

# **EXHIBIT 1067**

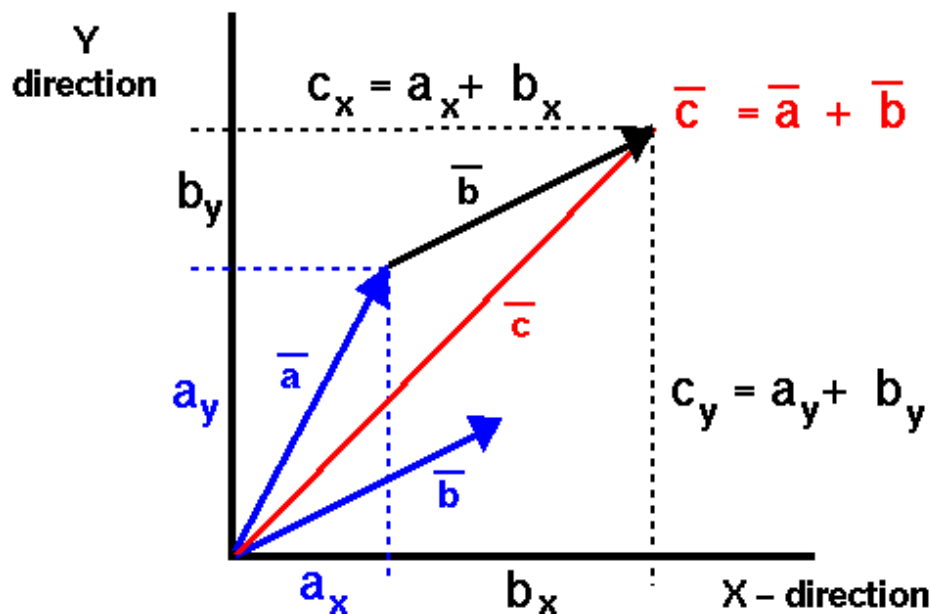


# Vector Addition

 Glenn  
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A **vector quantity** has both **magnitude** and **direction**.

Add the vector components.



Math and science were invented by humans to describe and understand the world around us. We observe that there are some quantities and processes in our world that depend on the **direction** in which they occur, and there are some quantities that do not depend on direction. Mathematicians and scientists call a quantity which depends on direction a **vector quantity**. A quantity which does not depend on direction is called a **scalar quantity**. A **vector quantity** has two characteristics, a **magnitude** and a **direction**. When **comparing** two vector quantities of the same type, you have to compare both the magnitude and the direction.

On this slide we describe the method for adding two vectors. Vector addition is one aspect of a larger vector algebra which we are **not** going to present at this web site. Vector addition is presented here because it occurs quite often in the study of propulsion and because it demonstrates some fundamental differences between vectors and scalars.

Vectors are usually denoted on figures by an arrow. The length of the arrow indicates the magnitude and the tip of the arrow indicates the direction. The vector is labeled with an alphabetical letter with a line over the top to distinguish it from a scalar. We will denote the magnitude of the vector by the symbol  $|\mathbf{a}|$ . The direction will be measured by an angle **phi** relative to a coordinate axis **x**. The coordinate axis **y** is perpendicular to **x**. **Note:** The coordinate axes **x** and **y** are themselves vectors! They have a magnitude and a direction. You first encounter coordinates axes when you learn to graph. So, you have been using vectors for some time without even knowing it!

If we construct a dashed line from the tip of the **vector a** running parallel to the x-axis, it cuts the y-axis at a location we label **ay**. Similarly, a line from the tip of the vector parallel to the y-axis cuts the x-axis at **ax**. The quantities **ax** and **ay** are called the **components** of the vector and both are scalar quantities.

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To add two vectors, **a** and **b**, we first break each vector into its components, **ax** and **ay**, and **bx** and **by**, as shown on the figure. From the rules which govern the [equality](#) of vectors, the **blue vector b** is equal to the **black vector b** because it has equal length and equal direction. Now since the components of **vector a** and **vector b** are scalars, we can add the **x-components** to generate the **x-component** of new **vector c**:

$$cx = ax + bx$$

Similarly, we can add the **y-components**:

$$cy = ay + by$$

The new components, **cx** and **cy**, completely define the new **vector c** by specifying both the magnitude and the direction. Looking carefully at the diagram, we see that adding two vectors produces a new vector which is **not** in the direction of either of the original vectors, and whose magnitude is **not** equal to the sum of the magnitudes of the original vectors. Vector algebra is very different from scalar algebra because it must account for both magnitude and direction.

**Note:** On this slide, for simplicity, we have developed the components in only two dimensions; there are two coordinate axes. In reality, there are three spatial dimensions and three components of all forces. This is important in our derivation of the general equations of with [motion](#) for flight trajectories and for the [Navier-Stokes](#) and [Euler](#) equations which describe the forces and resulting motion of fluids in the engine. We can break very complex, three-dimensional, vector problems into only three scalar equations.

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