Chap. 3 Rigid Bodies: Equivalent Systems of Forces

- Treatment of a body as a single particle is not always possible. In general, the size of the body and the specific points of application of the forces must be considered.

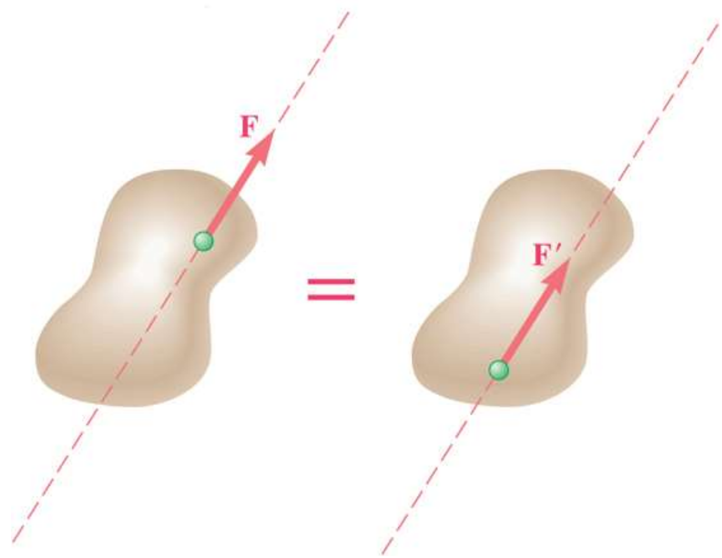
- To fully describe the effect of forces exerted on a rigid body, also need to consider:
    - moment of a force about a point
    - moment of a force about an axis
    - moment due to a couple

- Any system of forces acting on a rigid body can be replaced by an equivalent system consisting of one force acting at a given point and one couple.

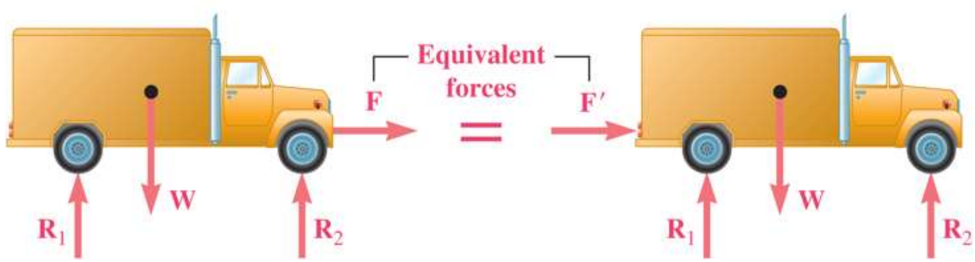
External/Internal Forces; Equivalent Forces

- **External forces** are shown in a free body diagram. **Internal forces** should not appear on a free body diagram.

- *Principle of Transmissibility* - Conditions of equilibrium or motion are not affected by *transmitting* a force along its line of action.
  NOTE: **F** and **F'** are equivalent forces.

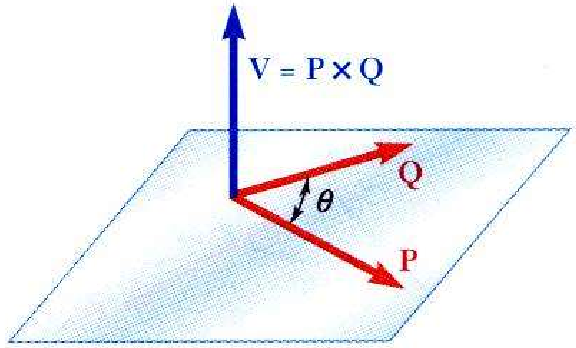


- Moving the point of application of the force **F** to the rear bumper does not affect the motion or the other forces acting on the truck.

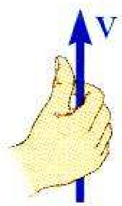


Vector Product of Two Vectors

- Vector product of two vectors ***P*** and ***Q*** (a concept needed for moment) is defined as the vector ***V*** which satisfies the following conditions:
  1. Line of action of ***V*** is perpendicular to plane containing ***P*** and ***Q***.
  2. Magnitude of ***V*** is $V = PQ \sin\theta$
  3. Direction of ***V*** is obtained from the right-hand rule.



(a)



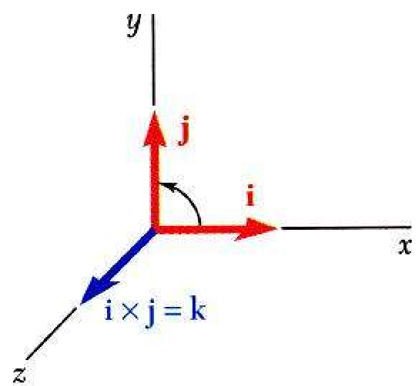
(b)

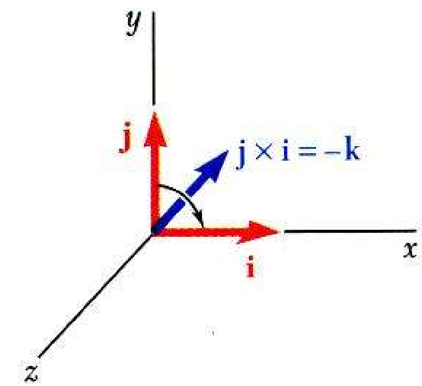
- Vector products:
  - are not commutative, $\boldsymbol{Q} \times \boldsymbol{P} = -(\boldsymbol{P} \times \boldsymbol{Q})$
  - are distributive, $\boldsymbol{P} \times (\boldsymbol{Q}_1 + \boldsymbol{Q}_2) = \boldsymbol{P} \times \boldsymbol{Q}_1 + \boldsymbol{P} \times \boldsymbol{Q}_2$
  - are not associative, $(\boldsymbol{P} \times \boldsymbol{Q}) \times \boldsymbol{S} \neq \boldsymbol{P} \times (\boldsymbol{Q} \times \boldsymbol{S})$

Vector Products: Rectangular Components

- Vector products of Cartesian unit vectors,

$$
\begin{array}{lll}
\vec{i}\times\vec{i}=0 & \vec{j}\times\vec{i}=-\vec{k} & \vec{k}\times\vec{i}=\vec{j} \\
\vec{i}\times\vec{j}=\vec{k} & \vec{j}\times\vec{j}=0 & \vec{k}\times\vec{j}=-\vec{i} \\
\vec{i}\times\vec{k}=-\vec{j} & \vec{j}\times\vec{k}=\vec{i} & \vec{k}\times\vec{k}=0
\end{array}
$$





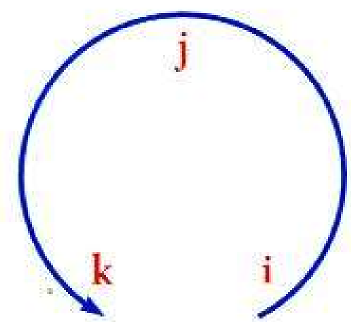
- Vector products in terms of rectangular coordinates

$$\vec{V}=\left(P_x\vec{i}+P_y\vec{j}+P_z\vec{k}\right)\times\left(Q_x\vec{i}+Q_y\vec{j}+Q_z\vec{k}\right)$$

$$=\left(P_yQ_z-P_zQ_y\right)\vec{i}+\left(P_zQ_x-P_xQ_z\right)\vec{j}$$

$$+\left(P_xQ_y-P_yQ_x\right)\vec{k}$$

$$=\begin{pmatrix}\vec{i} & \vec{j} & \vec{k}\\ P_x & P_y & P_z\\ Q_x & Q_y & Q_z\end{pmatrix}$$

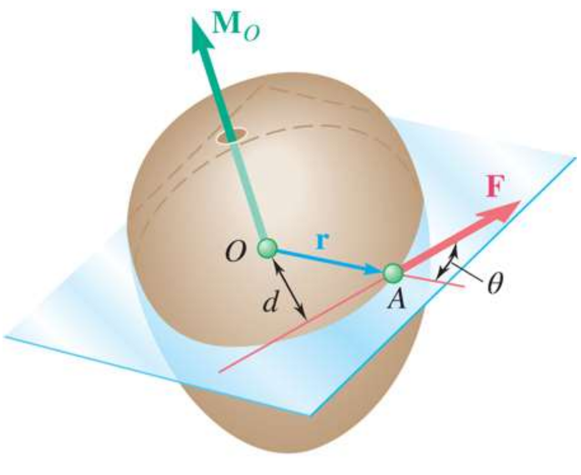


Moment of a Force About a Point

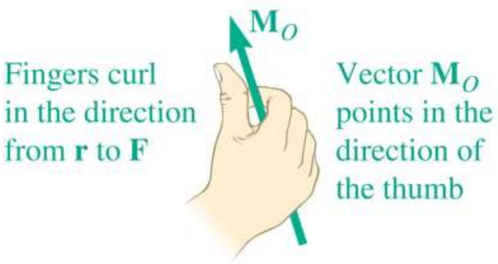
- A force vector is defined by its magnitude and direction. Its effect on the rigid body also depends on its point of application.
- The *moment* of ***F*** about *O* is defined as

$$\boldsymbol{M_O} = \boldsymbol{r} \times \boldsymbol{F}$$

- The moment vector $\boldsymbol{M_O}$ is perpendicular to the plane containing *O* and the force ***F***.
- Magnitude of $\boldsymbol{M_O}$, $M_O = rF \sin\theta = Fd$, measures the tendency of the force to cause rotation of the body about an axis along $\boldsymbol{M_O}$. The sense of the moment may be determined by the right-hand rule.
- Any force ***F'*** that has the same magnitude and direction as ***F***, is *equivalent* if it also has the same line of action and therefore, produces the same moment.



(a)



(b)

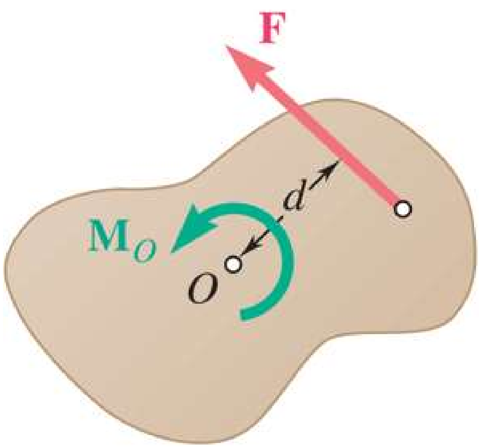
Moment of a Force About a Point

- *Two-dimensional structures* have length and breadth but negligible depth and are subjected to forces contained only in the plane of the structure.

