

OPTI 421/521 – Introduction to Optomechanical Engineering

Review for Midterm 2:

Midterm is 50 minutes, closed book, closed notes, no calculator

Review the material that was covered on the first exam. You are expected to know this.

Statics:

- Draw free body diagrams
- Solve for reaction forces and moments
- Determine state of constraint
- Kinematic constraints

Solid mechanics

- Know stress, strain relations for normal and shear
- Know how to use these relationships to derive force-displacement relationships for simple geometry
 - Axial load
 - Torque
 - Shear
 - Bending
- Use superposition, Maxwell's reciprocity
- Calculate stiffness, compliance for any geometry
- Calculate resonant frequency, self weight deflection
- Use above relationships to solve problems

(tables with beam bending relationships and calculation of I, A, K for complex cross sections will be provided if appropriate.)

Vibrations and shock

- Be able to apply the Transmissibility curve and equations for vibration isolation
- Calculate acceleration for an object dropped from some height.

Thermal effects

- Calculate thermal strains, use this to solve problems
- Know how to determine change in focal length with temperature.
- Athermalization
- Conductivity and transient thermal response relations

Materials

- Understand definitions for all important material properties
- Know approximate values for material properties
 - All of the properties for common materials (BK7, aluminum)
 - Important properties for special materials (HW 8)
 - Approximate properties of common adhesives (epoxy, RTV)
- Use these to solve problems

Mechanical failure

- Determine stress in glass, metal, or adhesive
- Apply strength of materials to design for survivability

Fasteners and adhesives

- Apply basic knowledge of fasteners and adhesives
- Calculate compliance and thermal stresses in bonded joints

Motion control

- Define the parts of a stage, what are limitations?
- Explain different types of bearings, what are relative advantages and disadvantages?
- Understand sources of error
- What are advantages and disadvantages of using flexures

