Chapter 12

Friction

In this chapter, you will learn the following to World Class standards:

- **A Review of Newton's Laws of Motion**
- **What is Friction?**
- **Determining the Amount or Coefficient of Friction**
- **Determining Different Coefficient of Frictions**
- **Computing the Coefficient of Friction of a Sliding Load**

A Review of Newton’s Laws of Motion

Imagine that we have a block of wood setting on a table top and we push the block of wood with our hand. According to Newton’s Third Law of Motion as shown in Figure 12.1, the block of wood resisted our force with an equal and opposite force. According to Newton’s Second Law of Motion as shown in Figure 12.1, the acceleration of the block of wood is the resultant external force divided by the mass of the block of wood. And in Newton’s First Law of Motion, the block of wood once in motion would continue in a straight line until an external force is applied to the block.

Newton’s First Law of Motion

An object in a state rest or in uniform motion will remain in that condition of rest or uniform motion unless an external force is applied to the object

Newton’s Second Law of Motion

The acceleration of an object is proportional to the resultant external force acting on the object and is inversely proportional to the mass of the object

$$a = \frac{f}{m}$$

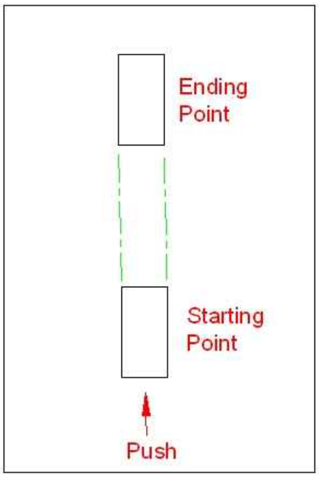
Newton’s Third Law of Motion

For every action, there is an equal and opposite reaction

Figure 12.1 – Newton’s Three Laws of Motion

If we conduct this experiment in our classroom, on our planet, where we are subject to the Earth’s gravitational pull, what do we think will happen?

Take a wood block and set the object on the table top. Using your hand, push the block on the side as shown in Figure 12.2. Repeat the experiment four more times, recording the test iteration in the column on the left and the distance moved in the column on the right. From our experience from conducting our previous experiments, how could we measure the amount of force we have used into each push?



Test	Distance

Figure 12.2 – Experiment with Friction

To conduct this first experiment, we do not need a precise measurement of the force, we only need to observe that a force was applied and that an invisible force has caused the wood block to come to rest.

With probably already know the answer to the question, “does the block continue to move in a straight line?” In our lives, we have pushed objects only to recognize that they will eventually stop moving, either on their own or from running into another object. If we did not push the blocked off the table then what caused the block to stop?

Many of us know the answer already, the opposing force is friction.

What is Friction?

Friction is a force upon an object that is caused by surface contact which is typically perpendicular or normal to the object. In Figure 12.3, the block of wood sits on the table top and we can see that if the force of the push equals zero, then there is not a reactionary force of friction opposing. We can say that without a force vector moving parallel to the table top, friction force is also zero.

Now when we apply the pushing force, depending on the surface texture of the table top, an opposing force acts against our efforts. If we give a slight push to the block of wood, and the tabletop is made of a material such as wood, plastic or metal, then in a few inches, our block of wood would come to rest. If this hidden force of friction is present, how does the mass of the object such as the wooden block play against our efforts to push?

