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ABSTRACT

THE DESIGN AND DEVELOPMENT OF A MOUNTING AND JETTISON ASSEMBLY FOR THE SHUTTLE ORBITER ADVANCED GIMBAL SYSTEM

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This paper describes the requirements, design, development, and qualification of the mounting and jettison assembly (MJA) which serves as the base structure for the advanced gimbal system (AGS) developed for NASA, Marshall Space Flight Center, for use during shuttle missions.

An engineering model of the MJA has been built and subjected to the following testing: stiffness and modal characterization, sine and random vibration, and a jettison function and energy release. A qualitative summary of the results and the problems encountered during testing, together with the design solutions, is presented.

ADVANCED GIMBAL SYSTEM – OVERALL DESCRIPTION

The AGS is a three-axis pointing system that will be used to point experimental payloads (e.g., a telescope) ranging in mass from 500 to 7200 kg that could span one shuttle pallet or the entire cargo bay. Fig. 1 is a drawing of the AGS flight design. The AGS is shown in Fig 2 in a payload pointing mode, mounted on a shuttle spacelab pallet, and in the launch/landing configuration in Fig. 3.

The mechanical system is composed of a payload mounting structure (PMS), three gimbals, and a MJA. The PMS is a 12.7 cm (5-inch) thick, 2-meter (78.7-inch) diameter honeycomb structure that provides the payload mechanical interface as well as thermal isolation of the payload. Three-axis pointing capability to within ±1/2 arcsec is provided by the three gimbals (brushless dc torque motors): an elevation and lateral gimbal (each 34 N-m (25 ft-lb)) and a roll gimbal (13.6 N-m (10 ft-lb)). This paper focuses on the MJA that forms the base structure for the AGS. Its main functions are to provide launch/landing load decoupling and jettison capabilities.

MJA REQUIREMENTS

The fundamental MJA requirements are to provide: 1) stiffness for pointing performance, 2) redundant jettison system, and 3) launch/landing load decoupling (separation mechanism). The MJA has been designed to meet these requirements under the following constraints:

- Weight: <75 kg (165 lb)
- Size: 43 cm (17-inch) dia; 41 cm (16-inch) long
- Stiffness: Meet system pointing performance requirements
- Jettison Energy Release to Payload: Minimize
- Operating Life: Fifty missions of 9 days duration each
- Vibration: Shuttle launch environment
- Thermal: Shuttle thermal environment
- Load Decoupling: Protect the AGS gimbals during launch and landing
- Alignment: Maintain initial alignment to within ±15 arcmin

