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THE EVOLUTION OF A RELEASE-ENGAGE MECHANISM FOR USE ON THE ORBITER

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ABSTRACT

The Release-Engage Mechanism (REM) is designed to secure a deployable payload in the orbiter during launch and to enable the payload to be released, deployed, and reattached for re-entry.

This paper presents the following: (1) the initial design concepts of the Release-Engage Mechanism; (2) the problems encountered during assembly, (3) the abnormalities that occurred during vibration testing, (4) the incompatibility of the Remote Manipulator System and REM operation, and (5) the resulting modifications to the REM that assured its successful performance on two Shuttle flights.

INTRODUCTION

In the development of payloads for the Space Transportation System, it was found that a mechanism would be required that could secure a deployable payload in the orbiter during launch, release the payload upon reaching orbit to permit acquisition of scientific data, and re-secure the payload for re-entry.

The requirements for this mechanism provided many new and unique design problems, one of which was a connection that could safely secure a large payload during launch but could be easily separated upon reaching orbit. The basic concept selected was to insert and retract a pin from a matching hole in mating pieces. The hole was an integral part of a supporting structure. The pin was attached to the payload. The mechanical action of inserting and retracting the pin was accomplished by motors and driving linkages that were part of the supporting structure.

The mechanism also had to have an operational capability compatible with the Remote Manipulator System (RMS). The RMS was used to deploy, maneuver, and berth the payload. When the initial concepts for the REM were being conceived, RMS operational data was not available.

ORIGINAL REQUIREMENTS

The original requirement for the Release-Engage Mechanism (REM) was for it to be used with the Induced Environmental Contamination Monitor (IECM). The IECM is a deployable

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scientific package that will detect and map contaminants in and around the cargo bay of the orbiter. The IECM takes data while attached to the orbiter and while being maneuvered by the Remote Manipulator Arm. The IECM is rectangular, 1.23 meters (48.5 inches) long, 0.85 meters (33.5 inches) wide, by 0.77 meters (30.57 inches) high, and weighs 370 kilograms (816 pounds).

The REM has three interfaces: (1) structural interface with the IECM; (2) structural interface with the orbiter support structure, in this case the development flight instrumentation pallet; and (3) operational capability of the Remote Manipulator System (RMS). The positional accuracy of the RMS was ±5 centimeters in any axis from a given point and one degree of rotation about any axis.

The IECM/REM Assembly was designed for the following load requirements:

IECM/REM LOAD FACTORS

x	+4.5	−0.4
y	+3.3	−3.3
z	+3.5	−3.1

ORIGINAL DESIGN CONCEPT

The design concept selected for development (figures 1a, 1b, and 2) had the following major design features: (1) two deployable rails, forward and aft, bolted to the payload (each rail had two structural pins, one round and one square); (2) motors, gear train and linkages which provided the latching and securing force for the payload; (3) an electrical feed-through system for the payload; and (4) the center frame or mounting structure. The center frame provided the four mating holes (nut plates) for the structural pins on the deployed rails. The center frame also provided a large flat surface area used in berthing the payload. Five position indicator switches were included as a design feature of the center frame. When actuated, these switches indicated that the payload was in a ready-to-be-latched position.

DESIGN CONSIDERATIONS

The structural pin-nut plate interface was of primary concern during the initial design effort. This interface provided the structural load path between the payload and Shuttle during launch and re-entry. It also had to be capable of separating and remating in orbit. Figure 3 shows the structural pins in the nut plates with the IECM installed.

Clearances between the pin and nut plate had to be kept small to minimize shock loads to the payload during vibration testing and launch and to provide a firm load path between the payload and orbiter.

It was realized that unnecessarily small clearances between the pin and nut plate would require the four pins to be manufactured, assembled, and maintained in near-perfect alignment so the pins could be mated with their respective nut plates. The alignment problem was complicated by the requirement that the payload and rails must be deployed in orbit, subjected to a changing thermal environment and, therefore, configuration distortion outside the orbiter bay. The four pins had to remain in alignment so they could be re-inserted into their respective holes for re-entry. A clearance of 0.02 millimeter (0.0008 inch) was selected. The transfer of metal between the pin and nut plate during vibration was also of concern.

The material selected for the initial pin-nut plate design was chrome-plated, 4130 steel heat-treated to 160 ksi for the pin and 301 stainless steel for the nut plates. Two different shapes for the structural pins were selected, one cylindrical and one square. The cylindrical shape could transmit load in two directions. The square pin, when mated with a rectangular hole, would allow for uneven thermal expansion/contraction between the payload and REM center frame in a horizontal or x-axis direction. A 0.16 centimeter (0.06 inch) gap was allowed. The 0.02 millimeter (0.0008 inch) clearance was maintained in the vertical or z-axis direction. A 0.32 centimeter (0.125 inch) gap between the aft deployable rail and its mating nut plates was specified to allow for the payload contraction in the y-axis direction.

The mating or sliding surfaces of the pin and nut plate were highly polished to reduce friction forces and make the latch/unlatch smooth. No lubrication was used between the sliding surfaces of the structural pin and nut plate.

The berthing procedure for the deployed payload was for the RMS to place the sliding surfaces or three feet of the deployed rails on the designated areas of the center frame (figure 1) and slide the rails against the side fence and forward into a ready-to-latch position. At this time, the five ready-to-latch switches would give an indication that the payload was within 0.25 centimeter (0.1 inch) of the desired position. A latch command could then be given. The above procedure was required to allow the RMS to position the pins into the required alignment to enter the nut plates. The latching action, a forward movement of 3.5 centimeters, mated the pins into the nut plates and also made the electrical feed-through connection for the payload.

The gear train (figure 4) has redundant motors driving through a series of spur gears, a differential and worm/worm gear final drive. The gear train has a reduction of 2812 to 1. A motor torque of 2.4 kg-cm (34 in-oz) produces an output torque of 31.8 kg meters (230 ft lbs). The motors have an integral spring-loaded brake that prevents the latching system from being back-driven, although the final worm/worm gear absorbs much of the back-drive load. The gears are lubricated with Brayco grease 3L-38RP. The gear train is thermally isolated, and heaters are used to keep the grease from solidifying. The heaters assure that the gear train will operate at low temperatures. The gear train rotates a bell crank. This movement, transmitted through a solid adjustable link-and-latch link, pushed the pins on the forward rail into their mating holes. Figures 5a and 5b show the latching linkage in unlock and lock positions, respectively. The latch/unlatch indicator switches serve two purposes: (1) they indicate to the REM operator the status of the payload and (2) they automatically cut power to the gear train motor when the bell crank reaches the desired position. The adjustable link provides the means of equalizing the pre-load between the round and square pin.

During a study made of the locking linkage kinematics, it was noted that the two latch links rotated different amounts for the same bell crank rotation (figure 6a). A close examination revealed that one latch link traveled approximately 0.5 centimeter farther than the other during latch/unlatch operations. This uneven travel resulted in only one latch link being in contact during latch/unlatch operations. An adjustment was available so that each latch link would apply equal force when the payload was in the latched position. Because of the spacing of the structural pins and aligning restraints provided by the center frame, this uneven movement was not a problem.

