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MANNED MANEUVERING UNIT LATCHING MECHANISM*

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INTRODUCTION

The Manned Maneuvering Unit (MMU) is a thruster type propulsion device which is being developed to provide maneuvering capability for an astronaut in the near vicinity of the Shuttle spacecraft. The device is worn on the astronaut's back just behind the Portable Life Support System (PLSS) backpack as shown in figure 1. The MMU can propel the wearer in any of three translational directions (fore and aft, left and right, and up and down) and any of three rotational directions (pitch, roll, and yaw). With this maneuverability, an astronaut can move away from the spacecraft beyond the reach of short tethers without relying on unmanageably long lifelines. This freedom will permit carrying out numerous tasks such as rendezvous and inspection of orbiting satellites as depicted in figure 2.

Such tasks will be feasible only if the MMU can demonstrate an acceptable degree of safety and reliability in performing its missions. But even more critical than reliability during a mission is the ability to remove the MMU when the mission is over. This is due to the fact that the spacecraft hatches are not large enough for an astronaut to pass through while wearing the MMU. The attachment latching mechanism must release with failsafe reliability so that reentry to the spacecraft can be accomplished when breathing air in the PLSS is expended.

In addition to the demanding requirement to both retain and release the MMU with failsafe reliability, the latching mechanism is required to perform its function under adverse environmental conditions. Temperature ranges encountered in orbit force the mechanism to accept dimensional variations due to differential expansion at all MMU/PLSS interfaces. Thermal differences also necessitate some control of heat transfer rates through the interface points. The hard vacuum of space permits cold welding or increased adhesion of parts in contact. Vibration and impact during operation tend to wedge clamping parts more tightly together.. In addition, the astronaut is confined to a restrictive space suit which limits hand and arm movements and field of vision.

DESCRIPTION OF LATCHING MECHANISM

The latching mechanism which has been developed to overcome the difficulties described above is a spring-loaded cam segment with a variable ratio pulley and cable release. The spring-loaded cam segment is functionally similar to an

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*A portion of this work - the release actuator - was performed under contract to Pan American by Mr. Sonne L. Hooper.

ordinary household door latch. As shown in figure 3, it is mounted in the MMU and retracts against a torsion spring when a striker plate on the PLSS moves past. As the PLSS approaches its proper position, the contact surface of the segment rotates into the striker plate until contact is made, locking the PLSS in place. Since the contact surface of the segment is cammed, some variation in relative position of striker plate and segment is allowed. This permits reasonable tolerances in the manufacture of both PLSS and MMU while still providing the needed rigidity between the two units when they are connected. The take-up characteristic of the cam surface is important in maintaining complete interchangeability among all PLSS units and all MMU units.

The striker plate, detailed in figure 4, is a hardened rectangular block with an open-ended slot facing forward. One striker plate is mounted in each side of the PLSS in a recess in the side face. The contact surface is machined at the appropriate angle to make contact with the cam segment contact surface. The striker plate/cam segment interface functions as a retention mechanism to prevent relative motion of the PLSS in a forward direction and in the side-to-side and up-and-down directions. The PLSS is seated against an MMU surface at its back face so that the striker plate does not have to provide retention of the PLSS for backward movement.

The release actuator consists of a variable ratio pulley connected by a cable to the cam segment. The variable ratio feature is achieved by bolting together two separate pulleys, each of which has a cammed drum surface as shown in figure 5. The pulley ratios are such that an approximate five-to-one mechanical advantage exists at the beginning of the release action to give the astronaut extra force for disengaging the cam segment in case it is jammed. When the initial friction has been overcome and fast rotation of the cam segment is desired, the variable ratio decreases smoothly until it reaches approximately one-to-one. This provides more travel of the cam segment for each increment of actuation motion. The configuration at the beginning and end of the release motion is shown schematically in figure 6. It can be seen that the tangent point of the cable on the driver cam is at a distance r_1 from the center and that this distance is roughly five times the distance r_2 of the tangent point of the cable on the driven cam at the beginning of rotation. At the end of the rotation, distances r_1 and r_2 are approximately equal.

