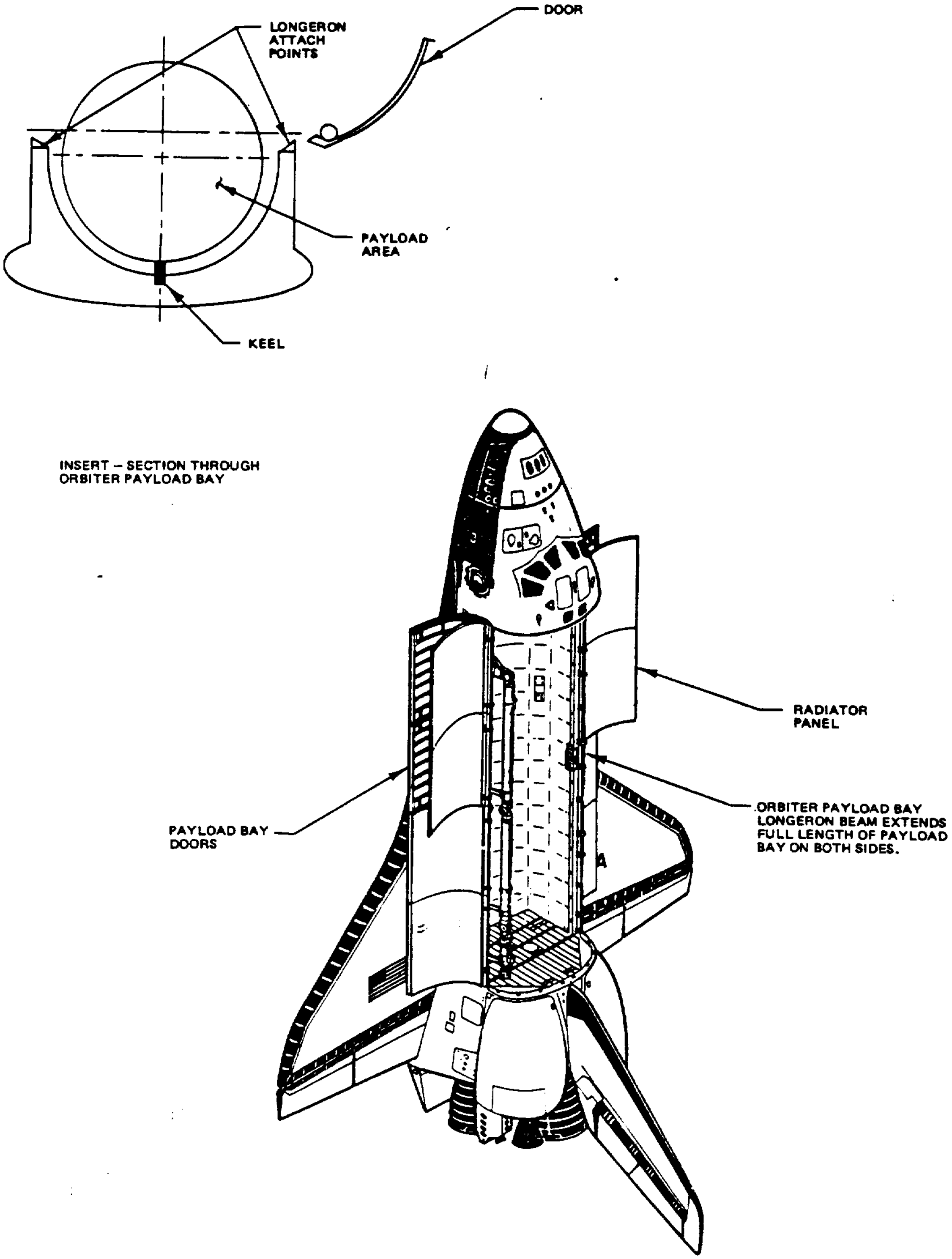


FIGURE 2. ORBITER CARGO BAY

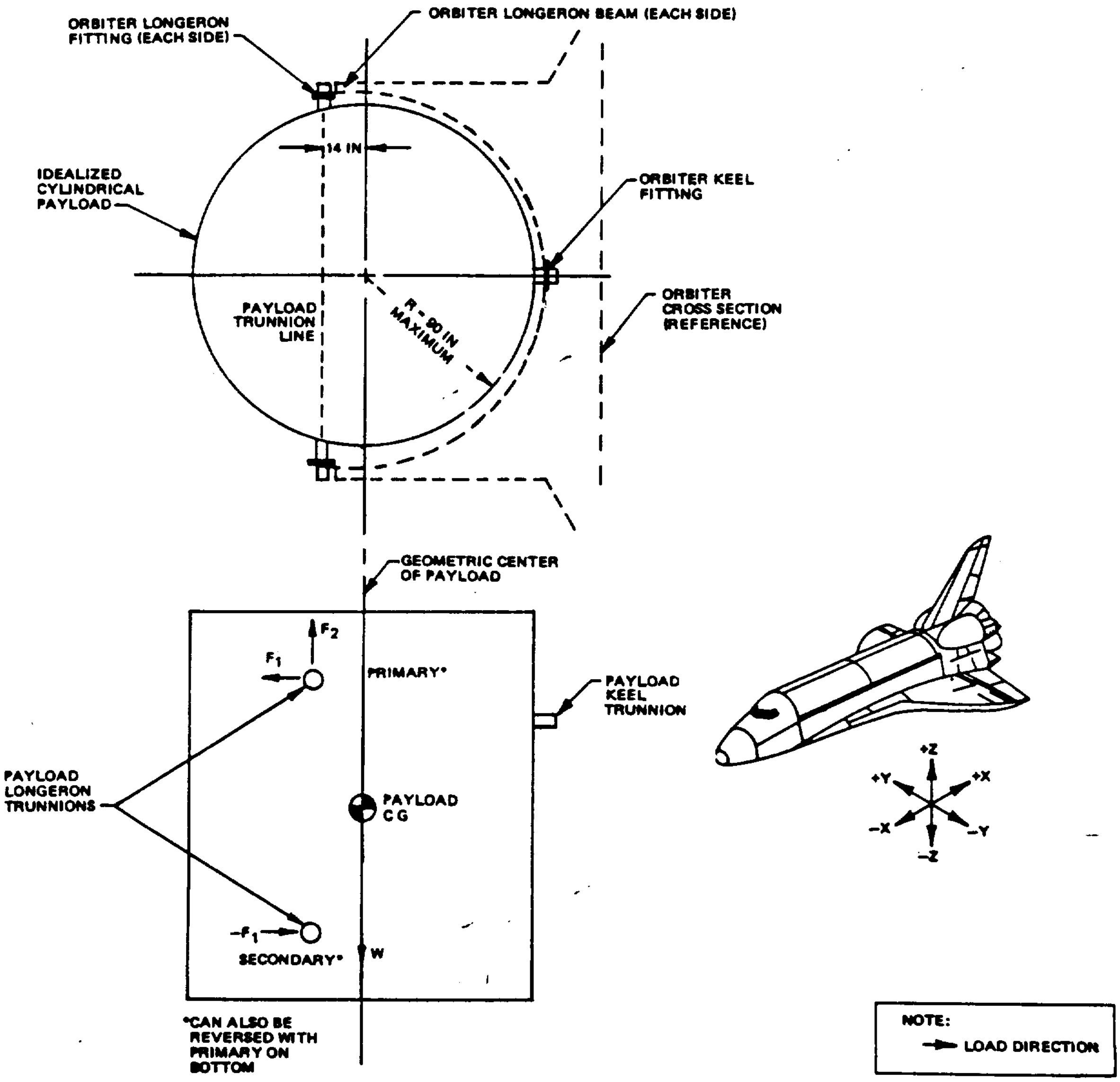


FIGURE 3. PAYLOAD TRUNNION FORCES

more flexibility is added to the system; the bending moment from the weight of the Orbiter and the payload will cause the SRB's to deflect. The assembled STS vehicle sitting at the pad also presents a sail area to the wind. These wind effects, which vary with direction and velocity, produce additional periodic movements that modify the static deflections. The result of all the loads is a deflection that has a point of apparent rotation located somewhere toward the base of the SRB segments. Looking at the STS vehicle from the side shows that the Orbiter is not only above but also off to the side of the vertical centerline of the SRB's. The effect of this is to create not only a deflection in the X direction, but a simultaneous deflection in the Z direction. The amount of deflection will vary along the length of the Orbiter, as can