After assembly, the unit with the IECM installed was subjected to three axes of vibration testing. A latch/unlatch cycle was attempted between each axis of testing. The structural pins could not be retracted from their mating nut plates after each vibration test. A fine black powder was generated by the chrome-plated pins abrading the stainless steel nut plates. The powder generated was enough to close the 0.02 millimeter (0.0008 inch) gap between the pin and nut plate and cause binding. The problem was corrected by increasing the gap to 0.076 millimeter (0.003 inch) and by adding Brayco 3L-38RP grease to the interface. The vibration tests were then successfully completed.

During a thermal vacuum test to determine the REM lower operational temperature, it was found that, at temperatures below -125°F, the grease used on the structural pins solidified to such a degree that an unlatch/latch operation could not be performed. At the time the thermal vacuum test was performed, this operational temperature was acceptable.

To determine if the RMS could perform the berthing procedure for the payload described earlier and place the payload in the required ready-to-latch position, the REM was shipped to Johnson Space Center for testing in the Manipulator Development Facility (MDF). The berthing procedure required the RMS to place the payload and deployed rails on the surface of the REM, and while maintaining contact with the REM surface with the three berthing feet, move the payload 15.2 centimeters (6 inches) in the x-direction, and then, upon making contact with the side fence, move the payload 15.2 centimeters (6 inches) in the y-direction. The berthing procedure was performed by the RMS operator viewing the operation on two closed circuit television monitors.

Several problems were identified during these tests. It was found that, when the payload deployed by the RMS was constrained from movement in one direction, accurate control of the payload could not be maintained in the other direction. With the RMS arm in some positions, and the payload constrained in one direction, a command to move in one direction would result in payload movement in the opposite direction. As stated, the payload had to be moved 30.5 centimeters while maintaining contact with the three berthing feet on the center frame surface. This requirement for constrained movement and the friction force of the feet sliding on the center frame surface transmitted to the RMS made this procedure undesirable. Complicating the procedure further, the feet could not be seen by the television cameras with the payload installed. This made the movement of the payload into the required latching positior difficult. The close positioning, 0.25 centimeter (0.1 inch) required to close the ready-to-latch switches was also very difficult and sometimes impossible to obtain.

Several times during berthing attempts, the payload rails would be placed into positions so that the rails would hang up and could not be freed by the RMS operator. This prevented the payload from either being locked up with the REM or from being moved away for another berthing attempt. Successful berthing of the payload was sometimes achieved, but it was not a smooth nor consistent operation. When berthing and lock up could be achieved, the average time required was approximately 30 minutes.

As a result of these tests, it was decided changes must be made to the REM hardware which would (1) remove all possibility of payload hang up during the berthing process, (2) provide highly visible markings on the REM that could be used by the RMS operator for orientation of the payload, (3) increase the payload capture range of the REM, and (4) expedite the berthing process.

A new method of berthing was also required. Instead of having to move the payload along the surface of the REM, a straight down motion of the payload would be attempted. This motion was easier to accomplish with the RMS, and the hardware changes would enhance this method.

The unit was shipped back to MSFC where the following design changes were made to the REM: (1) four "Y" guides were mounted to the center frame; (2) guide rods were attached to the deployed rails; (3) ready-to-latch switches were included to give an indication that the payload was ready to be latched over a 0.6 centimeter range; and (4) pin and nut plate lead-in configurations were changed to increase the permissible misalignment for a successful latch-up. The original configuration of the REM is shown in figure 2. Figures 7a and 7b show the configuration after modification.

The four guide rods and "Y" guides were desired by the RMS operators for two reasons. The 10 centimeter opening at the top of the "Y" guides would provide a large target for the rods on the deployed rails when the RMS operator attempted to berth the payload. As the payload was moved close to the center frame, the physical restraint of the "Y" guide placed the payload in the desired position for latch-up. The second reason for the rod and "Y" guide was for visibility. Alternating light and dark horizontal stripes, equally spaced and at equal distances above the center frame surface, were painted on the "Y" guides. The outboard ends of the rods were also striped for better visibility. The height reference of the horizontal stripes was an important aid and improved the berthing procedure. The physical restraint of the "Y" guides was both an advantage and disadvantage. The advantage was that, with the rods in the confines of the "Y" guide while maintaining a plane parallel to the center frame, the payload would be placed in a position that successful latch-up would be achieved. The disadvantage was that the frictional force generated by contact of the rod on the surface of the "Y" guide had to be overcome by the RMS. This surface on the "Y" guide was coated with Emralon 334, a dry lubricant, to minimize the frictional force.

The original type of switch selected to give a ready-to-latch indication was also changed. The original switch would provide an indication only when the berthing feet were positioned to within 0.25 centimeter of the surface of the center frame. This was a very stringent requirement on the RMS operator. Also, the actuation arm of the switch was deformed during the Johnson Space Center testing. Therefore, a larger and stronger switch having a 0.6 centimeter indication capability was selected, and redundant switches were provided.

The original blunt nose design of the pin and nut plate is shown in figure 6b. The redesign of the pin and nut plate is shown in figures 6c, 8a, and 8b. This redesign in configuration allowed the pin to be out of alignment with the mating hole approximately 1 centimeter and still be guided into the hole by the latching motion.

Also shown on figure 8b is a new configuration for the latch link. Figures 5a and 5b show the original configuration. The monoballs that were originally the contact between latch link and deployable rails were also the primary area of hang-up for the deployable rails. A hook on the deployable rails had thin fingers that could become lodged between the separate monoballs and could not be removed by the RMS operator. This area was totally invisible to the RMS operator. The latch links were replaced by a solid latch line. In addition to removing the hang-up potential of the monoballs, a conical shape was specified on the top surface that would provide a guiding surface for the hook as it was brought down vertically into ready-to-latch position (figure 8b).

After the new configuration was vibration tested, the REM was shipped back to Johnson Space Center for further testing in the MDF. These tests indicated that the added aids and larger capture range of the REM made it compatible with RMS capability. In addition to the testing at JSC in the manipulator docking facility, berthing tests using a flight-type of arm were conducted at SPAR, the Canadian manufacturer of the RMS. This testing also indicated that the RMS and the REM were compatible for joint operations on a mission.

The last modification required on the IECM REM before flight was to allow operational capability down to -200°F. As stated earlier, the grease applied to the structural pins solidified at -125°F, making operation at lower temperatures impossible. Several dry lubricants were considered before NPI 425 was selected for testing. After the lubricant was applied, the pins were burnished to remove all excess. Vibration testing was again performed and the REM operated satisfactorily. The thermal vacuum test was successfully accomplished at a temperature of -210°F.

Three REMS have been built, the first for qualification testing. The second unit was flown with the IECM on STS3 and STS4. It was not operated on STS3 because of the failure of an aft bulkhead camera and the RMS elbow camera, which were needed to safely berth the IECM. However, the unit was satisfactorily operated on STS4.

The third unit was flown on STS3 with the Plasma Diagnostic Package, which was deployed and berthed three times on this flight. The PDP/REM is scheduled to be flown again aboard Spacelab 2.

The IECM/REM has been operated through two cycles in flight and the PDP unit through three cycles. The average time required to berth a payload has been approximately six minutes, with one berthing of the PDP being accomplished in four minutes.

A fourth REM is being designed for a GSFC payload, SPARTAN, a 1134 kg (2500 ib) payload to be launched in July 1984.

