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# Handling 20 Tons of Honeycomb Mirror with a Very Gentle Touch

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## ABSTRACT

The 6.5 meter and 8.4 meter mirrors being produced at Steward Observatory have to be lifted, turned, ground, polished, shipped and installed without exceeding 0.7 MPa (100 psi) stress in the glass. Many pieces of specialized equipment and some innovations are required to do this on a tight budget. We have developed lifting fixtures that are either glued on or held by vacuum. We have also designed turning rings that fill our lab, and transportation boxes to hold the mirror horizontal, vertical or in a ship. The sheer size and mass of the mirrors and equipment, plus the very stringent constraints makes the solutions interesting. This may not be the part of telescope design and construction that attracts the most attention, unless...

**Keywords:** handling, large mirror, LBT Telescope, MMT Telescope, Magellan Telescope, optics fixtures

## 1. INTRODUCTION

There are several steps in the production of large telescope mirrors that require handling fixtures. The requirements and design are dictated by the specific needs of your process. Here at the University of Arizona's Steward Observatory Mirror Lab we have tried to reduce the number of handling devices and therefore cost to a minimum. Once a raw mirror comes out of the oven a lifting fixture is bonded to the front face plate. The lifting fixture then serves to lift the raw mirror with mold materials off the furnace and into a turning ring. The turning ring then is rotated to vertical, where a clean out station is built around it. The hard refractories and ceramic fiber cores are then removed, leaving the glass mirror blank. The mirror is rotated another 90 degrees, bottom up, where the turning ring and lifting fixture are lifted by the crane and transferred to an aircart. The turning ring is separated from the lifting fixture. The aircart then transports the mirror blank to the Large Optics Generator where the lifting fixture, now on the bottom, supports the mirror during edge and back faceplate generating and polishing. A reverse path to the turning ring allows the mirror to be turned over and installed in the polishing cell. The lifting fixture is then removed. When the mirror is polished to perfection, it is removed from the polishing cell and installed in the telescope cell with the same lifting fixture, modified to use vacuum pads. After mirror integration in the telescope cell the mirror is again lifted with the vacuum lifting fixture and placed in the shipping container. Finally the mirror is transferred from the shipping container back to the telescope cell on the mountain.

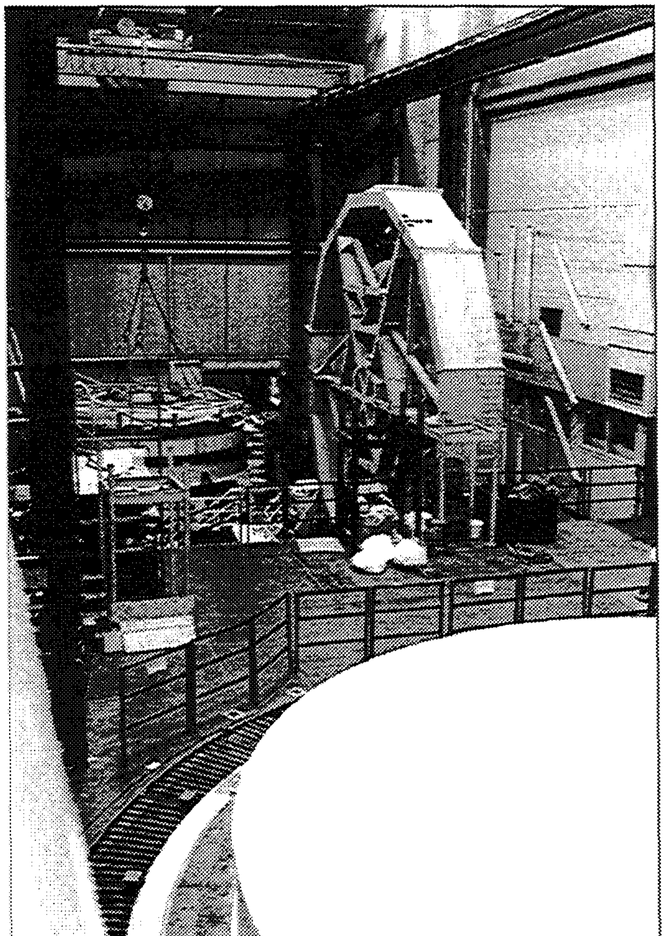


**Figure 1 Three mirrors in one room; LBT 8.4 on the oven bottom right, Magellan 6.5 vertical in ring behind lifting frame, MMT 6.5 on vacuum fixture being lifted from polishing cell**

## 2. HANDLING CONSTRAINTS

The ideal lifting fixture would handle any size mirror with absolute safety and have no cost. Practicality and constraints however dictates innovation and many compromises.

