

Chapter

4

Forces in a 3D Space

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

- 1. Force Vector in 3D Space**
- 2. Using the List Tool to Determine True Length and Direction**

Force Vector in 3D Space

Although the math is simpler when computing resulting forces on a 2D plane, many practical applications require the designer to calculate the resultant of forces in three-dimensional space. In the previous chapter, we added each individual vector graphically, attaching the end of one to the front of the preceding force illustration and found a new line originating from the starting point and ending at the point of the last added vector. This resultant has a length, which defines the total product of force acting on the object and a direction in which the line of action is pointing. We should believe that this approach to solving the engineering problem will work for vectors with magnitude and direction working anywhere in 3D space. In this chapter, we want to prove our supposition that we can use the technique of vector addition in any direction.

The biggest difference to solving the 3D exercise rather than the 2D problem is that we need to draw our entities on 3D Model Space. There are AutoCAD tools that can assist the designer in solving mechanical, such as List and Massprop. In our model, we will easily construct a line, which will call the resultant, but measuring the line can be difficult using the two dimensional measurement tools on the Dimension toolbar, since we will not get the true length of the compilation vector. The List tool on the Inquiry toolbar will give you true length, and all three of the subcomponent vectors that reside on the X, Y and Z-axis. There are two angles that we need in three-dimensional space. The first angular measurement method is the same as in last chapter, which gauges the angle of the resultant from the positive X-axis in a counterclockwise manner. The second angle will represent the circular distance above or below the XY plane in the positive or negative Z-direction. We will demonstrate this analysis in the first problem.

In these exercises, we encourage one to construct the diagrams in the CAD drawing file, and whenever do the experiment. Obtain a set of force meters, wooden blocks and some cables made of rope or heavy twine. In our lab, we can copy the setup shown in the CAD diagram and by experimentation confirm the drawing results.



Figure 4.1 – Conducting the Experiment

Let us take a block of wood that is 7 inches by 3.5 inches by 1.5 inches and nail the piece to the top of a table. Now, fasten a hook to the block of wood. Attach a force meter and pull cable to the fastener and tug the block with a small force. The gauge will show the force that we are pulling on the block. We can see that there is only one force acting on the entity and we can determine the magnitude and direction of the force.

Take another 7-inch by 3.5-inch by 1.5-inch wood block and attach three force meters and pull cables onto the hook. On the opposite side of the second block, attach the force meter and cable from the first block. Now, pull with a force on the first cable and have another individual draw

on the other line and one more pull on the third line. We can look at the reaction of the three forces by reading the force meter attached on the opposite side. We are using a principle which demonstrates that for any action (force) being applied, another action (force) will be created that is equal and opposite to those being applied.

In Figure 4.2, we will open the Computer Aided Design (CAD) program, create a solid box that is 1.5 x 3.5 x 7.0 and attach force vector exactly to scale. Draw a line 22.25 at 45.0 degrees above the X-axis and another line 30.00 units long at a minus 12.5 degree angle below the X-axis. Then draw a 21.0 line at 45.0 degrees above the X-axis in the Z direction. We can change the UCS to draw the last line.

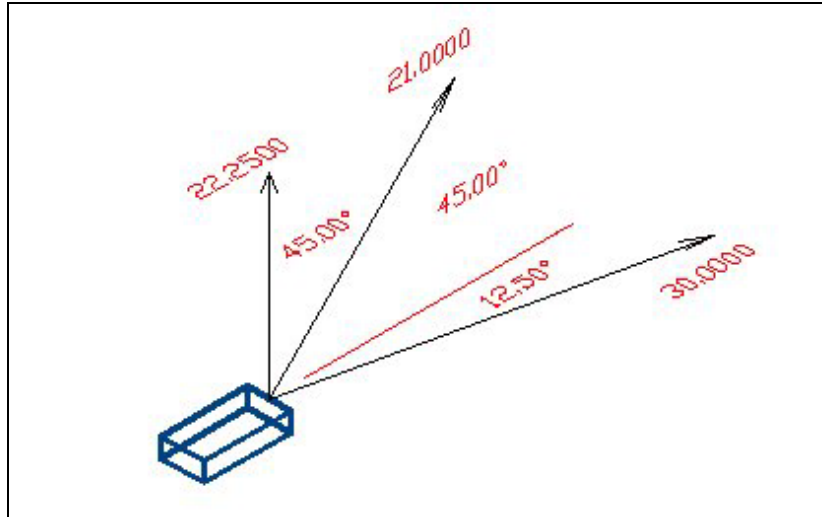


Figure 4.2 – Three Vectors Acting on an Object

How do we setup the experiment? On our second block with three meters attached, we will lay a protractor on the table and pull a 22.25 pound force on one cable at 45 degrees above the X-axis and on the other line we will pull a 30 pound force at a minus 12.50 degree angle below the X-axis. Then pull with a 21.0-pound force at 45 degrees above the X-axis in the Z direction as shown in Figure 4.5.