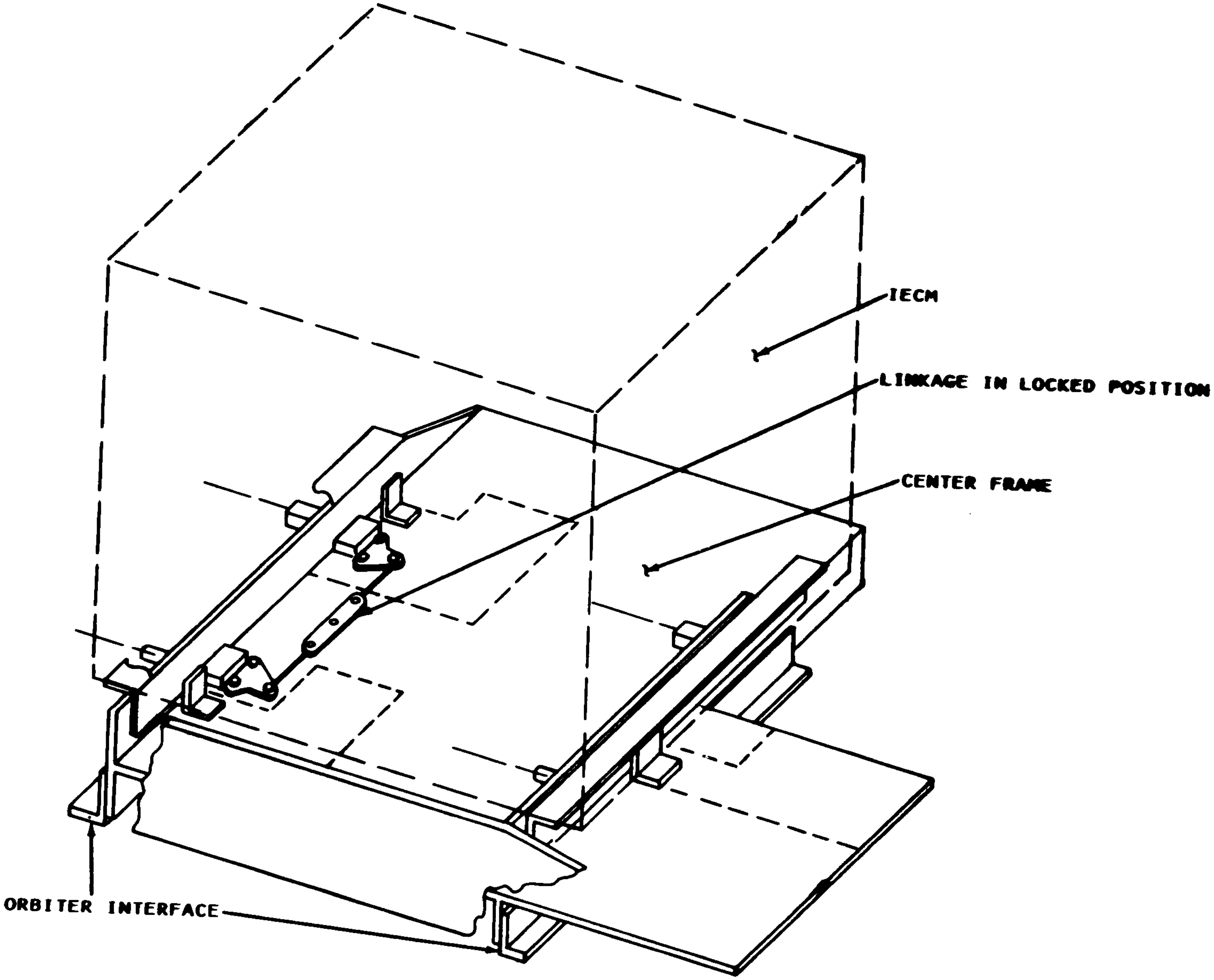

Figure 1a. Original Concept REM in Latched Position.

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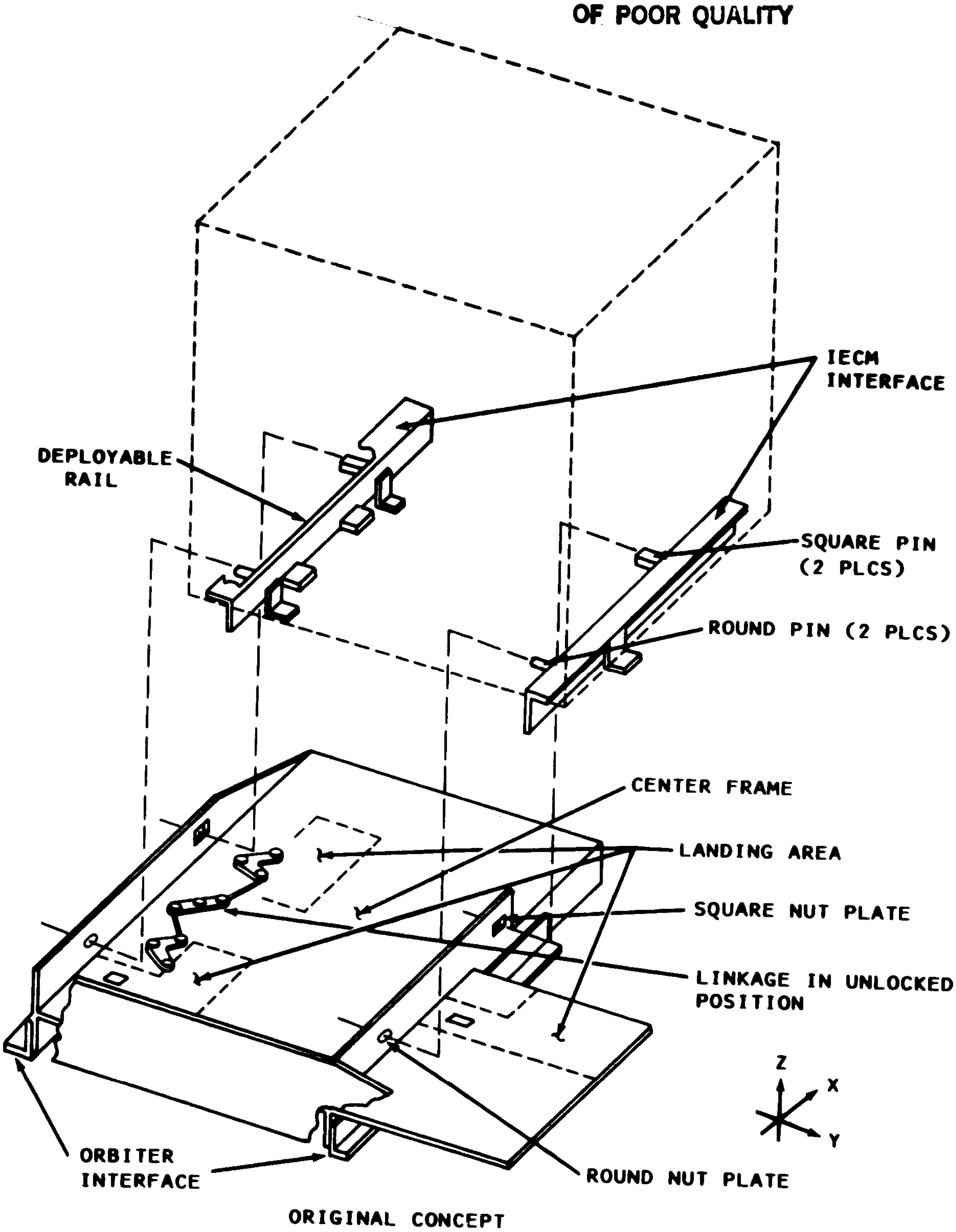

Figure 1b. REM with Payload Deployed.

