Mounting of Optical Components

Mirrors

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8. Mounting of mirrors

- Mounting small mirrors
  - Clamping
  - Bonding
- Issues with larger mirrors
  - Thermal
  - Self weight

Mounting of small mirrors

- Small mirrors: self-weight deflection is not important
- Mirror mounts usually need to control mirror tilt and axial position accurately
- Mounts for non-flat mirrors also must control lateral position
- Mirrors are sensitive to distortion due to over-constraint

- Methods of mounting small mirrors
  - Clamp them : but be careful not to cause distortions
  - Bond them : but watch out for thermally induced distortions
  - Use flexures to provide stress-free mounts that accommodate temperature changes

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Commercial mirror mounts

- Standard mirror mounts use a single set screw to clamp the mirror in place
- These work fine in the laboratory, as long as the screw is snug, but not tight.
- These are not adequate for an instrument. The mirror will not be stable as the instrument suffers even minor vibration or shock loading.
- Make this more stable by potting the mirror into the mount

Simple clamping for small mirrors

- **Small, stiff circular nonmetallic mirrors are frequently mounted in the same manner as lenses, i.e., held in a cell by a threaded retainer, flange, or elastomer.**

  - **Convex mirror**
  - **2nd surface mirror**

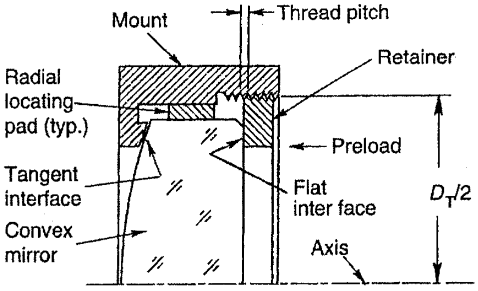


Figure 9.11

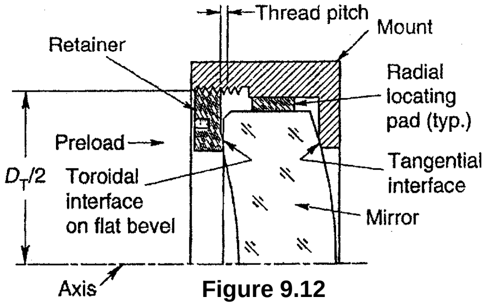
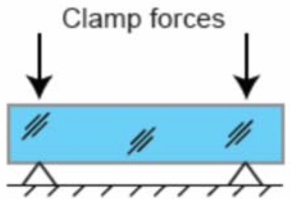


Figure 9.12

- Make certain that the preload force is in line (at the same radial location) as the constraint
- Depart from ring contact so mirror is define by three shims. Again make certain that preload force is in line with these three points



Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Stress from clamp ring

- If axially-directed preloads on the opposite surfaces of a lens, window, or small circular mirror are not applied at the same height from the axis, a **bending moment** is created within the optic. The figure shows a plano-plano window for which a stress equation is available from Roark (1954). The theory discussed here also applies approximately to optics with curved surfaces.

- The imposed moment will tend to deform the optic. One surface becomes more convex and the other more concave. These deformations may adversely affect performance.

- The tensile stress in a surface made more convex by bending is:

$$S_T = \frac{K_6 K_7}{t_E^2} \qquad (13.14)$$

$$K_6 = \frac{3P}{2\pi m} \qquad (13.15)$$

$$K_7 = 0.5(m-1) + (m+1)\ln\left(\frac{y_2}{y_1}\right) - (m-1)\left(\frac{y_1^2}{2y_2^2}\right) \qquad (13.16)$$

m = 1/Poisson's ratio
t_E = edge or axial thickness (whichever is the smaller)
y_1 = smaller contact height
y_2 = larger contact height

