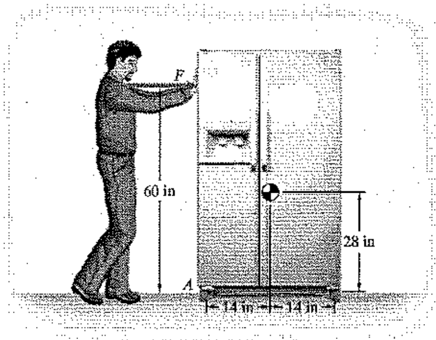
Problem 18.1 A horizontal force $F = 30$ lb is applied to the 230-lb refrigerator as shown. Friction is negligible.

(a) What is the magnitude of the refrigerator's acceleration?
(b) What normal forces are exerted on the refrigerator by the floor at A and B?



Solution: Assume that the refrigerator rolls without tipping. We have the following equations of motion.

$$\sum F_x : (30\text{ lb}) = \left(\frac{230\text{ lb}}{32.2\text{ ft/s}^2}\right) a$$

$$\sum F_y : A + B - 230\text{ lb} = 0$$

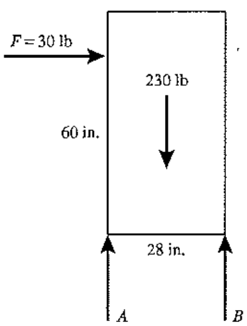
$$\sum M_G : -(30\text{ lb})(32\text{ in.}) - A(14\text{ in.}) + B(14\text{ in.}) = 0$$

Solving we find

(a) $\boxed{a = 4.2\text{ ft/s}^2}$

(b) $\boxed{A = 80.7\text{ lb},\ B = 149.3\text{ lb}}$

Since $A > 0$ and $B > 0$ then our assumption is correct.



Problem 18.2 Solve Problem 18.1 if the coefficient of kinetic friction at A and B is $\mu_k = 0.1$.

Solution: Assume sliding without tipping

$$\sum F_x : (30\text{ lb}) - (0.1)(A + B) = \left(\frac{230\text{ lb}}{32.2\text{ ft/s}^2}\right) a$$

$$\sum F_y : A + B - 230\text{ lb} = 0$$

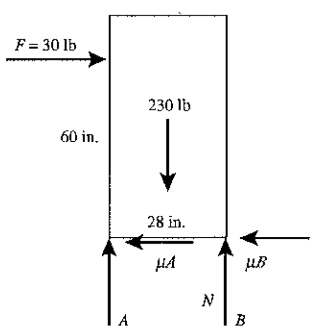
$$\sum M_G : -(30\text{ lb})(32\text{ in.}) - A(14\text{ in.}) + B(14\text{ in.})$$

$$- (0.1)(A + B)(28\text{ in.}) = 0$$

Solving, we find

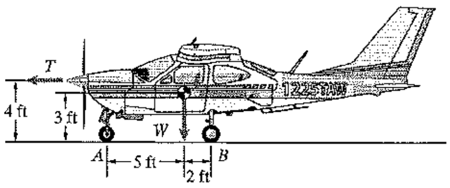
(a) $\boxed{a = 0.98\text{ ft/s}^2}$

(b) $\boxed{A = 57.7\text{ lb},\ B = 172\text{ lb}}$

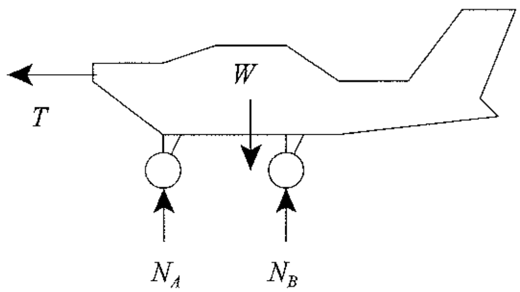


Problem 18.3 As the 2800-lb airplane begins its take-off run at $t = 0$, its propeller exerts a horizontal force $T = 1000$ lb. Neglect horizontal forces exerted on the wheels by the runway.