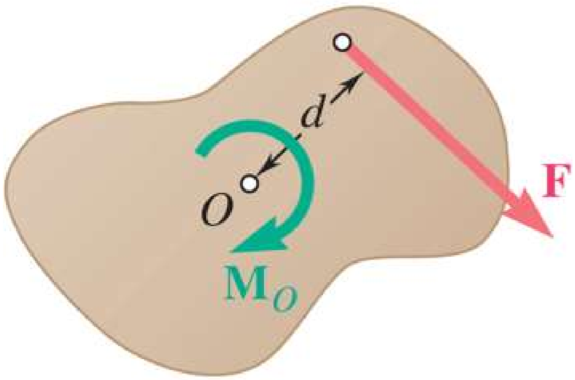
- The plane of the structure contains the point *O* and the force ***F***. $\boldsymbol{M_O}$, the moment of the force about *O* is perpendicular to the plane.

- If the force tends to rotate the structure clockwise, the sense of the moment vector is out of the plane of the structure and the magnitude of the moment is positive.

- If the force tends to rotate the structure counterclockwise, the sense of the moment vector is into the plane of the structure and the magnitude of the moment is negative.



(a) $\boldsymbol{M}_O = +Fd$



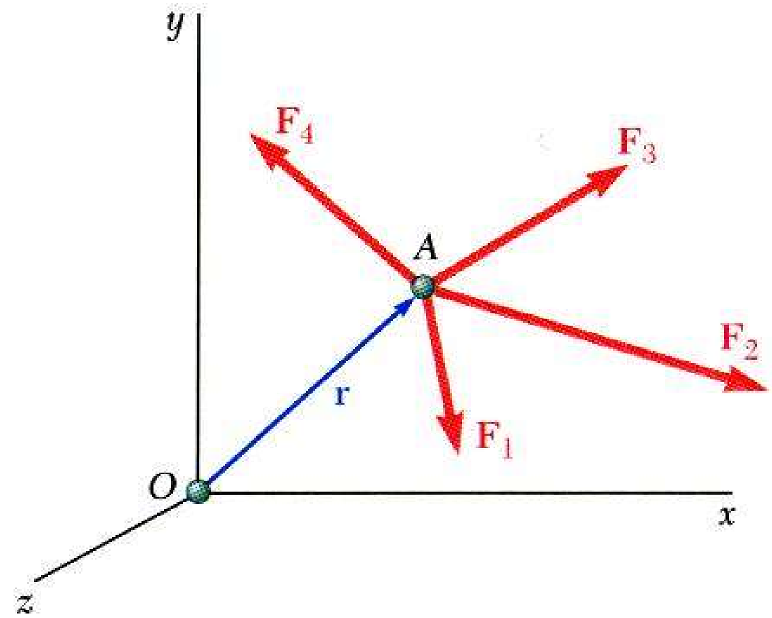
(b) $\boldsymbol{M}_O = -Fd$

Varignon's Theorem

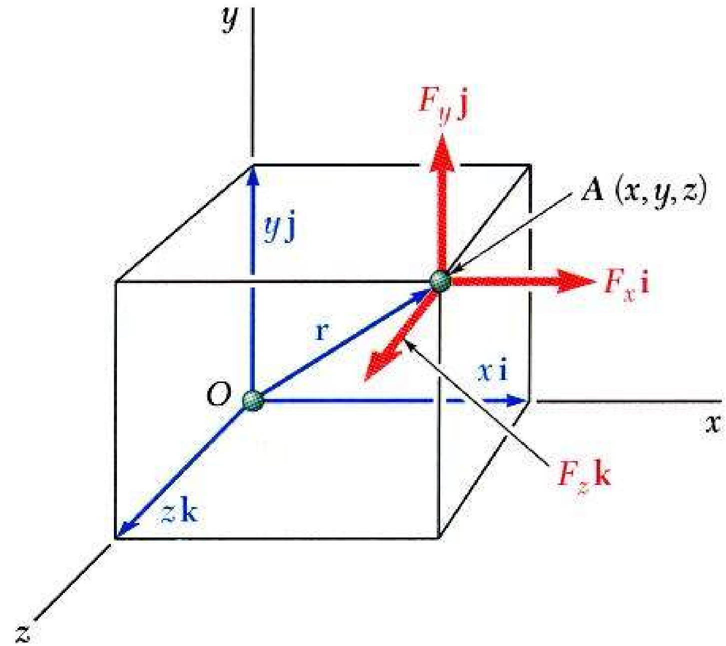
- The moment about a give point *O* of the resultant of several concurrent forces is equal to the sum of the moments of the various moments about the same point *O*.

$$\vec{r} \times \left(\vec{F}_1 + \vec{F}_2 + \cdots\right) = \vec{r} \times \vec{F}_1 + \vec{r} \times \vec{F}_2 + \cdots$$

- Varignon's Theorem makes it possible to replace the direct determination of the moment of a force ***F*** by the moments of two or more component forces of ***F***.



Rectangular Components of the Moment of a Force



The moment of ***F*** about *O*,

$$\vec{M}_O = \vec{r} \times \vec{F}, \qquad \vec{r} = x\vec{i} + y\vec{j} + z\vec{k}$$

$$\vec{F} = F_x\vec{i} + F_y\vec{j} + F_z\vec{k}$$

$$\vec{M}_O = M_x\vec{i} + M_y\vec{j} + M_z\vec{k} = \begin{pmatrix} \vec{i} & \vec{j} & \vec{k} \\ x & y & z \\ F_x & F_y & F_z \end{pmatrix}$$

$$= \left(yF_z - zF_y\right)\vec{i} + \left(zF_x - xF_z\right)\vec{j} + \left(xF_y - yF_x\right)\vec{k}$$

The components of $\vec{M}_o$, M_x, M_y, and M_z, represent the moments about the x-, y- and z-axis, respectively.

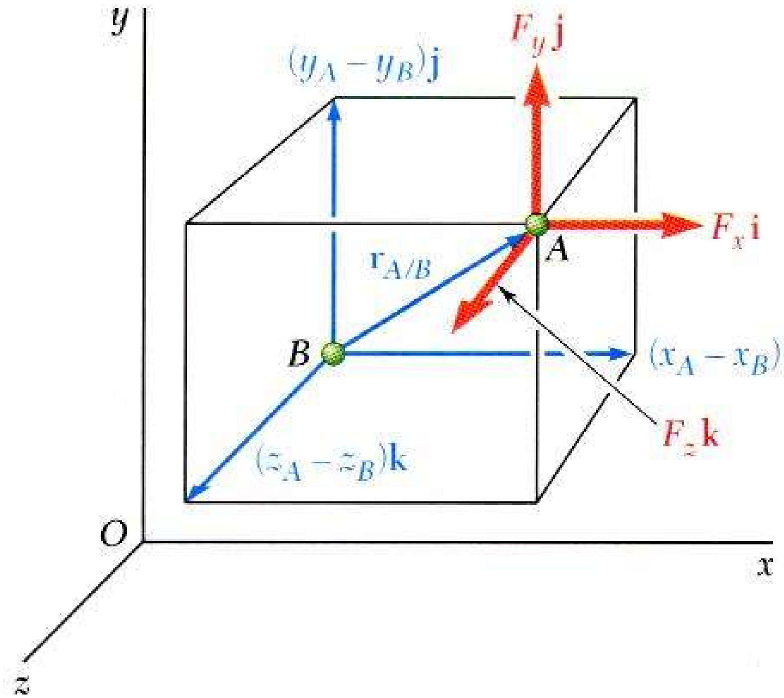
Rectangular Components of the Moment of a Force

The moment of ***F*** about *B*,

$$\vec{M}_B = \vec{r}_{A/B} \times \vec{F}$$

$$\vec{r}_{A/B} = \vec{r}_A - \vec{r}_B$$
$$= (x_A - x_B)\vec{i} + (y_A - y_B)\vec{j} + (z_A - z_B)\vec{k}$$

$$\vec{F} = F_x\vec{i} + F_y\vec{j} + F_z\vec{k}$$



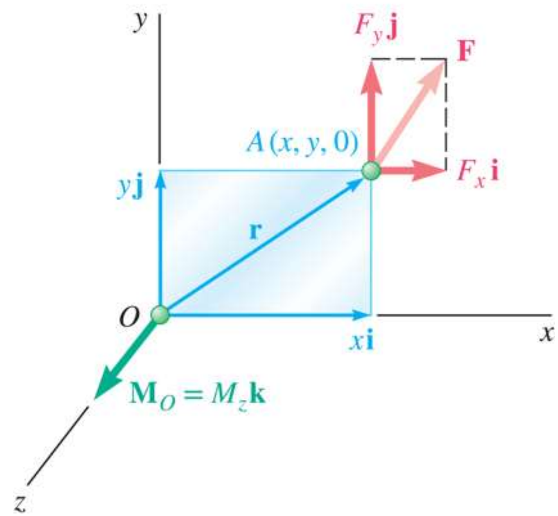
$$\vec{M}_B = \begin{pmatrix} \vec{i} & \vec{j} & \vec{k} \\ (x_A - x_B) & (y_A - y_B) & (z_A - z_B) \\ F_x & F_y & F_z \end{pmatrix}$$

Rectangular Components of the Moment of a Force

For two-dimensional structures,

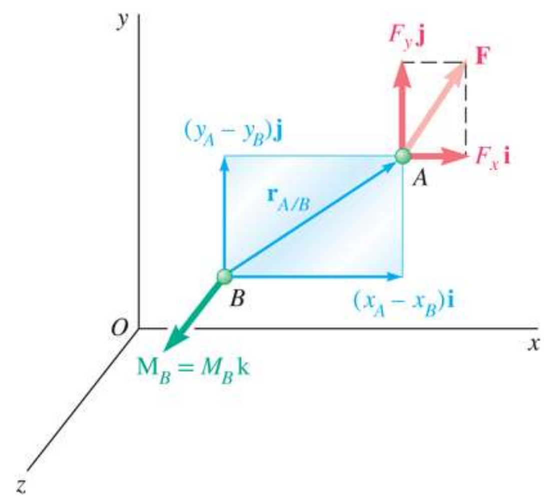
$$\vec{M}_O = \left(xF_y - yF_z \right) \vec{k}$$

$$M_O = M_Z$$
$$= xF_y - yF_z$$

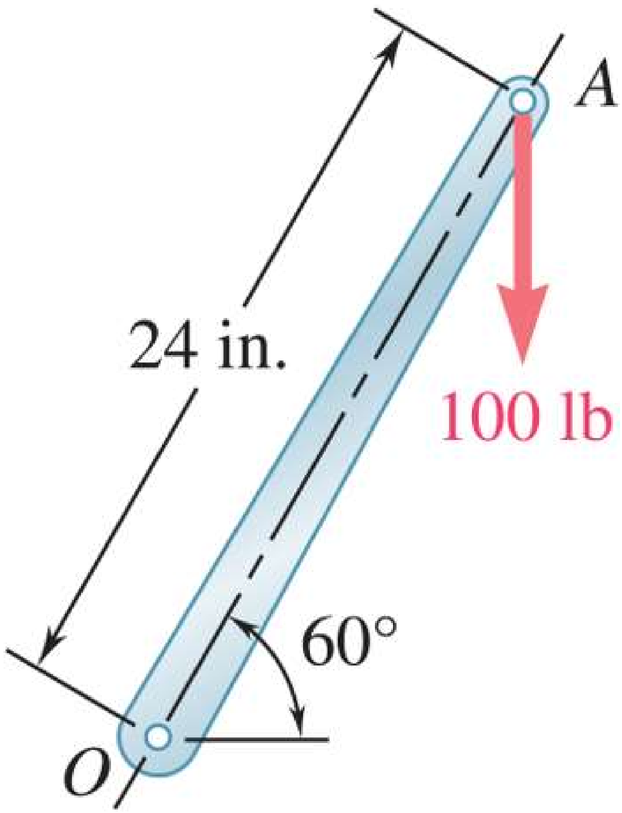


$$\vec{M}_B = \left[\left(x_A - x_B \right) F_y - \left(y_A - y_B \right) F_z \right] \vec{k}$$

$$M_B = M_Z$$
$$= \left(x_A - x_B \right) F_y - \left(y_A - y_B \right) F_z$$



Sample Problem 3.1



A 100-lb vertical force is applied to the end of a lever which is attached to a shaft (not shown) at *O*.