Figure 7 shows the complete latching mechanism with cam segment and variable ratio pulley. Also shown are the small pulley, the tensioner link, and the pull ring which actuates the release. The small pulley located near the cam segment serves only to turn the cable. The tensioner link located between the small pulley and the cam segment permits the cam segment to be depressed without loss of tension on the retraction cable. The tensioner link has its own torsion spring so that its motion is independent of the cam segment. The retraction cable is connected directly to the tensioner link, not the cam segment. The cam segment can rotate back through the tensioner link without moving it but when the tensioner link is retracted by the retraction cable it pulls the cam segment along with it. This is significant when the PLSS is in the process of entering the MMU. At that time, the cam segment can be depressed back out of the way without creating slack loops in the retraction cable.

The pull ring located near the variable ratio pulley is sized to receive the astronaut's gloved finger. A ramped relief pocket behind the pull ring provides a guided clearance surface for easier access and also permits the pull ring to be partially recessed to minimize inadvertent snagging. The back side of the pull ring is attached to two pull cables which maintain the horizontal alignment of the ring when it returns to its seated position. To receive the two pull cables, two driver pulleys are used on the variable ratio pulley rather than one. However, only one driven pulley is required. The variable ratio pulley is spring loaded by a torsion spring so that the pull ring returns to its seated position.

A complete latching mechanism with all the above described components is installed on each side of the MMU. Both mechanisms must be engaged to secure the MMU for operations and both segments would normally be disengaged to release the MMU. If one mechanism should jam or fail in any way to release, the astronaut can still remove the MMU by releasing only one mechanism and rolling out of the MMU in a side-to-side rotation, bypassing the jammed latch.

This rollout option is only one of several design precautions taken to reduce the risk or the consequences of a possible jam at the cam segment/striker plate interface. Other precautions include the variable ratio pulley release actuator, hard spring bearing points, and a nonstandard set of material selection criteria. The variable ratio pulley, described earlier, attempts to mechanically overcome a jam after it occurs. Hard spring bearing points are mounted in the MMU where the back side of the PLSS makes contact. These bearing points remain stationary under normal clamping loads, but yield slightly if a maximum established load is reached due to thermal expansion or vibration. This yielding effectively limits the buildup of forces at the cam segment/striker plate interface. Material selection was carried out with the objective of precluding excessive adhesion or cold welding of the cam segment to the striker plate.

MATERIAL SELECTION

Adhesion or cold welding is a concern since the cam segment and striker plate are in direct contact with each other, loaded with a substantial clamping force, and required to separate by tangential sliding. Candidate materials were chosen which were expected to have some resistance to cold welding. The susceptibility to cold welding is determined by such parameters as hardness, melting point, shear strength, effect of coatings and corrosion films, effect of alloying elements, response to load, and response to contact duration. Once the candidate materials were selected, they were subjected to friction testing in various combinations. Friction testing was necessary since a high coefficient of friction between cam segment and striker plate would constitute an adhesion problem.

Results of the friction testing are charted on figure 8 where coefficients of friction are plotted for eight materials in sixty-four combinations. Each combination consists of a pair of materials, one of which would be used for the cam segment and the other for the striker plate. As the graph shows, coefficients ranged from 0.18 to 0.47. The higher values were undesirable because they would result in higher forces required to disengage the cam segment. Extremely low values, however, were also undesirable since coefficients approaching 0.10 would result in a tendency for the cam segment to slip out of the latched position. This slippage would be due to a small tangential component of the clamping force which occurs on a ramped surface. A certain amount of surface friction is necessary to hold the cam segment in place. Friction coefficients within the range 0.18 to 0.20 were considered ideal and, as can be seen from the graph, 15 pairs of materials fell within the ideal range.

To further narrow the field of candidate pairs of materials, other design considerations were used in addition to the adhesion or friction characteristics. These considerations included thermal conductivity, weight, machinability, cost, and wear. Of these factors, only thermal conductivity proved to have any real influence - this due to a concern over thermal leakage between the MMU and the PLSS. Other interface points are insulated to some extent, but the cam segment/striker plate contact surface has to be metal-to-metal contact. A low thermal conductivity for at least one member of the pair is an advantage in reducing thermal leakage problems. Of the candidate materials, titanium had a significantly lower conductivity and the friction testing showed that, used as striker plate material, titanium was a member of several pairs in the ideal range. The cam segment material, stainless steel 17-4 PH, was selected based on factors enhancing the resistance to cold welding.