The first and most severe constraint is safety. As with all glass, we have to handle blanks that may have undetected flaws or cracks. We estimate the flaw size we think maximum and the time the glass is stressed, then failure theory dictates the stress we can put in the glass. Conservative assumptions lead us to a maximum tensile stress of 0.7MPa (100psi). This simple result dictates much of the philosophy that we must adopt. An 8.4 meter blank is 18,700 kg of glass, plus hard refractories and ceramic fiber for a total of 32,700 kg. We must have large contact areas at our lifting points. The lifting point must be well distributed to minimize global stress. We analyzed a "belly band" and found it had to push on the bottom, pull on the top and have a certain percent support in the inside hole of the mirror. In addition it required active horizontal force to keep the middle from bulging. It was clearly complex and costly. Without an edge band, the only other surface is the front face plate. After several patterns were analyzed we settled on a regular triangular pattern, even though the inside pads must have a reduced load. Attaching to the front faceplate also dictates the use of a glue. We use a one part Silicone RTV (G. E. Silicone II).

Cost is an ever present constraint since the more you spend on handling the less you can spend on the telescope. This is also a driver to use your fixtures for as many operations as possible. The support of the mirror in lifting, turning, clean out, back generating, back polishing, turning back over and placement into the polishing cell is done solely by the lifting fixture with its bonded rubber pads. This fixture fitted with vacuum cups then can be used to handle the finished mirror. The transportation box also serves as a mirror maintenance platform and storage container.

The size and shape of your facility can impose constraints. If they do not, then you spent too much money on them to start with. The transportation of the mirrors adds its share of constraints, with overpasses, narrow mountain roads and sea travel.

Schedule can impose restraints. For instance the need to use a lifting frame for a second mirror while it is still needed for the first.

## 3. 6.5 METER LIFTING FIXTURE

The 6.5 m lifting fixture was originally conceived as a universal fixture for 6.5 m and 8 m size mirrors but the joints and frame were not up to the task and it was welded in the 6.5 m configuration. The design principal used was that the main frame would have six equal deflection nodes where six load spreading subframes would be attached. Each subframe has six pads which have rubber "engine mounts" which act as springs. The philosophy is the springs deflect much more than the frames so the load is shared equally. The safety in the system is to have redundant pads so you can tolerate some failures. The use of kinematic frames and load spreaders would make a single point pad failure a true disaster. A secondary support system (like edge clips) was impractical because of the heavy masses. Figure 2 shows the lifting fixture in the turning ring with the MMT 6.5 m mirror in it. There are six ball joints with axial springs mounted at the equal deflection nodes. Subframes are then attached to each ball with six equal legs. Tilting end angles are mounted on all the subframe ends, each with a rubber engine mount. Either a 600 mm steel glue pad or a 600 mm vacuum pad then attaches to the

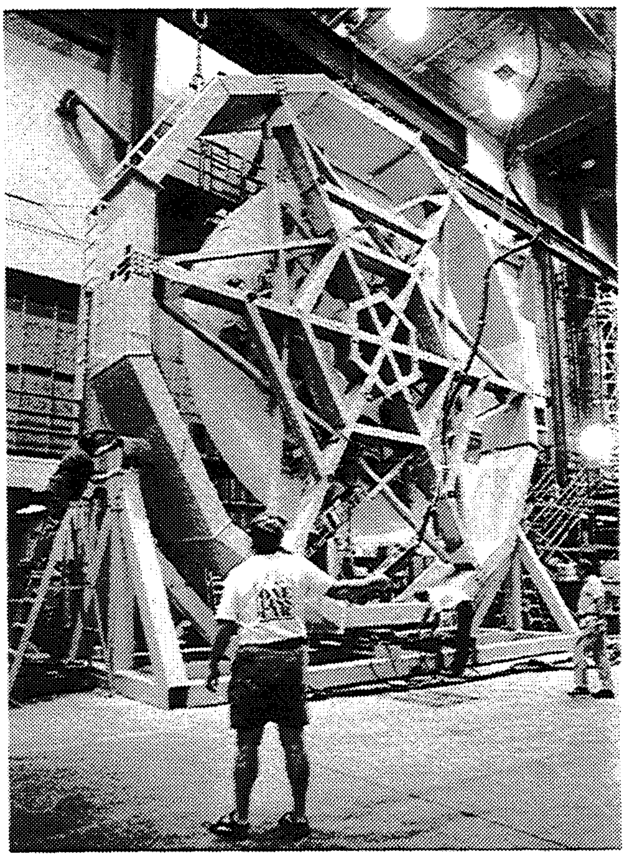


**Figure 2 6.5 Lifting fixture in turning ring with MMT mirror**

glass face plate. This simple geometry is all that is needed to match the steep faceplate geometry. The MMT variation of the lifting fixture has an outside diameter the same as the mirror so it can fit through the trunnion box of the telescope elevation frame. The reduced diameter and stiff frame made it an excellent dummy mirror for cell development with just the addition of a back plate. The dummy mirror is needed to test the support system, which is very desirable, so safety tests can be done without risking large glass mirrors.