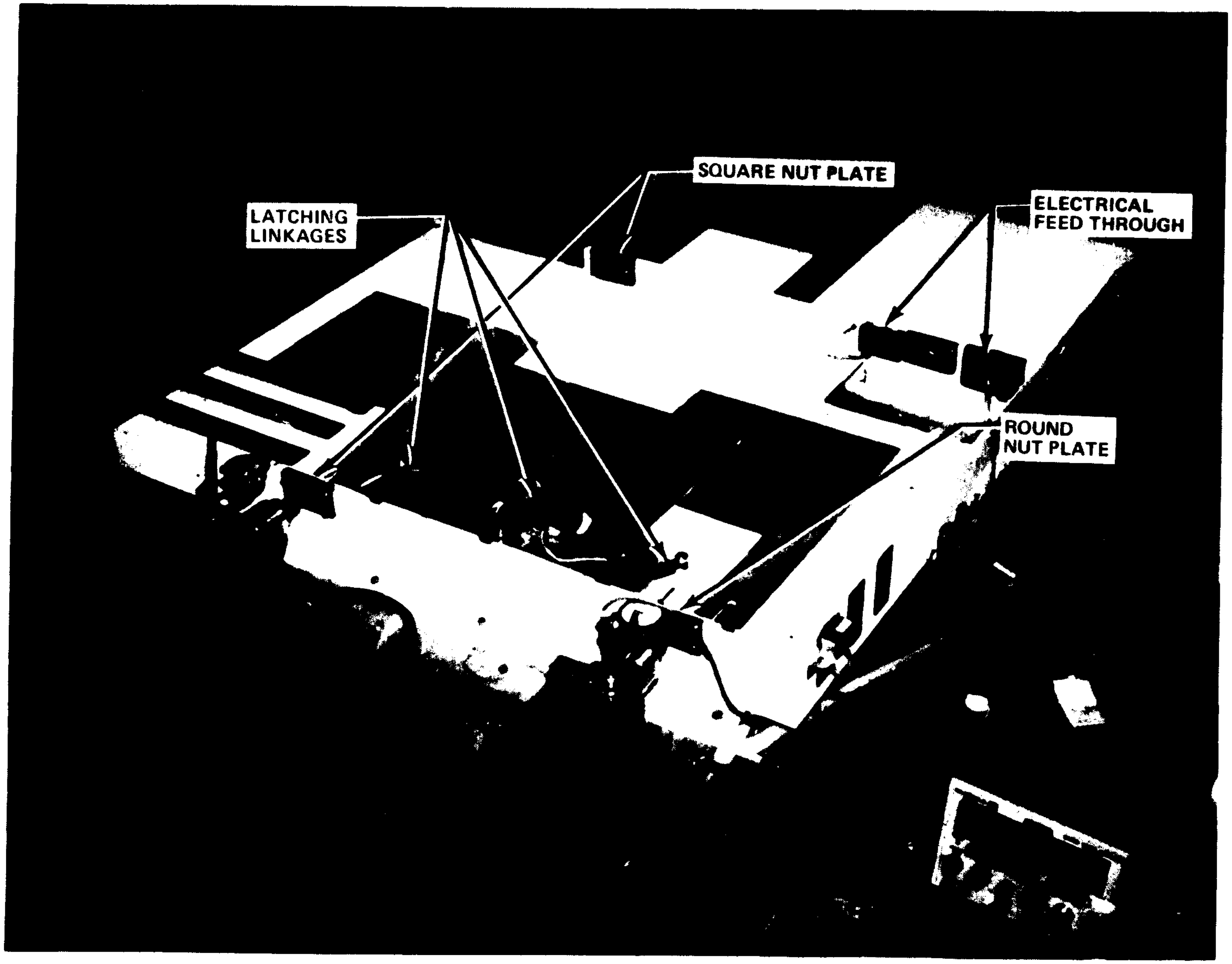

Figure 2. Center Frame Assembly and Calibration Equipment.