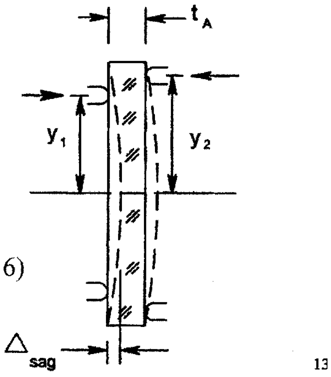


Figure 13.19

- See example in the text

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Deflection from clamp ring

- **These equations from Roark (1954) estimate the change in sagittal depth of the bent optic. The result can be compared to the tolerance on the component's surface figure to see if it is acceptable for the application.**

$$\Delta_{\mathrm{SAG}} = \frac{K_8 K_9}{t_E^3} \qquad (13.17)$$

$$K_8 = 3P\frac{\left(m^2-1\right)}{2\pi E_G m^2} \qquad (13.18)$$

$$K_9 = \frac{\left[\left(3m+1\right)y_2^2-\left(m-1\right)y_1^2\right]}{\left(2\right)\left(m+1\right)} \qquad (13.19)$$

- See example in the text Pages 582 & 583

Simple design for bonded mirror

- Mounting Small and Moderate-Sized Mirrors (Continued)
- First-surface mirrors can also be bonded on their back to their mounts if thick enough to prevent surface distortion from shrinkage and differential expansion (diameter-to-thickness ratio ≤ 6:1)
- Preferred bond configurations are triangle or ring at ~70% zone, see Fig. 9.15, pg. 368 of text. Total bond area is per Eq. (7.9)
- For small mirrors, similar to prism bonding

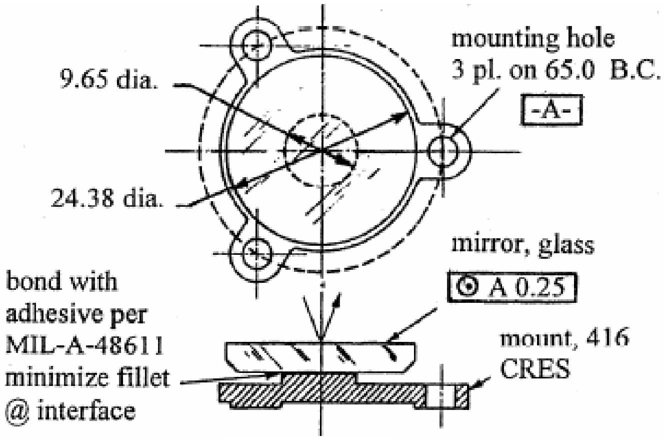


Figure 9.14

Potting small mirror into bezel

- **Another example of a precision mirror mounting:**

Flat mirror with elastomeric pads. Pad diameter determined by FEA of vibration response in 3 DOF and compared to system requirement of 300 Hz.

From Mammini et al (2003)

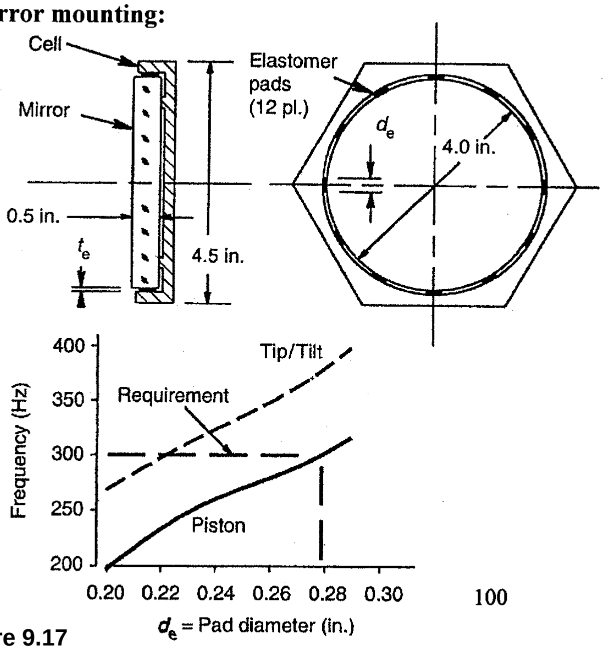


Figure 9.17

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Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Direct bonding : Optical contacting

- **Some precision mirror subassemblies are assembled by bonding. These examples are a face-mounted penta mirror and an edge-mounted cube corner mirror. Much better accuracy is achieved with the latter approach.**