Determine:

a) the moment about *O*,

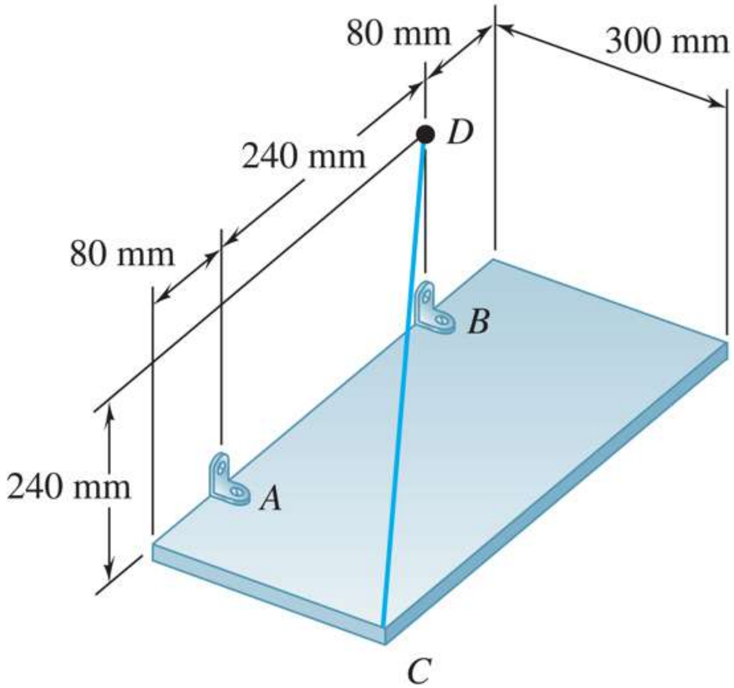
b) the horizontal force at *A* which creates the same moment,

c) the smallest force at A which produces the same moment,

d) the location for a 240-lb vertical force to produce the same moment,

e) whether any of the forces from b, c, and d is equivalent to the original force.

Sample Problem 3.4



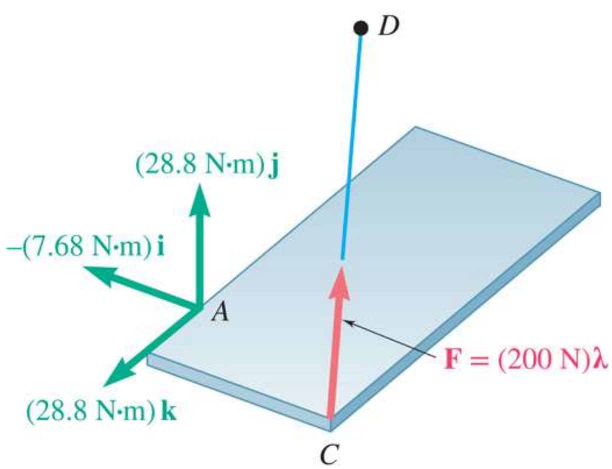
The rectangular plate is supported by the brackets at *A* and *B* and by a wire *CD*. Knowing that the tension in the wire is 200 N, determine the moment about *A* of the force exerted by the wire at *C*.

$$\vec{M}_A = \vec{r}_{C/A} \times \vec{F}$$

$$\vec{r}_{C/A} = \vec{r}_C - \vec{r}_A = (0.3\text{ m})\vec{i} + (0.08\text{ m})\vec{j}$$

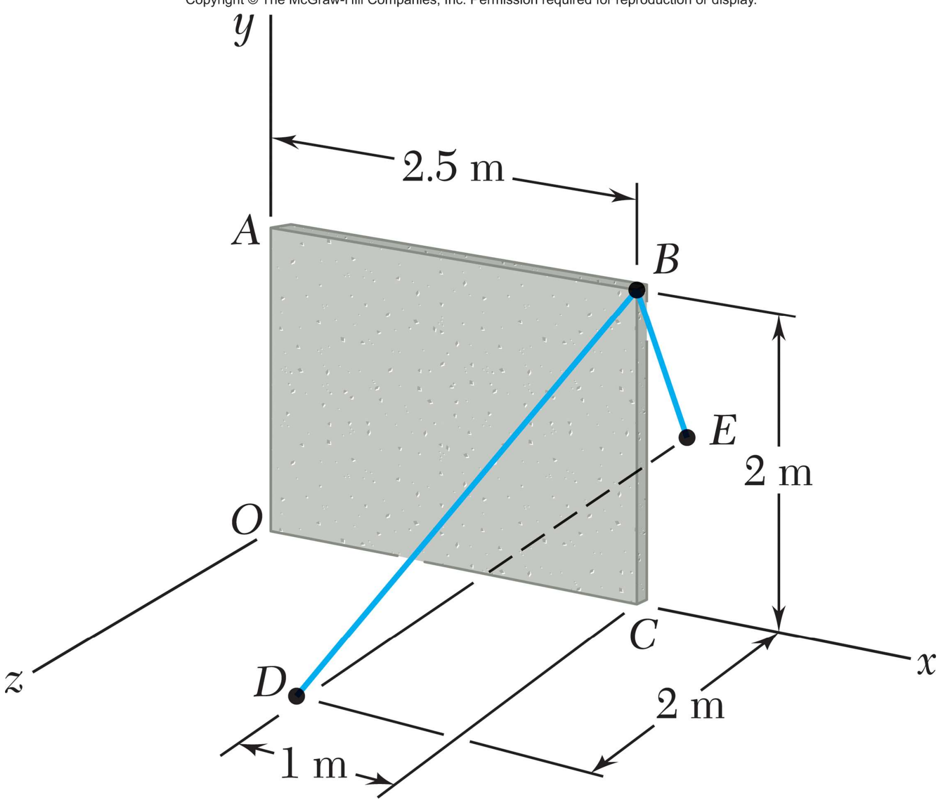
$$\vec{F} = (200\text{ N})\frac{-(0.3\text{ m})\vec{i} + (0.24\text{ m})\vec{j} - (0.32\text{ m})\vec{k}}{\sqrt{0.3^2 + 0.24^2 + 0.32^2}\text{ m}}$$

$$= -(120\text{ N})\vec{i} + (96\text{ N})\vec{j} - (128\text{ N})\vec{k}$$



$$\vec{M}_A = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ 0.3 & 0 & 0.08 \\ -120 & 96 & -128 \end{vmatrix} = -(7.68\text{ N}\cdot\text{m})\vec{i} + (28.8\text{ N}\cdot\text{m})\vec{j} + (28.8\text{ N}\cdot\text{m})\vec{k}$$

Problem 3.24



A precast concrete wall section is temporarily held by two cables as shown. Knowing that the tension in cable *BD* is 900 N, determine the moment about point *O* of the force exerted by the cable at *B*.

$$\mathbf{M}_O = \mathbf{r}_{B/O} \times \mathbf{F}$$

$$= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 2.5 & 2 & 0 \\ -300 & -600 & 600 \end{vmatrix}$$

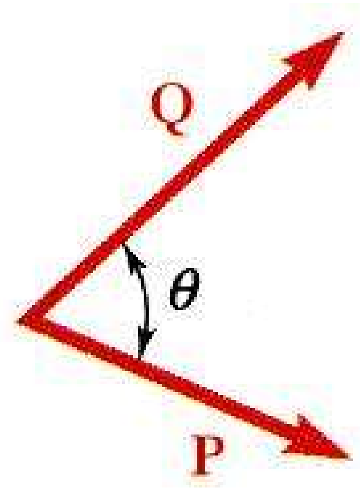
$$= 1200\mathbf{i} - 1500\mathbf{j} + (-1500 + 600)\mathbf{k}$$

Scalar Product of Two Vectors

- The *scalar product* or *dot product* between two vectors ***P*** and ***Q*** is defined as

  $\vec{P}\bullet\vec{Q} = PQ\cos\theta \quad (\text{scalar result})$

- Scalar products:
  - are commutative, $\vec{P}\bullet\vec{Q} = \vec{Q}\bullet\vec{P}$
  - are distributive, $\vec{P}\bullet(\vec{Q}_1+\vec{Q}_2) = \vec{P}\bullet\vec{Q}_1 + \vec{P}\bullet\vec{Q}_2$
  - are not associative, $(\vec{P}\bullet\vec{Q})\bullet\vec{S} = \text{undefined}$



- Scalar products with Cartesian unit components,

$$\vec{P}\bullet\vec{Q} = \left(P_x\vec{i} + P_y\vec{j} + P_z\vec{k}\right)\bullet\left(Q_x\vec{i} + Q_y\vec{j} + Q_z\vec{k}\right)$$

$$\vec{i}\bullet\vec{i} = 1 \quad \vec{j}\bullet\vec{j} = 1 \quad \vec{k}\bullet\vec{k} = 1 \quad \vec{i}\bullet\vec{j} = 0 \quad \vec{j}\bullet\vec{k} = 0 \quad \vec{k}\bullet\vec{i} = 0$$

$$\vec{P}\bullet\vec{Q} = P_xQ_x + P_yQ_y + P_zQ_z$$

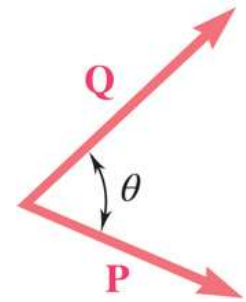
$$\vec{P}\bullet\vec{P} = P_x^2 + P_y^2 + P_z^2 = P^2$$

