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DESIGN OF A TELESCOPING TUBE SYSTEM FOR ACCESS AND HANDLING EQUIPMENT

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ABSTRACT

Spacecraft processing presents unique problems for the design of ground support equipment. Most access equipment must be fully self-supporting and completely independent of the spacecraft. Additionally, system reliability must be ensured to limit the risk of damage to critical hardware. Telescoping tubes are well suited to some of these unique requirements. A telescoping tube system consists of a number of nested structural tubes that can be extended and retracted (telescoped) while supporting a load. A typical telescoping tube system provides lateral, torsional, and vertical support for an access platform.

Following several incidents involving tube systems at the Kennedy Space Center (KSC), an effort was undertaken to develop improved telescoping tube designs. Several concepts were developed with emphasis placed on reliability, ease of maintenance, and cost effectiveness. The most promising concept was selected for detailed design and prototype development.

The prototype design utilizes adjustable rollers running on tracks bolted to the tube sections. A wire rope deployment system ensures that all tube sections are controlled during extension and retraction. Previous systems relied on gravity to extend the tubes. Track shimming and roller adjustment allow for fabrication of a high-precision tube assembly that does not require extensive machining or unusually large shop equipment. The use of rolling contact eliminates the contamination problems encountered with sliding tubes in previous designs. The prototype design is suitable for indoor or outdoor use. A prototype tube assembly has been fabricated and tested for strength, stiffness, maintainability, and endurance. The prototype tube assembly has met or exceeded all design requirements.

INTRODUCTION

Telescoping tube systems have been used to solve several unique access and handling problems at KSC. Tube systems have been or are currently in use in several areas including:

- Orbiter Processing Facility (OPF) Payload Bay Access Buckets.

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- Space Shuttle Orbiter Mate-Demate Device (MDD).

- Launch Pad 39B Line Replaceable Unit (LRU) Access Platform.

While the telescoping tube systems in use at KSC have generally worked well, there are a number of areas in each design that need improvement.

OPF Payload Bay Access Buckets

The OPF Payload Access Buckets (Figure 1) provide access to all areas of the Space Shuttle Orbiter payload bay for maintenance and inspection. The OPF buckets consist of a 0.8 m x 1.5 m (30 in. x 60 in.) work platform suspended from a four-section telescoping square tube assembly that allows 6.2 m (243 in.) of platform vertical motion. An electric hoist attached to the platform resists vertical loads, while the tube system resists lateral, torsional and eccentric (moment) loads. A bridge and trolley arrangement allows for horizontal motion of the platform.

Several problems exist with the current tube design. The primary problem is that the two intermediate tubes float freely between the inner and outer tubes and rely upon gravity for their deployment (the outer tube is attached to the trolley, and the inner tube is attached to the platform). Another problem with the OPF tubes is that the tubes slide on adjustable bronze bearings. Because of the sliding contact, the intermediate tubes sometimes bind and drop during extension. This can cause damaging impact loads on the structure. Also, the use of lubrication on the tubes is limited because of orbiter payload bay contamination concerns. This results in the generation of small bronze particles that create a contamination problem of their own. A more detailed account of problems with the OPF buckets and tubes may be found in reference 1.

Orbiter Mate-Demate Device

The Orbiter MDD is used to remove (or install) the Space Shuttle Orbiter from the Shuttle Carrier Aircraft (SCA). Telescoping tube systems are used to steady the orbiter and access platforms against wind loads. Three sets of similar tube assemblies are used. One set consisting of four tube assemblies provides lateral support for the orbiter lifting hardware. Each of these four-section square tube assemblies allows for 14 m (550 in.) of orbiter vertical motion while providing lateral support against wind load and allowing horizontal adjustment of the orbiter for mating operations. The remaining two sets of two tube assemblies provide lateral support for access platforms used during mating operations. Each four-section tube allows for 14.6 m (575 in.) of platform vertical motion while preventing the platforms from swaying and contacting the orbiter.

Like the tubes on the OPF buckets, the intermediate tubes on the MDD rely upon gravity for their deployment. This creates the risk of damage from free falling tubes. Also, the design of the MDD tubes required that the inside surfaces of the tubes be polished for the sliding bearings. This requirement significantly increased the fabrication cost of the tubes. The inner sliding bearings, located between the tubes, cannot be removed for inspection or repair without completely disassembling the tubes. Finally, the sliding surfaces of the tubes require a significant effort to control corrosion.

Pad 39B LRU Access Platform

The LRU Access Platform (Figure 2) was designed to provide access to the Space Shuttle Orbiter payload bay at the launch pad. The 4.3 m x 6.1 m (168 in. x 240 in.) platform was suspended from two telescoping tube assemblies that provided lateral support. Each five-section telescoping tube assembly allowed for 16.2 m (637 in.) of vertical motion. The design of the LRU platform tubes was nearly identical to the OPF tubes. Operational testing of the tubes revealed severe binding within the tube assemblies. Several incidents of binding and falling tubes culminated in the failure of the mechanical stops that prevent the tubes from over-extending. The tube assemblies were removed from the pad, and a simplified design was implemented to meet the pad operational readiness date.