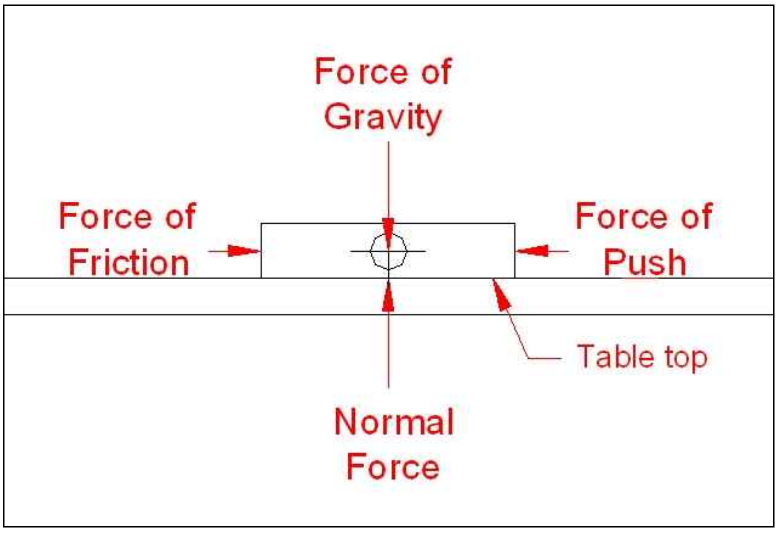
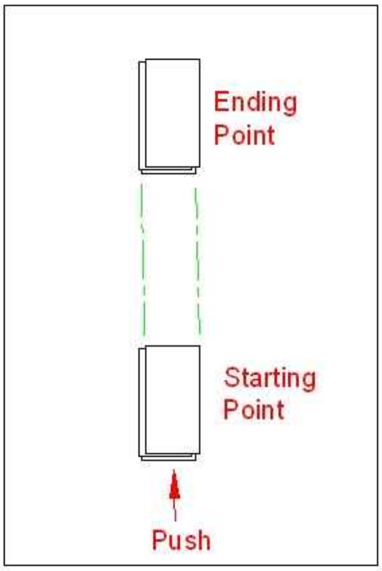


Figure 12.3 – Moving an Object on a Flat Surface

Again, we might already know the answer to this question through our own personal experiences moving objects outside of an engineering class. If the amount or coefficient of friction for any material remains the same, then the mass of the object times that amount or coefficient of friction creates the opposing force. So in simple terms, the larger the mass sitting on the table top, the greater the opposing force to our push.

We can conduct this experiment by placing two more blocks of seven-inch long wood on the top of the first block, then using approximately the same force, push the wood blocks across the table top. The question is, “did the blocks travel farther, the same or a lesser distance than the original single block?”

Take two wood blocks and set the objects on top of the first wood block on the table top. Using your hand, push the blocks on the side as shown in Figure 12.4. Repeat the experiment four more times, recording the test iteration in the column on the left and the distance moved in the column on the right. Did we discover that the larger mass of wooden blocks did not go as far with the same effort? How can we change the experiment to determine the force of the friction or the amount or coefficient of friction for the surface?



Test	Distance

Figure 12.4 – Second Experiment with Friction

Determining the Amount or Coefficient of Friction

What if we looked at the same problem in a little different set up? What if we increased the slope of the plane that the solid wood block rests? As we can observe in Figure 12.5, we no longer need to push the 7 inch long wooden block, since the force of gravity has a sub vector acting down the inclined plane.

