16.001 - Materials & Structures
Problem Set #1

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Problem M-1.1
Breguet Range Equation

(a) The purpose of this exercise is to estimate the range of the Airbus 340-500 from the flight data provided in lecture. Based on the charts given (you may also find it useful to consult the official specifications available on the Airbus web site estimate each one of the parameters in the Breguet Range Equation, explaning the process by which you obtain each parameter. Then, use the Range Equation to estimate the maximum range. If you don't find information about the *overall propulsive efficiency* and *aerodynamic efficiency* you can use the following values: $\eta_0 = 0.35, L/D = 17$. Compare your estimate with the information available online.

(b) Imagine that the aerodynamic design can be improved such that L/D increases by 3%. How many more passengers could the airplane carry just from the perspective of maintaining the same maximum range? (Hint: Assume that the weight of each passenger with luggage is on average 90 kg).

(c) We would like to perform a sensitivity analysis of several parameters on the maximum range of the airplane. What would be the relative variation in the maximum range, *ceteris paribus*, for the following scenarios?

- A new design using an increased amount of composites in some of the main structural components would satisfy all the structural requirements while reducing the structure weight by 5%
- An architect reorganizes the space inside the aircraft, which can now carry 12 more passengers ($\simeq$ 5 % more), without adding weight to the structure
- A new generation of engines allows to increase the propulsive efficiency by 5 %

Comment on your results.

Problem M-1.2
(M.O.: M4)

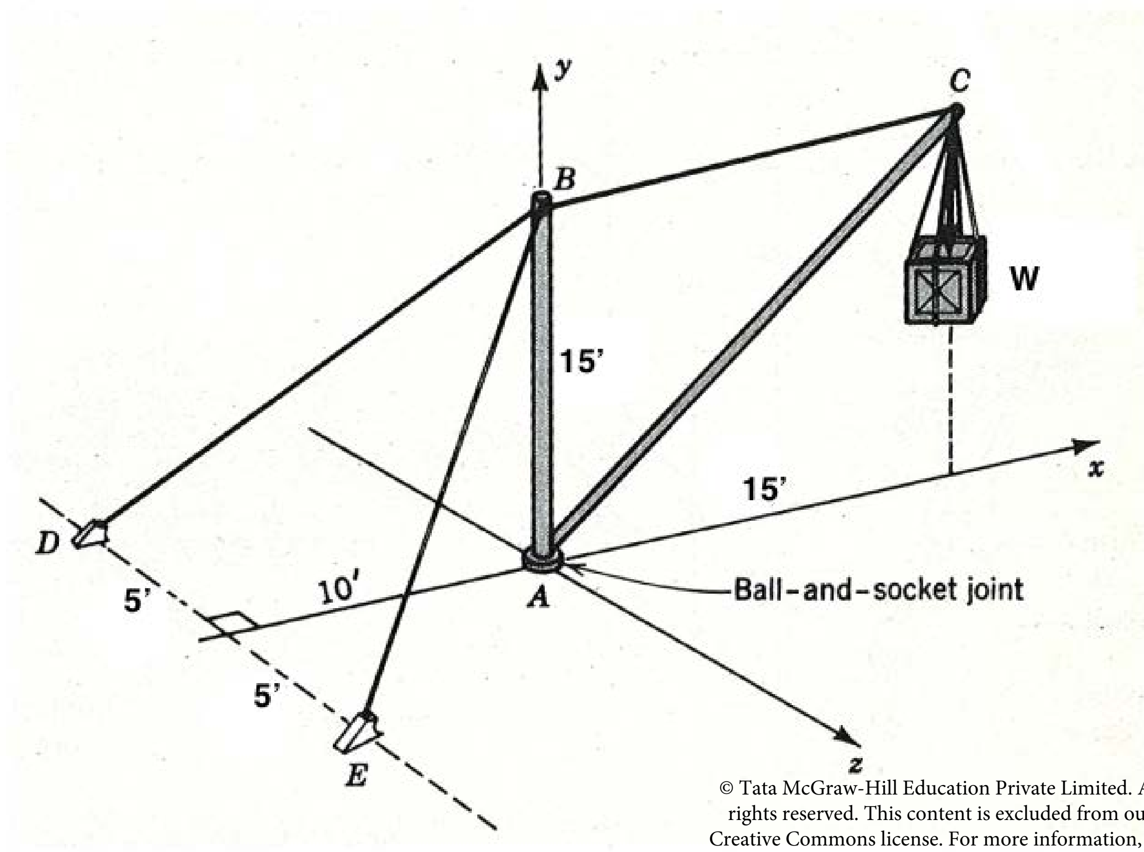

Figure 1: Crane Supporting a Weight

The crane shown in Figure 1 lifts a weight of W = 15,000 lb and is supported by cables BD and BE.