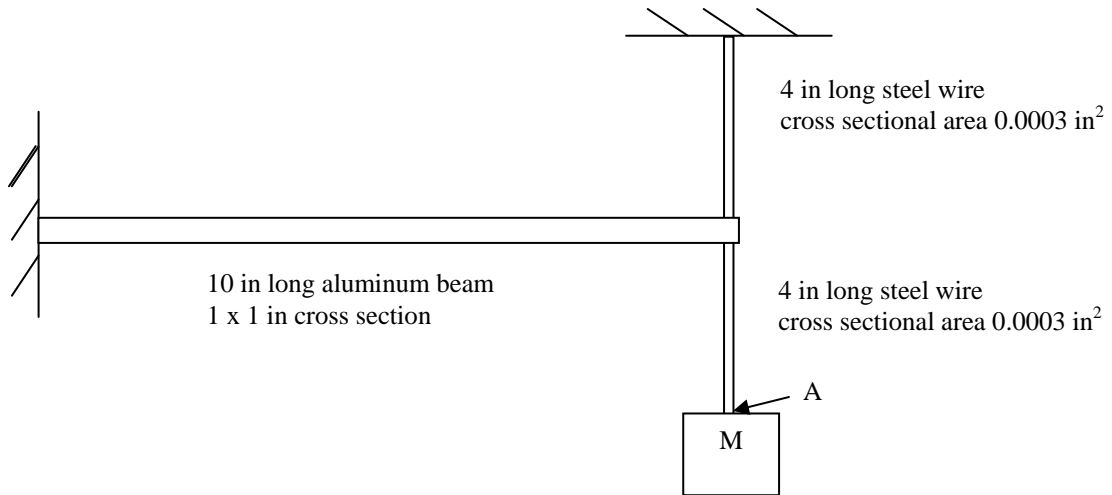
Optical Engineering 421/521

Midterm 2 Example questions

- 1.) Draw a plot showing the relationship between stress and strain for a metal. Label the slope of the curve. Show the microyield strength (Precision Elastic Limit), yield strength, ultimate strength.
- 2.) Name 3 materials with near-zero coefficient of thermal expansion. Give approximate values for their density.
- 3.) List two metals that have very low thermal conductivity. Give an approximate value for the conductivity of this material.
- 4.) Consider using a shaft made from 316 stainless steel for a cryostat feedthrough. Assume 10 cm length with one end at ambient temperature and the other at 77K. Determine the cross sectional area of the shaft that will limit the steady state conductive heat transfer to 1 W.
- 5.) Show how to use a combination of aluminum and titanium to maintain a spacing of 10 inches that does not change with temperature.
- 6.) A 10 mm diameter lens has a requirement of $R = 100 \pm 0.1$ mm. Calculate the tolerance in terms of the sag of the surface. Is this tight?
- 7.) A pitch polished aspheric mirror will typically have surface roughness of 20 angstroms rms. This causes wide angle scatter. Calculate the total amount of scatter from one of these mirrors at 400 nm light (Hints – get RMSWE, then Strehl ratio, use your understanding of the Strehl ratio to determine the scatter.)
- 8.) List a material with excellent specific stiffness. Give the approximate value for Young's modulus and for density.
- 9.) Calcium fluoride has excellent optical properties. Give the approximate refractive index for 300 nm wavelength light. It has poor mechanical properties. Give the approximate CTE at 20°C.
- 10.) If a mass m is loaded onto a compliant support that has stiffness k , determine the deflection δ . Give an expression for the resonant frequency of this system in terms of k and m . Derive an expression for the resonant frequency that depends only on δ and g (gravity).
- 11.) Sketch a plot of resonant frequency in Hz vs deflection from static loading.
- 12.) List a common material that transmits 3-5 μm wavelengths. Give approximate values for refractive index and dn/dT
- 13.) List a common material that transmits 250 nm wavelengths. Give approximate values for refractive index and CTE
- 14.) List an optical material with low stress-optic coefficient. Give approximate value for the dispersion of this material.
- 15.) Consider a BK7 prism bonded to aluminum with 1 mm thick RTV. The bond is circular, 20 mm diameter.
 - a) Calculate the shear stiffness for the bond
 - b) Calculate the torsional stiffness for the bond.
 - c) Use the bulk modulus to estimate that axial stiffness of the bond (ignore the edge effects)
 - d) Estimate the stress for a 20°C temperature change

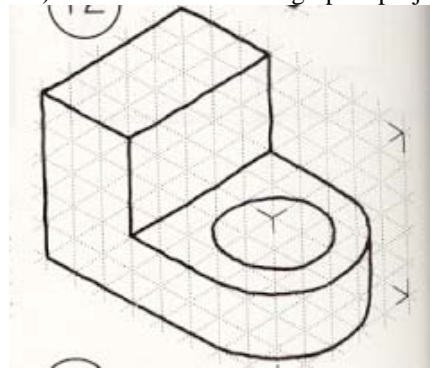
Show how finite element modeling works with a simple example – a bar in tension. Break the bar into 3 pieces and develop the equations that couple force to displacement.

16.) Consider the geometry below. A 10-in aluminum cantilever is supported at the end by a 4" long steel wire. A mass is suspended from the end by another thin wire.

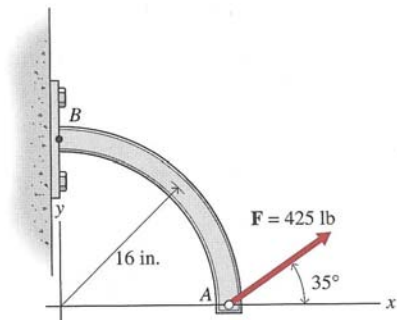


- Calculate the stiffness for each of the wires in tension and for the beam in bending.
- Determine the combined effect and give the total deflection at A as a 10 pound weight is suspended.
- Give the resonant frequency for this system (ignore the mass of the bar)

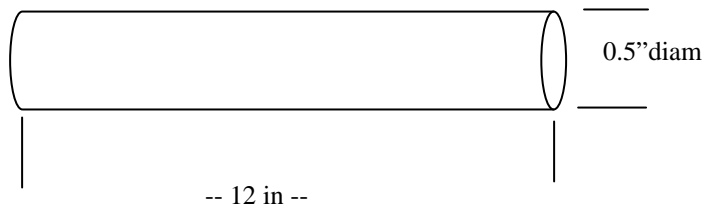
17.) Sketch a 3-view orthographic projection of the following part.



