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SPACE STATION MOBILE TRANSPORTER

James Renshall,* Geoff W. Marks,* Grant L. Young*

ABSTRACT

The first quarter of the next century will see an operational Space Station that will provide a permanently manned base for satellite servicing, multiple strategic scientific and commercial payload deployment, and Orbital Maneuvering Vehicle/Orbital Transfer Vehicle (OMV/OTV) retrieval replenishment and deployment. The Space Station, as conceived at the time of writing, is constructed in orbit and will be maintained in orbit.

The above construction, servicing, maintenance and deployment tasks, when coupled with the size of the Station, dictate that some form of transportation and manipulation device will be required.

The Transporter described in this paper will work in conjunction with the Orbiter and an Assembly Work Platform (AWP) to construct the Work Station. The Transporter will, later in its life, work in conjunction with the Mobile Remote Servicer to service and install payloads, retrieve, service and deploy satellites, and service and maintain the Station itself. Figure 1 shows the Transporter involved in Station construction when mounted on the AWP and later supporting a maintenance or inspection task with the Mobile Remote Servicer and the Flight Telerobotic Servicer.

INTRODUCTION

The Mobile Transporter is the device that will carry the Station manipulators, tools, payloads and orbit replaceable units around the Station. It has to be able to move around on a truss structure fabricated from cubic bays. It has to provide a firm base structure for the Space Station remote manipulators to operate from. It has to move in a variable rate controllable manner to avoid destabilizing the Space Station when carrying large payloads.

The Mobile Transporter must be able to reach any point on the external truss structure by virtue of its own mobility mechanisms; consequently, it must be able to move in a straight line, turn right angle corners and make 90-degree external plane changes.

The Mobile Transporter also has to be stowable within the Orbiter bay for launch and be deployed or erected to the same size as the Space Station truss for use.

*Astro Aerospace Corporation, Carpinteria, California

DESCRIPTION

The Mobile Transporter is comprised of three principal structures, a number of drives, an electronics control unit, and thermal protection and harnessing. Mobile Transporter operations are controlled in detail by the drive electronics unit. It receives high-level commands either from the Orbiter (when the Transporter is building truss) or from the Mobile Remote Servicer (MRS). The drive electronics unit consists of a multiplexing unit, a data processor, and a mechanism drive electronics unit. The data processor contains the detail algorithms that control the operation of the heaters and drive mechanisms. The multiplexer is an interface unit to the drive electronics which monitors and powers instrumentation. The mechanism's drive electronics unit generates DC power for the drive motors and heaters, and AC power for the drive module resolvers.

The Mobile Transporter has three degrees of freedom: translation, in-plane rotation, and a normal-to-plane rotation. There are three major structures in the Mobile Transporter: the upper base, the track base, and the lower base.

The general arrangement, in exploded form, is depicted in Figure 2.

The upper base is a self-deploying truss structure fabricated from a combination of two-inch-diameter and four-inch-square graphite tube. The upper base structure carries the MRS in its center position and it transfers the forces and torques generated by the MRS during payload manipulation into the Space Station truss. The upper base also attaches the Transporter to the AWP and transfers any Orbiter-induced perturbation loads into the truss segment that is being built.

The upper base has four node pin latches at its extremities. These are the latches that grip pins on the Space Station truss nodes, thus ensuring that the upper base is firmly attached to the Station truss when it has to be.

The upper base is attached by means of a ring in the center of its lower face to a turntable assembly. The turntable provides the in-plane rotational degree of freedom that the Mobile Transporter needs in order to be able to turn corners.

The turntable assembly itself is attached to the second major structural item, the track base assembly. The track base is an EVA* unfoldable graphite beam structure fabricated from square section tube, and as the name suggests, it is the linear track on which the translational degree of freedom drive runs. Attached to the underside of one of the track base longerons, which is 6.219 meters long, is a gear rack and track assembly. There are flat steel tape tracks attached to the top face of the "rack" longeron and to the top and bottom faces of the other longeron.

*Extravehicular activity

The track base assembly can run back and forth by 5.21 meters through the drive hinge assembly. The drive hinge assembly, which contains the normal-to-plane rotational and in-plane translational degrees of freedom, is attached to the lower base assembly. Consequently, the upper base can move 5 meters back and forth with respect to the lower base. Thus, the Mobile Transporter can move 5 meters one step at a time. Since the drive hinge assembly has the normal-to-plane rotational degree of freedom built into it, the upper base can be tilted up by 90 degrees, thus allowing the Mobile Transporter to change plane from one truss face to another.

The lower base assembly is an EVA unfoldable planar structure fabricated from graphite square section tubes. The lower base also has four node pin latches, similar to the ones on the upper base, which serve the same purpose as the upper base. The lower base assembly forms the attachment between the Mobile Transporter and the Space Station, while the upper base, MRS, payload combination is being translated or rotated. Sequential or combined use of the Mobile Transporter degrees of freedom, when properly latched to the Space Station truss by the relevant piece of Transporter structure, thus ensures secure progress around any part of the Space Station truss exterior.

A one-bay translation sequence is shown in Figure 3, "Translation motions and rates."

Photograph 1 shows both the upper and lower bases, one on top of the other and both fully locked to four node pins on the structure. This is the mode the Transporter would be in for any static operations of the Mobile Remote Servicer, which is normally attached to the upper base.

Photograph 2 shows that the upper base node pin locks have released the station truss node pins, fully retracted so as to allow movement, and that the upper base is moving. Translation motion is effected and controlled by the drive hinge and track base. When the upper base moves, the track base moves and the drive hinge is stationary; thus, the drive hinge rolls down a fixed track. The translation drive mechanism is described in greater detail elsewhere in the paper.

Photograph 3 shows that the upper base has arrived at the next bay, which is not quite the fullest extent of its possible travel, with the node pin latches closed onto the node pins. The Transporter is now attached to two bays at eight points.

Photograph 4 shows that the lower base has released itself from the station truss node pins, the latches have fully retracted to allow movement of the base, and the lower base is advancing.

Photograph 5 shows the lower base has fully advanced to the same bay that the upper base is attached to and has locked itself to the structure. The Transporter has now moved one complete bay. The time taken to perform this sequence is dependent upon payload mass. Predicted average rates for various size payloads are shown in Figure 3.

A direction change is shown in Figure 4, "Rotation motions." The Transporter would perform a direction change at a junction between a transverse boom and keel, or immediately prior to making a plane change.

