MMTO Conversion Technical Memorandum #00-5

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MMT Conversion f/9 Secondary Assembly Procedure

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May 25, 2000

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Abstract

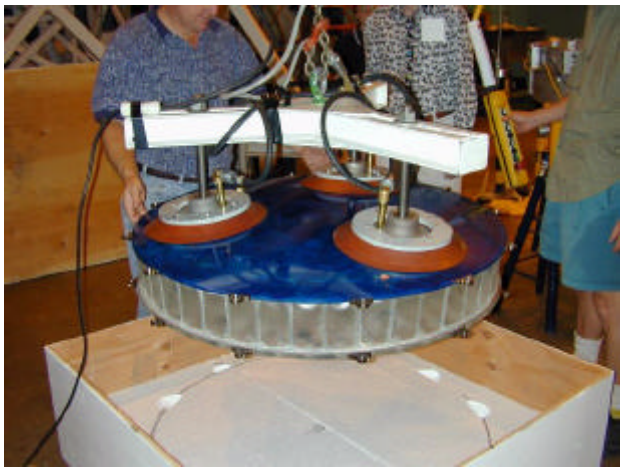
A detailed pictorial procedure for assembling and aligning the MMT f/9 secondary cell, mirror, and support system is given.

I. Overview

We document the assembly procedure used to integrate and adjust the f/9 mirror into its cell (*a la* automotive service manual style). Further details and clarifications can be found in B. Cuerden, "Install4 Rev A, MMT f/9 Secondary Mirror Installation into Cell, 24-Feb-00, *MMT Conversion Internal Technical Memo* #00-3, 24 May 2000). The photos and annotations are more clear using the color pdf version of this memo found on the MMT website (f9assembly.pdf).

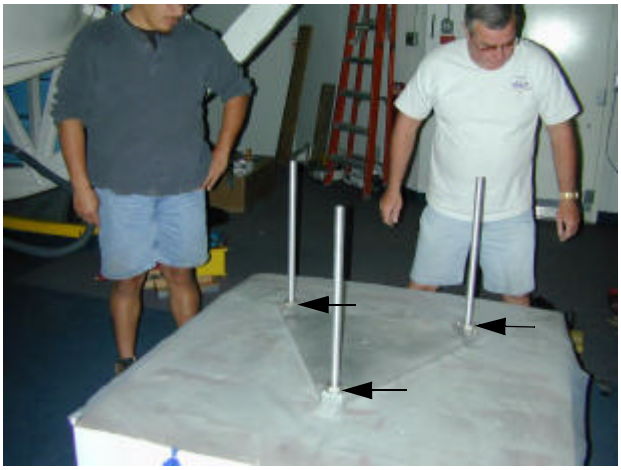
II. Cell and Tripod Setup

There are two ways to bring the mirror and cell together. The first uses a vacuum fixture applied to the faceplate of the mirror to lift the mirror into the cell. We will not use this procedure. However we show a photo in case this fixture is needed

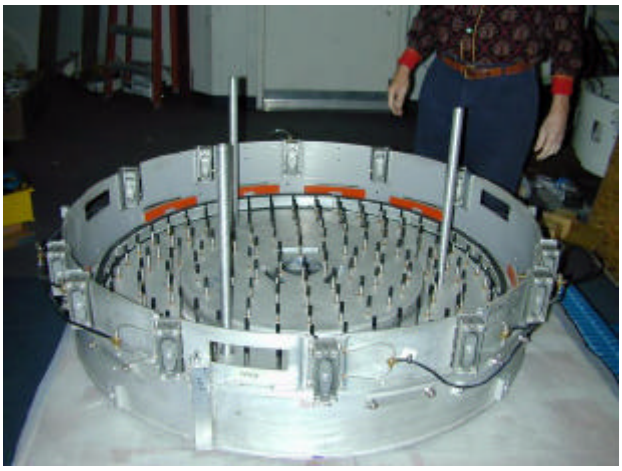


in the future.

Instead we will use fixturing that moves the cell up onto the mirror using a special tripod made for the purpose. Note the 3 nuts (arrows) must be installed prior to setting the cell onto the tripod.

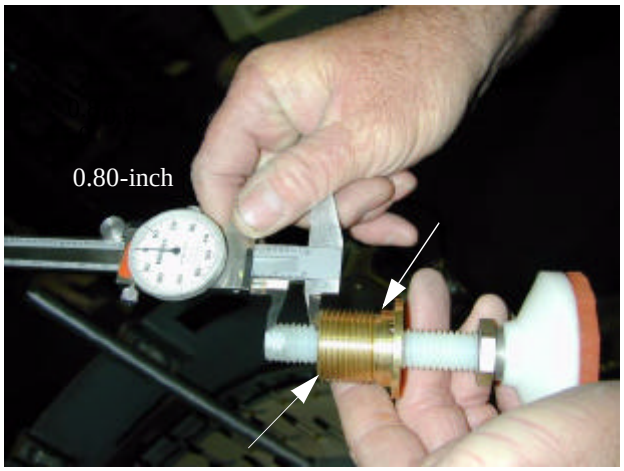


Now place cell over tripod.

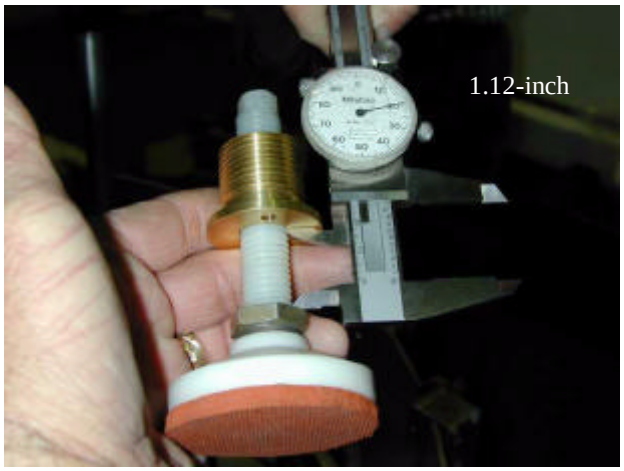


Next, set up the 3 pads on the tripod legs that will support the mirror. The next two photos show the pad dimensions prior to

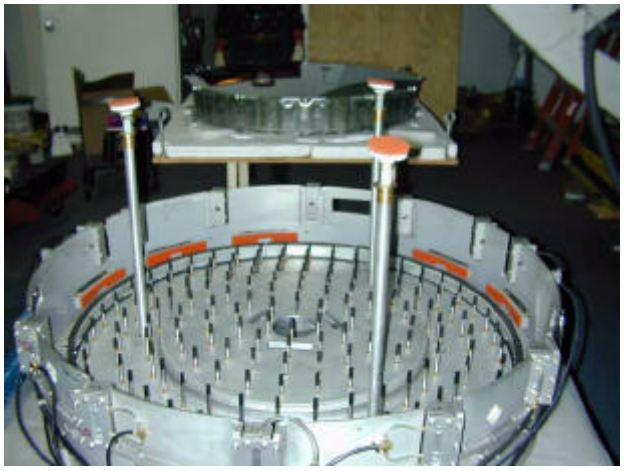
installing them onto the tripod legs. NOTE: taper brass at two



arrows before using these pads again to void severe catching of brass in cell holes.



