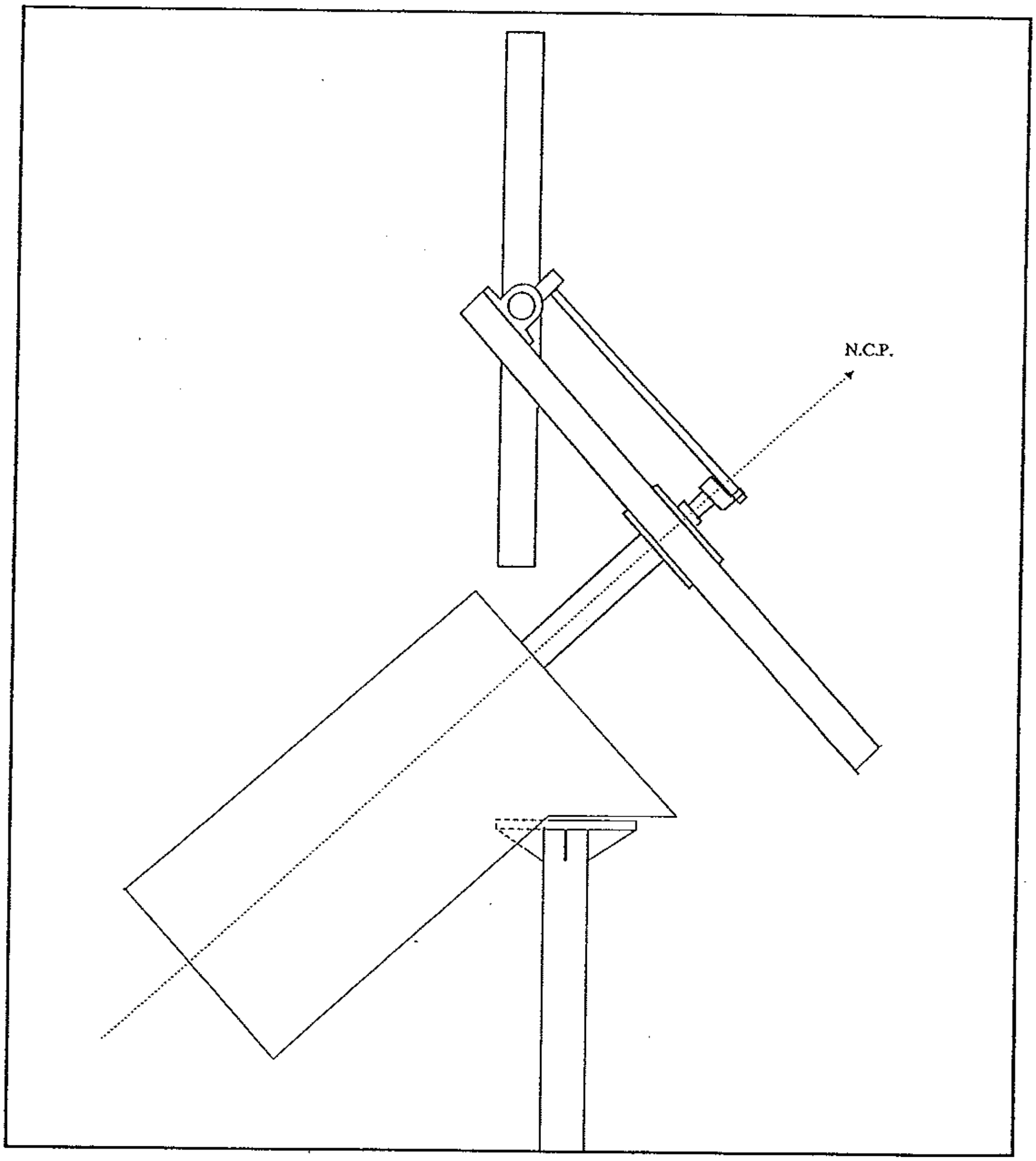
PHOTONICS CENTER HELIOSTAT DESIGN AND OPERATION



Kenneth Janes - May 1997

I. The Concept

Janet Saad-Cook's Sun Drawing sculptures are meant be placed in sunlight, to reflect the changing aspects of the Sun during the day. However, the Sun Drawing in the Photonics Center atrium is 70 feet down from the skylight, so and is never in direct sunlight. A *heliostat* is used to bring a beam of sunlight into the atrium, to a second set of mirrors that re-direct the light onto the Sun Drawing. The Photonics Center heliostat consists of a polished stainless steel mirror, driven by a single motor and a gear system that tracks the Sun in its daily path across the sky and adjusts for the seasonal changes in the Sun's elevation above the southern horizon. Because the it is mounted on the roof of the building, the heliostat operates automatically and continuously, tracking the Sun even when it is below the horizon. Each morning when the Sun rises, the heliostat mirror is oriented to catch the sunlight and direct it down to the secondary set of mirrors. The heliostat mirror is offset from the primary axis of rotation of the heliostat, so that the beam of sunlight appears to pivot about a point just below the skylight.

The secondary mirrors, mounted on the wall of the atrium between the 8th and 9th floors have a semi-circular shape, in part to reflect the shape of the atrium, and in part because the beam of sunlight coming from the heliostat makes an oval path along the wall at that level. The three secondary mirrors are separately adjusted so that as the beam of sunlight crosses each mirror, the light is directed to the Sun Drawing.

The heliostat was designed by Kenneth Janes and constructed by the Boston University Scientific Instrumentation Facility.

II. Design Considerations

The basic requirement for this heliostat is that it must deliver a bright spot of sunlight from the roof of the Photonics Center to the Sun Drawing sculpture above the 7th floor for several hours each day. To achieve this goal, several factors must be taken into consideration:

1. The heliostat must operate automatically, with little or no human intervention.

2. It must be able to take the environmental extremes likely to be found on the Photonics Center roof.

3. The beam of sunlight must be directed along a path to the Sun Drawing that takes into account the shape of the atrium and the orientation of the Photonics Center building relative to the direction to true North.

4. The beam of sunlight should not strike the Sun Drawing at a fixed angle, but should show some change or movement during the day, as it would if the Sun Drawing were in direct sunlight.

To accomodate the extremes of weather, the heliostat was constructed largely out of stainless steel and aluminum. The few parts not constructed stainless steel or aluminum are painted or oiled to keep them from rusting. It is driven by a single one rpm motor, through a gear train to two concentric drive shafts. The outer drive shaft turns the heliostat mirror once per solar (ordinary) day, and the inner shaft turns once per sidereal day, thereby making one extra revolution per year. A cam and rocker arm assembly driven by the inner shaft causes the heliostat mirror to oscillate north and south to track the seasonal changes in the position of the Sun.

An ordinary heliostat would send the sunlight along the polar axis of the heliostat, that is a line parallel to the axis of rotation of the Earth. From the roof of the Photonics Center, this path would send the sunlight to a spot on the upper wall of the atrium, along a line at an angle of about 9 degrees from the line of symmetry of the atrium. To get the sunlight further down into the atrium, and to preserve the aesthetics of the space as much as possible, the heliostat is offset to the west side of the skylight, and is strategically "misaligned" to direct the beam down to a spot centered on the South wall between the 8th and 9th floors. The heliostat mirror is offset from the axis and is oriented so that the beam of sunlight pivots about a point just below the skylight, which means that the sunlight always goes through the same windowpane, without being significantly blocked by the windowframe.

Three mirrors mounted between the 8th and 9th floors catch the beam of sunlight as it passes across the wall, following a path approximating the curved lower edge of the mirrors. The sunlight begins to strike the right-hand mirror shortly after 9:30am (standard time) and goes off the left-hand mirror around 2:30pm EST. Each mirror is oriented so that when the sunlight is centered in the mirror, the light is directed approximately to the center of the Sun Drawing. Thus the sunlight makes three separate passes across the Sun Drawing, striking it at somewhat different angles and orientations.

Engineering drawings for the major components are attached to this report.

III. Installation and Alignment

The heliostat is mounted on four posts attached to the roof of the skylight well, located so that the heliostat directs the sunlight through the third windowpane from the West side of the skylight. The electrical connection was made by the Walsh Brothers staff, with weather tight conduit running from the West wall directly to the heliostat gearbox. The heliostat is wired into the emergency power system of the Photonics Center, so it should never go off for more than a few seconds at a time. A switch on the wall can be used to turn the drive motor off for maintenance or repair.