18.) Calculate the reactions at B to maintain static equilibrium.



15) Consider an aluminum bar, 0.5 in diameter circular cross section, 12 in long



Circular cross section Diameter D $A = \pi D^2/4$ $I = \pi D^4/64$ $J = \pi D^4/32$

What is the mass or weight of the bar?

For 100 lbs (445 N) axial force, what is the stress in the material?

How much does the bar stretch when this 100 lb load is applied?

Sketch the deformation in the bar if a *bending* moment (not twisting) of 1 in-lb is applied to one end and reacted against the other? What is the change in angle from one end to the other?

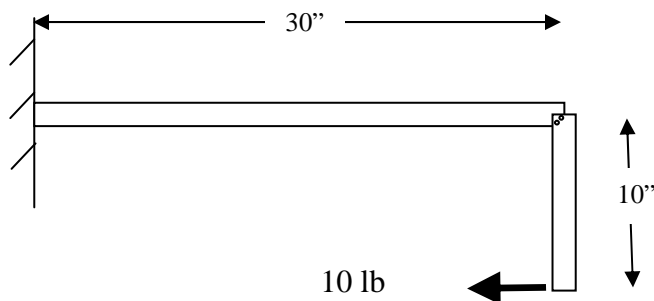
How much will the length of the bar expand if it is heated uniformly by 10°C?

What is the stress in the bar if it is heated by 10° F, yet fully constrained so it cannot expand?

Problem 16 .

Estimate A through F for a bar with the same dimensions as the previous problem, but made of fused silica, titanium, SiC, Zerodur, invar,

- 19.) Consider the structure below made by bolting two steel plates together. The plates are 2 inch wide, 0.5 inch thick. One plate is 10 inches long and the other is 30 inches long.



- a) Calculate the weight of each plate
- b) For the case of a 10 pound force as shown, sketch a free body diagram for the assembly
- c) Calculate reaction forces for static equilibrium
- 20.) For a BK7 glass cube beamsplitter 25 x 25 mm.
 What is the approximate weight (or mass)?
 Assume this is supported on 3 Delrin plastic pads, each has 1 mm² cross sectional area and 1 mm thickness (E = 3 GPa).
 If this is dropped 50 cm onto a hard surface, estimate the acceleration
 Calculate the stress in the glass at the Delrin pads and compare it with the approximate strength.
- 21.) Determine the critical flaw size for BK7 with the surface under 50 MPa tensile stress
- 22.) How does the optical power change with temperature for lens made of a fused silica?
- 23.) What size Allen wrench is used for a 1/4-20 socket head cap screw?
- 24.) What is a Belleville washer? How is this used?
- 25.) Give the diameter and thread pitch for an M6-1 screw.
- 26.) What is the difference between a Grade 2 and a Grade 5 fastener?
- 27.) For Titanium, Aluminum, stainless steel, SiC, Be, BK7, fused silica, polystyrene, give approximate values for CTE, E, density, thermal conductivity
- 28.) Give approximate strength, shear modulus, elastic modulus, for epoxy
- 29.) Give approximate strength, shear modulus, elastic modulus for RTV
- 30.) As a 50 lb optical system is mounted on isolators, the isolators deflect by 1 mm.
 What is the resonant frequency?
 If the isolators have 10% damping, what is the Q?
 Sketch a plot of the isolator transmissibility
 For base motion of 10⁻⁶ G²/Hz, calculate the rms acceleration for the isolated system.
 Calculate the rms displacement for this case.