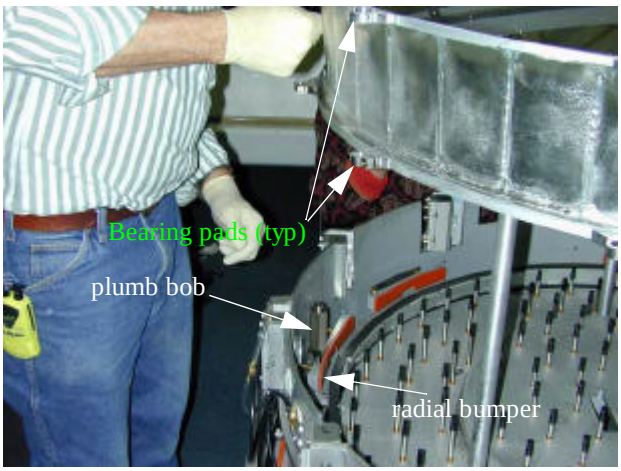
Install pads on tripod legs.



With 3 people each using both hands on mirror backplate, move mirror onto tripod taking care to align mirror and cell North orientations. Mirror backplate is marked with the pad

outlines.

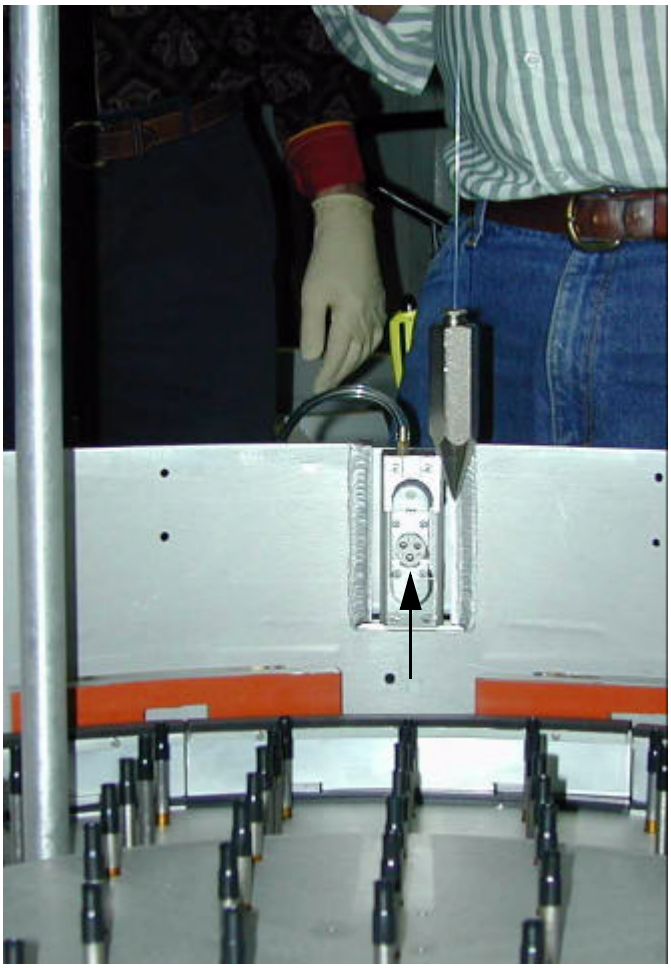
Check the mirror/cell alignment in two ways using a plumb line. First check the **centration** by dropping the line in 3 places from the edge of the mirror *back*plate to the orange radial bumpers. Carefully shift mirror until bob (*i.e.* mirror



backplate) is about 1mm inside of the radial bumpers.

Check **clocking** of the mirror by dropping the line from the north (L1) and south (L7) bearing pad centers to the actuator

bodies. Here the line is shown from the south bearing pads



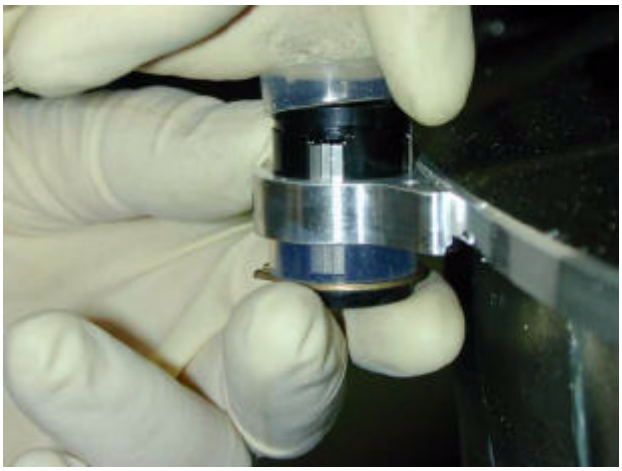
attached to the mirror to L7. When the mirror is properly clocked, the plumb point will be centered on the 3 ball bearings (arrow--mirror clocking is in error in this photo). Similarly, the plumb line off of the north mirror bearing pads to the L1 actuator will go through the center of the wire hole in that actuator body. Iteratively adjust centration and clocking by gently moving the mirror on the tripod legs as needed.

III. Preliminary support system attachments

This section describes several attachments to the lateral and axial supports that must be made prior to moving the cell and mirror together.

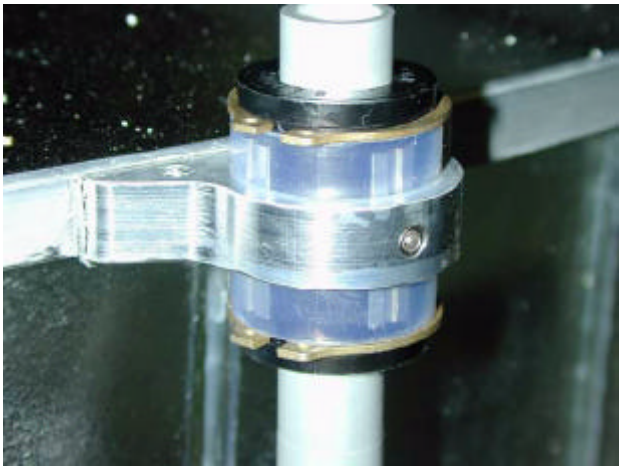
A. Lateral support rods and linear bearings

Now assemble the 11 linear bearings into each of the bearing pads attached to the mirror top plate. Prior to inserting into the



bearing pad, attach lower snap ring and clear bushing. Insert into bearing pad. Attach upper clear bushing, and *carefully* attach final top snap ring (not shown in this picture). Take care not to stress the bearing pad connection to the mirror or to let the snap ring launch onto the mirror surface.

Carefully insert lateral support rods through each bearing. Apply 242 loctite to set screw, and then very gently tighten the set screw into the groove [of one of the three] metal bearing holders as shown. When the proper preload is applied, the rod can be easily translated up and down without sticking, and the bearing is slightly loose in the pad. Next gently clamp the rod using the pad attached to mirror backplate (to hold the rod in position). Rods for the 6 lateral actuators (L2-L4 and L10-

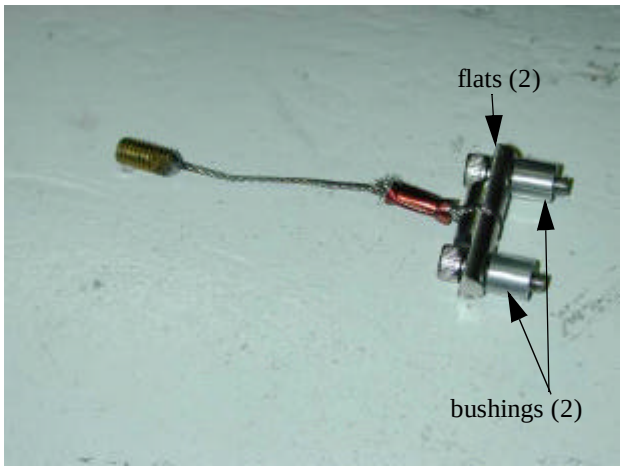


L12) have a single hole drilled through them with a very small flat centered on the hole. The rod for L1 has this and a large flat. The 5 rods for the compression actuators (L5-L9) have a flat milled into the side of the rod. Rods for L5 and L9 have a short flat, while the others have a long flat. The three rods for

L1, L5 and L9 are unique because they also accommodate the connection to the tangent arms (described later).