The primary cause of all the problems with the LRU Access Platform tubes was that they were simply an enlarged version of the tubes used in the OPF. Scaling up the marginal design of the OPF tubes increased the severity of the problems seen in the OPF to the point where the tubes would no longer function.

Summary

An investigation into all tube systems at KSC identified the above mentioned problems as well as other safety and maintenance concerns. A project was undertaken to improve telescoping tube assemblies at KSC. Specifically, the project tasks were to:

- Identify deficiencies in existing designs.
- Develop new design requirements.
- Design, fabricate, and test a prototype tube assembly.
- Develop design criteria or specifications for new tubes.

DESIGN DEFICIENCIES

As was previously discussed, design deficiencies and desired improvements were identified as follows:

- Unrestrained tube sections (gravity deployment).
- Contamination generation.

- Maintenance and inspection problems.
- Reliability.
- High fabrication costs and manufacturing problems.

PROTOTYPE DESIGN REQUIREMENTS

The prototype tube assembly size and loading approximates the system used for the OPF buckets. The specific design requirements were:

• Collapsed Length	4.3 m	(168 in.)
• Deployed Length	10.4 m	(408 in.)
• Lateral Stiffness (min.)	29 kN/m	(167 lb/in.)
• Lateral Load (max.)	2.2 kN	(500 lb)

- Redundant system for supporting intermediate tubes.
- Eliminate sliding bearings where possible.
- All lubricants sealed within assembly to minimize contamination. Grease preferred to oil.
- All moving parts easily accessible for removal or inspection.
- Three-section tube assembly expandable to at least four sections.
- Five thousand hour operating life on bearings.

TECHNICAL DESCRIPTION

Several design concepts were studied in an effort to fulfill all design requirements in a compact package at minimum costs. The prototype design (Figure 3) is fabricated from 300 series stainless steel. The two outermost tubes support rollers that engage on longitudinal tracks mounted to the two innermost tubes. A redundant system of wire ropes deploys and retracts the intermediate (middle) tube. The rollers and tracks and deployment ropes are designed to fit entirely between the tubes (Figure 4). This minimizes the collapsed length of the tubes and permits adding more tube sections to the assembly as desired. The number of tube sections is limited only by the strength and load capacity of the rollers and ropes. The tube assembly is designed such that no special or unusual equipment or material is required for fabrication. The prototype tube was fabricated under a fixed price contract with no significant difficulties.

Tube Sections

The three tube sections are 410 mm (16 in.), 330 mm (13 in.) and 250 mm (10 in.) square and 4.3 m (168 in.) long. Each tube is fabricated from two bent plates which are 6.3 mm thick and welded longitudinally. Each section also has a welded joint located 1.2 m (48 in.) from the top. The tubes were fabricated with the joints in order to demonstrate that unusual shapes and long tubes would not present problems for future designs.

The 410 mm (outer) tube has two angle brackets on one end for attachment to the test fixture. The 250 mm (inner) tube has a lug at the top for attachment of the hoist and provisions at the bottom for attachment of various loading fixtures.

Guide Track

The intermediate (330 mm) and inner tubes each have four tracks attached longitudinally, one bolted onto each side of the tube. Shims allow the tracks to be adjusted to the desired accuracy of the entire assembly. The track sections are 19 mm x 38 mm (.75 in. x 1.5 in.) cold-rolled stainless steel. The work hardening characteristics of the 303 stainless steel provide for a track surface of adequate hardness without requiring heat treatment or unusual materials. Each track section was provided with a joint at the location of highest load in order to demonstrate the effects of joints on longer tube sections.

Guide Rollers

The outer and intermediate tubes have four sets of guide roller assemblies on each side (16 total per tube). Each roller assembly contains two hardened rollers supported in a roller frame. A sealed ball bearing is press fitted into each roller. Teflon washers between the rollers and the roller frames prevent damage caused by inadvertent side loads on the rollers. The roller frame equalizes the roller loads and an adjustment bolt allows for roller alignment. The roller frames are easily removed to allow access to the rollers and bearings for inspection or replacement (Figure 5). The roller frames may be shimmed as required to eliminate inaccuracies or misalignment with the tubes. Removal of any one roller set does not compromise the adjustment of the tube assembly. The rolling contact of the roller and track arrangement and the sealed bearings minimize contamination problems.

Rope Deployment System

A redundant wire rope deployment system controls the intermediate tube. The outer tube is fixed and the inner tube is supported by a hoist. The deployment ropes maintain the intermediate tube centered between the outer and inner tubes (see Figure 6). Four sheaves are mounted to opposite corners of the intermediate tube (Figure 4). It should be noted that the intermediate tube is positively driven both up and down. For normal operations, gravity will force the tube down and the upper ropes will remain unloaded. If there is any binding, the tube will be forced down to eliminate the possibility of the tube falling freely. This feature will also allow the tubes to be operated in any orientation desired. Wire rope terminations are provided on the outer and inner tubes. The rope terminations are adjustable to allow load equalization; however, the system is designed to function on a single rope system. Testing has shown that the rope loads remain equal within about ten percent. With a safety pin installed in the tubes, all sheaves and wire ropes may be easily removed for inspection or replacement (Figure 5). If the design requires more than three tubes, alternating corners of the tubes may be used for sheave mounts and rope terminations.

