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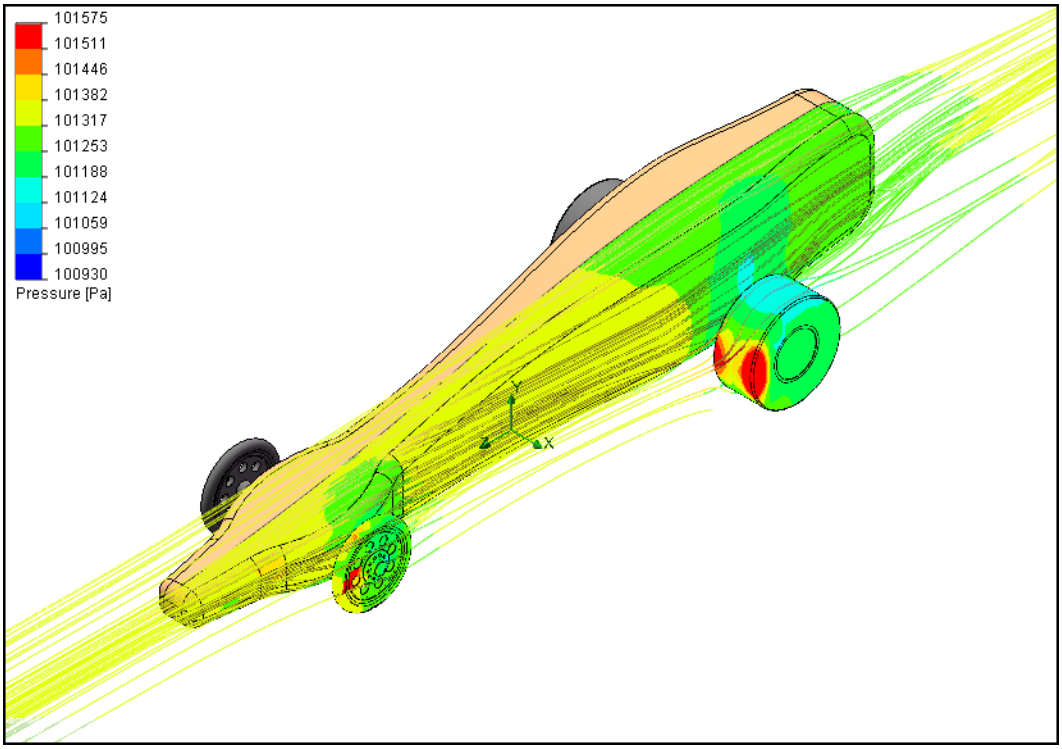
Engineering Design and Technology Series

CO_2 Car Design Project with SolidWorks® Software



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Lesson 2
Exploring and Assembling the Car

When you complete this lesson, you will be able to:

- Describe three factors important to the performance of a CO_2-powered dragster;
- Calculate the area of a solid's planar face;
- Calculate the volume of a solid, and, when given the density, calculate the mass;
- Create a new assembly;
- Insert components;
- Add mating relationships between components.

What is Important When Designing a Dragster?

Within the framework of the contest specifications, there are three factors to keep in mind when it comes to building a winning dragster. These are:

- **Friction**
  Energy used to overcome friction is energy that isn't being used to accelerate your dragster. Sources of friction include:
  - Wheels and axles: if the wheels do not spin freely, the dragster will be slow.
  - Misaligned axles: if the axle holes are not drilled perpendicular to the centerline of the dragster, the dragster will have a tendency to turn to the left or right. This will cost you speed.
  - Misaligned screw eyes: if the screw eyes are not positioned and aligned properly, the guideline can drag on them, the dragster body, or the wheels. This can slow the dragster dramatically.
  - Bumps or imperfections in the rolling surface of the wheel. The more perfectly round and smooth the wheels are, the better they will roll.
- **Mass**
  Sir Issac Newton's Second Law of Motion states that Force = mass x acceleration. There is a finite amount of thrust (or Force) produced by a CO_2 cartridge. It stands to reason that a car with less mass will accelerate quicker and travel down the track faster. Reducing the mass of your dragster is one way to build a faster car. Keep in mind that the contest specifications may stipulate a minimum mass for the vehicle.
- **Aerodynamics**
  The air exerts a resistance, or drag, as the dragster tries to move through it. To minimize drag, your car should have a smooth, streamlined shape.

Of these three factors – friction, mass, and aerodynamics – we will explore two: mass and aerodynamics, during this project.

About Balsa

Balsa trees grow naturally in the humid rain forests of Central and South America. Its natural range extends south from Guatemala, through Central America, to the north and west coast of South America as far as Bolivia. However, the small country of Ecuador on the western coast of South America, is the world's primary source of balsa for model building.

Balsa needs a warm climate with plenty of rainfall and good drainage. For that reason, the best stands of balsa usually appear on the high ground between tropical rivers. Ecuador has the ideal geography and climate for growing balsa trees.

Balsa wood imported into North America is plantation grown. Don't worry about destroying the rain forests by using balsa – it grows incredibly fast. In 6 to 10 years the tree is ready for harvesting, having reached a height of 18 to 28 meters (60 to 90 feet) and a diameter of about 115 centimeters (45 inches). If left to continue growing, the new wood on the outside layers becomes very hard and the tree begins to rot in the center. Unharvested, a balsa tree may grow to a diameter of 180 centimeters (6 feet) or more, but very little usable lumber can be obtained from a tree of this size.

Use balsa wood with a clear conscience. The rain forests aren't being destroyed when it's harvested.

Start SolidWorks and Open an Existing Part

1 **Start the SolidWorks application.**
From the **Start** menu, click **All Programs, SolidWorks, SolidWorks**.

