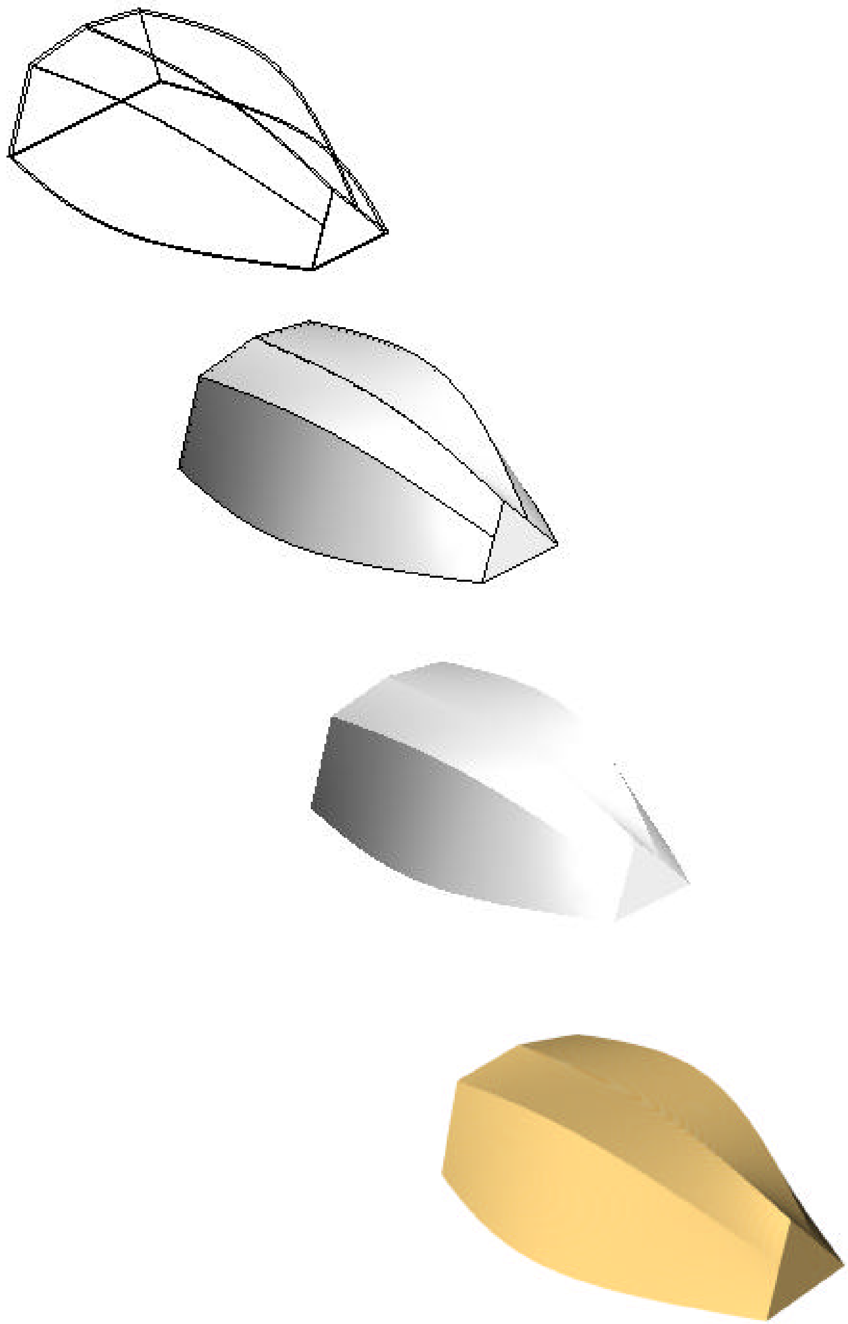
Boat Hull

Pro/DESKTOP® Tutorial

Advanced Level – Boat



Written by Tim Brotherhood

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Acknowledgements

John Hutchinson - The College of New Jersey

Feedback

In order to ensure these materials are of the highest quality, users are asked to report errors to PTC at schools@ptc.com.

Suggestions for improvements and other activities would also be very welcome.

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FILES FOR BOAT UNIT

The following files will be needed in order to successfully complete the project:

File Name

Dinghy.des

Bottle.des

Floating.des

Dinghy Hull.des

Educational Objectives of the Unit

To learn how to create shapes with complex curved surfaces using the loft feature and control the form of models using variables and design rules.

Performance Indicators

Students will be able to:

- Develop awareness and capability creating and editing lofted features.
- Create and edit offset and angled workplanes.
- Create constraints and edit variables to alter the form of a design.
- Use the *solver* to achieve a specific volume or other parameter.
- Create and edit design rules to control a design.
- Consider a range of uses for the loft feature.
- Use the album to represent materials including water.

Prior knowledge required

- Understanding of workplanes and sketches.
- Competence in creating and editing design constraints.
- Capability to create and edit sketches to form valid profiles.

Outcomes

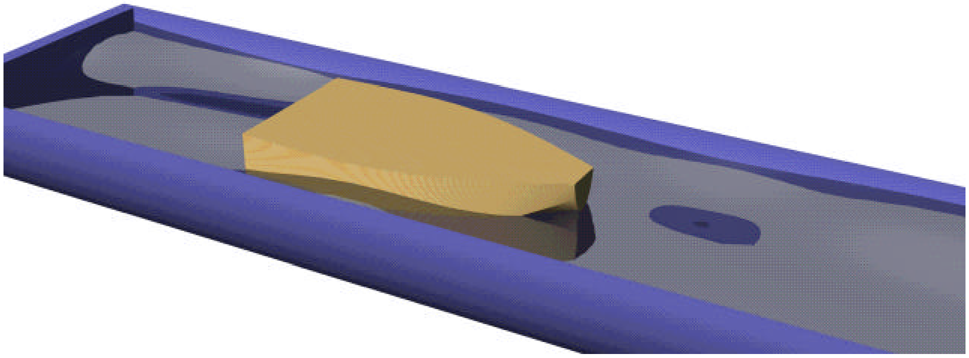
A boat hull will be created using the loft feature.

Variables will be edited to alter the size and shape of the hull.

Design rules will be used to identify the water line (and floating attitude) of the boat.

The hull will be assembled into a water tank and rendered in the album.

Design Considerations – Testing



Key considerations for the shape of a hull include resistance to movement, displacement, freeboard and stability.

Designs produced in Pro/DESKTOP can be machined and pulled along a test tank or piece of guttering to see how efficient they are.

Fair test?

You must make sure the towing force is consistent when testing alternative designs. How could you ensure this?

Sketching

Lofting is an advanced feature of Pro/DESKTOP and relies on 2 or more profile sketches. Each sketch must form a valid profile.

Recap valid profiles

A valid profile is a closed loop of lines. There must not be any gaps in the loop of lines or any overlapping lines. A useful analogy is to describe the line as an elastic band. It can only follow one path around the sketch and cannot have any breaks.

Note: While profiles for extrude and revolve features can have inner loops (nested shapes) that define holes in the object, loft sketches will not work with inner loops.

Lofting

Background to lofting

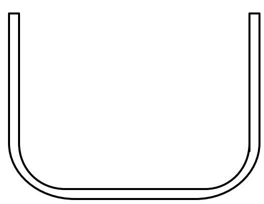
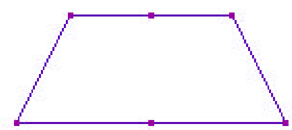
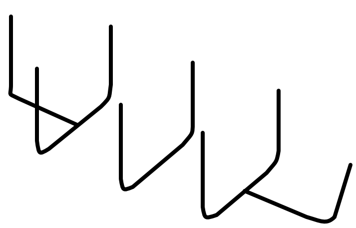
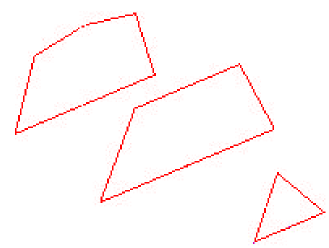
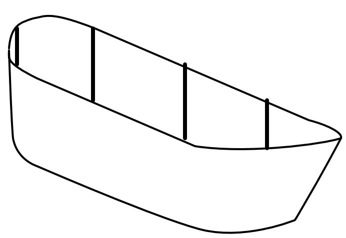
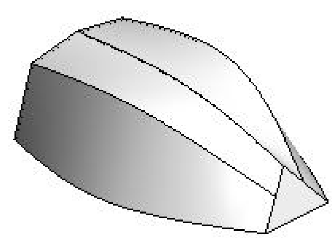
Many ships are constructed from vertical frames or bulkheads at regular intervals along the vessel with an outer skin fixed to these frames. **Lofting** is a nautical term that describes this process of using a number of cross-sections to construct the shape of the boat hull.