TESTING

Test requirements for the prototype tube assembly were developed to demonstrate tube operation, maintenance, and inspection based upon design requirements and projected user needs. The requirements were:

- No Load Functional Test
- Maintenance / Inspection Test
- Straightness / Side Play Test
- Stiffness Test
- Lateral Load Test
- Eccentric Load Test
- Torsional Stiffness Test
- Single Rope Operational Test
- Endurance Test

The tube assembly was installed and tested in a newly fabricated test stand at the KSC Launch Equipment Test Facility. Test loads are shown schematically in Figure 7. Most of these tests are self explanatory. Figure 8 shows the test fixture used to apply lateral loads to the tube assembly. This arrangement allowed the tube to be extended and retracted under constant lateral loads. The maintenance and inspection tests were used to demonstrate that the ropes, sheaves, and roller assemblies could be easily removed and installed. The lateral load test applied a 2.2 kN (500 lb) side load while the tube was extended and retracted. The eccentric load test applied a 9.3 kN-m (83 in. - kip) moment while the tube was extended and retracted. The endurance test was for 2000 extension and retraction cycles at full lateral load.

The prototype tube assembly met or exceeded all test requirements. The actual tube stiffness of 87 kN/m (500 lb/in.) was three times that specified in the design requirements. In addition to the above tests, the tube assembly has been subjected to two years of exposure to the KSC environment with no adverse effects (no maintenance has been required).

CONCLUSIONS

The prototype tube design eliminates all known deficiencies of existing systems and provides an economical and reliable solution to some of the unique problems of providing access to spacecraft. The prototype tube assembly has demonstrated that tube assemblies can be fabricated economically while providing improved maintainability and increased reliability. The prototype tube assembly can be used as a starting point for design of future systems or the modification of existing equipment. Design specifications for a telescoping tube assembly used on an X-Ray positioning system were developed based on the prototype tube assembly. The X-Ray system has been installed and has completed functional testing. A short design standard is being developed to ensure that the information learned from the prototype will be available to designers of new systems for use at KSC.

REFERENCES

1. Harris, J. L., Orbiter Processing Facility Service Platform Failure and Redesign, Proceedings of the 22nd Aerospace Mechanisms Symposium, May, 1988, NASA Conference Publication 2506.