If the system is dropped onto its isolators 50cm, determine the acceleration shock loading.

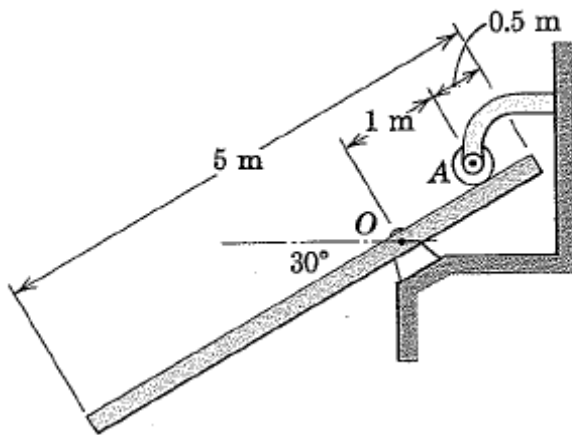
31.) Give the main advantage and disadvantage for using bearings of the type:

- Journal
- Ball bear
- Roller bearing
- flexure

32.) What material property is most important for flexures. Name one material that is good for flexures. What is the value of the relevant material property.

33.) How do you calculate glass strength? How do you account for critical flaws?

34.) Explain the relationship between bulk modulus and Young's modulus.

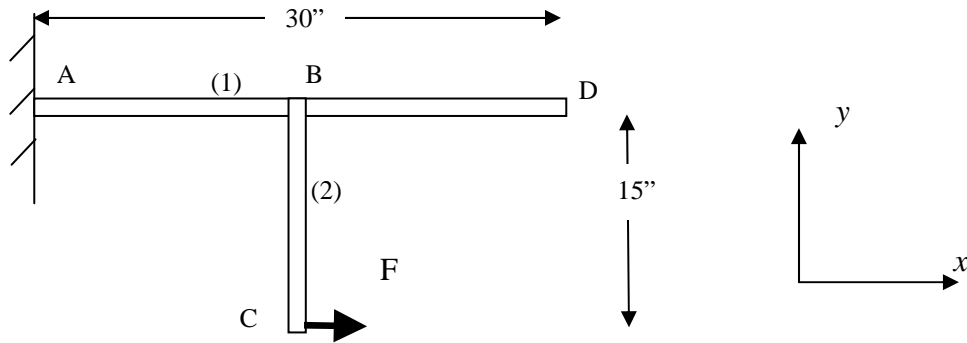


The uniform 5-m bar with a mass of 100 kg is hinged at O and prevented from rotating in the vertical plane beyond the 30° position by the fixed roller at A. Calculate the reaction force at A.

A. Calculate the reaction force at A.

-
J

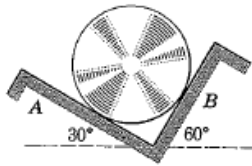
10). (20) Consider the structure below made by welding two aluminum bars together. The bars have 1" x 1" cross section. The 15" bar is welded at the midpoint of the cantilevered 30" bar.



You need to calculate the motion of point D as the force $F = 10$ lbs applied as shown at point C. Follow the four easy four steps below:

- Use the free body diagram and find the forces and moment exerted on (1) at point B due to force F.
- Determine the bending of section AB due to the force and moment at B
- Use superposition to determine the angle and displacement at B.
- Calculate the displacement at D due to displacement and angle at B.

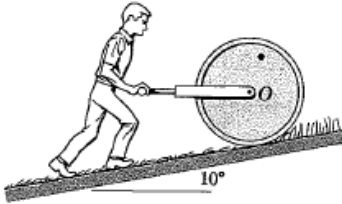
PROBLEMS



Problem 3/4

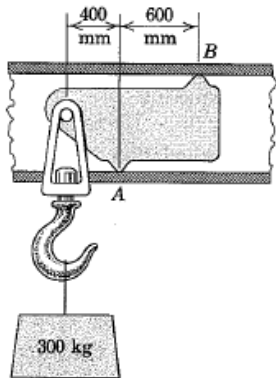
- 3/4 The homogeneous cylinder has a mass of 40 kg and rests on smooth surfaces A and B which are inclined 30° and 60° , respectively, from the horizontal. Determine the contact forces at A and B .