OBLIQUE ENTRY WEDGING PROBLEM

Although no instances of cold welding, adhesion or friction have occurred as yet, a wedging problem was recognized early in the development of the cam segment. As illustrated in figure 9, an oblique entry into the MMU can result in only one cam segment engaging at first. Further entry requires rotation of the PLSS in the clockwise direction which results in wedging. This could prevent adequate engagement of the opposite cam segment or it could result in too great a clamping force at the wedged side of the PLSS.

The problem was overcome by the addition of hard springs to the bearing points. The springs limit the wedge force that can be built up at the end of the PLSS positioning motion. As mentioned earlier, the hard spring bearing points were found to also serve as clamping load limiters for thermal expansion or vibration induced wedging action, but they were originally added to solve the oblique entry wedging problem.

MECHANISM TESTING

The oblique entry wedging problem was discovered during routine tests on a two-dimensional mockup of the latching mechanism. Extensive testing in the form of higher fidelity mockups has also been conducted in order to thoroughly evaluate the functioning of the mechanism. A high fidelity MMU mockup has been manufactured which contains cam segments made of the correct material and several prototype PLSS units exist which have striker plates also of the correct material. These units have been fit and function tested using both test subjects and astronauts in spacesuits in donning and doffing tests. Ambient conditions consisted of normal earth air pressure, temperature, and gravity in most cases, but some testing has been done in simulated zero gravity.

Two methods are available for simulating the weightless aspects of zero gravity. One is flight in a specially rigged KC-135 aircraft along a parabolic flight path and the other is underwater neutral buoyancy testing. The latching mechanism has been tested by both methods. In the aircraft, periods of near zero gravity are limited to 30-45 seconds but a fairly realistic donning or doffing procedure can be completed. Vacuum and temperature conditions such as would be found in orbit are not simulated on the aircraft. Underwater neutral buoyancy testing is carried out in a large water tank with special underwater versions of the MMU and PLSS. There is no time limitation on these tests, but friction characteristics are not realistic with the surrounding water acting as a possible lubricant. And some fluid drag can be expected to alter slightly the dynamics of moving parts such as spring returns. In addition, vacuum and temperature conditions are again not simulated in underwater testing.

In fact, no testing has as yet been done which does simulate the hard vacuum or the extreme temperatures which would be present in orbit. However, all testing and evaluation of the latching mechanism which has been conducted thus far has been considered successful. The current materials may be changed if further testing indicates a risk of adhesion problems under orbital conditions.

CONCLUSION

The astronaut/Manned Maneuvering Unit interface has presented a challenging set of requirements for a latching mechanism. The mechanism must hold reliably and release on demand to avoid jeopardizing the safety of the astronaut. It must perform its function under adverse environmental and operational conditions. The spring loaded cam segment with variable ratio pulley release actuator has been developed to meet these demanding requirements. To preclude jamming of the mechanism special precautions have been taken such as spring loaded bearing points and careful selection of materials to resist cold welding. The mechanism has successfully passed a number of tests which partially simulated orbital conditions.

