

## The Case of the TIPPING FORKLIFT

By Mitch Ricketts

**Math Toolbox is designed to help readers apply STEM principles to everyday safety issues. Many readers may feel apprehensive about math and science. This series employs various communication strategies to make the learning process easier and more accessible.**

**This Math Toolbox article** will be the first of two installments on the role of levers in occupational safety. Because levers can amplify force, they provide the basis for many helpful devices, including pry bars, wrenches, pliers and wheelbarrows. When we lose control of levers, on the other hand, their unchecked actions may cause injuries.

Figure 1 illustrates the tragic consequence of an out-of-control lever in the form of an overloaded forklift. In this case, the weight of two bundles of lumber caused an undersized forklift to tip forward. The top bundle struck and killed the truck driver, who was between the load and the trailer.

We will begin our exploration of levers with an introduction to some basic terminology and calculations. The next article will delve deeper and investigate concepts such as mechanical advantage and distinctions among the various classes of levers.

### Fundamentals of Levers

Before applying leverage concepts to forklifts, let's begin with a more basic example of a lever: a box-end wrench, as shown in Figure 2 (p. 46). A lever can be defined as a rigid device that pivots on a fulcrum. The fulcrum is the pivot point, or the point about which the lever rotates. In Figure 2, the wrench pivots on a fulcrum consisting of a bolt. The worker's hand exerts force, which is a push or pull in a particular direction with a particular magnitude. The magnitude of force is often specified in units of weight, such as ounces, pounds or newtons. [Magnitude is occasionally expressed as kilogram-force (not to be confused with kilogram-mass). One kilogram-force is equal to 9.8067 newtons or 2.2046 pound-force.]

When a lever pivots on a fulcrum, we quantify the rotational force as torque ( $\tau$ ), also known as moment ( $M$ ). Torque is a force that tends to cause an object to rotate or twist about an axis. Torque is stated in units of distance-times-weight, such as inch-ounces (in-oz), foot-pounds (ft-lb) and newton-meters (N-m). [Moment is

sometimes specified as kilogram-meters (kg-m), equivalent to 9.8067 N-m.] The direction of torque may be denoted with a positive sign for clockwise motion and a negative sign for counterclockwise rotation. We will simplify here by using the directionless, absolute value of torque, designated as  $|\tau|$ . The formula for torque (absolute value) is defined as follows (illustrated in Figure 2):

$$|\tau| = f \cdot d$$

where:

$|\tau|$  = torque (absolute value), also known as moment ( $M$ ); a turning or twisting force

$f$  = force applied perpendicularly (at a right angle) to the lever arm

$d$  = distance at which the force is applied; the distance from the fulcrum to the line of applied force (measured perpendicularly to the line of applied force)

*Note:* When force is not applied perpendicularly to the lever arm, a more general formula is used to account for the angle of applied force:  $\tau = f \cdot d \cdot \sin \theta$ , where  $\theta$  is the angle of the applied force. For simplicity, we will consider only those cases in which force is applied perpendicularly.

### Calculating Torque

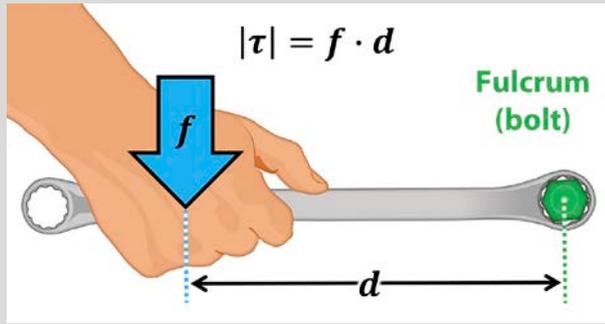
To illustrate the method for calculating torque, imagine you are using a wrench to loosen a bolt, as illustrated in Figure 3 (p. 46). Further imagine that with your hand, you apply a force of 18 lb perpendicularly to the wrench. We will consider this force to be applied at a point that represents the average location where your hand presses on the wrench. In our example, your hand presses on the wrench at an average distance of 0.75 ft from the center of the bolt (the fulcrum). Assuming

**FIGURE 1**  
**FORKLIFT TIP, INDIANA, 2006**

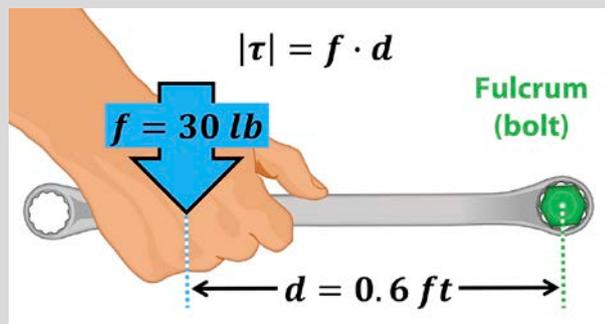


**FIGURE 2**  
**WRENCH AS A LEVER**

A box-end wrench is used as a lever to apply rotational force (torque) to a bolt. Torque is calculated as the product of the force ( $f$ , applied perpendicularly to the wrench) times the distance ( $d$ ) from the fulcrum. Distance in this case is measured from the center of the fulcrum to a point representing the average location of the hand on the wrench.



**FIGURE 4**  
**YOU DO THE MATH, PROBLEM 1**



the weight of the wrench is negligible, how many foot-pounds of torque are you applying to loosen the bolt? The data can be summarized as follows:

- A force of 18 lb is applied perpendicularly to the wrench. This is the value of  $f$  in the formula.
- The force is applied at an average distance of 0.75 ft from the fulcrum. This is the value of  $d$  in the formula.