Ans. $A = 340 \text{ N}$, $B = 196 \text{ N}$



Problem 3/5

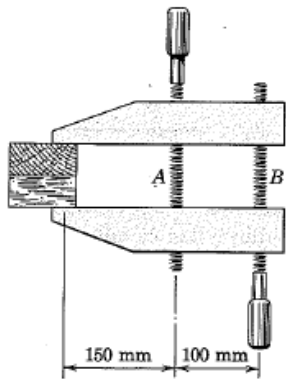
- 3/5 Determine the magnitude P of the horizontal force which the gardener must exert on the light handle of the 100-kg lawn roller to hold it in place on the 10° slope. Also determine the force exerted by the ground on the roller. The center of mass of the roller is at its center O .



Problem 3/6

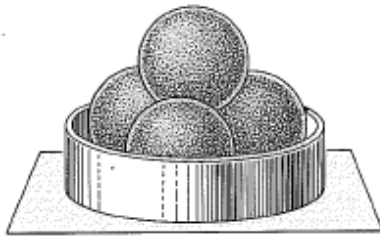
- 3/6 To facilitate shifting the position of a lifting hook when it is not under load, the sliding hanger shown is used. The projections at A and B engage the flanges of a box beam when a load is supported, and the hook projects through a horizontal slot in the beam. Compute the forces at A and B when the hook supports a 300-kg mass.

Ans. $A = 4.91 \text{ kN}$, $B = 1.96 \text{ kN}$



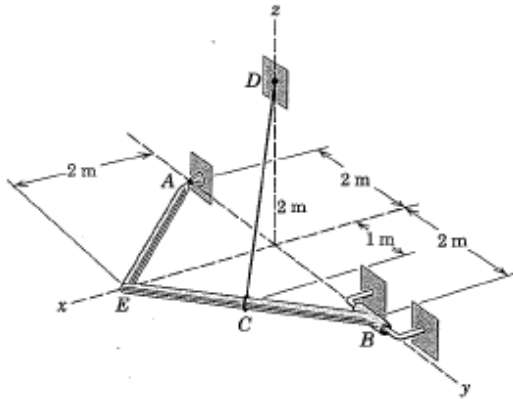
Problem 3/7

- 3/7 If the screw B of the wood clamp is tightened so that the two blocks are under a compression of 500 N, determine the force in screw A . (Note: The force supported by each screw may be taken in the direction of the screw.)



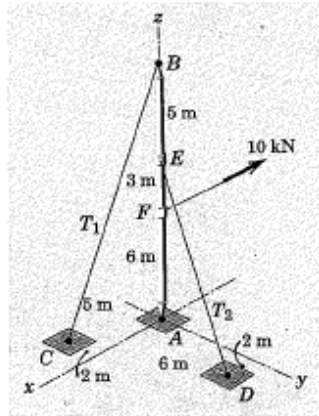
Problem 3/97

3/97 Three identical steel balls each of mass m are placed in the cylindrical ring which rests on a horizontal surface and whose height is slightly greater than the radius of the balls. The diameter of the ring is such that the balls are virtually touching one another. A fourth identical ball is then placed on top of the three balls. Determine the force P exerted by the ring on each of the three lower balls.