(a) What distance has the airplane moved at $t = 2$ s?
(b) what normal forces are exerted on the tires at A and B?



Solution: The unknowns are N_A, N_B, a.



The equations of motion are:

$$\Sigma F_x : -T = -\frac{W}{g}a,$$

$$\Sigma F_y : N_A + N_B - W = 0$$

$$\Sigma M_G : N_B(2\text{ ft}) - N_A(5\text{ ft}) + T(1\text{ ft}) = 0$$

Putting in the numbers for T, W, and g and solving we find

$$N_A = 943\text{ lb}, \quad N_B = 1860\text{ lb}, \quad a = 11.5\text{ ft/s}^2.$$

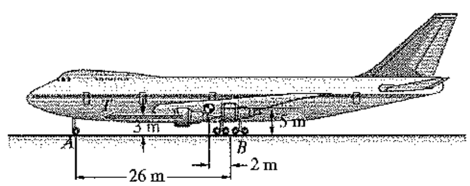
(a) The distance is given by $d = \frac{1}{2}at^2 = \frac{1}{2}(11.5\text{ ft/s}^2)(2\text{ s})^2 = 23$ ft.

$\boxed{d = 23\text{ ft.}}$

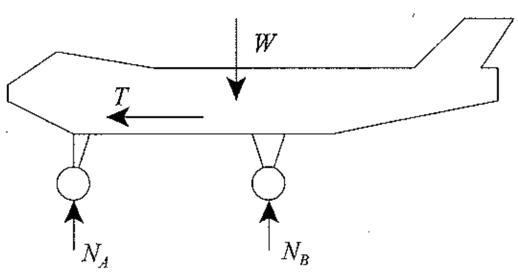
(b) The forces were found to be

$\boxed{N_A = 943\text{ lb}, \quad N_B = 1860\text{ lb.}}$

Problem 18.4 The Boeing 747 begins its takeoff run at time $t = 0$. The normal forces exerted on its tires at A and B are $N_A = 175$ kN and $N_B = 2800$ kN. If you assume that these forces are constant and neglect horizontal forces other than the thrust T, how fast is the airplanes moving at $t = 4$ s? (See Active Example 18.1.)



Solution: The unknowns are T, W, a. The equations of motion are:



$$\Sigma F_x : -T = -\frac{W}{g}a,$$

$$\Sigma F_y : N_A + N_B - W = 0,$$

$$\Sigma M_G : N_B(2\text{ m}) - N_A(24\text{ m}) - T(2\text{ m}) = 0.$$

Putting in the numbers for N_A and N_B and solving, we find

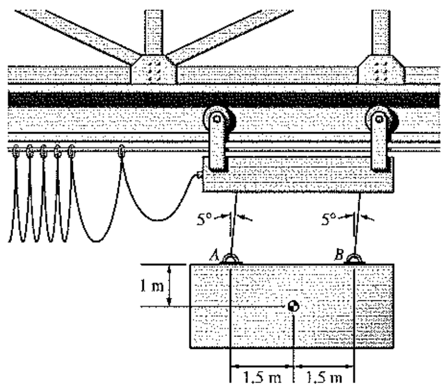
$$a = 2.31\text{ m/s}^2, \quad T = 700\text{ kN}, \quad W = 2980\text{ kN}.$$

The velocity is then given by

$v = at = (2.31\text{ m/s}^2)(4\text{ s}) = 9.23$ m/s. $\boxed{v = 9.23\text{ m/s.}}$

Problem 18.5 The crane moves to the right with constant acceleration, and the 800-kg load moves without swinging.

(a) What is the acceleration of the crane and load?
(b) What are the tensions in the cables attached at A and B?