The heliostat is presently aligned for optimum operation; in principle, most of the alignment steps will never need to be done again. However, for the record, the complete alignment procedure is as follows:

1. Using the leveling screws on the heliostat base plate, adjust the elevation of the polar axis for the latitude of Boston (42° 20′ North). (A slightly steeper angle will cause the sunlight beam to make a straighter path across the secondary mirrors - the polar axis is presently set to about 45°)

2. At local solar noon (11:45 EST), rotate the solar axis of the heliostat so that the top and bottom edges of the mirror are horizontal.

3. At the same time, within a few minutes, orient the azimuth of the polar axis so that the beam of sunlight strikes the middle (in the left-right sense) of the central mirror inside the atrium.

4. Orient the sidereal axis so that the cam plus rocker arm are set to the correct day of the year.

5. Finally, adjust the length of the rocker arm so that the sunlight goes to the middle of the central secondary mirror.

If the heliostat is ever turned off, or if high winds or deep snow and ice cause it to stall out, then steps 2 and 5 will need to be re-done. Unless the heliostat is completely disassembled, the other steps will never need to be repeated.

IV. Maintenance

The heliostat should require little or no human intervention in its ordinary operation. But it is a machine with moving parts, so periodic inspection, adjustment and lubrication will be necessary. It is also possible that unusually strong winds or heavy snow could knock the heliostat out of position, but this should not happen very often.

A semiannual lubrication schedule should be set up, once in the late spring and once in the late fall. The following actions should be taken:

1. Lubricate the gear train. White lithium grease, available at most hardware stores, works fine for this purpose.
2. Check the gears, particular the large worm gears, for signs of wear or other problems.
3. Use a standard grease gun to lubricate the main bearings of the heliostat.
4. Check for signs of rust and either spray any affected parts with a penetrating oil such as WD-40 or paint with Rustoleum.
5. If needed, adjust the orientation of the mirror for the time of day and the season.
6. Clean the mirror surface *gently* with a soft cloth and water.

If these simple steps are taken, the heliostat should run for many years without any other attention.

The secondary mirrors on the 9th floor wall should not ordinarily be touched. If they need cleaning, it will be necessary to bring in a lift or construct a scaffolding for the job.

V. Limitations and Future Enhancements

Although the heliostat is a precision instrument, it is not intended for ordinary astronomical use. It would not be possible, for example, to use it to get an actual image of the sun for example. Many people have suggested that a "modern" device should be set up under computer control with sensors to find the Sun, or fixed with controls that could be operated by spectators, etc. While these things could certainly be done, they would have added substantially to the cost and complexity of the project. In addition, they would not really fit with the artistic vision of the Sun Drawings - Janet Saad-Cook's idea is that the Sun Drawings should follow, as closely as possible, the natural daily and seasonal changes of the sun.

The heliostat does not at the moment account for an effect known as "The Equation of Time." The true Sun does not cross the meridian at a fixed time as measured by ordinary clocks, but at some seasons is as much as 15 minutes ahead or behind clock time. Because this phenomenon has not been accounted for, the sunlight will at some seasons (late fall and early spring) fall somewhat lower on the secondary mirrors than it will at other seasons. It would be possible to correct for this effect, and modifications could be easily made to the heliostat, if this should turn out to be a serious problem.

VI. Parts List and Drawings

1. Drive Train

a. *Polar Axis Shaft* – Stainless steel tube, 2" O.D., 3/8" wall, 30" long.
b. *Sidereal Rate Shaft* – Stainless steel rod, 1" O.D., 36" long.

c. Polar Axis Bearings (2) – Dodge Engineering Type E pillow block bearings, 2-bolt base. (2" bore, Cat. No. 060374). If item 1 is turned down, replace with 1 15/16" bore, Cat. No. 060362.

d. Shaft Collars (2) – McMaster-Carr Cat. No. 6462K43, stainless steel, one-piece collars, 2" bore (or equivalent).

e. Shaft Collars (2) – McMaster-Carr Cat. No. 6462K25, stainless steel, one-piece collars, 1" bore (or equivalent).

f. Declination Cam – Stainless steel rod, 1.5" diameter, 2.5" long, machined as in the figure.

g. Ball Joint Rod End (2) – McMaster-Carr Cat. No. 59915K84, stainless steel 0.375" bore, 3/8-24 thread (female).

h. Threaded Rod – Stainless steel, 3/8-24, 14" long, approx.

i. Rocker Arm – Stainless steel rod, 2 7/8" long × 0.5" square, as shown in the figure.

2. Declination Axis

a. Declination Axis Crosspieces (2) – Steel square tubing, 2" O.D, 1/8" wall, 24.5" length.

b. Declination Axis Supports (2) – Steel square tubing, 2" O.D, 1/8" wall, 34" length.

c. Declination Axis Bearings (2) – Dodge Engineering Type LM800 pillow blocks, (3/4" shaft) (Cat. No. 033692).

d. Declination Flange – Steel plate, 6" square × 1/8".

d. Declination End Plate – Steel plate, 29" × 2" × 1/8".

d. Declination Counterweight Plates (several) – Steel plates, 28" × 2" × 1/8".

e. Declination End Plates (2) – Steel plate 2" square × 1/8".

f. Declination Axis Shaft – Stainless steel shaft, 3/4" O.D., 29" long.

3. Polar Axis Housing

a. Polar Axis Base Plate – Steel plate, type "Cor-ten", 15" × 10" × 1/2".

b. Heliostat base plate – Steel plate, type "Cor-ten", 13.5" × 10" × 1/2".

c. Polar Axis Side Plates (2) – Steel plate, type "Cor-ten", 26" × 9.5" (approx/) × 1/4". See figure.

d. Gearbox Top End Plate – Steel plate, type "Cor-ten", 4.25" × 10" × 1/4".

e. Gearbox Bottom Plate – Steel plate, type "Cor-ten, 11.25" × 10" × 1/4".

f. Gearbox Lower End Plate – Aluminum plate, 12.75" × 10.5" × 1/8". (The top end rounded to a 5.25" radius).

f. Polar Axis End Plate – Aluminum plate, 17.5" × 10.5" × 1/8". (The top end rounded to a 5.25" radius).

4. Mirror Support Structure

a. Mirror Center Rib – Steel bar, 1/8" thick. 30" × 1 7/8".

b. Mirror end Ribs (2) – Steel bar, 1/8" thick. Two pieces, 30" × 2".

c. Mirror Cross Ribs (2) – Steel bar, 1/8" thick. Two pieces, 23 3/4" × 1 3/4".

d, Mirror Back Plate – Steel plate, 1/16" thick. 30" × 24".

e, Mirror Top & Bottom Plates – Steel plate, 1/16" thick, 23 3/4" × 2".

f, Mirror anchor posts (8) – 1/2" square × 1".

g, Mirror side clips (8) – 3/8" square × 1", as shown in drawing.

5. Heliostat Base/Support Assembly

a. Pedestal – Stainless steel tube, 4 1/2 feet long, 2 1/2" diameter.

b. Top Plate – Stainless steel plate, 10" square by 1/2" thick.

c. Support Beams – Aluminum I-beams (4) Approx 3.5 feet long.

d. Base Posts – Galvanized steel pipe nipples, 2" dia. by 12" long, with top and bottom flanges.

