

Chapter 10

Obtaining the Center of Gravity, Volume, Weight and More

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

- **The Importance of the Center of Gravity**
- **The Inquiry Toolbar**
- **Using the Mass Properties Tool on the Inquiry Toolbar**
- **Showing the Center of Gravity with a Point**
- **Moving the Center of Gravity of a Part to the Drawing Origin**
- **Writing the Mass Properties Analysis to File**
- **Analyzing a Simple Part**

The Importance of the Center of Gravity

For every designer, the center of gravity is important when analyzing a part or assembly. In the study of rigid bodies, the weight of the entire part can be drawn through this single point. When one or more external forces act on a rigid body, their force vectors can be scrutinized in relationship to the center of gravity, telling the observer whether the part will be subject to a twisting motion. In this chapter, we will learn how to find and mark the center of gravity of a solid. We will also learn how the computer program finds the center of gravity of a part.

After analyzing the 3D component's center of gravity, we will extract the part's volume and Moment of Inertia from the engineering data. The volume along with the material's density will allow us to compute the part's weight. The information from the computer program will help us orientate the part in the direction to resist forces and we will use the figures to compute the maximum weight on the beam.

First, in AutoCAD, draw a 3D solid that is 4 by 3 by 2. In the simple 3D part as shown in Figure 10.1, the block has a center of gravity that is at the intersection of three axis that run through the center of the three planes, XY, YZ and ZX. Many designers can spot the center on a symmetrical part without complex calculations. But in many cases, we will need complex calculations or we will use a computer program to find the center of gravity.

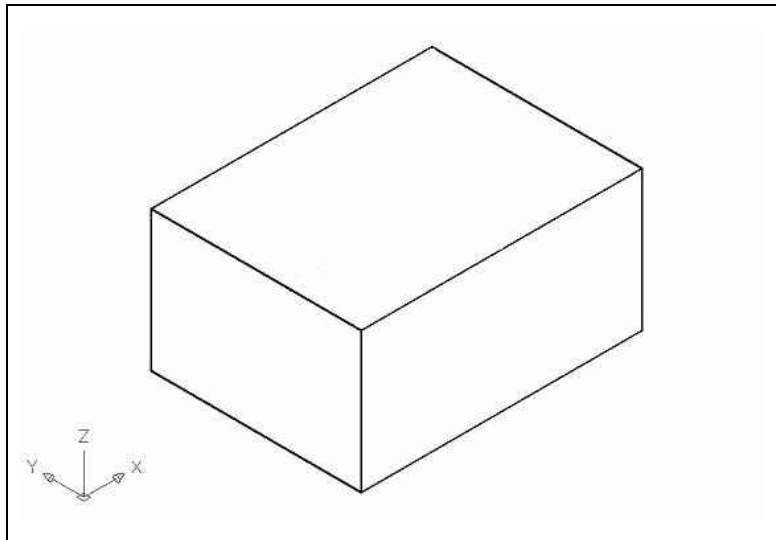


Figure 10.1 – Drawing a Simple 3D Part

The Inquiry Toolbar



The Inquiry Toolbar has a number of tools that help retrieve data from a drawing. The five commands are Distance, Area, Mass Properties, List and ID. They are used to find many facts and figures of a part including true distances in 3D space, the surface area and volume of a solid.

Distance – This tool will give the user the true distance after selecting two points in three-dimensional Model Space. The command will return the angle in the XY plane



and the angle from the XY plane. The three subcomponents of the true distance, Delta X, Delta Y and Delta Z are given. See the example shown below.

```
Command: '_dist Specify first point: Specify second point:
Distance = 5.3852, Angle in XY Plane = 323, Angle from XY Plane = 338
Delta X = 4.0000, Delta Y = -3.0000, Delta Z = -2.0000
```

Area – gives the user the area of a solid after specifying “O” for object. If architectural units are set the answer is given in square inches and square feet. If the object is a circle or Polyline, the perimeter is given.



```
Command: area
Specify first corner point or [Object/Add/Subtract]: o
Select objects:
Area = 52.00 square in. (0.3611 square ft.), Perimeter = 0'-0"
```

Mass Properties – gives the bounding box, centroid, moment of inertia, product of inertia, radii of gyration and the principal moments and X-Y-Z directions about centroid. An example is shown in the next section of this chapter.