Solution: From Newton's second law: $F_x = 800a$ N.
The sum of the forces on the load:

$$\sum F_x = F_A \sin 5^\circ + F_B \sin 5^\circ - 800a = 0.$$

$$\sum F_y = F_A \cos 5^\circ + F_B \cos 5^\circ - 800g = 0.$$

The sum of the moments about the center of mass:

$$\sum M_{CM} = -1.5F_A \cos 5^\circ + 1.5F_B \cos 5^\circ$$

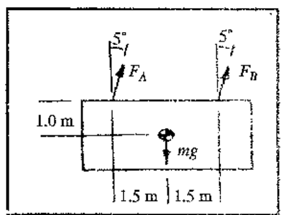
$$- F_A \sin 5^\circ - F_B \sin 5^\circ = 0.$$

Solve these three simultaneous equations:

$\boxed{a = 0.858 \text{ m/s}^2}$,

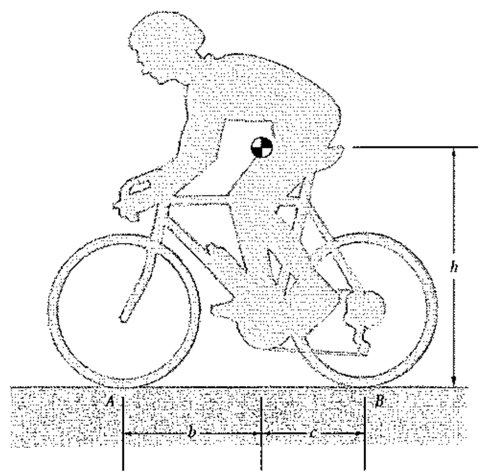
$\boxed{F_A = 3709 \text{ N}}$,

$\boxed{F_B = 4169 \text{ N}}$



Problem 18.7 The total weight of the bicycle and rider is 160 lb. The location of their combined center of mass is shown. The dimensions shown are $b = 21$ in., $c = 16$ in., and $h = 38$ in. What is the largest acceleration the bicycle can have without the front wheel leaving the ground? Neglect the horizontal force exerted on the front wheel by the road.

Strategy: You want to determine the value of the acceleration that causes the normal force exerted on the front wheel by the road to equal zero.



Solution: Given: $b = 21$ in., $c = 16$ in., $h = 38$ in.

Find: a so that $N_A = 0$

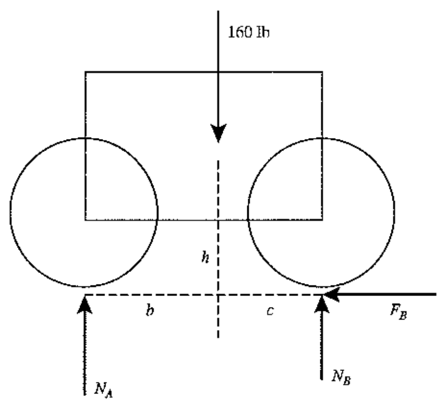
$$\sum F_x : -F_B = -\left(\frac{160 \text{ lb}}{32.2 \text{ ft/s}^2}\right) a$$

$$\sum F_y : N_A + N_B - (160 \text{ lb}) = 0$$

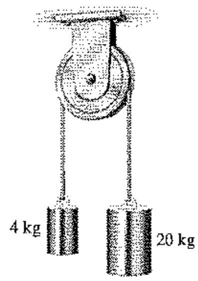
$$\sum M_G : -N_A b + N_B c - F_B h = 0$$

$N_A = 0$

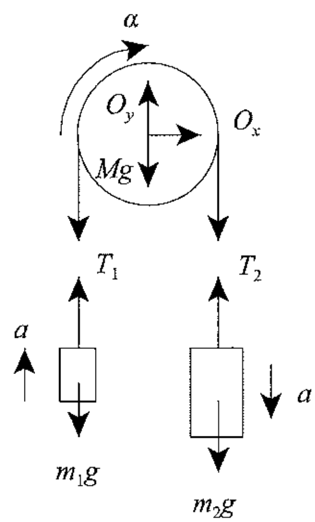
Solving we find $N_B = 160$ lb, $F_B = 67.4$ lb, $\boxed{a = 13.6 \text{ ft/s}^2}$



Problem 18.16 The radius of the pulley is 125 mm and the moment of inertia about its axis is $I = 0.05$ kg-m^2. If the system is released from rest, how far does the 20-kg mass fall in 0.5 s? What is the tension in the rope between the 20-kg mass and the pulley?