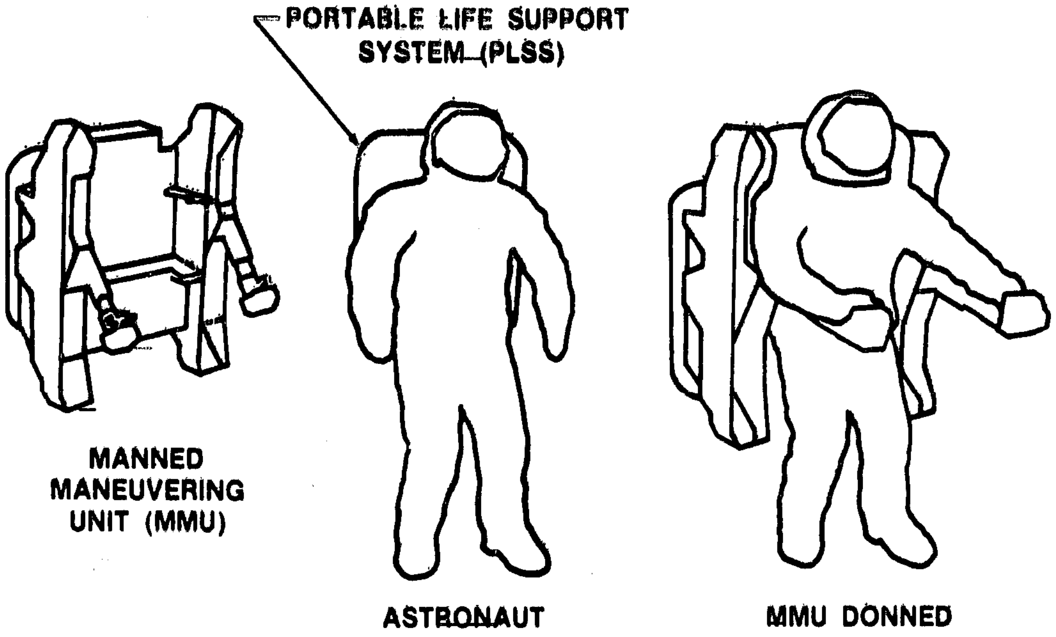

Figure 1.- Manned Maneuvering Unit.

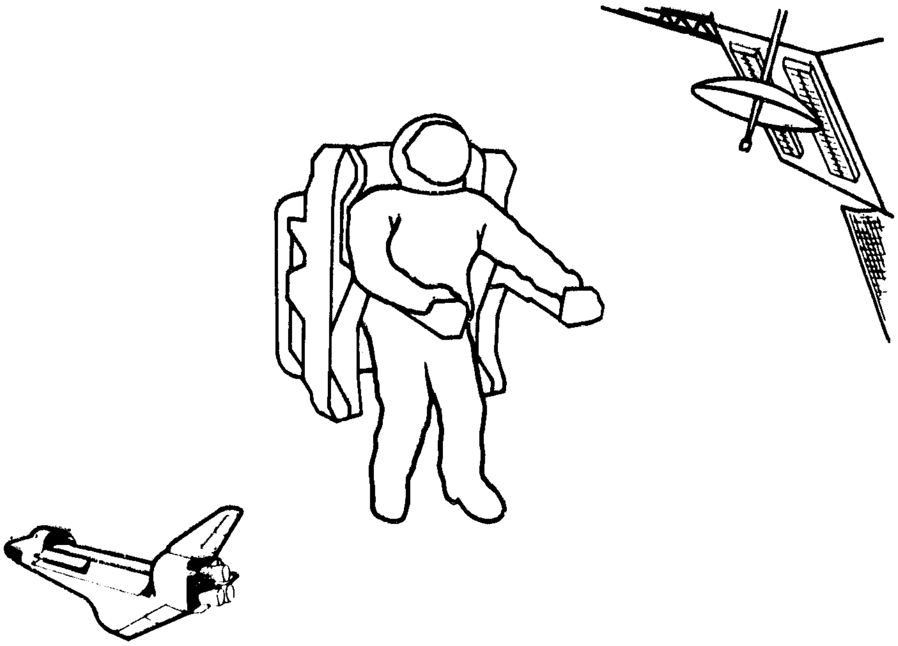

Figure 2.- Operational use of the Manned Maneuvering Unit.

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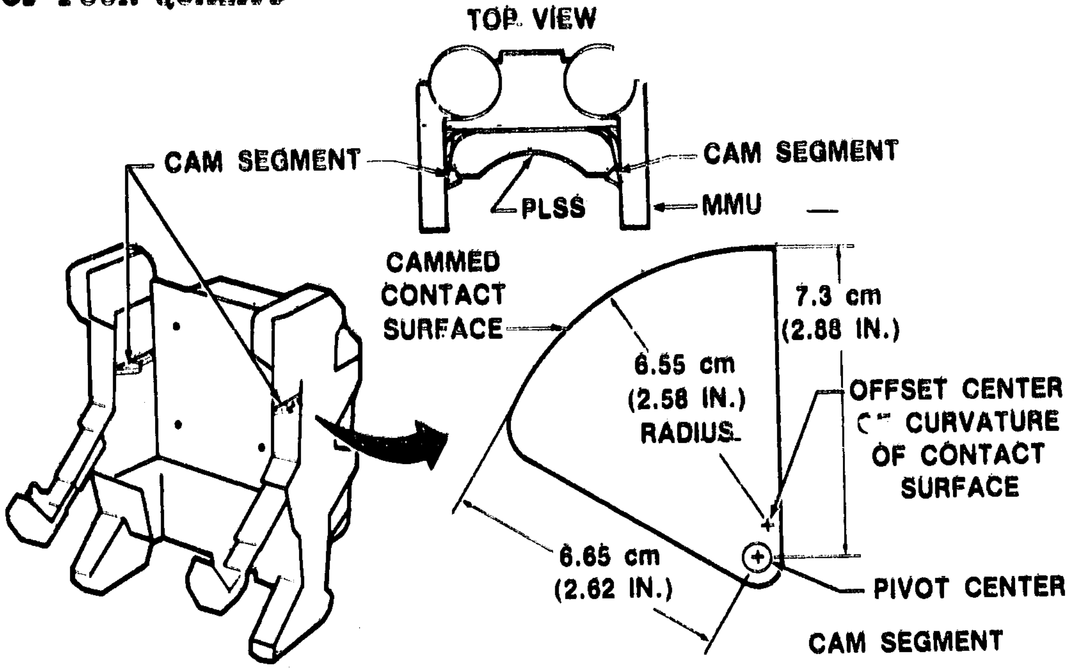