List – Gives the user information about the 3D part, such as entity type and layer name. The List report



```
Command: _list
Select objects: 1 found
Select objects:
    3DSOLID Layer: "0"
        Space: Model space
        Handle = c1
        History = Record
    Show History = No
    Solid type = Box
    Position, X = 5.0000 Y = 3.5000 Z = 0.0000
    Length: 4.0000
    Width: 3.0000
    Height: 2.0000
    Rotation: 0
```

ID – gives the user the X, Y and Z ordinates of a point selected in 3D model space. See the example shown below.



```
Command: id
Specify point: X = 3.0000 Y = 5.0000 Z = 0.0000
```

Using the Mass Properties Tool on the Inquiry Toolbar

Where the other tools in AutoCAD are helpful in physical design where the parts can be shown to fit together, the mass properties uses the size and shape of a part to help us to select material.

The physical shape of the homogenous solid can determine the resistance to bending and therefore the ability to resist breakage. Add the Moment of Inertia data to the Modulus of Elasticity of a material in the homogenous part and we can predict the point of failure. The data we are about to see, could be calculated by other means such as using a calculator, pencil and paper, but the results would take half an hour or much more depending on the complexity of the part. This program will provide the engineering data in seconds.

Select the Mass Properties tool on the Inquiry toolbar and then choose the 3D part. After opting for the part, Enter to see the data describing the bounding box, centroid, moments of inertia, products of inertia, radii of gyration and the principal moments and X-Y-Z directions about centroid.



Bounding Box - The minimum values on the X, Y and Z-axis and the maximum values on the X, Y and Z axis that envelope the 3D solid.

Centroid – This three dimensional point defines the center of volume (balance) for the 3D solid. For homogenous parts, the point is the same as the Center of Gravity, where the forces acting on the solid will not rotate the part.

Moments of Inertia - This number shown in units to the fourth power represents the capacity of 3D solid to resist bending. For solids designed in inches, the moment of inertia is in inches to the fourth power. For metric drawings, the answer is millimeters to the fourth power.

Products of Inertia – This is a measure of the imbalance of the area with the respect to the two planar axis chosen. The Products of Inertia will be zero when the centroid is at the origin.

Radii of Gyration - This three dimensional point defines the distance from the axis where all the mass can be concentrated and equals the same as the Moment of Inertia.

Principal Moments and X-Y-Z Directions about Centroid - This number shown in units to the fourth power represents the capacity of 3D solid to resist bending when the centroid is at 0,0,0 point. For solids designed in inches, the moment of inertia is in inches to the fourth power. For metric drawings, the answer is millimeters to the fourth power. We know this value as the principal axes of inertia, which have their origin at the center of gravity.

```

AutoCAD Text Window - Drawing1.dwg
Edit
Command: massprop
Select objects: 1 found
Select objects:
----- SOLIDS -----
Mass:                24.0000
Volume:              24.0000
Bounding box:       X: 3.0000 -- 7.0000
                   Y: 2.0000 -- 5.0000
                   Z: 0.0000 -- 2.0000
Centroid:           X: 5.0000
                   Y: 3.5000
                   Z: 1.0000
Moments of inertia: X: 344.0000
                   Y: 664.0000
                   Z: 944.0000
Products of inertia: XY: 420.0000
                   YZ: 84.0000
                   ZX: 120.0000
Radii of gyration:  X: 3.7859
                   Y: 5.2599
                   Z: 6.2716
Principal moments and X-Y-Z directions about centroid:
I: 26.0000 along [1.0000 0.0000 0.0000]
J: 40.0000 along [0.0000 1.0000 0.0000]
K: 50.0000 along [0.0000 0.0000 1.0000]
Write analysis to a file? [Yes/No] <N>:

```

Figure 10.2 – Run Massprop

Showing the Center of Gravity with a Point

Place a point at the center of gravity of the 3D solid by selecting the Point tool on the Drawing toolbar and entering the X, Y and Z values from the centroid value from the report we can see from the Mass Properties command. A node will appear on the graphical display showing the position of the centroid. To make the centroid appear as a symbol and not a single point, select Format from the Menu Bar and pick Point Style. The Point Style dialog box will appear on the graphical display. Choose the point style as shown in Figure 10.3 and press the OK command button. A large point symbol similar to the actual center of gravity symbol used in industry will replace the single node.