Solution: The free-body diagrams are shown.



We have six unknowns

$$T_1, T_2, O_x, O_y, a, \alpha.$$

We have five dynamic equations and one constraint equation available. We will use three dynamic equations and the one constraint equation

$\Sigma M_O : (T_1 - T_2)(0.125 \text{ m}) = -(0.05 \text{ kg-m}^2)\alpha,$

$\Sigma F_{y1} : T_1 - (4 \text{ kg})(9.81 \text{ m/s}^2) = (4 \text{ kg})a,$

$\Sigma F_{y2} : T_2 - (20 \text{ kg})(9.81 \text{ m/s}^2) = -(20 \text{ kg})a,$

$a = (0.125 \text{ m})\alpha.$

Solving we find

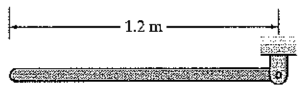
$$T_1 = 62.3 \text{ N},\ T_2 = 80.8 \text{ N},\ a = 5.77 \text{ m/s}^2,\ \alpha = 46.2 \text{ rad/s}^2.$$

From kinematics we find

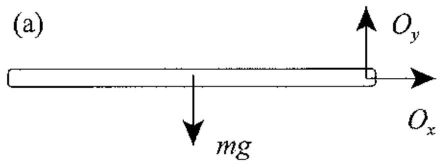
$d = \frac{1}{2}at^2 = \frac{1}{2}(5.77 \text{ m/s}^2)(0.5 \text{ s})^2 = 0.721 \text{ m}.$

$\boxed{d = 0.721 \text{ m},\ T_2 = 80.8 \text{ N}.}$

Problem 18.18 The 5-kg slender bar is released from rest in the horizontal position shown. Determine the bar's counterclockwise angular acceleration (a) at the instant it is released, and (b) at the instant when it has rotated 45°.



Solution:

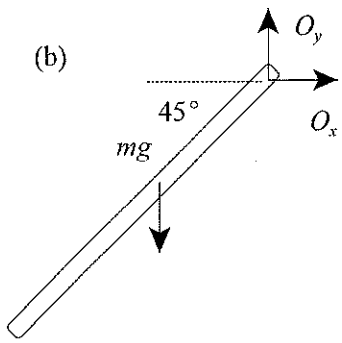


(a) The free-body diagram is shown.

$$\Sigma M_O : mg\frac{L}{2} = \frac{1}{3}\, mL^2\alpha$$

$$\alpha = \frac{3g}{2L} = \frac{3(9.81\ \text{m/s}^2)}{2(1.2\ \text{m})} = 12.3\ \text{rad/s}^2.$$

$$\boxed{\alpha = 12.3\ \text{rad/s}^2.}$$



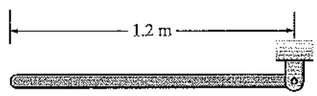
(b) The free-body diagram is shown.

$$\Sigma M_O : mg\frac{L}{2}\cos 45^\circ = \frac{1}{3}\, mL^2\alpha$$

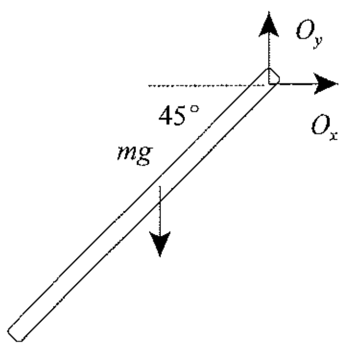
$$\alpha = \frac{3g}{2L}\cos 45^\circ = \frac{3(9.81\ \text{m/s}^2)}{2(1.2\ \text{m})}\cos 45^\circ$$

$$\boxed{\alpha = 8.67\ \text{rad/s}^2.}$$

Problem 18.19 The 5-kg slender bar is released from rest in the horizontal position shown. At the instant when it has rotated 45°, its angular velocity is 4.16 rad/s. At that instant, determine the magnitude of the force exerted on the bar by the pin support. (See Example 18.4.)