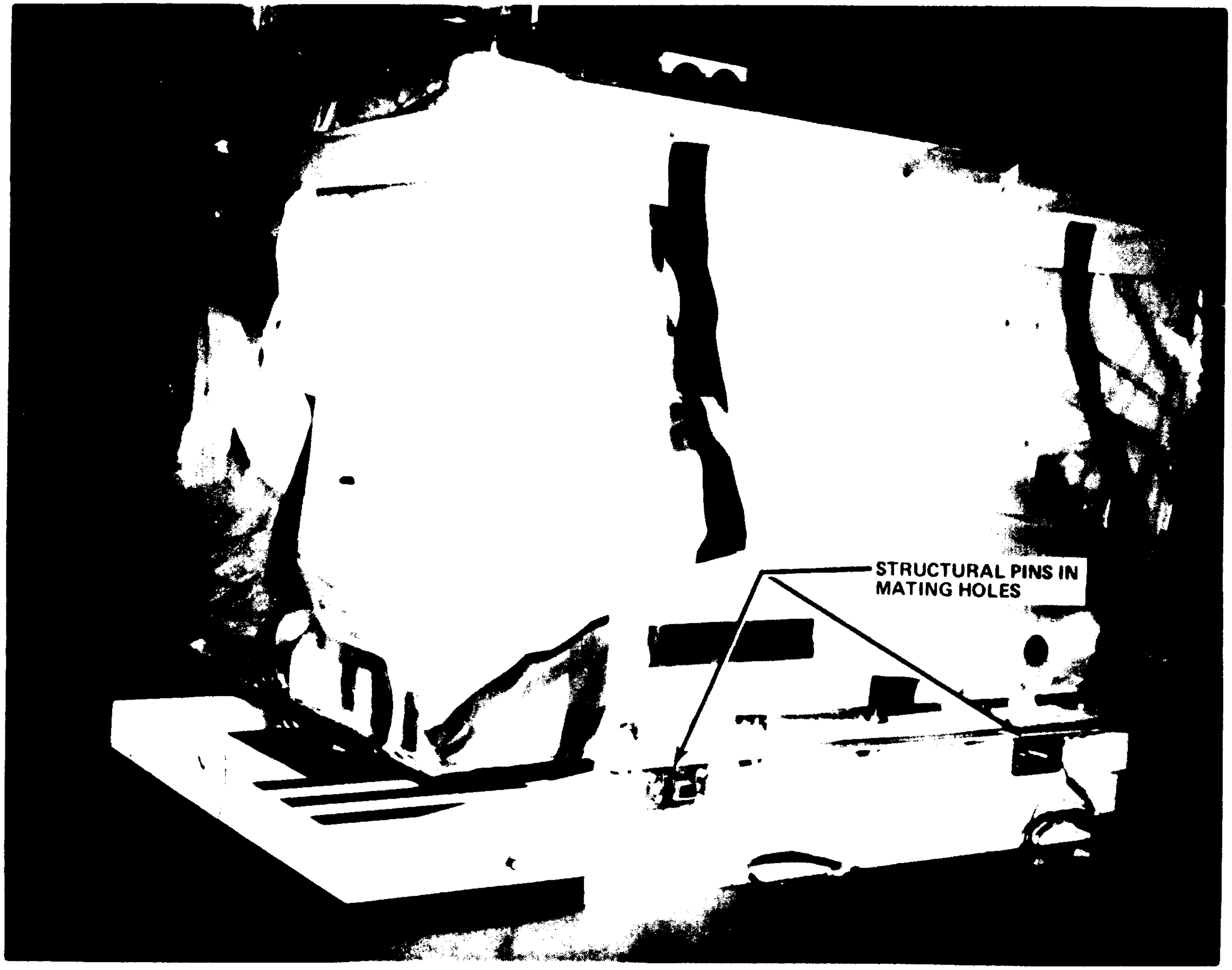

Figure 3. Release Engage Mechanism with Induced Environmental Contamination Monitor Installed.

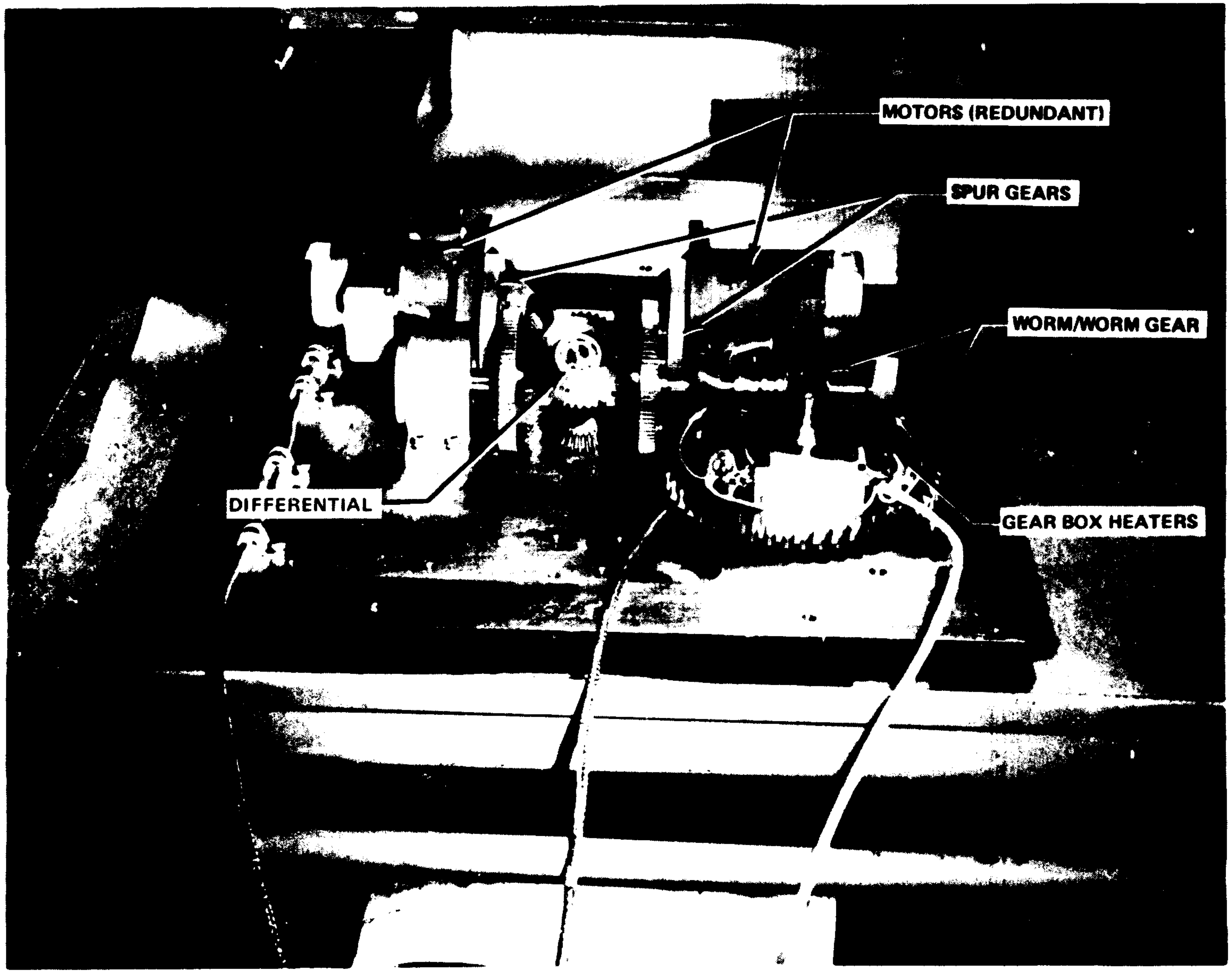

Figure 4. REM Gear Train.