Accurate templates are needed to mark out the shape of each bulkhead and these can be very big. In order to mark out and cut the templates, a room with a large clear floor space is required. The room that most often fits these criteria is the roof space or loft. Lower floors have pillars to support the weight of the floor and machinery above.

Over hundreds of years the process of drawing the gentle curving shapes and templates for a new ship has become known as 'lofting'.

Principles of lofting

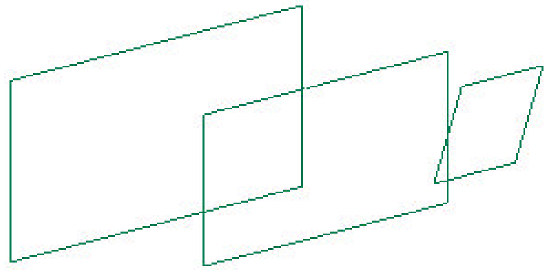
A simple way to explain the loft command refers to the way many modern ships and boats are constructed.

Ship illustration	Description	Pro/DESKTOP
	A series of frames are cut to the cross sectional shape of the hull at a number of positions along the length of the boat.	
	Frames are spaced apart at the correct distances.	
	Sheet material is fixed to the outside of the frames to create a skin.	

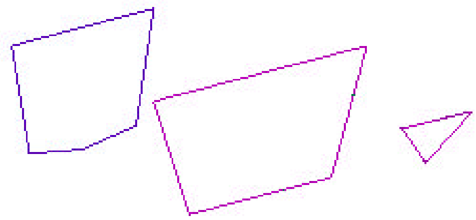
Note: The Loft feature in Pro/DESKTOP creates a solid. The shell command can then be used to hollow the solid hull shape.

Outline of the task

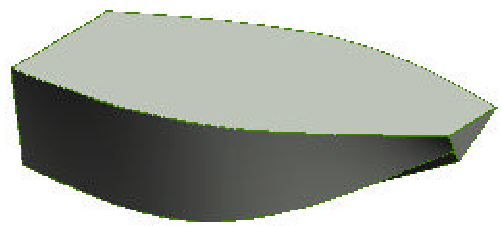
Three workplanes will be used. All three are offset, but the third workplane is also angled.



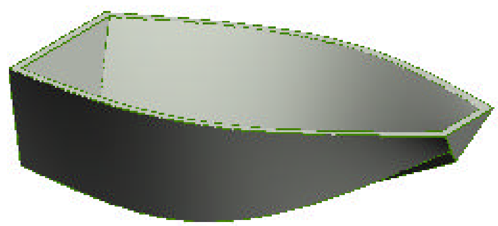
Profile sketches are drawn on each workplane.



The sketches are used to create the lofted solid.



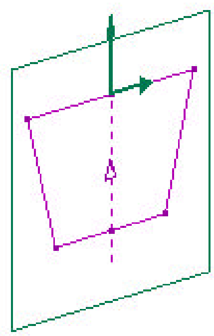
The solid shape is then hollowed to produce a recognizable hull for a small dinghy.



A design has been started for you.

Open the file called **Dinghy.des**

The design contains one workplane called Central with a sketch named Center. This has a profile for the middle of the dinghy.

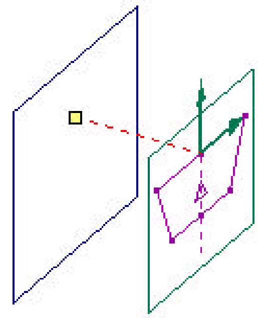


Offset Workplane

An offset workplane will now be created for the stern of the hull.

Open the Workplane pull-down menu and select **New Workplane**.

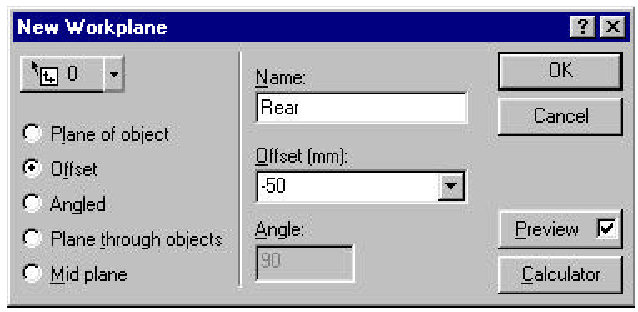
Drag the yellow handle until the new workplane is a distance of -50 mm behind the existing one.



Make sure the **Offset** distance reads -50.

Change the workplane name to **Rear**

Click 



A new workplane created in this way does not contain a sketch.

Creating a sketch

In the Workplane browser, right click over the **Central** workplane.

Select **New sketch** from the floating menu.

Name the sketch **Transom.**

Click on .

Sketching a profile

The Transom sketch should be active.

When drawing the transom sketch it will be easier to hide the center sketch.

Hiding sketches

Open the Workplane pull-down menu.

Select **Hide Other Sketches**

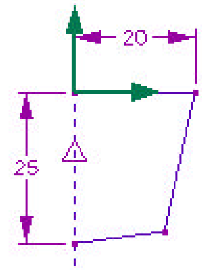
You will now have a clear screen ready to draw the transom sketch.

Drawing the transom

Draw the sketch shown here to form the right half of the transom sketch.

You don't need to add the constraints.

Note: The vertical construction line is fixed.

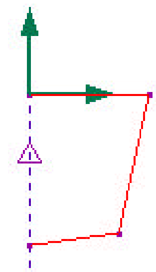


Click on the  tool.

Select the three profile lines of the hull (shown in red).

Open the **Line** pull-down menu

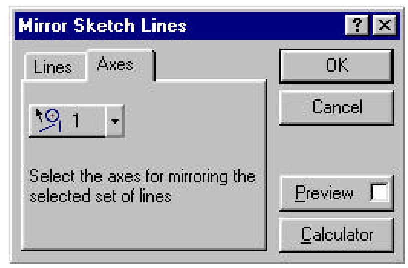
Click on the **Mirror...** tool.



This dialogue window opens.

Click on the **Axes** tab.

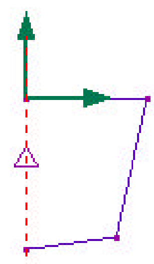
Leave the mirror dialogue window open. Next you will select the mirror axis.



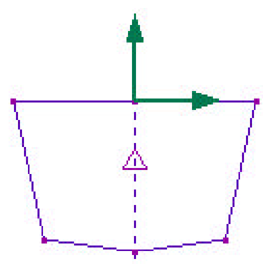
Click on the center (construction) line to select it as the mirror axis.

Click on 

to close the mirror dialogue window.



The Trasom sketch is now complete



You may want to make other sketches visible again.

Making sketches visible

Open the Workplane pull-down menu

Select **Show All Sketches**

The next part of this tutorial shows you how to create an angled workplane ready for the bow sketch.

Angled workplane

This is a three-stage process. An offset workplane is created 50mm in front of the Central workplane. A horizontal line is drawn to form the 'hinge' for creating another angled workplane.

In the Workplane browser double click on the **Center** sketch to make it active.

Open the Workplane pull-down menu.