Photograph 1 shows the Transporter as it was in Photograph 5 of Figure 3. Both bases are locked onto the same bay and the track base is aligned with the truss.

Photograph 2 shows that the lower base node pin latches have been opened and fully retracted, and the lower base is being rotated by the turntable. The turntable connects the upper base to the track base. This mechanism is fully described later in the paper.

Photograph 3 shows the lower base drive hinge and track base fully rotated through 90 degrees and relatched onto the node pins. The track base is now realigned with a new direction of travel, and translation could proceed at this point. However, Photographs 4 and 5 show the sequence being completed by a rotation of the upper base performed similarly to the lower base rotation shown in Photographs 1, 2 and 3.

A plane change is shown in sequence in Figure 5, "Plane change motions." Plane changing amounts to stepping out over the side of the truss, rotating about an axis parallel to the truss longerons into a plane parallel to the new plane, and grasping the new plane bay node pins with one of the bases. That motion is followed by the other base to complete the sequence.

Photograph 1 shows the two bases locked onto a side face of the truss. A direction change has just been completed and the track base is aligned at 90 degrees to the truss in the correct direction for a plane change.

Photograph 2 shows the upper base released itself from the node pins and advancing vertically upwards.

Photograph 3 shows the upper base tilting over toward the new plane. It can be seen that the upper base has translated to an approximate midpoint of the travel prior to the tilting motion. This is done so as to minimize tilting inertia and torque on the Space Station. The mechanism that controls the plane change is the rollover drive portion of the drive hinge assembly. It is described in detail later in the paper.

Photograph 4 shows the upper base fully tilted over through 90 degrees and rolling across the upper face on the track base toward the node pins.

Photograph 5 shows the two bases now firmly latched to the truss on two faces at eight node pins.

Photograph 6 shows the lower base has been released from the node pins, and the rollover drive is now pulling it up toward the new plane.

Photograph 7 shows the lower base fully rotated through 90 degrees and ready to be rolled in by the translation drive.

Photograph 8 shows the lower base rolled in underneath the upper base toward the node pins where it is latched 90 degrees away from where it started.

MECHANISMS INSTRUMENTATION AND LUBRICATION

Key requirements that have driven the concept design of the Transporter generally, and the mechanisms particularly, are the need for 30 years life-time with maintenance and full single failure tolerance without any loss of performance. The first requirement will drive the lubrication system design

and cause the mechanisms to be configured as orbit replaceable units. The second requirement causes the mechanisms to be fully redundant, both mechanically and electronically.

The Transporter mechanisms are the node pin latches, a turntable and the drive hinge assembly. All the mechanisms use a common motor resolver and brake module even though the mechanisms are somewhat different. The node pin latches are shown in Figure 6. The node pin latches are grippers, they have a pair of jaws attached by pivots to the front of the latch body. The jaws are opened or closed in the following manner. The motor module contained within the latch body causes a threaded shaft, which protrudes from the rear of the latch body, to rotate. There is a gimbal mounted nut running on the threaded shaft and the nut is part of a "U" bracket which "wraps" around the latch body toward the front of the latch. When the threaded shaft is rotated, the "U" bracket moves back or forth. The front of the "U" bracket is connected to the latch jaws by a pair of pivoted push/pull rods.

Consequently, as the motor rotor turns, the threaded shaft rotates, the "U" bracket is moved forward, the push rods are moved forward, and the latch jaws close onto the node pin.

The motor resolver and brake are all dual wound and the Transporter can still function if only three out of the four latches are functional.

Each latch is mounted on a spring compliance system that allows motion in a radial direction only. Thus, the pattern of four latches can "breathe" to allow differential expansion between the Transporter and the truss.

The turntable assembly is shown in Figure 7. It is electrically quadruple redundant and mechanically dual redundant. It has two crossed roller wire race bearings, two drive modules, an upper housing, a lower housing, and a "floating" internal ring gear. The bearings are 40 inches in diameter. Figure 7 shows the turntable sectioned, the wire race crossed roller bearing concept, and the predicted force-speed characteristic.

The bearings and drive are fully redundant and operate in the following manner. When the prime drive is running, the redundant drive is locked by its integral power-off brake. Because the redundant drive cannot rotate, the internal ring gear is rotationally grounded to the lower housing, so in consequence, the upper housing rotates on the upper wire race bearing and the prime drive pinion rolls around the internal ring gear. When the redundant drive is running, the prime drive is locked, consequently, the ring gear is rotationally grounded to the upper housing. Thus, the lower bearing rotates in the lower housing and the redundant drive pinion drives the ring gear and upper housing around.

The turntable is configured to be removable from below through the track base.

The drive hinge assembly contains two separate drives; the rollover drive for plane changing and the translation drive for moving in a straight line.

Figure 8 shows a side view of the rollover drive. It is a double-ended screw jack with a common, high precision, threaded, tubular shaft having two motor-driven planetary roller nuts running on it. One of the motor-driven nuts is gimbal mounted to the Transporter lower base structure, the other motor-driven nut is similarly attached to the drive hinge structure. The threaded shaft is prevented from rotating so that when either of the roller nuts is rotated, the threaded shaft is passed through that roller nut. The linear motion of the jack shaft is converted into rotary motion of the drive hinge by having the rollover hinge pivot offset from the jack shaft line of action.

Dual redundancy is achieved because either motored nut can rotate the drive hinge. The threaded jack shaft exterior is protected, over its ends, by tubular shields attached to the drive module housings and by an expandable metal bellows between the drive module housings. The two characteristics shown in Figure 8 relate jack output force to jack extension rate and output torque at the hinge pivot to the angle of rotation of the hinge. The shape of the second characteristic is so because the distance from the jack line of action to the hinge pivot changes as the hinge rotates.

Figure 9 is a composite view of the various translation drive components and the translation drive characteristic. The translation drive is a rack and pinion drive, the rack is attached to the underside of the track base along its full length. The rack has two rows of teeth, one prime and one redundant, with a full tooth depth separation groove between them. The bearing roller strips can be seen in Figure 9 attached to the track base. The rolling strips on the left hand longeron, as shown, only provide normal to plane location. The rolling strips on the right-hand longeron provide in-plane as well as normal-to-plane location by virtue of the vee roller arrangement and the two inclined strips on the underside. The rollers that bear on the rolling strips are mounted "fore" and "aft" on the drive hinge structure on a 40-inch stance to provide pitch stability for the track base.

The rollers that run on the upper bearing strips, as shown, are compliantly mounted to allow for manufacturing tolerances and differential expansion.