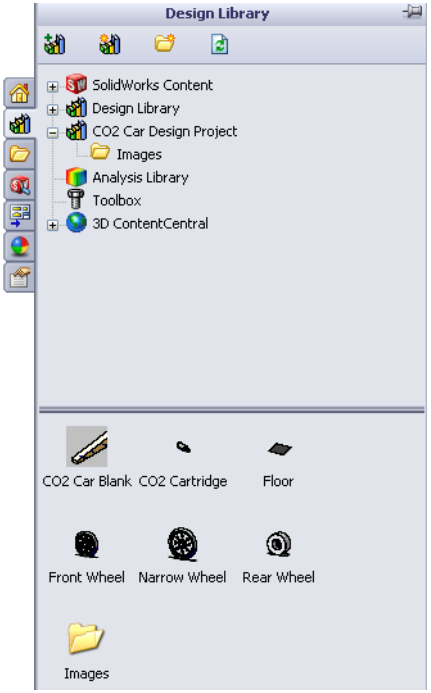
2 **Task pane.**
Click **Design Library** to open the Design Library task pane.

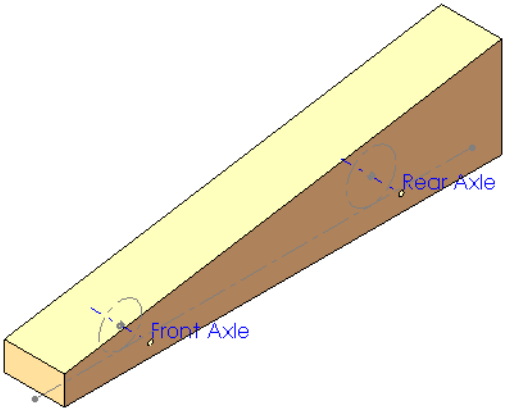
3 Open the `CO2 Car Blank`.

In the **Design Library**, click on the folder `CO2 Car Design Project`.

The contents of the folder appear in the lower portion of the **Design Library** window.

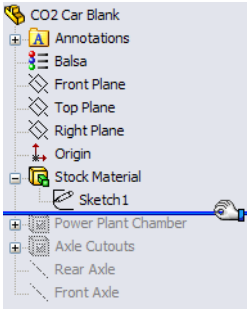
Drag and drop the part named `CO2 Car Blank` into the graphics area of the SolidWorks window.



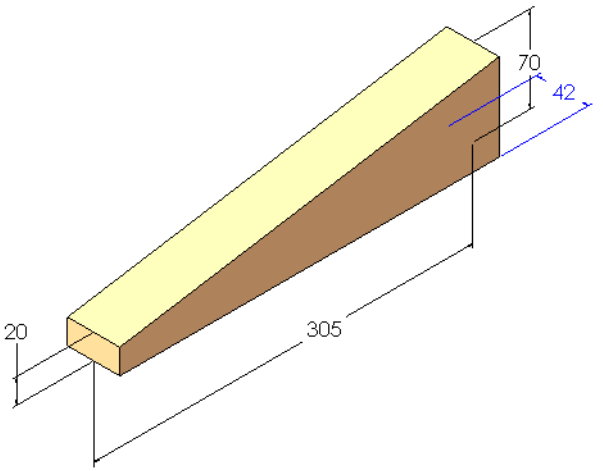


4 Rollback the FeatureManager design tree.

Drag the rollback bar upwards to a position right before (above) the `Power Plant Chamber` feature.



5 Dimensions of the blank.
Right-click the `Annotations` folder and select **Show Feature Dimensions** from the shortcut menu.



6 Turn off the dimension display.
Select **Show Feature Dimensions** again to turn off the dimension display.

Determining the Mass of the Blank

Mass is the amount of matter an object has. Calculating the mass is done by multiplying the density of the material times the volume of the object. So, to determine the mass of the car body blank, we need to know two things:

- The density of the material, in this case, balsa wood
- The volume of the blank

Density

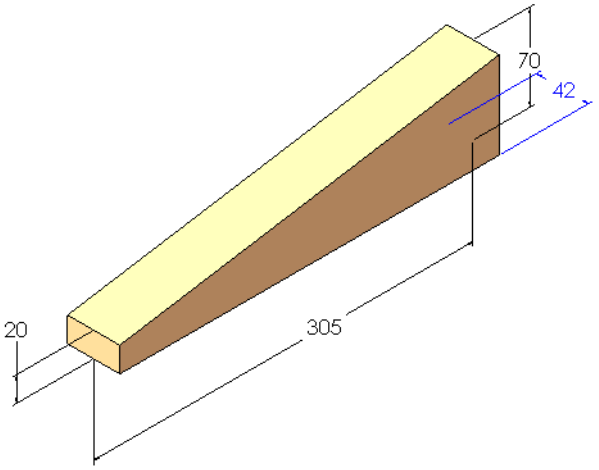
The density of balsa wood ranges from 100 kg/m^3 to 300 kg/m^3 depending on a number of factors including where the tree was grown, how old the tree was when it was cut, what part of the tree the wood was cut from, and how dry the wood is.

Typical, medium-density balsa wood is in the range of 140 kg/m^3 to 192 kg/m^3.

In this example, we use a density of 160 kg/m^3.

Calculating Volume

The car body blank is a trapezoidal prism. To calculate the volume, multiply the area of the trapezoid by the depth of the prism.

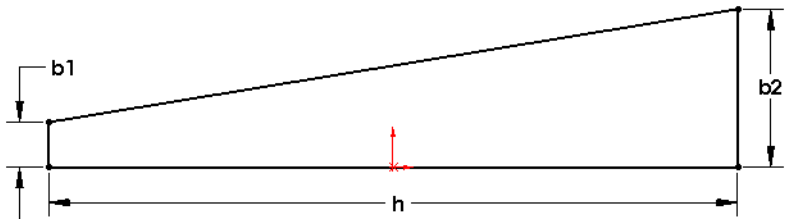


Area of a Trapezoid

A trapezoid is a quadrilateral (a 4-sided figure) with exactly one pair of parallel sides.