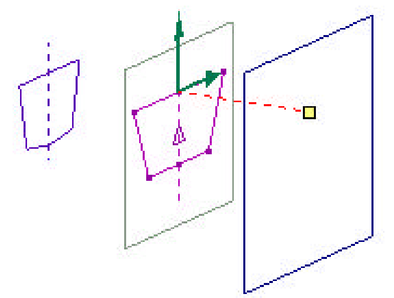
Select New workplane.

In the dialogue window select the **Offset** option

Use the Drag handle to position the new workplane **50mm** in front of the **Central** workplane.

Name the workplane **Vertical bow**.

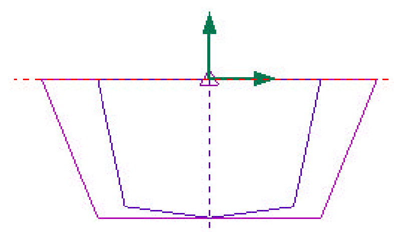
Click on OK.



Create a new sketch named **Bow line** on the **Vertical bow** workplane.

View **Onto Workplane**.

Draw a horizontal line level with the top edge of the existing sketches. (Shown here as a fixed construction line in red)



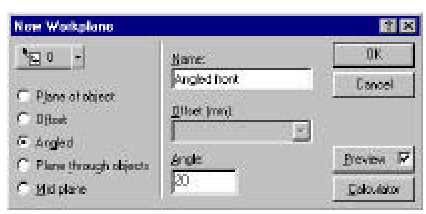
View **Trimetric**.

Open the **Workplane** pull-down menu.

Select **New Workplane...**

Click on the **Angled** option.

Type in 20 degrees for the **Angle**:



Change the name of the Workplane to **Angled front**.

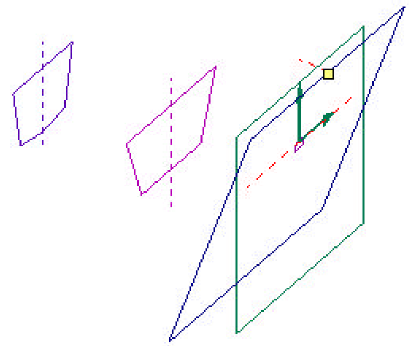
Open the 0 Pick list.

Select **Lines**.

Click on the horizontal hinge line you drew on the **Bow line** sketch.

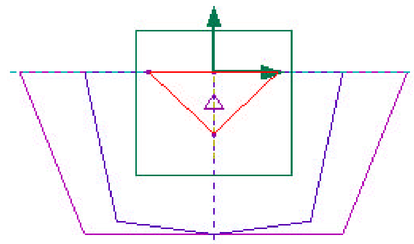
The new angled workplane will be shown on screen like this.

Click on OK to close the New workplane dialogue window.



View **Onto Workplane**

Create this shape for the bow sketch using the same mirror method used for the transom sketch.



You now have the three sketches needed to create the hull loft.

Starting a loft

Open the **Feature** pull-down menu.

Select **Loft Through Profiles**

The Loft Profiles dialogue window will open.

The Bow profile was the current sketch and if any of the lines in the sketch were highlighted the Bow sketch should already be in the list of **Profiles**:

If none of the sketch lines were selected the list of sketches will be empty.

Note: The Loft profiles dialogue window must be left open for the next few steps. Do not close it until instructed to do so.

Adding sketches

With the Loft profiles dialogue window still open on screen.

If the bow sketch is not in the list, click on one of the bow sketch lines.

The bow sketch will now appear in the list.

Click on one of the lines in the **Center** sketch.

The Center sketch is added to the list of profiles.

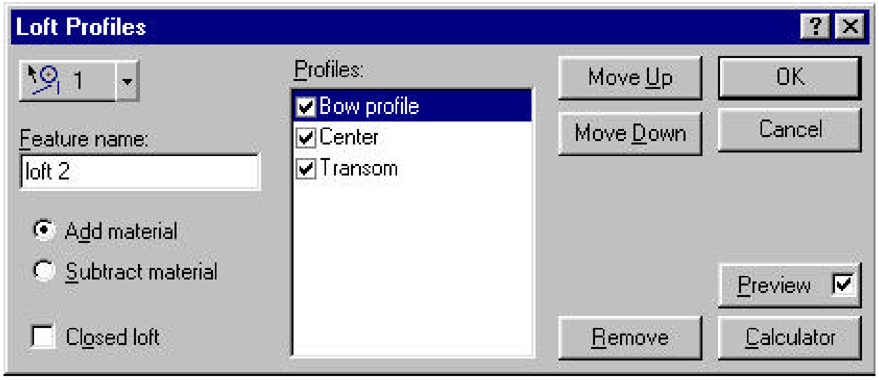
Click on a line in the **Transom** sketch.

The Transom sketch is added to the list of profiles.

The next step is to define which corner of each sketch must line up. This is called the loft line.

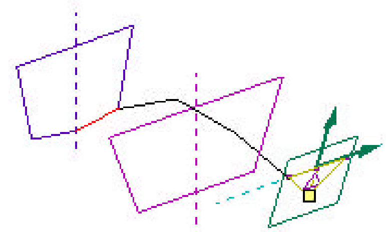
Defining loft line

One of the Profiles listed will be highlighted



The Bow profile is highlighted in the above example.

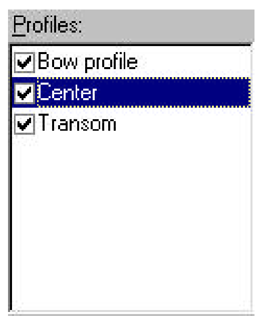
In the design window a **loft line** will appear joining a corner on each sketch and a yellow 'handle' shows where the loft line is located on the currently highlighted sketch.



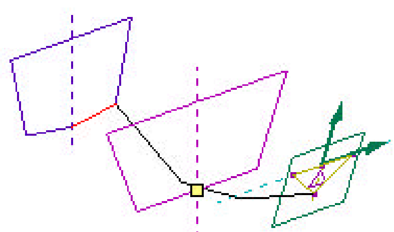
You will relocate the loft line on each sketch to the keel position.

The Loft profiles dialogue window should still be open.

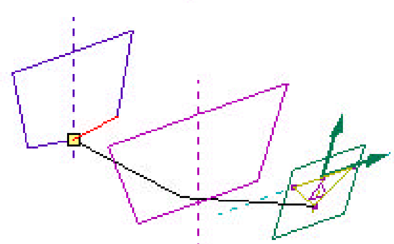
Click on **Center** in the list of profiles.



Drag the yellow handle to reposition the loft line at the keel position on the Center sketch.

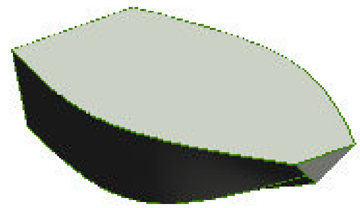


Repeat the previous two steps to position the loft line at the keel of the Transom sketch.



You are now ready to close the Loft Profiles dialogue window.

Completing the Loft



Click on OK to close the Loft Profiles dialogue window.

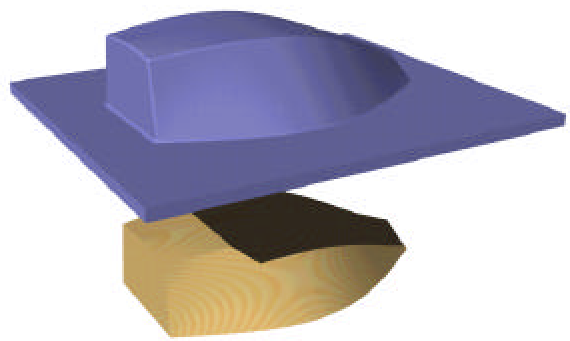
You should now see the Dinghy hull shown on the right.

Save your work.

Design Considerations – Manufacture

To make a realistic hull model in Pro/DESKTOP it will need to be shelled out.

If you intend to vacuum form the hull you can machine the shape as a solid block to create the mold or "plug" for the shell.