be seen by extending one radius line from the base of the SRB's to the top of the payload-bay area and another to the bottom. If both radii are rotated counterclockwise equally a few degrees, it is apparent that there are differences in the X and Z movements of the ends.

The structure that houses the PGHM is on a base separate from the STS vehicle. It also presents a sail area to the wind, resulting in a periodic deflection. The frequency of this movement is different from the frequency of the vehicle's movement. In addition, there are static deflections caused by variation in the amount and location of loads within.

Transferring a payload from the ground to the flight vehicle thus requires transferring the payload from one moving structure to another with the accuracy to align the trunnion to the flight fittings and to compensate for the additional change of deflections when the loads are actually transferred. At no time is the Orbiter tied to the ground, since this would cause unknown loads to be transmitted to the Orbiter and possibly damage the flight vehicle.

The new device is shown in figure 4. A bridge similar to that from a bridge crane is supported from ceiling rails that allow the unit to traverse the room from front to back to clear the doors that maintain clean conditions during absence of the Orbiter. Hanging from the bridge is a structural stem that is the supporting frame for the mechanisms mounted on its front (Orbiter) side. The stem also contains five levels for personnel and equipment, and slung below these levels are access platforms. These access platforms allow variable positioning for personnel to service the cargo elements.

GROSS PAYLOAD TRANSLATIONS

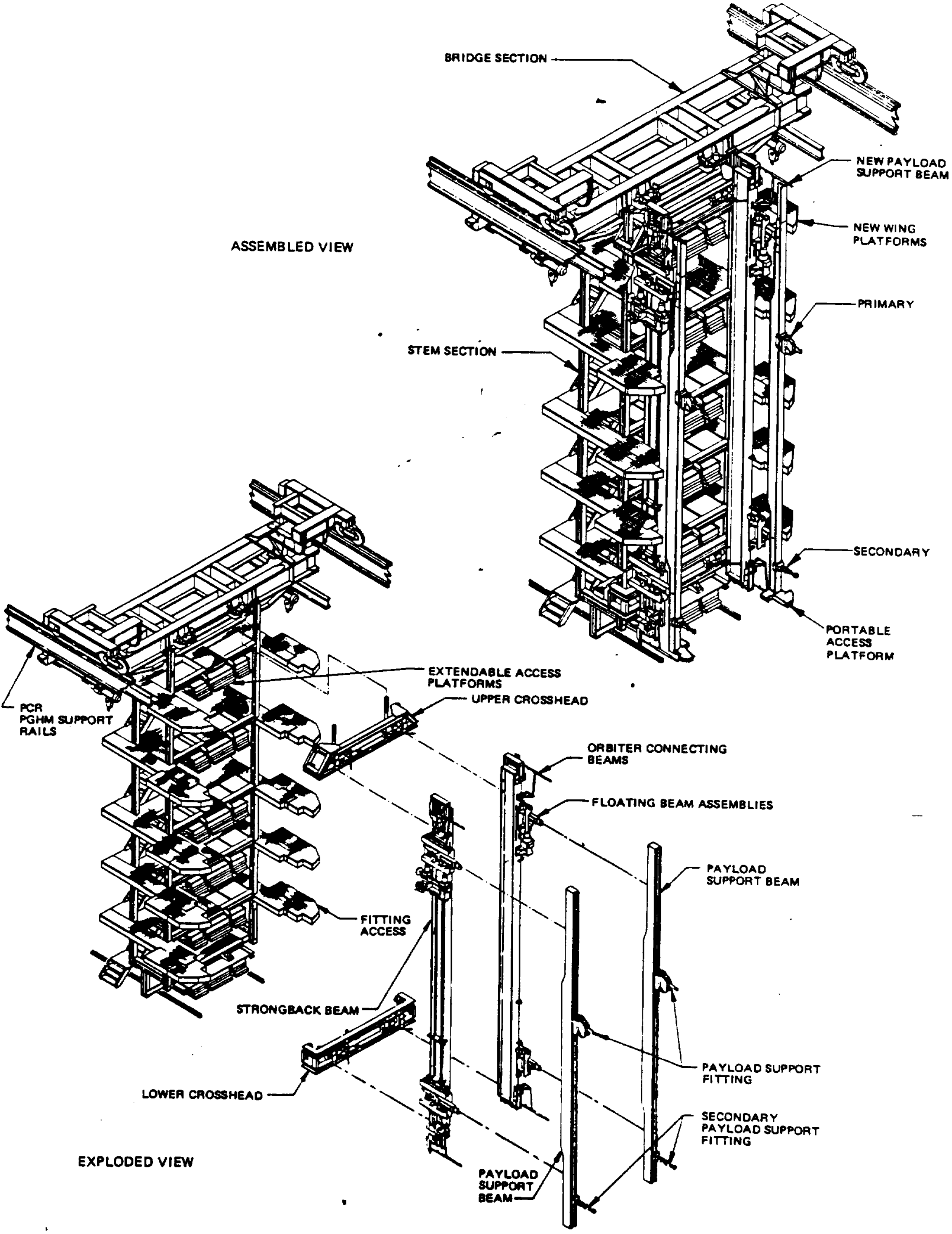
To best explain the operation of the mechanism, a typical usage will be described. This will cover the arrival of the cargo from its preparatory facility, the transfer of the cargo to the PGHM, and finally its insertion into the Orbiter.