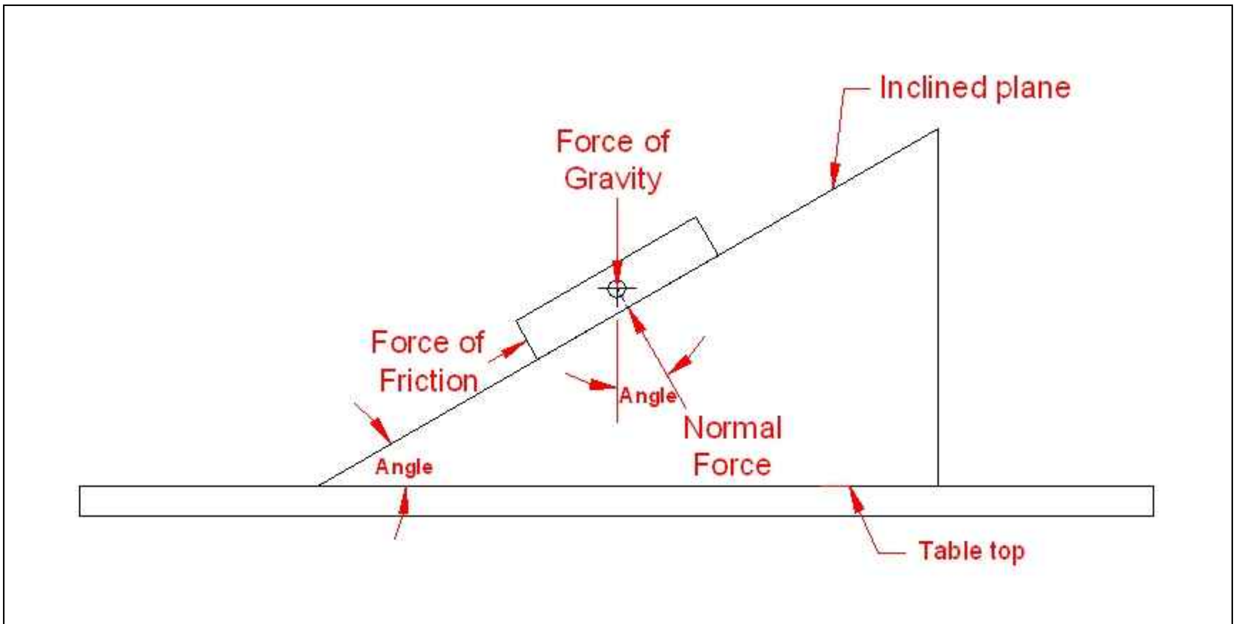


Figure 12.5 – Experiment with Friction

If the force of friction equals the normal force time the amount of friction the material has, called the coefficient of friction

$$F_f = F_N \mu$$

Then the coefficient of friction must be have been

$$\mu = \frac{F_f}{F_N}$$

When using simple algebra to rearrange the terms. And when we observe Figure 12.6, we see the trigonometry of the where the tangent of the angle equals the opposite side divided by the adjacent side of the triangle, so

$$\text{Tan (angle)} = \frac{F_f}{F_N}$$

Then we combine both formulas to find the coefficient of static friction, which is the amount of friction that holds a mass in place until the object begins to move.

$$\text{Tan (angle)} = \frac{F_f}{F_n} = \mu \text{ (coefficient of static friction)}$$