Figure 3.- Cam segment.

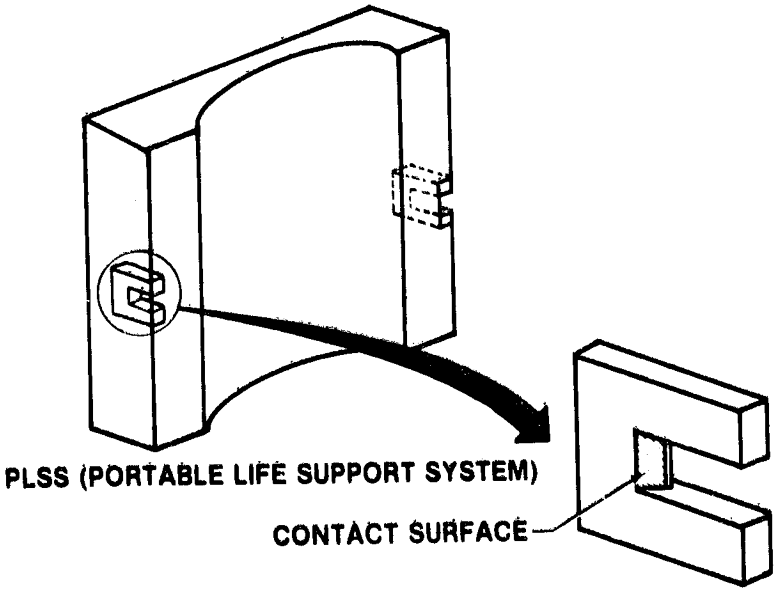

Figure 4.- Striker plate.

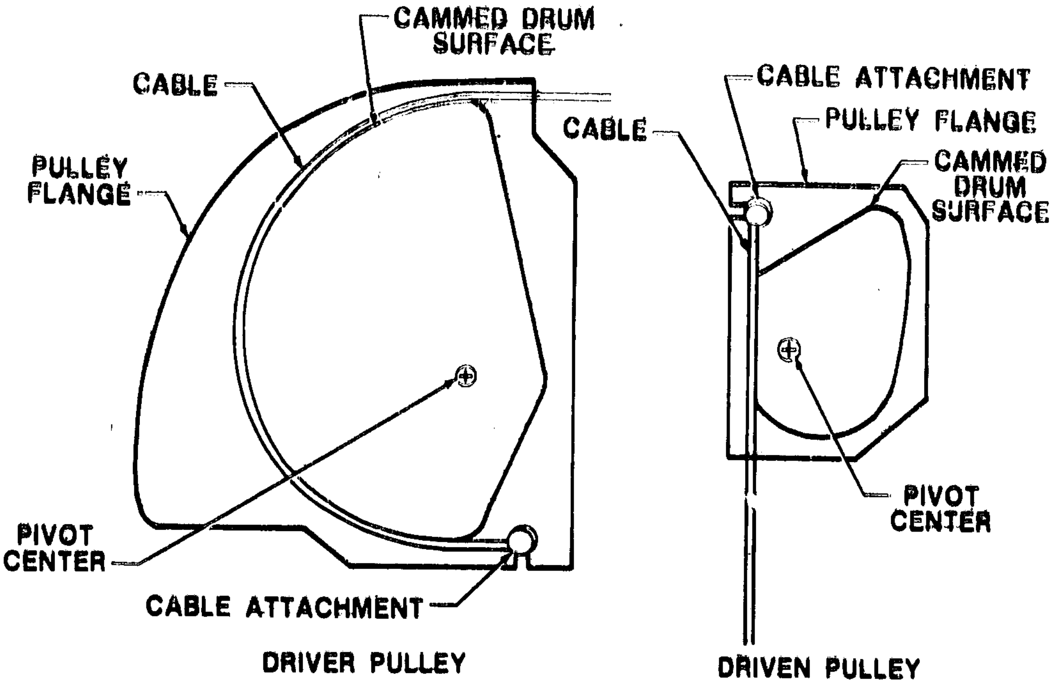

Figure 5.- Release actuator driver and driven pulleys.