The method chosen to carry the cargo around the John F. Kennedy Space Center is a simulated midbody of the Orbiter called the payload canister. This structure duplicates the space within the Orbiter payload bay, along with the retention points and methods of holding the cargo. This canister is carried from point to point on its transporter; and for carrying payloads to the pad, it is used in the vertical position. Once it arrives at the pad, a 90-ton hoist on top of the PCR is used to lift the canister so that it is positioned in front of the PCR in exactly the same spot as the Orbiter will be later. Once it is secured to the PCR structure (which is the only difference between this operation and the Orbiter operation), the doors to the room and the doors to the canister are opened. This now allows the PGHM to move forward from the rear of the room so that it can remove the payloads from the canister. A fast movement is first used to approach the payload rapidly, but then motion automatically reverts to a slow mode for the final approach. Manual adjustments then make the final extention to engage the PGHM payload-retention fittings to the payload trunnions.

VERNIER PAYLOAD TRANSLATIONS

The payload fittings on the PGHM (figures 5 and 6) are pairs of small, relocatable mechanisms that allow the operator to create precise linear movements in three mutually perpendicular (X, Y, and Z) directions to engage the trunnion and then, after unlocking the canister retention fitting, to move the payload away from the canister. These fittings are positioned by use of water-based hydraulic systems. The primary fitting has independent adjustments in the X, Y, and Z directions, while the secondary fitting has a single powered movement in the Z direction and is allowed to pivot freely in the remaining directions. A compressed-GN_2 accumulator overload-protection system has been incorporated into the hydraulic system to protect the Orbiter from bearing contact damage. Any out-of-plane trunnion is automatically accounted for through this accumulator system. The use of this system will be discussed more later.