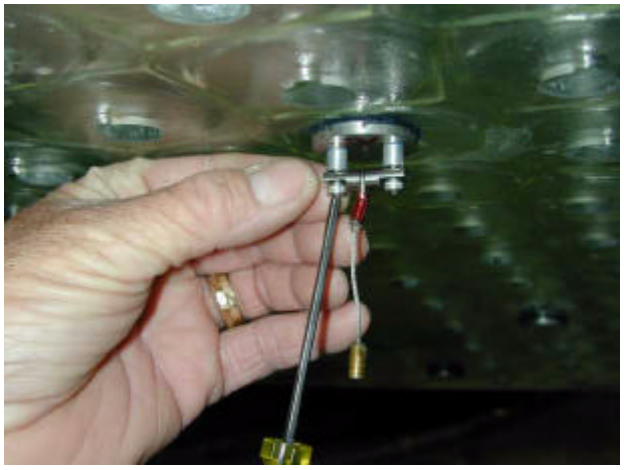
B. Axial support wires

Locate the 18 axial wire assemblies. Each one is unique and



must be mated with the appropriate axial puck (already glued onto the mirror backplate). Note the two spacer bushings and the flat surfaces oriented toward the bolt heads.

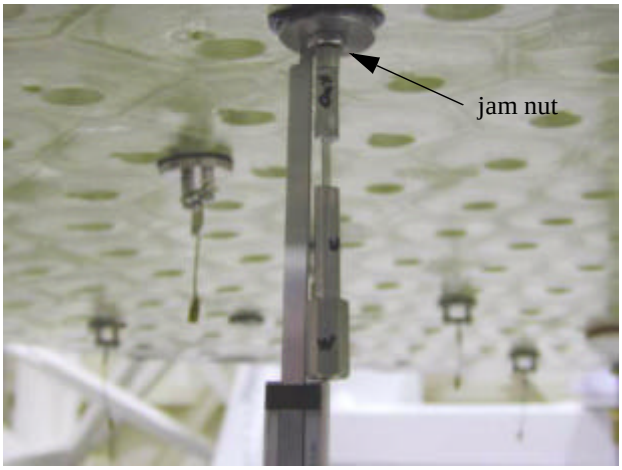
Attach each wire assembly to the appropriate invar puck using 242 loctite.



Locate the 3 axial hardpoint flexures. Each should be labelled

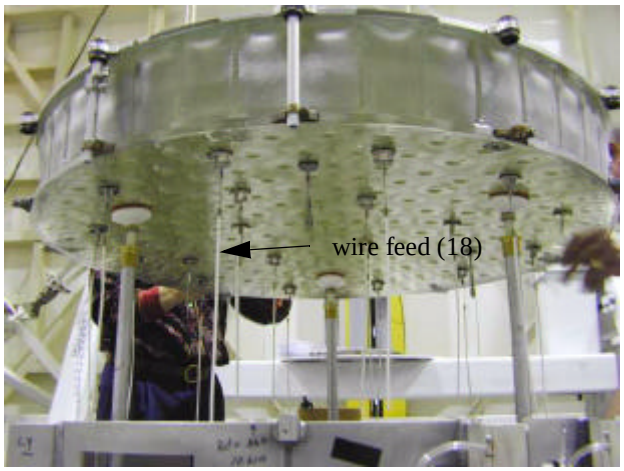
with a location (W, NE, or SE) which corresponds to the labelling on the 3 mirror pucks.

Attach each flexure to a puck taking care to keep the length dimension unique to each using a depth micrometer (W: 3.478-inch, NE: 3.475, SE: 3.460). Apply 242 loctite to thread



and use jam nut when length is correct. Do NOT bend flexures.

Screw wire feed-throughs onto the brass screw on each axial support wire assembly. These allow the axial wires to be

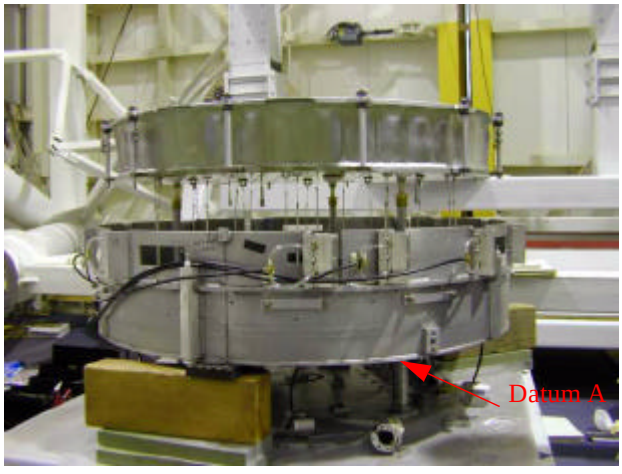


steered through the holes in the cellplate.

IV. Mate cell and mirror

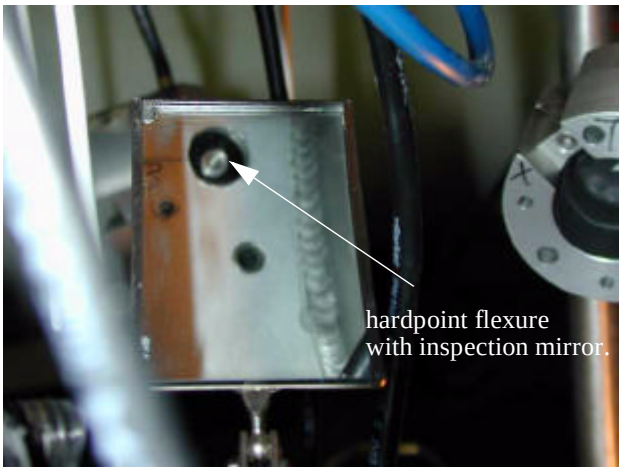
NOTE: For this procedure, we used scissor jacks and wood cribbing. It should *not* be done this way again. A better way would be to make a support for the mirror cell attached to a precision fork lift.

Using 3 scissor jacks, elevate cell until wire feeds just touch cell plate. Continue elevating while carefully placing each wire feed through its appropriate hole in the cell.



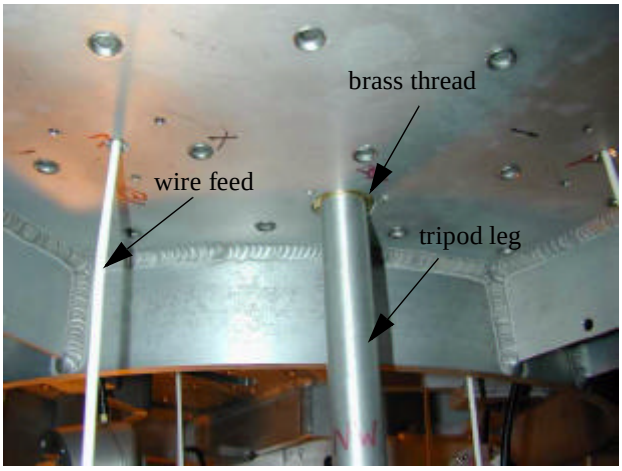
Take care to keep mirror centered and clocked properly as the cell is lifted. Also make certain that the tripod legs remain centered in their clearance holes in the cell plate. Use plumb bob as needed. Also, gently pull on wire feed-throughs to make sure axial cable doesn't buckle as cell is lifted.