Based on these data, we can calculate the torque ( $|\tau|$ ) in ft-lb as follows:

**Step 1:** Start with the equation for torque:

**Step 2:** Insert the known values for applied force ( $f = 18$  lb) and distance ( $d = 0.75$  ft). Then solve for  $|\tau|$  in ft-lb:

$$|\tau| = f \cdot d = 18 \cdot 0.75 = 13.5 \text{ ft} - \text{lb}$$

**Step 3:** We interpret our calculation to indicate that you are applying a torque of 13.5 ft-lb in your effort to turn the bolt. If 13.5 ft-lb of torque is sufficient to overcome friction, the bolt will move. Otherwise, it will not budge.

**Alternate example:** This time, we will calculate torque in international units of newton-meters. Once again, you apply a force of 18 lb perpendicularly to the wrench at an average distance of 0.75 ft from the center of the bolt.

The international unit of force is newtons (N). One pound is equivalent to about 4.4482 N. Thus, we multiply 18 lb by 4.4482 to convert the force to newtons, as follows:

$$f = 18 \text{ lb} \cdot 4.4482 = 80.07 \text{ N} \quad (\text{rounded two places beyond the decimal})$$

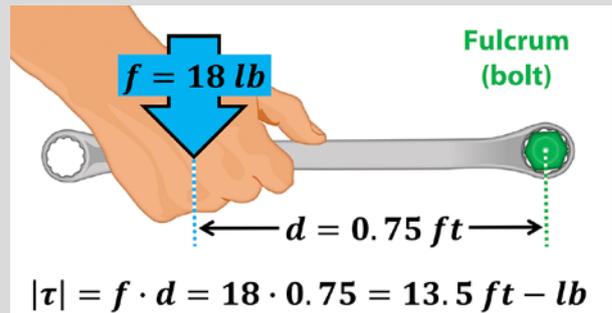
Knowing that our 18 lb of applied force is equivalent to about 80.07 N, we next convert the distance of 0.75 ft to meters. One foot is equivalent to about 0.3048 m. Multiplying 0.75 ft by 0.3048, we find the distance in international units is about 0.23 m:

$$d = 0.75 \text{ ft} \cdot 0.3048 = 0.23 \text{ m} \quad (\text{rounded})$$

We can now summarize our data as follows:

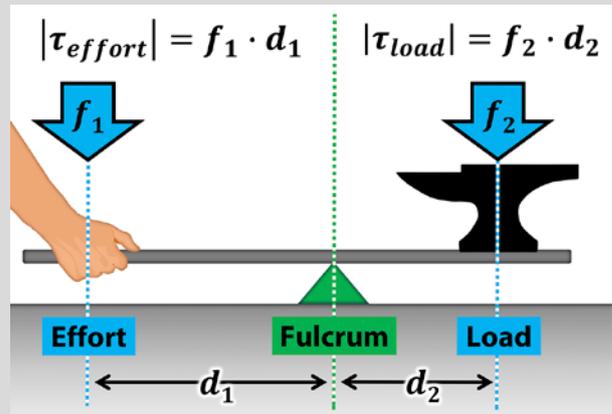
**FIGURE 3**  
**EXAMPLE: WRENCH AS A LEVER**

Example problem. When a force of 18 lb is applied perpendicularly to a wrench at an average distance of 0.75 ft from the center of the bolt, the torque is 13.5 ft-lb.



**FIGURE 5**  
**TWO SIDES OF A LEVER**

Opposing torques may be created in the effort and load arms of a lever, designated  $|\tau_{\text{effort}}|$  and  $|\tau_{\text{load}}|$ , respectively.



• A force of 80.07 N is applied perpendicularly to the wrench. This is the value of  $f$  in the formula.

• The force is applied at an average distance of 0.23 m from the fulcrum. This is the value of  $d$  in the formula.

To calculate the new value for torque in international units of N-m, use the original equation to solve for  $|\tau|$ :

$$|\tau| = f \cdot d$$

Next, insert the values of force ( $f = 80.07$  N) and distance ( $d = 0.23$  m) to obtain the following result:

$$|\tau| = f \cdot d = 80.07 \cdot 0.23 = 18.42 \text{ N} - \text{m}$$

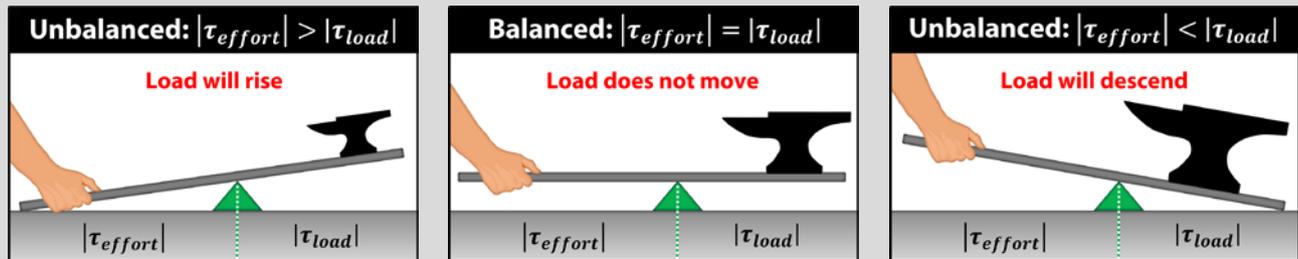
The calculation indicates that a torque of 18.42 N-m is being applied to turn the bolt (which, based on our earlier figures, is equivalent to about 13.5 ft-lb).