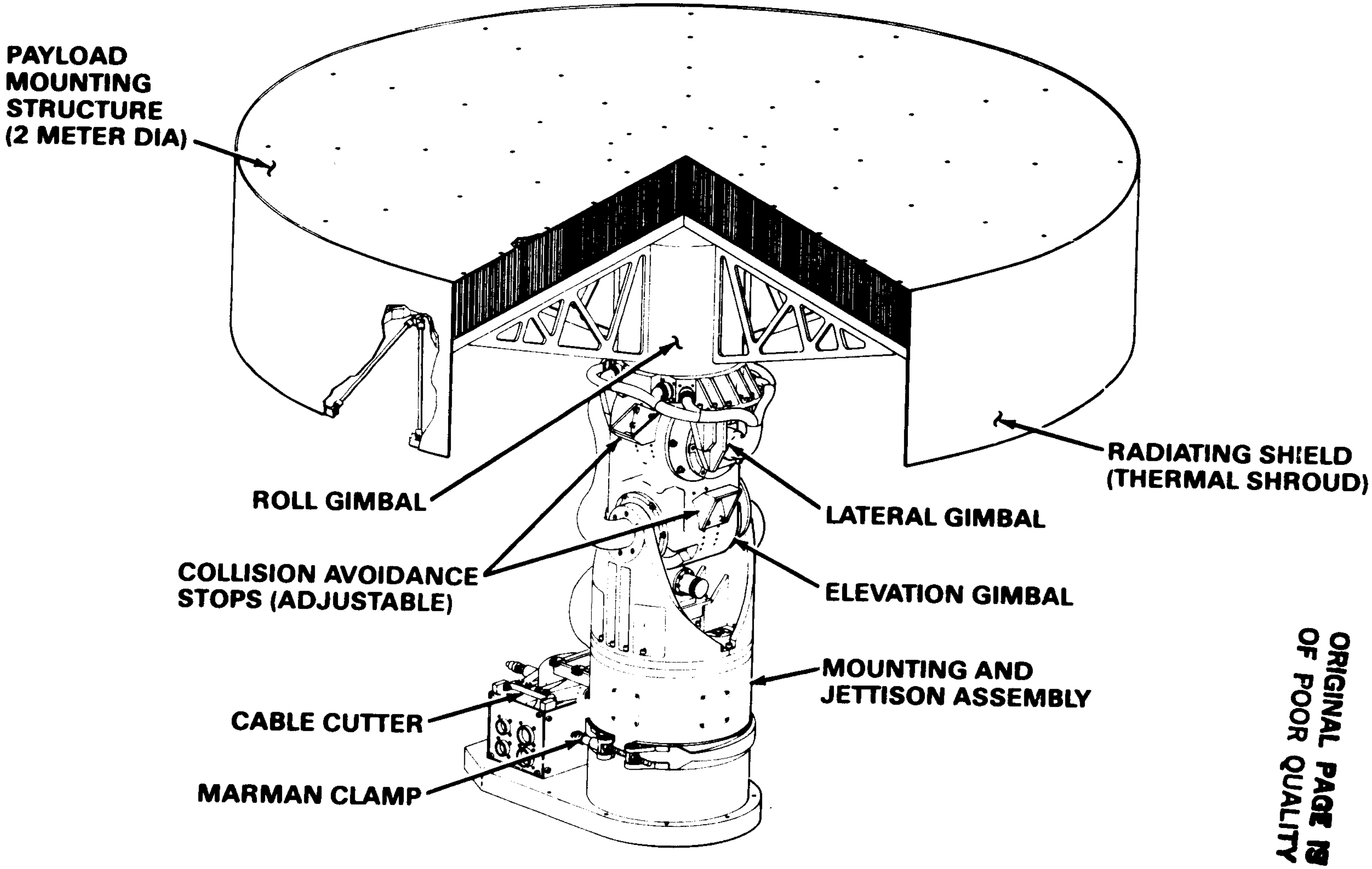

Fig. 1 Advanced Gimbal System Flight Design

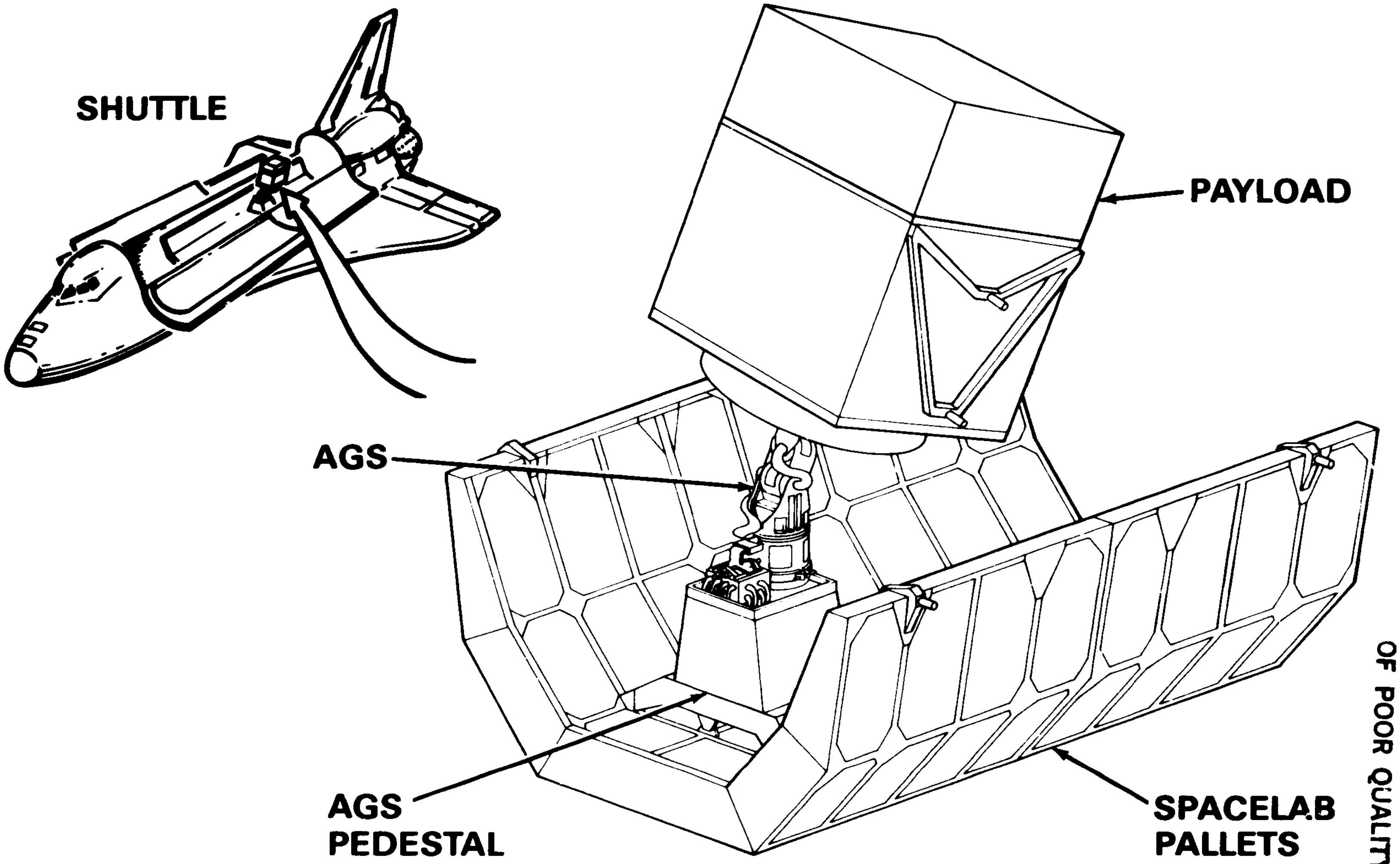

Fig. 2 AGS – Payload Pointing

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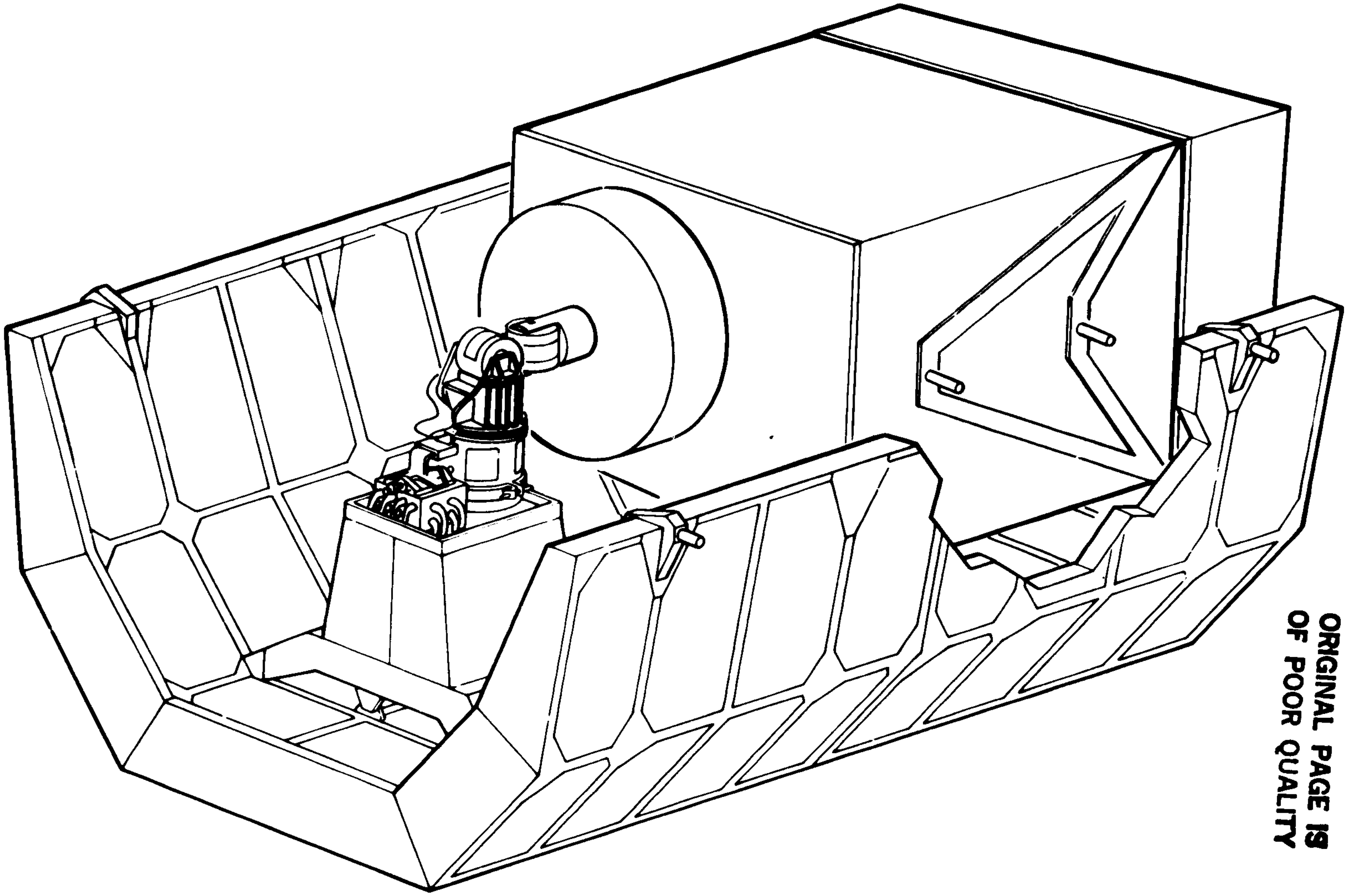

Fig. 3 Payload Caged for Launch or Landing

ENGINEERING MODEL MJA OVERALL DESCRIPTION

The MJA contains both the separation mechanism and jettison system. The engineering model AGS is shown in Fig. 4; Fig. 5 is a cutaway view of the engineering model MJA. The actual launch and landing separation (3 cm nominal) is provided by the separation mechanism which has the following components: linear actuator, pull down rods, catch plate, and spring seat assemblies, which are primarily located in the upper half of the MJA. Separation occurs between the MJA and gimbal flanges. Launch/landing gimbal constraint is provided by the cantilever beam. The jettison system is pyrotechnically activated and is located in the lower half of the MJA. Its main function is to completely sever all physical ties to the shuttle. Jettison system components (Fig. 6) are jettison clamp, bolt extractor, separation nut, cable cutter, and the jettison interface (curvic coupling).

ENGINEERING MODEL JETTISON SYSTEM DESCRIPTION

The AGS is a two failure tolerant system. As such, the jettison system is a last resort safety backup to be used in the event that the payload cannot be restowed for re-entry. During a jettison sequence, the first action would be to cut the AGS electrical harness. Once microswitch confirmation has been received that the harness has been cut, the jettison interface preload would be released. The shuttle would then back away from the payload. A minimum energy transfer requirement is critical since the AGS can be in any pointing orientation when failure occurs. Any payload c.g. offset will result in payload tumbling when jettisoned, the degree of which is dependent on the amount of energy transferred.

The most desirable jettison operation would completely cut all physical ties and transfer zero energy to the jettisoned payload so that jettison is controlled and the shuttle can simply back away. This condition is very hard to meet in actual practice since there is always some recoverable strain energy associated with the sudden release of the preload at the jettison interface. Every effort has been made to minimize the energy transferred to the jettisoned payload.

Electrically activated pyrotechnic devices are used in the jettison system to attain reliable rapid release. Dual NSI-1 initiated pyrotechnic devices manufactured by Space Ordnance Systems are used in the engineering model jettison system. Three clamp/nut separator devices along with bolt extractors provide the required preload across the curvic coupling (jettison interface) and two cable cutters are used to sever the AGS electrical harness. (See Figs. 5 and 6.)

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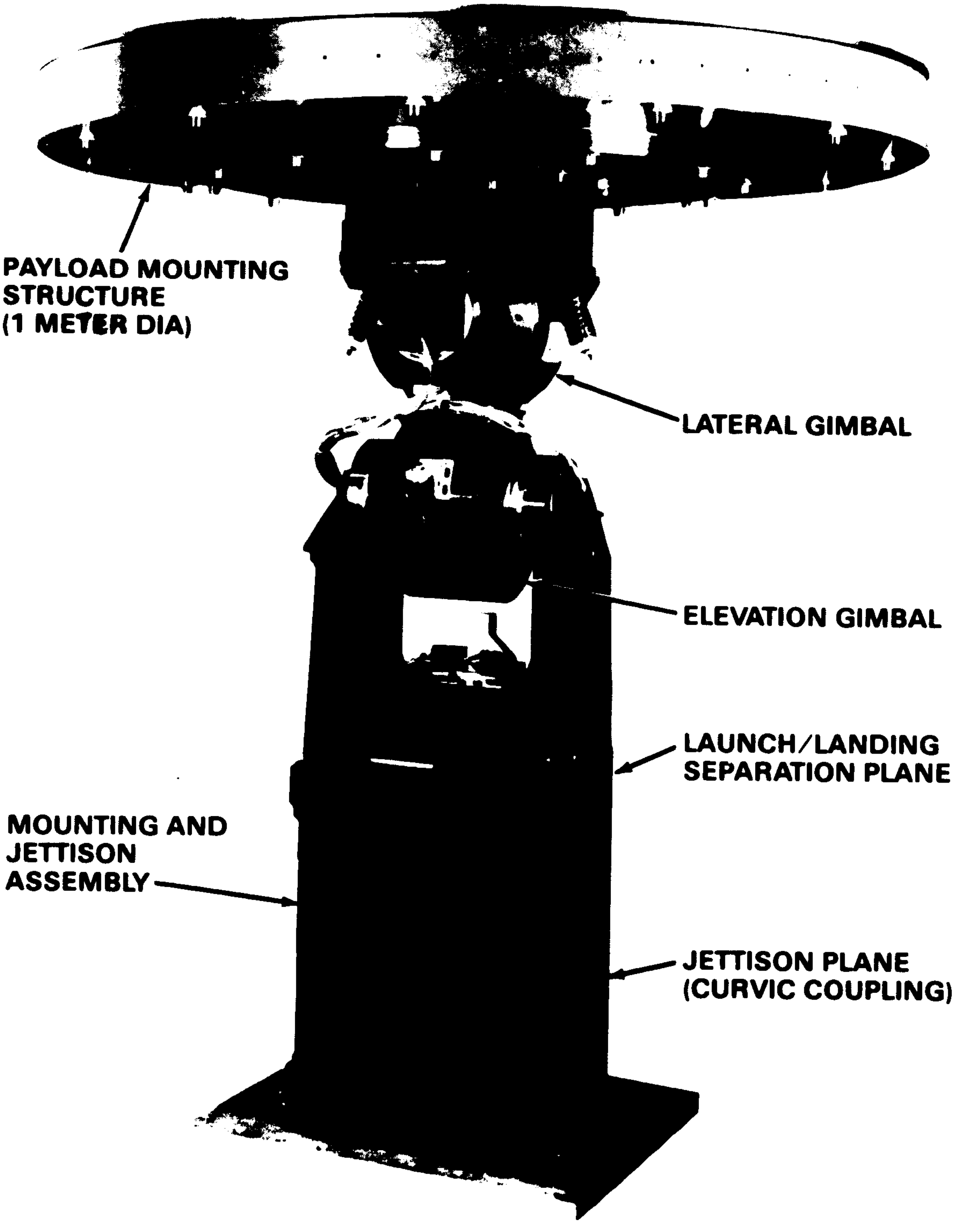

Fig. 4 Advanced Gimbal System – Engineering Model (No Roll Gimbal)