Continue jacking and cribbing. Occasionally inspect hardpoint flexures to insure they proceed through their cell clearance holes without binding. NOTE: Also check the clearance



between the mirror backplate and the radial bumpers to make sure that the mirror doesn't hang up there. Pay special attention to the brass threads on the ends of the axial wires so they proceed through their clearance holes without binding or hanging up.

Watch for contact with the 3 cell clearance holes and the brass thread on the ends of the tripod legs. Be careful not to jack tri-



pod base off the platform because the brass thread binds with the clearance hole! Make sure to check hardpoint flexure clearance during this process.

While continuing to lift the cell, screw nut (at base of tripod leg) onto the brass thread. When cell is lifted, the brass thread

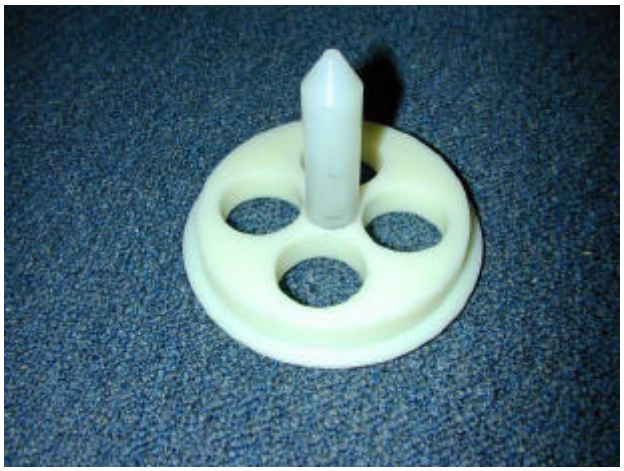
will extend below the nut by about 1/8-inch. There's a shoulder on the brass thread that WILL catch the clearance hole, so hopefully this was tapered per the note earlier. In practice, we had difficulty tightening these nuts, and ended up putting a stackup of 3 thick washers between the cell and nut.

Now, the 3 hardpoint flexures should be through the cell plate along with the 18 axial wire assembly brass ends. The 3 nuts should be securely tightened to the brass threads on the ends of the tripod legs. At this point, the mirror is resting on the 3 pads above the tripod legs. It is NOT resting on the axial bumpers under the mirror backplate.

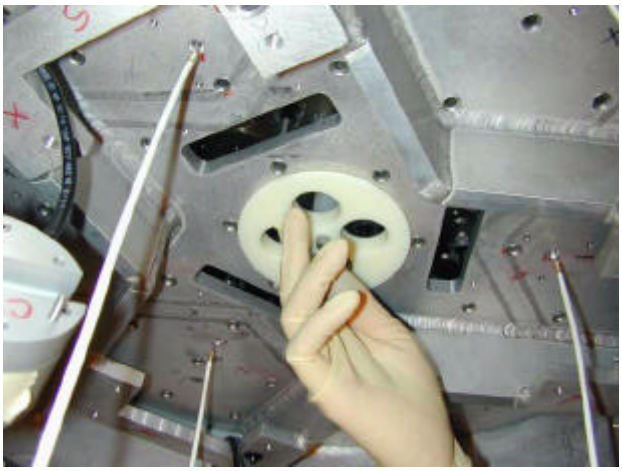
At this point, try to center the mirror so that the backplate has equal clearance with the radial bumpers all around. Wedging plastic shims (~1mm thick) between the bumper and backplate works pretty well.

V. Exact-Alignment of Mirror and Cell

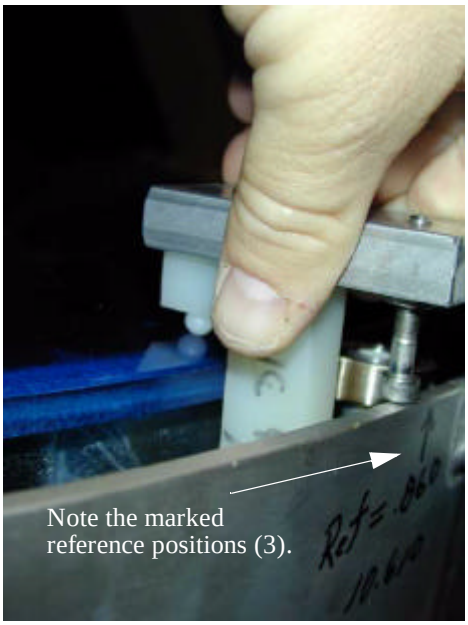
The centration tool engages both the central clearance hole in the cell and the backplate hole in the center pocket of the mirror.



When the mirror is well centered, this tool is easily inserted and rotates freely.

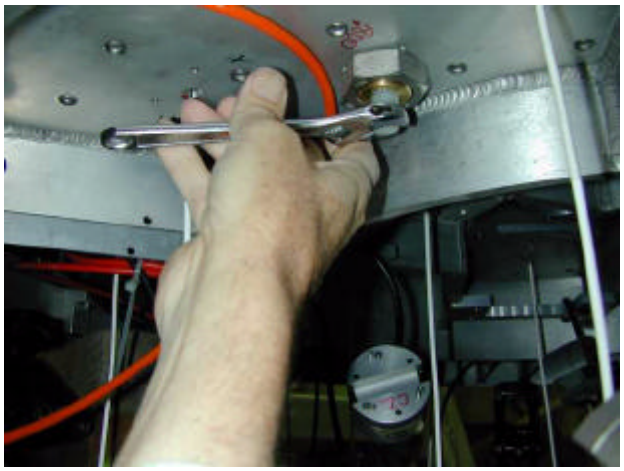


The height of the mirror is adjusted relative to datum A of the cell by using the mirror height tool at the 3 reference positions that are marked on the side of the cell. When inserted prop-



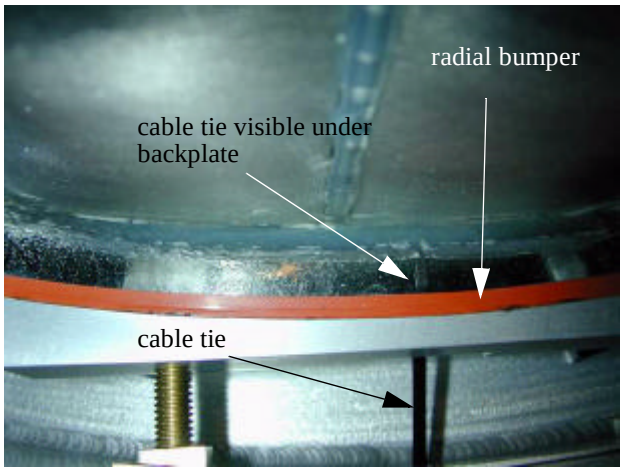
erly, this tool simultaneously touches the mirror surface and the top of the cell wall. In addition, the tool is pushed up against the sides of the mirror front and back plates. Height should be adjusted at 3 reference positions to within +/-0.010-inch.

The mirror height is adjusted with the nylon nuts from the 3 tripod pads.