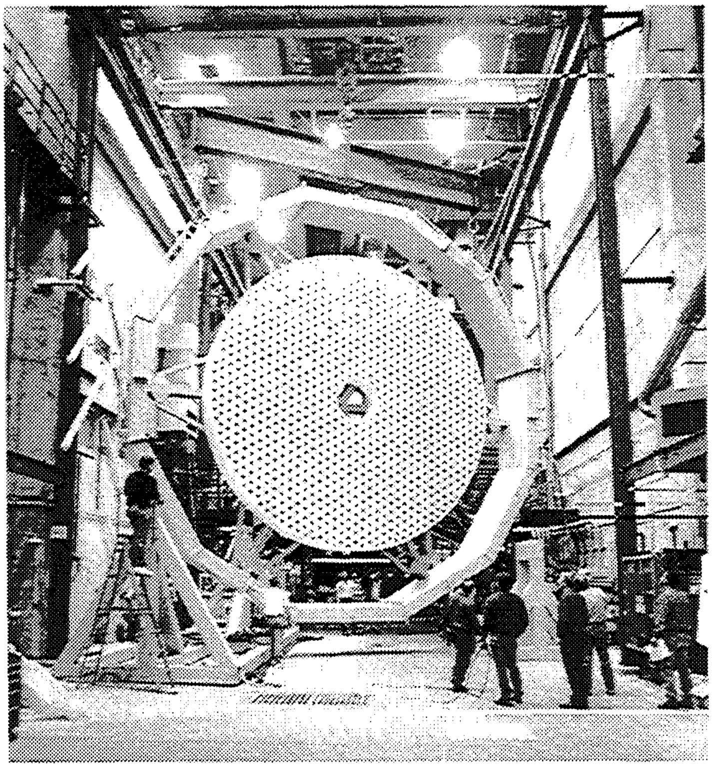


**Figure 3 Turning ring with MMT mirror**

## 4. TURNING RING

When a new casting is lifted from the oven with the lifting frame it is bolted to the turning ring. The turning ring has trunnions on one side. The other side is lifted until the ring is near vertical where hydraulic cylinders assist alignment, stability and tie down. A clean out station is then brought in so the hard and soft refractories can be removed from the casting. After the blank is cleaned and inspected, the ring is lifted from the trunnions, rotated, set back down and lowered to horizontal. This puts the lifting ring on the bottom so the turning ring serves an attachment point for cables and a load spreader. After polishing the ring is used to turn the mirror back over. Figure 3 shows the ring being rotated with the MMT 6.5 m mirror in it.

## 5. 6.5 METER TRANSPORTATION CONTAINER

### 1. The Basic Design

The MMT is located on the summit of Mt. Hopkins, 40 miles south of Tucson, Arizona, at the Smithsonian Institution's Fred Lawrence Whipple Observatory. The roads include smooth interstate highway that require the box be transported flat and steep mountain roads with banks that require the box to be nearly vertical. The Magellan Telescope will be located at the Observatories of the Carnegie Institution of Washington, Las Campanas Observatory, Chile. The trip there will also include a sea voyage. The finished 6.5 m mirror weighs 9000 kg. The support system for a 6.5 m mirror requires the bonding of steel pucks, most of which are attached to loadspreaders. Figure 4 shows the basic structure of the transportation container. For the transportation box we connect two three-puck load spreaders with an invar beam for a support point. The total is 204 pucks on 68 loadspreaders, with 34 support beams. The support beams are supported by two rubber mounts that act in shear in the two gravity directions and has steel springs in the third direction. All three directions have the same spring constant. The inner box frame has only 4 members in the principal direction and a cross member on each end. The springs bolt directly to clips on the main beams. The inner frame is mounted in an outer frame with three axial and two lateral pneumatic supports, arranged in a kinematic configuration. Both the inner and outer structure is 300 mm x 600 mm x 8 mm wall structural tube. The outer frame supports a cover of light structural steel and insulated sandwich panels. The outer frame can then be tortured during transportation with twisting truck beds, turning on