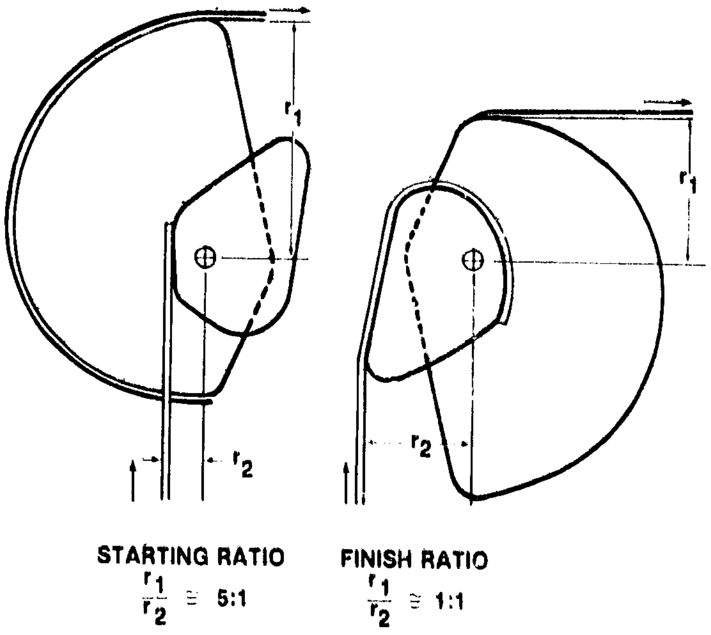

Figure 6.- Release actuator ratio variation.

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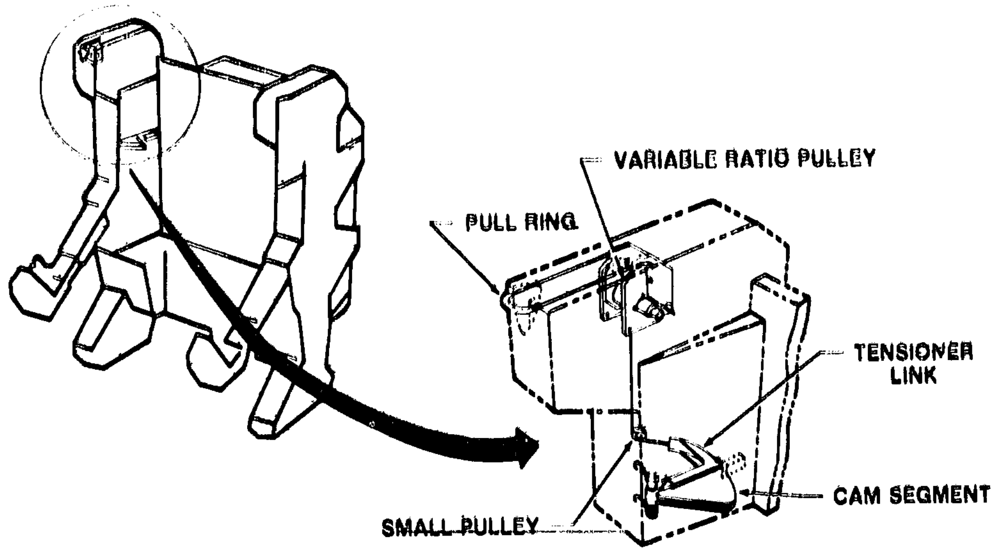

Figure 7.- Latching mechanism with release actuator.