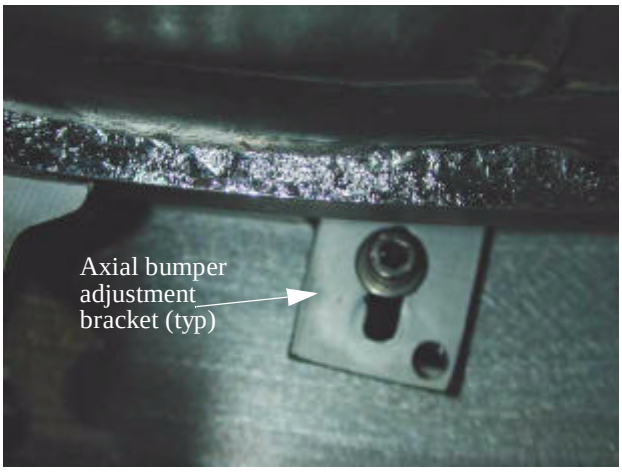


Check all the radial bumpers to insure they have a uniform clearance of about 0.040 to 0.05-inch from the edge of the mirror backplate. Adjustments are provided by the jam nut assemblies outside the cell OD.

Using small holes in cell sidewalls, insert a cable tie (thickness of about 0.03 to 0.04-inch) between the mirror backplate and the axial bumper system under the mirror. The axial



bumpers are directly under the mirror sidewall, so some care must be taken to push the tie in properly and far enough. Verify clearance for all axial bumpers. If adjustment is necessary, the radial bumper above it must be backed away from the mirror edge to allow access to the axial bumper brackets. This is a



difficult adjustment indeed.

Adjust centration, height and clocking precisely before proceeding. Verify proper radial and axial bumper clearances for this mirror position.

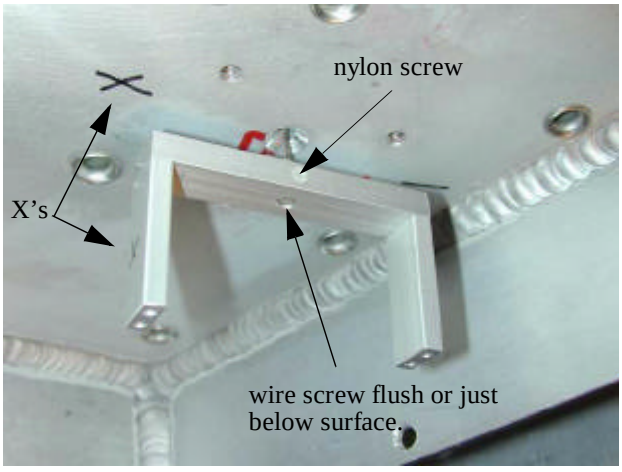
Finally, remove all the wire feed-throughs.

VI. Installation and Adjustment of the Axial Actuators

There are 18 axial actuators arranged in an outer and inner ring.

A. Installing the axial hardware

Attach a U-shaped hanger to the end of each axial wire. Screw

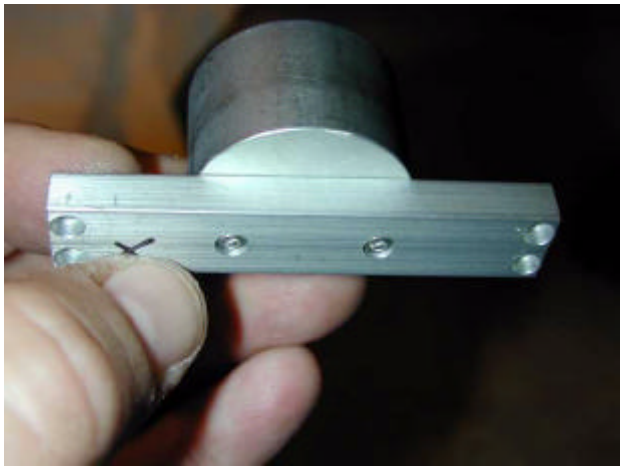


each hanger on until both of these conditions are met: 1) The "X" on the hanger and cellplate line up, and 2) the nearest revolution where the wire screw is flush or doesn't protrude from the lower surface of the hanger. It's important that the wire screw NOT protrude since the screw would limit actuator

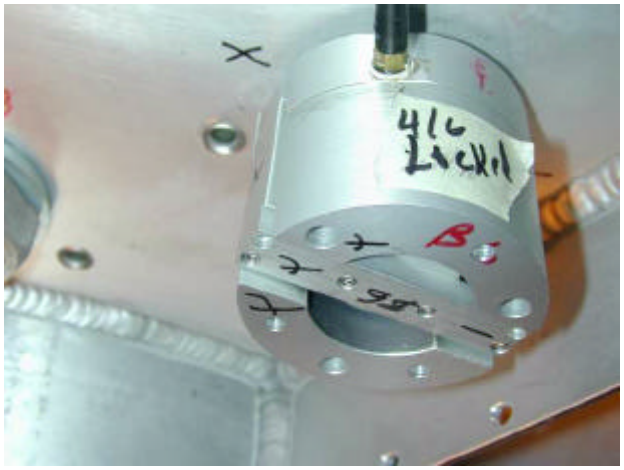
travel rather then the hanger surface. End by slightly tightening the nylon screw.

Next attach the actuator cylinder to the cell by first aligning the X's on the actuator with the X's on the hangar and cell. There are 3 pairs of push-pull screws (the pullers are in the 3 larger diameter holes in the actuator face). Use the pullers to just snug the actuator body up against the cell for now. NOTE: the puller screws for the outer ring of actuators are shorter than those for the inner ring of actuators.

Locate the bellofram piston and crossbar for the unit.



Install it onto the hanger ends using the 4 screws with 242 loctite.



NOTES: Once assembled, grab the hanger with gentle force and make sure it has unrestricted clearance to go up and down by 1 or 2 mm each way. Do NOT assemble in a way that tensions the axial wire rope, because you could pull the puck off of the mirror backplate. In this same spirit, be very careful making mirror height adjustments henceforth. Raising the mirror height relative to the cell could tension the wire ropes!

B. Adjusting the axial actuators

If re-assembly goes well and all of our previous loctiting holds firmly, nothing more than a verification of alignment will be necessary. The full procedure is provided here in case it is needed.

Datum A is the thick lower flange on the cell shown a few pages back. Level this flange in both X and Y to +/-0.05-deg using a digital level.

C. Verification of actuator alignment

Verify proper mirror height in cell.

Tighten the puller screws on one actuator unit.

Check the actuator level in X and Y by placing the level on the bottom of the actuator housing. It should be level to +/-0.10-deg.

Next, use the axial actuator height gauge to determine if the neutral position of the wire is at the center of the actuator travel. This is done by pushing the gauge against the housing

bottom as shown. Gently pull on hangar with a pound or two of force (taking care not to tilt the hangar). The lower surface of the crossbar should just touch the gauge. If there is more than 0.010-inch of gap or if the gauge is pushed away from the housing bottom by the same amount, the piston of the actuator must be adjusted. This tool has a 0.125-inch step and positions the hanger so it can move +/-1/8-inch during normal operation.

So long as the actuators are level to +/- 0.10-deg and the piston is within 0.010-inch, you are done (just make sure the puller screws are tightened up before making the measurements).

D. adjusting out of spec actuators

This is a relatively difficult adjustment since 2-D tilt and piston must be controlled with 3 push-pull screw pairs! NOTE: the pusher screws consist of two set screws in series. The upper screw engages the cell plate, while the lower screw acts as a jam. The 3 jam screws must be removed prior to adjusting the pushers.

Once the actuator is adjusted to spec, apply loctite 242 to jam screws and insert snugly.

NOTE: during this process, occasionally check mirror height since some flow of the 3 tripod foam pads can occur. Also be sure to properly preload all the push-pull pairs against each other.