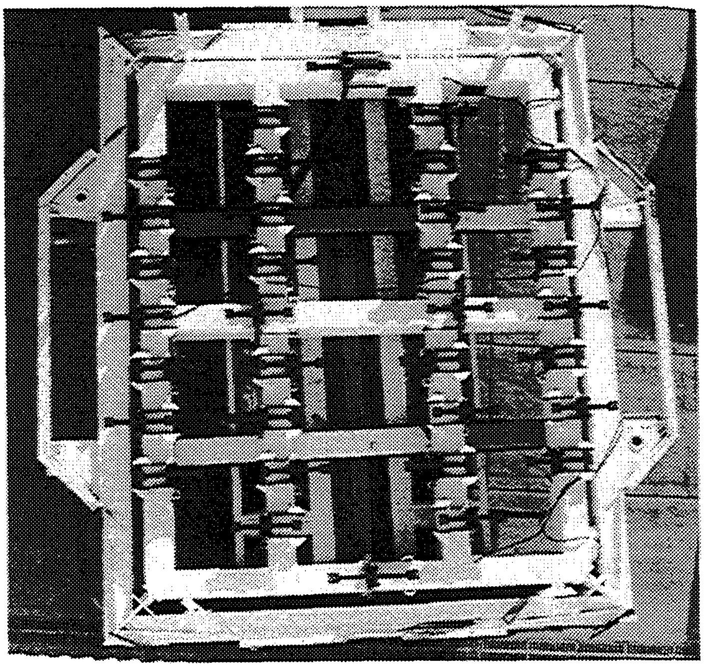


**Figure 4 The frame of the transportation container showing the 34 support beams**

edge, setting in trunnions, uneven lifting cables, welded to ships and setting on uneven ground in the sun with little risk to the mirror.

2. **Inspection and Maintenance Platform**

The support on only four beams provides a very open structure for any inspections or maintenance that might be needed, especially during the manufacturing phase. The redundant nature of the support also allows a limited number of them to be removed if desired.

3. **Design Principal**

The basic theory is to reduce the hard bumps and vibrations seen by the mirror by mounting it on springs. What would be a hard shock during a short period can be reduced to a soft displacement for a longer period, much reducing the stress the mirror sees. The downside of this is that moderate bumps can be amplified or a resonance can cause excessive motion. The way we have found around this is to make two isolation systems. The first is to mount the mirror on many rubber isolators, which commonly have their resonance above 10 Hz and a travel of a couple of inches. The platform for these rubber mounts is then mounted in a kinematic manner with pneumatic isolators, which commonly have their resonance about 5 Hz and a travel of several inches. The pneumatic isolators have rubber snubbers near the end of their travel for very large bumps or an air failure. This system gives the mirror a very redundant support to tolerate failures and a box very forgiving of transportation support problems.

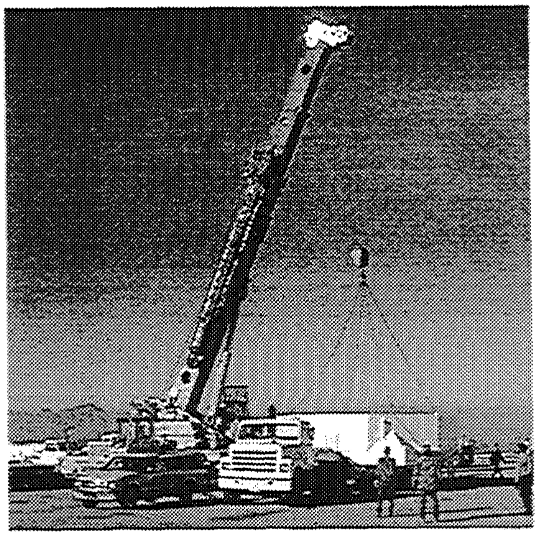


**Figure 5 Lifting the 6.5 box from the highway transportation truck with a crane**

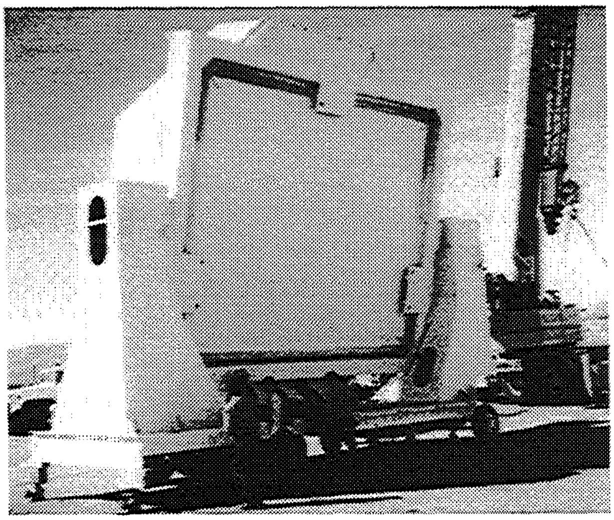


**Figure 6 Transportation box on edge for the mountain trip**

## 4. Low Cost

The cost of the transportation container for the 6.5 m mirrors is very economical. Simple straight and repetitive members were used wherever possible and where special parts were needed they were obtained from different vendors. J. T. Williams was able to purchase and finish it for $120,000 US. This is about $2.15 per pound. The MMT and Magellan have split the price and I presume Magellan II will reach a deal so the container can carry three mirrors.