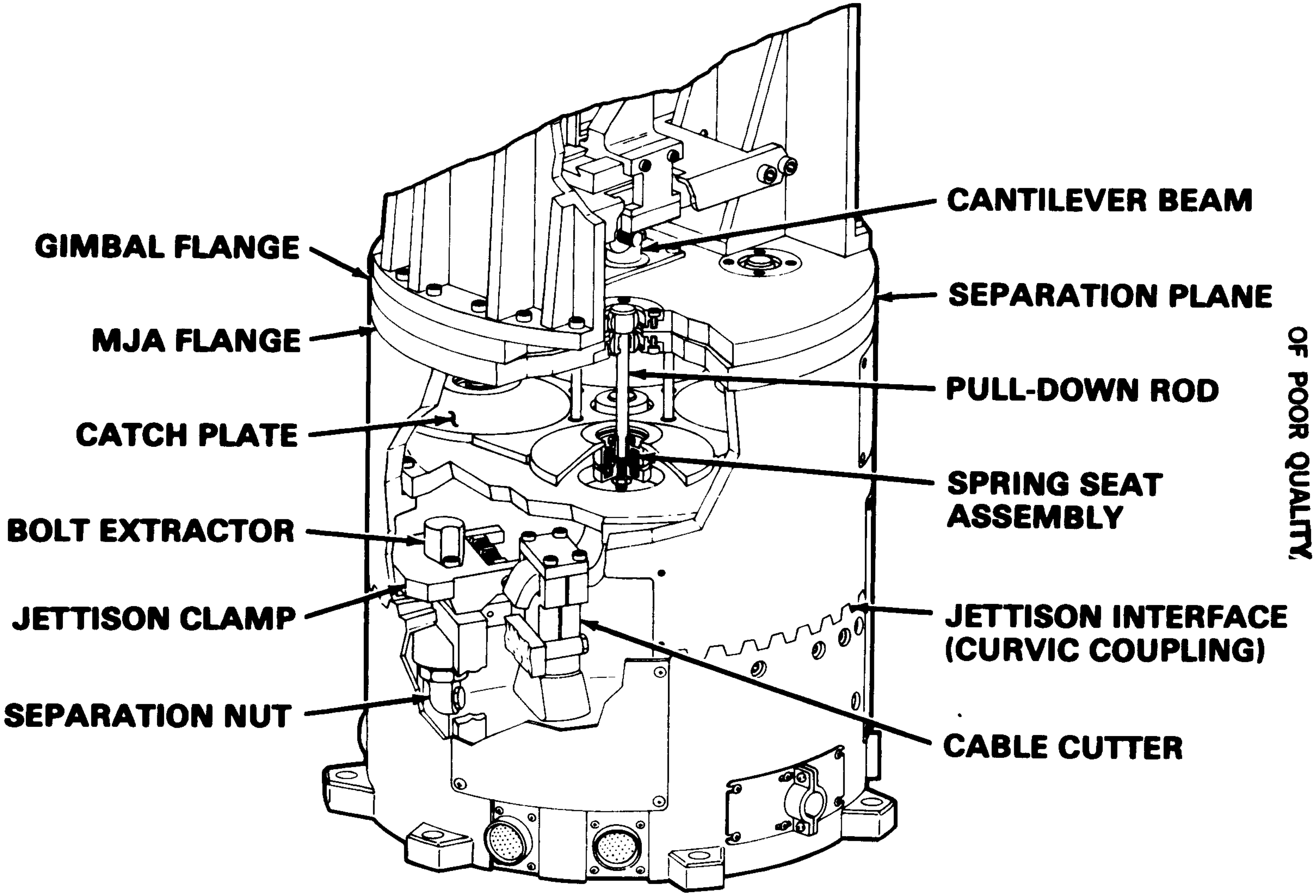

Fig. 5 Engineering Model MJA Cutaway

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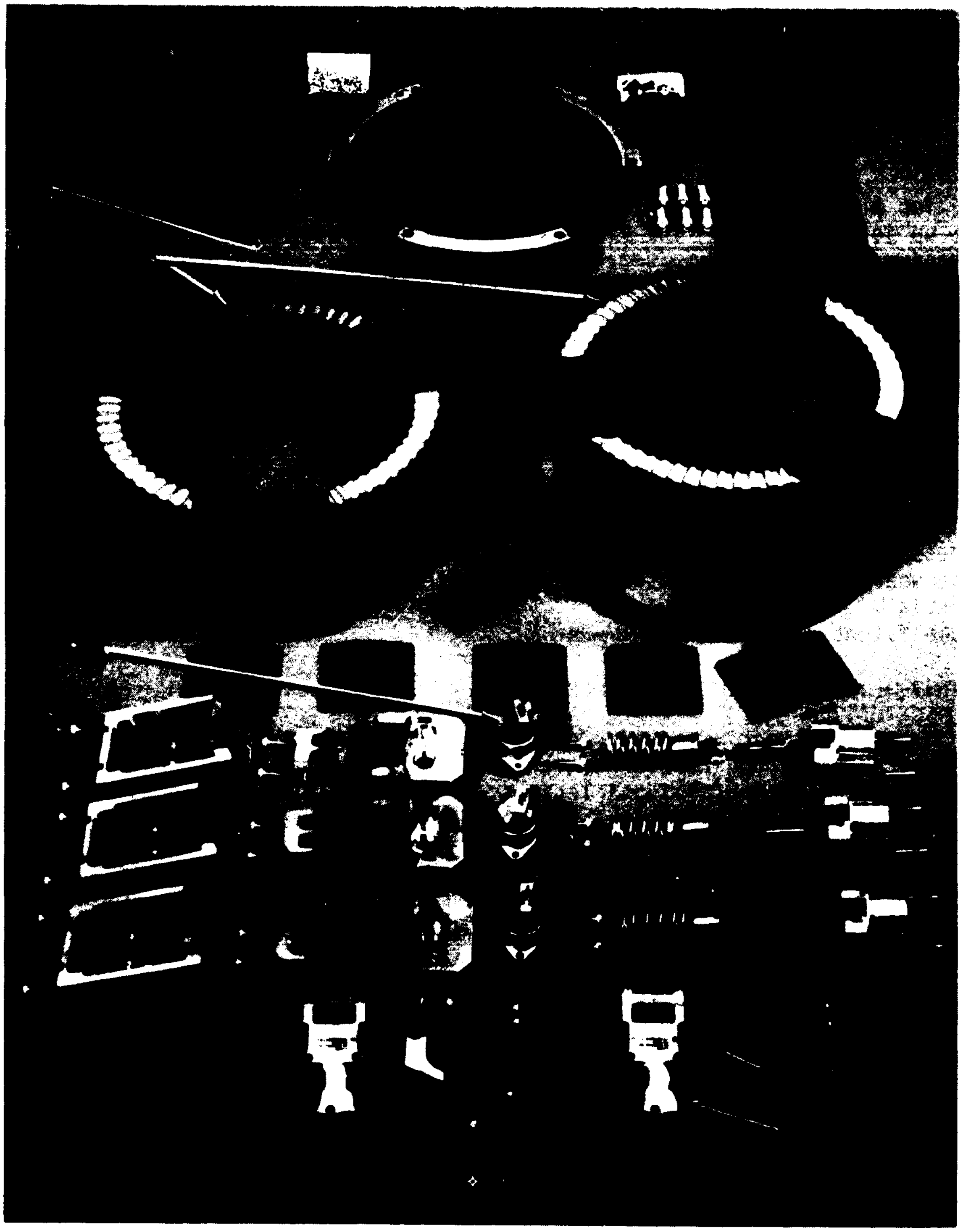


Fig. 6 Engineering Model Jettison System Components

Torsional stiffness at the jettison interface was a design driver. A curvic coupling, which is widely used between turbine rotors to transmit high torques, was selected as the jettison interface. The stiffness requirements are met using this interface as proven by extensive testing.

JETTISON SYSTEM DEVELOPMENT PROBLEMS AND SOLUTIONS

Two problems arose during the jettison development program prior to the full up jettison test. The first involved the separation nut bolt ejection mechanism. For the clamp/separation nut mechanism to open properly, the preload bolts (9.5 mm (3/8 inch) dia) had to be ejected from the clamp to allow the clamps to rotate open. The original design relied on a built in bolt ejector pin and a bolt catcher to get the bolt out of the way. Repeated testing showed that the ejector pin was not ejecting the bolt fast enough for it to clear the clamp and the clamp partially rotated open with the bolt jammed. A spring loaded bolt extraction device was designed to replace the bolt catcher and the full up jettison test of the revised design was successful.

The second problem involved electrical harness growth. The electrical harness diameter grew during the engineering model development program to a point where both cable cutters were completely filled with no growth potential. This problem was corrected by using a single large cable cutter in the flight design.

ENGINEERING MODEL JETTISON TEST

A jettison test was performed on the engineering model MJA in April 1980. The jettisoned portion of the MJA was horizontally suspended at four points using 4 meter (13-foot) lengths of 3 mm (1/8-inch) dia bead chain, and the stationary portion was fixtured to ground. (See Fig. 7 for test setup.) The jettisoned portion was then meticulously aligned so that the bead chain would not load the interface (i.e., cause the jettisoned portion to fall away or be pulled away during the test). Hycam 5000 frame per second movie cameras and photographic targets along with stadia wires were used to record the jettison velocity for the first 1.25 cm of travel. Engineering model jettison velocity was .26 m/sec for a jettison mass of 9.4 kg which is a 0.31 N-m (0.23 ft-lb) energy release.

PROTOFLIGHT JETTISON SYSTEM DESIGN CHANGES

A change in customer requirements to include mechanical as well as electrical jettison redundancy resulted in a design change for flight. The three clamp/nut separators were replaced with a Marman clamp and two pyrotechnic clamp separators positioned 180 degrees apart. (See Fig. 8.) The design is such that the activation of either clamp separator is sufficient to physically disconnect the jettison interface. A single large cable cutter was incorporated into the design to handle the flight harness and allow for future growth.

Fig. 7 Engineering Model – Jettison Test Setup

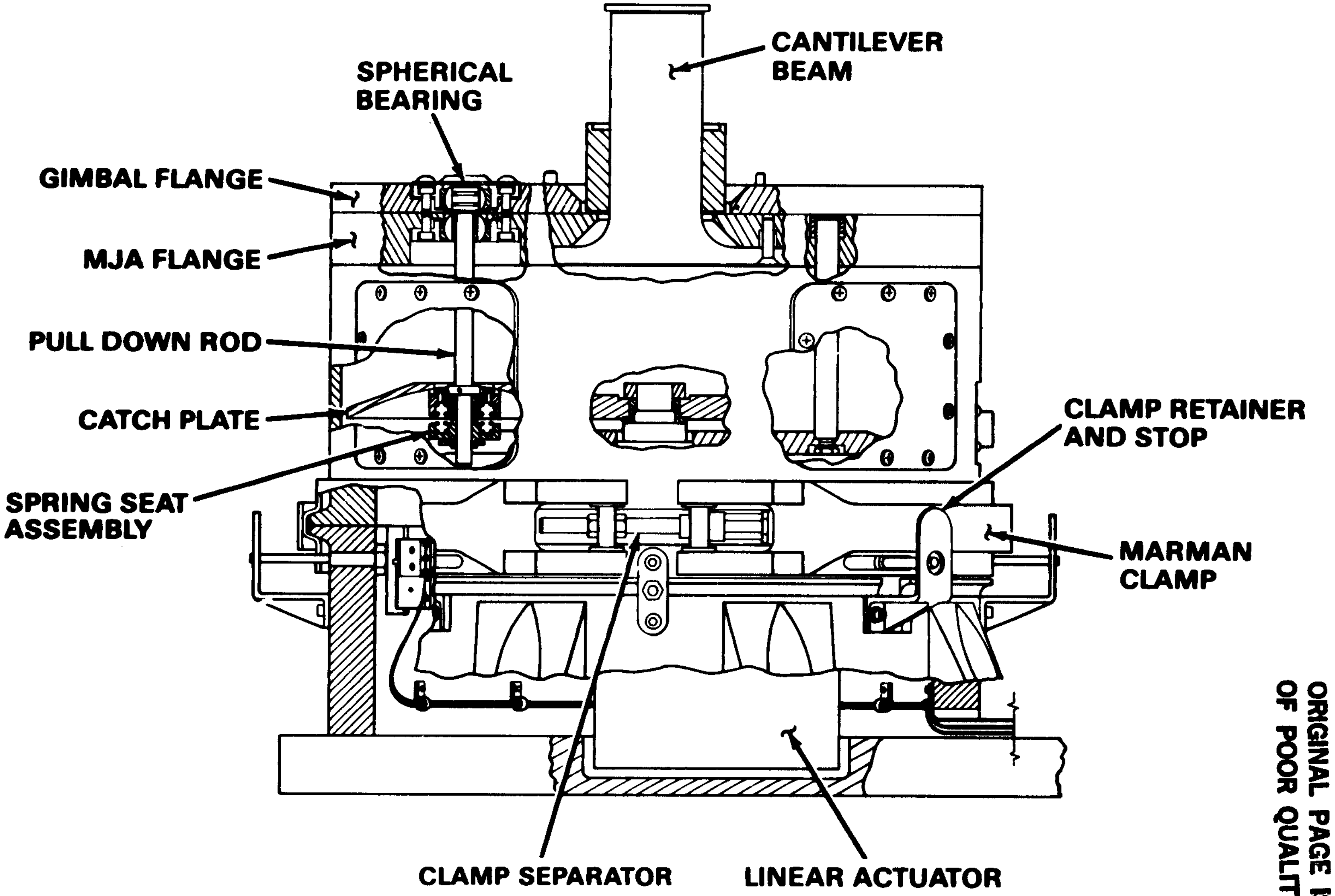


Fig. 8 MJA Flight Design

The engineering model MJA was modified to simulate the flight configuration, and the jettison test was repeated with a jettison energy release of 0.01 N-m which is considerably lower than the engineering model design. The reduction is due to the slower way in which the Marman clamp releases the interface. The Marman clamp retainer bands (Fig. 8) move radially away from the MJA tube and slide along the MJA tube flanges thereby absorbing some of the released energy.