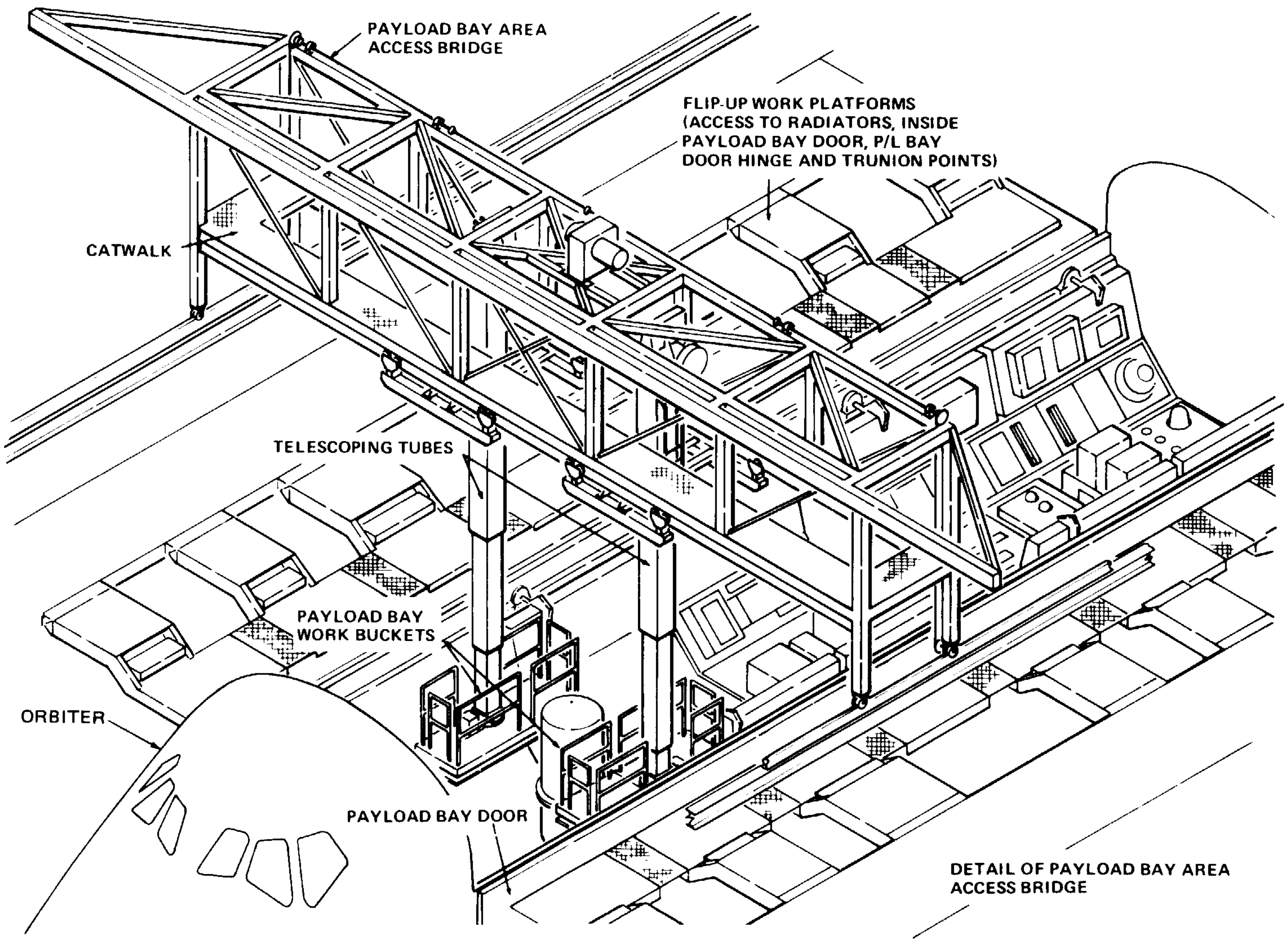

Figure 1. Orbiter Processing Facility payload bay access buckets.

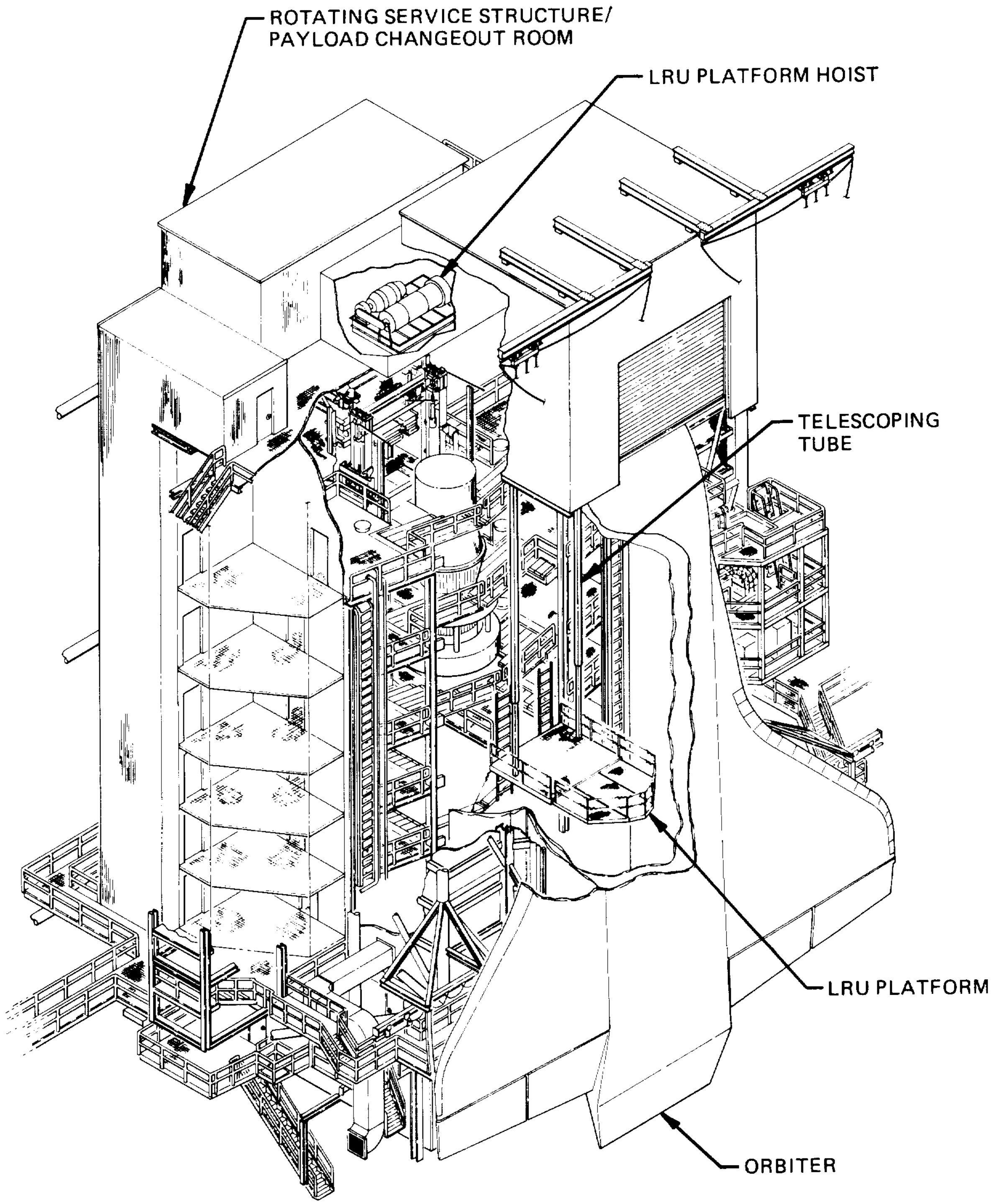

Figure 2. Launch Pad 39B LRU access platform.