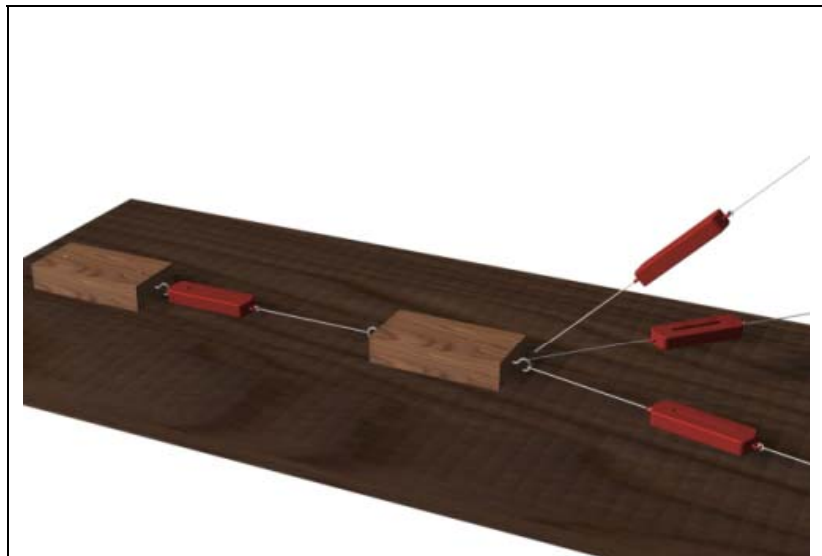


Figure 4.3 – Setting Up the Experiment

We need to make some modifications in the test's measuring system since we can already observe that the block on the right will lift off the table when pulling upward. We might need a larger protractor or a perfectly square box to get the angles correct when they are physically far above the XY plane (tabletop). Precisely machined blocks with parallel sides can be stacked on the surface of the test bed to allow us to use smaller measuring devices. Remember, the forces acting on the block are relationship to the table (X, Y and Z-axis) and we will ignore the twisting angle of the second block.

Using the List Tool to Determine True Length and Directions

We copy the three force problem to just the right of the setup diagram and moved each force representation to perform vector addition. We changed the black vector lines to the dotted blue lines and removed their arrowheads. Now when we draw the Resultant, we can see the three-subcomponent vectors in blue. We also draw the three lines representing each axis and label each one as shown in Figure 4.4. We select List on the Inquiry toolbar in AutoCAD to see the magnitude and direction of the resultant.