Problem 3/98

3/98 Each of the two legs of the welded frame has a mass of 50 kg. A wire from C to D prevents the frame from rotating out of the horizontal plane about an axis through its bearing at B and its ball-and-socket joint at A . Calculate the tension T in the wire and the magnitude of the total force supported by the connection at A . *Ans.* $T = 1201$ N, $A = 601$ N

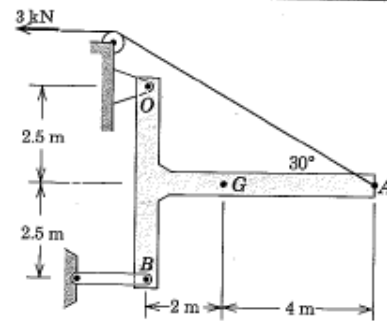


Problem 3/99

3/99 The mast has a mass of 300 kg and is supported by a ball-and-socket joint at A . Calculate the tension T_1 if the horizontal 10-kN force is applied at F . *Ans.* $T_1 = 11.34$ kN

3/16 The 200-kg T-frame has its mass center at G . Calculate the total force supported by the pin at O after the 3-kN force is applied to the cable.

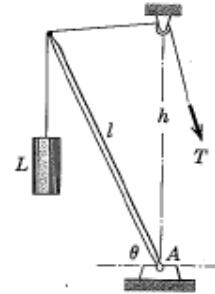
Ans. $O = 2.36$ kN



Problem 3/16

3/17 A jet airplane having a mass of 8 Mg is flying horizontally at a constant speed of 1000 km/h under a thrust of 16 kN from its turbojet engines. If the pilot increases the fuel rate to give a thrust of 20 kN and noses the plane upward to maintain a constant 1000-km/h air speed, determine the angle θ made by the new line of flight with the horizontal. Note that the air resistance in the line of flight at the particular altitude involved is a function of air speed.

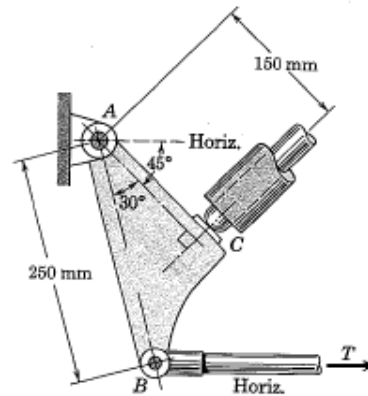
Ans. $\theta = 2.92^\circ$



Problem 3/18

3/18 If the mass of the boom is negligible compared with that of the load L , find the force F on the ball joint at A and show that the magnitude F is constant for all values of θ . Determine the limiting value of T as θ approaches 90° .

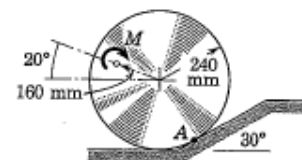
3/19 The hinged member is used to activate a latching device for securing a large trailer body to its undercarriage. If a tension $T = 400$ N is required in the horizontal control rod to trip the plunger against which the member acts at C , estimate the force supported by the pin at A by means of a free-hand vector solution.



Problem 3/19

3/20 Calculate the value of the couple M required to roll the 40-kg wheel up the incline. Also determine the contact force R at A . The surface of the incline is sufficiently rough to prevent slipping.

Ans. $M = 47.1$ N·m, $R = 393$ N



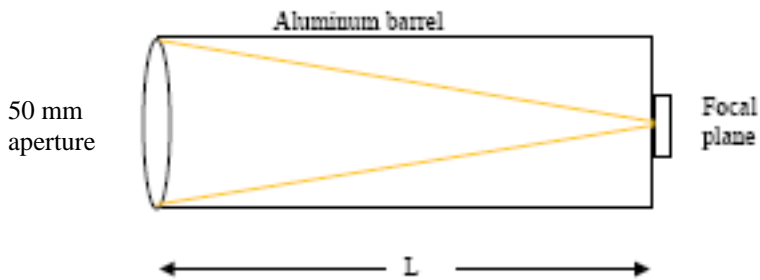
Problem 3/20

Draw a plot showing the relationship between stress and strain for 6061 aluminum. Label the axes and give units. On the same plot, provide an approximate curve for 17-4 stainless steel. Indicate Young's modulus and the yield strength for both.