### You Do the Math

Apply your knowledge to the following question. The answer is on p. 63.

## FIGURE 6 BALANCED & UNBALANCED TORQUES

A lever is balanced when torque created through the effort arm equals torque created by the load arm. An unbalanced condition may raise the load (as when torque created by the effort arm exceeds the torque created by the load arm), or lower the load (as when torque created by the effort arm is less than torque created by the load arm).



1. Imagine you are using a wrench to loosen a bolt. As shown in Figure 4, you apply a force of 30 lb perpendicularly to the wrench at an average distance of 0.6 ft from the center of the bolt. Assuming the weight of the wrench is negligible, how many foot-pounds of torque are you applying to the bolt? Use the equation for torque ( $|\tau|$ ) and solve in units of foot-pounds (ft-lb).

### Two Sides to Every Lever

Let's now expand our understanding of levers beyond the specific case of wrenches. As noted, a fulcrum may consist of any point about which a lever rotates, such as the bolt in the case of a wrench. Other examples of fulcrums (or fulcra) include the hinge as the fulcrum of a door; the heel as the fulcrum of a pry bar; and the front axle, which may become the fulcrum of a forward-tipping forklift.

Every lever also has "arms" that are free to rotate. The effort arm (or arm of applied force) is the portion of the lever to which we apply the effort, or input force. For example, the effort arm of a wrench consists of the handle gripped by the worker. The effort arm of the lever in Figure 5 also consists of the portion grasped by the worker. The load arm (or output arm) is the portion of the lever directly connected to the load. In the case of a box-end wrench, the load arm consists of the box end (the part in direct contact with the bolt). For the lever in Figure 5, the load arm is the portion on which the anvil rests.

When we push on the effort arm of a lever, our effort meets resistance. The lever will move the load only if the torque created through the effort arm overcomes friction and any torque created through the load arm. For example, a wrench must overcome friction to turn

the bolt, while the lever in Figure 5 must overcome torque created in the load arm (assuming friction is negligible).

As illustrated in Figure 5, we must consider the opposing torques on both sides of a lever to determine whether we can move a load. To calculate opposing torques, we apply our previous formula separately to each side of the lever. By convention, the force and distance values for the effort arm are often designated  $f_1$  and  $d_1$ , respectively. On the other hand, the force and distance values for the load arm are normally designated  $f_2$  and  $d_2$ .

Figure 6 illustrates how opposing torques affect the motion of a lever. When torque created by the effort arm equals torque created by the load arm, a lever will be balanced (i.e., the system will be in a state of equilibrium). On the other hand, when torque from the effort arm exceeds torque from the load arm, a lever will be unbalanced, and the load will rise. Finally, the load will descend when the effort arm produces less torque, compared with the load arm.

### Opposing Torques in a Tipping Forklift

We are now ready to examine leverage concepts in the case of a tipping forklift. Note that the capacities depicted on forklift data plates include many considerations not explored in this article (e.g., forklift movement, height of the load, strength of materials, sideways tipping). Furthermore, forklift data plates are simplified to allow measurement of distance from the forklift carriage, rather than the front axle. The purpose here is to examine the most basic leverage concepts involved in forward tipping. The interpretation of data plates is considered later.

To keep forward-tipping calculations simple, we will assume the forklift and load are stationary (not moving), the

roadway is level, friction is negligible, and the load's center of gravity is at the same height as that of the forklift.

### Forklift Body: An Effort Arm to Resist Forward Tipping

Figure 7 (p. 48) depicts a loaded forklift. When a forklift tips forward due to leverage, the front axle serves as the fulcrum. The portion of the forklift located behind the front axle (highlighted in yellow) serves as the effort arm to resist forward tipping.

As always, the effort arm develops torque ( $|\tau_{\text{effort}}|$ ) from force ( $f_1$ ) multiplied by distance ( $d_1$ ). The force ( $f_1$ ) includes all weight located behind the front axle (including the weight of the driver). The distance ( $d_1$ ) is measured from the center of the front axle to the weight's center of gravity (CG, the average location of the weight behind the front axle).

**Example:** Imagine you are operating a forklift, as shown in Figure 8 (p. 48). The weight of all forklift components behind the front axle equals 5,000 lb (this includes your weight, as the operator). The center of gravity for this 5,000-lb weight lies 2.5 ft behind the center of the front axle. Considering all components behind the front axle as an effort arm, how many foot-pounds of torque ( $|\tau_{\text{effort}}|$ ) are available to resist forward tipping? The data for this example can be summarized as follows:

- A force of 5,000 lb is applied perpendicularly to the effort arm. This is the value of  $f_1$  in the formula.
- The force is applied at an average distance of 2.5 ft from the fulcrum. This is the value of  $d_1$  in the formula.

Based on these data, calculate the torque ( $|\tau_{\text{effort}}|$ ) in ft-lb as follows:

**Step 1:** Start with the equation for torque generated by the effort arm:

$$|\tau_{\text{effort}}| = f_1 \cdot d_1$$

**Step 2:** Insert the known values for applied force ( $f_1 = 5,000$  lb) and distance ( $d_1 = 2.5$  ft). Then solve for  $|\tau_{effort}|$  in ft-lb:

$$|\tau_{effort}| = f_1 \cdot d_1 = 5,000 \cdot 2.5 = 12,500 \text{ ft} - \text{lb}$$

**Step 3:** Our calculation indicates the effort arm of the forklift can generate a torque of 12,500 ft-lb to resist forward tipping. If 12,500 ft-lb is sufficient to overcome forward tipping forces, the forklift will remain upright. Otherwise, it may tip.