Once the payload weight has been assumed by the PGHM fittings, hydraulics are used to move the payload a few inches away from the canister fittings. Further retraction is made by use of manual adjusters contained in the front mechanisms, followed by engagement of the slow-speed movement and fast


ASSEMBLED VIEW

EXPLODED VIEW

FIGURE 4. PAYLOAD GROUND HANDLING MECHANISM

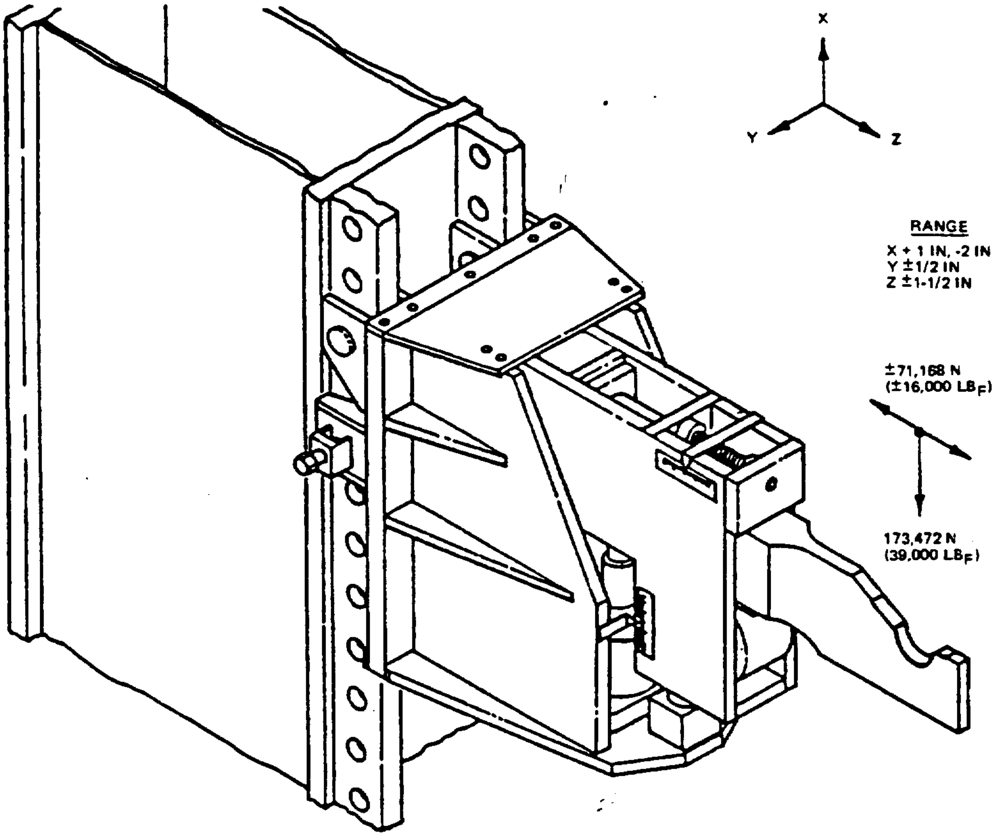


FIGURE 5. PRIMARY PAYLOAD SUPPORT FITTING MOUNTED TO SUPPORT BEAM

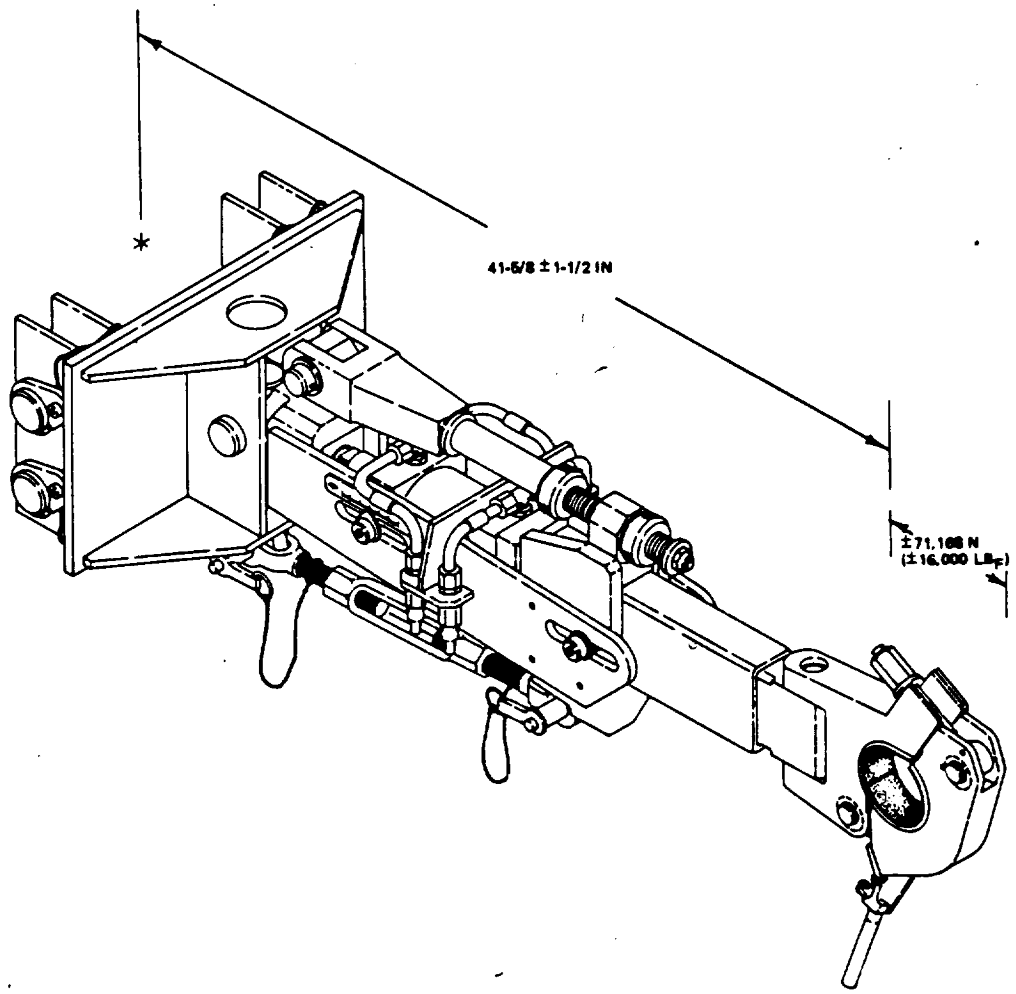


FIGURE 6. SECONDARY PAYLOAD SUPPORT FITTING MOUNTED TO SUPPORT BEAM

movement to the rear of the room. The doors to the canister are closed, the doors to the PCR are closed, and the canister is removed.

At the rear of the PCR, provisions have been made for accessing the various work points on the payloads (figure 1). When the Orbiter is ready to receive the payload, the RSS is pivoted around so that it encompasses the same portion of the Orbiter as it previously had on the canister. The difference now, however, is that the RSS does not hold on to the Orbiter as it did the canister, but, instead, stands free. The door to the PCR is again opened, and the doors to the Orbiter are opened. The PGHM moves forward, as it did before, and approaches the Orbiter. At this point, since the Orbiter and RSS are free of each other, different alignments must be made to account for tolerances inherent in the stacking and assembly of the STS vehicle. The Orbiter side of the PGHM contains adjusters that allow the entire cargo assembly to be moved as a unit to align with the plane of the Orbiter. The top of the mechanism contains large jackscrews for gross vertical adjustments; the crossheads contain side-to-side (Y) adjusters that move either together or opposite from each other to allow angular adjustment when combined with the vertical motion of the strongback beams. Individual adjustments can then be made on each side for X- and Z-direction motion. Once the payloads are aligned with the Orbiter, the hydraulic systems are used to place them within a fraction of an inch of seating in the Orbiter fittings. At this point, the Y adjuster on the PGHM fitting is used to center the payload keel in the Orbiter keel fitting prior to its closing.