To determine the area of a trapezoid:

1. Add the lengths of the 2 parallel sides.
2. Divide the sum by 2 to get the average length of the parallel sides.
3. Multiply this by the distance between the parallel sides.



This can be written as: $area = h \times \left(\frac{b1 + b2}{2}\right)$

where $b1$ and $b2$ are the two parallel sides and h is the distance between them.

Substituting the dimensions of the car body blank, we get:

$$area = 305mm \times \left(\frac{20mm + 70mm}{2}\right) = 305mm \times 45mm = 13{,}725mm^2$$

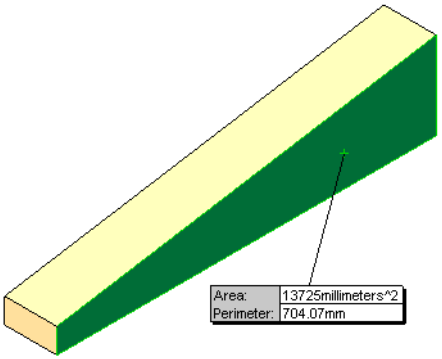
Checking Our Math

SolidWorks has tools for measuring values such as length and area as well as for calculating volume and mass.

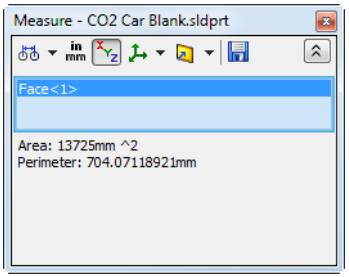
7 Measure.
Click **Tools, Measure**, or click **Measure** on the Tools toolbar.

Select the trapezoidal face of the car body blank.

The area is given as 13,725 mm^2, which matches our calculation.



8 Close the dialog box.
Right-click in the graphics area and select **Close Measure Dialog** from the shortcut menu. Or, click the "x" in the upper right corner of the dialog box.



Volume of a Trapezoidal Prism

To calculate the volume, multiply the area of the trapezoidal face, 13,725 mm^2, by the depth, 42 mm, which we saw in step **5**. Thus:

$$13{,}725mm^2 \times 42mm = 576{,}450mm^3$$

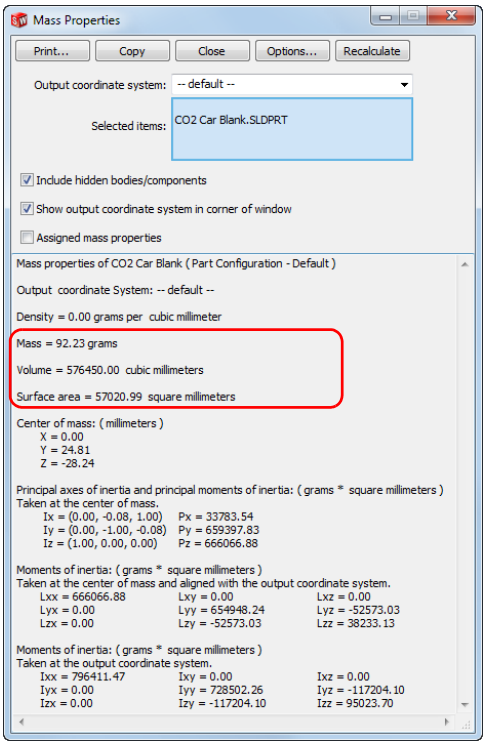
9 SolidWorks mass properties calculations.

Click **Tools, Mass Properties**, or click **Mass Properties** on the Tools toolbar.

A window appears giving all sorts of information about the part, including its volume.

Notice the volume equals 576,450 cubic millimeters. This matches our calculations.

The mass is 92.23 grams.



Why is the Density 0.00?

By default, the precision of the units in this part are set to two decimal places. That means a density of 0.00016 is displayed as 0.00. This does not effect the accuracy of the calculations, only the display of the results.

The number of decimal places in the report can be changed.

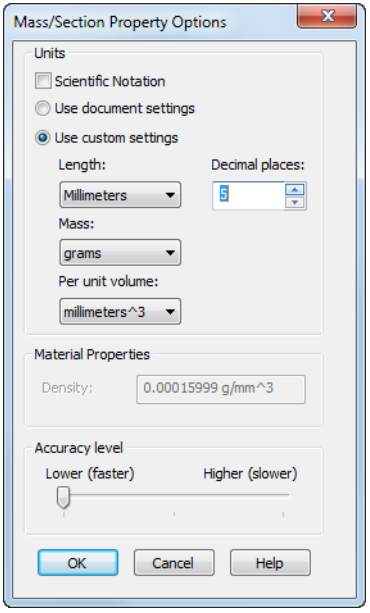
10 Options.

In the **Mass Properties** report window, click **Options**.

Click **Use custom settings**.

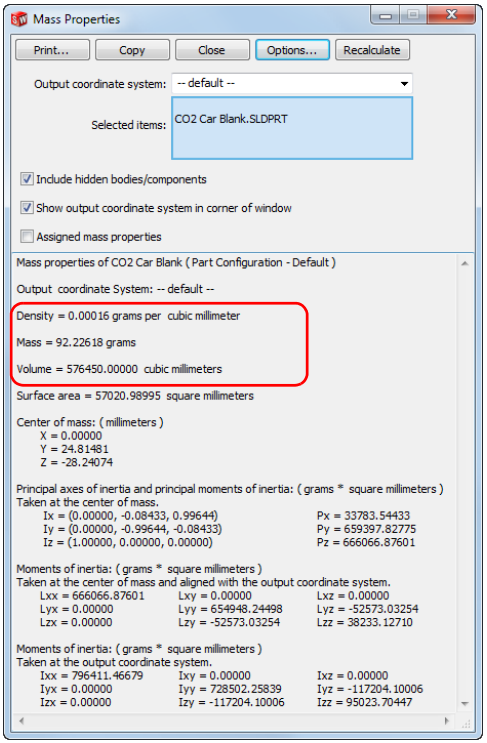
Under **Decimal places**, change the number to **5**.