Applications of the Scalar Product

- Angle between two vectors:

$$\vec{P} \bullet \vec{Q} = PQ \cos\theta = P_x Q_x + P_y Q_y + P_z Q_z$$

$$\cos\theta = \frac{P_x Q_x + P_y Q_y + P_z Q_z}{PQ}$$

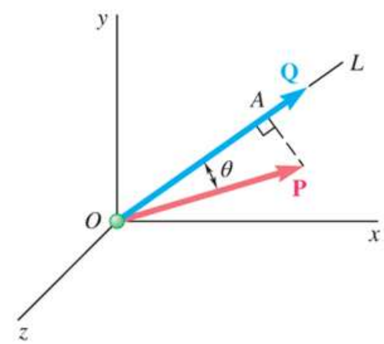


- Projection of a vector on a given axis:

$$P_{OL} = P\cos\theta = \text{ projection of } P \text{ along } OL$$

$$\vec{P} \bullet \vec{Q} = PQ\cos\theta$$

$$\frac{\vec{P} \bullet \vec{Q}}{Q} = P\cos\theta = P_{OL}$$

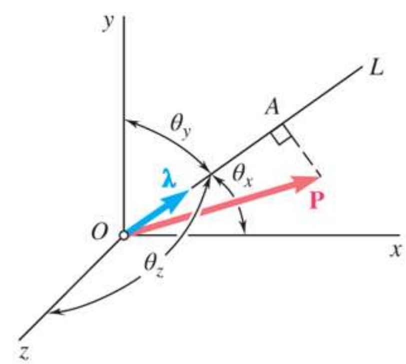


(b)

- For an axis defined by a unit vector:

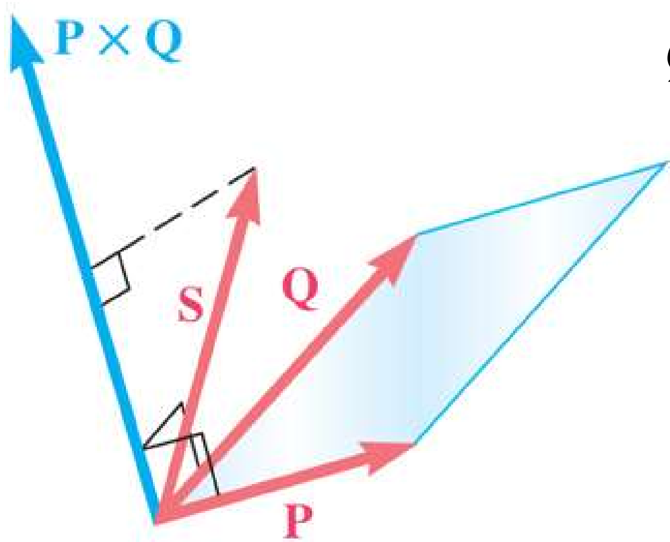
$$P_{OL} = \vec{P} \bullet \vec{\lambda}$$

$$= P_x \cos\theta_x + P_y \cos\theta_y + P_z \cos\theta_z$$



(c)

Mixed Triple Product of Three Vectors



(*a*)

- Mixed triple product of three vectors,

  $\vec{S}\bullet\left(\vec{P}\times\vec{Q}\right)=\text{scalar result}$

- The six mixed triple products formed from ***S***, ***P***, and ***Q*** have equal magnitudes but not the same sign,

$$\vec{S}\bullet\left(\vec{P}\times\vec{Q}\right)=\vec{P}\bullet\left(\vec{Q}\times\vec{S}\right)=\vec{Q}\bullet\left(\vec{S}\times\vec{P}\right)$$
$$=-\vec{S}\bullet\left(\vec{Q}\times P\right)=-\vec{P}\bullet\left(\vec{S}\times\vec{Q}\right)=-\vec{Q}\bullet\left(\vec{P}\times\vec{S}\right)$$

$$\vec{S}\bullet\left(\vec{P}\times\vec{Q}\right)=S_x\left(P_yQ_z-P_zQ_y\right)+S_y\left(P_zQ_x-P_xQ_z\right)$$
$$+S_z\left(P_xQ_y-P_yQ_x\right)$$
$$=\begin{pmatrix} S_x & S_y & S_z \\ P_x & P_y & P_z \\ Q_x & Q_y & Q_z \end{pmatrix}$$

Chapter 3 Exercises

- A force of F = 2 i + 3 j + 4 k is applied to an object at a point (3, -3, 2) from the origin. What is the moment exerted about the origin?

- To exert the same moment about the origin, what is the minimum force that is required to be applied at the same point of the object?

Moment of a Force About a Given Axis

- Moment $\boldsymbol{M_O}$ of a force $\boldsymbol{F}$ applied at the point $\boldsymbol{A}$ about a point $\boldsymbol{O}$,

$$\vec{M}_O = \vec{r} \times \vec{F}$$

- Scalar moment M_{OL} about an axis $\boldsymbol{OL}$ is the projection of the moment vector $\boldsymbol{M_O}$ onto the axis,

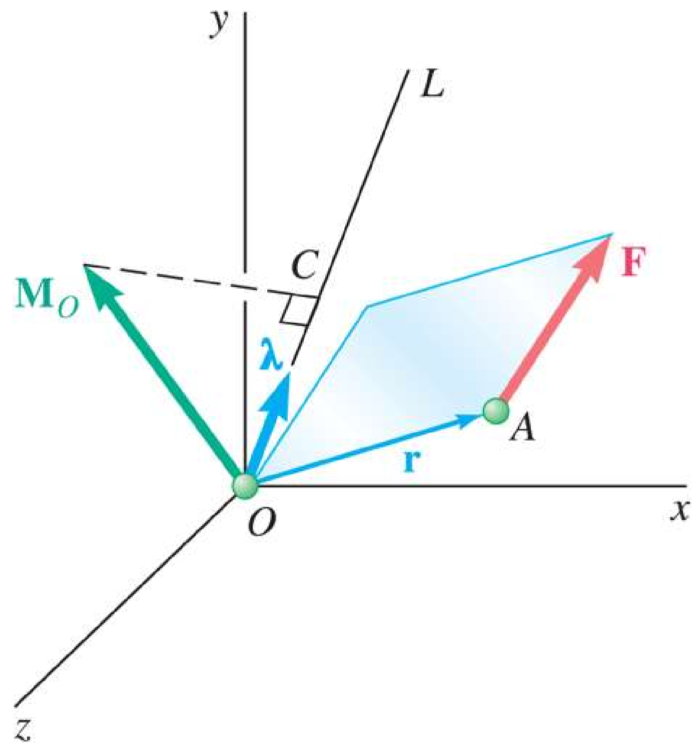
$$M_{OL} = \vec{\lambda} \bullet \vec{M}_O = \vec{\lambda} \bullet \left(\vec{r} \times \vec{F}\right)$$

- Moments of $\boldsymbol{F}$ about the coordinate axes,

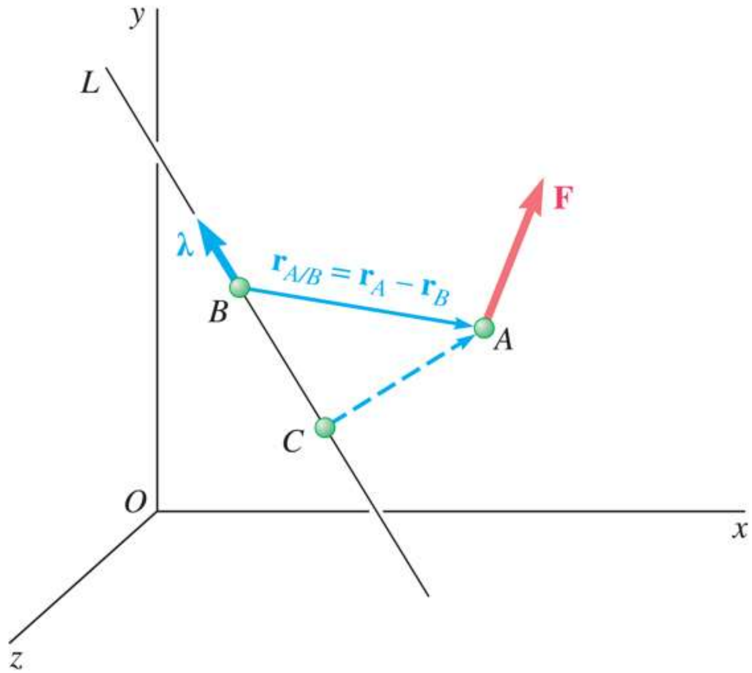
$$M_x = yF_z - zF_y$$

$$M_y = zF_x - xF_z$$

$$M_z = xF_y - yF_x$$



Moment of a Force About a Given Axis



- Moment of a force about an arbitrary axis,

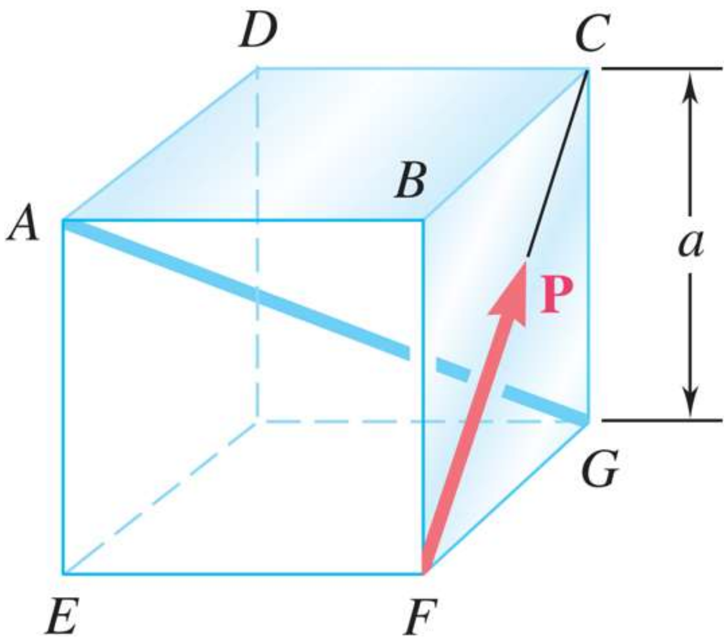
$$M_{BL} = \vec{\lambda} \bullet \vec{M}_B$$

$$= \vec{\lambda} \bullet \left(\vec{r}_{A/B} \times \vec{F} \right)$$

$$\vec{r}_{A/B} = \vec{r}_A - \vec{r}_B$$

- The result is independent of the point *B* along the given axis. For example, the same result can be obtained using $\vec{r}_{A/C}$