VII. Lateral actuators

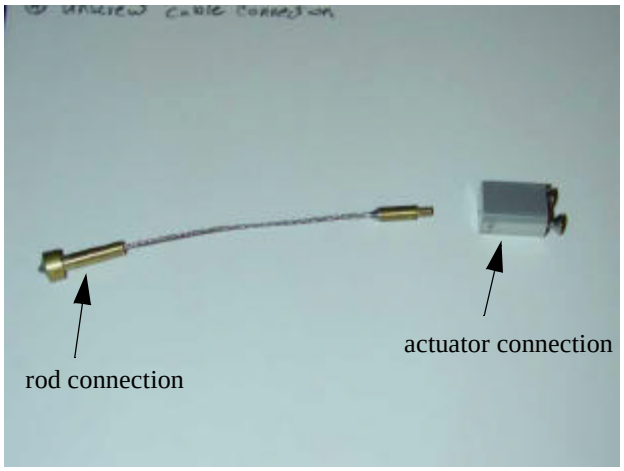
There are 12 lateral actuators. 7 of them are wire-rope tension units while the other 5 are of compression ball-decoupler type. *NOTE: all the pneumatic fittings on the actuator bodies are sealed with loctite 567.*

The adjustment goal is to bring the lateral actuator force action points and their corresponding attachments to the rods into the cg plane of the mirror. This is accomplished by monitoring the overturning moment of the mirror reacting against the axial hardpoints.

Verify mirror height before proceeding and monitor periodically.

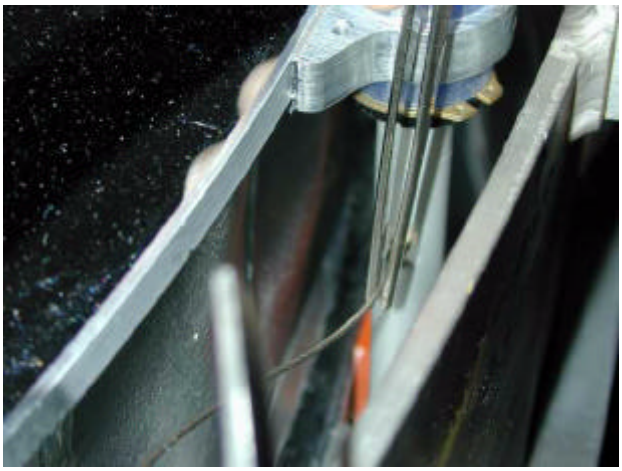
A. Installing the wire ropes

The 7 tension actuators (L1-L4 and L10-L12) apply force to the mirror by wires connecting to the lateral rods. Each wire is



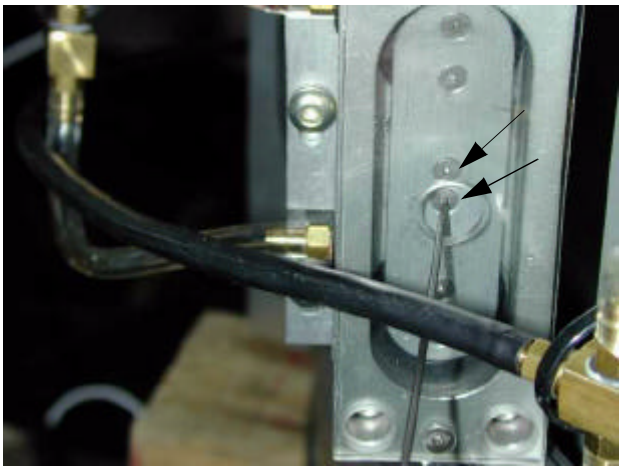
labelled to fit a certain actuator.

Unclamp the rod and rotate it until the wire can be easily threaded through using a tweezer. The small flat on the rod



should face away from the actuator. Pull wire through until brass shoulder on end of wire is against the flat.

Screw actuator connection to wire, insert into interior actuator hole, and lock using the two screws shown and 242 loctite.

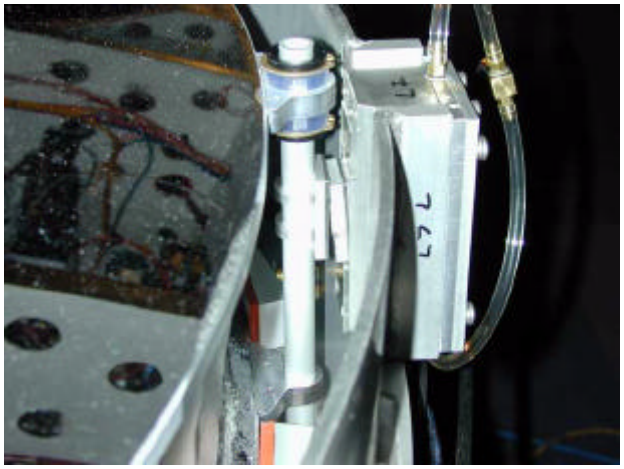


In addition to the short wire for L1, install the tangent arm connection onto this rod.

Loctite the brass shoulder on the wire end to the rod flat so it doesn't pop out when the support system is de-energized.

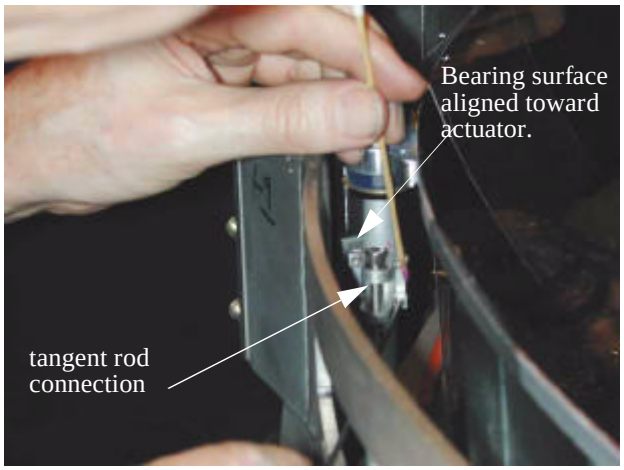
B. Installing the compression actuator bearing surfaces

Install bearing surface on rods for actuators L6-L8 and rotate



rod to give rough alignment with the actuator piston--then clamp.

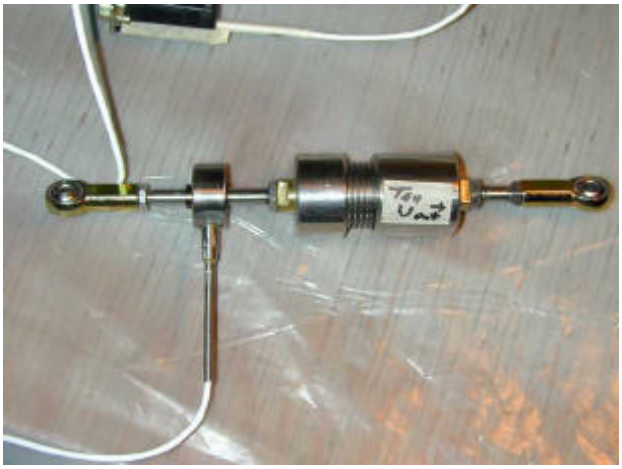
On actuators L5 and L9, install the bearing surfaces that also contain the tangent arm connection. Again, rotate rod to be roughly true with actuator piston.



After installation and tightening, use penetrating loctite (we used 222) on the clamp screws holding the hardware onto the rod as shown in this picture.