**Alternate example:** This time, we will calculate torque in international units of newton-meters. Once again, the weight of all forklift components behind the front axle equals 5,000 lb, with a center of gravity located 2.5 ft behind the center of the front axle. Considering all components behind the front axle as an effort arm, how many newton-meters of torque ( $|\tau_{effort}|$ ) are available to resist forward tipping?

Since one pound is equal to about 4.4482 N, multiply 5,000 lb by 4.4482 to convert the force to newtons:

$$f_1 = 5,000 \text{ lb} \cdot 4.4482 = 22,241 \text{ N}$$

Next, convert the distance to meters by multiplying 2.5 ft by 0.3048:

$$d_1 = 2.5 \text{ ft} \cdot 0.3048 = 0.76 \text{ m} \text{ (rounded)}$$

Following is a summary of the data:

- A force of 22,241 N is applied perpendicularly to the effort arm of the forklift. This is the value of  $f_1$  in the formula.
- The force is applied at an average distance of 0.76 m from the fulcrum. This is the value of  $d_1$  in the formula.

We calculate torque in international units of N-m by inserting the values of force ( $f_1 = 22,241$  N) and distance ( $d_1 = 0.76$  m) as follows:

$$|\tau_{effort}| = f_1 \cdot d_1 = 22,241 \cdot 0.76 = 16,903.16 \text{ N} - \text{m}$$

Our calculation indicates the effort arm of the forklift can generate a torque of 16,903.16 N-m to resist forward tipping (which, based on our earlier result, is equal to 12,500 ft-lb).

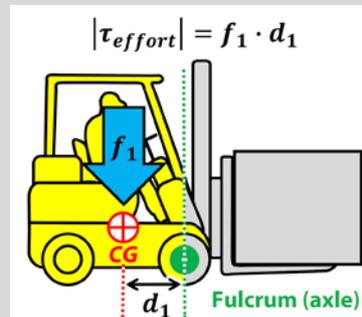
## You Do the Math

Apply your knowledge to the following question. The answer is on p. 63.

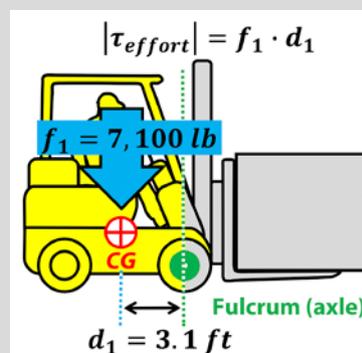
2. Imagine you are operating a forklift, as shown in Figure 9. The weight of all forklift components behind the front axle equals 7,100 lb (including your weight, as the operator). The center of gravity for this 7,100-lb weight lies 3.1 ft behind the center of the

## FIGURE 7 FORKLIFT BODY: EFFORT ARM TO RESIST FORWARD TIPPING

The forklift components located behind the front axle serve as an effort arm to resist forward tipping. The forklift may tip if torque developed by the rearward components (yellow) does not exceed the torque developed by the forward components (gray).



## FIGURE 9 YOU DO THE MATH, PROBLEM 2



front axle. Considering all components behind the front axle as an effort arm, how many foot-pounds of torque ( $|\tau_{effort}|$ ) are available to resist forward tipping?

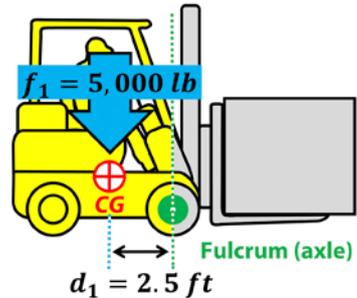
## Load Arm That May Cause Forward Tipping

Remembering there are two sides to every lever, we will now calculate the torque created through the forklift's load arm, the torque that may trigger forward tipping. Figure 10 depicts a loaded forklift. The load arm that induces forward tipping is represented by all components located ahead of the front axle (in gray). Torque in the load arm ( $|\tau_{load}|$ ) develops from force,  $f_2$  (all weight located ahead the front axle, including the load), multiplied by distance,  $d_2$  (measured from

## FIGURE 8 EXAMPLE: FORKLIFT EFFORT ARM

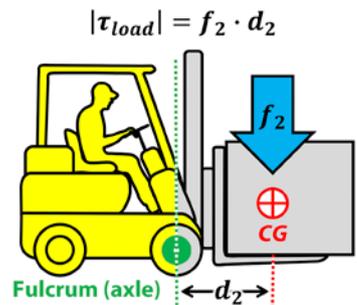
Sample problem: Torque developed by the rearward components of the forklift to resist forward tipping.

$$\begin{aligned} |\tau_{effort}| &= f_1 \cdot d_1 \\ &= 5,000 \cdot 2.5 \\ &= 12,500 \text{ ft} - \text{lb} \end{aligned}$$



## FIGURE 10 LOAD ARM THAT MAY CAUSE FORWARD TIPPING

All components located ahead the front axle serve as a load arm that may cause the forklift to tip forward. The forklift may tip if the torque developed by the forward components (gray) exceeds the torque developed by the rearward components (yellow).



the center of the front axle to the forward weight's center of gravity).