6. Drive System

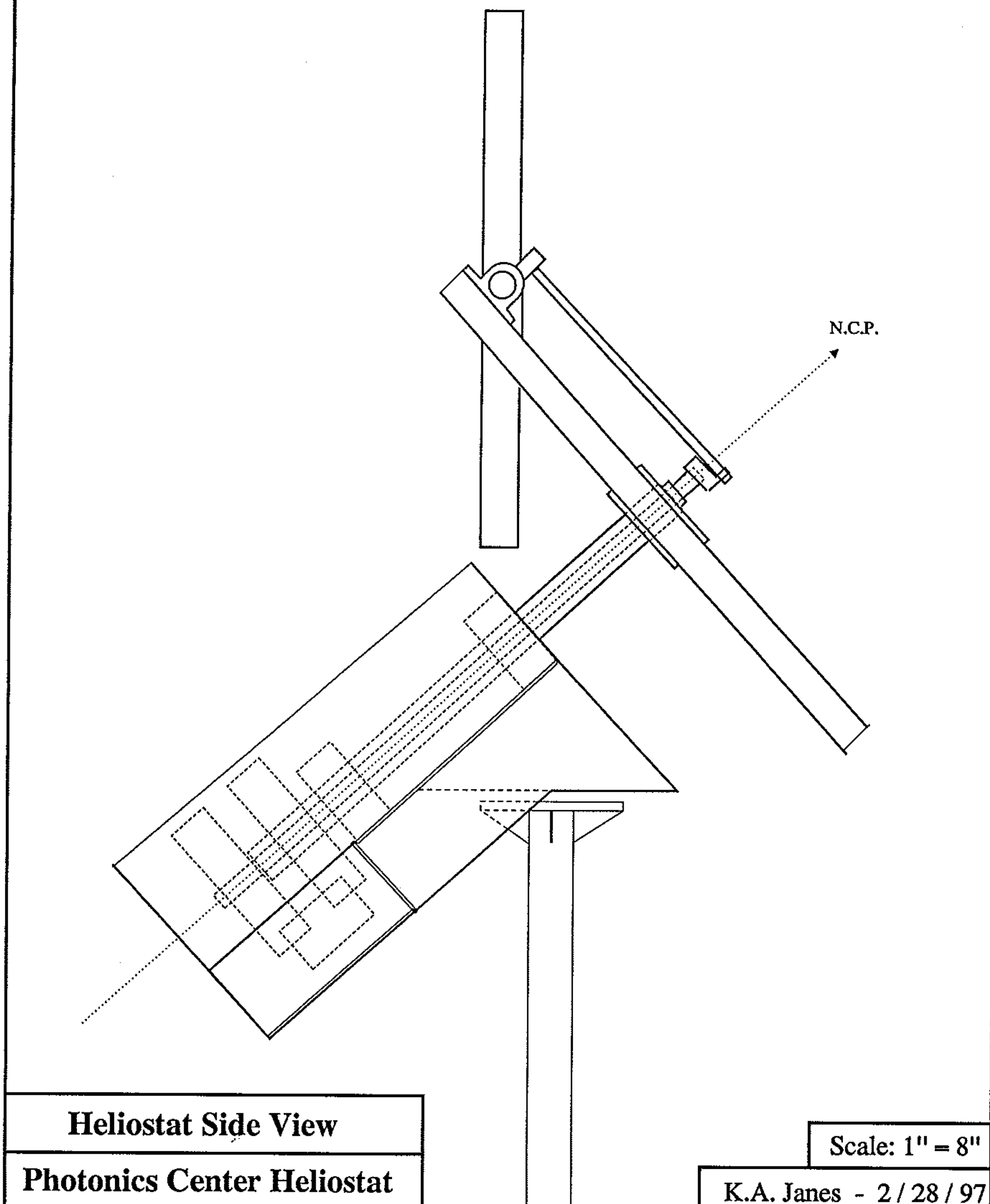
a. Drive motor - Hurst model "T", one rpm, AC synchronus motor.

b. Gear Train - 32-pitch, stainless-steel spur gears on 1/4" shafts:

1. 32-tooth gear (3)
2. 25-tooth gear (1)
3. 19-tooth gear (2)
4. 17-tooth gear (1)
5. 96-tooth gear (1)
6. 107-tooth gear (1)

c. Worm and worm-gear assemblies - 9-inch diameter, 32-pitch, 285 tooth aluminum worm gears and matching stainless-steel worms. (2)

Drive system Base plate - Aluminum plate, 3/8" thick, 10 1/4" long by 9 1/2" wide.



Heliostat Side View

Photonics Center Heliostat

Scale: 1" = 8"

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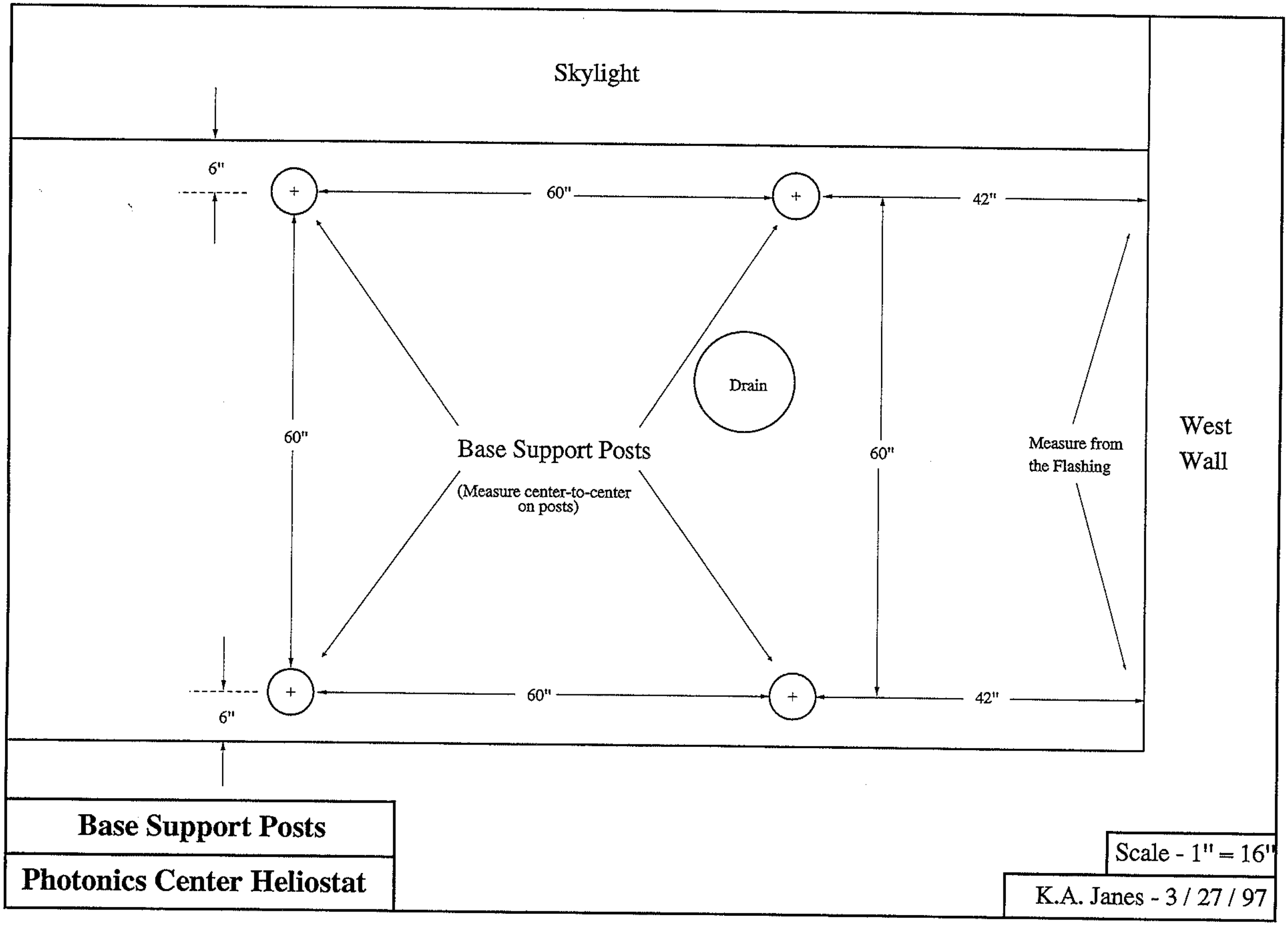
Skylight
6"
60"
42"
60"
Drain
Base Support Posts
(Measure center-to-center on posts)
60"
Measure from the Flashing
West Wall
60"
42"
6"
Base Support Posts
Photonics Center Heliostat
Scale - 1" = 16"
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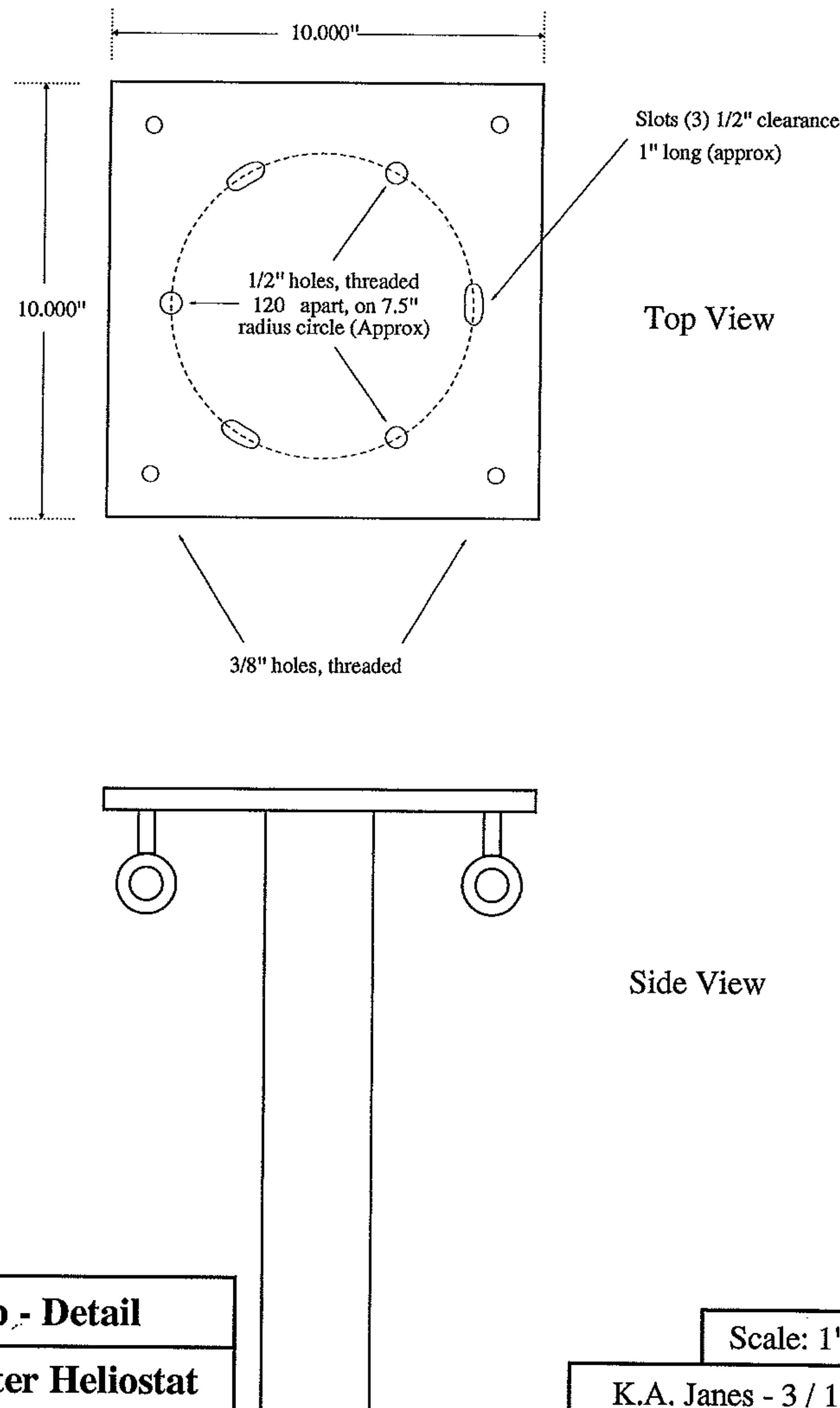