(a) Determine the cable tensions in BC, BD and BE (denote these as F_{BC}, F_{BD}, and F_{BE}, respectively).

(b) Assume that the crane may pivot about the xy-plane, so that cable BC now makes an angle α with the positive x-axis. Determine an expression for the ratio of cable tensions $\frac{F_{BD}}{F_{BE}}$ in terms of this angle α. What is the value of α when $\frac{F_{BD}}{F_{BE}} = 3$? *Note:* Follow the right-hand rule in selecting the positive convention for α.

(c) For what value α will cable BE experience no loading? For what value α will cable BD experience no loading? Lastly, what will happen if α falls out outside this range?

○ **Problem M-1.3**

The top of a tin can is removed, and the empty can is inverted over a pair of billiard balls on a table as shown in the sketch.

Diameter of ball	45 mm
Weight of ball	2.0 N
Diameter of can	70 mm
Weight of empty can with lid removed	1.0 N

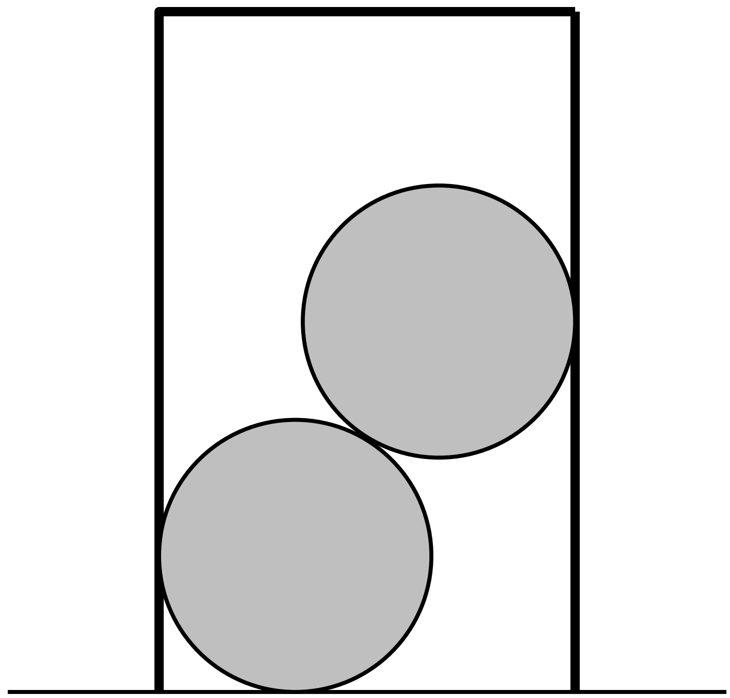

Figure 2: Billiard balls in a tin

(a) For the parameters listed, is the system stable or will it tip over?

(b) Will a third ball added on top of these two provide a stabilizing force?

(c) Can any changes to this third ball's weight or radius be made to stabilize this system?

Problem M-1.4

A small box of mass m hangs from three massless ropes as shown in Figure 3. The ropes are attached to a ball joint which is located at the origin O of the Cartesian coordinate system Oxyz. Two of these ropes are also attached to the ball joints A and B which are fixed to a rigid wall; the third one is connected to the ball joint C which is attached to a rigid block of mass M. The latter stands on a plane surface; the coefficient of static friction between it and the surface is μ_s. Note that the gravity g acts on the small box and the block which are both made from a homogeneous material.

Hint:

- Static friction is the force F that acts between two solid surfaces which are in contact but do not move relative to each other. It opposes the relative lateral motion of the two surfaces which would occur in the absence of the friction due to applied external forces. The static friction force acts tangentially to the two contacting surfaces. According to the Coulomb model, it fulfills the condition

$$|F| \leq \mu_s N$$

where μ_s is the coefficient of static friction corresponding to the considered pair of surfaces, and N is the acting normal force between the two surfaces. (If the condition was violated, the surfaces would start moving relative to each other.)