**Example:** Imagine you are operating a forklift, as shown in Figure 11. The weight of the load and all forklift components ahead of the front axle equals 1,000 lb. The center of gravity for this 1,000-lb weight lies 3 ft ahead of the center of the front axle. Considering all components ahead of the front axle as a load arm, how many foot-pounds of torque ( $|\tau_{load}|$ ) are created to induce forward tipping? The data for this example can be summarized as follows:

- A force of 1,000 lb is applied perpendicularly to the load arm. This is the value of  $f_2$  in the formula.
- The force is located an average distance of 3 ft from the fulcrum. This is the value of  $d_2$  in the formula.

Based on these data, calculate the torque ( $|\tau_{load}|$ ) in ft-lb as follows:

**Step 1:** Start with the equation for torque in the load arm:

$$|\tau_{load}| = f_2 \cdot d_2$$

**Step 2:** Insert the known values for force ( $f_2 = 1,000$  lb) and distance ( $d_2 = 3$  ft). Then solve for  $|\tau_{load}|$  in ft-lb:

$$|\tau_{load}| = f_2 \cdot d_2 = 1,000 \cdot 3 = 3,000 \text{ ft} - \text{lb}$$

**Step 3:** Our calculation indicates the load arm of the forklift creates a torque of 3,000 ft-lb to induce forward tipping. If 3,000 ft-lb of torque is sufficient to overcome the torque developed by the effort arm, the forklift may tip. Otherwise, the forklift will remain upright.

**Alternate example:** This time, we will calculate torque in international units of newton-meters. Once again, the weight of the load and all forklift components ahead of the front axle equals 1,000 lb, with a center of gravity located 3 ft ahead the center of the front axle. Considering all components ahead of the front axle as a load arm, how many newton-meters of torque ( $|\tau_{load}|$ ) are created to induce forward tipping?

We convert force to newtons by multiplying 1,000 lb by 4.4482:

$$f_2 = 1,000 \text{ lb} \cdot 4.4482 = 4,448.20 \text{ N}$$

Next, we convert the distance from feet to meters by multiplying 3 ft by 0.3048:

$$d_2 = 3 \text{ ft} \cdot 0.3048 = 0.91 \text{ m} \text{ (rounded)}$$

We calculate the value for torque in international units of N-m by inserting the values of force ( $f_2 = 4,448.20$  N) and distance ( $d_2 = 0.91$  m) as follows:

$$|\tau_{load}| = f_2 \cdot d_2 = 4,448.20 \cdot 0.91 = 4,047.86 \text{ N} - \text{m} \text{ (rounded)}$$

Our calculation indicates the load arm of the forklift applies a torque of 4,047.86 N-m to induce forward tipping (which, based on our earlier result, is equal to 3,000 ft-lb).

### You Do the Math

Apply your knowledge to the following question. The answer is on p. 63.

3. Imagine you are operating a forklift, as shown in Figure 12. The weight of the load and all forklift components ahead of the front axle equals 1,600 lb. The center of gravity for this 1,600-lb weight lies 3.4 ft ahead of the center of the front axle. Considering

all components ahead of the front axle as a load arm, how many foot-pounds of torque ( $|\tau_{load}|$ ) are created to induce forward tipping?

### Opposing Torques: Will the Forklift Tip Forward?

Figure 13 depicts a loaded forklift. Based on the principles of leverage we have explored, the forklift will remain upright if the torque developed by the forklift body behind the front axle exceeds the torque created by the load and forklift components ahead of the front axle. This condition can be stated mathematically as  $|\tau_{effort}| > |\tau_{load}|$  or as  $f_1 \cdot d_1 > f_2 \cdot d_2$ . Alternatively, the forklift will tip forward if  $|\tau_{effort}| < |\tau_{load}|$ , which means  $f_1 \cdot d_1 < f_2 \cdot d_2$ . These statements assume the forklift and load are stationary, the roadway is level, friction is negligible, the load's center of gravity is at the same height as that of the forklift, and no additional forces are introduced.

**Example:** We do not know the torques or relevant operating conditions from the incident that caused the death of the truck driver in Figure 1 (p. 45). To fully illustrate how these formulas may predict forklift tipping, imagine you are operating the forklift shown in Figure 14 (p. 50). The weight of all forklift components behind the front axle equals 4,500 lb (including your weight, as the operator). The center of gravity for this 4,500-lb weight lies 3.3 ft behind the center of the front axle. The weight of the load and all forklift components ahead of the front axle equals 3,500 lb, with a center of gravity 3.7 ft ahead of the center of the front axle. Considering the opposing torques on both sides of the front axle, will the load cause the forklift to tip forward? We solve this problem in three separate parts, as follows:

**Part 1:** Calculate the antitipping torque generated by the portion of the forklift located behind the front axle. As before, we insert the values for applied force ( $f_1 = 4,500$  lb) and distance ( $d_1 = 3.3$  ft) to solve for  $|\tau_{effort}|$  in ft-lb:

$$|\tau_{effort}| = f_1 \cdot d_1 = 4,500 \cdot 3.3 = 14,850 \text{ ft} - \text{lb}$$