Solution: First find the angular acceleration.



$$\Sigma M_O : mg\frac{L}{2}\cos 45^\circ = \frac{1}{3}\, mL^2\alpha$$

$$\alpha = \frac{3}{2}\frac{g}{L}\cos 45^\circ = \frac{3(9.81\ \text{m/s}^2)}{2(1.2\ \text{m})}\cos 45^\circ = 8.67\ \text{rad/s}^2$$

Using kinematics we find the acceleration of the center of mass.

$$\mathbf{a}_G = \mathbf{a}_O + \boldsymbol{\alpha} \times \mathbf{r}_{G/O} - \omega^2\mathbf{r}_{G/O}$$

$$\mathbf{a}_G = 0 + (8.67)\mathbf{k} \times (0.6)(-\cos 45^\circ\mathbf{i} - \sin 45^\circ\mathbf{j})$$

$$- (4.16)^2(0.6)(-\cos 45^\circ\mathbf{i} - \sin 45^\circ\mathbf{j})$$

$$= (11.0\mathbf{i} + 3.66\mathbf{j})\ \text{m/s}^2.$$

From Newton's second law we have

$$\Sigma F_x : O_x = ma_x = (5\ \text{kg})(11.0\ \text{m/s}^2) = 55.1\ \text{N}$$

$$\Sigma F_y : O_y - mg = ma_y$$

$$O_y = m(g + a_y) = (5\ \text{kg})(9.18\ \text{m/s}^2 + 3.66\ \text{m/s}^2) = 67.4\ \text{N}$$

The magnitude of the force in the pin is now

$$O = \sqrt{O_x^2 + O_y^2} = \sqrt{(55.1\ \text{N})^2 + (67.4\ \text{N})^2} = 87.0\ \text{N}.$$

$$\boxed{O = 87.0\ \text{N}.}$$

Problem 18.31 Points B and C lie in the $x-y$ plane. The y axis is vertical. The center of mass of the 18-kg arm BC is at the midpoint of the line from B to C, and the moment of inertia of the arm about the axis through the center of mass that is parallel to the z axis is 1.5 kg-m^2. At the instant shown, the angular velocity and angular acceleration vectors of arm AB are $\boldsymbol{\omega}_{AB} = 0.6\mathbf{k}$ (rad/s) and $\boldsymbol{\alpha}_{AB} = -0.3\mathbf{k}$ (rad/s^2). The angular velocity vector of arm BC is $\boldsymbol{\omega}_{BC} = 0.4\mathbf{k}$ (rad/s). If you want to program the robot so that the angular acceleration of arm BC is zero at this instant, what couple must be exerted on arm BC at B?

Solution: From the solution of Problem 18.30, the acceleration of point B is $\mathbf{a}_B = -0.323\mathbf{i} - 0.149\mathbf{j}$ (m/s^2). If $\alpha_{BC} = 0$, the acceleration of the center of mass G of arm BC is

$$\mathbf{a}_G = \mathbf{a}_B - \omega_{BC}^2 \mathbf{r}_{G/B} = -0.323\mathbf{i} - 0.149\mathbf{j}$$

$$- (0.4)^2(0.45\cos 50°\mathbf{i} + 0.45\sin 50°\mathbf{j})$$

$$= -0.370\mathbf{i} - 0.205\mathbf{j} \text{ (m/s}^2\text{)}.$$

From the free body diagram of arm BC in the solution of Problem 18.30. Newton's second law is

$$\sum \mathbf{F} = B_x\mathbf{i} + (B_y - mg)\mathbf{j} = m\mathbf{a}_G:$$

$$B_x\mathbf{i} + [B_y - (18)(9.81)]\mathbf{j} = 18(-0.370\mathbf{i} - 0.205\mathbf{j}).$$