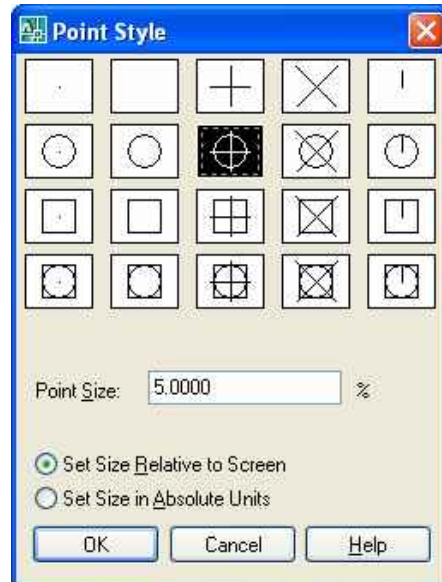


Figure 10.3 – Point Style Dialog Box

Moving the Center of Gravity of a Part to the Drawing Origin

When we wish to examine a 3D solids ability to resist bending and then use the Moment of Inertia value to select a material that will not break under stress, then we will move the solid so the centroid is at the drawings origin. Select the solid and for the first point of displacement, pick the point representing the centroid of the part. For the second point, type 0,0,0 for the origin of the drawing.

Select the Mass Properties tool on the Inquiry toolbar and then choose the 3D part again. After opting for the part, Enter to see the data describing the bounding box, centroid, moments of inertia, products of inertia, radii of gyration and the principal moments and X-Y-Z directions about centroid. Now the value of the centroid will be 0,0,0. The Moments of Inertia will now reflect the parts to ability to resist bending about its own axis.

Writing the Mass Properties Analysis to File

We can write the Mass Properties data to an external file by answering yes to the query at the end of the function. After affirming the desire to keep the data, pick a file location in the project or parts folder. We can make a sub folder called Engineering Data and save the file with the part name or number. Now we will be able to locate the information easily for future reference.

```
----- SOLIDS -----
Mass:                24.0000
Volume:              24.0000
Bounding box:        X: -2.0000 -- 2.0000
                    Y: -1.5000 -- 1.5000
                    Z: -1.0000 -- 1.0000
Centroid:            X: 0.0000
                    Y: 0.0000
                    Z: 0.0000
Moments of inertia: X: 26.0000
                    Y: 40.0000
                    Z: 50.0000
Products of inertia: XY: 0.0000
                    YZ: 0.0000
                    ZX: 0.0000
Radii of gyration:  X: 1.0408
                    Y: 1.2910
                    Z: 1.4434
Principal moments and X-Y-Z directions about centroid:
                    I: 26.0000 along [1.0000 0.0000 0.0000]
                    J: 40.0000 along [0.0000 1.0000 0.0000]
                    K: 50.0000 along [0.0000 0.0000 1.0000]
```