Sample Problem 3.5



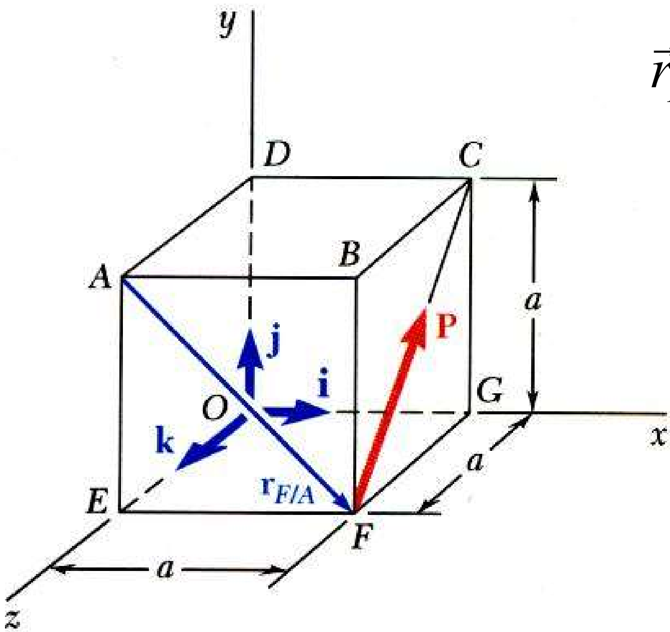
A cube is acted on by a force ***P*** as shown. Determine the moment of ***P***

a) about *A* $\qquad \vec{M}_A = \vec{r}_{F/A} \times \vec{P}$

b) about the edge *AB* and

c) about the diagonal *AG* of the cube.

d) Determine the perpendicular distance between *AG* and *FC*.



$$\vec{r}_{F/A} = a\vec{i} - a\vec{j} = a\left(\vec{i} - \vec{j}\right) \qquad \vec{P} = P\left(\sqrt{2}\,\vec{i} + \sqrt{2}\vec{j}\right) = P\sqrt{2}\left(\vec{i} + \vec{j}\right)$$

$$\boxed{\vec{M}_A = \left(aP\sqrt{2}\right)\left(\vec{i} + \vec{j} + \vec{k}\right)}$$

$$M_{AB} = \vec{i} \bullet \vec{M}_A = aP\sqrt{2}$$

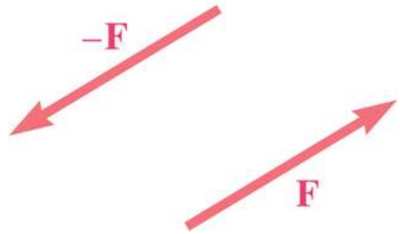
$$M_{AG} = \vec{\lambda}_{AG} \bullet \vec{M}_A \qquad \vec{\lambda}_{AG} = \frac{1}{\sqrt{3}}\left(\vec{i} - \vec{j} - \vec{k}\right)$$

$$M_{AG} = -\frac{aP}{\sqrt{6}}$$

$$\boxed{d = \frac{a}{\sqrt{6}}}$$

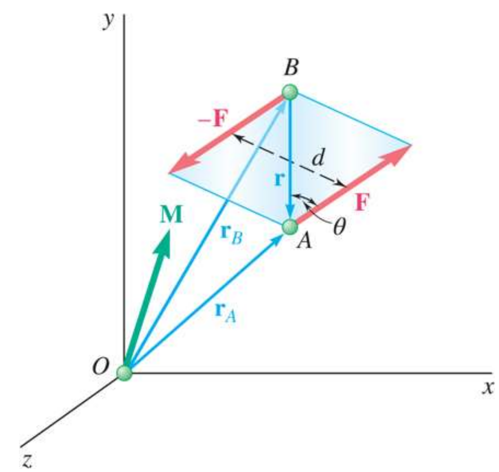
Moment of a Couple

- Two forces ***F*** and -***F*** having the same magnitude, parallel lines of action, and opposite sense are said to form a *couple*.

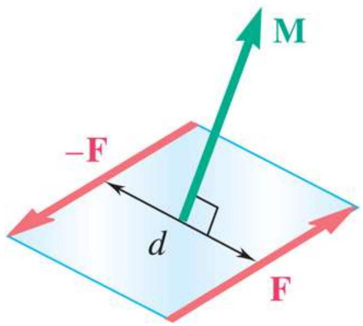


- Moment of the couple,

$$\vec{M} = \vec{r}_A \times \vec{F} + \vec{r}_B \times \left(-\vec{F}\right)$$
$$= \left(\vec{r}_A - \vec{r}_B\right) \times \vec{F}$$
$$= \vec{r} \times \vec{F}$$
$$M = rF \sin\theta = Fd$$

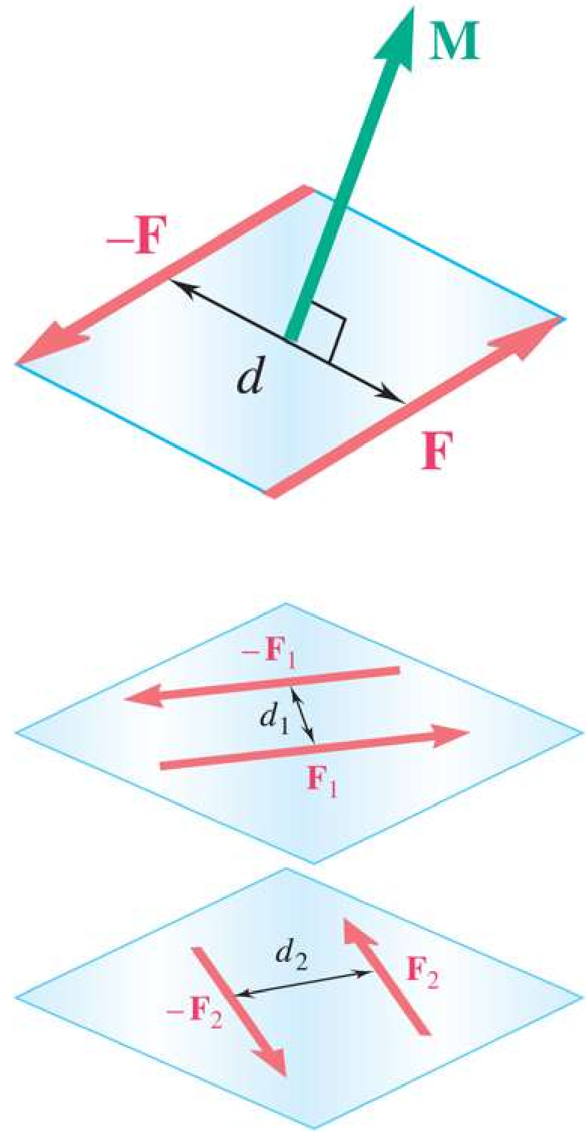


- The moment vector of the couple is independent of the choice of the origin of the coordinate axes, i.e., it is a *free vector* that can be applied at any point with the same effect.

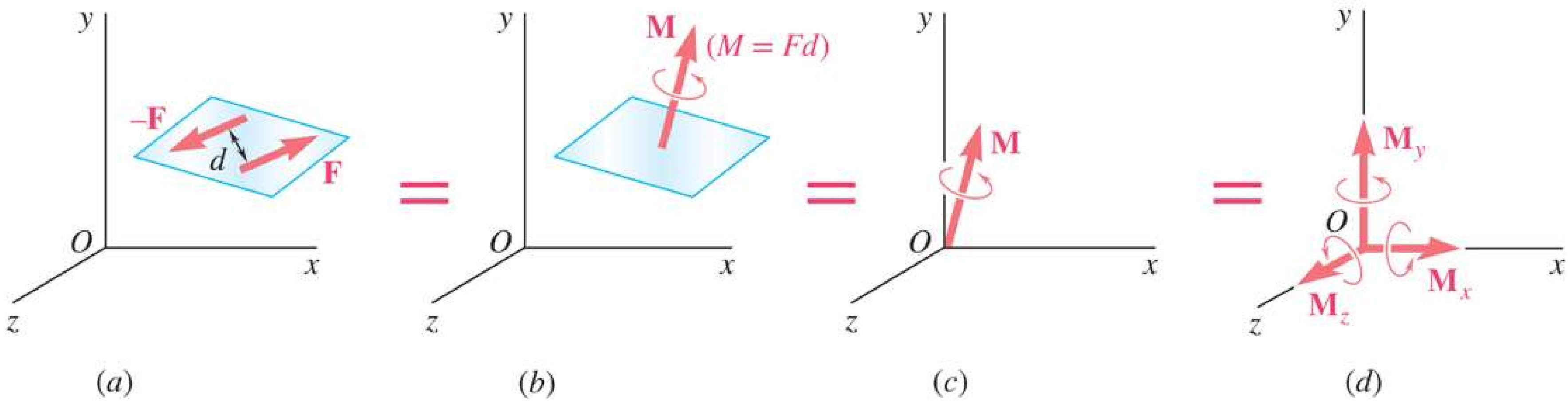


Moment of a Couple

- Two couples will have equal moments if.
- $F_1 d_1 = F_2 d_2$.
- the two couples lie in parallel planes, and.
- the two couples have the same sense or the tendency to cause rotation in the same direction.

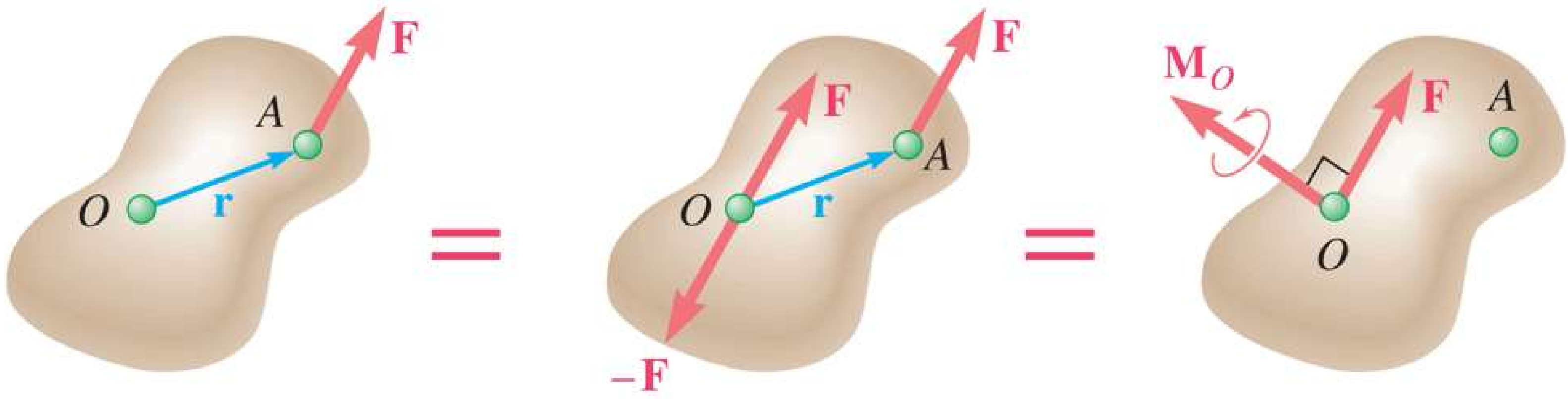


Couples Can Be Represented by Vectors



- A couple can be represented by a vector with magnitude and direction equal to the moment of the couple.
- *Couple vectors* obey the law of addition of vectors.
- Couple vectors are free vectors, i.e., there is no point of application – it simply acts on the body.
- Couple vectors may be resolved into component vectors.