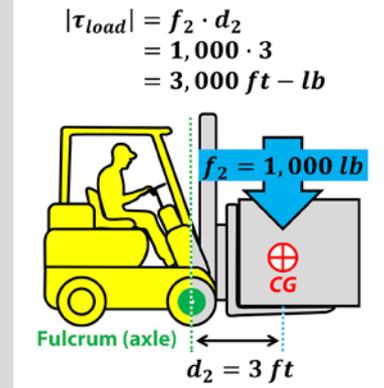
**Part 2:** Calculate the tipping torque generated by the portion of the forklift located ahead of the front axle. Insert the values for force ( $f_2 = 3,500$  lb) and distance ( $d_2 = 3.7$  ft) to solve for  $|\tau_{load}|$  in ft-lb:

$$|\tau_{load}| = f_2 \cdot d_2 = 3,500 \cdot 3.7 = 12,950 \text{ ft} - \text{lb}$$

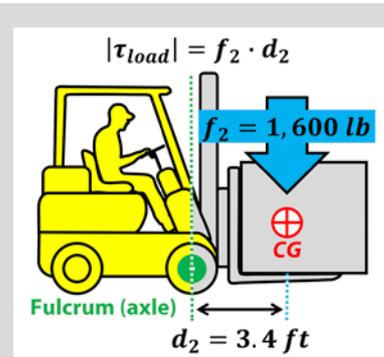
**Part 3:** Compare the antitipping torque ( $|\tau_{effort}|$ ) with the tipping torque ( $|\tau_{load}|$ ). The

## FIGURE 11 EXAMPLE: FORKLIFT LOAD ARM

Sample problem: Torque developed by the forward components of the forklift and load that may cause forward tipping.

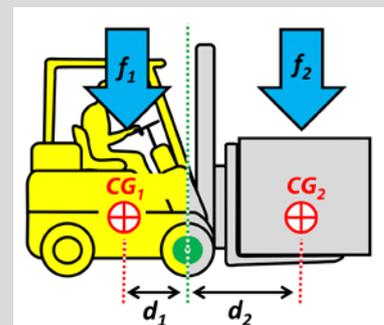


## FIGURE 12 YOU DO THE MATH, PROBLEM 3



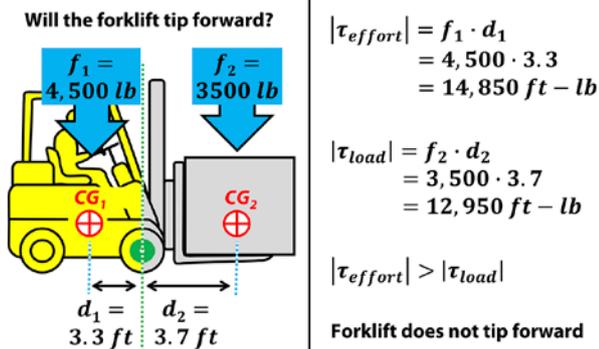
## FIGURE 13 TO PREVENT TIPPING, $|\tau_{effort}|$ MUST EXCEED $|\tau_{load}|$

Two sides of the forklift lever. If torque developed by the forklift effort arm exceeds the torque developed by the load arm, the forklift will remain upright. Otherwise, the forklift will tip.

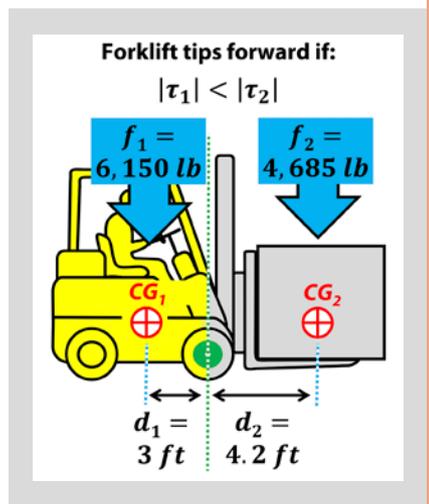


**FIGURE 14**  
**EXAMPLE: OPPOSING TORQUES**

Example problem: The load does not cause the forklift to tip forward because  $|\tau_{\text{effort}}|$  (14,850 ft-lb)  $>$   $|\tau_{\text{load}}|$  (12,950 ft-lb).



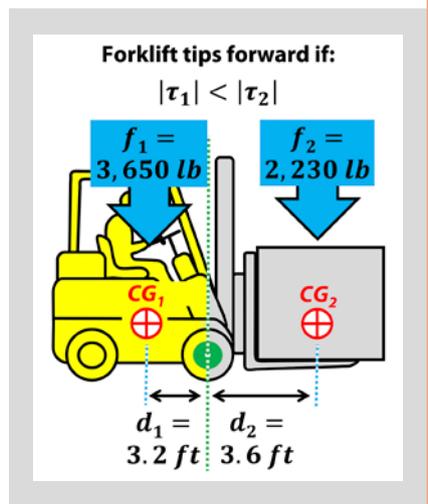
**FIGURE 15**  
**YOU DO THE MATH, PROBLEM 4**



forklift will remain upright if  $|\tau_{\text{effort}}| > |\tau_{\text{load}}|$ . Alternatively, the forklift will tip forward if  $|\tau_{\text{effort}}| < |\tau_{\text{load}}|$ . Our calculated result for  $|\tau_{\text{effort}}|$  is 14,850 ft-lb, which is greater than the calculated result of 12,950 ft-lb for  $|\tau_{\text{load}}|$ . Thus, we expect the forklift to remain upright.