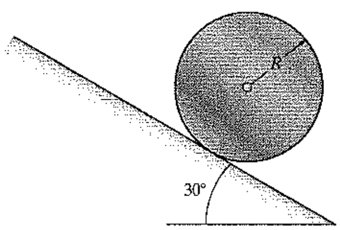
Solving, we obtain $B_x = -6.65$ N, $B_y = 172.90$ N. The equation of angular motion is

$$\sum M_G = I_{BC}\alpha_{BC} = 0:$$

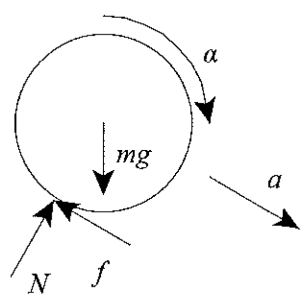
$$(0.45\sin 50°)B_x - (0.45\cos 50°)B_y + M_B = 0.$$

Solving for M_B, we obtain $M_B = 52.3$ N-m.

Problem 18.32 The radius of the 2-kg disk is $R = 80$ mm. Its moment of inertia is $I = 0.0064$ kg-m^2. It rolls on the inclined surface. If the disk is released from rest, what is the magnitude of the velocity of its center two seconds later? (See Active Example 18.2).



Solution: There are four unknowns (N, f, a, α), three dynamic equations, and one constraint equation. We have



$\Sigma M_G : -fr = -I\alpha,$

$\Sigma F_{\searrow} : mg\sin 30° - f = ma$

$a = r\alpha$

Solving, we find

$$a = \frac{mgr^2 \sin 30°}{I + mr^2}$$

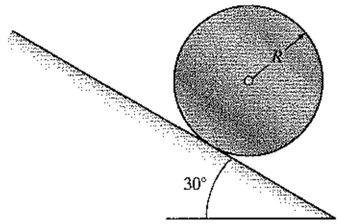
$$= \frac{(2 \text{ kg})(9.81 \text{ m/s}^2)(0.08 \text{ m})^2 \sin 30°}{0.0064 \text{ kg-m}^2 + (2 \text{ kg})(0.08 \text{ m})^2}$$

$$= 3.27 \text{ m/s}^2.$$

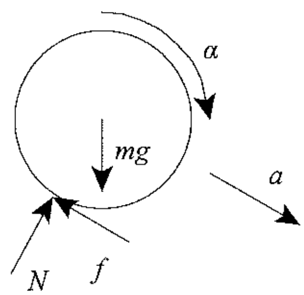
From the kinematics we have

$v = at = (3.27 \text{ m/s}^2)(2 \text{ s}) = 6.54$ m/s. $\boxed{v = 6.54 \text{ m/s.}}$

Problem 18.33 The radius of the 2-kg disk is $R = 80$ mm. Its moment of inertia is $I = 0.0064$ kg-m^2. What minimum coefficient of static friction is necessary for the disk to roll, instead of slip, on the inclined surface? (See Active Example 18.2.)



Solution: There are five unknowns (N, f, a, α, μ_s), three dynamic equations, one constraint equation, and one friction equation. We have



$\Sigma M_G : -fR = -I\alpha,$

$\Sigma F_{\searrow} : mg \sin 30^\circ - f = ma,$

$\Sigma F_{\nearrow} : N - mg \cos 30^\circ = 0,$

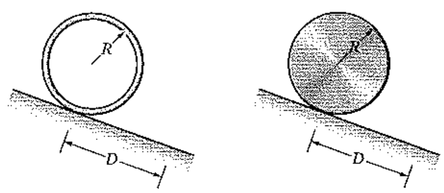
$a = R\alpha,$

$f = \mu_s N.$

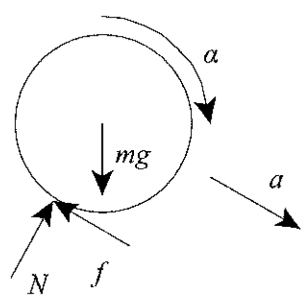
Putting in the numbers and solving, we find

$N = 17.0$ N, $f = 3.27$ N, $a = 3.27$ m/s^2, $\alpha = 40.9$ rad/s^2, $\boxed{\mu_s = 0.192.}$

Problem 18.34 A thin ring and a homogeneous circular disk, each of mass m and radius R, are released from rest on an inclined surface. Determine the ratio $v_{\text{ring}}/v_{\text{disk}}$ of the velocities of the their centers when they ave rolled a distance D.