# 6. 8.4 METER LIFTING FIXTURE

The 8.4 meter lifting fixture concept is similar to the 6.5 meter one but the implementation is considerably different. The pattern of the pads had to be improved to keep the stress acceptable on the larger, heavier honeycomb mirror. We went from equal length legs in the substars to three long and three short. We placed them on a uniform triangular pattern and still had to reduce the force on the inside pads by a factor

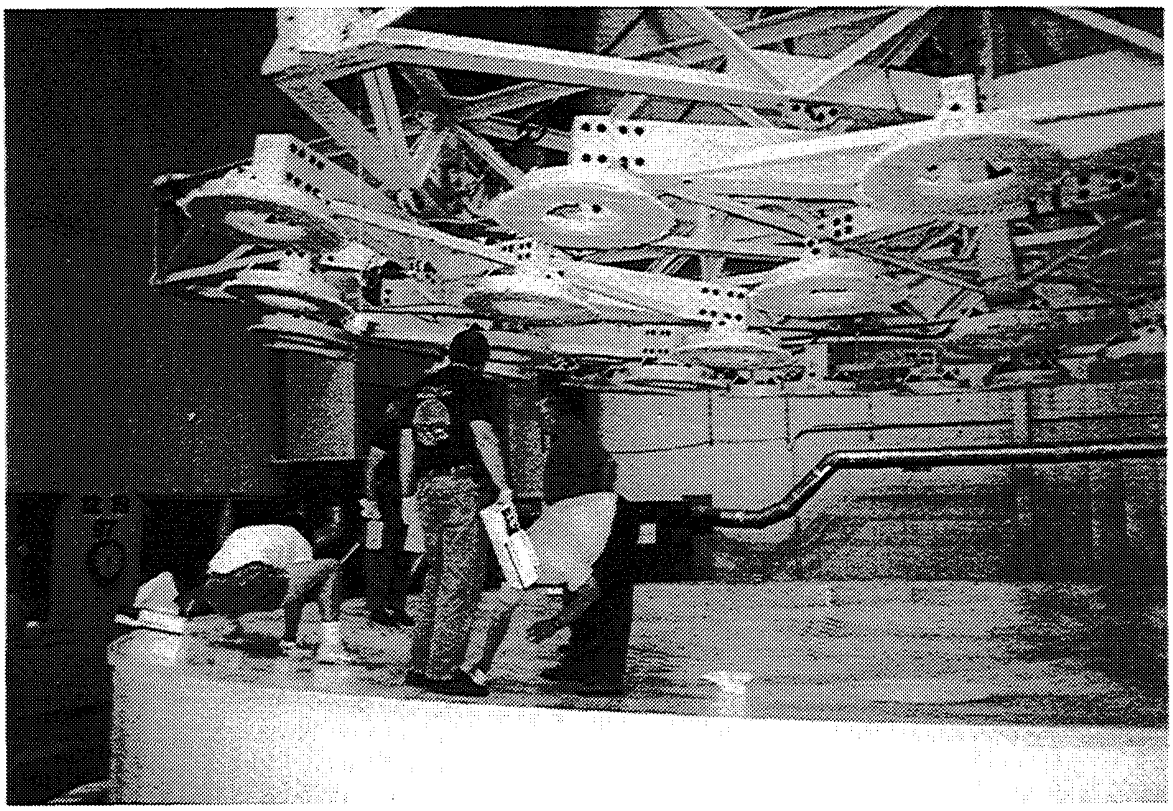
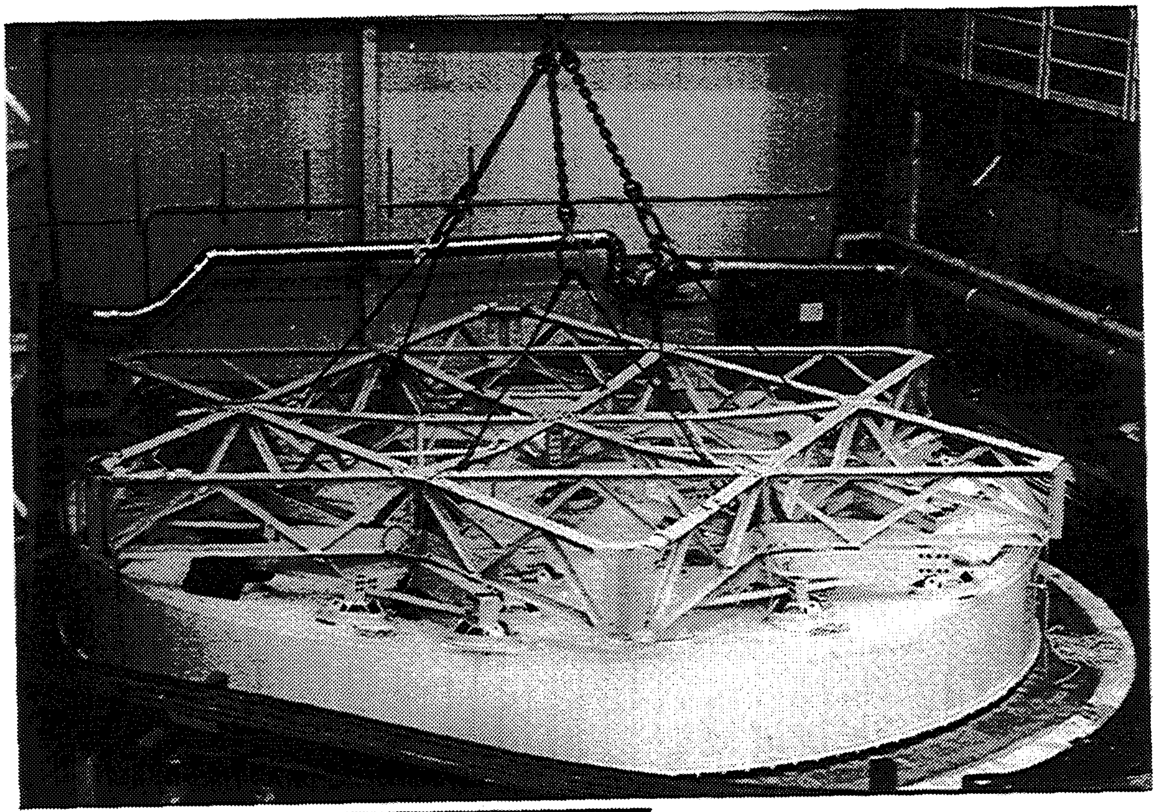