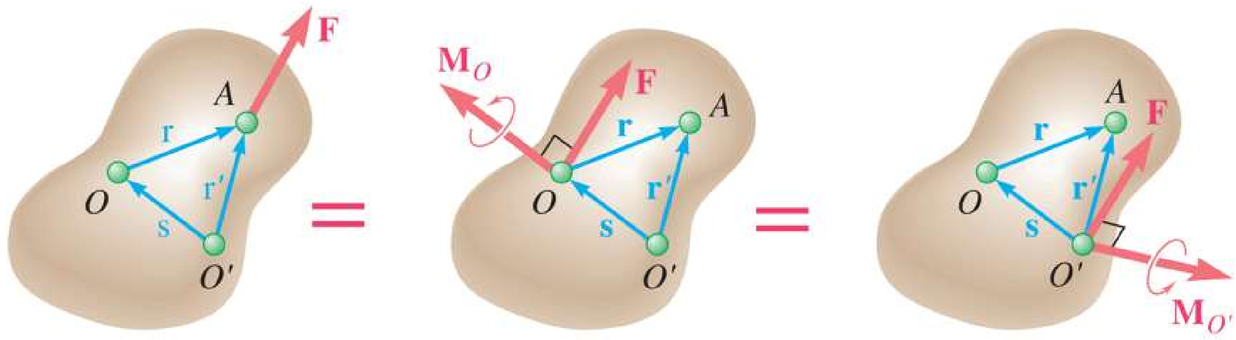
Resolution of a Force Into a Force at *O* and a Couple



(*a*) (*b*) (*c*)

- Force vector ***F*** can not be simply moved to *O* without modifying its action on the body. Attaching equal and opposite force vectors at *O* produces no net effect on the body. The three forces may be replaced by an equivalent force vector and couple vector, i.e, a *force-couple system*.

Resolution of a Force Into a Force at O and a Couple



(a) (b) (c)

- Moving ***F*** from *A* to a different point *O'* requires the addition of a different couple vector $\boldsymbol{M_{O'}}$

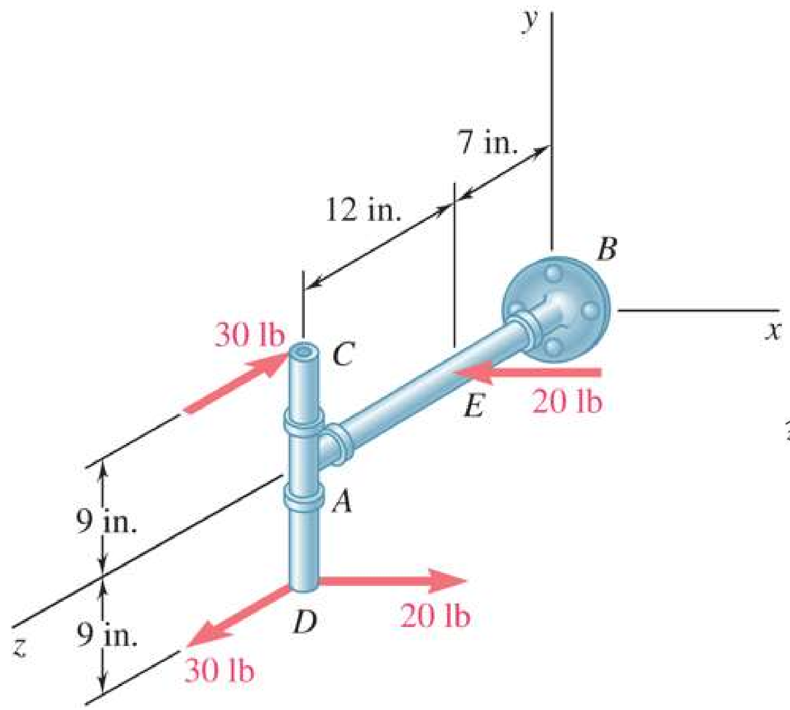
$$\vec{M}_{O'} = \vec{r}\,' \times \vec{F}$$

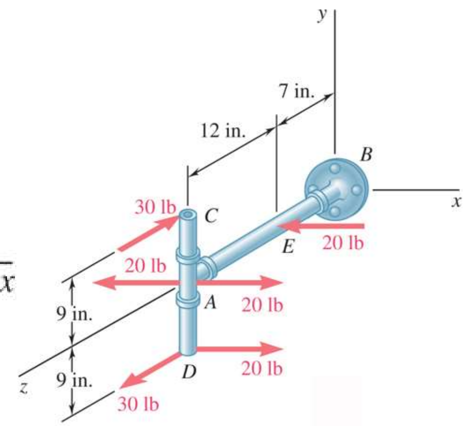
- The moments of ***F*** about O and *O'* are related,

$$\vec{M}_{O'} = \vec{r}\,'\times\vec{F} = (\vec{r} + \vec{s})\times\vec{F} = \vec{r}\times\vec{F} + \vec{s}\times\vec{F}$$
$$= \vec{M}_O + \vec{s}\times\vec{F}$$

- Moving the force-couple system from *O* to *O'* requires the addition of the moment of the force at *O* about *O'*.

Sample Problem 3.6





Attach equal and opposite 20 lb forces in the $\pm x$ direction at A

Determine the components of the single couple equivalent to the couples shown.

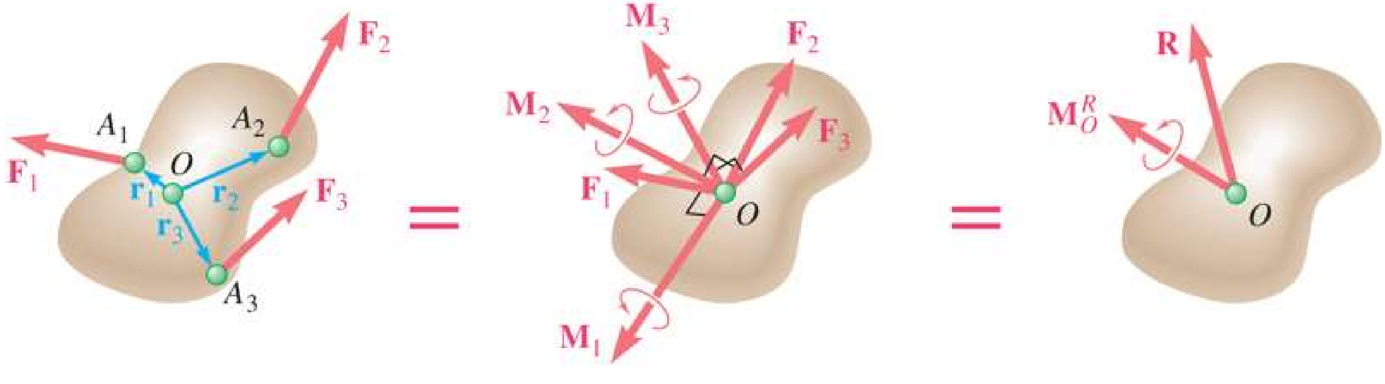
$$M_x = -(30\text{ lb})(18\text{ in.}) = -540\text{ lb}\cdot\text{in.}$$

$$M_y = +(20\text{ lb})(12\text{ in.}) = +240\text{lb}\cdot\text{in.}$$

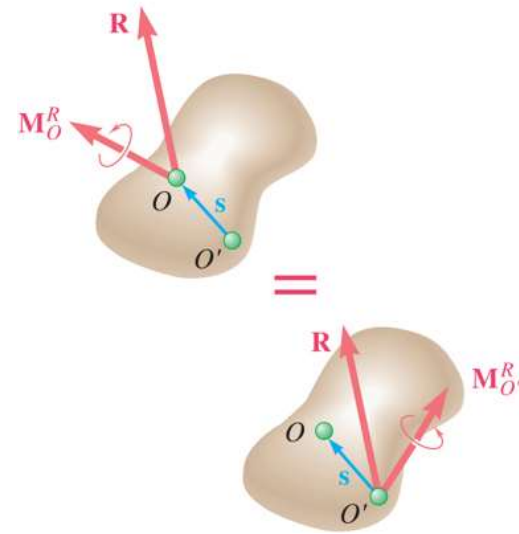
$$M_z = +(20\text{ lb})(9\text{ in.}) = +180\text{ lb}\cdot\text{in.}$$

$$\vec{M} = -(540\text{ lb}\cdot\text{in.})\vec{i} + (240\text{lb}\cdot\text{in.})\vec{j} + (180\text{ lb}\cdot\text{in.})\vec{k}$$

System of Forces: Reduction to a Force and Couple



(a) (b) (c)



- The force and couple vectors may be combined into a resultant force vector and a resultant couple vector,

$$\vec{R} = \sum \vec{F} \qquad \vec{M}_O^R = \sum\left(\vec{r} \times \vec{F}\right)$$

- The force-couple system at O may be moved to O' with the addition of the moment of ***R*** about O' ,

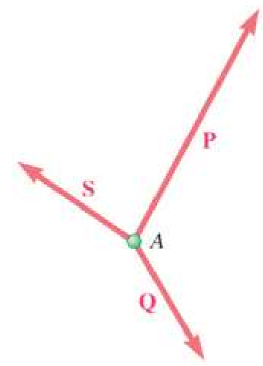
$$\vec{M}_{O\text{n}}^R = \vec{M}_O^R + \vec{s} \times \vec{R}$$

- Two systems of forces are equivalent if they can be reduced to the same force-couple system.

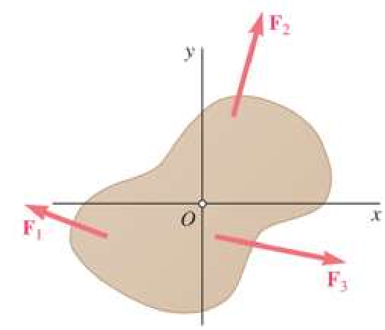
Further Reduction of a System of Forces

- If the resultant force and couple at *O* are mutually perpendicular, they can be replaced by a single force acting along a new line of action.

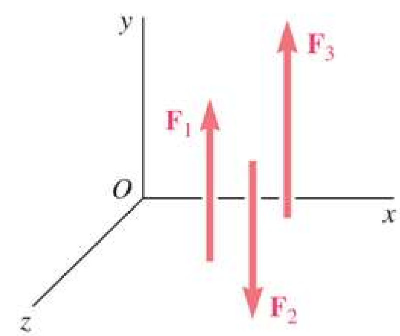
- The resultant force-couple system for a system of forces will be mutually perpendicular if:
  1) the forces are concurrent,
  2) the forces are coplanar, or
  3) the forces are parallel.