CUSHIONING OF VERNIER TRANSLATIONS

The closing action of the Orbiter keel, if not precisely aligned to the keel trunnion, will sideload the payload. This side load will then cause a deflection within the hydraulic/pneumatic system of the PGHM fittings and allow compliance with the "wishes" of the Orbiter, thus preventing any possibility of Orbiter overload. The limitation of load is achieved by varying the pressure of the gas in the accumulatrs so that any additional load on the hydraulic cylinder will cause compression of the gas trapped within the system (figure 7). The force required to cause compression can be varied by the initial precharge pressure. Thus, any misalignment or movement between the Orbiter and the PCR will cause a deflection in the ground system through a force low enough to prevent damage to the Orbiter.

Once the keel is locked, the PGHM fittings move the payload trunnions into the Orbiter fittings, protecting them through the gas spring action, and the Orbiter fittings are locked. At this point, the PGHM is lowered away and prepared for retraction. Since the stem portion of the PGHM is hanging from the bridge on a pivot, a change of load on the front end could cause the stem to change the hang angle. This is prevented by use of clamps between the bottom of the stem and the PCR floor. Once the payloads are transferred onto the PGHM from the canister or given up to the Orbiter, the stem must be brought to its neutral angle for the new load condition. This is done simply by adjusting the screwjacks between the stem and the floor. Once the load in the jack is zero, the clamps are opened and motion can begin.

TESTING

The completed PGHM was proofloaded at 125 percent of the maximum design load and then successfully used to install payloads in the Orbiter for STS-5.

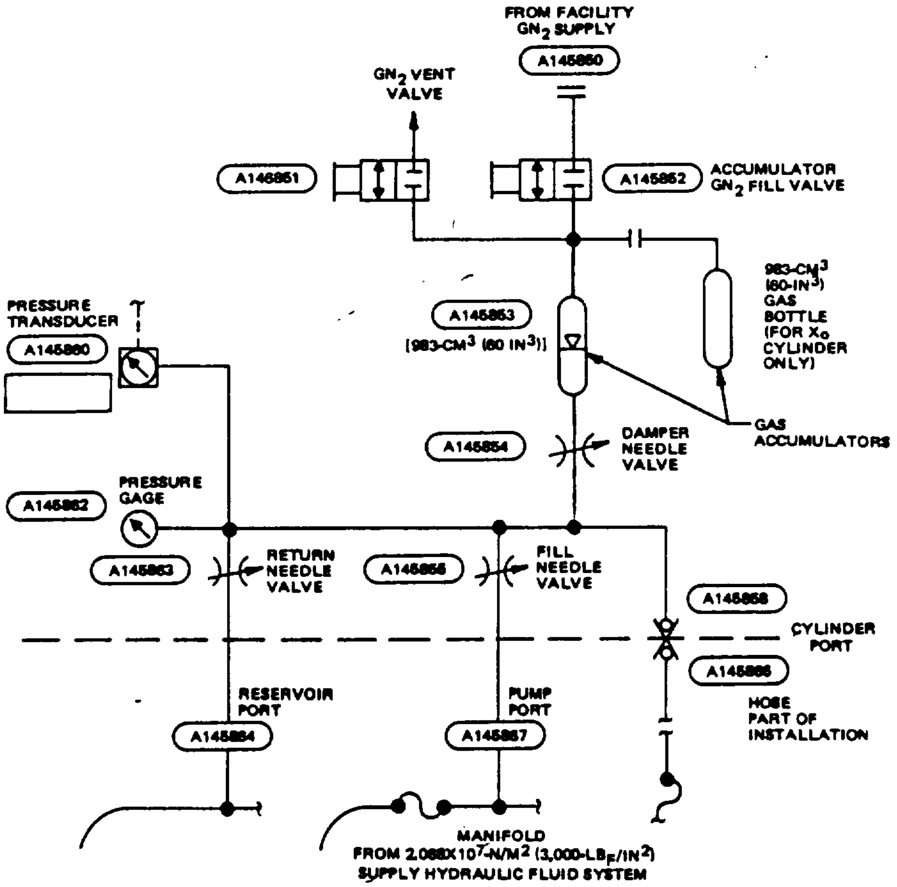


FIGURE 7. TYPICAL FITTING HYDRAULIC CONTROL SYSTEM (TYPICAL AT EACH RETRACT OR EXTENTION POSITION)