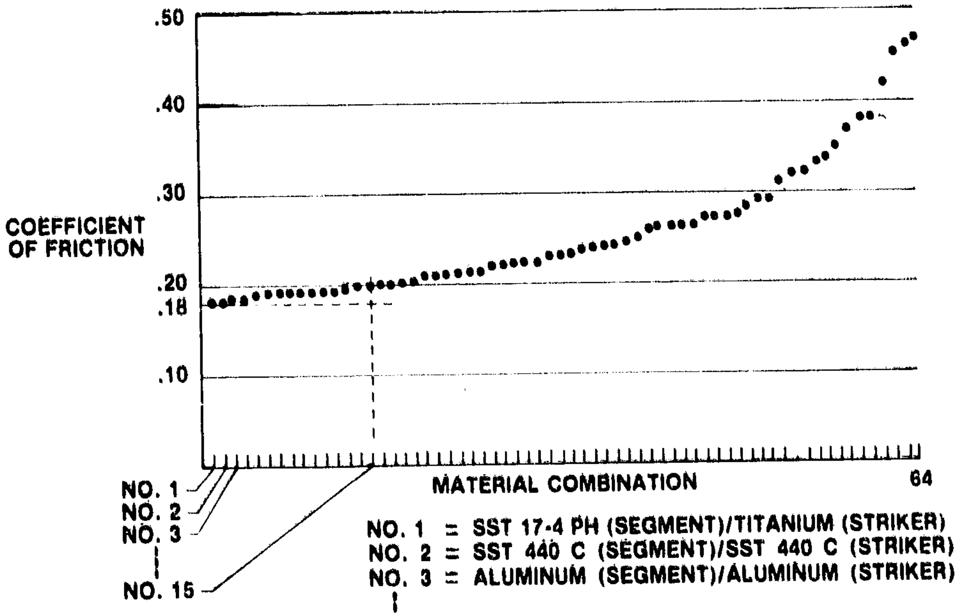

Figure 8.- Friction coefficients of material combinations.

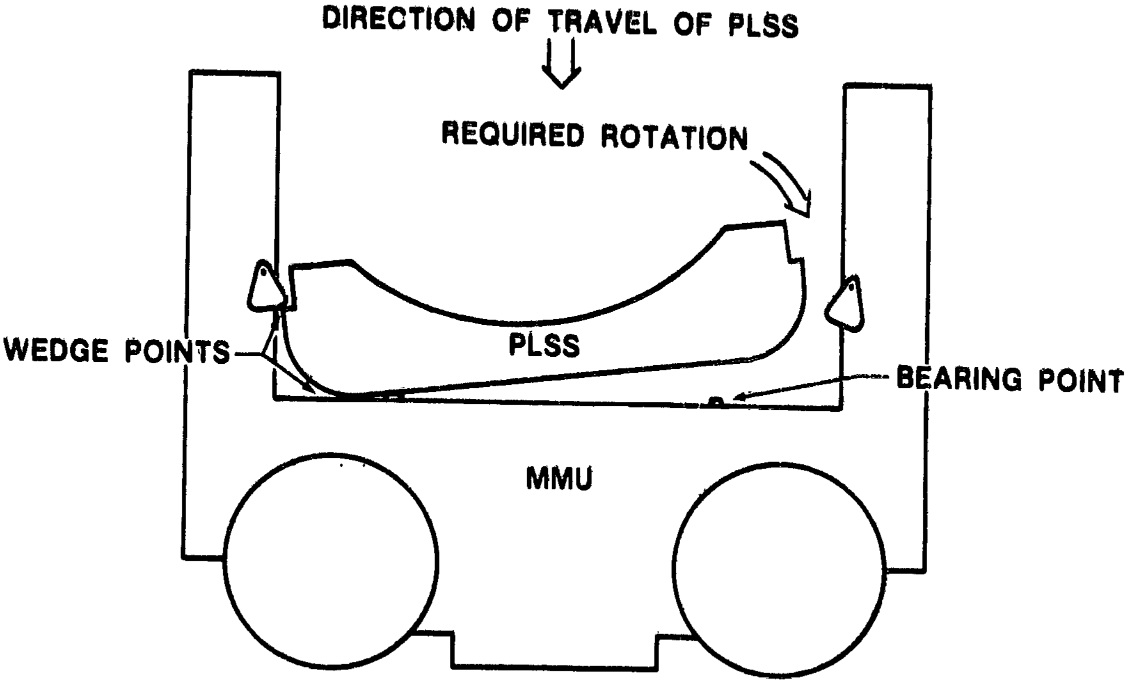

Figure 9.- Wedging problem due to oblique entry.