SEPARATION MECHANISM DESCRIPTION

The AGS payload is secured to the Spacelab pallet with a system of clamps and struts which attach to pallet hard points. The MJA is also attached to pallet hard points through its own separate support structure. (See Fig. 3.) As such, the resultant AGS/payload/pallet assembly constitutes a statically indeterminate structure with the AGS gimbal bearings in the primary load path. The AGS separation mechanism provides a means of decoupling the AGS gimbals during launch and landing to relieve these static loads and to control dynamic loads that are applied to the AGS caused by gravitational, quasi-static acceleration, vibration, and thermal effects. Decoupling is accomplished by the separation mechanism in conjunction with the cantilever beam mechanism which partially constrains the AGS gimbals. The cantilever beam is sized to ensure that the allowable gimbal bearing loads are not exceeded and that minimum launch/landing structural frequency (35 Hz) is maintained across the separation mechanism. During launch and landing, the separation mechanism linear actuator is extended and the gimbal and MJA flanges are separated a nominal 3 cm.

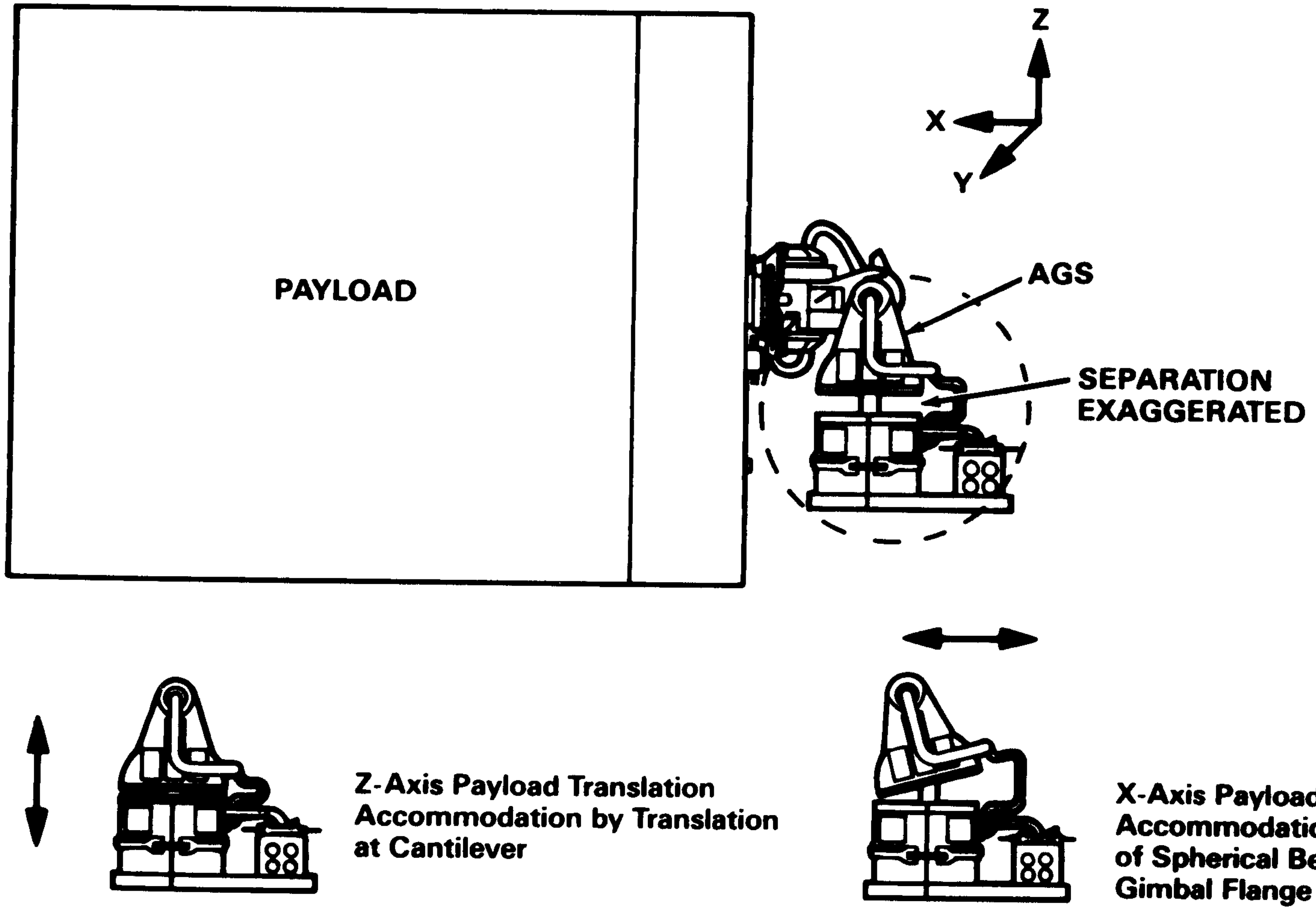
Fig. 9 shows the overall separation mechanism operation. If the base of the MJA is considered to be fixed, translations of the payload are accommodated by the cantilever beam mechanism as follows:

Z-Axis: Translation of the gimbal flange relative to the cantilever

X-Axis: Rotation of the spherical bearing relative to the gimbal flange

Y-Axis: Rotation of the spherical bearing about the cantilever beam

Rotations of the payload about the X, Y or Z axes are accommodated by combinations of the above motions plus rotations about the AGS gimbals. (Note: The gimbals are free to rotate during launch and landing.)



Z-Axis Payload Translation Accommodation by Translation at Cantilever

X-Axis Payload Translation Accommodation by Rotation of Spherical Bearing in Gimbal Flange

Y-Axis Payload Translation Accommodation by Rotation of the Spherical Bearing About the Cantilever and Tipping of the Gimbal Flange

Fig. 9 AGS Separation Mechanism Operation

The AGS separation mechanism is made up of a linear actuator, pull down rods, spherical bearings, catch plate, spring seat assemblies, two flanges, and a gimbal launch/landing constraint device (cantilever). (See Figs. 8 and 11.) Functions of these components are as follows:

- Linear Actuator - The linear actuator's main function is to provide the joining force (set at 600 lb) to maintain a preload across the two plates (MJA and gimbal flanges) to provide structural rigidity for pointing. The linear actuator is a 28 volt dc redundant ball screw actuator made by Sperry Electro Components in North Carolina and has a stroke of approximately 6.4 cm (2.5 inches).

- Pull Down Rods - The pull down rods are fixed to the gimbal flange in spherical bearings and pass through similar spherical bearings in the MJA flange. The spring seat assemblies are fixed to their lower ends.

- Catch Plate - The catch plate is fixed to the end of the linear actuator shaft and transmits the actuator joining force to the pull down rods by pushing on the spring seat assemblies.

- Spring Seat Assemblies - The spring seat assemblies are fixed to the lower end of the pull down rods and are made up of two nested springs in a spring cup assembly. Adjustment capability is provided to set preload. The catch plate impacts the integral rulon on the spring seat assembly surface that compresses the springs to provide the precalibrated preload. This spring preload arrangement allows for variation due to thermal growth and assembly tolerance stack up and also allows for a reduction in the actuator microswitch stop setting tolerances.

- Flanges (MJA and gimbal) - The launch/landing separation occurs between these two plates. The gimbal flange provides the top anchor point for the pull down rods, and the MJA flange provides spherical bearing guides and an alignment mechanism to realign the two flanges during the joining sequence.

- Cantilever - A 1.9 cm (3/4 inch) diameter cantilever serves to restrain the gimbals during launch/landing. It is fixed to the MJA flange and rides in a spherical bearing fixed in the gimbal flange that serves to prevent relative planar translation between the two flanges. The spherical bearing is also constrained by pins and roller bearings so that rotation about the X-axis is constrained and rotation about the Y-axis is permitted.

OPERATION

Separation for Launch/Landing

The engineering model AGS in the launch/landing configuration is shown in Fig. 10. The linear actuator is extended and positions the catch plate in the full extend position (6.4 cm (2.5 inch) of travel). This allows the two flanges to be separated by the payload clamp system so that the MJA side of the separation mechanism can be displaced relative to the gimbal side within a 6 cm sphere about the 3 cm nominal position. This relative motion is accommodated by rotations about the AGS gimbals and a tipping about the Y-axis of the gimbal flange relative to the MJA flange. The cantilever constrains ±X and ±Y translation plus rotation about the X-axis while allowing ±Z translation and rotation about the Y- and Z-axes.

Joining

For joining, the actuator is retracted and pulls on the catch plate. The catch plate makes contact with the spring seat assemblies which realign the two flanges about Z. A precision alignment and torque restraint is provided by an alignment core that guides the alignment about Z (alignment in ±X and ±Y is provided by the cantilever) within the last portion of actuator travel. The spring seat assembly nested springs are compressed thereby applying the preload between the flanges.

SEPARATION MECHANISM DEVELOPMENT PROBLEMS AND SOLUTIONS

The biggest change in the design occurred with the addition of an optional roll gimbal (the initial contract called for a two gimbal AGS, elevation and lateral). The roll gimbal added another degree of freedom (rotation about the X-axis) that had to be constrained. As a solution, the cantilever spherical bearing was pinned along the Y-axis and the pins were supported with roller bearings. This allowed the cantilever bearing cartridge design to be variable so that a pinned cartridge assembly could be used in the three gimbal system and an unpinned cartridge assembly could be used in the two gimbal system.

Flatness between the MJA and gimbal flanges reduced stiffness across the interface. The initial design utilized a full contact surface which warped when other components were installed and the preload applied. As a solution, both plates were relieved in their centers which left an outer contact ring approximately 1.5 cm wide. Preload across this interface was also increased from 300 to 600 pounds.