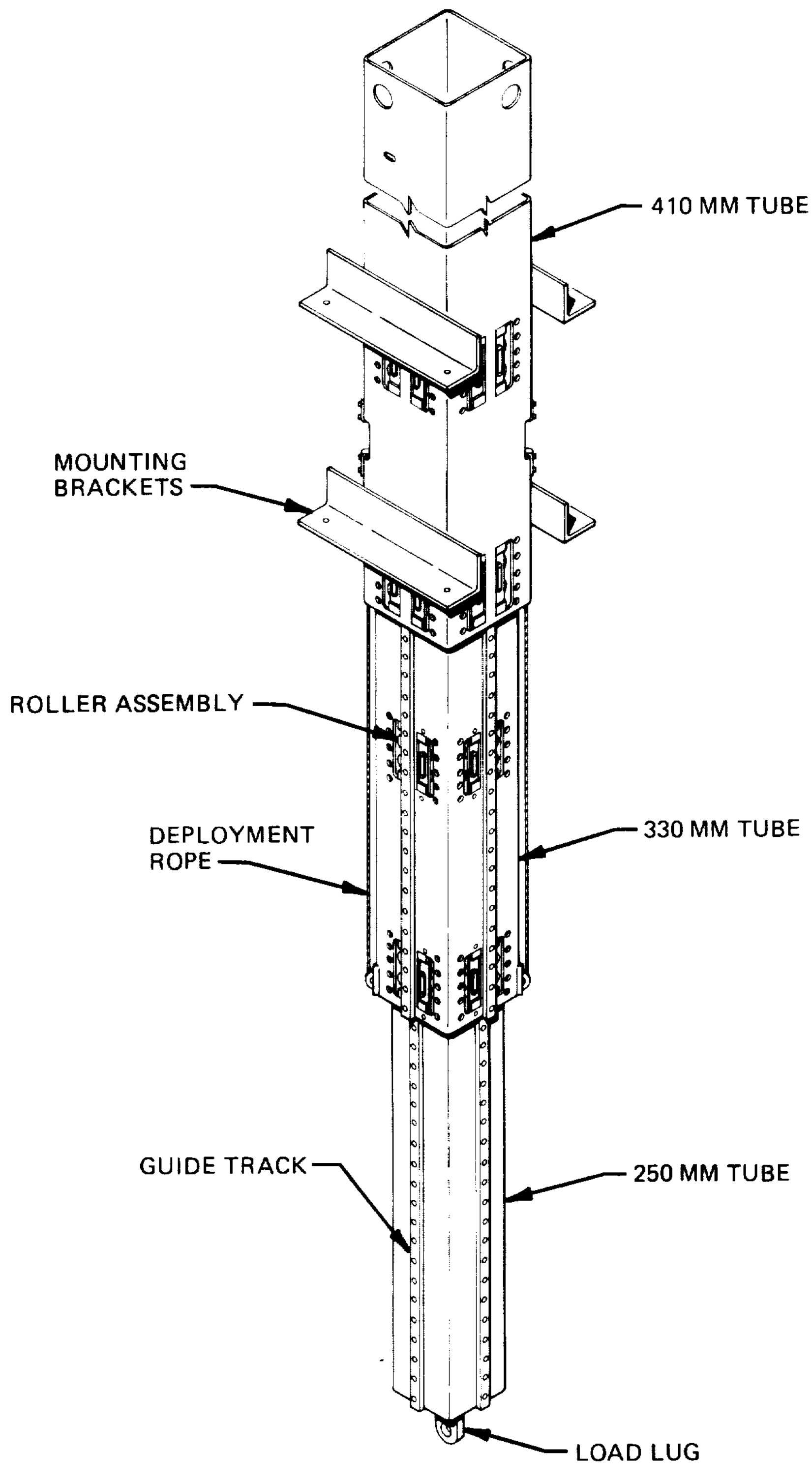

Figure 3. Prototype telescoping tube assembly.