**Figure 7 Lifting fixture being prepared to glue on to the LBT 8.4 m mirror**

of two. The 6,400 kg main frame was replaced by a 2,600 kg frame to lift twice the weight. The two rubber "engine mounts" with 4 mm deflection were replaced by three sandwich mounts with up to 50 mm of travel. The ball joints between the main frame and substars were replaced by three links so the pivot joint would be well inside the glass at the local center of gravity. Figure 7 shows the lifting fixture being prepared to be attached to the LBT 8,4 m mirror sitting on the furnace. This figure also indicates a new era in mirror production where several people are required to **walk** on the mirror at one time. Figure 8 shows the lifting structure attached to the LBT 8.4 m mirror ready to lift off the furnace. Figure 9 shows the bottom of the LBT 8.4 m mirror. The hard refractories are almost all that is visible. The furnace floor with spacers and thermocouples is in the bottom of the picture. Figure 10 has the lifting fixture in the turning ring, which nears the vertical clean out position.



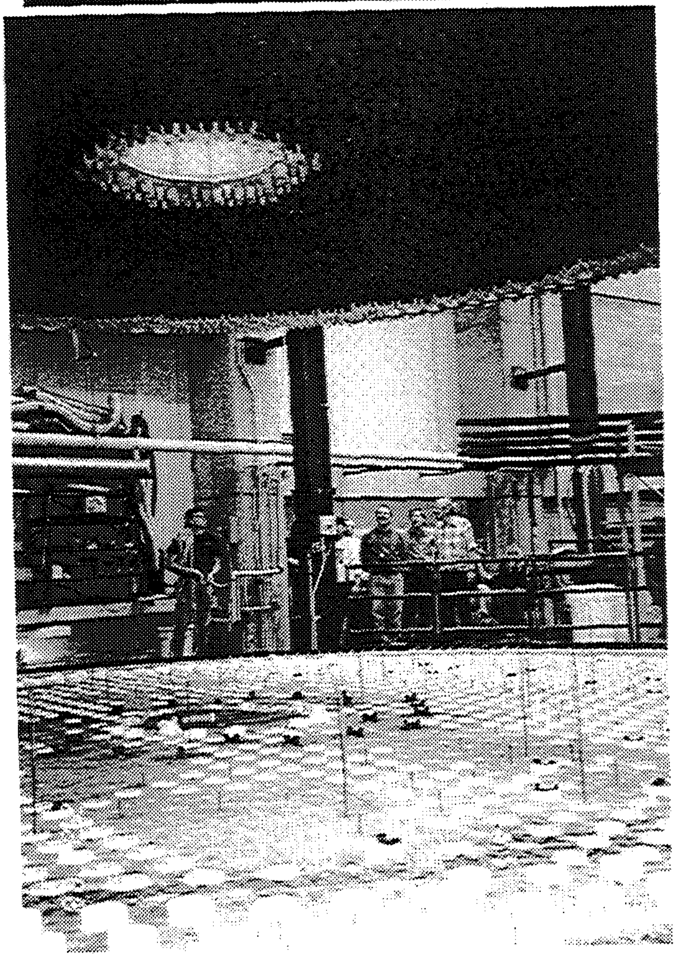


Figure 8 The lifting fixture with the LBT 8.4 m mirror before it is lifted off the furnace

Figure 9 The LBT 8.4 m mirror base (top) lifted off the furnace (bottom)

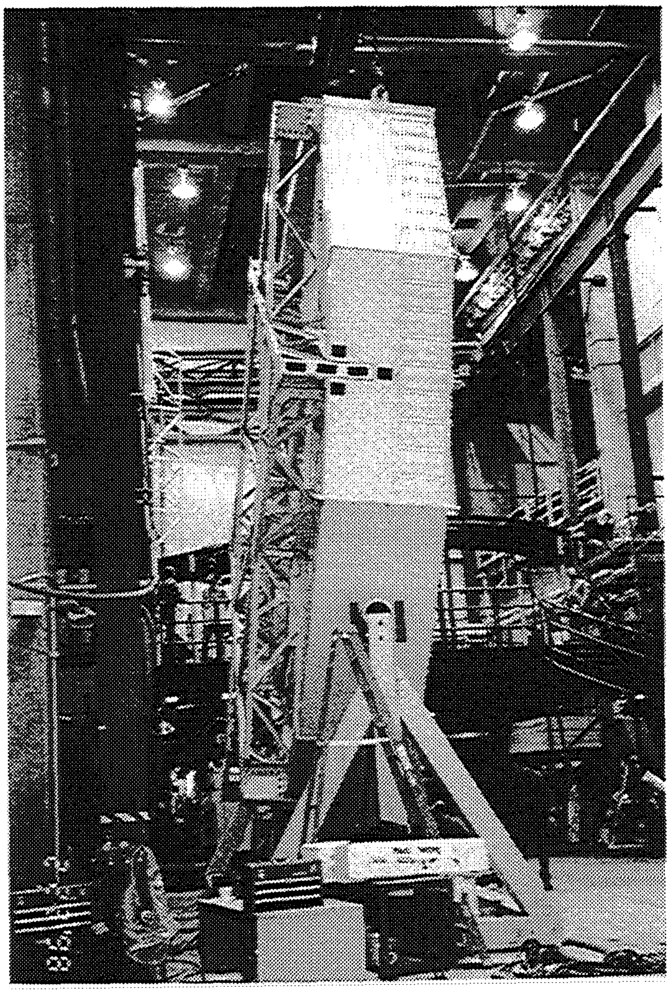


**Figure 9 Lifting fixture with LBT 8.4 m mirror in turning ring, near vertical**

## 7. VACUUM LIFTING FIXTURE

The vacuum lifting fixture is a combination of the lifting fixtures above and a set of 36 vacuum pads. The frame and the rubber mounts are the same but the steel pads glued on by RTV have been replaced by vacuum pads. Figure 11 shows the MMT 6.5 m finished mirror (with Opticote on the