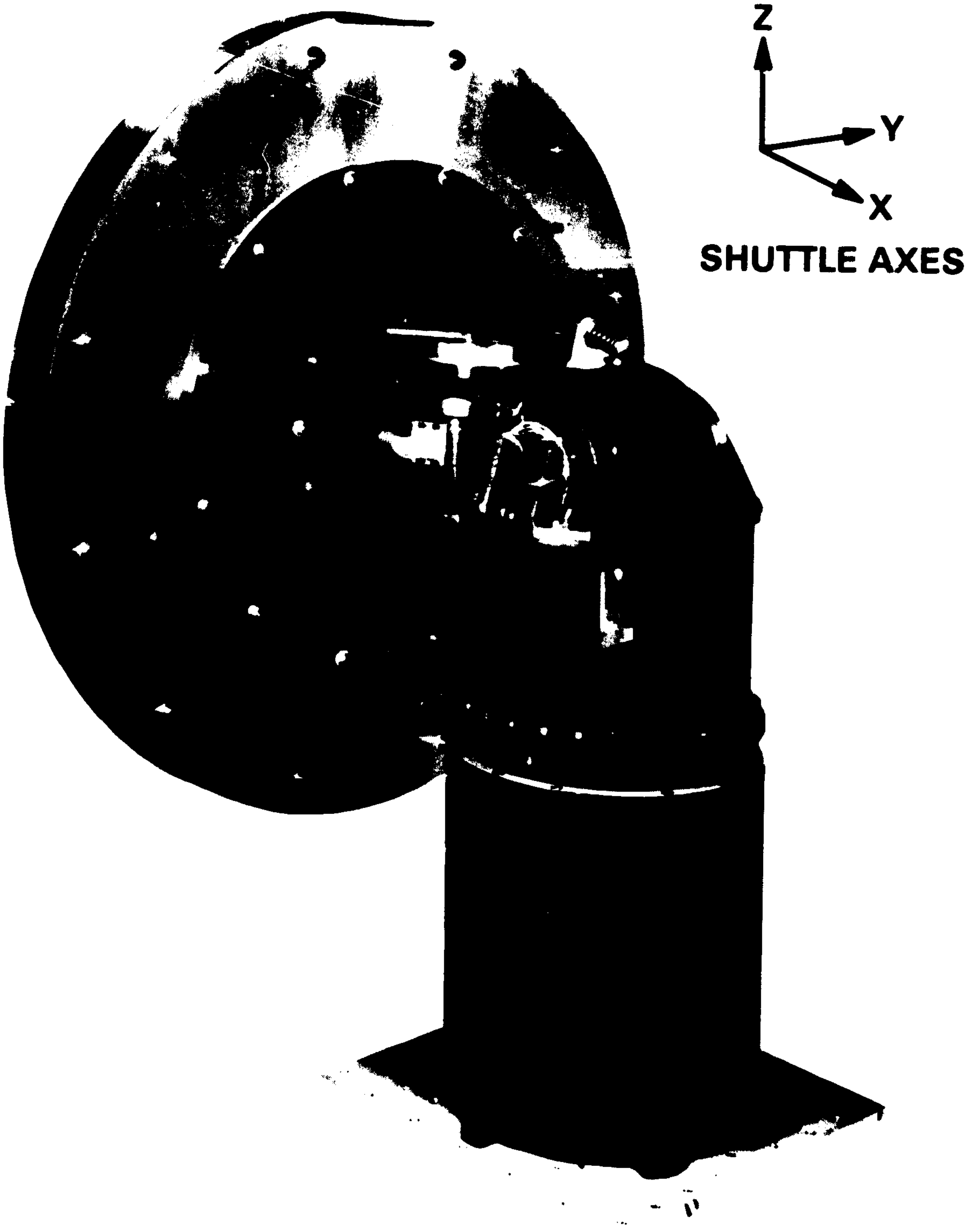


Fig. 10 Engineering Model AGS – Launch/Landing Configuration

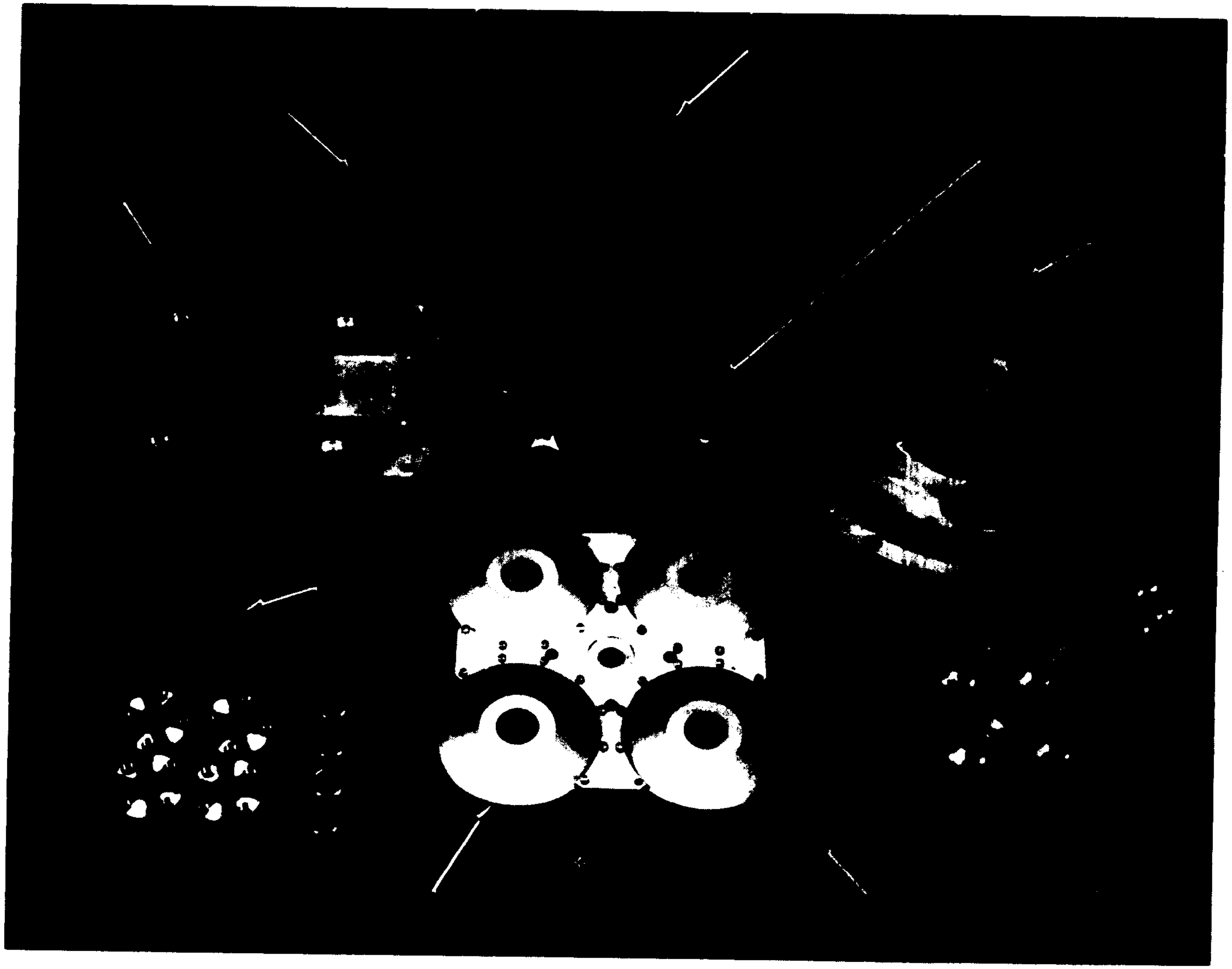


Fig. 11 Separation Mechanism Components

PROTOFLIGHT SEPARATION MECHANISM DESIGN CHANGES

The AGS contract was modified for the protoflight design to eliminate the two gimbal version of the AGS. The gimbal bearings were also increased in size to increase stiffness. With this change, the pinned spherical bearing concept was further refined and the cantilever beam was increased in size to 5 cm (2-inch) diameter to increase launch and landing stiffness. The spherical bearing was replaced with a trunnion assembly that was supported in bushings along the Y-axis with a tight running fit for the cantilever in the center.

MJA ENGINEERING MODEL TESTING

The MJA and its components have been subjected to the following testing:

- Subassembly Level:
  - Actuator Characterization
  - Jettison (See Fig. 7.)
- Assembly Level:
  - Separation Mechanism Characterization
  - Mode Shape
  - Sine and Random Vibration (See Fig. 12.)

The primary problem was encountered during the system flexibility testing. In most analyses, an interface is assumed to be rigid. This is only true if the interface is perfectly flat and there is no misalignment or the interface is preloaded high enough to make up for any inconsistencies. During flexibility testing, many interfaces were discovered where precision machining at the subassembly level significantly increased the overall system stiffness. This knowledge was applied to the protoflight design.

CONCLUSION

The MJA is an innovative design that meets the design requirements for stiffness, alignment, load decoupling, and jettison. During system flexibility and modal testing, it was discovered that mechanical interface characteristics were crucial to ensuring that system stiffness requirements were met. Jettison testing proved the feasibility of designing a system for minimum energy transfer to the jettisoned payload. The vibration testing demonstrated overall mechanical integrity and verified that the separation mechanism/cantilever beam load decoupling does protect the gimbal bearings.