The translation drive has two separate drive modules attached to the drive hinge structure by rocking brackets mounted on a common pivot. Drive torque from the drive module is transmitted through a drive spindle and pinion to the drive rack. The drive pinion is held in mesh with the rack by a changeover actuator which pulls or pushes the relevant rocking drive mount over to its driving position. When the prime drive is engaged, the redundant drive is completely disengaged. If the prime drive experiences a complete mechanical failure, then the changeover actuator rotates the redundant

drive into loose mesh with the rack on the redundant tooth row, then rotates the prime drive completely out of mesh and then finally correctly meshes the redundant drive with the rack. This is accomplished by the changeover actuator interacting with cam profiles in the rocking drive mounts.

During its 30-year lifetime, the Mobile Transporter will experience 160,000 temperature cycles associated with orbital eclipses. Lubrication systems that would be used on geosynchronous satellite mechanisms have to withstand 3,700 temperature cycles for a 10-year lifetime. A low earth orbit spacecraft mechanism may have 11,000 cycles due to orbital eclipses. The Mobile Transporter is clearly in a different regime with regard to lubricant lifetime. Maintainability analysis, using such data that may be available within NASA from orbiter missions, will predict lubrication life and as a consequence, mean time between maintenance actions.

The above predictions will be verified by development testing to be performed during the design, development, test, and evaluation phase of the contract.

The Mobile Transporter lubrication concept is based on the use of Braycote grease. For the most part, the mechanisms are fully housed and sealed, the translation rack, however, is exposed. The volatility of the grease, albeit very low, may be such that some form of reservoir or replenishment method may be required. The reservoir may take the form of a sintered plastic pinion gear impregnated with grease or oil that is attached to the drive hinge and permanently runs on the rack. To aid deposition of the lubricant on the rack, the pinion could be heated to create thermal siphoning.

The Transporter instrumentation consists of resolvers in each drive module, an absolute encoder on the drive hinge axis for measuring rollover angle and geared encoders on the turntable and translation drive.

The translation geared encoder is a multi-turn encoder with a resolution of eight bits corresponding to 0.05 inches of linear displacement. The absolute position is determined by viewing four linear encoder tracks etched onto the track base with redundant reading heads.

The Mobile Transporter also has to detect which bay it is on at any time. Various methods of encoding truss locations and reading the codes will be studied. The possible coding methods may be optical, magnetic, capacitive or inductive.

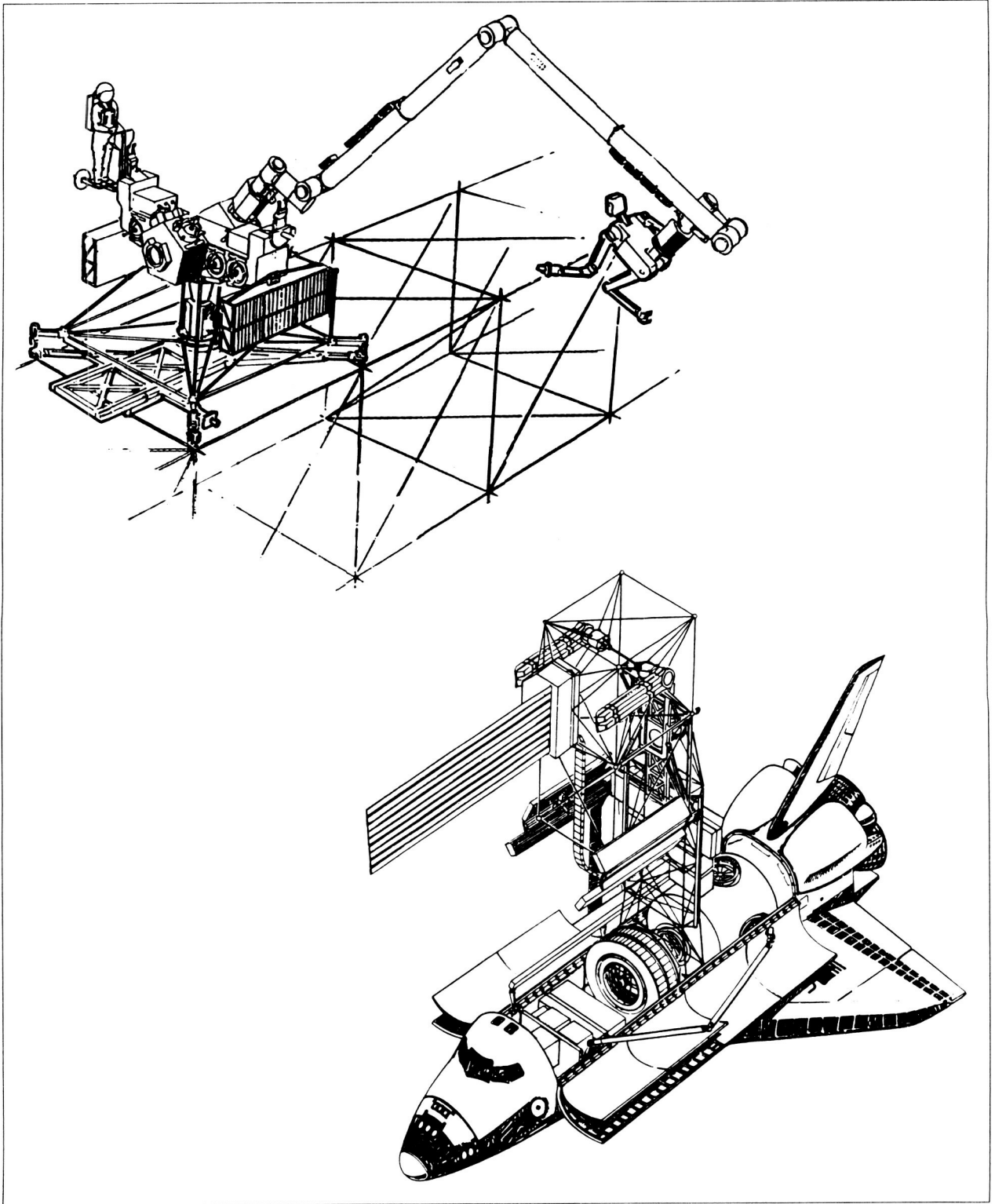


Figure 1. Transporter uses.