polished surface) being lifted and transferred to the transportation box frame for inspection, cleaning and installing some additional parts. Figure 12 shows it being installed in the telescope cell for "cell integration". The foreground is filled with a foam mat if it is necessary to set the mirror down. The basic system was purchased from Vac-U-Lift which has been producing them for a very long time. The 36 pads are divided into 6 circuits, and each circuit is evenly distributed on the glass. Loss of one circuit would be no problem. Loss of two circuits will increase the glass and operator stress into the uncomfortable range. Loss of three circuits does not precipitate doom with certainty but four does. The pumps run continuously and with power loss auxiliary reserve tanks are automatically engaged. Power can be off for at least a day and probably a week before things get critical. This should be enough time to lower the mirror or find a portable generator. Lots of glass has been handled with these devices but we are still a little paranoid. We have special shaped pads that match our radius of curvature and a thick waffle pad to be sure. The stress from the edge reaction of a disk would be worrisome to any curved thin plate, but if the vacuum is locally reacted against there is little problem. We thoroughly tested the damage to glass, optical coatings, applying optical coatings afterwards and lifting with protective coatings between the glass and pads. The system was remarkably tolerant and very gentile. Our preferred lift is with the glass, Opticote, and the pad. An aluminized mirror with Opticote would probably lift with no damage to the surface. This system will work with either 6.5 or 8.4 meter mirrors.