Click **OK**.



11 Updated results.

The values in the report window are automatically updated to display with five decimal places.



12 Close.

Click **Close** to close the report window.

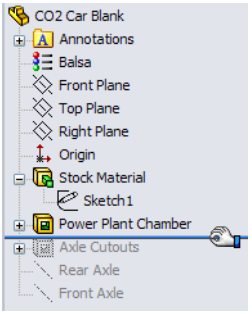
What About the Hole for the CO_2 Cartridge?

The car body blank used when writing this book has a hole predrilled for the CO_2 cartridge. To accurately determine the volume and mass of the blank, this has to taken into account. That is, the volume of the hole has to be subtracted from the volume of the blank.

Rather than deal with more complicated mathematics, we will use SolidWorks to do the calculation.

13 Roll forward.

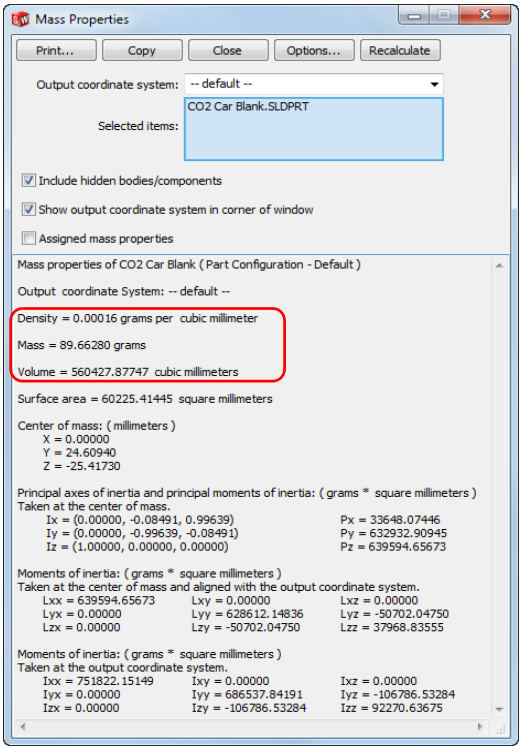
Drag the rollback bar downward to the position right below the feature named `Power Plant Chamber`.



14 Repeat the mass property calculations.

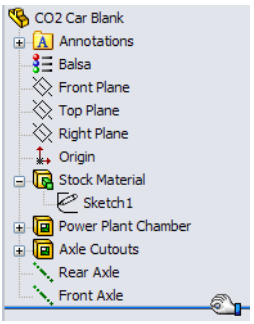
Click **Tools, Mass Properties**, or click **Mass Properties** on the Tools toolbar.

The report window now indicates a mass of 89.66280 grams and a volume of 560,427.87747 cubic millimeters.



15 Roll forward.

Drag the rollback bar downward to the bottom of the FeatureManager design tree.



More to Explore

What is the density of *your* balsa wood blank? To find out, follow this procedure:

1. Using a scale that is accurate to ±0.1 grams, measure the mass of your car body blank. Write the value here:_____
2. Divide the mass by the volume of 560,427.88 cubic millimeters that we obtained in step **14**. Remember: $Density = \frac{Mass}{Volume}$
3. Write the value here:_____

Converting Units

A quantity is made of two parts: the *magnitude* and the *units*. For example, if you measure the length of something to be 42 mm long, then the magnitude is *42* and the unit is *mm*.

The same quantity can be expressed in different ways. For example, the same length can be stated as 42 mm or 1.65 inches. The magnitude and units change but the quantity, that is the length, is the same. Quantities that represent the same thing are said to be *equivalent*. This is typically indicated by the = sign.

The key to converting units is to understand that you are not changing the quantity – only changing the way it is expressed. If you had 10 pennies and you gave them to someone in exchange for a dime, you would still have the same amount of money. Just because you went from having 10 things called pennies to having one thing called a dime doesn't mean you have less money. You just have fewer coins.

Let's look at the math: $10\ pennies = 1\ dime$

Note: We use the = sign because the quantities are equivalent.

Divide both sides of the equation by 1 dime: $\frac{10\ pennies}{1\ dime} = \frac{1\ dime}{1\ dime} = 1$

By this process we have progressed from an equivalent, $10\ pennies = 1\ dime$, to a conversion factor, $\frac{10\ pennies}{1\ dime} = 1$

Tip: The best way to write a conversion factor is to have the number 1 on one side of the equals sign.

This demonstrates that the conversion factor between pennies and dimes is just a specialized way of expressing the number 1.

This leads to two important realizations:

- The key to converting units is to multiply by the right form of the number 1.
- When you multiply something by 1 you do not change its value.

Another Example

Suppose we want to convert 60 miles/hour to feet/second. First list the equivalents that you know (or can look up):

- 1 mile = 5,280 feet;
- 1 hour = 60 minutes;
- 1 minute = 60 seconds.

Tip: Remember that any of these can be written in reverse order. For example, 5,280 feet = 1 mile.

Now write them as conversions factors, fractions that equal 1. These are the specialized forms of the number 1 that we can use.

- $\frac{5{,}280\ feet}{1\ mile} = 1$
- $\frac{1\ hour}{60\ minutes} = 1$
- $\frac{1\ minute}{60\ seconds} = 1$

Now write the equation where we multiply by various specialized forms of the number 1.

$$\frac{60\ miles}{1\ hour} \times \frac{1\ hour}{60\ minutes} \times \frac{1\ minute}{60\ seconds} \times \frac{5{,}280\ feet}{1\ mile}$$

Tip: Write the conversion factors so the units cancel out. Since we started with miles per hour, hours is in the denominator. That means the next conversion factor should have hours in the numerator. This in turn determines the arrangement of the next conversion factor, and so on.