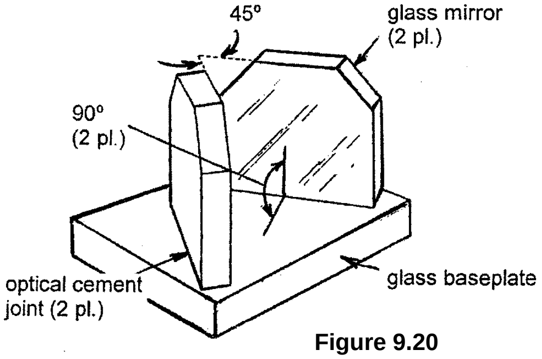

Figure 9.20

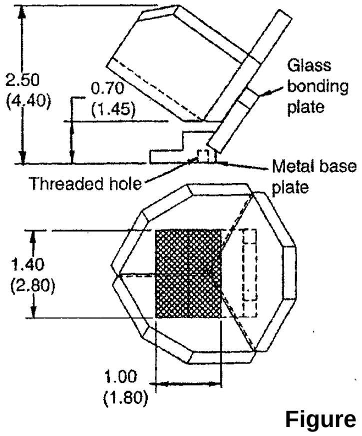

Figure 9.28

Courtesy of PROSystems, Inc., Kearneysville, WV

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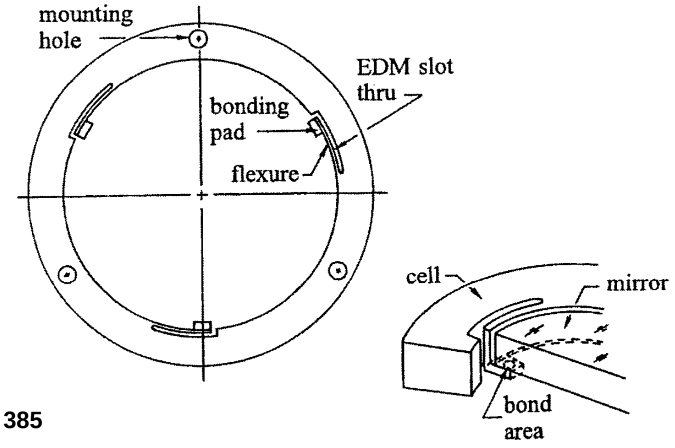
- **Precision mirror subassemblies assembled by optical contacting are shown in Figs. 9.22 and 9.23 on pg. 373 of the text. They are highly stable under temperature changes because they use no adhesive.**

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Accommodate thermal mismatch with flexures

- Bond flexure to the glass. Flexure accommodates radial motion from thermal expansion

- **Concept for a circular ULE mirror flexure-mounted in an aluminum cell. This design is similar to that for a lens shown on pg. 44 of these Notes.**



Alternatively, the bonds might be located between the mirror rim and concave cylindrical pads on the ends of the flexures (see Figure 9.39 page 385 of the text).

Flexure mounting for small mirrors

- Allow thermal expansion with use of radial flexures

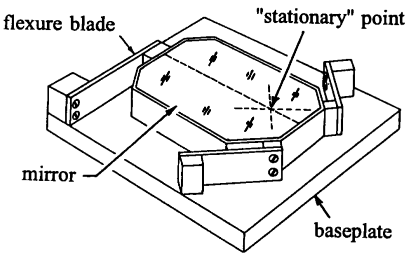
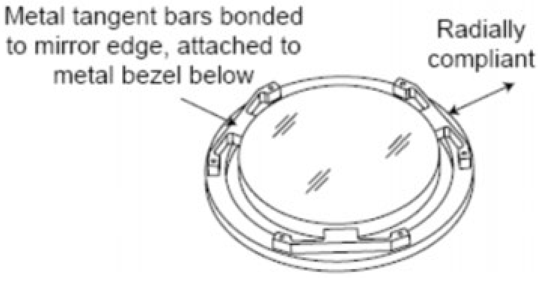


Fig. 9.37 Concept for a flexure mounting for a cell-mounted rectangular mirror. (From Yoder.[4])



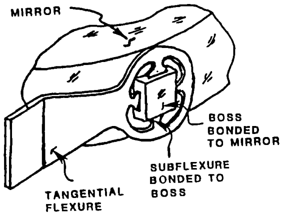


Fig. 9.34 A possible interface between the free end of a cantilevered flexure blade and a boss bonded to the rim of a circular mirror. (Adapted from Vukobratovich.[15])

Metal mirrors with integral flexures

- Precision metal mirrors in the size range of interest here are usually made by single point diamond turning (SPDT) methods. Optical and mounting surfaces are created in a single set-up on the machine for greatest accuracy.
- Mounting is simplified by screwing directly to the interface. Flexures are frequently used to isolate the optical surface from mounting forces.