Solution: There are four unknowns (N, f, a, α), three dynamic equations, and one constraint equation. We have



$\Sigma M_G : -fR = -I\alpha,$

$\Sigma F_{\searrow} : mg \sin\theta - f = ma,$

$a = R\alpha,$

Solving, we find $a = \dfrac{mgr^2 \sin\theta}{I + mr^2}$

For the ring $I_{\text{ring}} = mr^2 \Rightarrow a_{\text{ring}} = \dfrac{g}{2} \sin\theta$

For the disk $I_{\text{disk}} = \dfrac{1}{2} mr^2 \Rightarrow a_{\text{disk}} = \dfrac{2g}{3} \sin\theta$

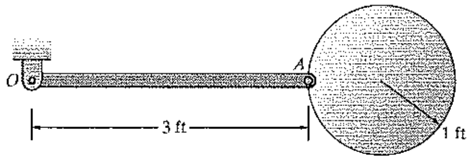
The velocities are then

$$v_{\text{ring}} = \sqrt{2a_{\text{ring}} D} = \sqrt{gD \sin\theta},\ v_{\text{disk}} = \sqrt{2a_{\text{disk}} D} = \sqrt{\frac{4}{3} gD \sin\theta}$$

The ratio is

$$\frac{v_{\text{ring}}}{v_{\text{disk}}} = \frac{\sqrt{gD \sin\theta}}{\sqrt{\frac{4}{3} gD \sin\theta}} = \sqrt{3/4} \quad \boxed{\frac{v_{\text{ring}}}{v_{\text{disk}}} = \sqrt{3/4}}$$

Problem 18.49 The 5-lb horizontal bar is connected to the 10-lb disk by a smooth pin at A. The system is released from rest in the position shown. What are the angular accelerations of the bar and disk at that instant?



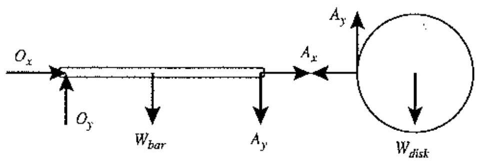
Solution: Given

$g = 32.2\ \text{ft/s}^2,\ W_{bar} = 5\ \text{lb},\ W_{disk} = 10\ \text{lb},$

$m_{bar} = \dfrac{W_{bar}}{g},\ m_{disk} = \dfrac{W_{disk}}{g}$

$L = 3\ \text{ft},\ R = 1\ \text{ft}$

The FBDs



The dynamic equations

$$\sum M_O : -m_{bar} g \frac{L}{2} - A_y L = \frac{1}{3} m_{bar} L^2 \alpha_{bar}$$

$$\sum M_{Gdisk} : -A_y R = \frac{1}{2} m_{disk} R^2 \alpha_{disk}$$

$$\sum F_y : A_y - m_{disk} g = m_{disk} a_{ydisk}$$

Kinematic constraint

$$\alpha_{bar} L = a_{ydisk} - \alpha_{disk} R$$

Solving we find

$\alpha_{disk} = 3.58\ \text{rad/s}^2,\ \alpha_{bar} = -12.5\ \text{rad/s}^2,\ a_{ydisk} = -34.0\ \text{m/s}^2,$

$A_y = -0.556\ \text{N}$

Thus $\boxed{\alpha_{disk} = 3.58\ \text{rad/s}^2\ \ CCW,\ \alpha_{bar} = 12.5\ \text{rad/s}^2\ \ CW}$