Figure 10.4 – Point Style Dialog Box

Analyzing a Simple Part

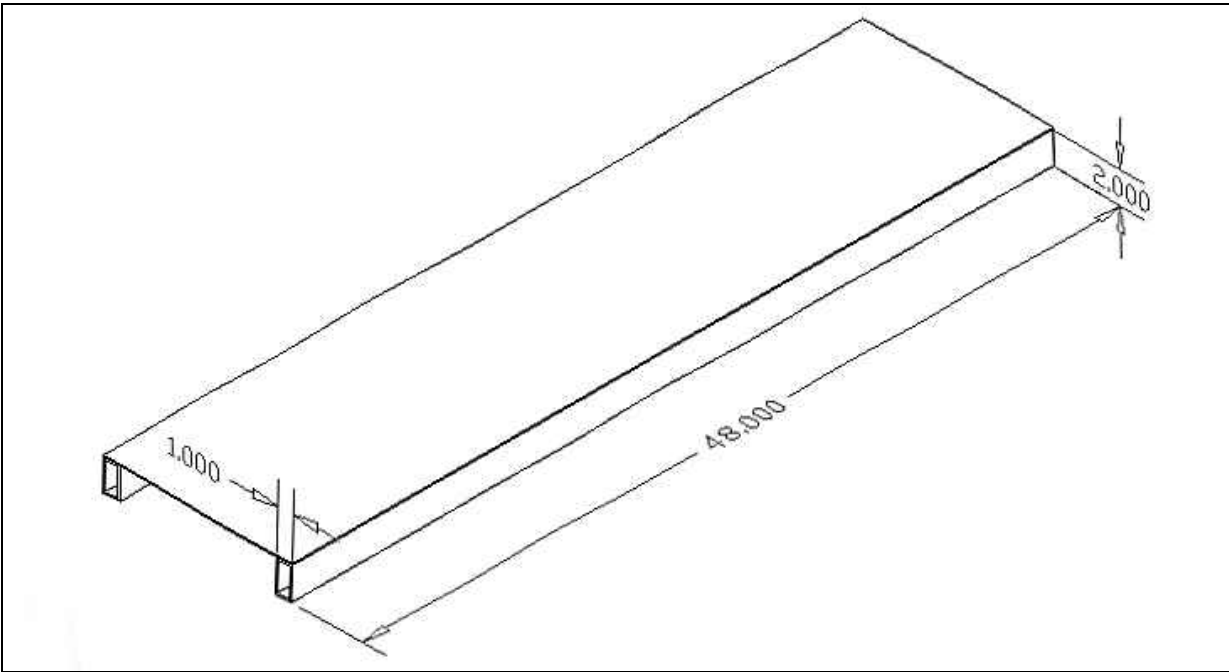


Figure 10.5 – Sketch of a Single Shelf in the Design

Let us say an engineer asks us to design a shelf using 1/8 x 1 x 2 aluminum tube that we have in stock and we want to determine the weight of the two supports holding the aluminum sheet. We would also like to determine the Moments of Inertia of the aluminum tube. The engineer provides a sketch of a single shelf as shown in Figure 10.5.

In our CAD program, draw a single 1 x 2 x 48 long hollow tube with a 0.125 wall. Run the Mass Properties tool from the Inquiry toolbar. Answer these questions.

What is the volume of the tube?

What is the density of 6061 aluminum?

What is the weight of the tube?

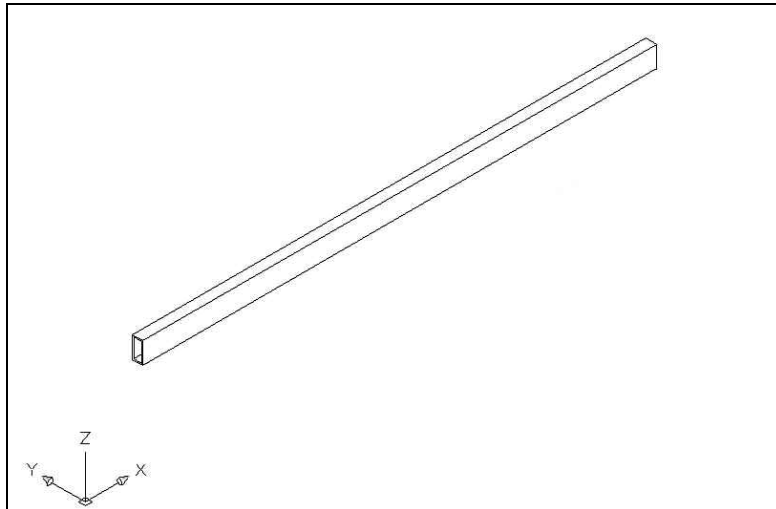


Figure 10.6 – Draw a 1/8 Walled x 1 x 2 x 48 Long Tube

In order to find the weight of a part, we will determine the volume of the solid. From the Mass Properties data as shown in Figure 10.7, we see the volume of the tube is 33 cubic inches.