(a)

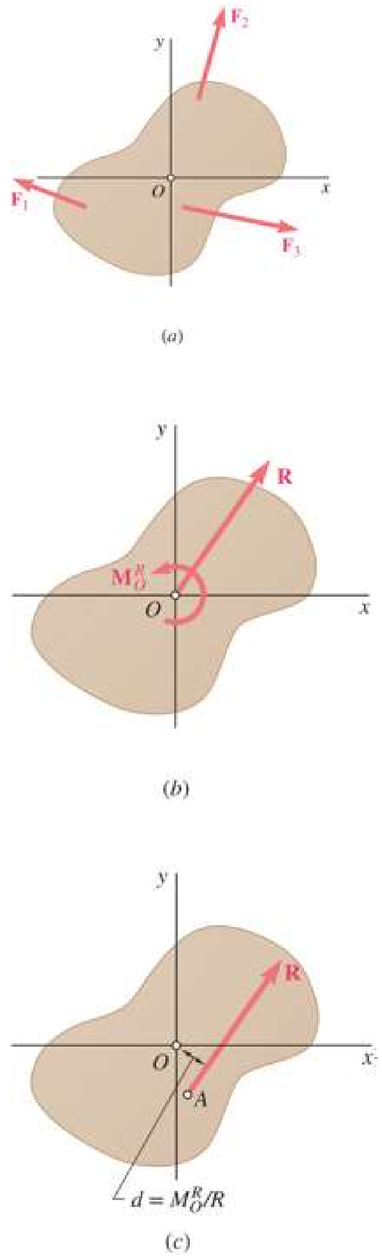


(a)



(a)

Further Reduction of a System of Forces

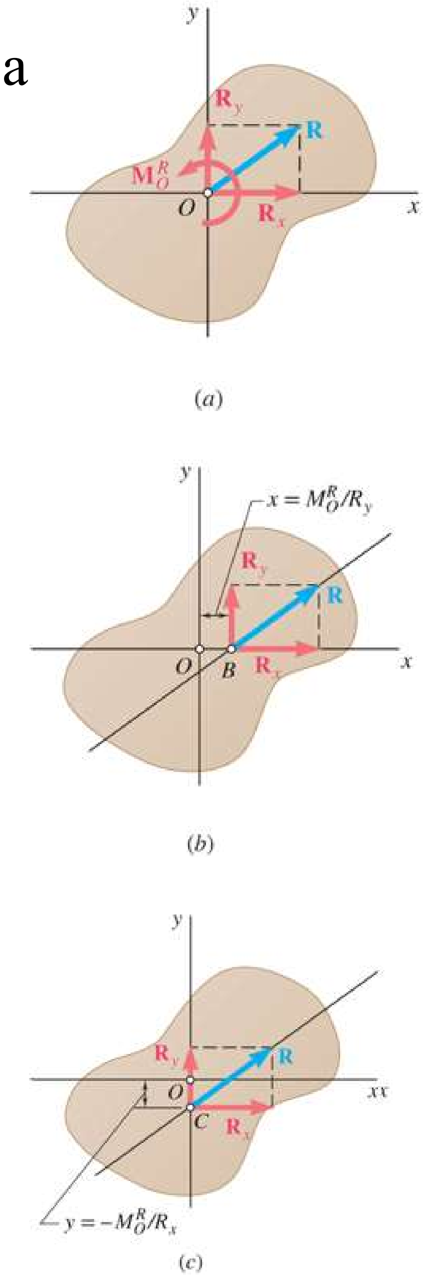


- System of coplanar forces is reduced to a force-couple system $\vec{R}$ and $\vec{M}_O^R$ that is mutually perpendicular.

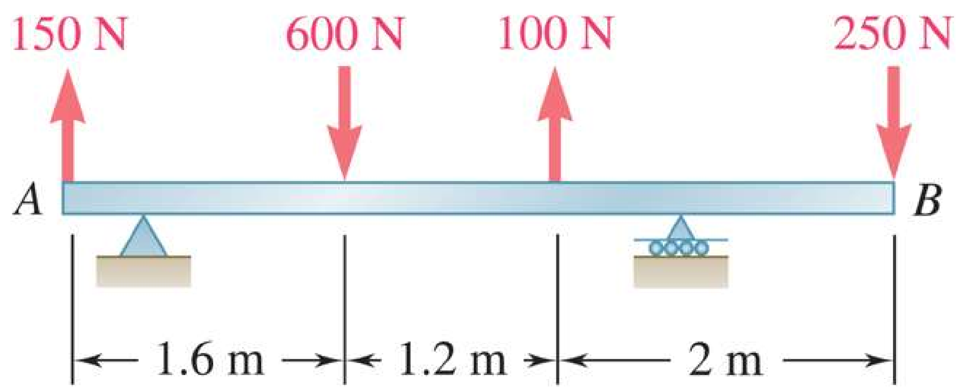
- System can be reduced to a single force by moving the line of action of $\vec{R}$ until its moment about O becomes $\vec{M}_O^R$

- In terms of rectangular coordinates,

$$xR_y - yR_x = M_O^R$$

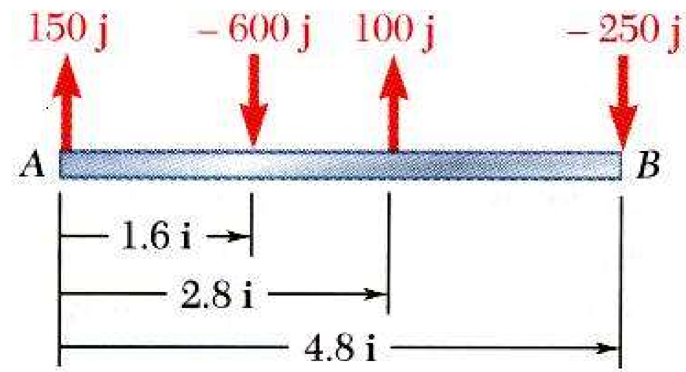


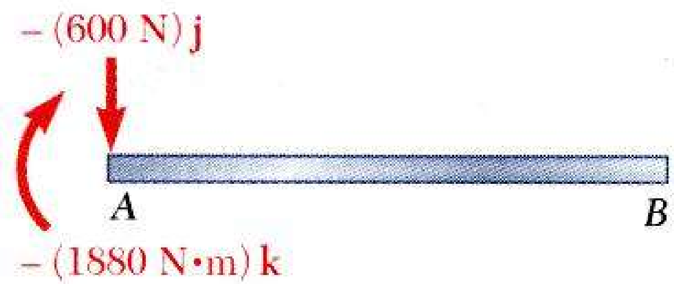
Sample Problem 3.8

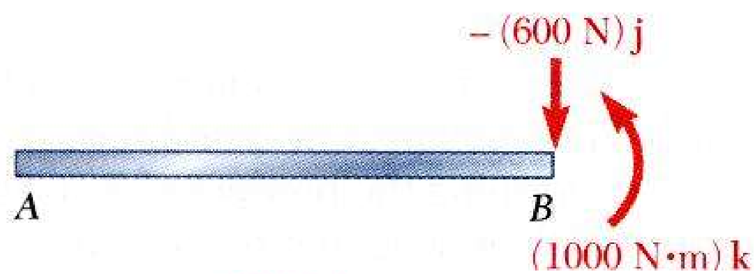


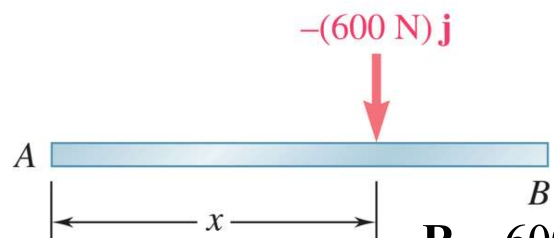
For the beam, reduce the system of forces shown to (a) an equivalent force-couple system at *A*, (b) an equivalent force couple system at *B*, and (c) a single force or resultant.

Note: Since the support reactions are not included, the given system will not maintain the beam in equilibrium.



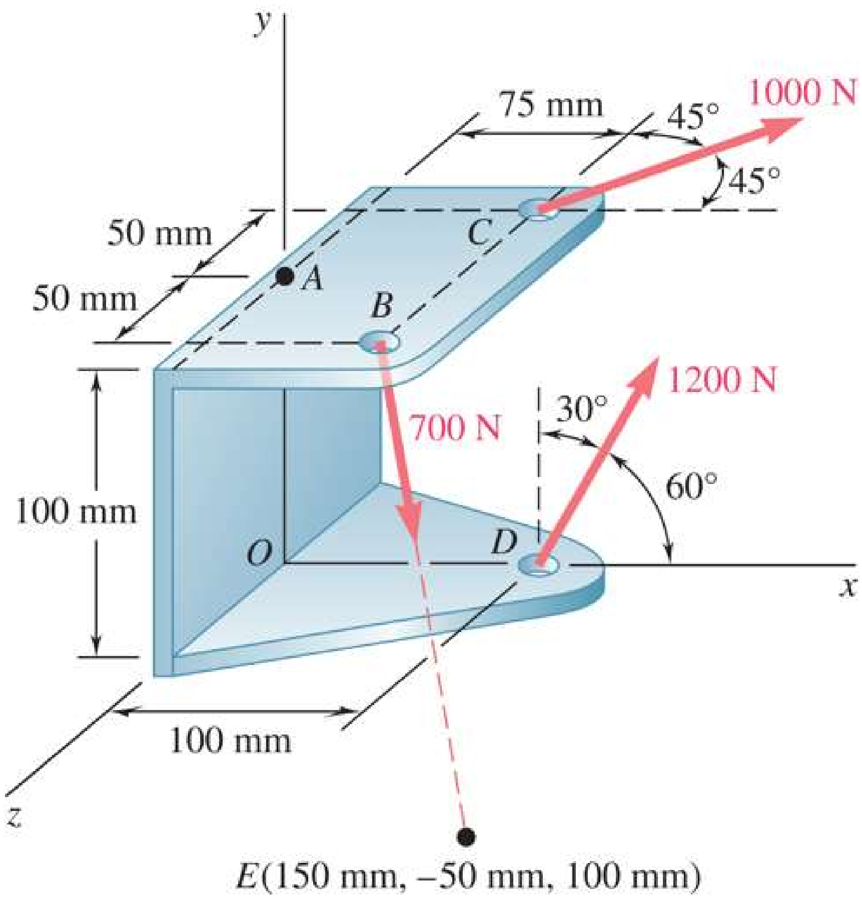






$\mathbf{R} = 600\text{ N}\downarrow, \quad x = 3.13\text{ m}$

Sample Problem 3.10



Three cables are attached to the bracket as shown. Replace the forces with an equivalent force-couple system at *A*.