Shell the hull

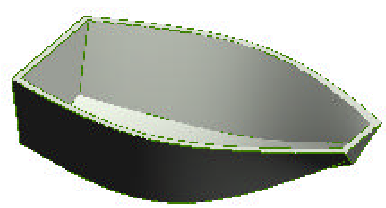
Select the **Select Faces** tool

Highlight the top face of the hull

Select the **Shell Solids** tool

Enter **2mm** for the **Offset**

Click on OK.



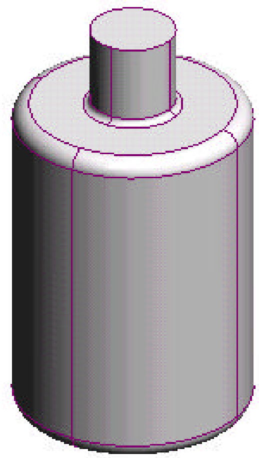
The next section uses **measurements variables** and the **Solver** in Pro/DESKTOP to show where the hull would float in water.

Later in the tutorial we return to lofting to explore a number a number of issues you need to know when creating solids with the loft tool.

This short activity shows how the solver works before tackling the more complex floating boat problem.

- Open the file **Bottle.des**. If the file is not available, create a bottle using the **revolve** feature and the following constraints: radius=1.4”, overall length=5”, radius of neck=0.5”, bottom to shoulder=4”

The water bottle has been created with the revolve feature and all key sizes have been constrained.



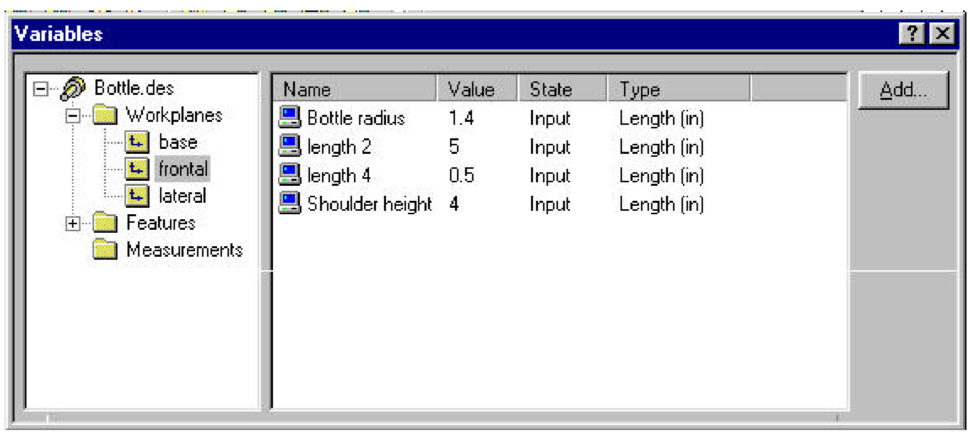
You will use the solver to change the size of the bottle so that its volume is suitable for a 16oz drink. You will need to change the units to inches.

- Open **Tools**, select **Options**.
- Click on the **Units** tab.
- Select **Inches** in both lists.
- Click on 

.

Checking variables

- Open the **Tools** pull-down menu and select variables.



- Click on **Frontal** in workplanes to show constraint variables on that workplane.

You will see the list of constraints controlling the bottle size.

- Try to open the **Measurements** folder in the **variables** window.

Notice there are no files or folders here.

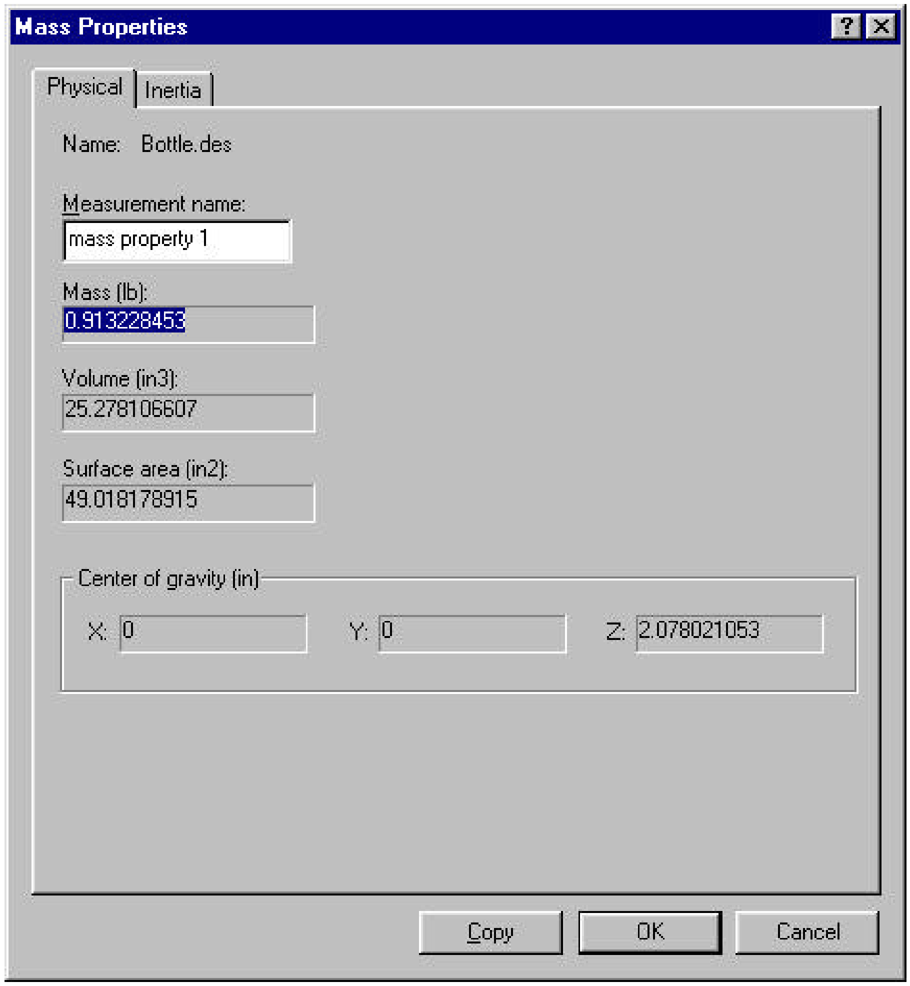
You will now interrogate Pro/DESKTOP to find out the volume of the bottle solid.

- Leave the variables window open for the next few steps.

Finding the volume

- Open the **Tools** pull-down menu.
- Select **New Measurement** then **Mass Properties.**

This dialogue window will open.



This window displays several measurements for the current solid.

If you cancel this window Pro/DESKTOP will take no action.

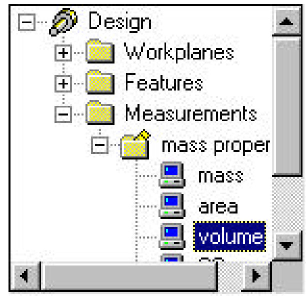
However, clicking on OK will transfer all of these measurements into the variables list.

- Click on 

.

- Now look in the variables list (should still be open) in the measurements folder.

  You will see a range of measurements that were not there before, including the volume.



This is the one you will use to re-size the bottle.

Design Considerations – Ounces to Cubic Inches

Volume

Notice the volume is expressed as in^3 (cubic inches).

Air gap

Have you noticed there is a small air gap above the liquid in a sealed bottle?

- Why do you think this is?

Here are some clues.

- Can you compress a liquid?
- Can you compress a gas?

The answer can be found before the next sub heading in inverted green text.

You will design a bottle with a capacity of 17 oz to provide room for the essential air gap.