**Alternate example:** Let's calculate a different example in which the weight of all forklift components behind the front axle equals 2,500 lb (including your weight, as operator) and the center of gravity lies 2.9 ft behind the center of the front axle. The weight of the load and all forklift components ahead of the front axle equals 2,000 lb, with a center of gravity 3.9 ft ahead of the center of the front axle. Considering the opposing torques on both sides of the front axle, will the load cause the forklift to tip

**FIGURE 17**  
**HOW MUCH HAVE I LEARNED, PROBLEM 5**



forward? Again, we solve the problem in three separate parts:

**Part 1:** Calculate the antitipping torque generated by the portion of the forklift located behind the front axle by inserting the values for applied force ( $f_1 = 2,500$  lb) and distance ( $d_1 = 2.9$  ft) to solve for  $|\tau_{\text{effort}}|$  in ft-lb:

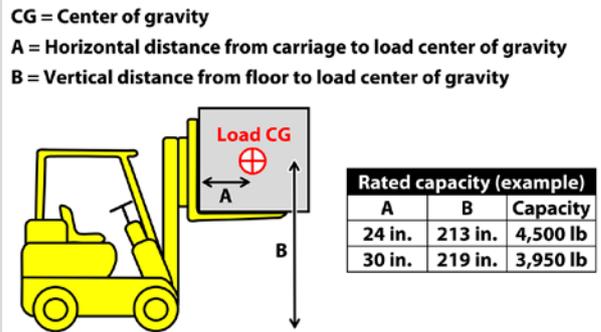
$$|\tau_{\text{effort}}| = f_1 \cdot d_1 = 2,500 \cdot 2.9 = 7,250 \text{ ft} - \text{lb}$$

**Part 2:** Calculate the tipping torque generated by the portion of the forklift located ahead of the front axle by inserting the values for force ( $f_2 = 2,000$  lb) and distance ( $d_2 = 3.9$  ft) to solve for  $|\tau_{\text{load}}|$  in ft-lb:

$$|\tau_{\text{load}}| = f_2 \cdot d_2 = 2,000 \cdot 3.9 = 7,800 \text{ ft} - \text{lb}$$

**FIGURE 16**  
**SAMPLE FORKLIFT CAPACITY CHART**

In the workplace, we determine forklift capacities by referring to charts located on manufacturers' data plates, as illustrated here. Although we may certainly handle lesser loads, we cannot use our formulas to justify greater weights or distances for many reasons as discussed in the text.



**Part 3:** Comparing the antitipping torque ( $|\tau_{\text{effort}}|$ ) of 7,250 ft-lb with the tipping torque ( $|\tau_{\text{load}}|$ ) of 7,800 ft-lb, we expect the forklift to tip forward because  $|\tau_{\text{effort}}| < |\tau_{\text{load}}|$ .

### You Do the Math

Apply your knowledge to the following question. The answer is on p. 63.

4. Imagine you are operating a forklift, as shown in Figure 15. The weight of all forklift components behind the front axle equals 6,150 lb (including your weight, as operator). The center of gravity for this 6,150-lb weight lies 3 ft behind the center of the front axle. The weight of the load and all forklift components ahead of the front axle equals 4,685 lb, with a center of gravity 4.2 ft ahead of the center of the front axle. Answer the following questions:

- Considering all components behind the front axle as an effort arm, how many foot-pounds of torque ( $|\tau_{\text{effort}}|$ ) are available to resist forward tipping?
- Considering all components ahead of the front axle as a load arm, how many foot-pounds of torque ( $|\tau_{\text{load}}|$ ) are created to induce forward tipping?
- Considering the opposing torques on both sides of the front axle, will the load cause the forklift to tip forward?

### Interpreting Rated Capacity as Listed on a Forklift Data Plate

As we have seen, the potential for forward-tipping in forklifts can be examined in the context of leverage. Additional factors will affect tipping in the workplace, including the relative heights of the centers of gravity, movement of the forklift or load, the angle of the roadway and other factors. For these and other reasons, manufacturers list rated capacities of forklifts

on data plates for each model such as the one illustrated in Figure 16.

Figure 16 indicates that, when measured according to the data plate and when operated according to the manufacturer's instructions, this particular forklift can safely lift a load up to 4,500 lb to a height up to 213 in., providing the load's center of gravity is located no further than 24 in. from the carriage. The chart also indicates the allowable load may be less when conditions differ. For example, the rated capacity declines to 3,950 lb at a height of 219 in., with center of gravity 30 in. from the carriage.

Although we may handle loads involving lesser weight or distance, we cannot extrapolate to justify greater weights or distances from those listed in the charts. Besides the lack of information about material strength and design factors, forklift capacity charts do not provide the data needed to calculate torques. For example, capacity charts do not include the weight of forklift components located behind and ahead of the front axle. Furthermore, these charts do not specify horizontal distances from the center of the front axle. Instead, the distances

in charts are measured (A) horizontally from the forklift carriage to the load's center of gravity, and (B) vertically from the roadway to the load's center of gravity.

### How Much Have I Learned?

Try this problem on your own. The answer is on p. 63.

5. Imagine you are operating a forklift, as shown in Figure 17. The weight of all forklift components behind the front axle equals 3,650 lb (including your weight, as operator). The center of gravity for this 3,650-lb weight lies 3.2 ft behind the center of the front axle. The weight of the load and all forklift components ahead of the front axle equals 2,230 lb, with a center of gravity 3.6 ft ahead of the center of the front axle. Answer the following questions:

a. Considering all components behind the front axle as an effort arm, how many foot-pounds of torque ( $|\tau_{\text{effort}}|$ ) are available to resist forward tipping?

b. Considering all components ahead of the front axle as a load arm, how many foot-pounds of torque ( $|\tau_{\text{load}}|$ ) are created to induce forward tipping?

c. Considering the opposing torques on both sides of the front axle, will the load cause the forklift to tip forward?