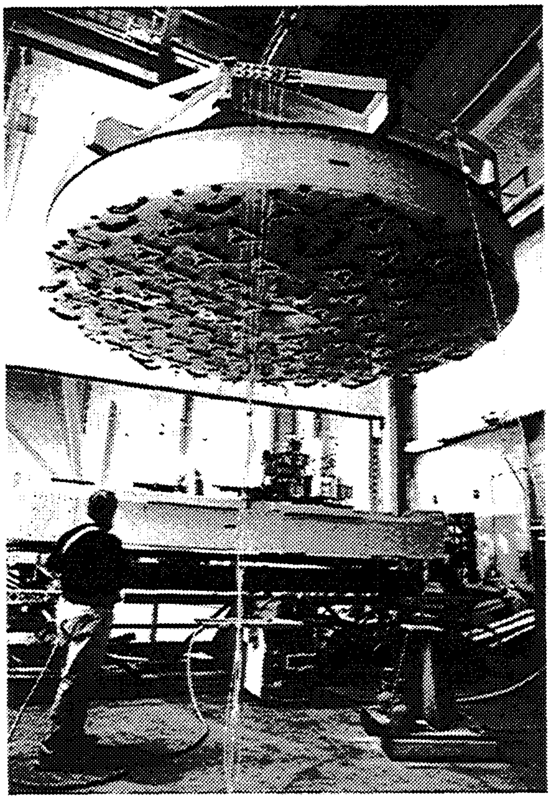


**Figure 11 Transfering the MMT 6.5 with the Vacuum Lifting Fixture onto the base of the transportation box for inspection**

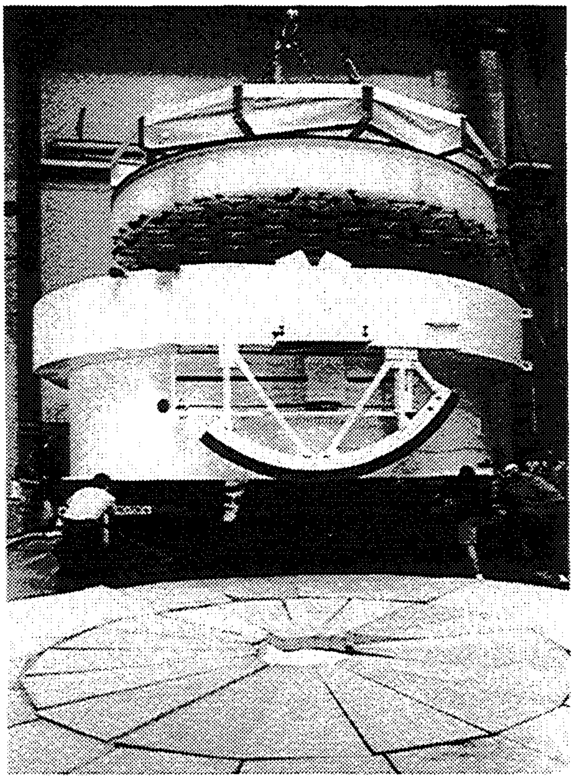


**Figure 12 Vacuum lifting fixture with the MMT 6.5 mirror being installed into the telescope cell in the lab**

## 8. HANDLING EQUIPMENT QUANTITIES

The mirror handling equipment that has been created for the two 6.5 m and the 8.4 m mirrors is quite a list for such universal fixtures. The 6.5 m lifting was the first. The turning ring is truly universal serving both the turning and clean out functions of both size mirrors. Schedule and fitting into the MMT telescope cell has required the construction of a second fixture, which was a copy of the first but trimmed to the size of the mirror. The MMT Observatory made its fixture so it could be converted with plates to a dummy mirror, which has proven invaluable in the initial cell integration, transportation and telescope tests. The 6.5 m MMT dummy mirror has also served as the core for an 8.4 m dummy mirror. The Magellan telescope requires a lifting fixture simply because of its distance from Arizona. The LBT 8.4 m mirror has only one lifting fixture. The MMT and Magellan are partners in the 6.5 m transportation box. The minimum expansion of this list is for an 8.4 m transportation box.

## 9. CONCLUSION

The handling of the large 6.5m and 8.4 m mirrors at the University of Arizona Mirror Lab is being done with a minimum of moves and fixtures. The driving reasons are the knowledge that every time you handle glass there is a chance of breakage, our limited space and our desire to put the money into telescope instead of special equipment. We have endeavored to minimize both the risk and the cost although they are competing criteria. The sharing of designs, fixtures and boxes among the MMT, Magellan, LBT and the mirror lab has also been very effective in reducing the costs.