Converting ounces to cubic inches

Pro/DESKTOP uses in^3 (cubic inches) for volume so you will need to find the equivalent of in^3 for a volume of 17 oz? The conversion is:

$$1 \text{ fl oz} = 1.805 \text{ in}^3$$

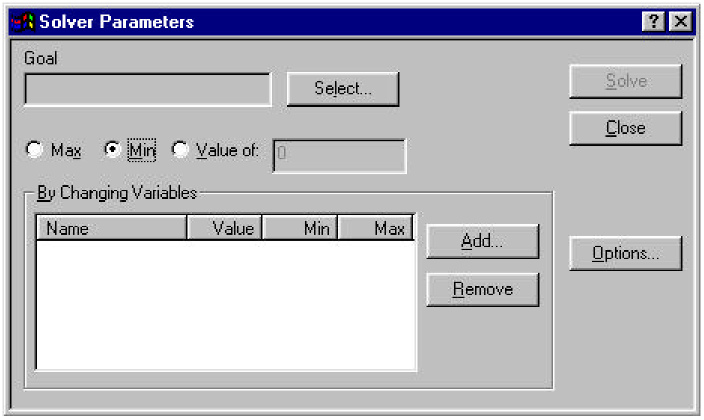
Work out on paper or using a calculator how many in^3 there are in 17oz.

Record the answer for the next section.

If the bottle was full of liquid and warmed, the liquid will expand and force the top off the bottle. The bottle might even explode!

Starting the Solver

- Open the **Tools** menu and select **Solver**.



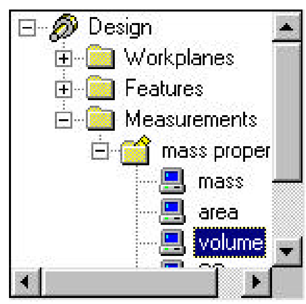
In this window you will need to identify the goal (output) variable, its value, and the variable that Pro/DESKTOP can change in order to achieve it (input).

Selecting the goal

- Click on 

.
- In the next window open the **Measurements** folder and then the **mass properties** folder.
- Select **volume** from the list
- Click on 

.



Setting the target volume

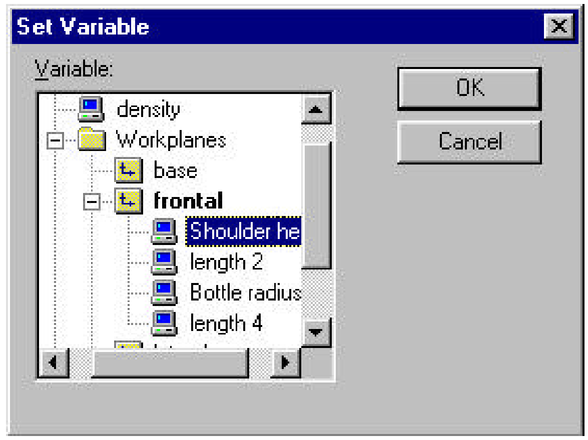
- In the **Solver Parameters** window click on the **Value of:** button and in the adjacent box type in the value for volume (in^3) that you worked out previously using a calculator.

Selecting the variable to change

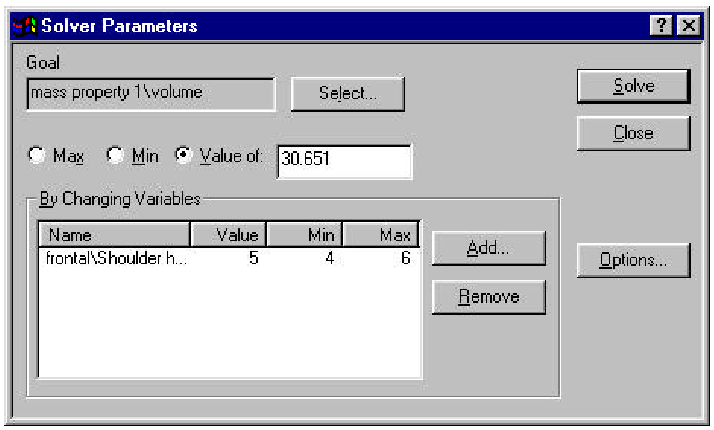
Click on the 

button.

- Open the folder for the **frontal** workplane and select the variable **Shoulder height.**
- **Click on** OK**.**



You will return to the **Solver Parameters** window



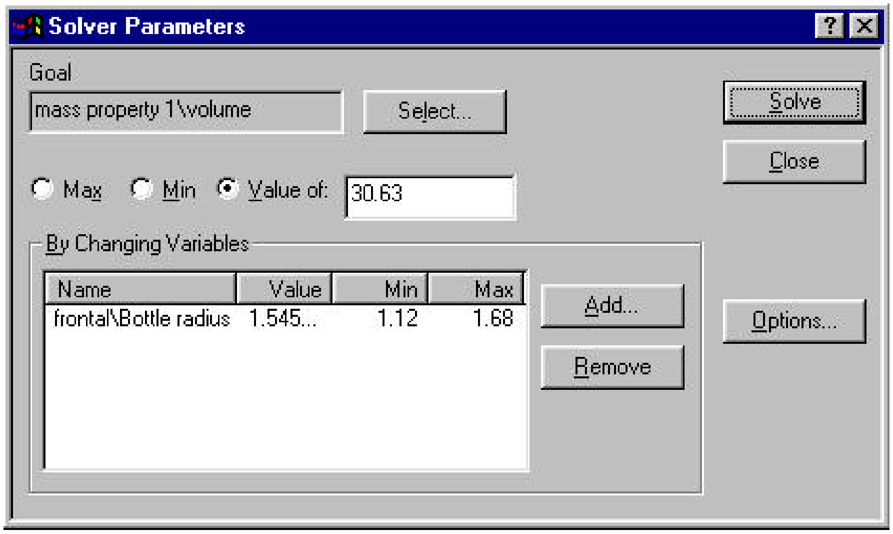
Notice Pro/DESKTOP has entered values for the current value of shoulder height (5) and a minimum and maximum change value.

You are now ready to get Pro/DESKTOP to solve the volume.

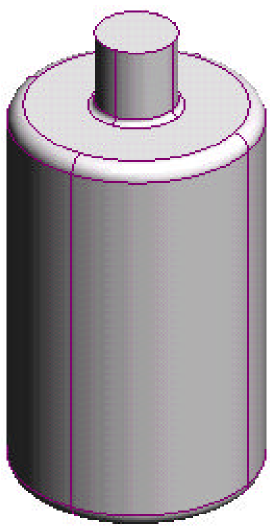
- Before you proceed, drag the solver window so that you can also see the bottle.
- Click on the Solve button.

You will see the numbers changing in the solver window. The number in the **Value of** window should gradually get closer to the goal value.

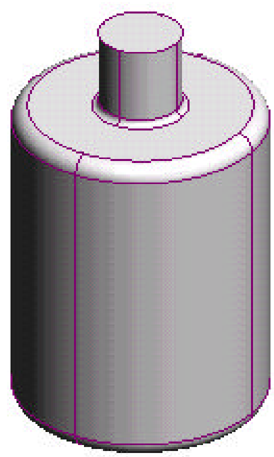
After a few seconds the numbers will stop changing.



The goal value should be almost exactly the number you typed in and the bottle should have got shorter until it's volume matches the values in the solver.



Before solving



After solving

- Close the solver.

  You now have a bottle the desired size for a 16 oz drink.

  Think how much more difficult this task would be without a computer. Could you have done it without using trial and error?

Changing just the height of the bottle may leave it squat or tall and thin. It would be much better to change the height and radius together so the proportions of the bottle remain constant.

Artists and designer have evolved a proportion called **the Golden Rectangle** or **Golden Ratio**. It has a ratio of 1 : 1.61

Many products use this proportion because it looks balanced and is pleasing to the eye.