C. Install Tangent Arms

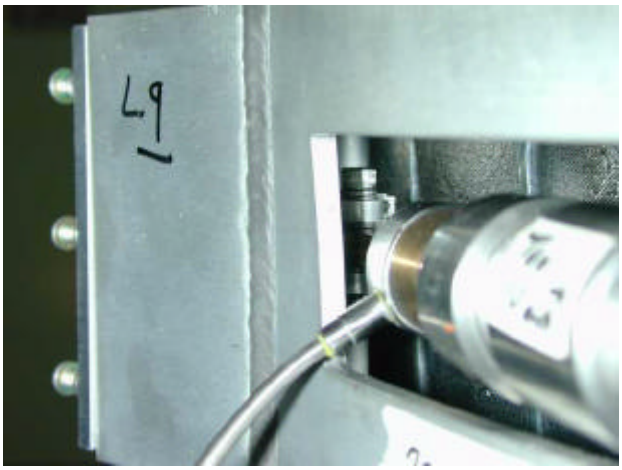
Locate the 3 tangent arm assemblies. Their positions in the



cell are labelled. They have integral tension/compression breakaways, so that they become “soft” when 15-lbs of force is applied to them. On both rod ends, there are spacer washers epoxied to each side of the spherical bearing. Take care to keep these intact.

The tangent arms have been precisely adjusted for the proper mirror alignment, so take care not to loosen or change them in any way.

Install the tangent arms per the next two photos. Apply loctite 242 to the bolt connections on both ends of each. The first photo shows the connection to the lateral rod.

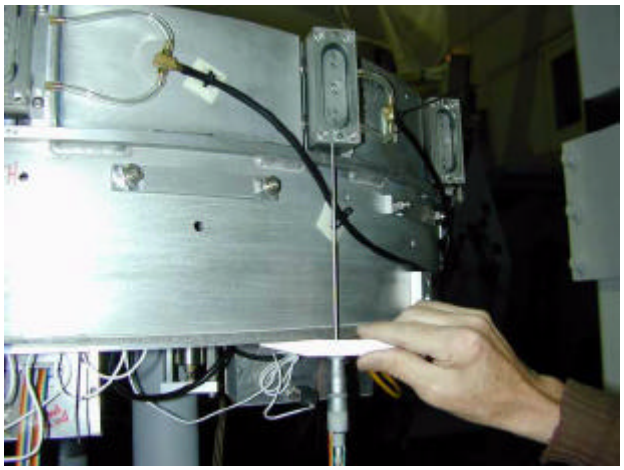


This photo shows the external connection to the cell. Note the

two spacer stackup (arrows) is *underneath* the rod end.

D. Preliminary Alignment of the Lateral Supports

The actuator housings have been precisely milled. They are 4.000-inch in height, and the line of force is halfway between. By adjusting and locking the actuator bottoms with respect to Datum A, all the actuators are brought into the same plane.

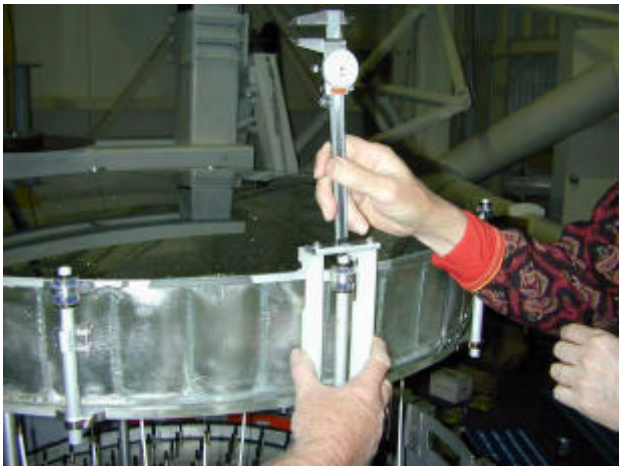


Set the depth micrometer to 6.325-inches, and adjust all lateral actuators to this position. This puts the line of force at 8.325-inches from datum A. Take care to uniformly align these to within +/-0.005 of each other. (NOTE: cg-calculations suggest that the cg is closer to datum A -- perhaps 6.310 or less -- but we were unable to adjust the actuators without hitting the cell midplane flange).

We adjust the heights of the rods attached to the mirror edge so that the cable attachments are in plane with the actuator lines of force. Note that the cables are attached 2.720-inches from the top of the rods. The force is applied 2.000-inches below the top surface of the actuator housing. Therefore, the tops of the rods must be adjusted 0.720-inch above the tops of the housings.

Choose a housing near a rod (e.g. L1,L2, or L12). Unclamp rod, and adjust height of rod top (with depth gauge) to 0.72-in above housing. Reclamp taking care to keep rod rotation so that wire points directly to actuator. NOTE: because we were unable to reach the cg plane with the actuators, we cheated slightly and set the rods 0.695-inches from the housing top (rather than 0.72). The residual torque and spurious forces were reduced significantly by doing this. However, next time, we need to modify the actuator housings so that everything can be adjusted in the same plane and "by the book".

Now use the rod-height tool to measure the depth of the rod top under the tool's top surface--and record. The use of the



tool is shown in the photo (mirror is above cell for clarity). The tool must contact the top and bottom edge of the mirror and the balls on the surface of the mirror.

For all rods that don't have a tangent arm connection, use the rod height tool to set the rod heights to the same as the rod that was measured from the actuator housing.

This is the final adjustment for the rods that support the compression actuators. Rotate and clamp in place.

For rods L5 and L9, set rod height to 0.20-inches above the top of the black bearing surface. Adjust for proper rotation and clamp rod in place. These will not need further adjustment. This rod height accommodates the preset length of the tangent arms.

E. Further Adjustment of the Lateral Supports

As described below, if the lateral supports require further adjustments, follow this procedure. The compression rods need no further adjustments though.

VIII. Final Adjustment of the Lateral Actuators

A. Move mirror and cell to iron maiden

Using a smooth fork lift, move mirror and cell onto the iron maiden and attach to the dummy hexapod. Be sure that cell N

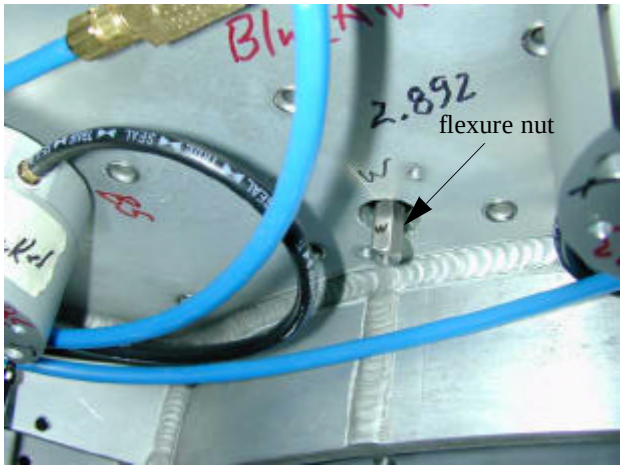
and S are perpendicular to the trunnion axis.

B. Install and Adjust the Axial Hardpoint Units

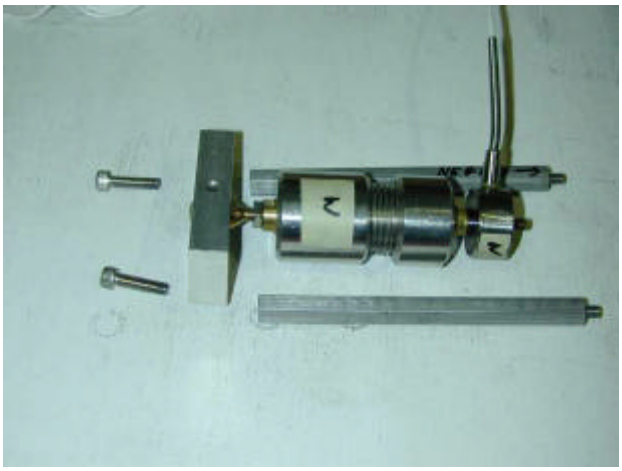
Installation of the axial hardpoints was delayed until now to facilitate moving the cell with a fork lift. If a special fixture is made for the lift to provide clearance for the hardpoints, they could be installed just after the axial actuators (just before section VII).