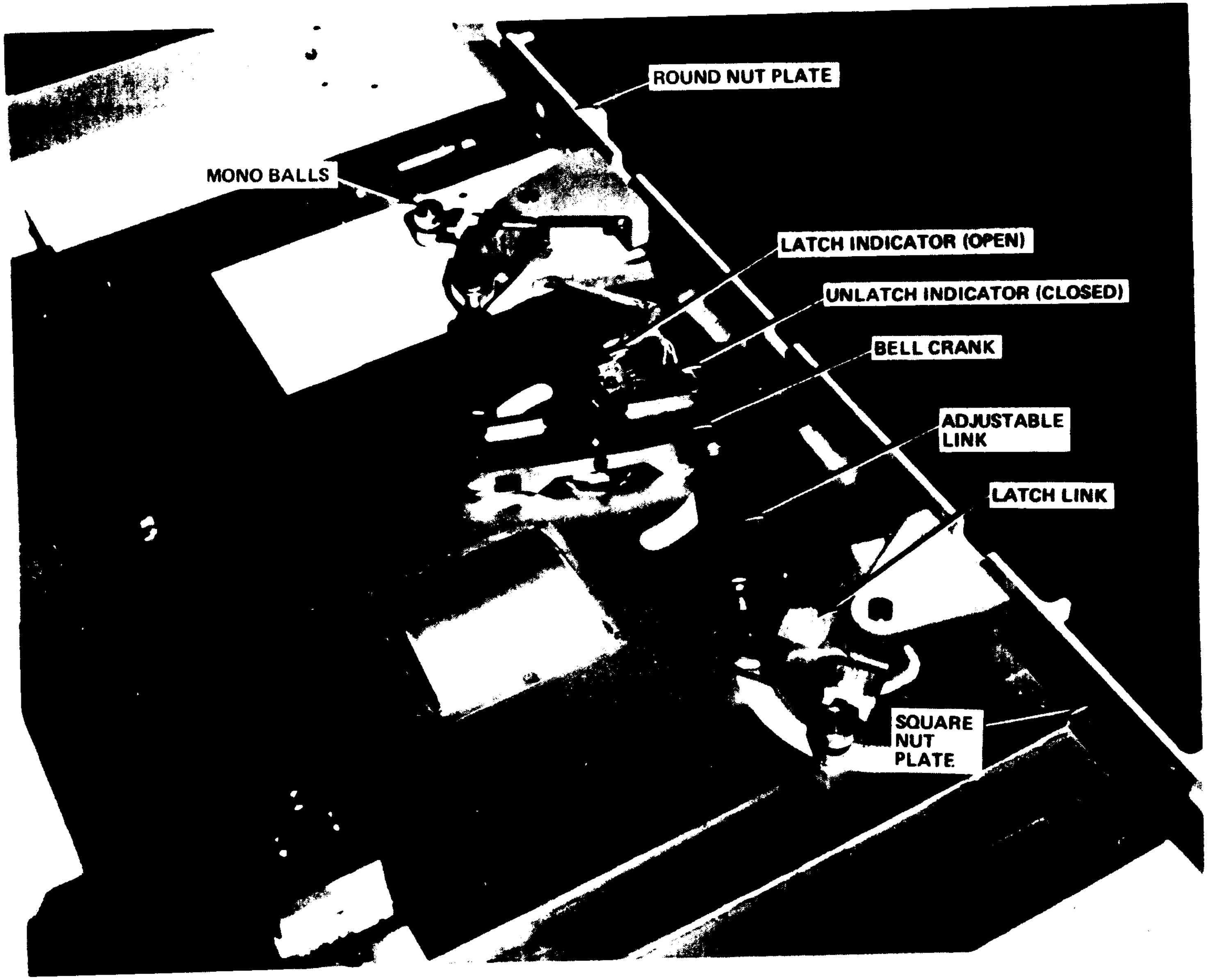

Figure 5a. Latch Linkage in Unlock Position.

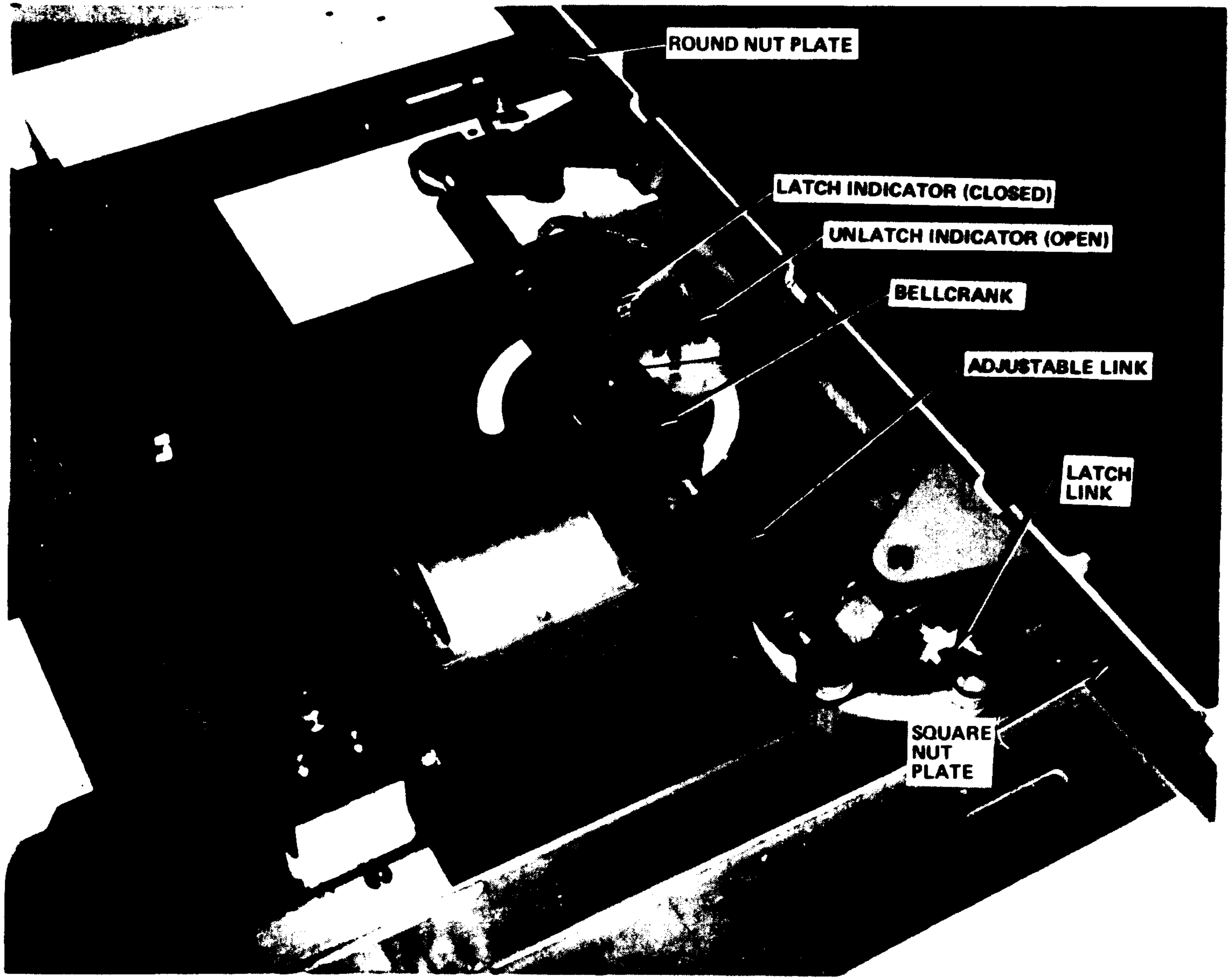

Figure 5b. Latch Linkage in Lock Position.

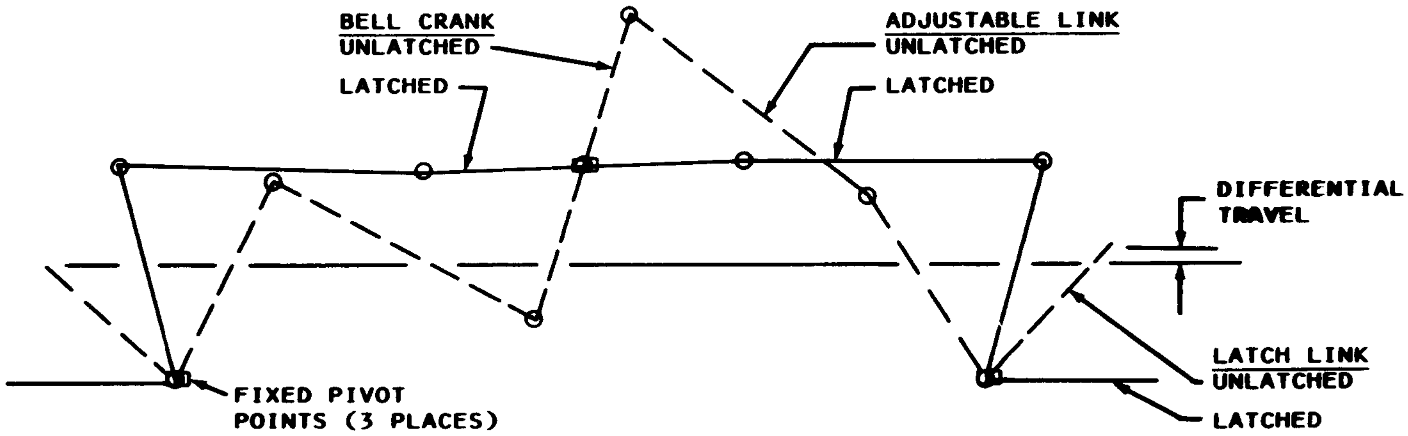

Figure 6a. Kinematics of Latching Linkage.