### For Further Study

Learn more from the following source: *ASSP's ASP Examination Prep: Program Review and Exam Preparation*, edited by Joel M. Haight, 2016. **PSJ**

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emergency department, our right to information ceased. There is an assumption in the finding of the investigation that the kratom found in the worker's belongings caused the overdose. Also, because it was an overdose, local police were on scene and the police report stated that no drugs were found on the patient's person. We felt that the evidence was enough to make an educated determination.

Kratom is marketed as an alternative to opioids and a natural treatment for opioid withdrawal, but, like other substances, is often used recreationally for a legal high. It can be purchased over the counter at dispensaries, online or even at gas stations in some states. A few states have passed legislation making kratom illegal, but a group of vendors sued the government to prevent U.S. Drug Enforcement Administration from federally classifying it as a Schedule I substance (Silverman, 2016). These advocates argue that kratom provides a viable method of coping with opioid withdrawal, which could help thousands of people per year. U.S. Drug Enforcement Administration held a public comment period and is currently gathering more information for a future determination. This article is not intended to discredit advocates, or to argue either way on the benefits or risks of the drug, but rather aims to raise awareness among OSH professionals that employees may be using kratom.

For me as a safety professional, the entire experience was eye opening. Don't get me wrong, legal highs are nothing new. Salvia, prescription medication, even caffeine pills can all cause varying degrees of overdose or adverse health effects if abused. Prescription drugs have certainly been on everyone's radar for many years. It is worth adding kratom to everyone's knowledge base about what may be in a workplace.

Construction employees often work long, physically demanding hours. It is not unreasonable to think that workers may turn to a substance that is natural and legal to help them get through the day. The employee in the event described was regarded as a hard worker who always treated everyone with respect, did the overtime and put the job first. He was going through a tough time at home in the weeks leading up to the event, and the night before had been particularly difficult, which may have led to an increase in kratom use. It is important not to take employees for granted and consider how truly hard the work hours are on the body and the mind, and

how there can be potential repercussions on relationships at home.

Readers can use this information as they choose, but the takeaways for those involved were the following:

- Engage with workers. Do not pry for personal information, but create an environment in which workers feel comfortable approaching you with work-related or personal concerns.

- Stay up to date on CPR training.
- Include overdose recognition with CPR training. There are similarities between cardiac arrest and overdose, but they have very important differences and require different emergency treatment.

- According to Harm Reduction Coalition [n.d.(a)], CPR for an overdose victim focuses on rescue breaths, not compressions. The intent is to provide oxygen to the brain as quickly as possible. Compressions will help, as they did in this event, but breaths are preferred. For anyone who has recent CPR training, rescue breaths are generally discouraged, making this difference critical to understand.

- Have naxolone nasal spray available and include how to administer it with the training.

- Communicate the dangers of kratom and similar legal substances on the market. Many people use kratom without realizing that overdose is possible.

## Conclusion

Kratom is easily accessible, inexpensive and offers benefits attractive to

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## Math Toolbox, continued from pp. 45-51

### Answers: The Case of the Tipping Forklift You Do the Math

Your answers may vary slightly due to rounding.

$$1. |\tau| = f \cdot d = 30 \cdot 0.6 = 18 \text{ ft} - \text{lb}$$

$$2. |\tau_{\text{effort}}| = f_1 \cdot d_1 = 7,100 \cdot 3.1 = 22,010 \text{ ft} - \text{lb}$$

$$3. |\tau_{\text{load}}| = f_2 \cdot d_2 = 1,600 \cdot 3.4 = 5,440 \text{ ft} - \text{lb}$$

$$4a. |\tau_{\text{effort}}| = f_1 \cdot d_1 = 6,150 \cdot 3 = 18,450 \text{ ft} - \text{lb}$$

$$4b. |\tau_{\text{load}}| = f_2 \cdot d_2 = 4,685 \cdot 4.2 = 19,677 \text{ ft} - \text{lb}$$

help at work. The available information is limited, but alarming. Stay vigilant, start a conversation and you might be surprised what you hear. Personally, I told my mother (who works at a rehabilitation hospital) that I performed CPR on someone at work because he overdosed on "this new substance called kratom." She replied that she had taken it herself for a couple of weeks to treat pain at the suggestion of a coworker at her hospital. She had no idea there was risk of lethal overdose. Spread the word and share what you hear. **PSJ**

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4c. Comparing the antitipping torque ( $|\tau_{\text{effort}}|$ ) of 18,450 ft-lb with the tipping torque ( $|\tau_{\text{load}}|$ ) of 19,677 ft-lb, we expect the forklift to tip forward because  $|\tau_{\text{effort}}| < |\tau_{\text{load}}|$ .

### How Much Have I Learned?

$$5a. |\tau_{\text{effort}}| = f_1 \cdot d_1 = 3,650 \cdot 3.2 = 11,680 \text{ ft} - \text{lb}$$

$$5b. |\tau_{\text{load}}| = f_2 \cdot d_2 = 2,230 \cdot 3.6 = 8,028 \text{ ft} - \text{lb}$$

5c. Comparing the antitipping torque ( $|\tau_{\text{effort}}|$ ) of 11,680 ft-lb with the tipping torque ( $|\tau_{\text{load}}|$ ) of 8,028 ft-lb, we expect the forklift to remain upright because  $|\tau_{\text{effort}}| > |\tau_{\text{load}}|$ .