Verify and adjust mirror height and centration as needed.

Locate the 3 hardpoint flexure nuts under cell plate.



Locate the 3 axial hardpoint assemblies and attachment hardware. Each hardpoint is marked W, NE, or SE with corre-



sponding labels on the cell plate. Each hardpoint has integral compession and tension breakaways that activate at 15-lbs.

Screw each hardpoint onto the corresponding flexure nut. The

electrical cable coming out of the load cell interferes with the circular flange in the cell -- carefully handle flexure while screwing hardpoint on. Also, apply torque only to load cell body. Slightly tighten load cell against flexure nut.

Attach the two standoff posts to the cell. If the load cell cable interferes with any hardware, place a washer in series with its connection to the flexure nut to clock it in its tightened position.

Adjust the thread on the rod-end until the lower block just mates with these posts. Tighten the jam nut. You have to pick

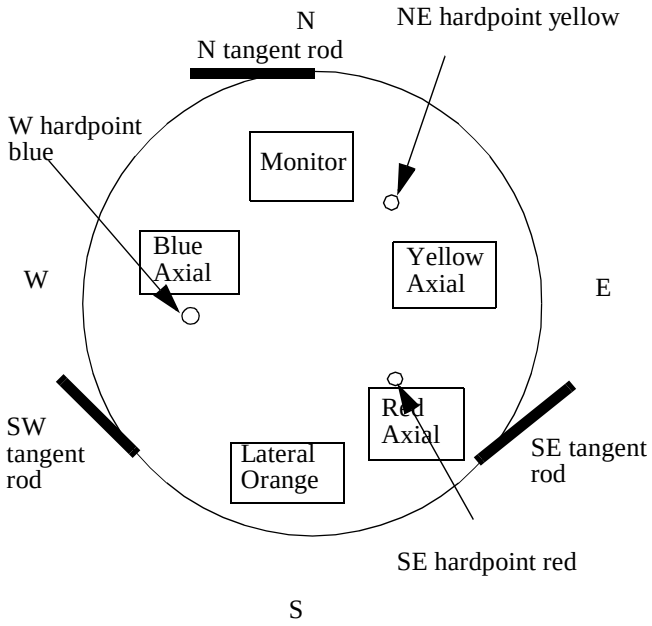
the nearest half-turn, so they won't mate perfectly. Do NOT

screw the two halves of the hardpoint breakaway against each other (large central thread). If the hardpoint was carefully removed, adjustment should be unnecessary.

Verify that the bolt going through the rear rod-end is tight on each unit. In fact, tightness is critical on these units, so check and adjust them carefully.

C. Electrical and Pneumatic Connections

There is a box for each of the 4 pneumatic zones (3 axial and 1 lateral). An additional box is installed too. The hardware is attached to the back of the cell with the following orientation.



- Connect axial load cells to corresponding color axial boxes.
- Connect red, orange, blue, and yellow pneumatic hoses to "OUT" on corresponding boxes.
- Connect N tangent arm load cell to box labelled Monitor.
- Connect SE and SW tangent arms to S box labelled Lateral. The connections can be reversed and proper operation still results (we only care about the sum of these load cell outputs).
- From the small distribution PC board, connect ribbon cables to the boxes: orange lateral -> DR3, red axial -> DR1, yellow axial -> DR2, LCM Monitor -> DR4, and blue axial -> DR5.
- An additional monitor cable gets connected to DR6 where the load cells may be monitored with digital meters: SE red axial -> pins 1,14; NE yellow axial -> 7,20; W blue axial -> pins 5,18, and N tangent arm -> 9,22.
- Connect red lead to +15, blue/purple to -15, and black to the common ground of a dual power supply.
- Set up nitrogen bottle with a regulator adjusted for 35 psi. Distribute to the 4 boxes to the ports labelled IN.

NOTE: the load cell sensitivities as measured from DR6 are all 80mv/lb.

This photo shows the whole system attached to the iron

maiden.

D. Preliminary Power Up

IMPORTANT NOTE: The pressurized air MUST be supplied to the cell prior to turning on the electronics. When powering off, the air is turned off AFTER the electronics.

Lower mirror onto the axial bumpers by jacking the nylon screws under the 3 tripod leg pads. Be certain that pads are backed away from the mirror backplate.

Rotate cell to horizon-pointing with N up (*never* rotate S up). Set datum A to 90.0-deg with precision level. Turn on air then turn on electronics. Mirror should come back to operating position under servo control.

Verify mirror height and centration.

Measure N tangent load cell. After removing electronic offset, verify residual force on tangent rods is < 0.25-lb. If larger, there is a clocking error that must be corrected.

We measured the load cell offsets. Also, (+) voltage corresponds to compression and (-) to tension.

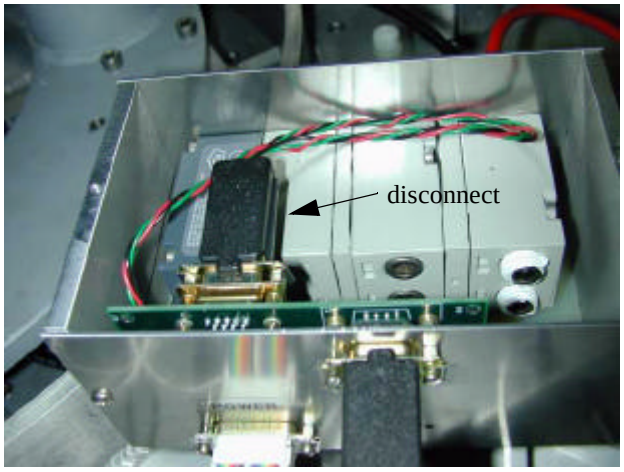
Table 1: Load cell electronic offsets.

load cell	offset V
N tangent	Not measured
NE axial	-0.075
SE axial	-0.015
W axial	-0.120

Power off electronics.

E. Final Lateral Support Measurements/Adjustments

With power off at horizon pointing, remove the lids on the 3 axial zone electronics boxes. Disable the axial servos by disconnecting the visible connector.



Power on air, then electronics. Now mirror is hanging by lateral servo system only. Any overturning moment due to a misalignment between the lateral supports and the mirror cg plane reacts directly against the axial hardpoints producing residual forces.

The lateral actuators must be adjusted until there is no more than 0.2-lbs force on any hardpoint and the sum of hardpoints no more than 0.1-lb (see Cuerden section 10).

Verify that load cell readings repeat when power is cycled and/or the mirror is jiggled by hand.

In practice, we ran out of lateral actuator travel before achieving the specs printed in Cuerden's document. Within the allowed travel, the best lateral support plane we could find is that specified in section VII D--preliminary adjustment of lateral actuators.

Here's a sample of our data vs. the position of the lateral support plane from datum A. The load cell voltages have the electronic preload removed. Only the NE and SE hardpoints react gravity torque since the W unit lies directly on the X-axis. The lever arm for the NE and SE hardpoints are both 11-inches.

Table 2: Axial hardpoint readings vs. lateral actuator plane.

A->act (i)	NE V	SE V	W V	Res Torque in-lbs
8.491	0.232	-0.033	-0.024	36.4
8.412	0.182	0.053	0.035	17.7
8.325	0.135	0.098	0.028	5.2

Power off electronics.

Reconnect axial servo system.

Power on. Rotate mirror as needed to verify that all is well.