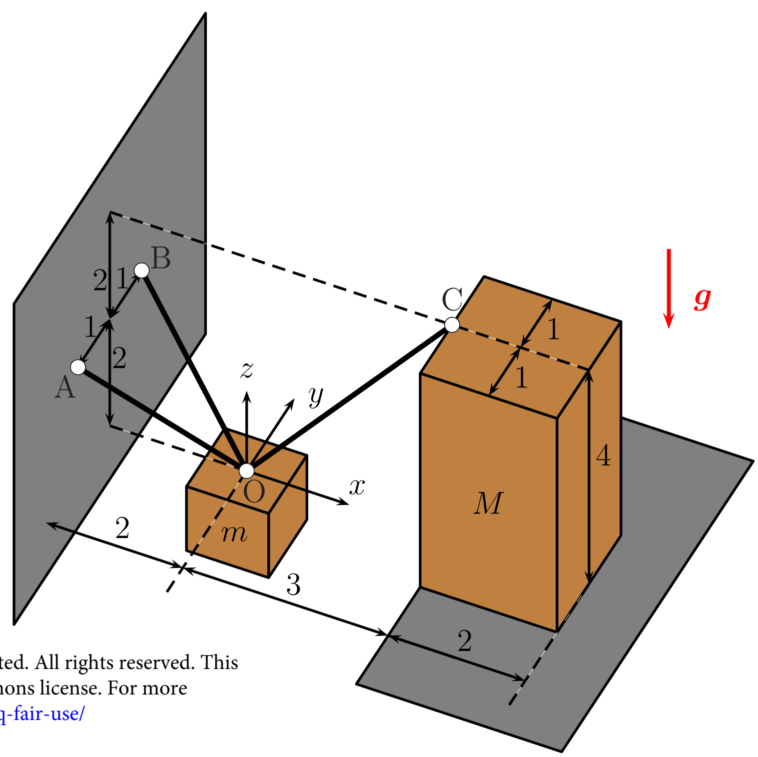

Figure 3: Box hanging from three ropes.

Questions:

(a) For safety reasons, the magnitude of the tensile force in the ropes must not exceed the maximum admissible value F_{max}. What is the maximum value for the mass m of the small box so that this safety condition is met?

(b) If the mass m of the small box was chosen too large, the block of mass M might tilt over. Assuming that the coefficient of static friction between the block and the surface is large enough to prevent sliding, what is the maximum value for the mass m of the box at which no tilting of the block occurs?

(c) For which value of the coefficient of static friction μ_{s} would the block start sliding (assuming that no tilting has occurred yet)? Using the result from the previous part, how should the value of the coefficient of static friction μ_{s} be chosen so that sliding and tilting would occur for the same value of the mass m?

○ **Problem M-1.5**

The circular cylinder A rests on top of two half-circular cylinders B and C, all having the same radius r, as shown in Figure 4. The weight of A is W, and the weight of B and C is $\frac{1}{2}W$ each. All cylinders are made from a homogeneous material. Assume that the coefficient of friction between the flat surfaces of the half-cylinders and the horizontal table top is f. Determine the maximum distance d between the centers of the half-cylinders to maintain equilibrium.

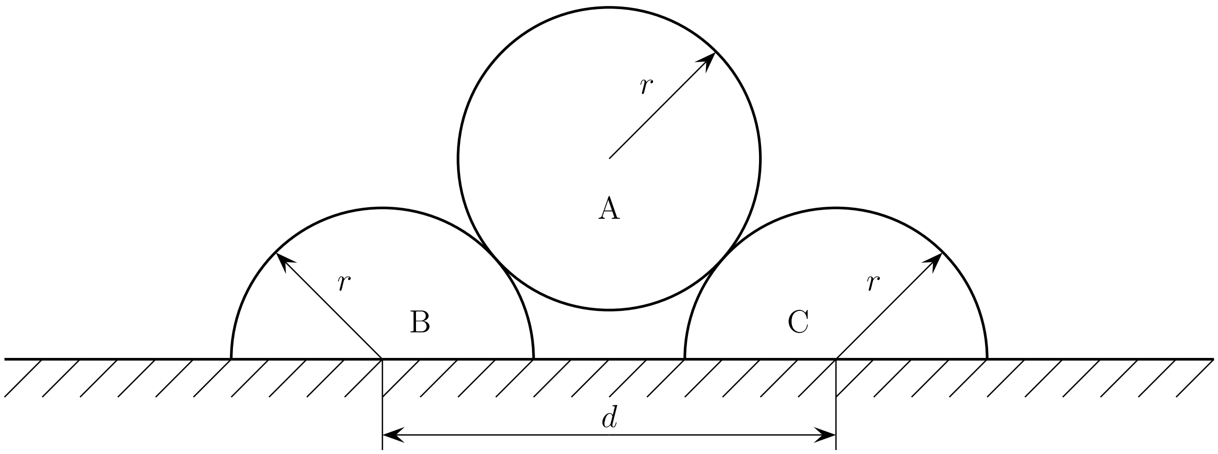

Figure 4: Circular cylinder A resting on half cylinders B and C.