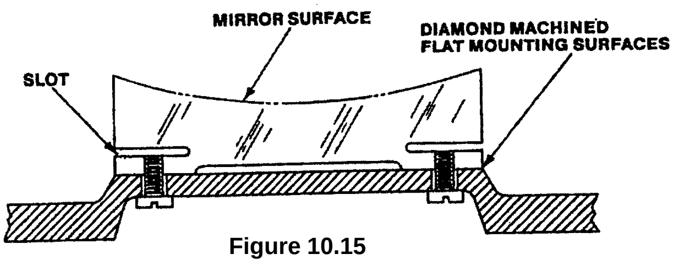


Figure 10.15

- A photo of an actual mirror made with integral mounting features by SPDT is shown in Fig. 10.16. Pg. 412 of the text.

From Zimmerman (1981)

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Precision interfaces with SPDT optics

- View (a) illustrates favorable design features for the interface between two SPDT components to ensure proper radial and axial alignment.
- View (b) shows an example of such an interface.

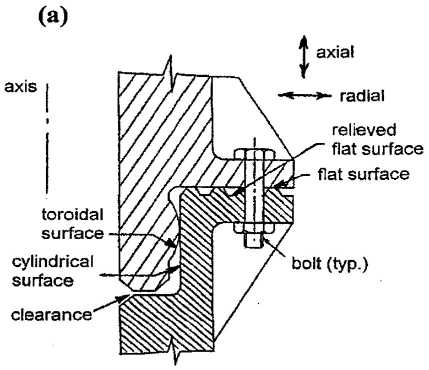


Figure 10.13

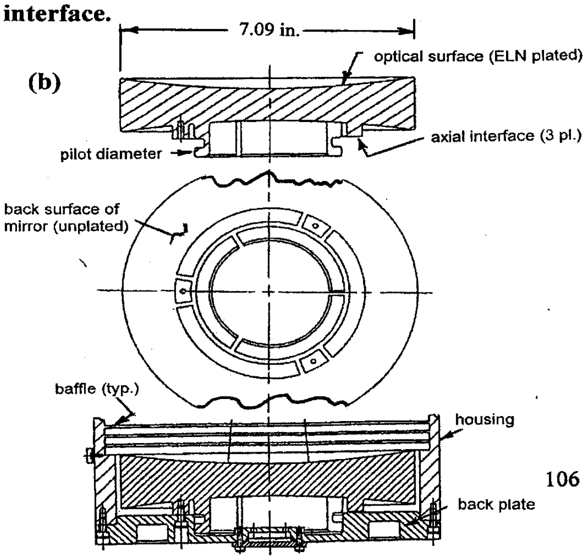


Figure 10.14

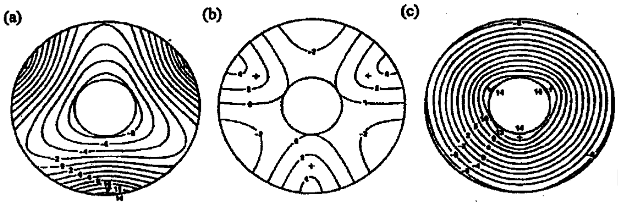
Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Larger mirrors

- Self-weight deflection must be considered
- Consider several cases
  - Fixed orientation relative to gravity
  - Variable orientation
  - Manufactured in 1G, but used in space with 0G
- For fixed orientation optics, we frequently make the optic so that it has the correct shape in the desired orientation
- Support variable orientation optics by separating lateral constraints from the axial.
- Large dimensions allow for large thermal mismatch

Self weight deflection for edge supported mirror, face up

- **Surface deflections of axis vertical mirrors depend upon the number of supports. With three points at different radii, surface contours are:**