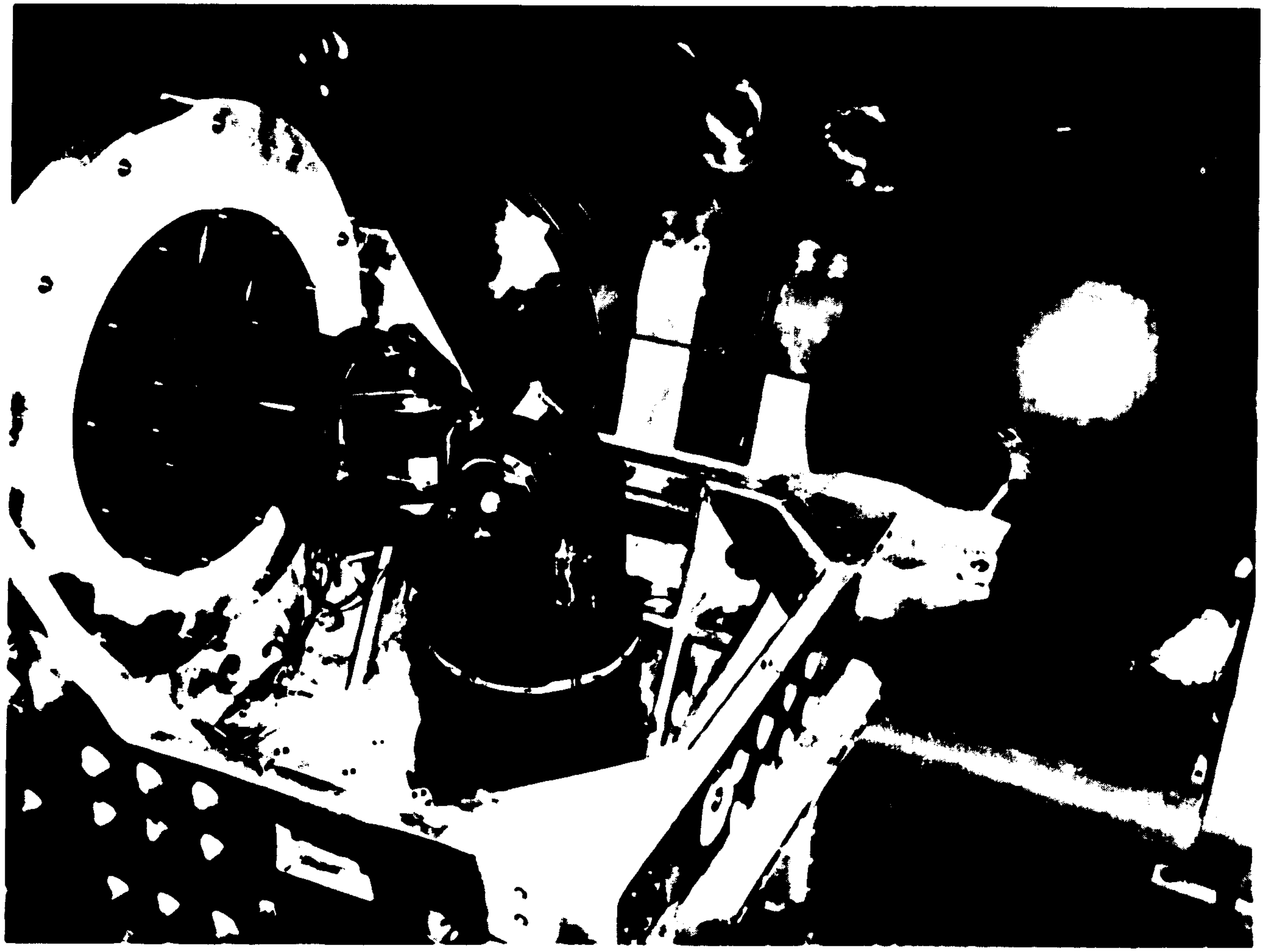


Fig. 12 Y-Axis Vibration Test Setup at Marshall Space Flight Center

ACKNOWLEDGEMENTS

The design and development work presented in this paper was performed under contract with Marshall Space Flight Center, Huntsville, Alabama. The author wishes to thank NASA, Marshall Space Flight Center, and Sperry Flight Systems for their permission to publish this paper and to acknowledge the many engineers, technicians, and designers at Sperry that contributed to this project.

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ROLLING BEAM UMBILICAL SYSTEM

By Bemis C. Tatem, Jr.*

ABSTRACT

The decision to make the Centaur vehicle a Space Transportation System (STS) payload meant that new ground support equipment provisions at Launch Pads Pads 39A and 39B were required. These new equipment provisions were needed to service the Centaur vehicle while it was installed in the Orbiter's payload bay prior to launch. This paper describes the design of a new rolling beam umbilical system (RBUS) being added to the pad fixed service structure (FSS) in order to provide the primary functions of liquid hydrogen (LH_2) fill, drain, and vent. The carrier plate itself is a Government-furnished equipment item and of necessity became a T-0 disconnect. This permits quick offloading in the event of an abort prior to lift-off. In addition to the rolling beam structure, mechanisms, and fluid lines, it was necessary to design and build a carrier plate simulator to support early development testing of the mast at the Launch Equipment Test Facility at Kennedy Space Center.

The RBUS is designed to be compatible with the rotating service structure (RSS) to the extent that the umbilical may be deployed with the RSS mated with the vehicle. It is also designed to clear the RSS as the RSS rotates back out of the way. Accessibility to the Orbiter aft compartment via the 50-1 door had to be maintained.

The RBUS consists of an umbilical assembly that supports the carrier plate on the end of a truss beam extending from a carriage assembly that translates on double rails by means of crane track wheels. A porch structure was added to the FSS to mount the incline portion of the assembly that contains the rails. A suitable storage location on the FSS dictated a 6-degree incline up to the Centaur interface located on the port side of the Orbiter in essentially the same location as the previous T-4 interface on the port side. The rolling beam travels a distance of 11 m (36 ft) to the stowed position in the FSS. Power for acceleration of the rolling beam assembly is provided by a dropweight assembly. A linear disk brake decelerates the rolling beam to its parked or stowed position. Upon initial motion of the carriage, the rolling beam separates itself from the ground supply lines as well as from the vehicle. This was dictated by the long retract distance. This paper presents important design approaches considered but not used, in addition to describing the rolling beam, which is in the process of being implemented.

This RBUS was designed by Planning Research Corporation, Systems Services Company under contract to NASA's Kennedy Space Center in Florida.

*Bemis C. Tatem, Jr., Planning Research Corporation, Kennedy Space Center, Florida

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INTRODUCTION

In early 1981, an extensive trade study was conducted to determine the best approach to take to provide for the STS/Centaur LH_2 servicing requirements. Numerous concepts were prepared, and the ones considered most promising are:

a. Tail service mast (TSM) with Centaur service added

b. RBUS

c. TSM mounted reusable payload umbilical mast

d. TSM mounted expendable payload umbilical mast

TSM With Centaur Service Added. Necessary additional lines would be added to the existing TSM's carrier plates as depicted in figure 1. Lines would be routed down the service masts as shown in figure 2. An overriding disadvantage of this approach was its adverse effect on Orbiter flight weight for the LH_2 service functions.

RBUS. An elevation view of this approach is shown in figure 3 and is described in more detail in this paper. The overriding advantage of this approach is that it is located on the FSS with no impact on the Vehicle Assembly Building (VAB) or the mobile launcher platform.

TSM Mounted Reusable Payload Umbilical Mast. An elevation view of this approach is shown in figure 4. This system is similar to a short rolling beam except it retracts into a hardened housing mounted on top of the TSM. The carriage moves on a small track. Dropweight initiation would be by a trigger actuated by the TSM dropweight. The TSM would require structural additions to support the added weight and blast load due to added sail area of the payload umbilical mast. The installation has major impact on VAB platforms as well as the RSS.

TSM Mounted Expendable Payload Umbilical Mast. The carrier plate support is similar to the rolling beam, but a rotating mast with counterweight is used to retract the carrier plate past the vehicle lift-off drift curve. Lanyards penetrate the top of the TSM and use the TSM dropweights for the normal retraction. This approach is depicted in figure 5. This approach was ruled out because of closeness to the Orbiter wing and impact on the VAB.

The conclusion of these studies was that the RBUS approach was selected to perform the task of providing LH_2 service for the STS/Centaur at Launch Pads 39A and 39B. The design of the prototype RBUS was just completed at the time of submission of this paper. This prototype is to be tested at the Launch Equipment Test Facility this summer.

ROLLING BEAM DESCRIPTION

Major assemblies of the selected RBUS include:

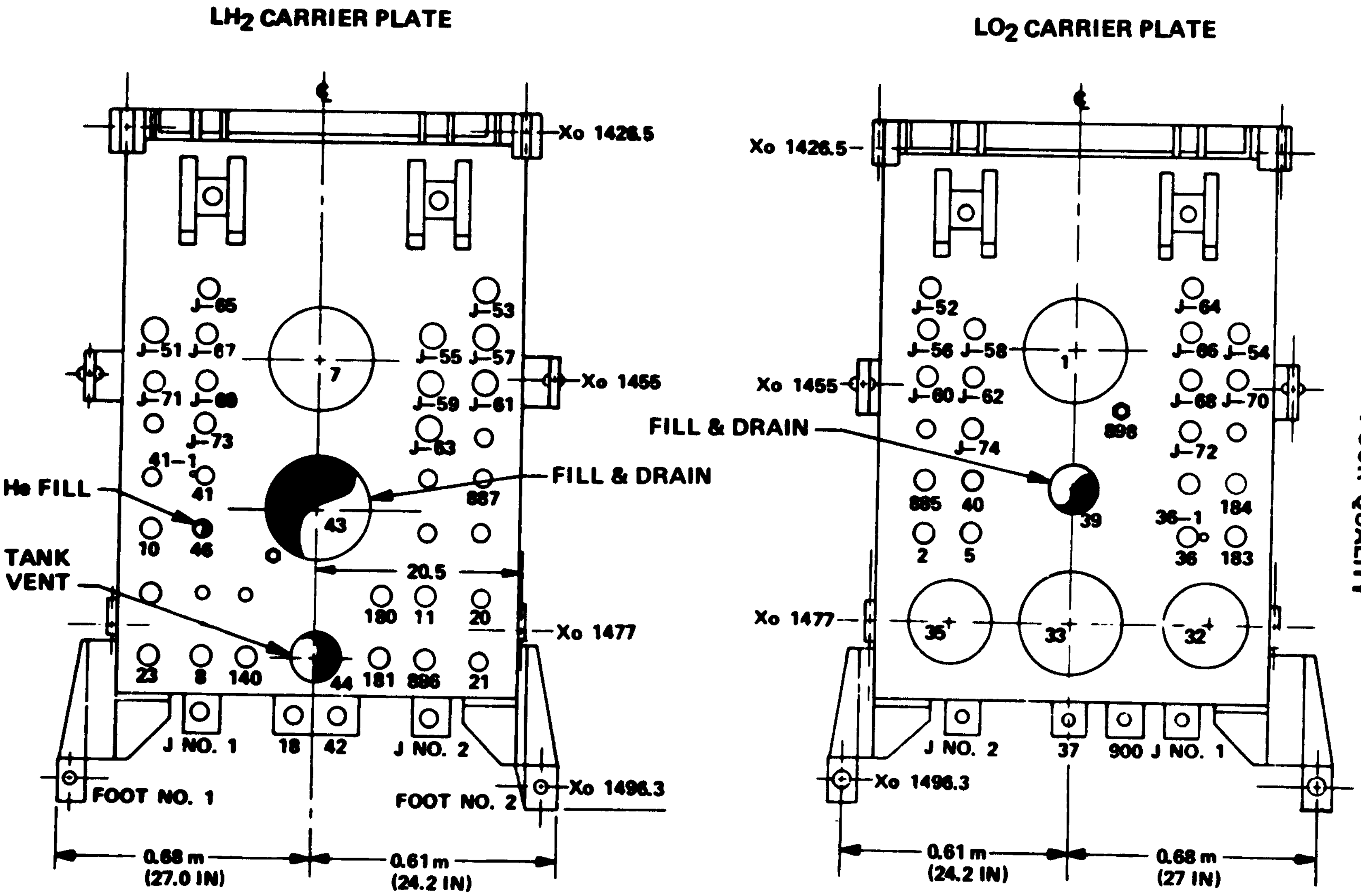

Figure 1. LH_2 and LO_2 Carrier Plates - TSM

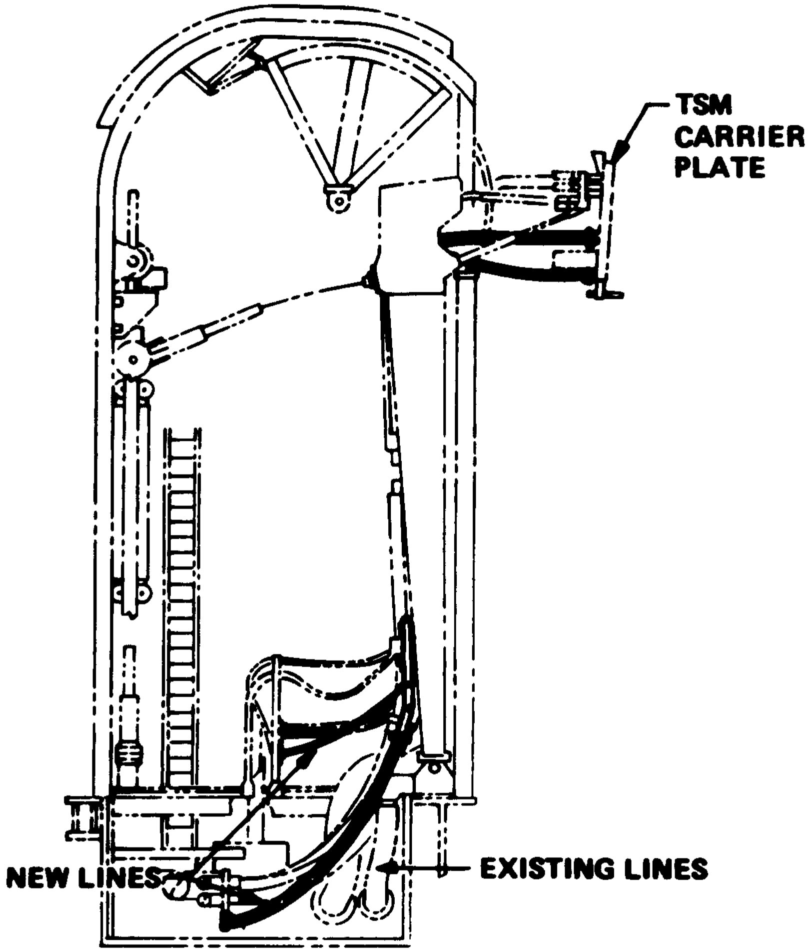

Figure 2. TSM With Centaur Service Added - LH_2

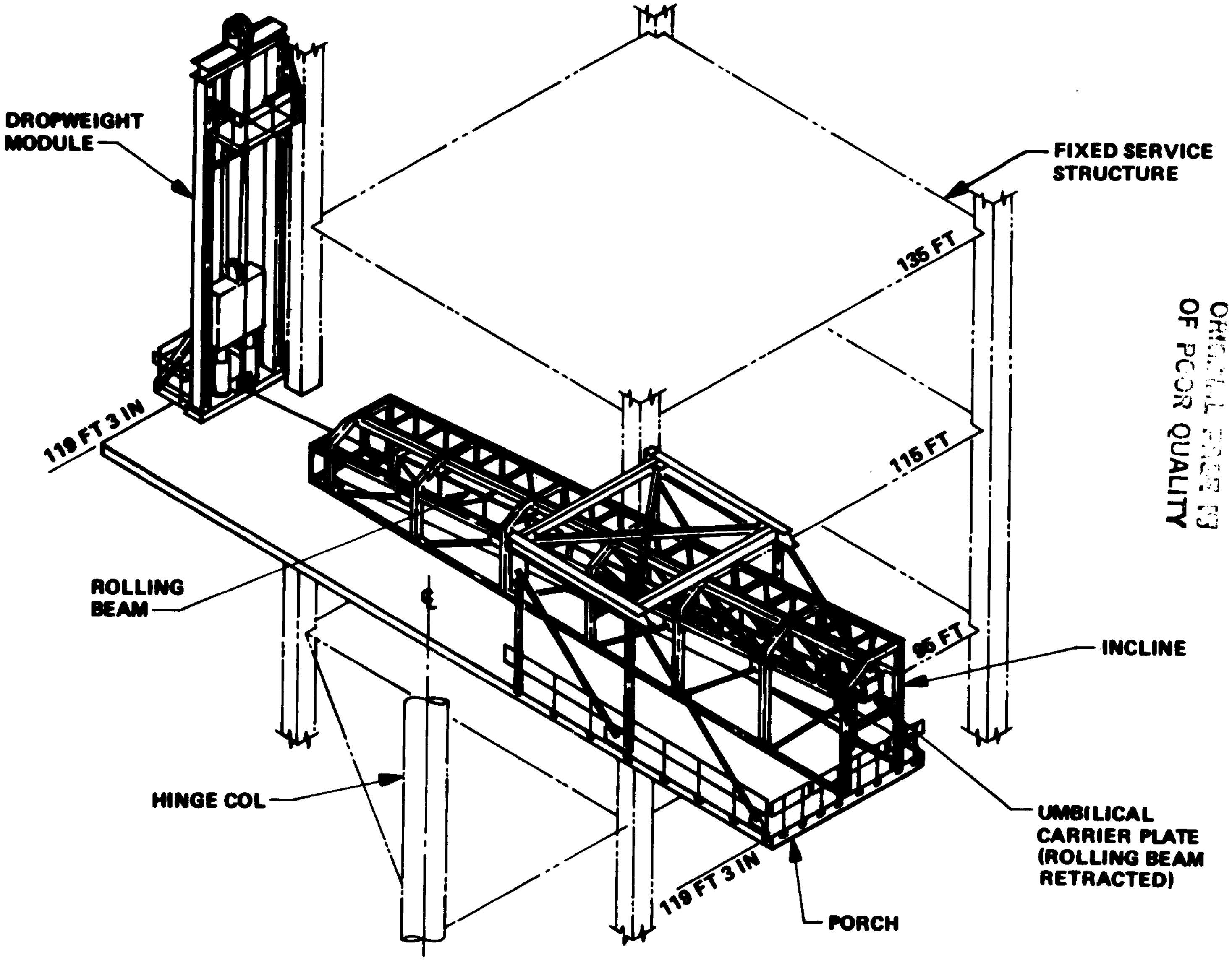

Figure 3. Centaur/STS Rolling Beam Umbilical System-Launch Pad 39A Installation

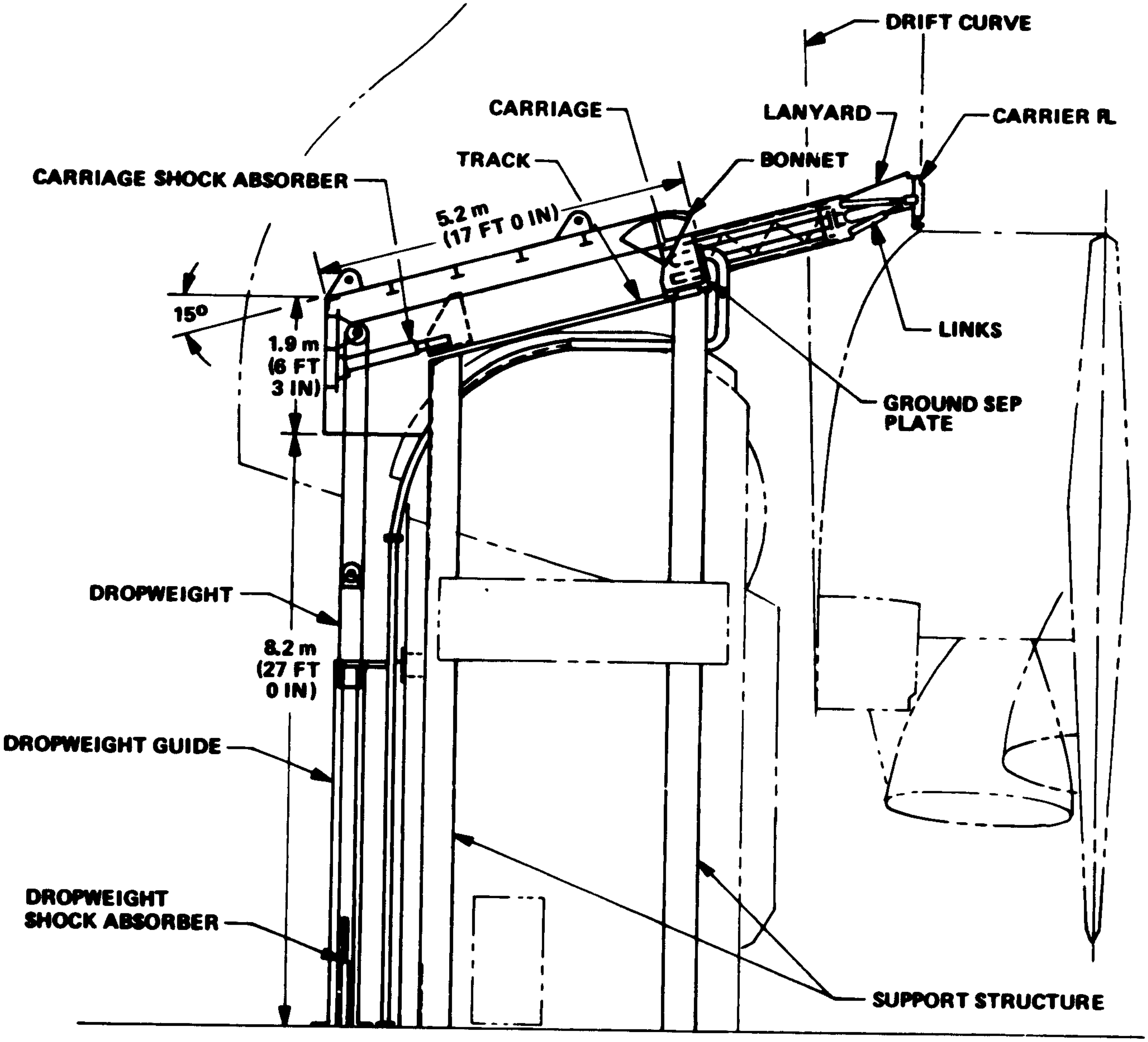

Figure 4. Payload Umbilical Mast – Reusable-Elevation View

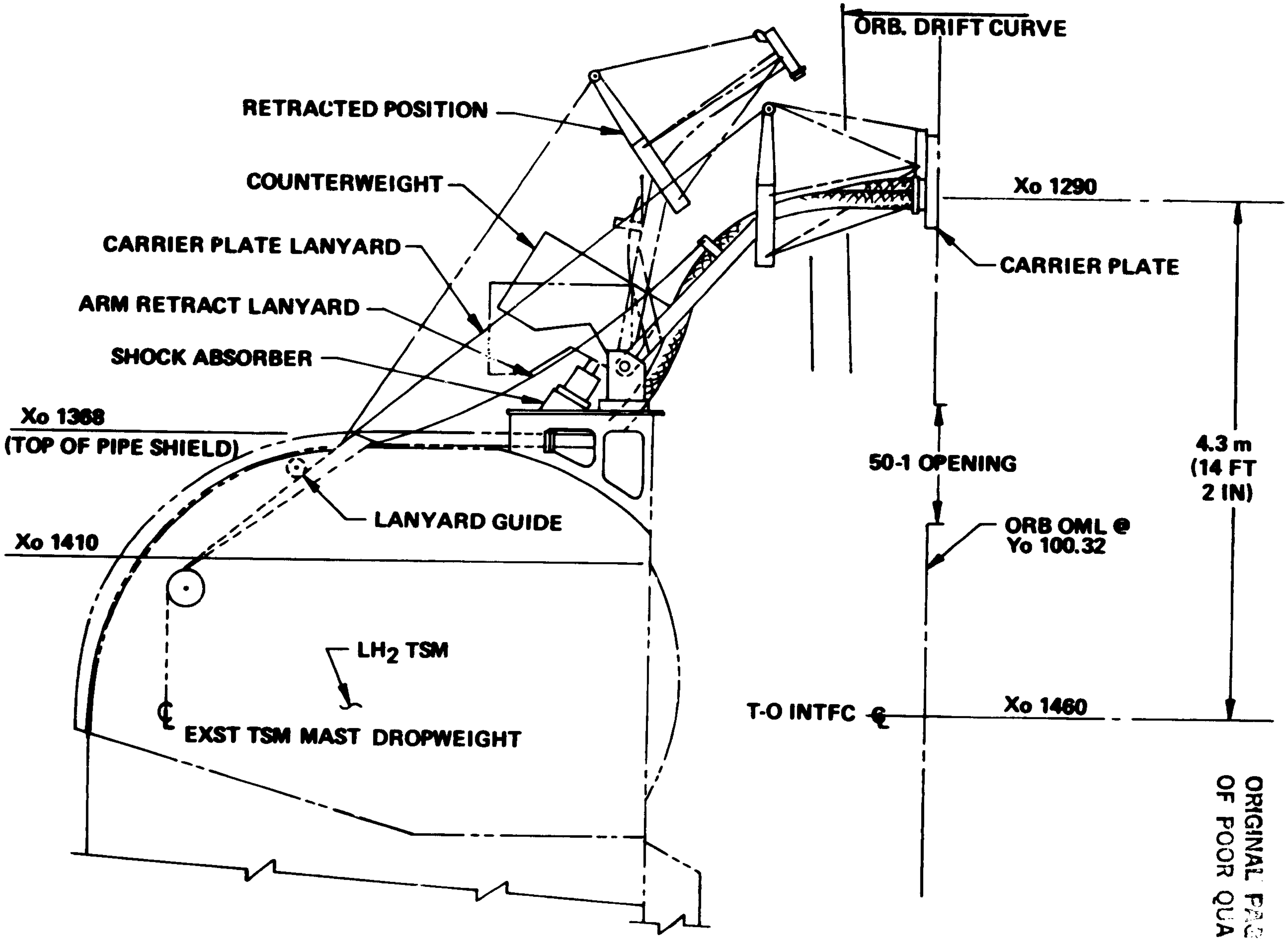

Figure 5. Payload Umbilical Mast — Expendable-Elevation View

a. STS/Centaur rolling beam assembly (figure 6)

b. Umbilical carrier plate assembly (figure 7)

c. Dropweight tower assembly (figure 8)

Installation of this equipment at the Launch Equipment Test Facility for test evaluation and development prior to delivery to Launch Complex 39A is shown in figure 9. A description of the cryogenic supply system is beyond the scope of this paper.

Umbilical Assembly. The umbilical assembly consists of the ground carrier plate (supplied by Rockwell International) supporting links, the LH_2 fill and drain vacuum-jacketed (VJ) flex line, and the LH_2 vent VJ flex line. The links will be equipped with ball joints to permit side-to-side motion as well as up and down. These links support the carrier plate after disconnect. The umbilical assembly includes the hockey stick disconnect lanyards and the static lanyards to prevent rotation of the ground carrier plate towards the Orbiter after disconnect.

Rolling Beam Assembly. The rolling beam assembly consists of a tapered truss beam. One end of the beam supports the umbilical assembly. The other end of the beam is bolted to the carriage assembly. The carriage assembly contains wheels that capture the carriage