Solution by brute force:

$$\vec{r}_{B/A} = 0.075\vec{i} + 0.050\vec{k}\ (\mathrm{m})$$

$$\vec{r}_{C/A} = 0.075\vec{i} - 0.050\vec{k}\ (\mathrm{m})$$

$$\vec{r}_{D/A} = 0.100\vec{i} - 0.100\vec{j}\ (\mathrm{m})$$

$$\vec{F}_B = 300\vec{i} - 600\vec{j} + 200\vec{k}\quad (\mathrm{N})$$

$$\vec{F}_C = 707\vec{i} - 707\vec{j}\quad (\mathrm{N})$$

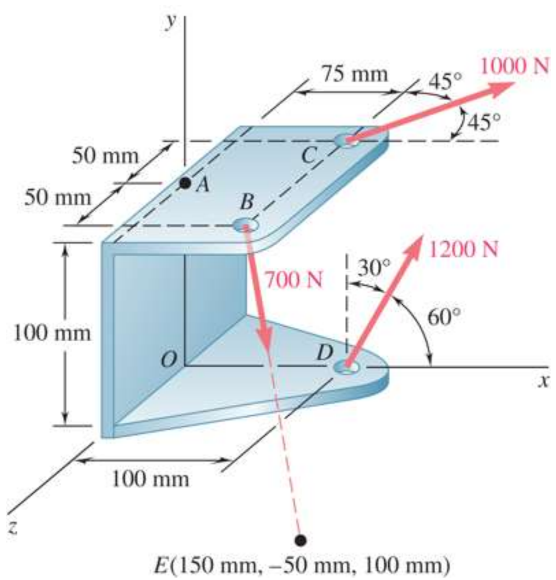
$$\vec{F}_D = 600\vec{i} + 1039\vec{j}\quad (\mathrm{N})$$

Sample Problem 3.10

- Compute the equivalent force,

$$\vec{R} = \sum \vec{F}$$
$$= (300 + 707 + 600)\vec{i}$$
$$+ (-600 + 1039)\vec{j}$$
$$+ (200 - 707)\vec{k}$$

$$\vec{R} = 1607\vec{i} + 439\vec{j} - 507\vec{k} \quad (\text{N})$$



- Compute the equivalent couple,

$$\vec{M}_A^R = \sum (\vec{r} \times \vec{F})$$

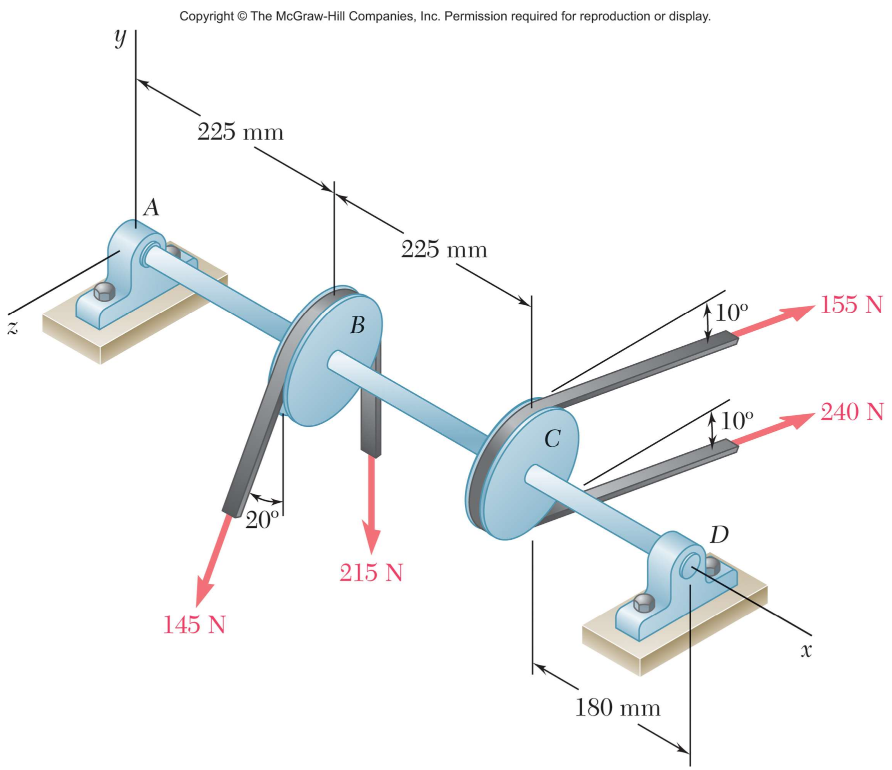
$$\vec{r}_{B/A} \times \vec{F}_B = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ 0.075 & 0 & 0.050 \\ 300 & -600 & 200 \end{vmatrix} = 30\vec{i} - 45\vec{k}$$

$$\vec{r}_{C/A} \times \vec{F}_c = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ 0.075 & 0 & -0.050 \\ 707 & 0 & -707 \end{vmatrix} = 17.68\vec{j}$$

$$\vec{r}_{D/A} \times \vec{F}_D = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ 0.100 & -0.100 & 0 \\ 600 & 1039 & 0 \end{vmatrix} = 163.9\vec{k}$$

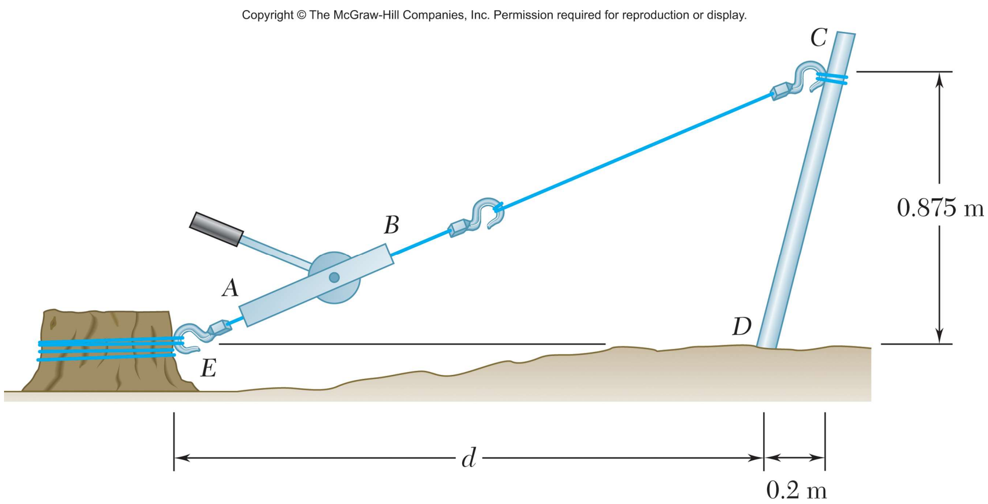
$$\vec{M}_A^R = 30\vec{i} + 17.68\vec{j} + 118.9\vec{k}$$

Problem 3.120



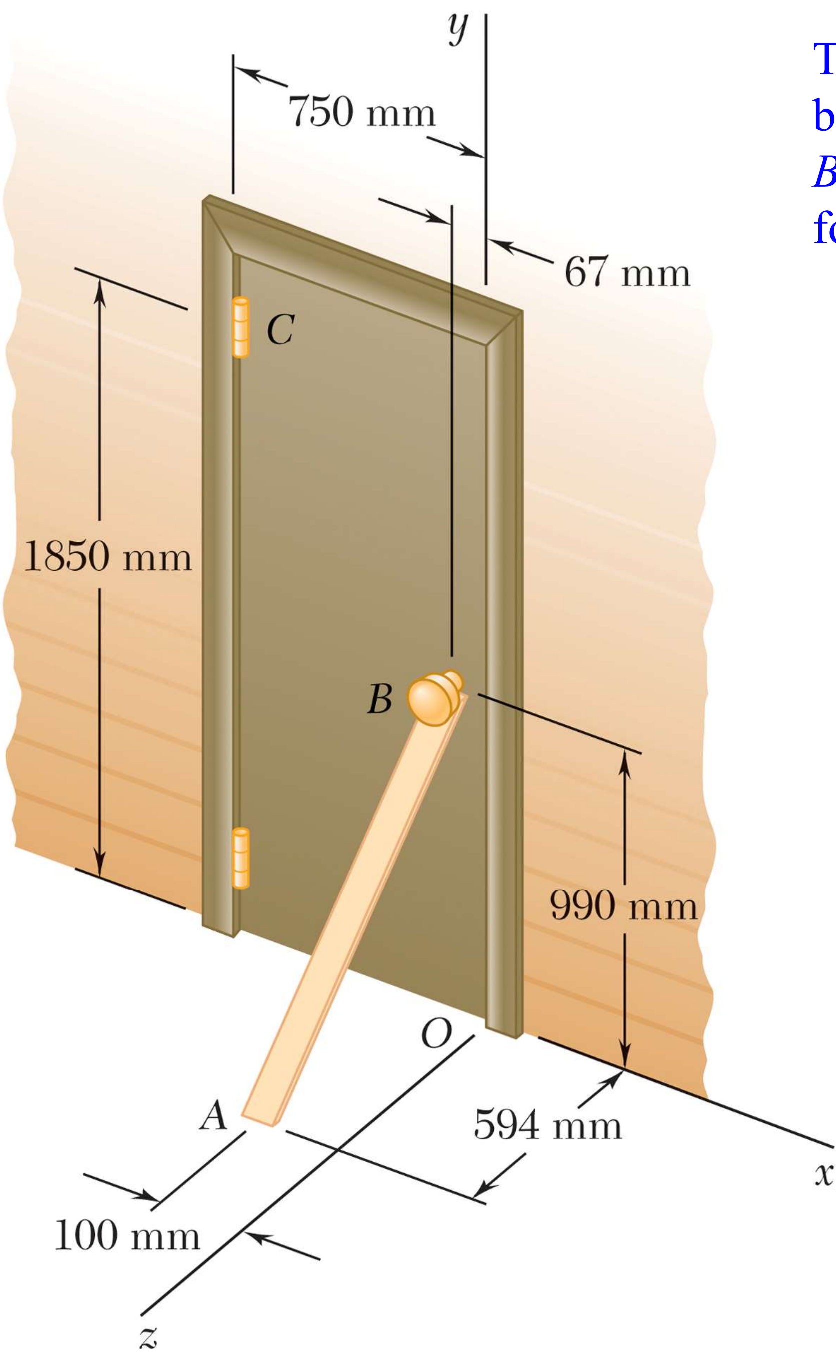
Two 150-mm-diameter pulleys are mounted on line shaft *AD*. The belts at *B* and *C* lie in vertical planes parallel to the *yz* plane. Replace the belt forces shown with an equivalent force-couple system at *A*.

Problem 3.13



It is known that a force with a moment of 960 *N*m* about *D* is required to straighten the fence post *CD*. If the capacity of winch puller *AB* is 2400 N, determine the minimum value of distance *d* to create the specified moment about point *D*.

Problem 3.97



To keep a door closed, a wooden stick is wedged between the floor and the doorknob. The stick exerts at *B* a 175-N force directed along line *AB*. Replace that force with an equivalent force-couple system at *C*.