Cancel out the units and two of the 60 values:

$$\frac{60\ \cancel{miles}}{\cancel{1\ hour}} \times \frac{\cancel{1\ hour}}{\cancel{60\ minutes}} \times \frac{\cancel{1\ minute}}{60\ seconds} \times \frac{5{,}280\ feet}{\cancel{1\ mile}}$$

This leaves us with feet per second, which is what we want:

$$\frac{5{,}280\ feet}{60\ seconds} = 88\ feet\ per\ second$$

So How Does This Apply to Density?

Convert the density you calculated for *your* balsa wood blank from g/mm^3 to kg/m^3. You will need to use some or all of these conversion factors:

- 1 kilogram = 1,000 grams;
- 1 meter = 1,000 millimeters;
- 1 cubic millimeter = 1 millimeter x 1 millimeter x 1 millimeter;
- 1 cubic meter = 1 meter x 1 meter x 1 meter;
- 1 cubic meter = 1,000 millimeters x 1,000 millimeters x 1,000 millimeters;

For illustration purposes, we will use the density 0.00016 grams/mm^3 that we obtained in step **11** on page 15.

Write the equation where we multiply by various specialized forms of the number 1.

$$\frac{0.00016\ grams}{mm^3} \times \frac{1\ kg}{1{,}000\ grams} \times \frac{1{,}000^3\ mm^3}{m^3}$$

Cancel out the units: $\frac{0.00016\ \cancel{grams}}{\cancel{mm^3}} \times \frac{1\ kg}{1{,}000\ \cancel{grams}} \times \frac{1{,}000^3\ \cancel{mm^3}}{m^3}$

This leaves us with: $\frac{0.00016\ kg \times 1{,}000^3}{1{,}000\ m^3}$

Dividing out 1,000 from the numerator and denominator give us:

$\frac{0.00016\ kg \times 1{,}000^2}{m^3}$ which is $\frac{160\ kg}{m^3}$

You Do It

Take the density you calculated for your balsa wood blank (see page 17) and using the procedure above, convert it from grams/mm^3 to kilograms/m^3.

Write your answer here:_____

Summary

- When you multiply something by 1 you do not change its value.
- Conversion factors are equivalents, written as fractions that equal 1.
- The key to converting units is to multiply by the right form of the number 1.
- Sometimes you have to multiply by several different forms of the number 1.

Creating an Assembly

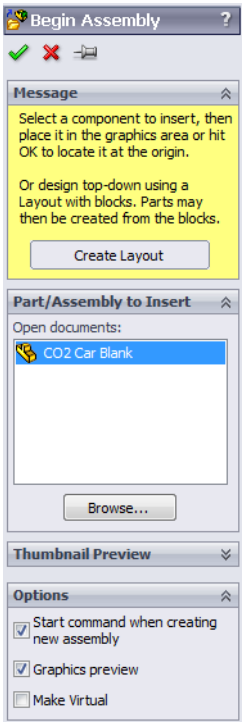
1 Create an assembly.
Click **Make Assembly from Part/Assembly** on the Standard toolbar.

2 Insert component.
The **Insert Component** PropertyManager automatically appears.

The `CO2 Car Blank` part file is listed in the **Open documents** list.

Be sure the **Graphics preview** option is selected.

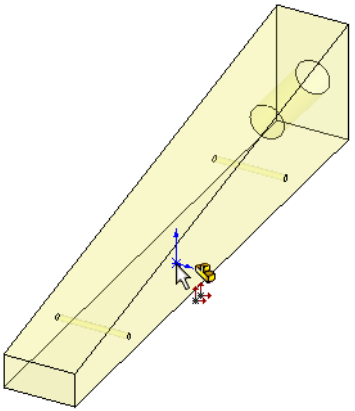
Select the `CO2 Car Blank.sldprt` part file.



3 Show origin.
Click **View, Origins** to turn on the display of the origins.

4 Locate component.
Move the cursor onto the origin and place the component at the origin by placing the cursor over the origin symbol. The double arrow symbol appears when the cursor is snapping to the origin.

The part will appear in the assembly FeatureManager design tree as `Fixed(f)`.



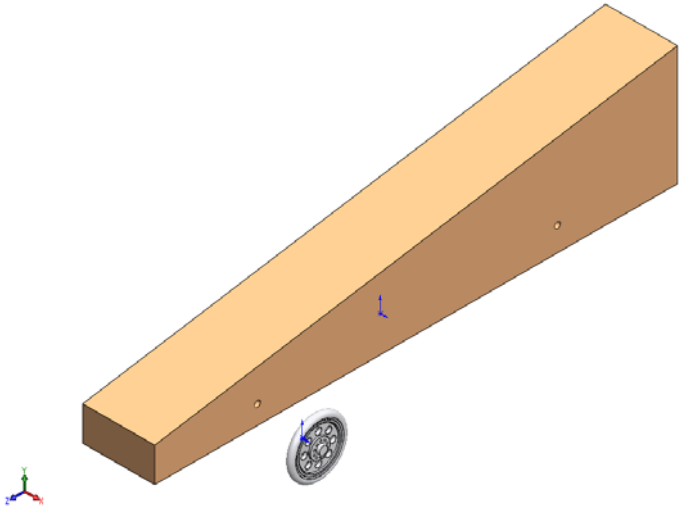
Note: The initial component added to the assembly is **Fixed** by default. Once you have inserted a fixed component into position in an assembly it cannot be moved unless you float it.