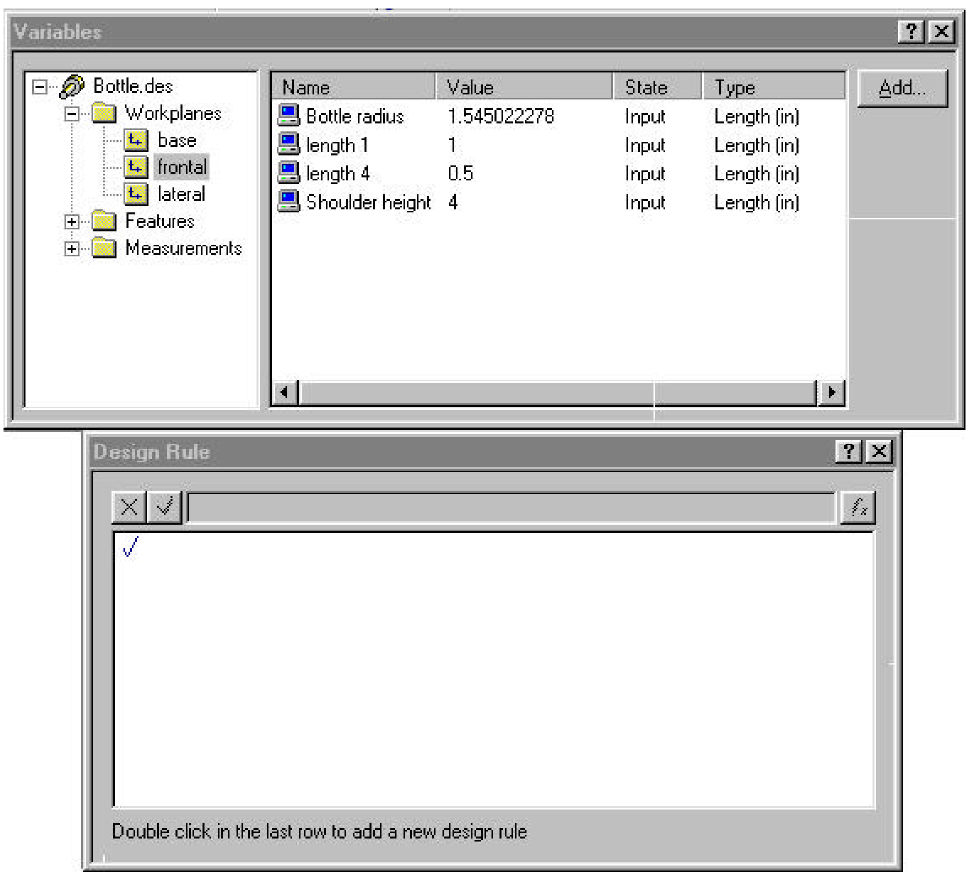
You might like to research this proportion.

Design rules

You will learn how to add a design rule linking shoulder height to bottle radius in the Golden Ratio.

Bottle.des should still be open in Pro/DESKTOP.

- Reduce the window with the bottle to the left side of the screen.
- Open both **Variables** and **Design** rules windows from the **Tools** pull-down menu.



- Arrange them like this to the right of the Pro/DESKTOP screen so that you can also see the bottle on the left.

Adding a design rule

The rule or formula we need to use is:

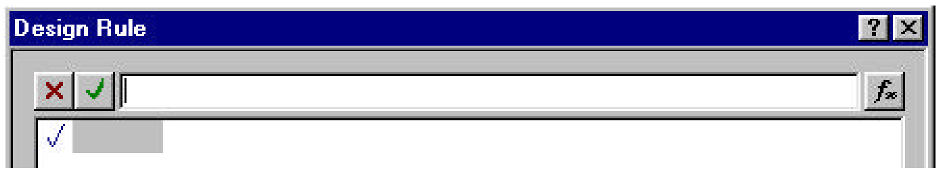
Shoulder height = Bottle radius * 3.22

(3.22 is the multiplier because we are using radius not diameter, so it is twice the value)

Unfortunately Pro/DESKTOP requires more than this.

- Click on the tick in the **Design Rule** window.

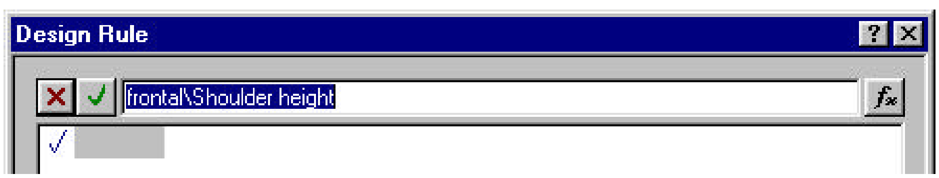
  A flashing text cu rsor appears next to the cross/check box.



You could type in the design rule but the chances of you getting the syntax correct are slim.

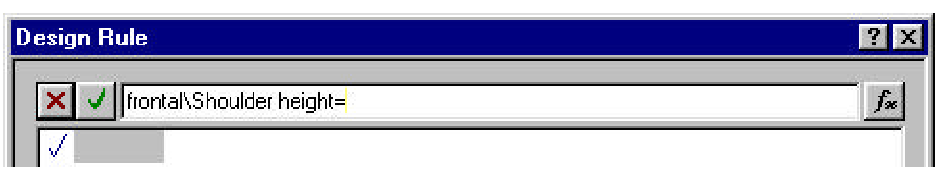
It is much better to click on variables in the top window as necessary.

- Click on Shoulder height in the variable window



The first part of the formula appears in the Design rule window.

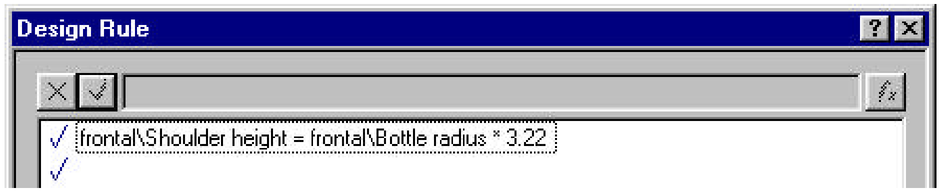
- Click at the end of the blue highlighted text to remove the highlight.
- Use the keyboard to type an equals (=)



- Click on **Bottle radius** in the **Variables** window.
- This will be added to the rule.

- Click at the end of the blue highlighted text to remove the highlight
- Type in *** 3.22**.
- Click on , the green check.

  Your design rule has been added to the list.



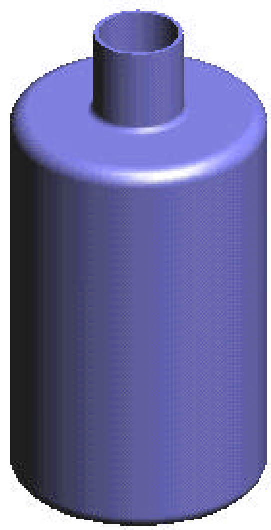
The Pro/DESKTOP model will not have changed

- Use the update button , to refresh the design window.

You can now use the solver again to find the correct size bottle of these proportions to create a 17oz bottle.

This is the same as you did before. Refer back to the instructions if you need to.

Once the bottle is the correct size you can shell it to hollow it out and set a suitable materials color.



Floating and sinking

The solver in Pro/DESKTOP is able to solve complex problems by doing repetitive calculations very quickly, a form of trial and error slowly homing in on a target or goal value.

Working out displacement is an important technique in a number of fields. The density of a material is related to its volume and mass and there are tables that list the density of all materials.

Fact or fiction?

Legend has it that a King had some pure gold that he wanted made into a crown. He commissioned a jeweler to make it, supplying him with the gold. The king was careful to weigh the gold before handing it over.

When the crown was delivered the King was suspicious that not all of the gold had been used so he weighed it. It matched the weight of gold given to the jeweler.

Still the king was not happy suspecting that other, less valuable metals had been mixed with the gold. He asked all the learned scientists in the land to find out if this had happened. However, he insisted the crown must not be damaged in any way.

"Impossible" everyone shouted. Except for one scientist. She took the crown and immersed it in a jug that was brimming full with water catching every drop that spilled out.

She repeated the experiment with a block of pure gold weighing the as the crown. If they were both made of pure gold the exact same amount of water should have spilled out.

The amount of water displaced was different. The king sent for the Jeweler and when faced with the evidence he confessed.