----- SOLIDS -----	
Mass:	33.0000
Volume:	33.0000
Bounding box:	X: -24.0000 -- 24.0000
	Y: -0.5000 -- 0.5000
	Z: -1.0000 -- 1.0000
Centroid:	X: 0.0000
	Y: 0.0000
	Z: 0.0000
Moments of inertia:	X: 20.9688
	Y: 6351.9219
	Z: 6341.0469
Products of inertia:	XY: 0.0000
	YZ: 0.0000
	ZX: 0.0000
Radii of gyration:	X: 0.7971
	Y: 13.8738
	Z: 13.8619
Principal moments and X-Y-Z directions about centroid:	
	I: 20.9687 along [1.0000 0.0000 0.0000]
	J: 6351.9219 along [0.0000 1.0000 0.0000]
	K: 6341.0469 along [0.0000 0.0000 1.0000]

Figure 10.7 – Mass Properties Data of the 1/8 Walled x 1 x 2 x 48 Long Tube

Different materials are denser than others and we have seen this in our lives. Pick up a piece of plastic and a piece of similar sized glass. We notice that the glass is considerably heavier than the plastic. This observation is true because the density of the plastic is much less than the glass. If we obtain a density chart of materials, we will always have the ability to record the weight of the part on the mechanical drawing. Who uses this data? The machinist, the assembly personnel, shipping and receiving staff, and other people on the engineering team.

The density of some common materials is in the chart below:

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 10.8 – Density Table of Common Construction Materials

The centroid of the tube was not even on the part, but located inside the hollow tube, 18 inches from the end. We moved the centroid of the tube to the origin as we can see in Figure 10.8 by noticing that the centroid is 0,0,0.

Now, we need to compute the weight of the tube. The formula for determining the weight is:

$$PartWeight = Volume \times Density$$

$$PartWeight = 33.0in^3 \times 0.099lbs / in^3 = 3.267lbs$$

The last data we need to use is the Moment of Inertia. The Moment of Inertia is the sum of the area times the distance to the centroid of the area to the second power. Therefore the answer will be the unit of measurement to the fourth power. Most likely this will be inches or feet in English units and millimeters or meters in Metric units.

There are three Moments of Inertia for a part and for our tube. One bending moment is around the X-axis, which is 20.9688 in^4 . Another bending moment is around the Y-axis, which is 6351.9219 in^4 . And the last bending moment is around the Z-axis, which is 6341.0469 in^4 . The largest force on the shelves will be from the items placed on the top, so the bending will be around the Y-axis.

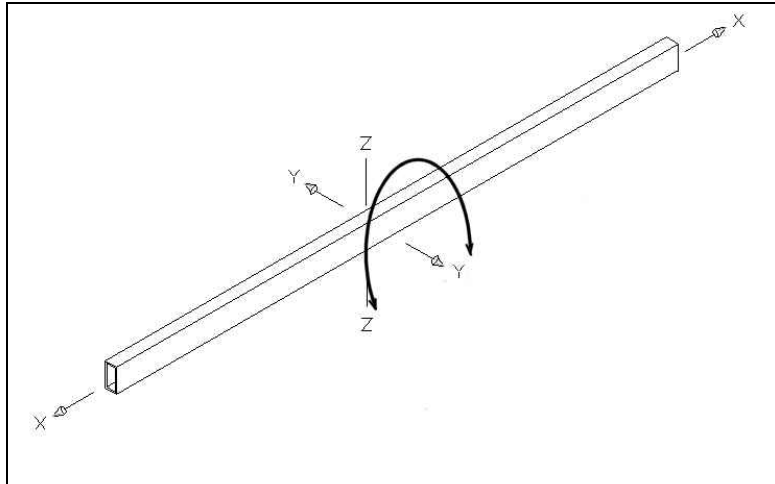


Figure 10.9 – Bending on the Y Axis

We can evaluate by reading the numbers that the best resistance to a bending moment around the Y-axis is with the tube oriented in the vertical alignment where it is slightly stronger to oppose the load. The Moment of Inertia we will use for the design is 6351.9219 in^4 .

*** World Class CAD Challenge 10-30 * - Draw a 3D solid of a 1/8 walled, 2 x 4 x 36 inch long aluminum tube. Determine and mark the centroid, find the volume, weight and Moment of Inertia of the tube. Save the drawing as 2x4x36_tube.dwg**

Continue this drill four times using some forces you have determined, each time completing the drawing under 5 minutes to maintain your World Class ranking.