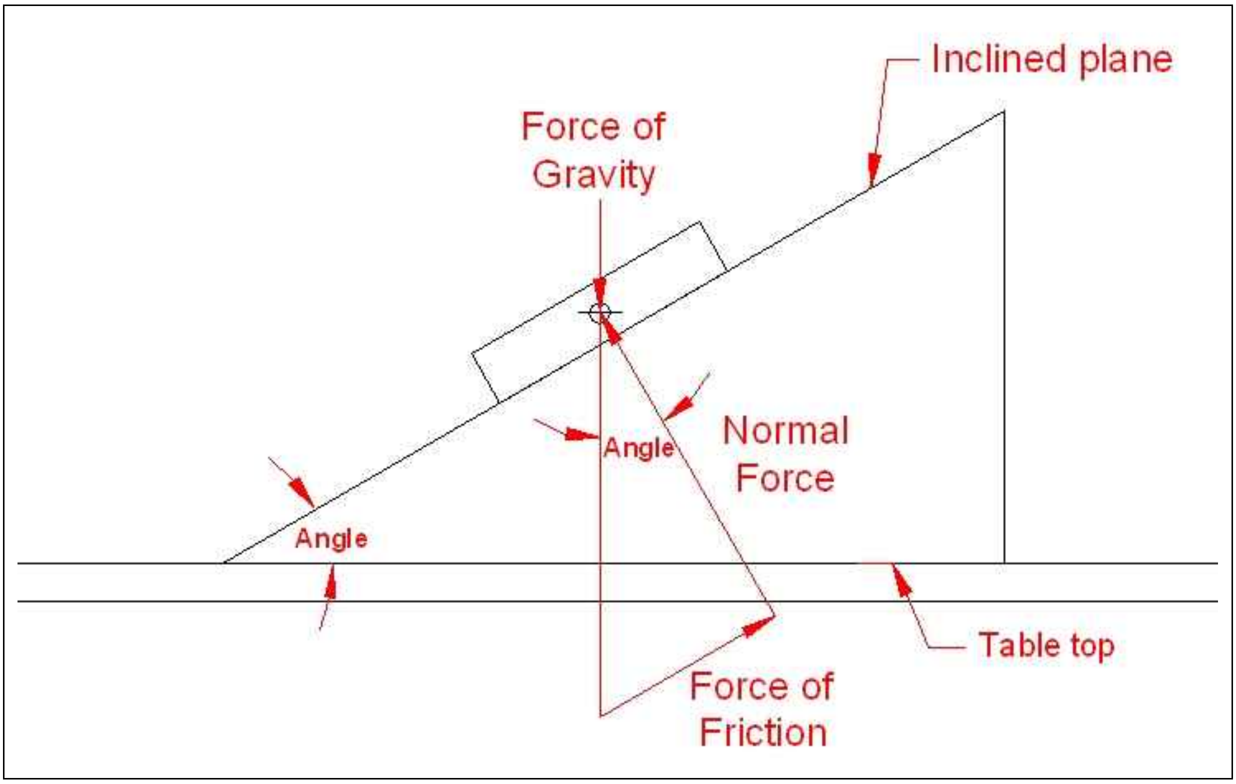


Figure 12.6 – Coefficient of Friction Equals

Place a 1 x 6 x 24 on the table top. Place a single wood block on the middle of the 1 x 6. Using a protractor to measure the angle, raise the 1 x 6 wood as an inclined plane gradually until the wood block begins to move. Record the result in the table in Figure 12.7.

When we performed the experiment, the wooden block began to move at 16.7°. We repeated the trials multiple times to check for accuracy and found the angle to be correct. To find the coefficient of static friction, we entered 16.7 into the Windows calculator, and pressed the tangent button to get 0.3000, which is the value of the static coefficient of friction for wood on wood surfaces.

Figure 12.7 – Coefficient of Friction Equals

The Determining Different Coefficient of Frictions

What kinds of surfaces cause friction? Now we should make a list of materials that can come into contact with the wood block and determine the amount of friction they cause in slowing down the wooden block. Compare your answers to a table of Coefficient of Static Friction such as the one shown in Appendix A of this textbook.

Material	Angle of the Incline Plane	Coefficient of Friction Tan (angle)
Air		
Aluminum		
Oil		
Paper		
Plastic		
Rubber		
Sand		
Steel		
Water		
Wood		

Figure 12.8 – The Coefficient of Friction for a Wood Object on Different Materials

Computing the Coefficient of Friction of a Sliding Load

Now that we know how to compute the static coefficient of friction, we will look at the affect of friction on a moving component sliding down a 30° ramp at uniform speed in the manufacturing process. Since the steel pot is moving at uniform speed, the forces of gravity and the force of friction are in equilibrium.

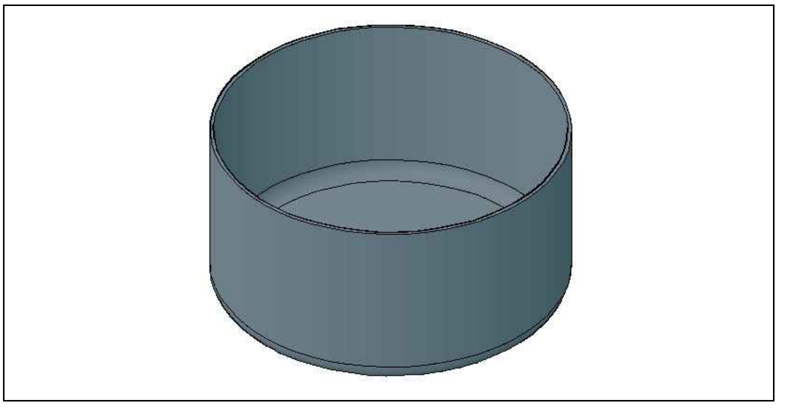


Figure 12.9 – Image of the Steel Pot

In Figure 12.9, we see an image of a steel pot that is 12 inches in diameter, is made of 11 gauge steel, and is 6 inches tall. At the base of the steel pot, there is an internal radius of 0.5 inch.

In our Computer Aided Design (CAD) program, draw a three dimensional solid using the dimensions shown in Figure 12.10. Use the Sheet Metal Gauge table that is shown in Figure 12.11 to determine the actual thickness of the sheet metal. Once the 3D solid is completed, use the Mass Properties tool in your program such as AutoCAD to find the volume of the steel pot.