Minimum deflection is at ~68% zone:

$$\Delta y_{\text{MIN}} = 0.343\rho\left(R_{\text{MAX}}{}^{4}\right)\frac{(1-\nu^{2})}{E_{G}t^{2}} \quad (9.6)$$

Figure 9.47

- **If circular or rectangular mirrors are supported around their rims:**

Deflections are:

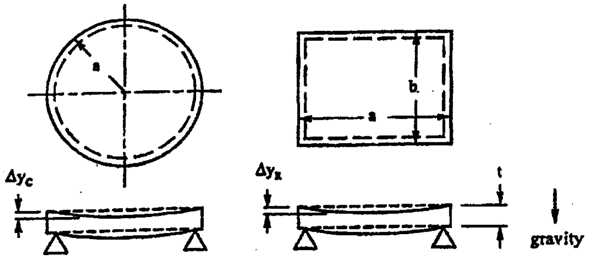


Figure 9.46

$$\Delta y_{\text{CIRC}} = \frac{(3W)(m-1)(5m+2)\left(a^{2}\right)}{\left(16\pi E_{G} m^{2} t_{A}^{3}\right)} \quad (9.4)$$

$$\Delta y_{\text{RECT}} = \frac{0.1442 w b^{4}}{\left[E_{G} t_{A}^{3}\left(1+2.21\xi^{3}\right)\right]} \quad (9.5)$$

where $\xi = b/a$ **110**

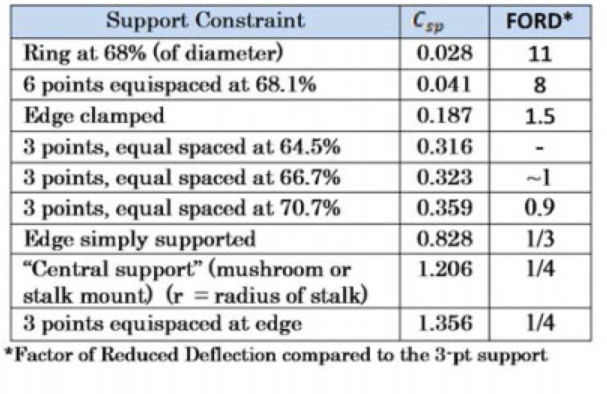
Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Self-weight induced shape change for mirror with other supports

Approximate the self-weight distortion for zenith pointing mirror (face up) as

$$\delta_{V\max} = C_{SP}\left(\frac{\rho g}{E}\right)\frac{r^4}{h^2}\left(1-\upsilon^2\right)$$

$\delta_{V\max}$ is maximum displacement
(rms shape change is ~$0.25*\delta_{Vma}$)
C_{SP} is constant, depending on configuration
ρg is weight density of the mirror material
E is Young's modulus for mirror
ν is Poisson ratio for mirror material
r is half of the mirror diameter
h is mirror thickness

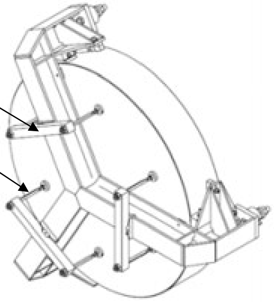


Support Constraint	C_{sp}	FORD*
Ring at 68% (of diameter)	0.028	11
6 points equispaced at 68.1%	0.041	8
Edge clamped	0.187	1.5
3 points, equal spaced at 64.5%	0.316	-
3 points, equal spaced at 66.7%	0.323	~1
3 points, equal spaced at 70.7%	0.359	0.9
Edge simply supported	0.828	1/3
"Central support" (mushroom or stalk mount) (r = radius of stalk)	1.206	1/4
3 points equispaced at edge	1.356	1/4

*Factor of Reduced Deflection compared to the 3-pt support

Vukobratovich, D., Introduction to Optomechanical Design, SPIE Short Course SC014

To use a six-point mount without overconstraining the mirror, use a design like this:



Rockers (3)

Flexures (6)

Decrease deflections: add more support points

- Use Nelson relationships to estimate performance, finite element modeling to optimize
- Each linkage adds something that can go wrong
  - Reduce system stiffness, decrease lowest resonant frequency
  - Create parasitic force and moment that can distort the optic

- **Adding supports with a Hindle (whiffletree) mount reduces the surface sags between supports. Approximate design equations for 9- & 18-point mounts are given on pg. 395 of the text.**