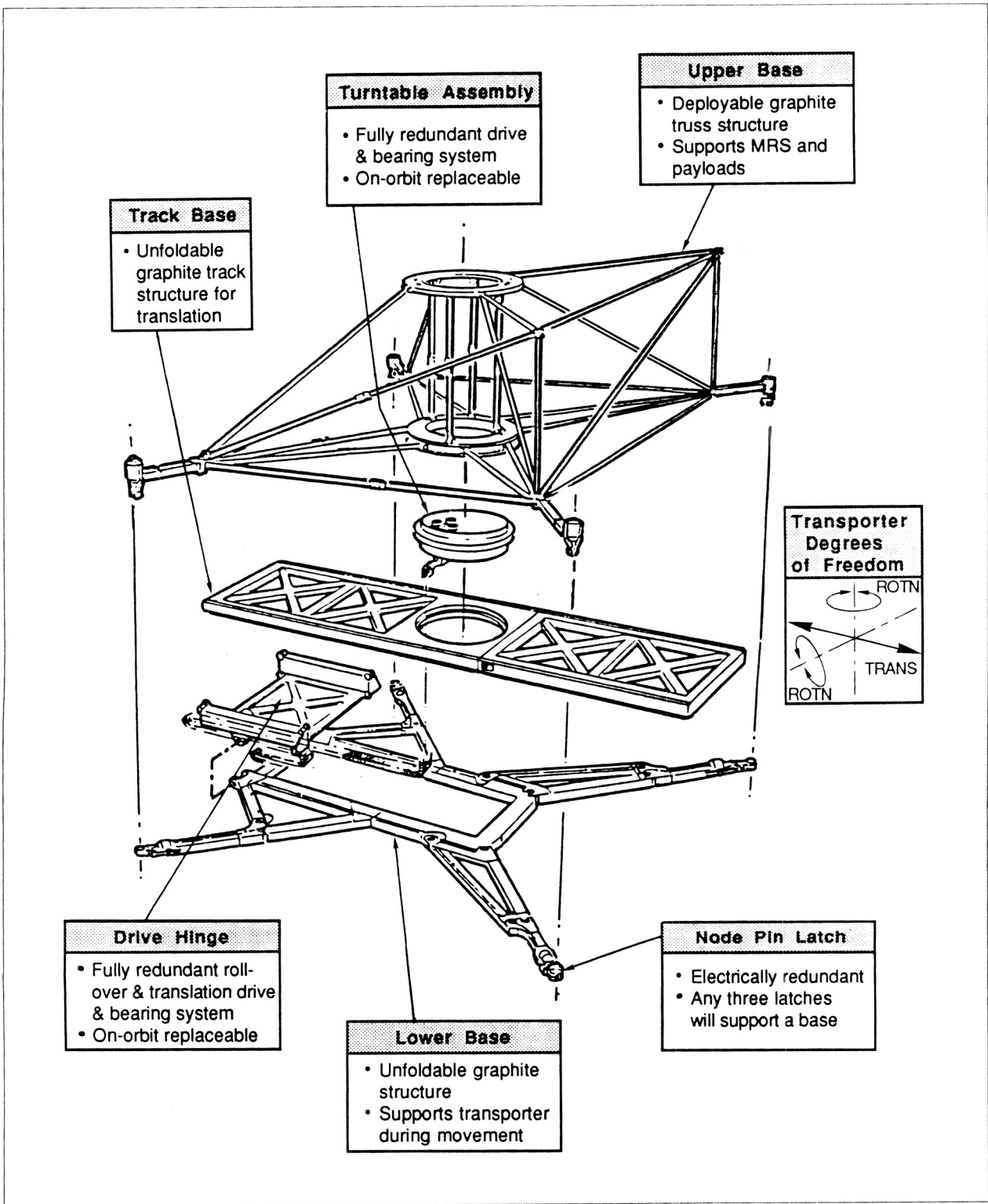
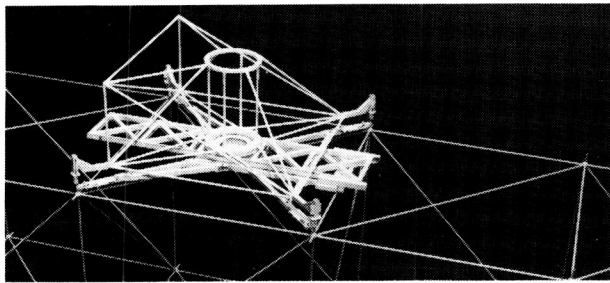
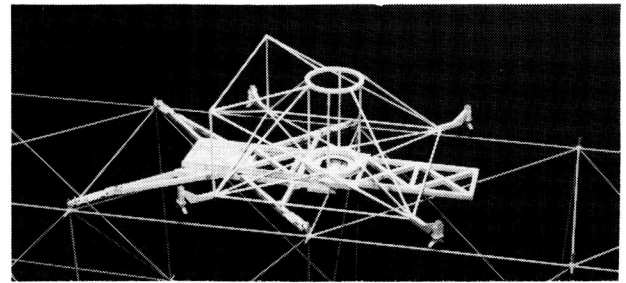


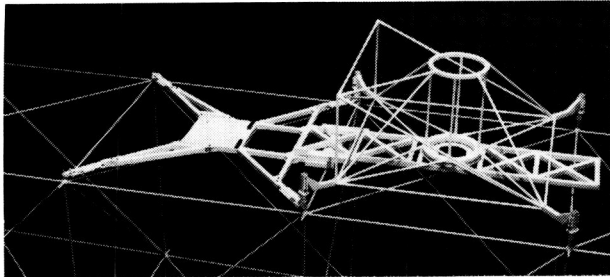
Figure 2. Transporter general arrangement.



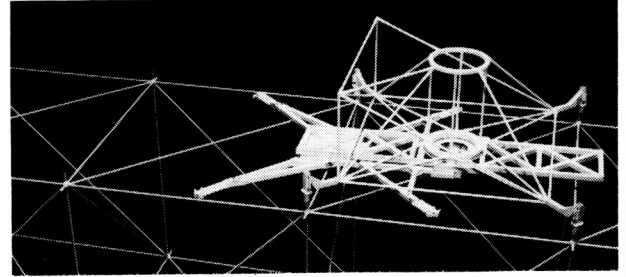
1. Both bases locked.