We select the Mass Properties tool on the Inquiry toolbar and then select the 3D solid. In Figure 12.12, we see that the volume of the steel pot is 38.6862 cubic inches.

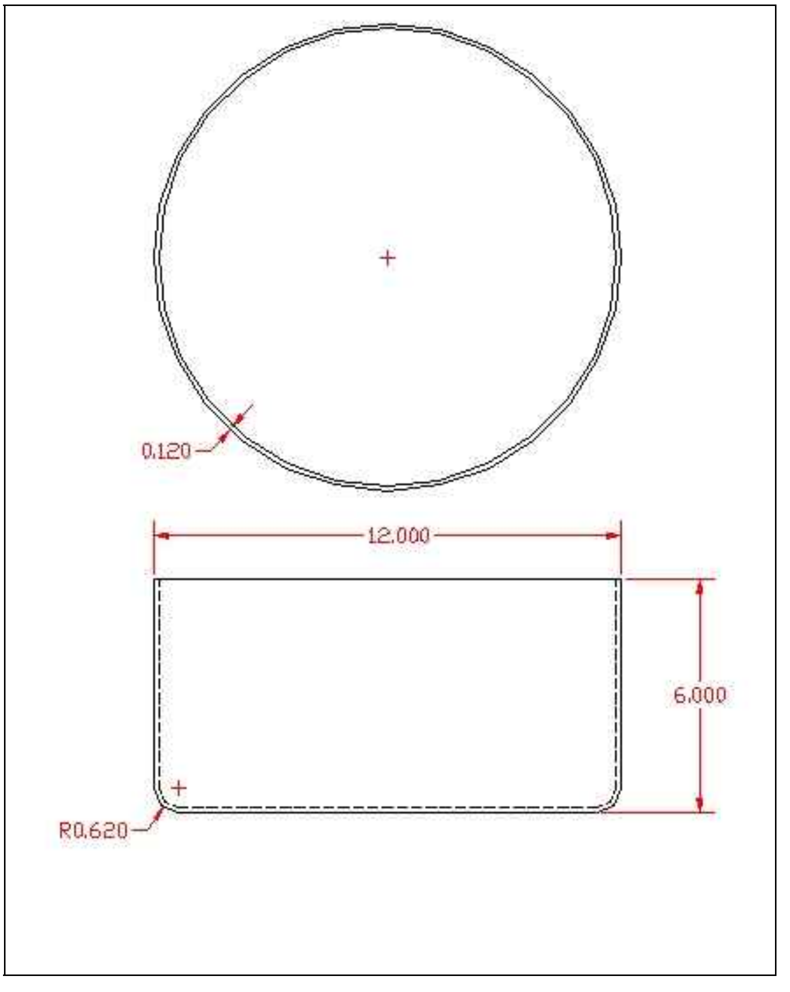


Figure 12.10 – Detail Dimensions of the Steel Pot

Gauge (ga)	Standard Steel Thickness (inches)	Galvanized Steel Thickness (inches)	Aluminum Thickness (inches)
9	0.1495	0.1532	0.1144
10	0.1345	0.1382	0.1019
11	0.1196	0.1233	0.0907
12	0.1046	0.1084	0.0808
13	0.0897	0.0934	0.0720
14	0.0747	0.0785	0.0641
15	0.0673	0.0710	0.0571
16	0.0598	0.0635	0.0508
17	0.0538	0.0575	0.0453
18	0.0478	0.0516	0.0403
19	0.0418	0.0456	0.0359
20	0.0359	0.0396	0.0320
37	0.0064		
38	0.0060		

Figure 12.11 – Sheet Metal Gauge Table

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----------------   SOLIDS    ----------------

Mass:                        38.6862
Volume:                      38.6862
Bounding box:             X: 5.0933   --   17.0933
                          Y: 112.8702   --   124.8702
                          Z: 0.0000   --   6.0000
Centroid:                 X: 11.0933
                          Y: 118.8702
                          Z: 2.0978
Moments of inertia:       X: 547527.3409
                          Y: 5647.3413
                          Z: 552531.7172
Products of inertia:     XY: 51013.9818
                         YZ: 9646.8161
                         ZX: 900.2668
Radii of gyration:        X: 118.9666
                          Y: 12.0821
                          Z: 119.5090
Principal moments and X-Y-Z directions about centroid:
                          I: 716.3380 along [1.0000 0.0000 0.0000]
                          J: 716.3380 along [0.0000 1.0000 0.0000]
                          K: 1130.1944 along [0.0000 0.0000 1.0000]
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Figure 12.12 – Mass Properties Data for the Steel Pot