SiC is used because of its outstanding specific stiffness and thermal conductivity. Give approximate values for the density, Young's modulus, and thermal conductivity.

How does the focal length change with temperature for lens made of BK7?
(include both dn/dT and CTE effects)

Consider a 50 mm diameter BK7 lens mounted in an aluminum barrel.
Assume the focal length $f = L = 100$ mm:



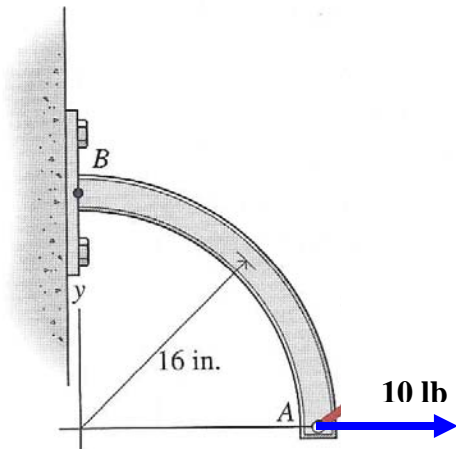
- Calculate the focus error that would be caused by a 10°C temperature change? (include both the change in the lens focal length and the change in the aluminum tube length.
- Determine the wavefront error due to the defocus above. Assume 500 nm wavelength

Name an optical material that has good UV transmission. List one difficulty or limitation for using this material.

Consider a fused silica prism bonded to aluminum with 300 μm thick 2216. The bond is circular, 10 mm diameter. (shear modulus $G \approx 300$ MPa,)
 $A \approx 80$ mm²

- What is the approximate strength of RTV for shear?
- Calculate the strength of this particular bond in the shear direction. (How much shear force is required to cause the bond to fail?)
- Calculate the shear stiffness for the bond (ratio of shear force to shear displacement).
- Calculate the resonant frequency of the prism as mounted
- Estimate the stress in the adhesive for a 10°C temperature change

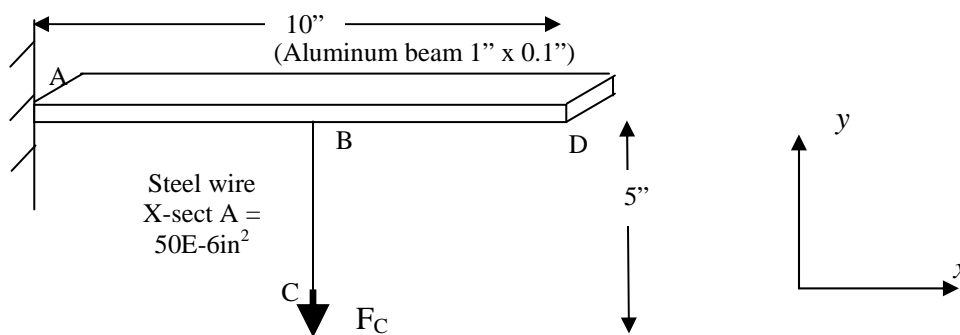
Calculate the reactions at B for static equilibrium when a 10 lb horizontal force is applied at A.



Name 3 materials with near-zero coefficient of thermal expansion. Give approximate values for the density of each material.

What determines the strength of glass? How can you determine allowable stresses for glass?

Consider a 10" cantilevered aluminum bar. A 304 stainless wire with $50E-6 \text{ in}^2$ cross sectional area is attached at the center and a load of 1 lb is applied at the end of the wire. The bar has 0.1" x 1" cross section. (The 1" dimension is into the page as shown.)



You need to calculate the motion of point D as the force $F_C = 1 \text{ lbs}$ applied as shown at point C. Follow the four easy four steps below:

- 1) Use the free body diagram and find the forces and moment exerted on the beam at point B due to force F_C .
- 2) Determine the bending of section AB due to the force and moment at B
- 3) Use superposition to determine the angle and displacement at B.
- 4) Calculate the displacement at D due to displacement and angle at B.