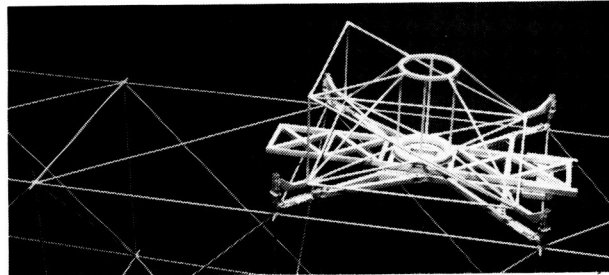
2. Upper base unlocked and moving.



3. Upper base locked down one bay ahead.



4. Lower base unlocks and moves.



5. Both bases realigned and relocked.

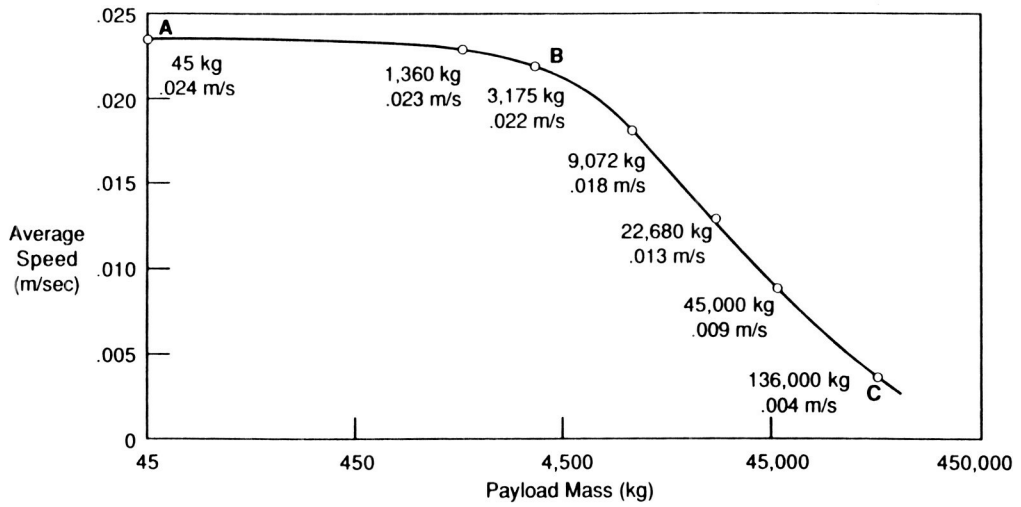
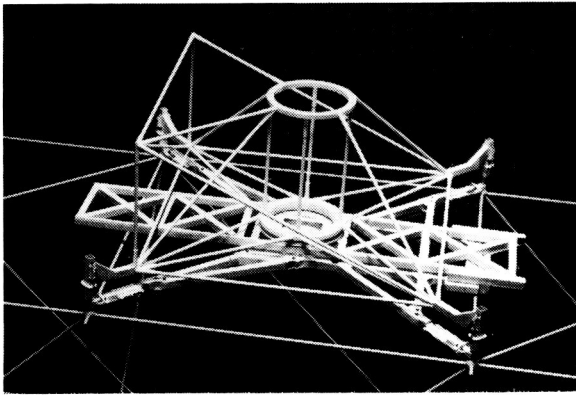
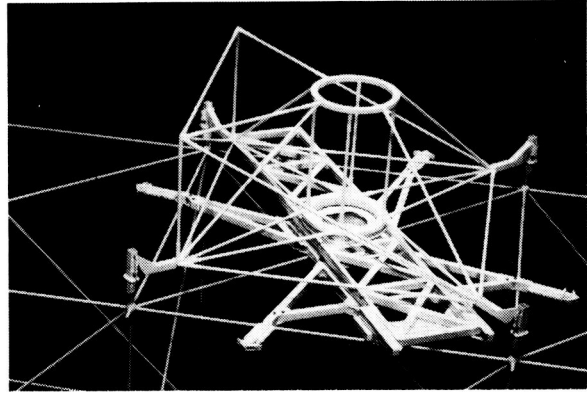


Figure 3. Translation motions and rates.

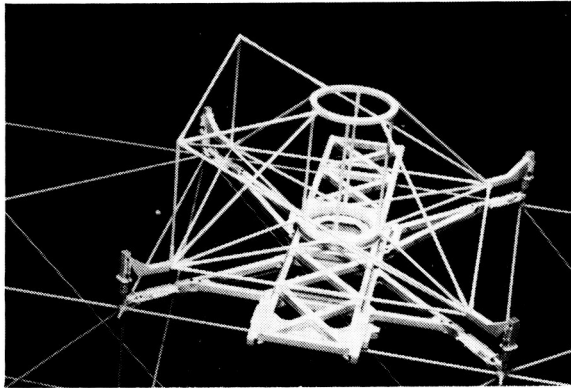
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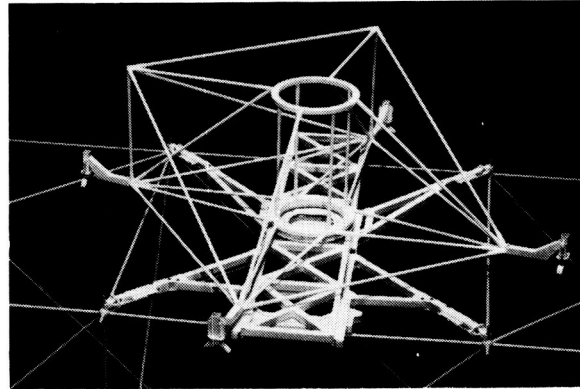
1. Both bases locked onto one bay.



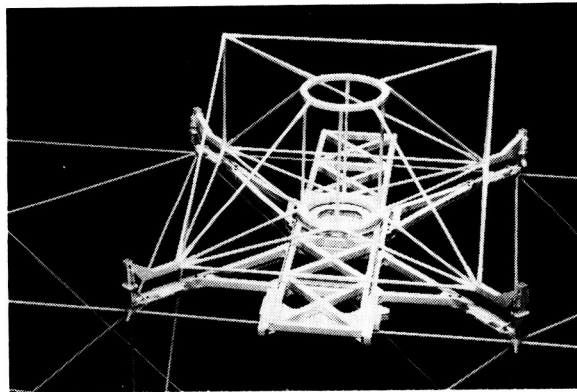
2. Lower base rotates.



3. Lower base locked down fully rotated.



4. Upper base rotates.



5. Both bases fully rotated.

Figure 4. Rotation motions.