No one knows what became of the jeweler but the legend suggests the king had an interesting stand upon which he stored his crown!

Floating the hull

In the early days of sea transportation unscrupulous ship owners would overload vessels to gain more money from each trip. Unfortunately overloaded ships were more likely to sink and insurance companies didn't like having to pay out for damages. They looked for a way to easily tell whether a ship was overloaded before it left port. A member of British Parliament, Samuel Plimsoll, devised a way to do this. His system required every ship to have a scale painted on the hull showing the level of water for empty and fully loaded. The harbormaster can simply look at the Plimsol mark to see if the vessel is correctly loaded. The Plimsol mark was fixed by loading the ship and then painting the mark on the side.

Using Pro/DESKTOP we can accurately determine the level our boat hull will float in water. In order to do this we must know the density of the hull material. Pro/DESKTOP will work out the mass of the hull. Then, knowing the density of water, Pro/DESKTOP knows the interference between boat and water and can work out the height the boat should ride in the water.

Finding the mass of the hull

For this exercise we will use an assembly with a solid hull floating in water.

- Open the file **Floating.des**

The hull is assembled into the water with three aligns. The variable you will need to vary, associated with how high the hull floats in the water, is called the **Freeboard**.

In order to change the density and find out the mass of the hull you will need to open the hull component.

- Open the component **Dinghy hull.des** 'in context'.

Changing the density

- Open the **Tools** pull-down menu and select **Variables**
- Click on **Dinghy hull.des**, the top entry in the list.

You will see a variable. '**density'** with the value 0.**000001** kg mm^{-3}

This is the density of water. We will assume the boat hull will be made from pine. This has a density around **0.00000035** kg mm^{-3}

- Change the value for density to that of wood.
- Leave the **Variables** window open on screen.

DESIGN CONSIDERATIONS – VOLUME AND MASS

The international standard (ISO) for volume is gm/cm^3 (gram per cubic centimeter). Pro/DESKTOP uses kg/mm^3 (kilogram per cubic millimeter) for volume. This means the following activity will use very small numbers, for example 0.000001 kg mm^3 for the density of water.

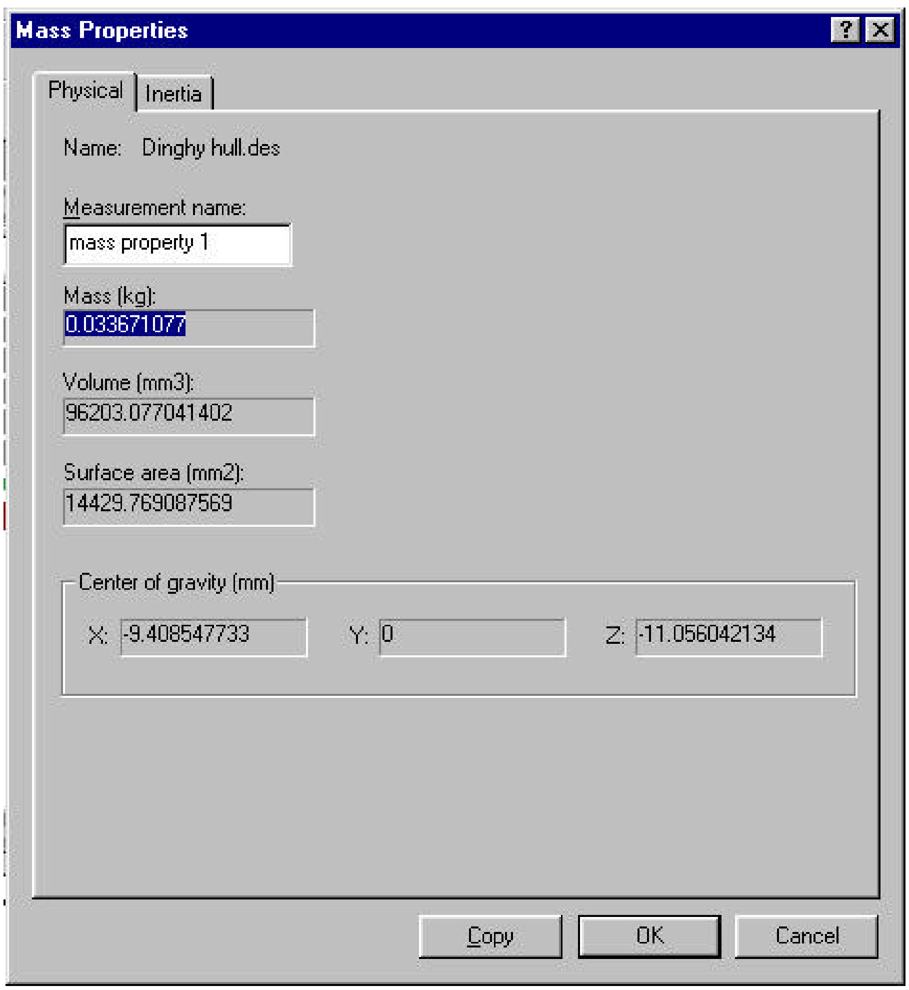
Volume and mass of the hull

For this you will use Pro/DESKTOP to take a new 'measurement'.

The component **Dinghy hull.des** should be open in Pro/DESKTOP.

- Open the **Tools** pull-down menu.

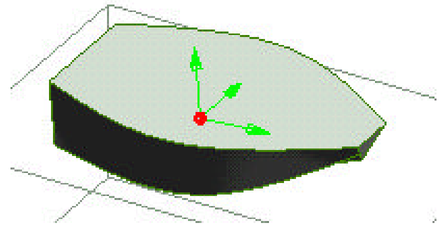
  Select **New Measurement** and then **Mass Properties**



This window opens with values for Mass, Volume, Surface area, etc. Make a note of the value for mass. In this example it was 0.033671077 kg.

Before closing the new measurement window notice it also gives co-ordinate values for the center of gravity.

- Drag the window to one side and you will see an icon indicating the location of the C of G for the hull.



- Close the **New measurement** window.

  The **Variables** window should now contain an entry in the Measurements folder called mass properties.

- Click on the folder and check the value for mass you noted is there.
- Save and close the **Dinghy hull.des** to return to the **Floating.des** assembly.

Using the solver

The **Solver** is an extremely powerful tool that will find a solution to calculations where an element of trial and error is required to find the answer.

You will ask the Solver to arrive at a displacement volume of water that has the same mass as the boat hull. This value would float the boat.

Volume of water

The volume of water is found by dividing the mass of the boat by the density of water.

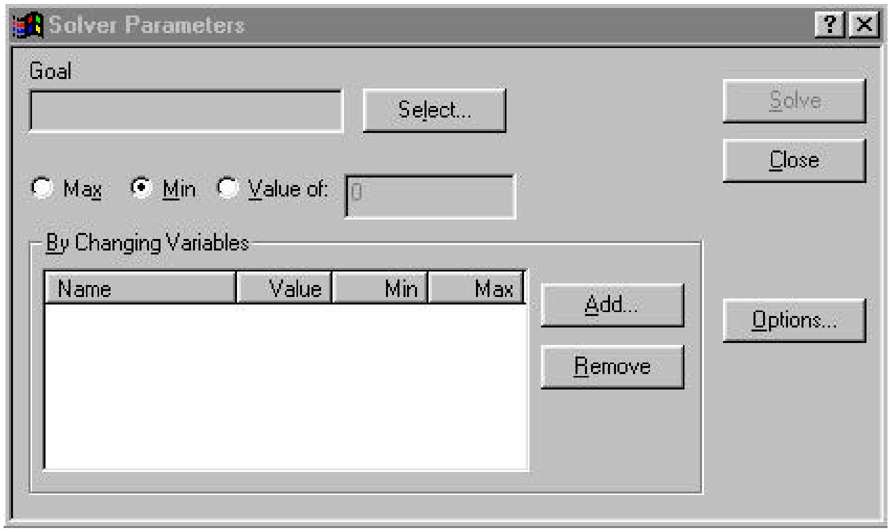
$$\text{Volume of water required} = \frac{\text{Mass of boat}}{\text{Water Density}} = \frac{0.033671077}{0.000001}$$

The result is = 33671.077 mm^3

So, about 33671 cubic millimeters of water will need to be displaced by the boat hull to make the boat float in the water.