To find the weight of the steel pot, we will multiply the volume of the steel pot times the density of the 1010 steel. In Figure 12.13, the density of 1010 steel is 0.284 pounds per cubic inch. So we do the following math:

$$\text{Weight of the Steel Pot} = 38.6862\ \text{in}^3 \times 0.284\, lbs/\, in^3 = 10.987\ \text{lbs}$$

Material	Density	
	English	Metric
	(lbs per cubic inches)	(grams per cubic cm)
Acrylic	0.042	1.163
Aluminum, 6061	0.098	2.713
Aluminum, cast	0.097	2.685
Brass, free cutting	0.307	8.498
Cast Iron	0.252	6.975
Copper	0.323	8.941
Polycarbonate	0.043	1.190
Stainless steel	0.302	8.359
Steel, 1010	0.284	7.861
Teflon	0.078	2.159
Wood – pine	0.023	0.650
Zinc, cast	0.240	6.643

Figure 12.13 – Density Table of Common Construction Materials

Now we place the 10.987 steel pot on the 30° incline as shown in Figure 12.14.

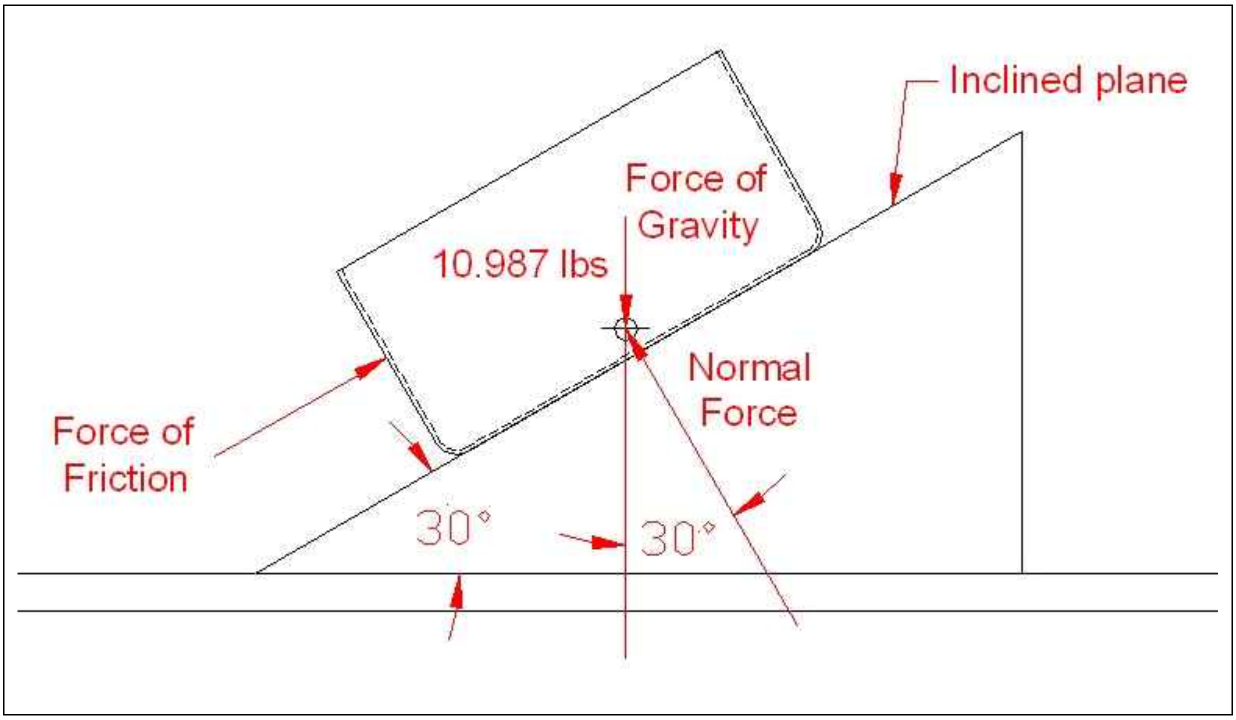

Figure 12.14 – The Sliding Steel Pot

The force of friction is equal to the force of gravity (the hypotenuse of the triangle) times the Sine of the angle which is 30°.