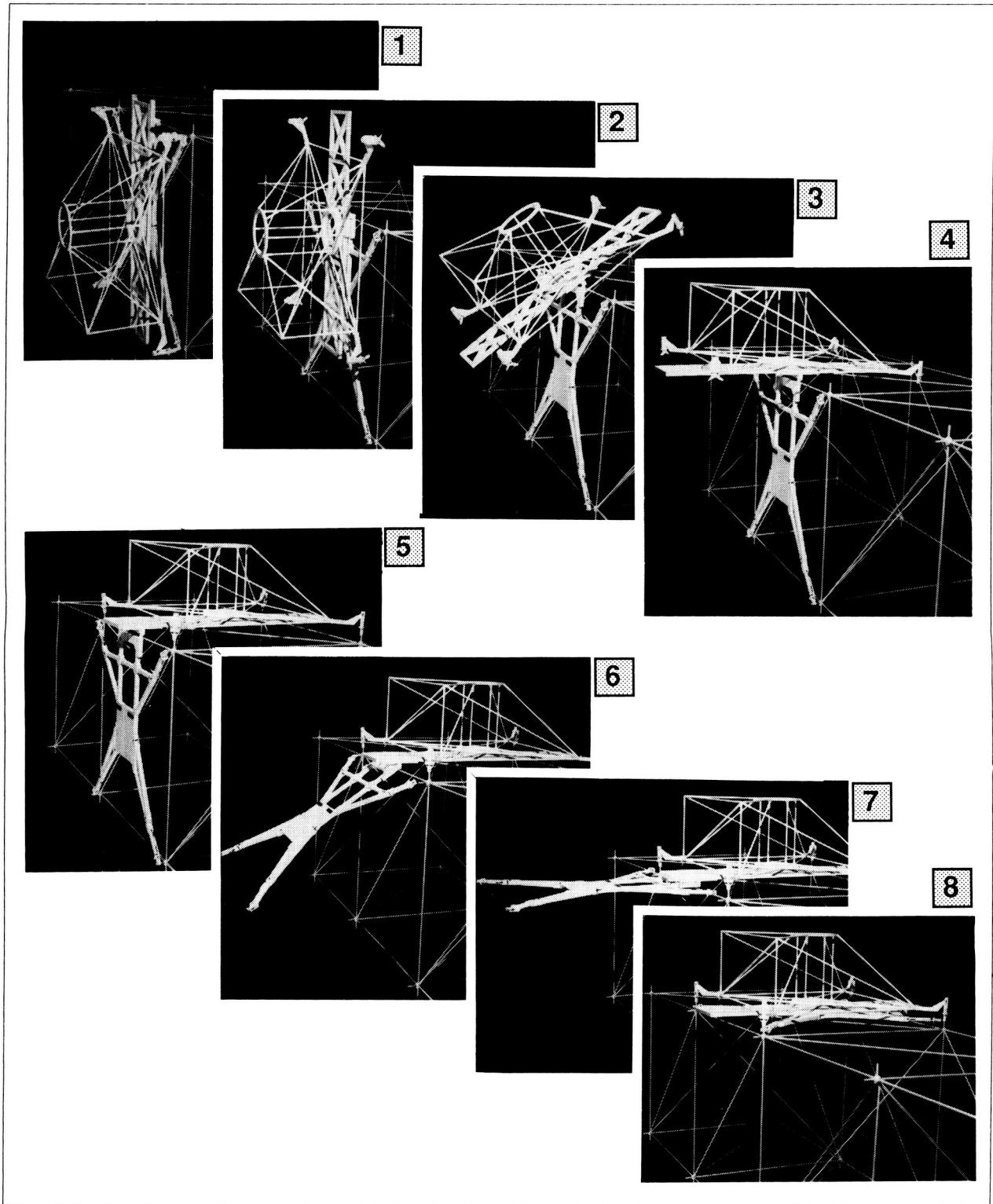


Figure 5. Plane change motions.

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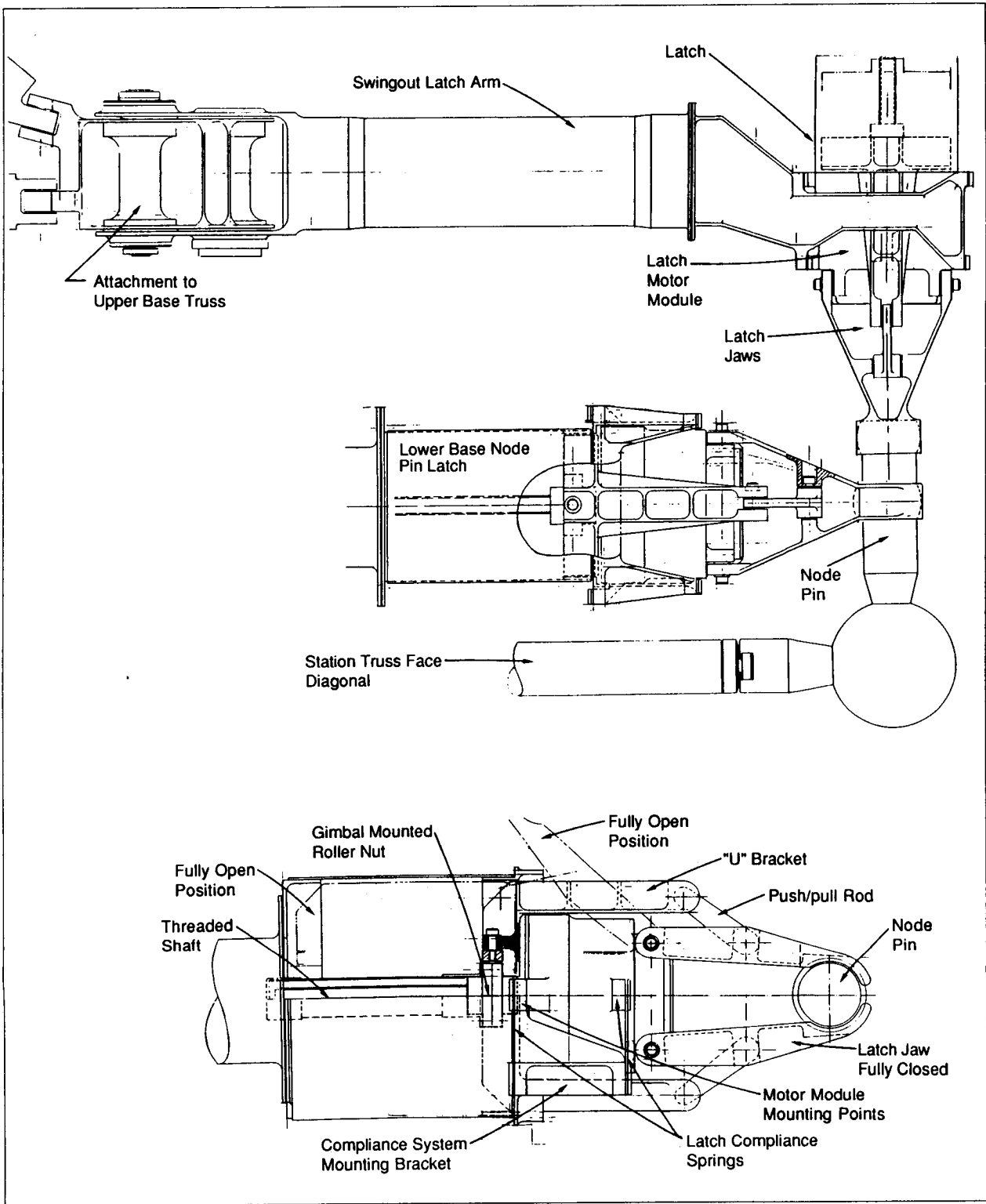