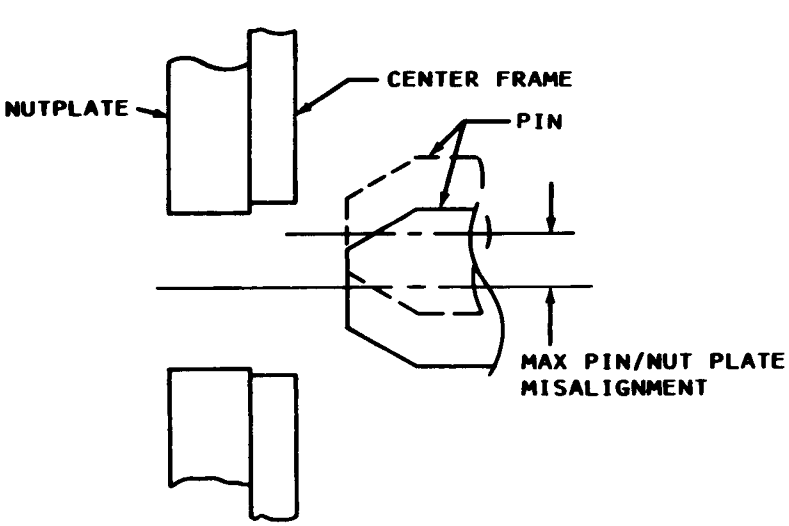

Figure 6b. Original Configuration.

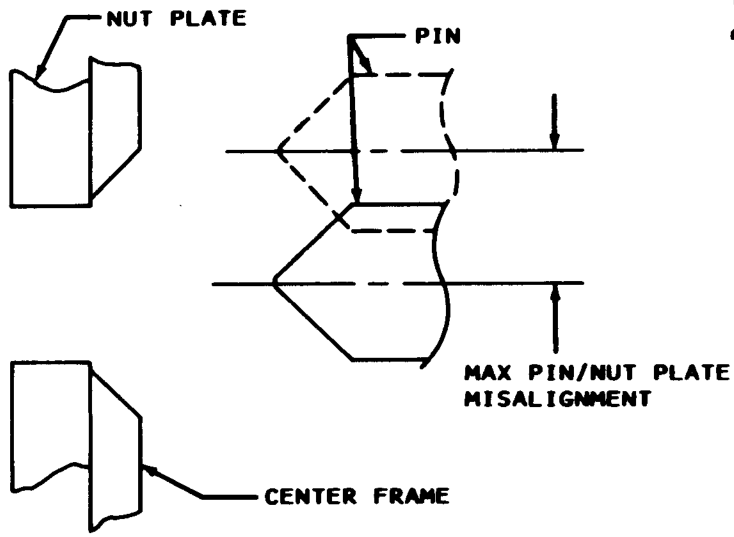

Figure 6c. Redesigned Configuration.

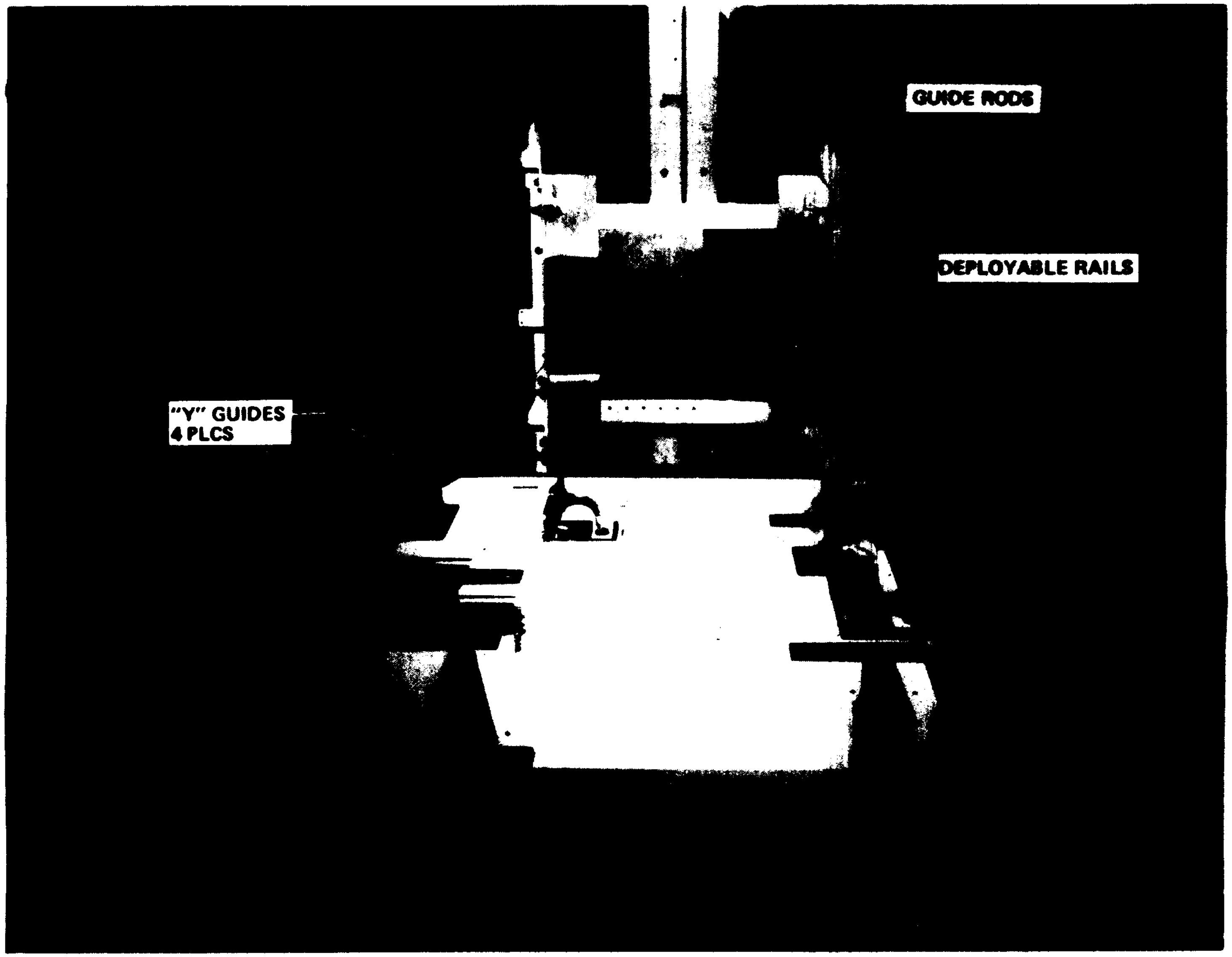

Figure 7. Reconfigured REM (Overall View).