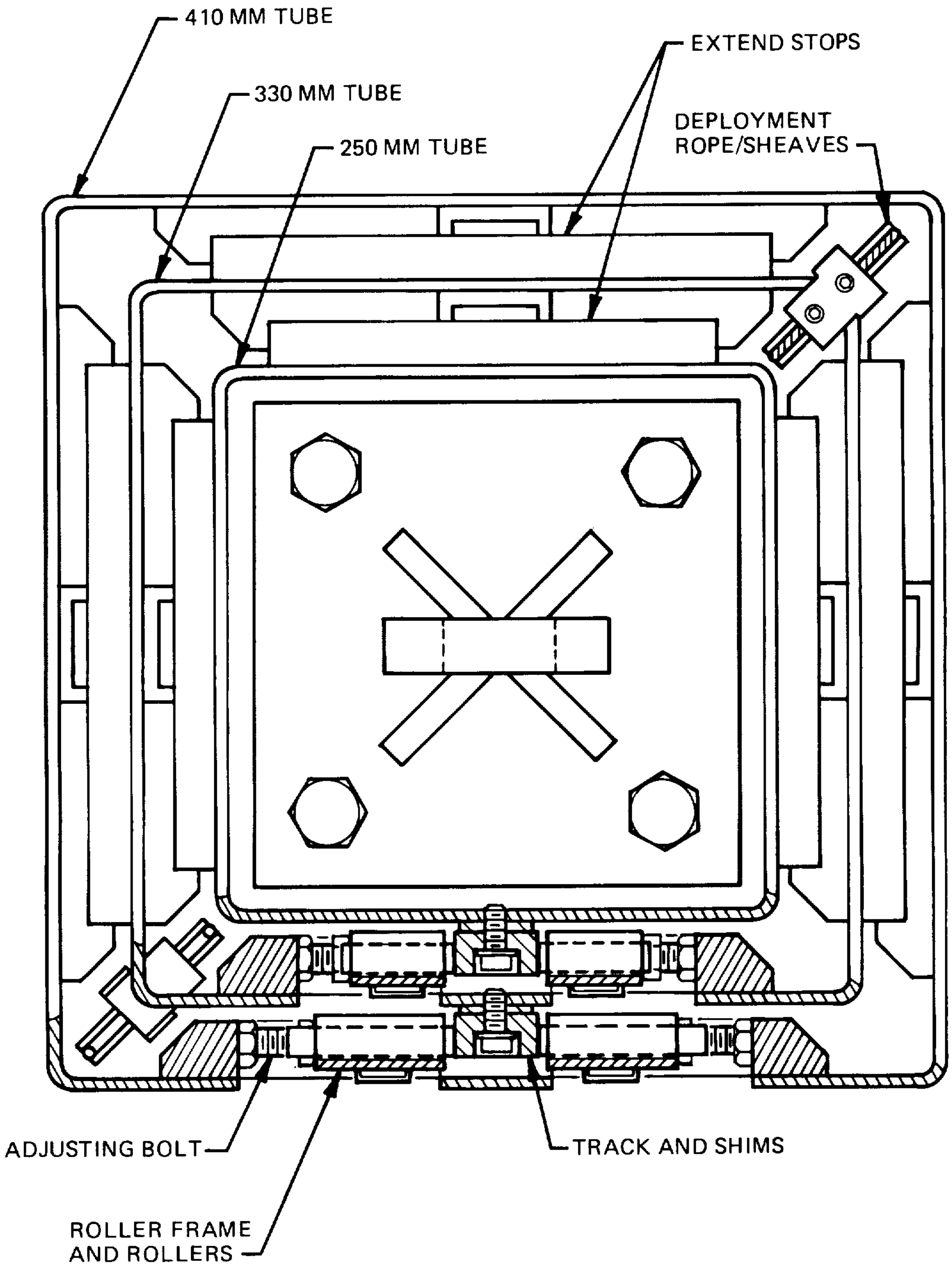

Figure 4. Top view of tube assembly sectioned at rollers.