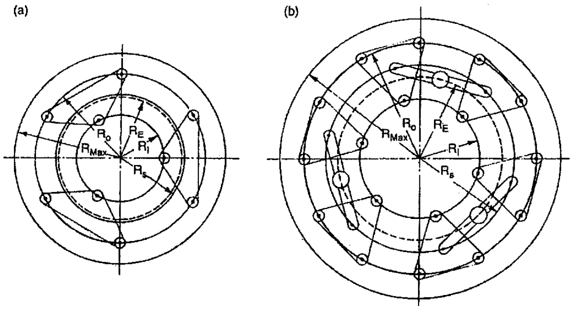


Figure 9.48

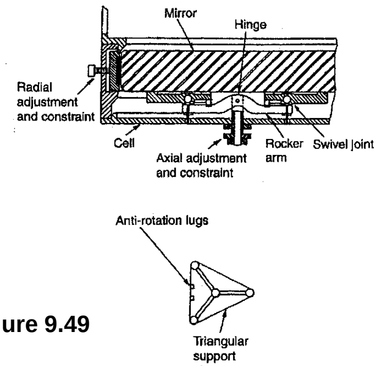


Figure 9.49

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Continuous support

- **Air bag back supports provide nearly continuous support. See photo pg. 454.**

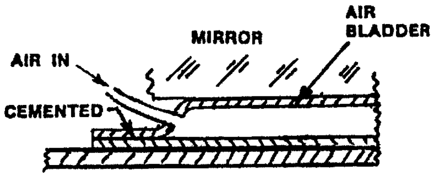


Figure 11.21

- **Some bags are segmented**

Others form concentric rings

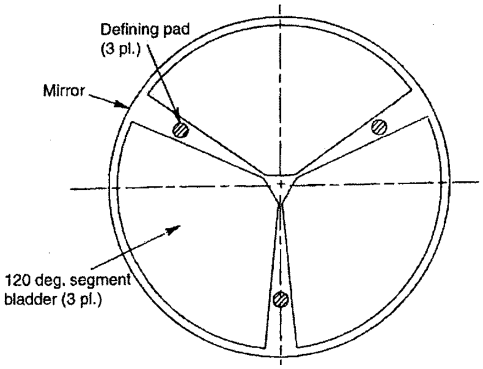


Figure 11.23

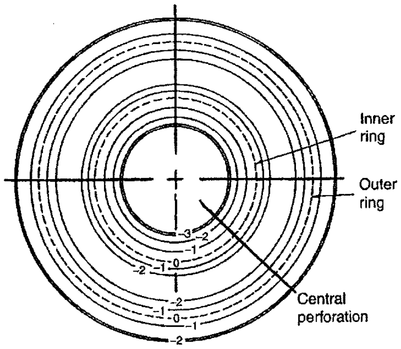


Figure 11.27

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Mirrors with axis horizontal (mirror on edge)

- Lateral supports constrain the mirror against this motion
- Self-weight deflection is much smaller because applied forces are nominally normal to the optical surface
- Effects from lateral support are:
  - Poisson effect: transverse strain causes localized bump near compression
  - Mirror bending due to error in transverse force. The constrain should be made so that the force is applied at the neutral plane of the optics. A departure from this will cause distortion
  - Mirrors with complex shapes have complex distortion
    - Steeply curved mirrors
    - Mirrors with holes
    - Mirrors with contoured backs
  - These are usually treated using finite element modeling
  - Estimate distortions of a solid mirror
    (2 point support at ±45° or band across 180°)

$$\delta_{Hrms} = \left(a_0 + a_1\gamma + a_2\gamma^2\right)\left(\frac{2\rho g}{E}\right)r^2$$

$$\gamma = \left(\frac{sag}{thickness}\right) = \left(\frac{r^2}{2Rh}\right)$$

r = half mirror diameter
h = mirror center thickness
R = mirror radius of curvature
ρg = mirror weight density
E = Young's modulus

	2 Point Support	Edge Band
a_0	0.05466	0.073785
a_1	0.2786	0.106685
a_2	0.110	0.03075

(Vukobratovich, D., Introduction to Optomechanical Design, SPIE Short Course SC014)