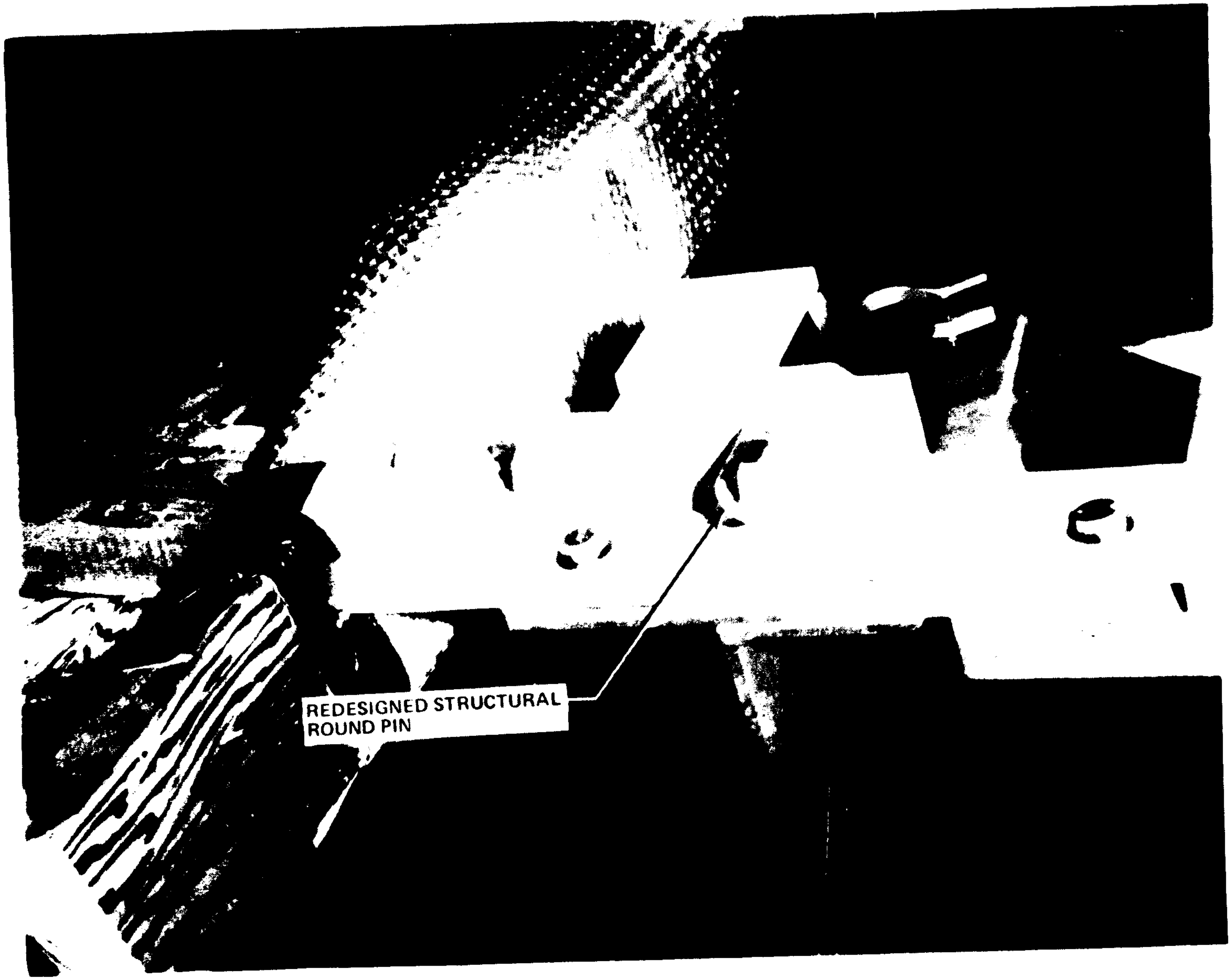

Figure 8a. Reconfigured REM (Round Pin).

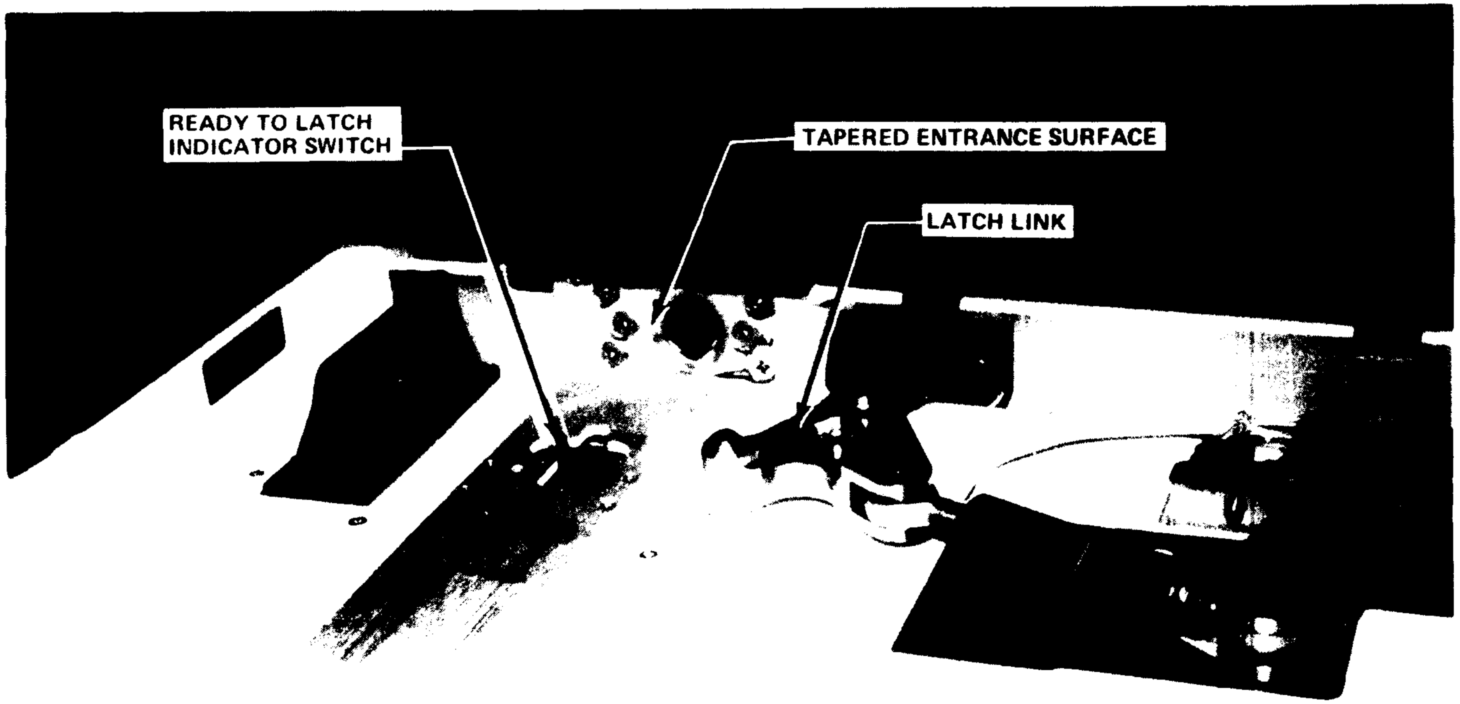

Figure 8b. Reconfigured REM (Center Frame).