$$F_f = F_g \sin(30) = 10.987\ lbs(0.50) = 5.494 \text{ Lbs}$$

The normal force, which is the force of the steel pot against the incline plane is

$$F_N = F_g \cos(30) = 10.987 lbs (0.866) = 9.515 \text{Lbs}$$

The coefficient of kinetic friction is

$$\mu = \frac{F_f}{F_N} = \frac{5.494 Lbs}{9.515 Lbs} = 0.577$$

So now we can compute the coefficient of kinetic friction.

*** World Class CAD Challenge 10-40 * - Draw a wooden crate made from 2 x 4's and 1 x 4's shown in figures 14.15 and 14.16. If the crate should slide at uniform speed down a ramp, what would that angle be for the wood crate on the steel ramp? Compute the weight of the wooden crate, the angle of slide, the friction force and the normal force. Save the drawing as wooden_crate.dwg**

Continue this drill four times using some forces you have determined, each time completing the drawing under 60 minutes to maintain your World Class ranking.

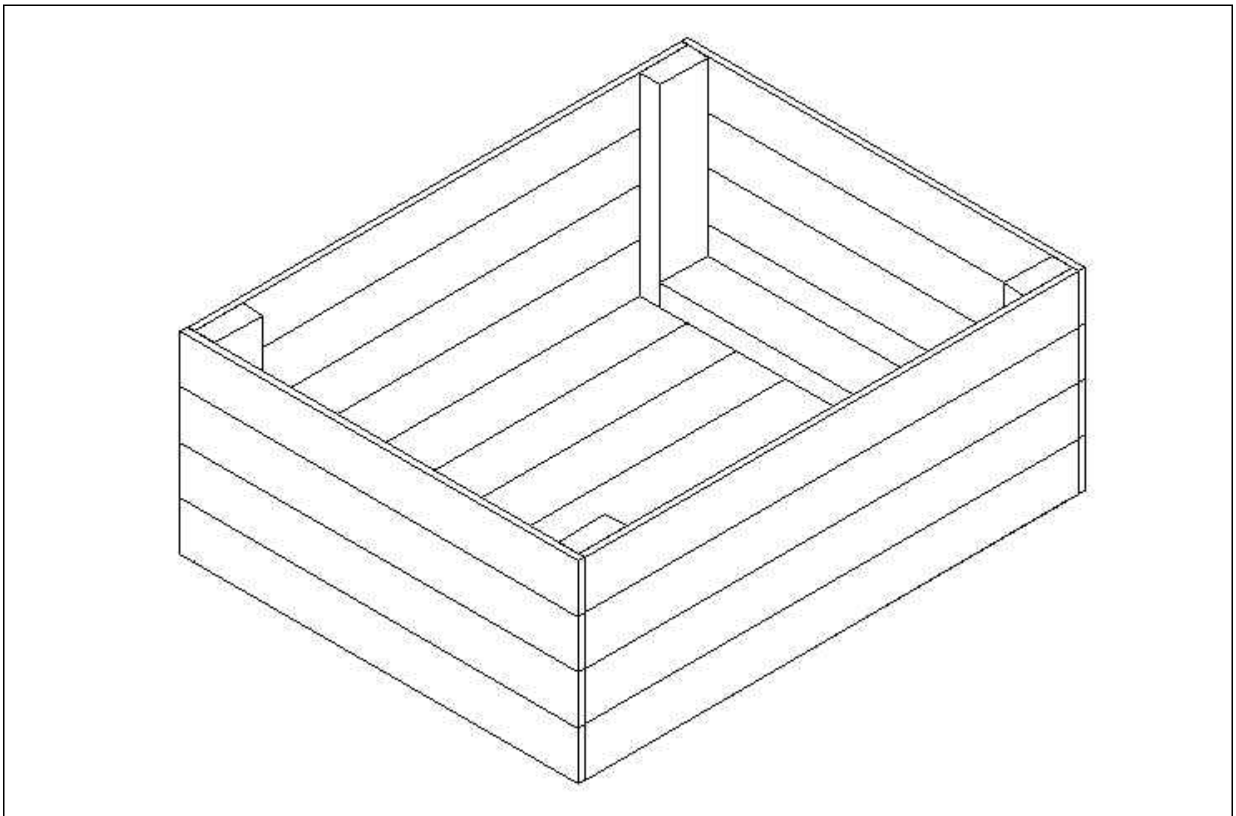

Figure 12.15 – The Sliding Wooden Crate

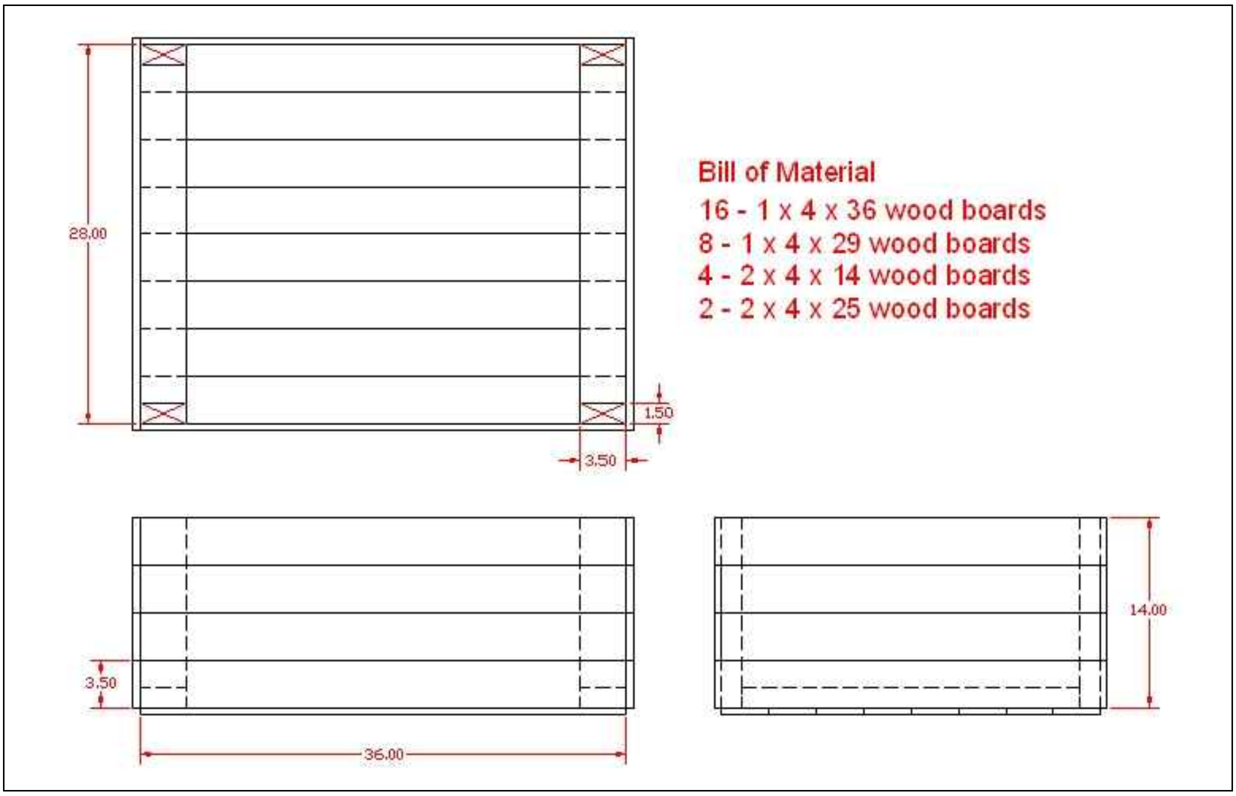

Figure 12.16 – The Dimensions of the Sliding Wooden Crate