Figure 6. Node pin latches.

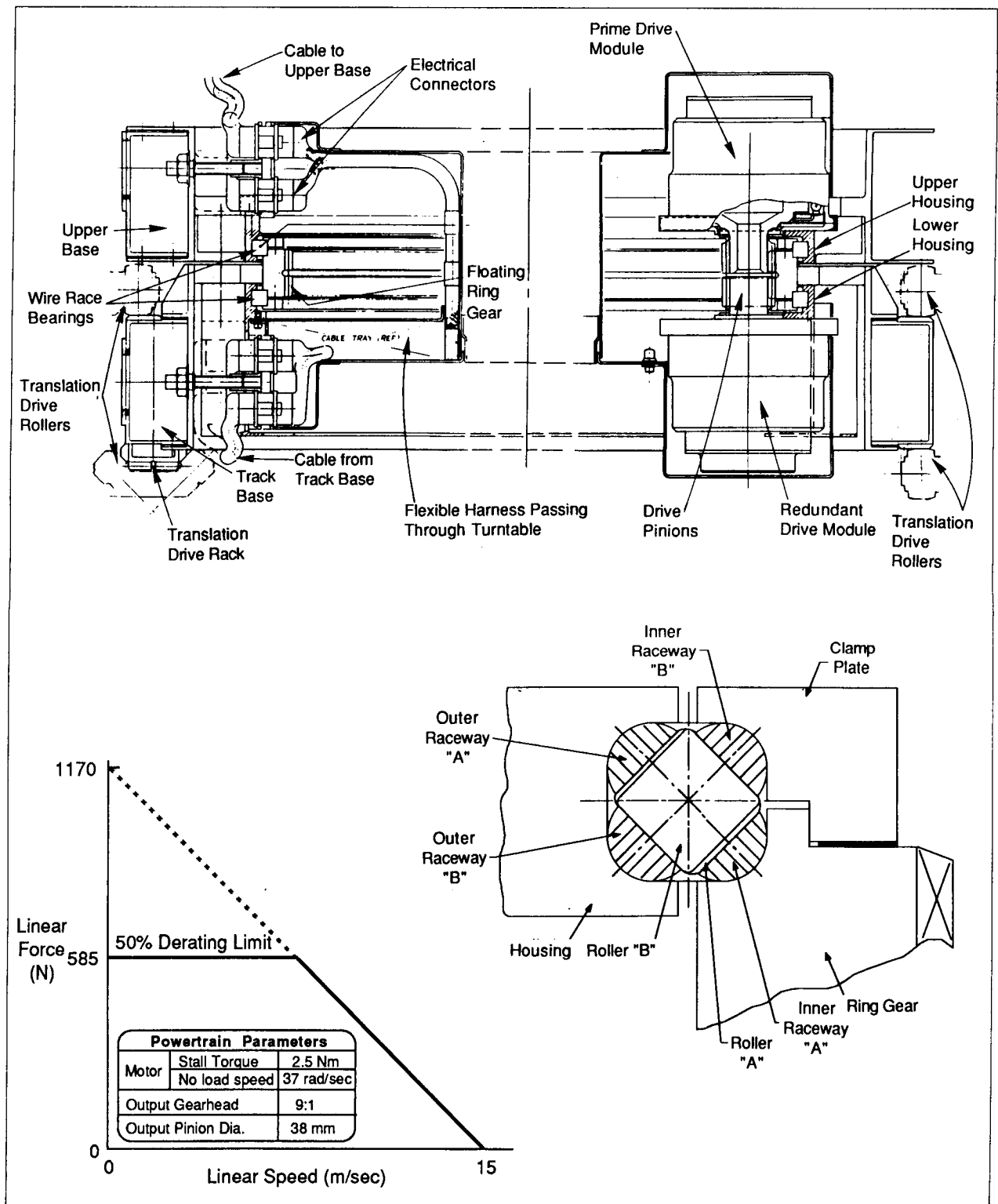


Figure 7. Turntable components and characteristics.