Horizontal supports for mirrors

- **Horizontal axis mirrors are typically supported radially at their rims by (a) Vee-block, (b) whiffletree, (c) strap, (d) mercury-tube, or (e) push-pull mounts**

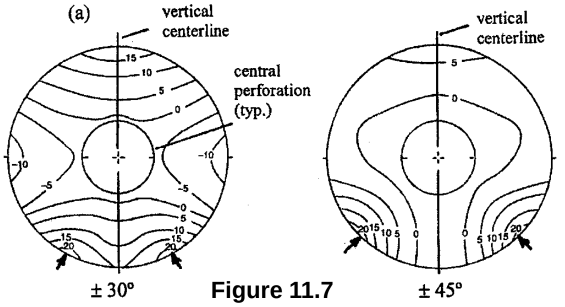


Figure 11.7

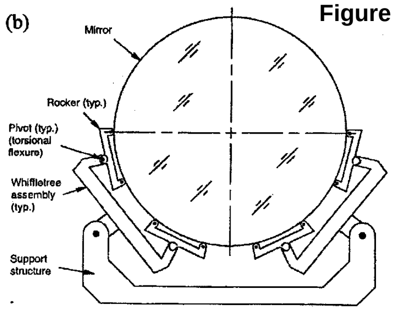


Figure 11.8

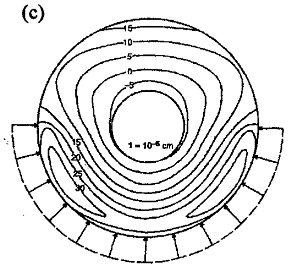


Figure 11.18

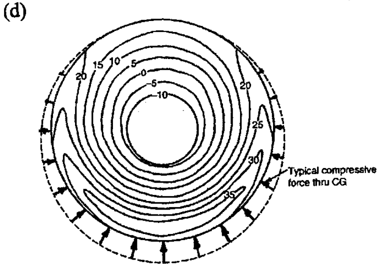


Figure 11.20

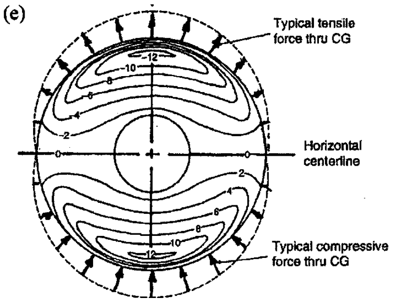


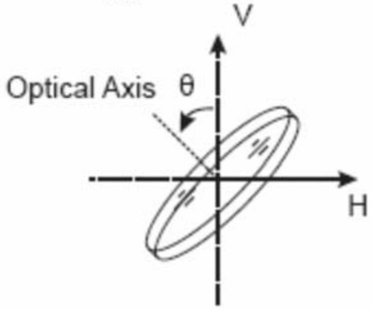
Figure 11.10

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Mirrors used a variable orientation

- Separate the axial constraint from the lateral constraint
- Model each to determine the distortions
  - δ_{Vrms} is RMS displacement for orientation with axis vertical (mirror face up)
  - δ_{Hrms} is RMS displacement for orientation with axis horizontal (mirror on edge)
- Combine as root sum square to get net surface deflection δ_{rms}

$$\delta_{rms} = \sqrt{\left(\delta_{V\,rms}\cos\theta\right)^2 + \left(\delta_{H\,rms}\sin\theta\right)^2}$$



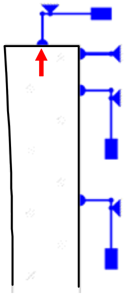
Thermal issues with large mirrors

- Large mirrors must be held at discreet points
- Metal pucks are usually bonded to the mirror at the each support point
- Multiple attachments create significant possibility for overconstraint
- Avoid overconstraint using force controlled actuators
- Avoid overconstraint using flexures
  - Stiff in the desired loaded direction
  - Soft in all other directions

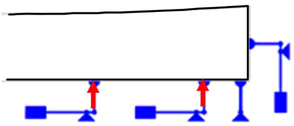
Position constraint for floatation supports