5 Isometric view.
Click **Isometric** on the Standard Views toolbar.

6 Save the assembly.
Save the assembly under the name `CO2 Car Baseline` in the `CO2 Car Project` folder.

7 Add the front wheels.

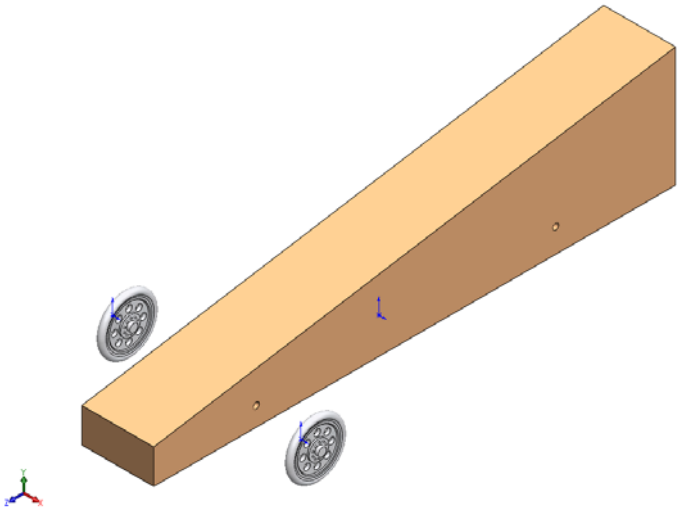
Drag and drop the `Front Wheel` from the Design Library window into the assembly window.



Do not click **OK** yet. Continue with the next step.

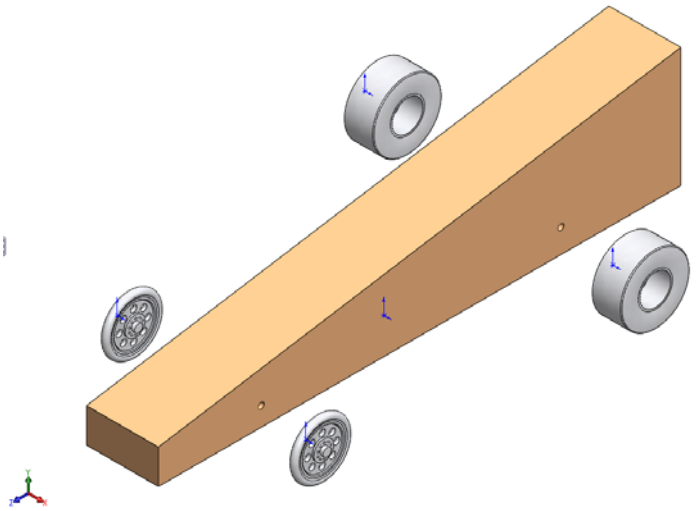
8 Add another front wheel.

Click in the graphics area to add a second wheel.



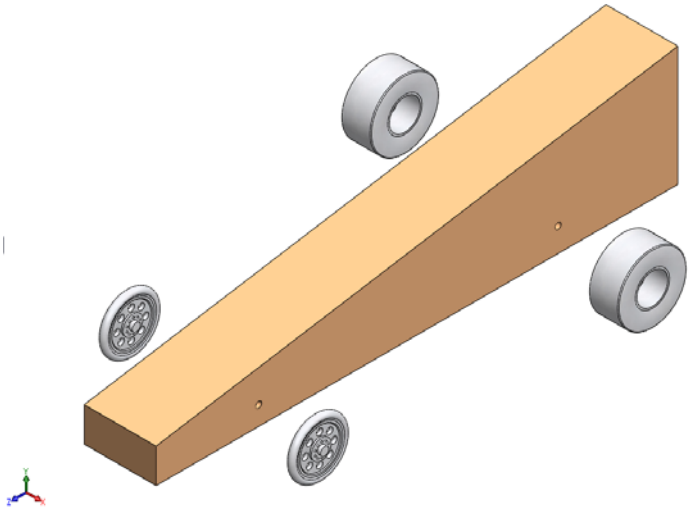
9 Add the rear wheels.

Drag and drop two copies of the `Rear Wheel` from the Design Library window into the assembly window.



10 Turn off the origins.

Click **View**, **Origins** to toggle off the display of the origins.



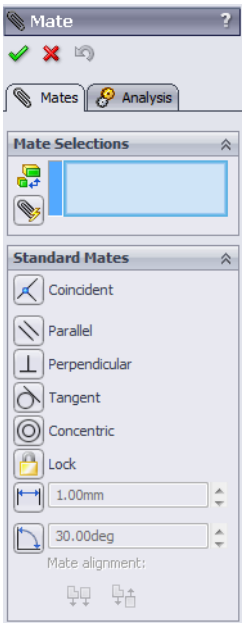
Insert Mate

An assembly is a document in which two or more parts and other assemblies (sub-assemblies) are mated together. Parts and sub-assemblies are called *components* in an assembly. Mates are used to create relationships between components. Faces are the most commonly used geometry in mates. In this case the existing sub-assemblies are mated to build an assembly based on the car part you created.

There are three types of mates, the **Standard Mates**, the **Advanced Mates** and the **Mechanical Mates**.

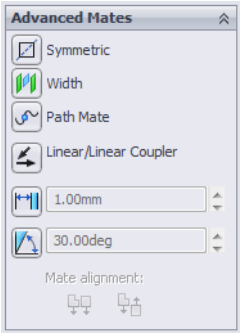
Standard Mates

- Coincident
- Parallel
- Perpendicular
- Tangent
- Concentric
- Distance
- Angle

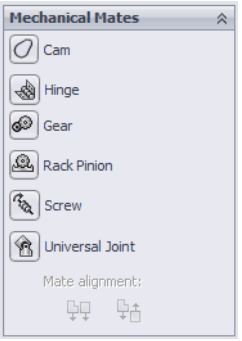


Advanced Mates

- Symmetric
- Width
- Path Mate
- Linear/Linear Coupler
- Distance/Angle Limit



Mechanical Mates



- Cam
- Hinge
- Gear
- Rack Pinion
- Screw
- Universal Joint

You can select many different types of geometry to create a mate:

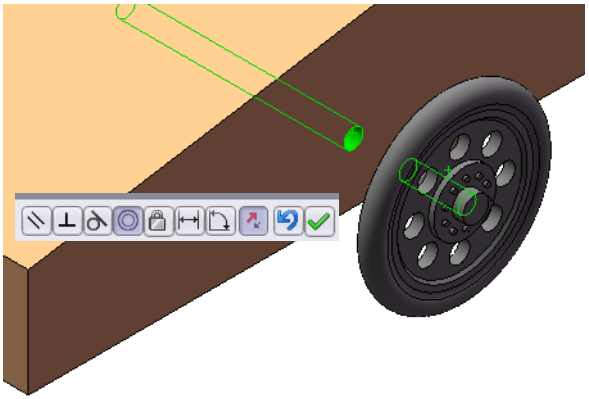
- Faces
- Planes
- Edges
- Vertices
- Sketch lines and points
- Axes and Origins

11 Mate one of the front wheels to the body of the car.

Click **Insert**, **Mate…**, or click the **Mate** tool on the Assembly toolbar.

12 Selections and preview.

Select the cylindrical faces of the axle hole in the body and the hole in the wheel as indicated.



Tip: Zoom and/or rotate the view to make it easier to select the faces you want to mate.

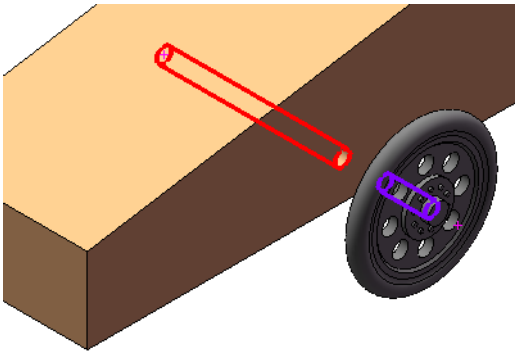
The Mate pop-up toolbar appears to make selections easier by displaying the available mate types right in the graphics area. The mate types that are available vary by geometry selection and are the same as those that appear in the PropertyManager. Either the on-screen toolbar or PropertyManager can be used.

Concentric is selected as the default and the results of the mate are previewed.

Click **Add/Finish Mate** to accept the **Concentric** mate.

Tip: When the mate is previewed, the mouse pointer changes to look like this: . Clicking the right mouse button enters **OK** and applies the mate.

Planning Ahead



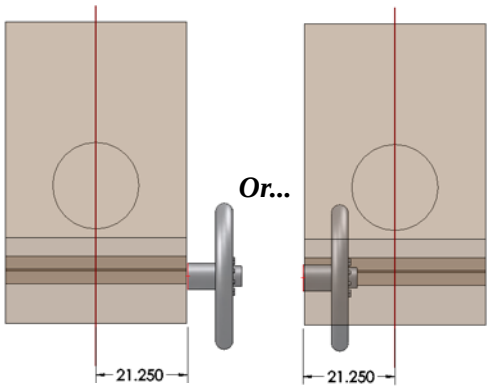
Now that we have the wheel mated so it is concentric with the axle hole, we have to control its position along the axis of the hole. In other words, how far out from the centerline of the car body is the wheel?

At first thought it might make sense to add a **Coincident** mate between the side of the car body and the inner face of the hub of the wheel.

However, this is not the best strategy. A **Coincident** mate requires two planes, either faces or reference planes. If we modify the shape of the car body so that the side is no longer planar, then the **Coincident** mate will fail.

A better approach is to plan ahead and use a type of mate that will define the location of the wheel regardless of what happens to the shape of the car body. The best mate to use in this situation is a **Distance** mate.

Distance Mates



Distance mates are a bit more complicated than some other types of mates. The reason for this is when you specify a distance between two objects, there are two solutions.

The illustrations at the right show a front view of the car body and wheel.

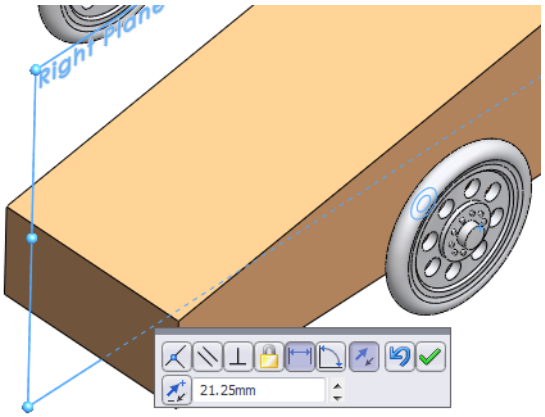
In the leftmost picture, the wheel is positioned 21.25mm to the *right* of the `Right` reference plane.

In the rightmost picture, the wheel is positioned 21.25mm to the *left* of the `Right` reference plane.

Both solutions are technically correct. However, only one is the solution we want.

When you add a **Distance** mate, pay attention to the preview in the graphics window. If the previewed solution is not the one you want, click **Flip Dimension** on the Mate pop-up toolbar.

13 Add a Distance mate.



The **Mate** PropertyManager stays active so you can continue adding mates without having to restart the command.

In the FeatureManager design tree, expand the features of the `CO2 Car Blank` and select the `Right` reference plane.

Next select the planar face on the hub of the wheel.

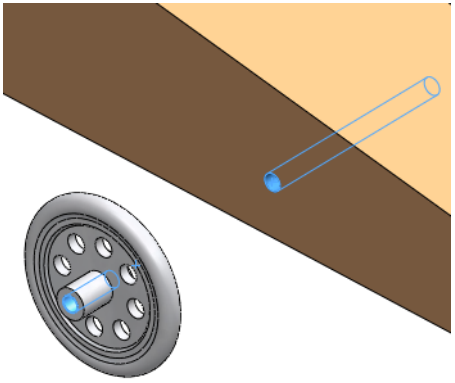
The system assumes you want a **Coincident** mate, which unfortunately is not what we want.