Pedestal Top - Detail

Photonics Center Heliostat

Scale: 1" = 4"

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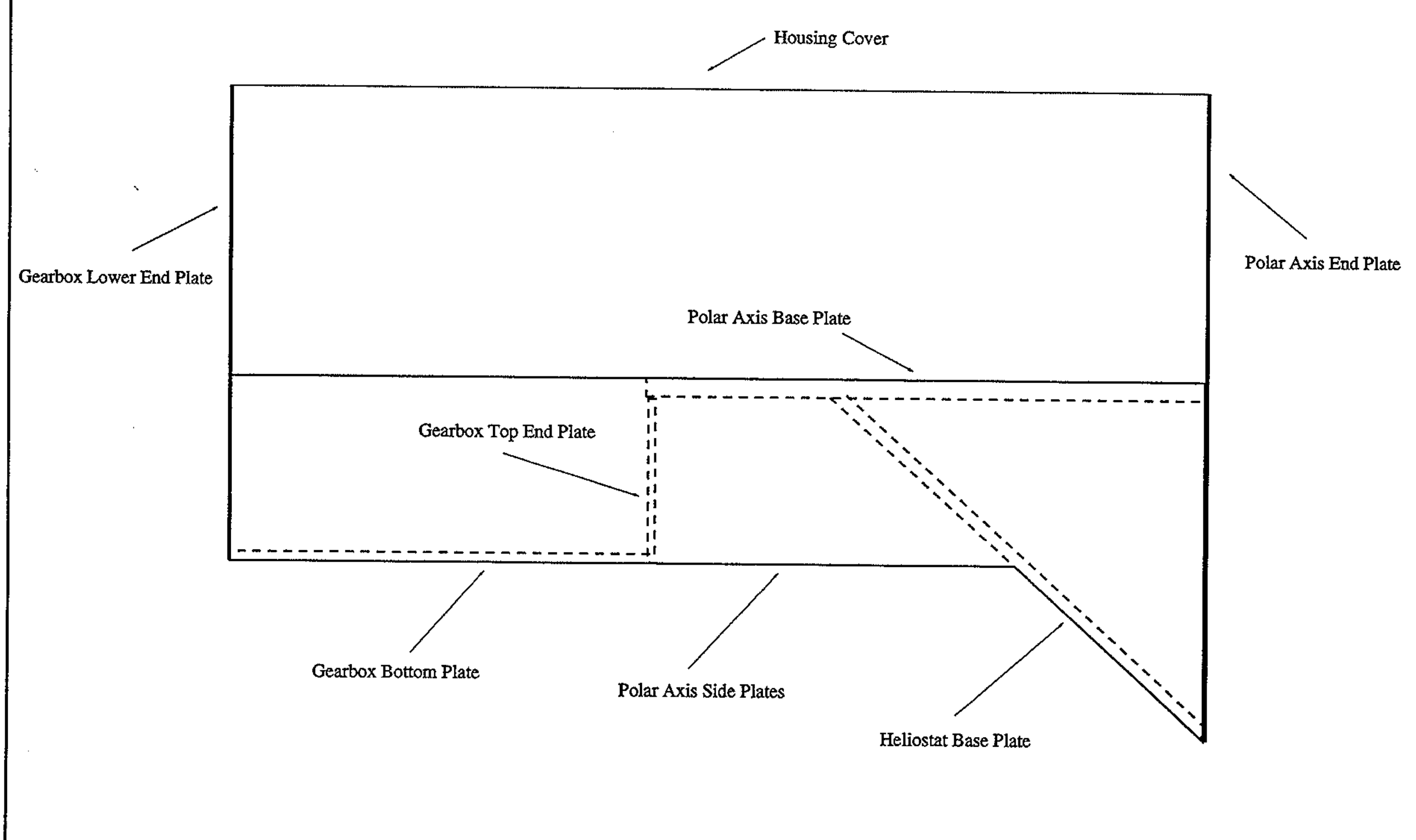

Polar Axis Housing - Side

Photonics Center Heliostat

Scale 1" = 4"