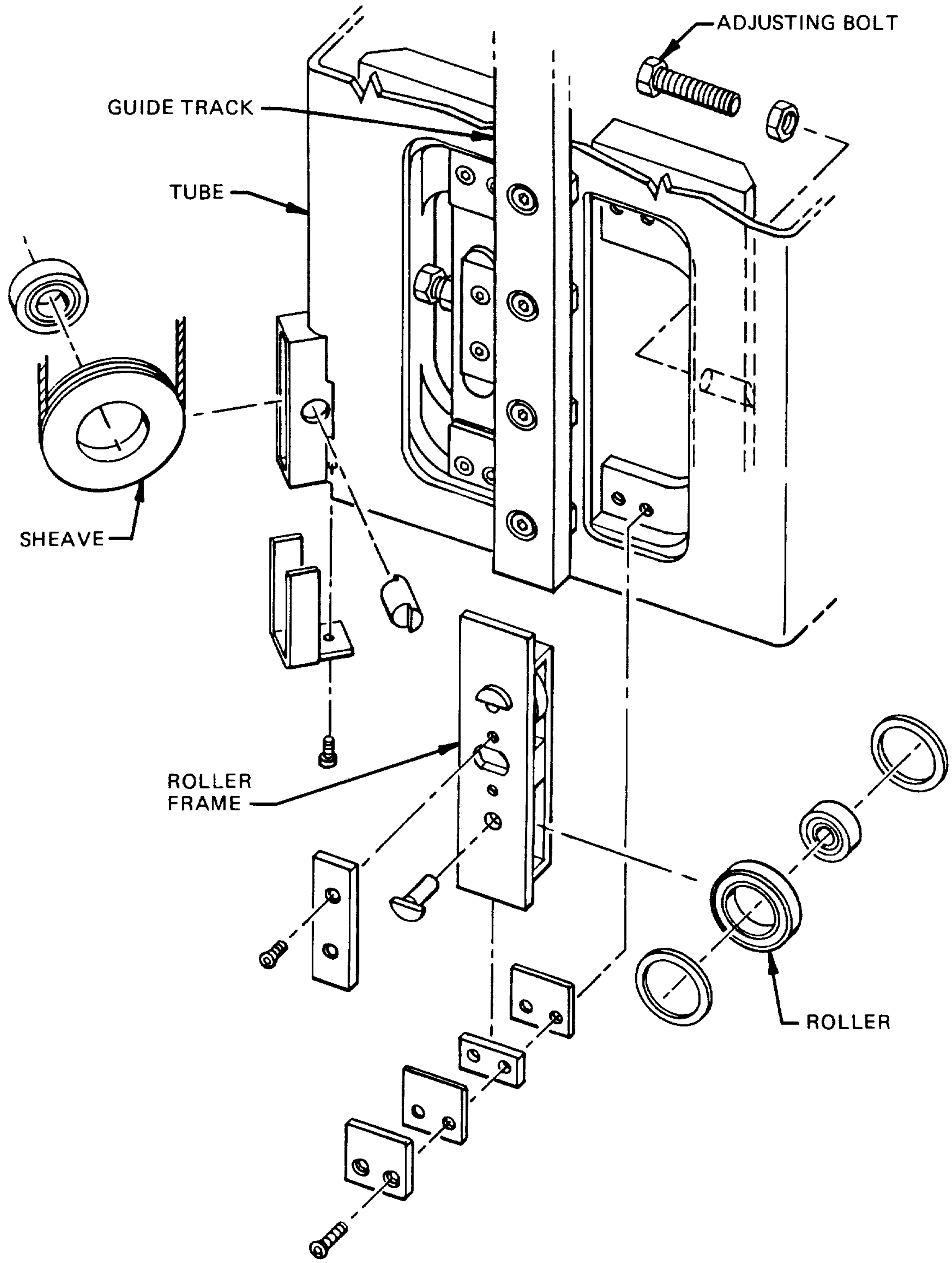

Figure 5. Detail of telescoping tube rollers and sheaves.

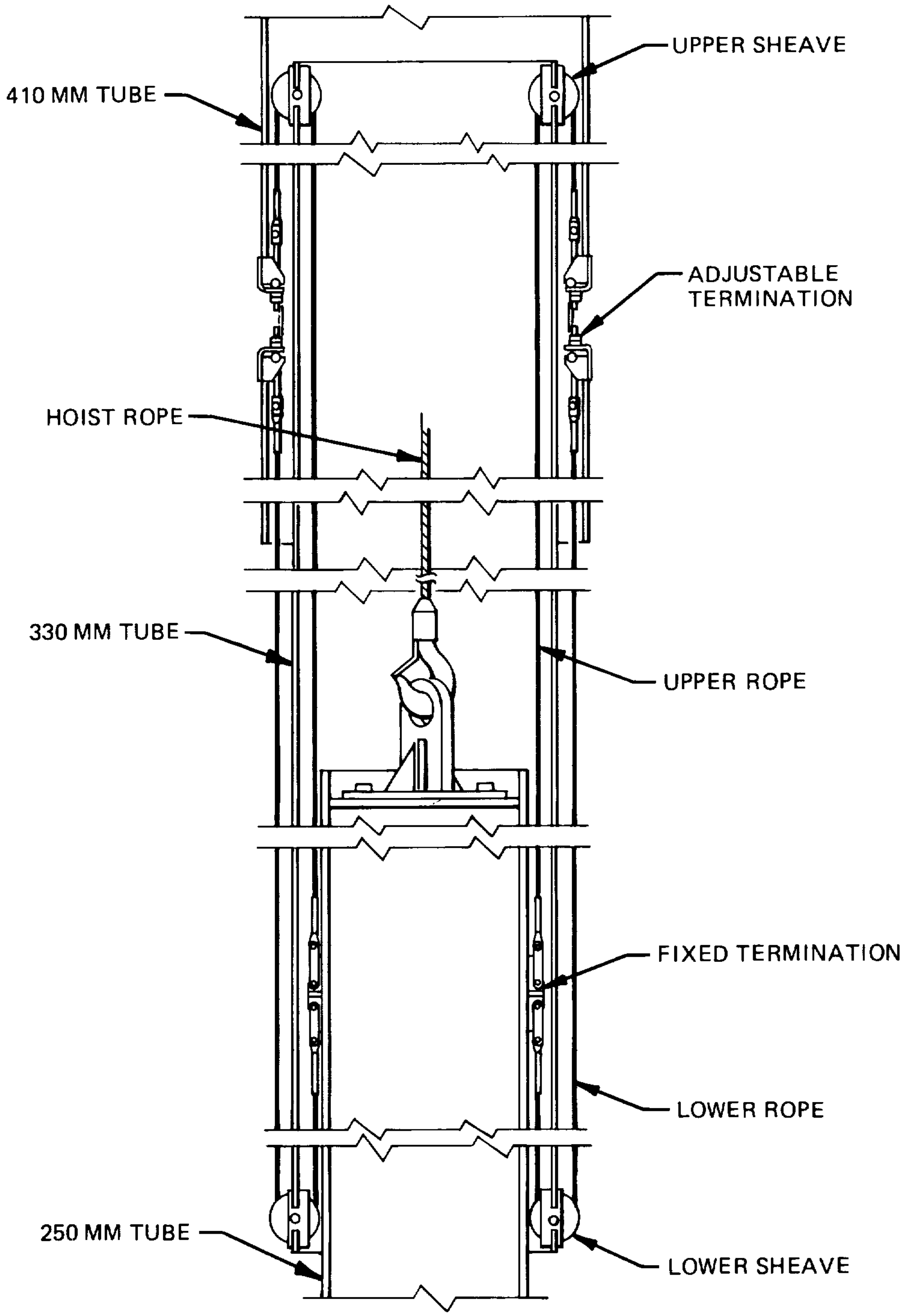

Figure 6. Deployment rope system.