Click **Distance** on the Mate pop-up toolbar and enter a distance value of **21.25 mm**.

Look at the preview to make sure the solution is correct.

Click **Add/Finish Mate** to accept the mate.

14 Mate the other front wheel.



Select the cylindrical faces of the axle hoes in the body and wheel like you did in step **12**.

The system assumes you want a **Concentric** mate, which in this case is correct.

However, the wheel is oriented the wrong way. This is because **Concentric** mates also have two solutions. By default, the system gives you the solution closest to the way the parts are already oriented. There are two ways to address this problem:

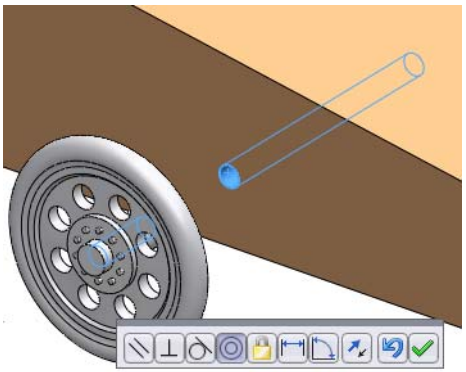
1. Click **Flip Mate Alignment** on the Mate pop-up toolbar.
2. Or, rotate the wheel around so it is more or less in the correct orientation *before* you add the mate.

15 Flip mate alignment.

Since we have already started adding the **Concentric** mate, click **Flip Mate Alignment** on the Mate pop-up toolbar.

The wheel rotates so it is aligned correctly.

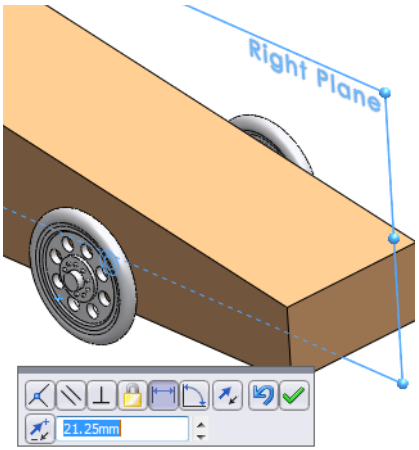
Click **Add/Finish Mate** to accept the mate.



16 Add a Distance mate.

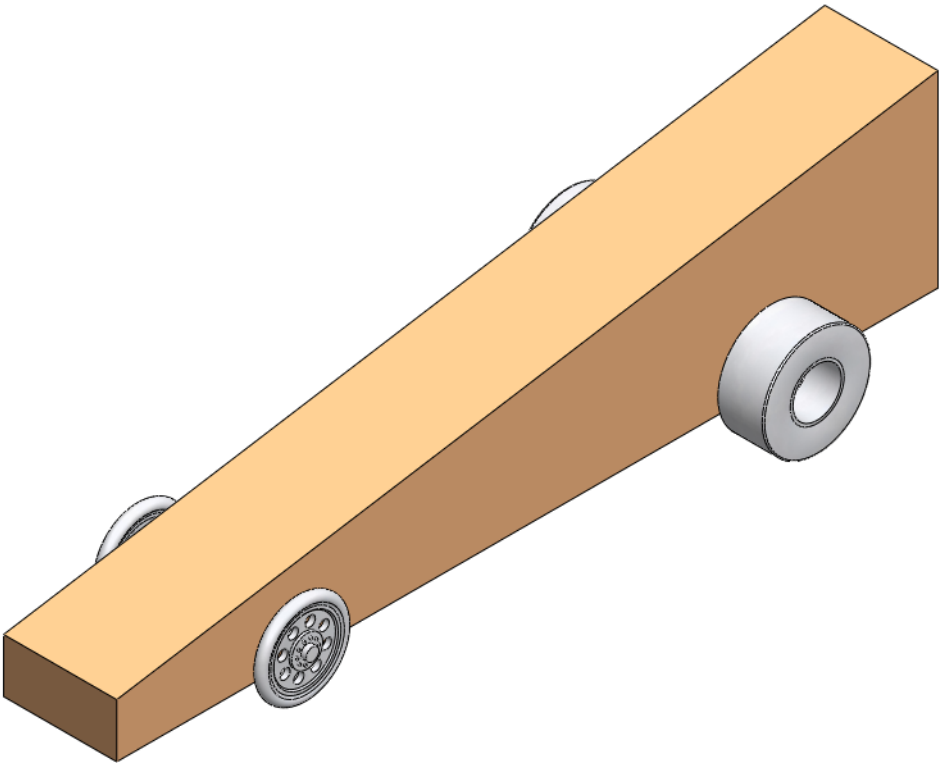
Following the same procedure as in step **13**, mate the wheel to the `Right` reference plane of the car body using a **Distance** mate.

Because this wheel is located on the opposite side of the reference plane you should pay particular attention to the graphic preview. You may have to click **Flip Dimension** on the Mate pop-up toolbar to get the correct result.



17 Mate the rear wheels.

Repeat step **12** through step **16** mating the rear wheels to the body of the car using **Concentric** and **Distance** mates.



18 Mass calculation.

Now that we have added the wheels to the assembly, what is the total mass?

Click **Tools, Mass Properties**, or click **Mass Properties** on the Tools toolbar.

The total mass is 107.29 grams.

Is this correct?

Not really. This assembly doesn't contain any axles. We could increase the accuracy by modeling the steel axles and adding them to the assembly, but that is beyond the scope of this lesson. The point is, the accuracy of the calculations is no better than the accuracy of the models we create.

19 Save the file.

Turn off the **RealView Graphics** tool, if the RealView Graphics mode is on.

Save the assembly file.