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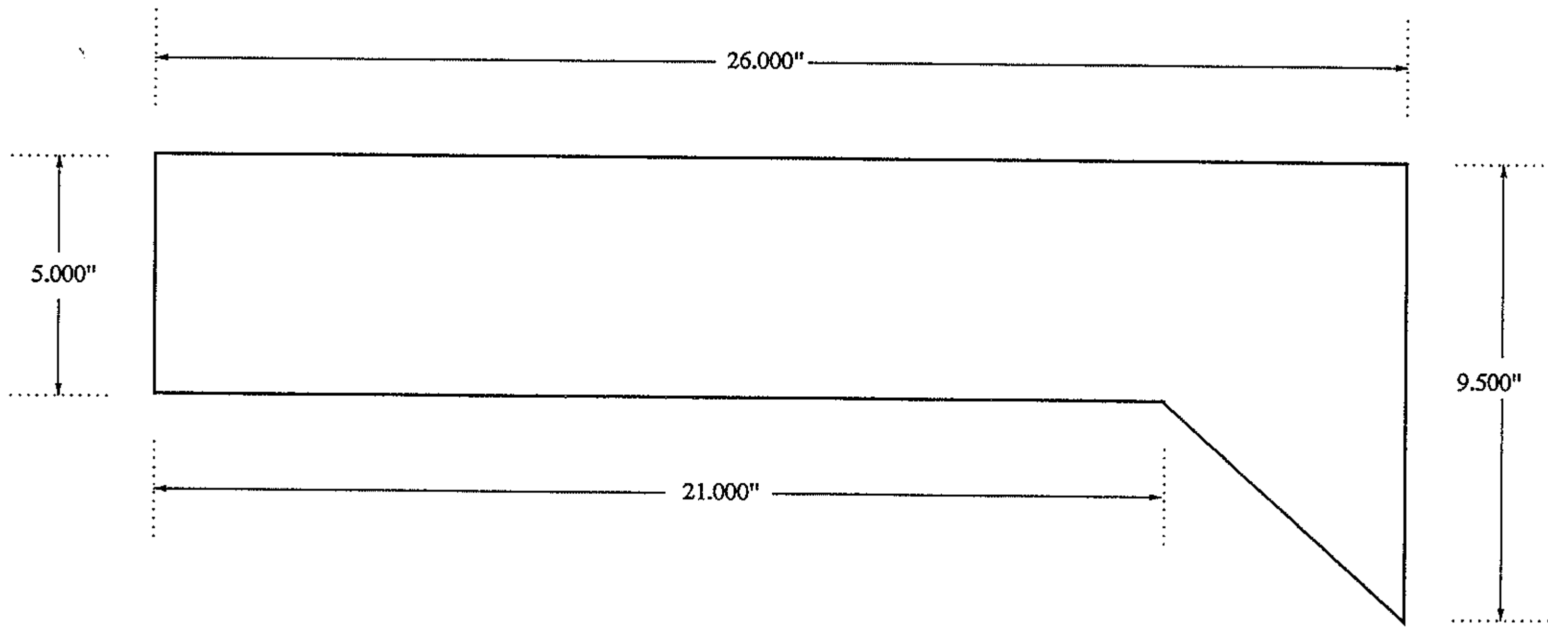

Polar Axis Side Plates

Photonics Center Heliostat

Scale 1" = 4"

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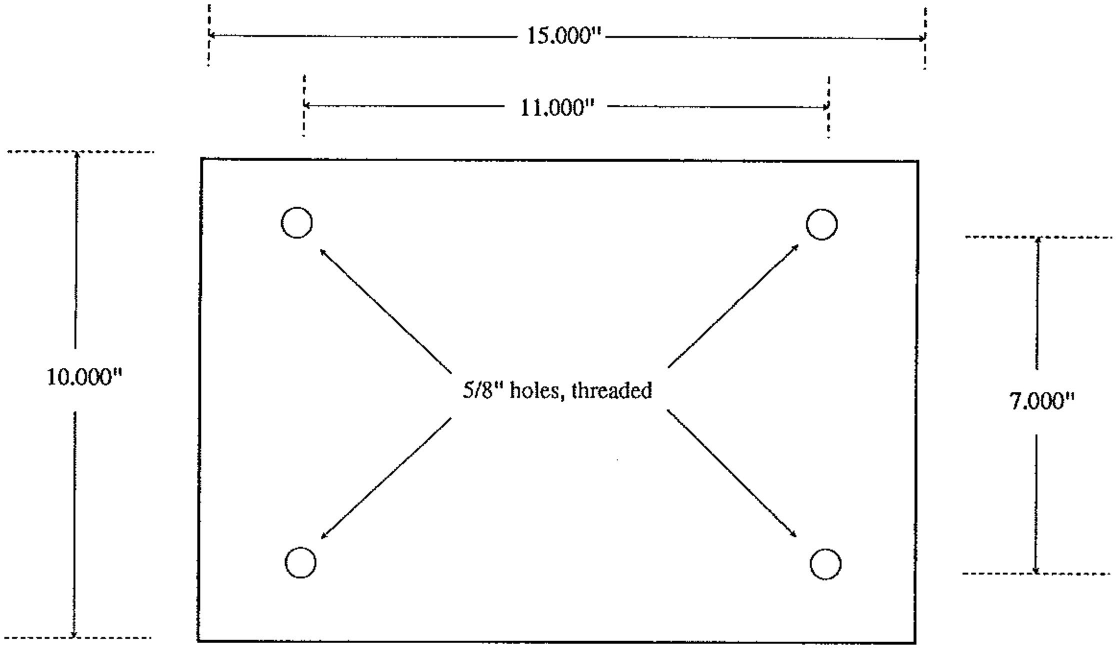
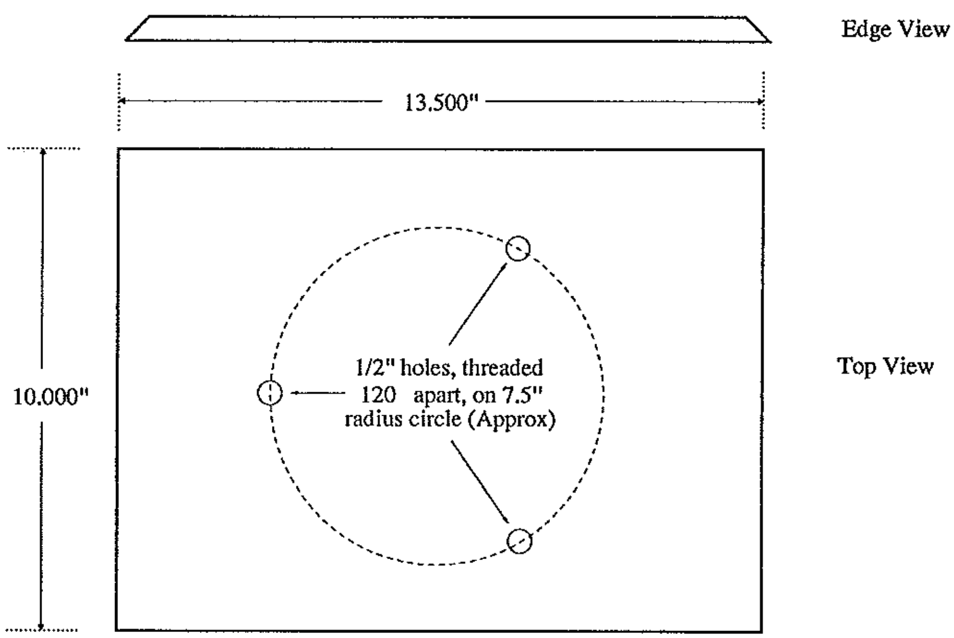


Polar Axis Base Plate



Heliostat Base Plate

Polar Axis Housing - Detail

Photonics Center Heliostat

Scale: 1" = 4"