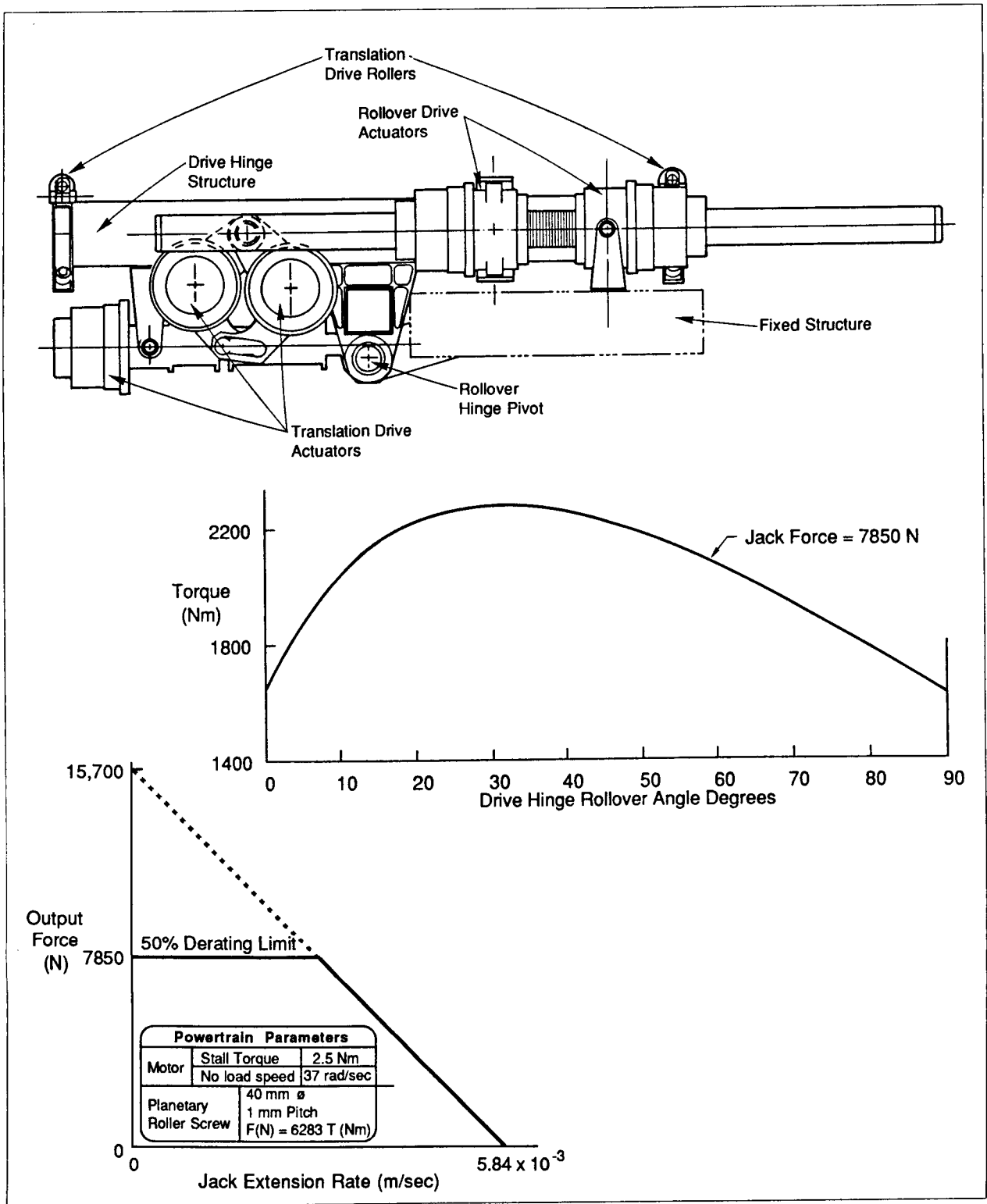


Figure 8. Rollover drive components and characteristics.

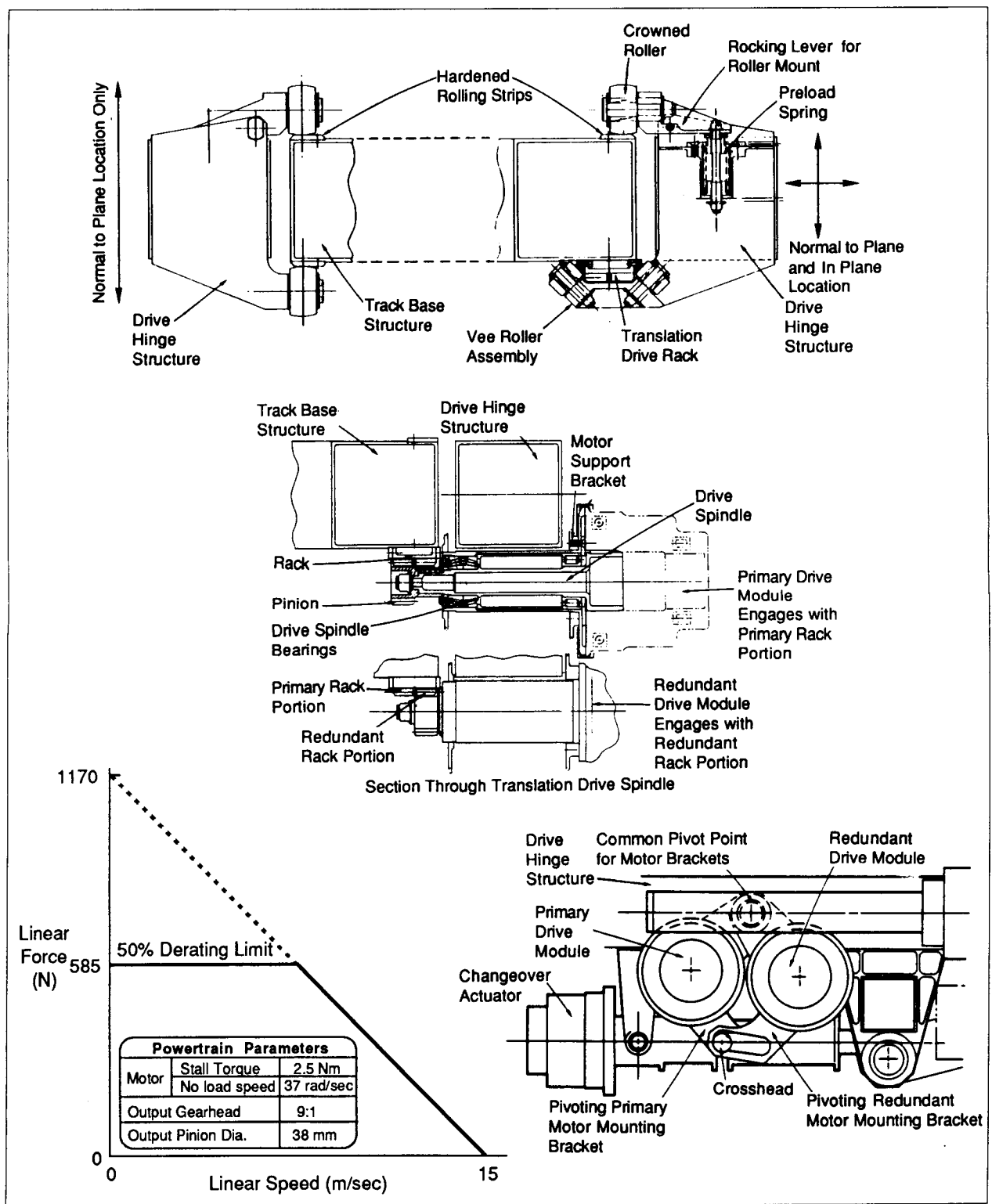


Figure 9. Translation drive components and characteristics.