- Counterweights apply controlled force to support the mirror
- Additional position constraints must be used
- Use 3 bipods for semikinematic rigid connection of glass to the metal frame
- These take no static load:
  - Force sensors in line. Adjust trim weights until force is zero for all attitudes
- These are very stiff, but they are not strong.
  - Use spring loaded “breakaway”. As long as force is less than preload, the strut is solid. If the force exceeds the preload in compression or tension, the stiffness is only defined by the preload spring

Horizon Pointing

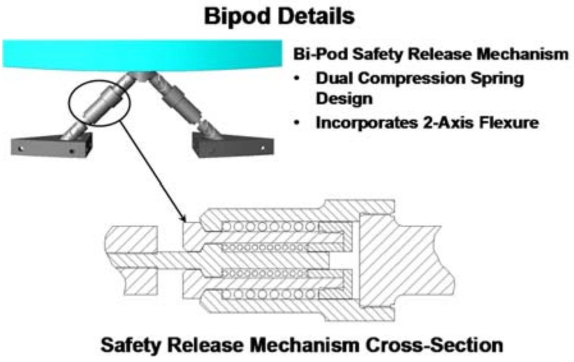


Zenith Pointing



Counterweighted design provides support in any gravity orientation

Hard points define mirror position, but take no load

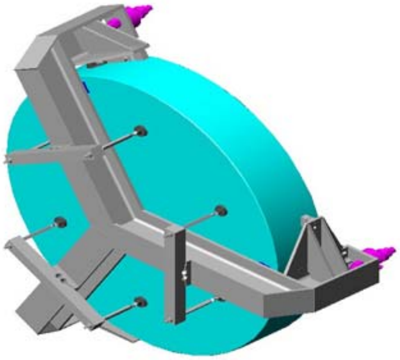


Mirror design example

26” solid mirrors, used a variable angle

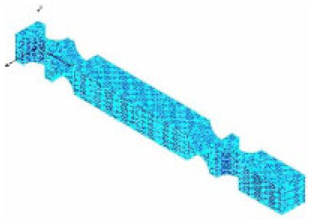
- Axial support 3-pairs of axial rods on mirror back
  - Rods thread into 1” dia pucks bonded to back
  - Each pair connected by a seesaw flexure to provide 3-point mounting to cell
  - Differential screws at each rod end
    - Equalize pre-load
    - Provide fine tilt adjustment

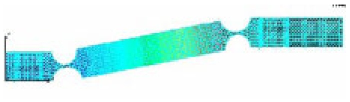
- Lateral tangent support
  - 3 rods spaced 120° apart
    - 0.5” square X-section
    - 0.030” thick cross circular flexures at each end
  - 1.5” dia pucks bonded to mirror with Milbond
    - Thru hole for threaded rod end

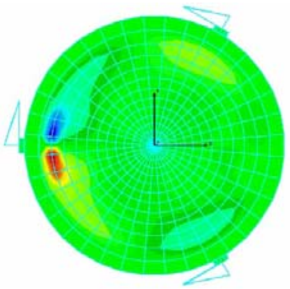


Design of mirror support

- Start with concept, evaluate base performance using finite element modeling
- Choose flexure geometry, evaluate 6 DOF stiffness, look for buckling
- Calculate influence of parasitic forces from flexures
- Set tolerances for machining and assembly to limit the bending of the flexures so that the parasitic forces and moments are all accounted for and they are acceptable
- Evaluate stress in flexures and bonds to insure survival







Mz = 1 in-lb

Large Mirrors

- For large mirrors with high value, use more sophistical mirror designs and more complex supports
- Structured lightweight mirrors have better stiffness/weight ratio and improved thermal performance. Some configurations are
  - Contoured back
  - Open back structure, consisting of optical facesheet and ribs
  - Closed back sandwich structure, with facesheet, backsheet, and ribs
  - Cost goes up for the substrate and for the mounting as the weight comes down!
- Materials other than glass have specific mechanical and thermal advantages
  - Beryllium
  - Silicon carbide
  - Silicon
- Support of mirror can use many actuators, each with controlled force
  - Possible close the loop around a wavefront sensor – active optics
  - This allows the use of a very thin mirror. Put the weight and complexity in the control system, rather than the glass
- These are really cool, but outside the scope of this class