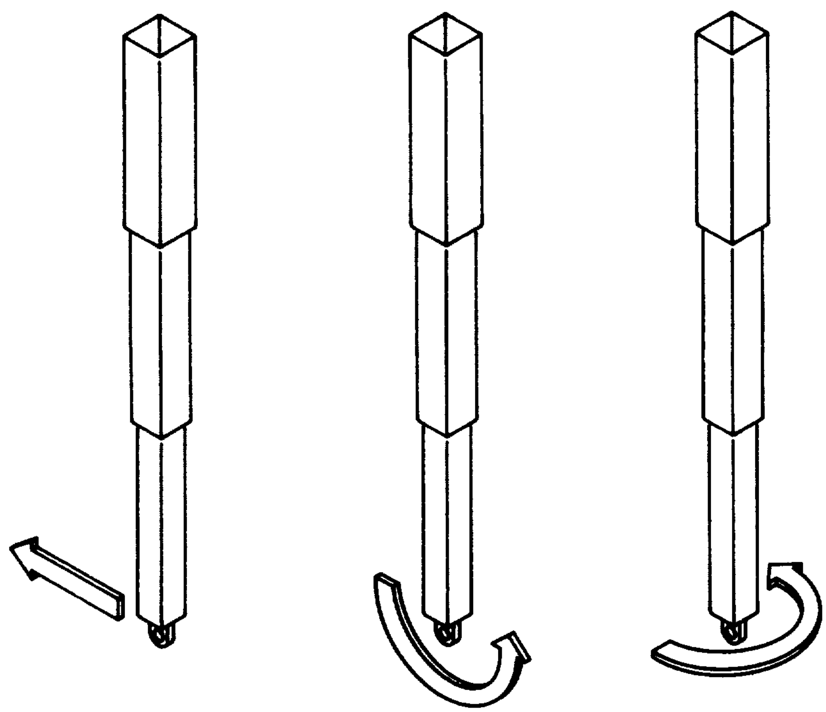

Figure 7. Telescoping tube assembly test loadings.

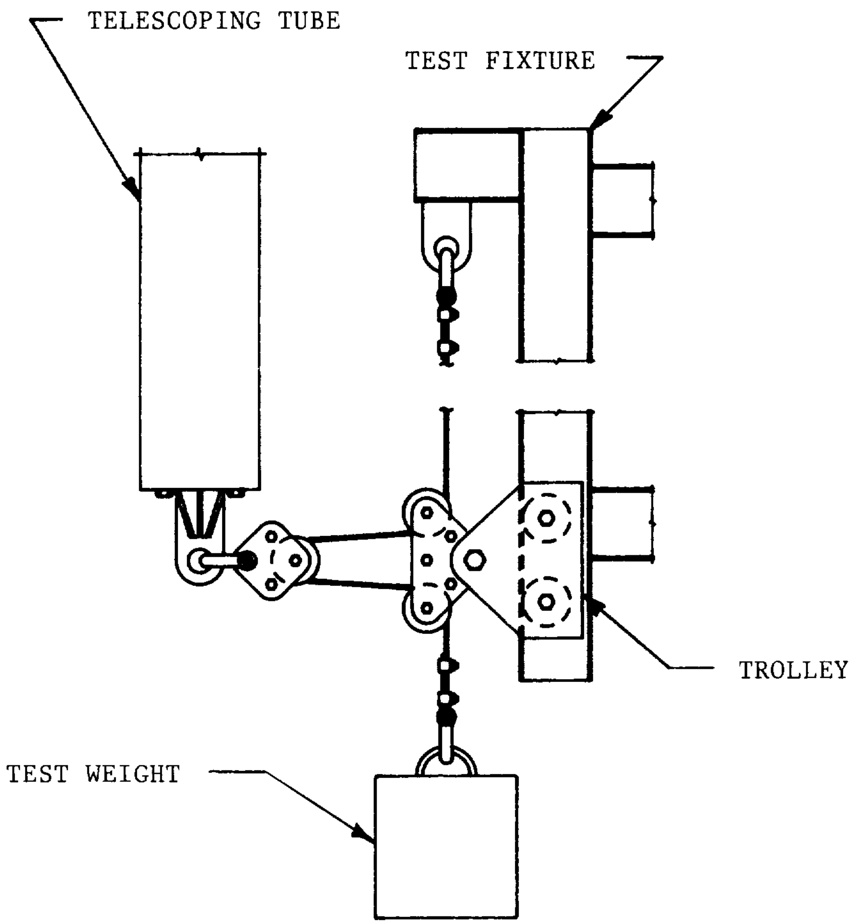

Figure 8. Lateral load test fixture.