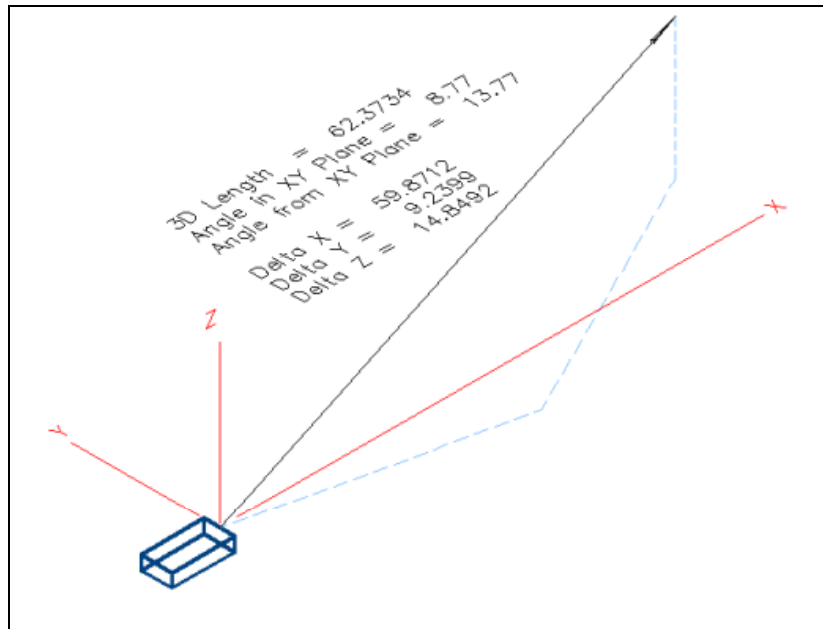


Figure 4.4 – Using Vector Addition to Find the Resultant

In Figure 4.5, we can read that the 3D Length is 62.3734, so the measurement in our experiment should be very close to that answer. The angular direction from the X-axis is 8.77 degrees and the angle above the XY plane is 13.77 degrees. We copied the data from the Text Display and pasted the data into the drawing as a text entity as we observe in Figure 4.4.

```
Command: List
Select objects: 1 found

Select objects:
      LINE      Layer: "0"
                Space: Model space
      Handle = 1f1d
      from point, X= 0.0000 Y= 0.0000 Z= 0.0000
      to point, X= 59.8712 Y= 9.2399 Z= 14.8492
      In Current UCS, Length = 60.5801, Angle in XY Plane = 8.77
      3D Length = 62.3734, Angle from XY Plane = 13.77
      Delta X = 59.8712, Delta Y = 9.2399, Delta Z = 14.8492

Command: |
```

Figure 4.5 – Display Showing the True Data for the Resultant Using the List Tool

The CAD program provides three additional key pieces of information, which are resulting subcomponents of the resultant. We see the total force in the X-direction (Delta X) is 59.8712 pounds, the total force in the Y-direction (Delta Y) is 9.2399 pounds, and the total force in the Z-direction (Delta Z) is 14.8492 pounds. These measurements are important to the designer or engineer, since we can determine the stress on adjacent parts connected in the assembly. For example, if the finished product was sitting on the foundation, exerting a 100-pound force, we would be confident that the concrete could manage the load. However, if the structure also had

force acting sideways at 500 pounds at the same point, our design may need to change to handle a load in the X or Y direction and not just the Z, which in many cases is projecting downward.

In Figure 4.6, we show the entire solution in a third representation. We copy the solution from Figure 4.4, and remove the three-subcomponent forces used in vector addition. Now we draw a 3D box using the blue dashed lines enclosing the resultant vector. Draw three new vectors, one on the X-axis, the Y-axis and the Z-axis. Check the measurement against the results in the List text display. Finally, use standard dimension to display the magnitude and directions.

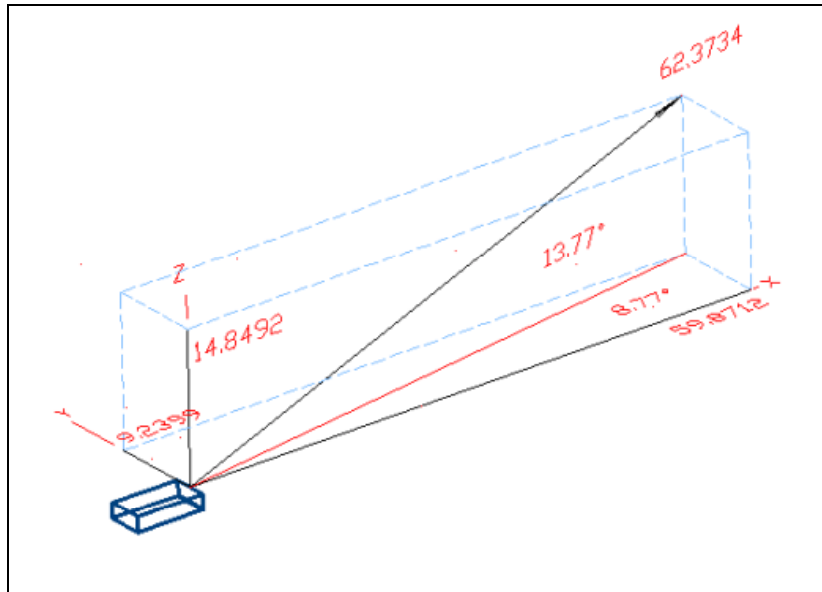


Figure 4.6 – Two Force Vectors Acting on an Object

A CAD Note: We can turn off the dimension lines, arrows and the dimension extension lines, since these images can appear on the drawing similar to those that appear in a mathematical exercise versus on an ANSI or ISO controlled document, where dimensional appearances are prescribed by regulation. In Figure 4.6, we turned off the many of the dimensional attributes, except the actual dimension. Dimensioning procedures are the same.

*** World Class CAD Challenge 10-4 * - Draw a 7 inch by 3.5 inch by 1.5 inch solid block and illustrate a 22.25 pound force vector at 45 degrees above the X-axis and a 30 pound force vector at 12.5 degrees below the X-axis. Add one more vector of 21 pounds force at 45 degrees above the XY-plane. Measure the magnitude and direction of the Resultant. Save the drawing as Adding 3D Vectors.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.

After completing this chapter, do the addition 3D vector problems in Appendix A and then continue to the Equilibrium Section: Free Body Diagrams in chapter 5.