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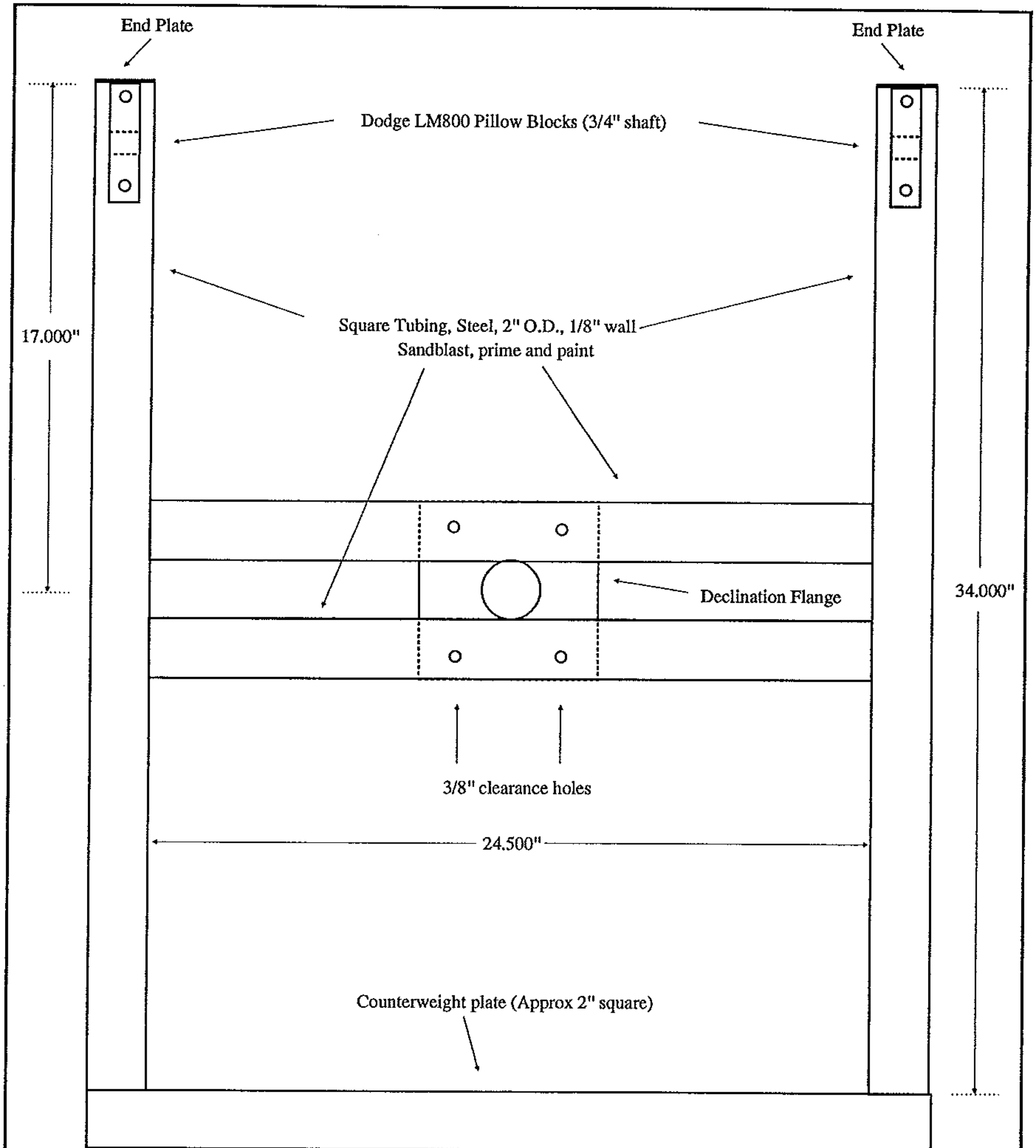

Declination Axis Support

Photonics Center Heliostat

Scale 1" = 5"

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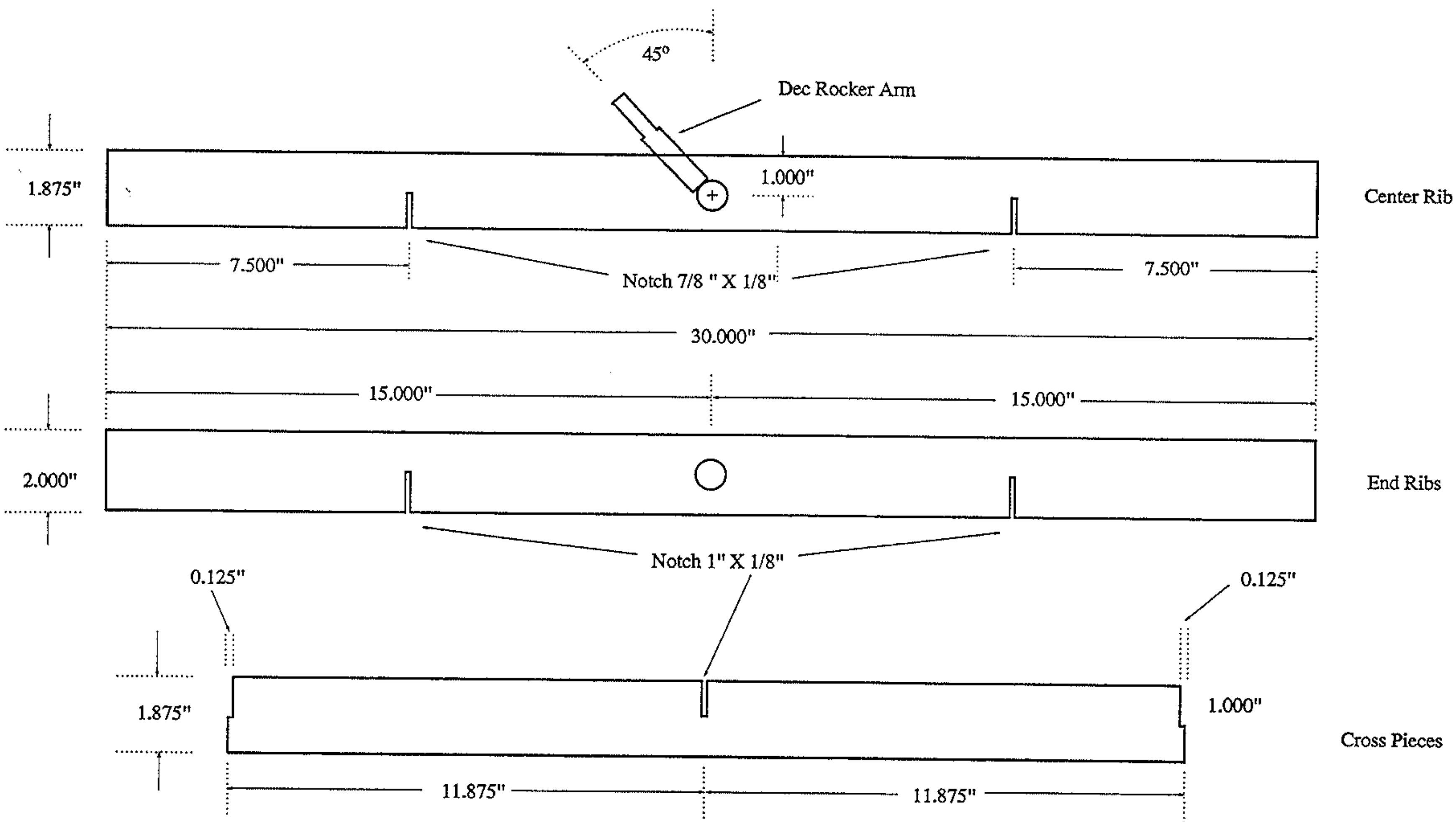

Mirror Support Sections

Photonics Center Heliostat

Scale 1" = 4"

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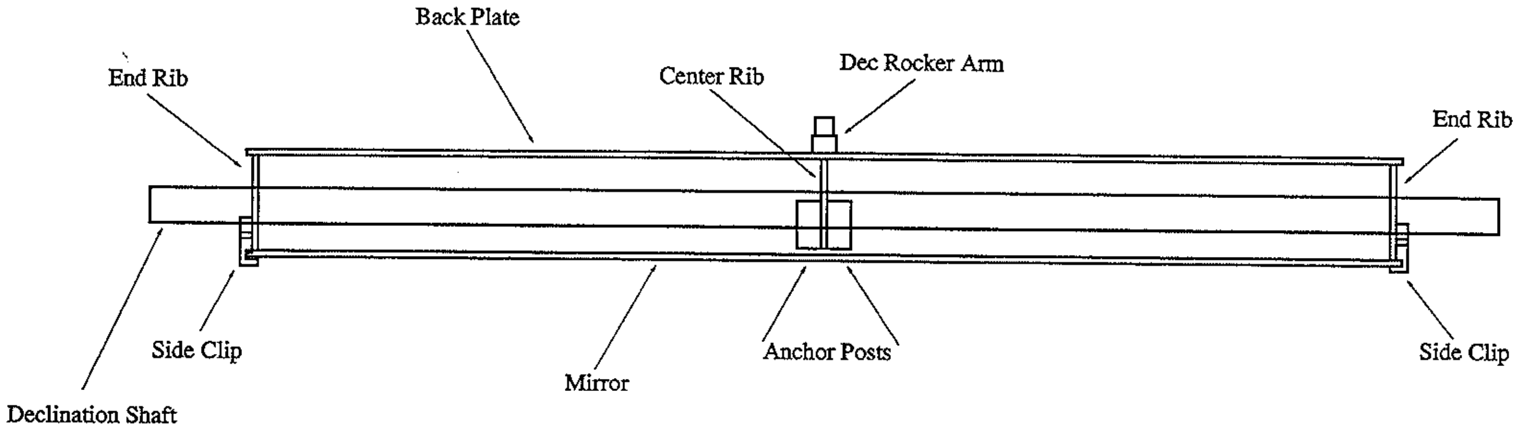