to the rails. The carriage assembly contains a ground separation plate to support the carriage mounted cryogenic line quick disconnects, the carrier plate purge disconnect, and the various hazardous gas sensing line disconnects. The LH_2 fill and drain lines make a 180-degree turn from the beam to line up in the carriage with the ground separation plate.

Linear Brake. A linear brake acts on a friction plate mounted to the carriage to stop the rolling beam assembly. The brake system includes guide rollers in front of the brake. The brake consists of two spring-actuated caliper-disk-type units that are pneumatically retracted.

Incline Assembly. The incline assembly sets the rolling beam on a 6-degree angle necessary to interface with the Orbiter and provide stowage capability upon retract within the FSS. In addition to the linear brake described above, the incline contains final overrun stop energy absorbers designed for 11,340 kg (25,000 lb) over a distance of 0.472 m (18.6 in). The incline assembly supports the static half of the ground separation plate for the LH_2 fill and drain lines and the gaseous hydrogen vent line. A pneumatically powered winch provides the capability to lift the rolling beam up the incline. Upper guide rail and rollers limit carriage sway. Stairs and access platforms are provided on the incline, giving access to the rolling beam including umbilical and ground separation plates. Cooling water nozzles and piping will be mounted to the incline to protect the umbilical carrier plate.

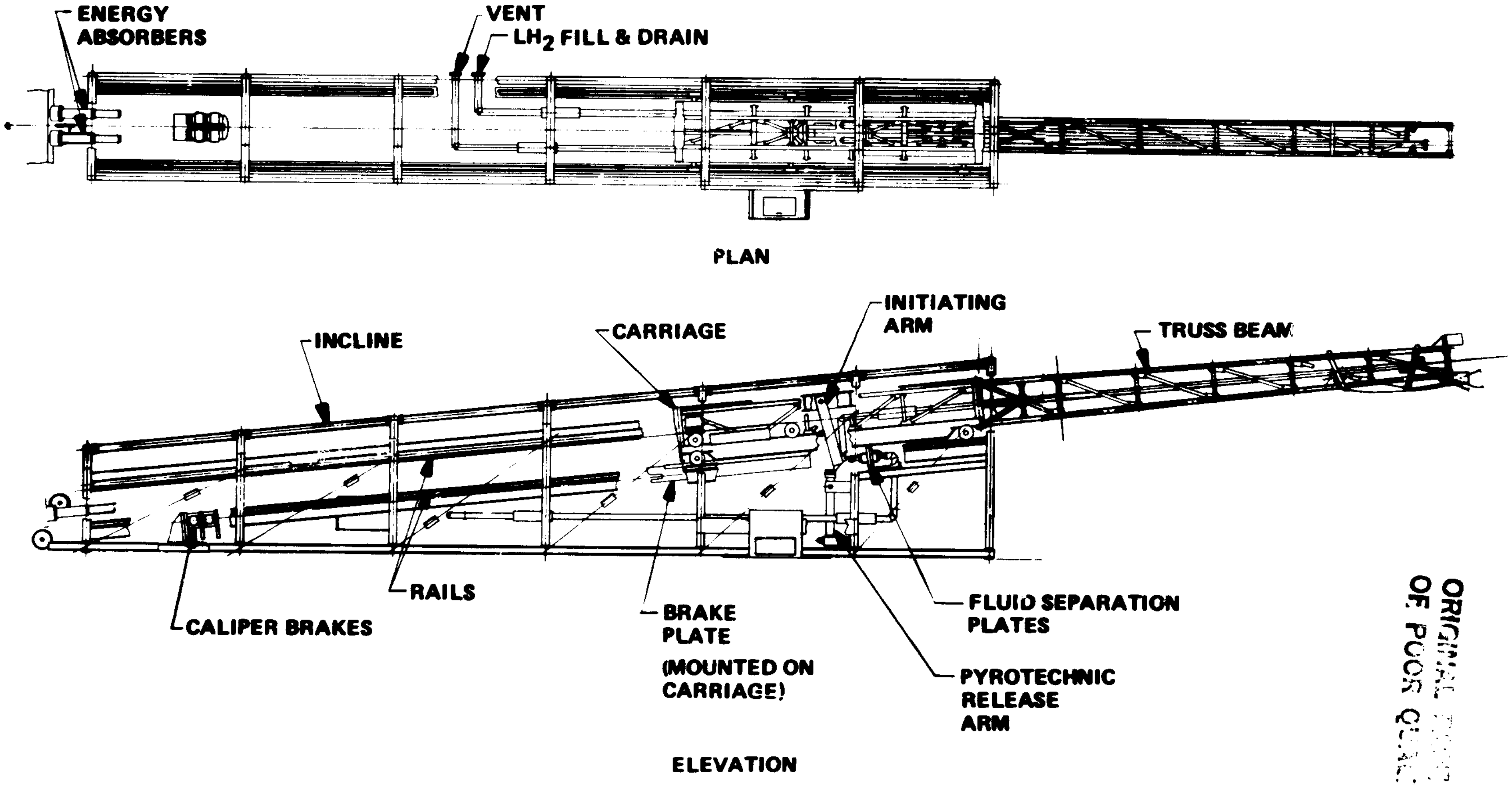

Figure 6. STS/Centaur Rolling Beam Assembly

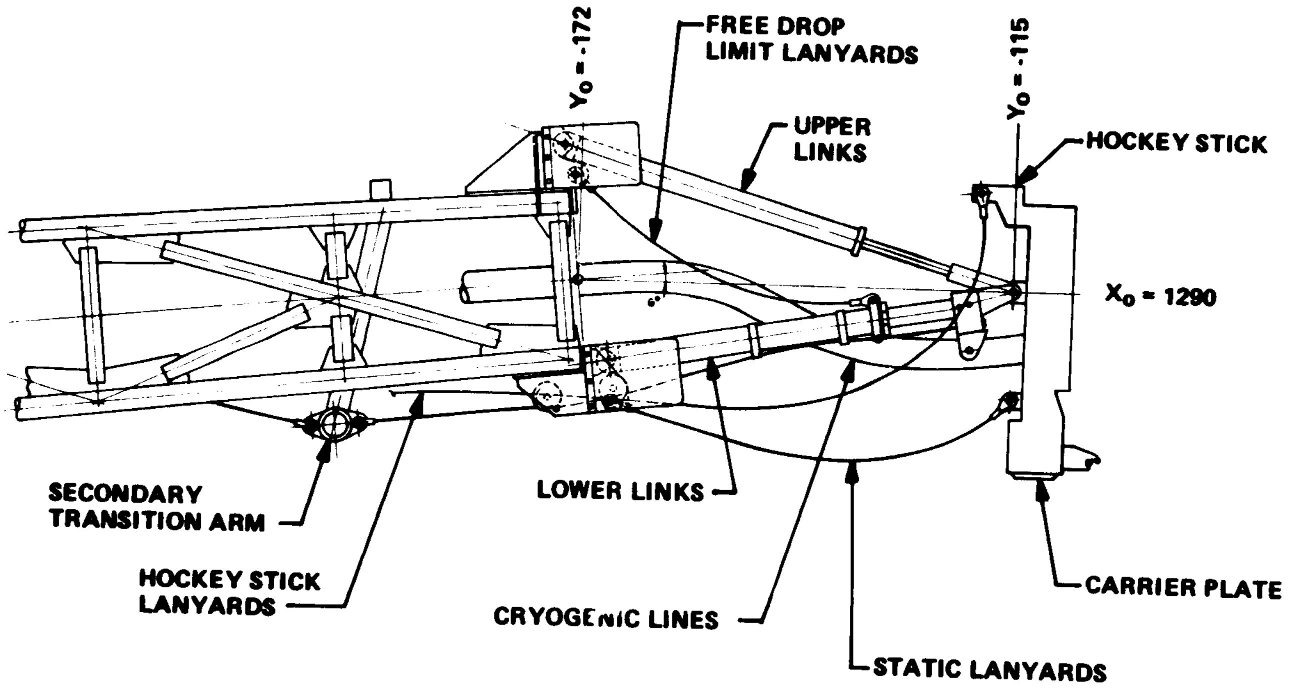

Figure 7. STS/Centaur Umbilical Carrier Plate Assembly