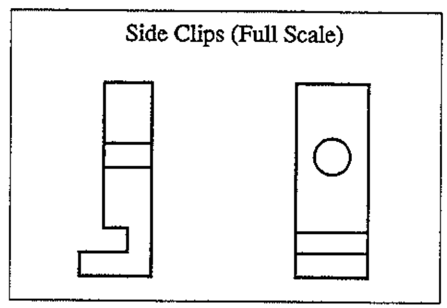

Mirror Mount - Top

Photonics Center Heliostat

Scale 1" = 4"

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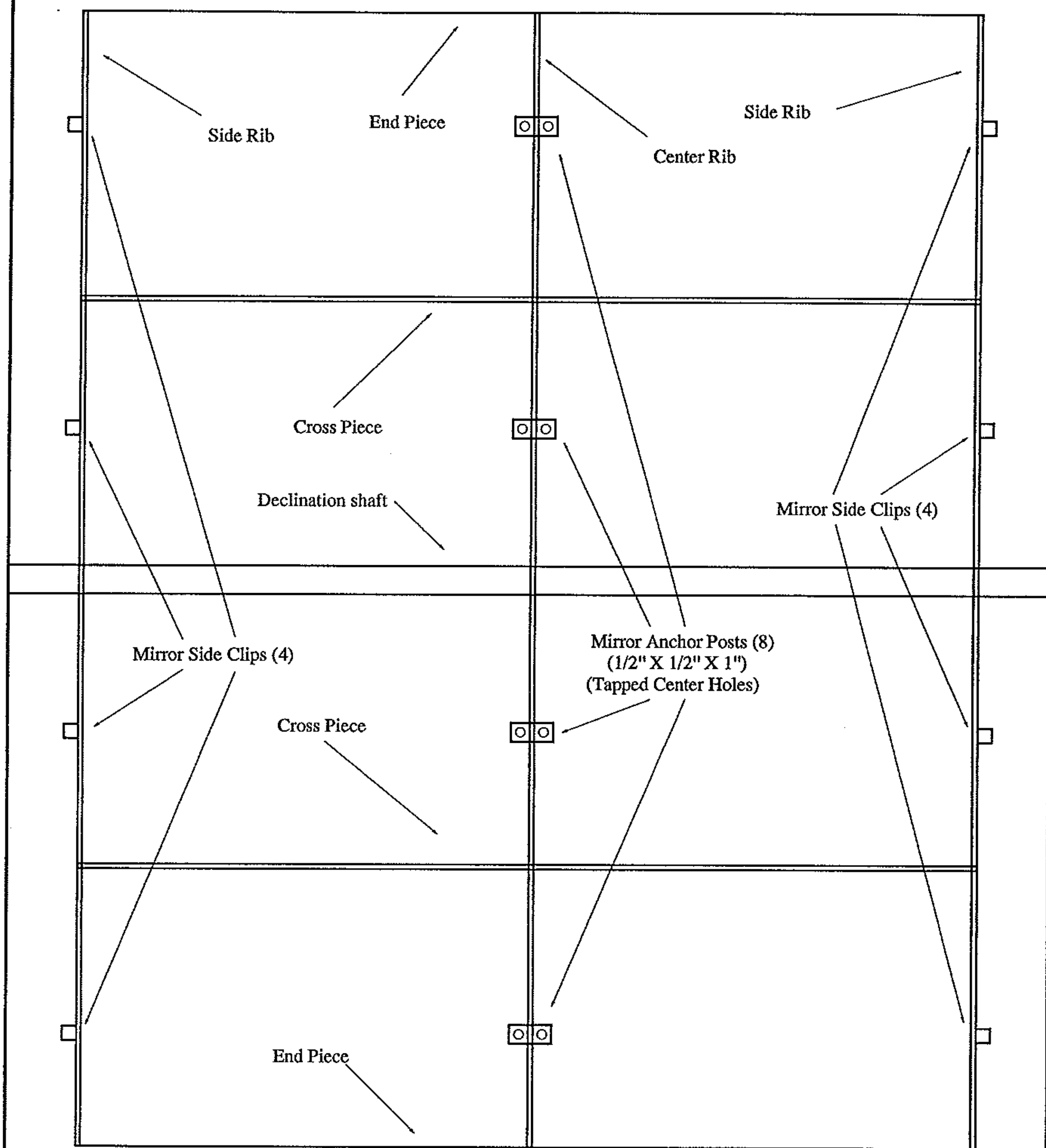

Mirror Mount (Front)

Photonics Center Heliostat

Scale: 1" = 4"

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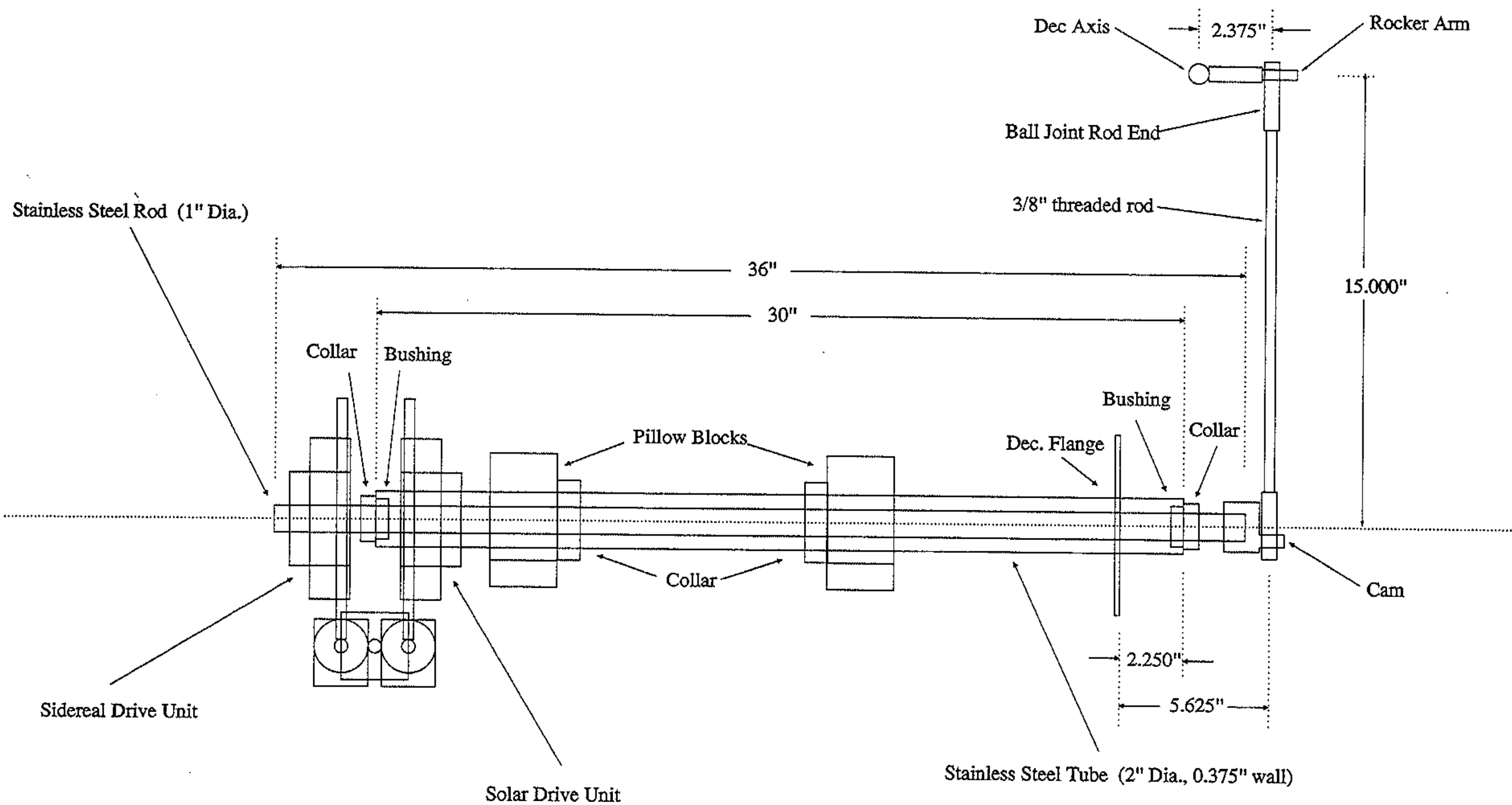

Drive Train

Photonics Center Heliostat

Scale 1" = 6"

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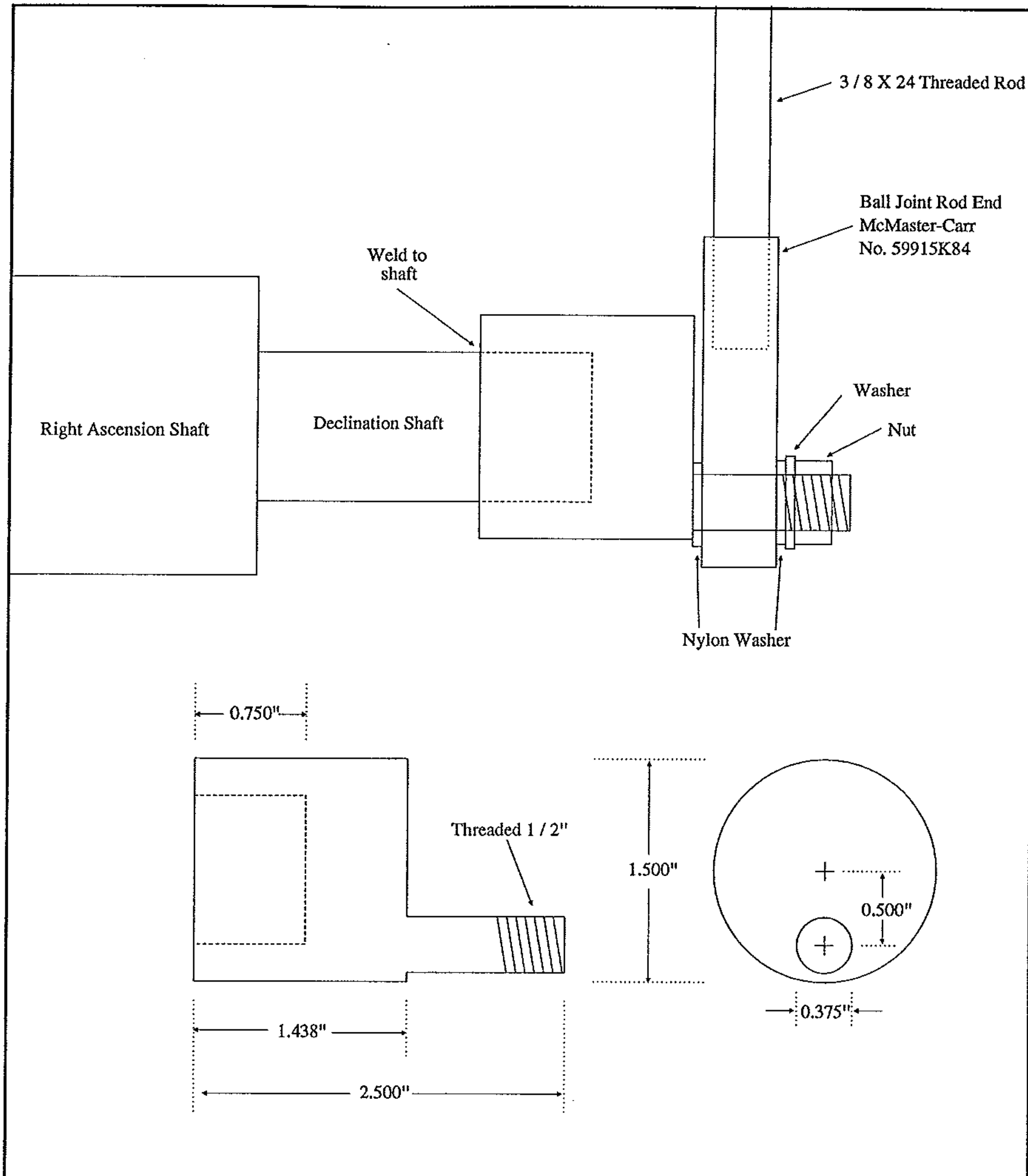

Declination Cam

Photonics Center Heliostat

Full Scale

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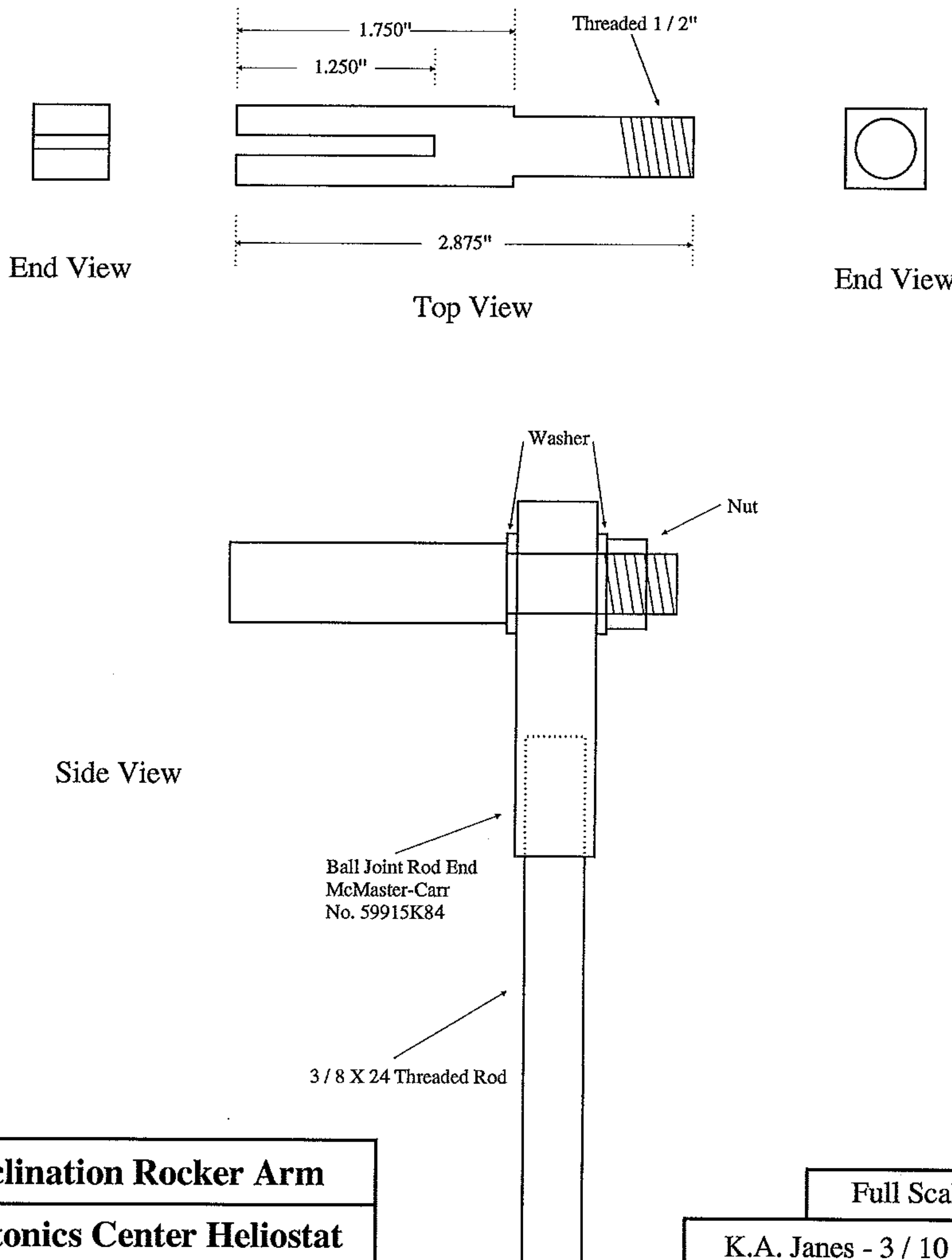

Declination Rocker Arm

Photonics Center Heliostat

Full Scale

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