Starting the Solver

- Open the **Tools** pull-down menu
- Select **Solver**…



Setting up the solver involves four steps.

1. Selecting the goal variable (output).
2. Specifying the output value to be achieved.
3. Selecting the variable Pro/DESKTOP can change (input).
4. Specifying the minimu m and maximum range for the input.

Setting the goal

- Click the Select... button.

The variables list will appear.

- Open the measurements and interference folder.
- Select volume

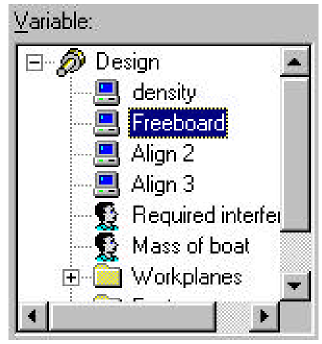
Click on OK.

Select the **Value of** option and fill in 33671 for the value.

Selecting the input variable

Click on Add... in the solver window.

This list will appear.



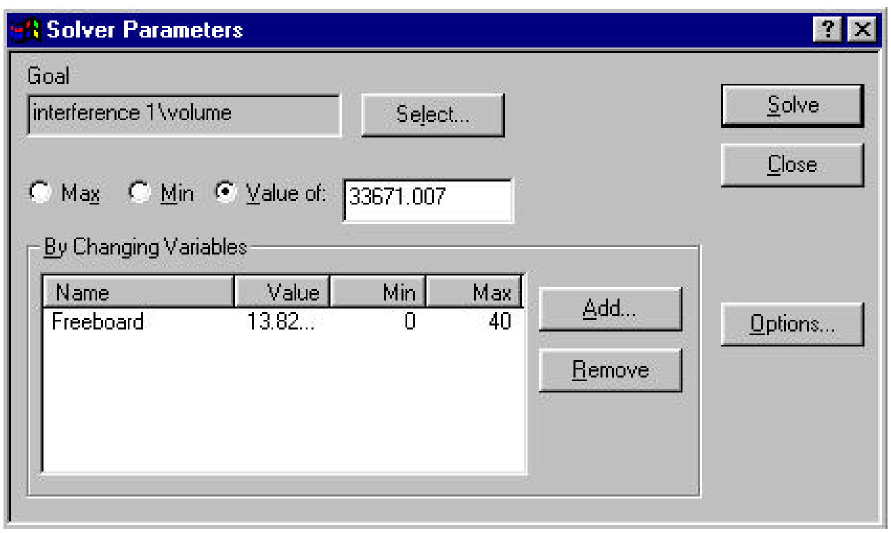
- Select Freeboard as the variable to be changed.

Freeboard will appear in the **By Changing variables** list.

- Enter 0 (zero) for the minimum value and 40 for the maximum.

If the freeboard of the boat reaches zero the boat will sink with the slightest movement!

Should the freeboard reach 40mm the hull would be airborne!



You are now ready to ask Pro/DESKTOP to solve the riddle.

- Before you precede drag the solver window so that you can see both the hull floating and the solver window.
- Click on the Solve button.

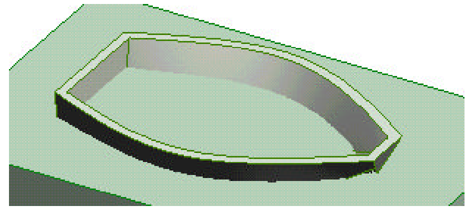
You will see the numbers changing in the solver window with the Value of gradually getting closer to the goal value.

After a few seconds the numbers will stop changing with the goal value very similar to the number you input.

DESIGN CONSIDERATIONS – HOLLOWED HULL

How would you establish the freeboard of a hollowed out hull?

If you try to 'float' a shelled out hull Pro/DESKTOP is too clever to let you do it. It reports the interference between just the shell of the boat and the water. This is the same as assuming the boat will be floating with water inside!



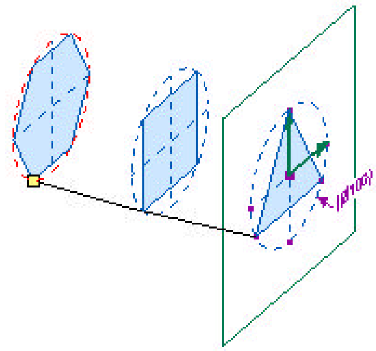
If you wanted to show the floating level of a hollowed hull these are the steps you would need to follow.

1. Create the hollow hull.
2. Change the density variable to the intended hull material.
3. Use a New Measurement to find the mass of the hollow hull.
4. Suppress the shell feature update the design and save.
5. Open the water component. Assemble a solid version of the hull into the water with a freeboard constraint applied.
6. Use the solver to establish the floating level of the hull.
7. Subtract the solid hull from the water using the Use component tool. Makes sure you leave the boat (tool) visible!
8. Open the hull in context and un-suppress the shell. Update, save and close the hull.
9. The hollowed hull is now floating in the correct position for its mass and displacement.

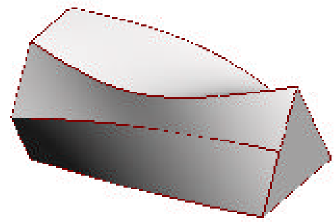
TROUBLESHOOTING – LOFTING

Number of nodes

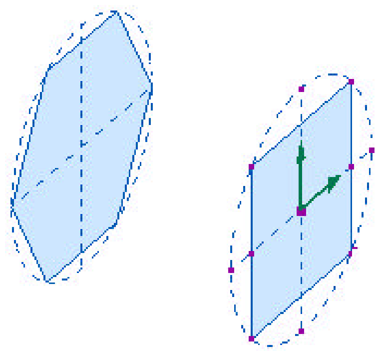
You will soon meet the situation where there are a different number of lines in adjacent sketches.



Pro/DESKTOP will blend extra 'nodes'. Normally you have little control over which nodes are lost between sketches.

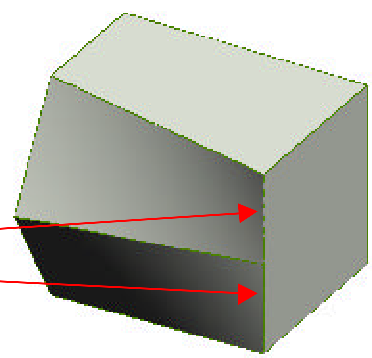


To regain control, draw each sketch with the same number of nodes.



This example shows how a spare node on one sketch can be forced to blend to the join between two short collinear straight lines.

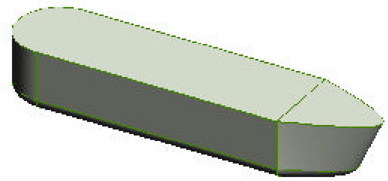
Two short lines



Deform/shell from lofted surfaces

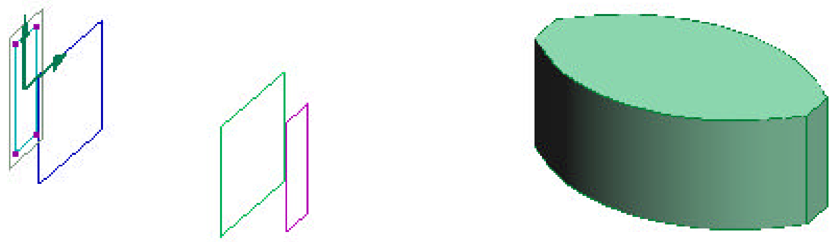
Lofting can create what appears to be a flat surface.

Sometimes these flat surfaces refuse to deform or act as the opening face for the shell command.

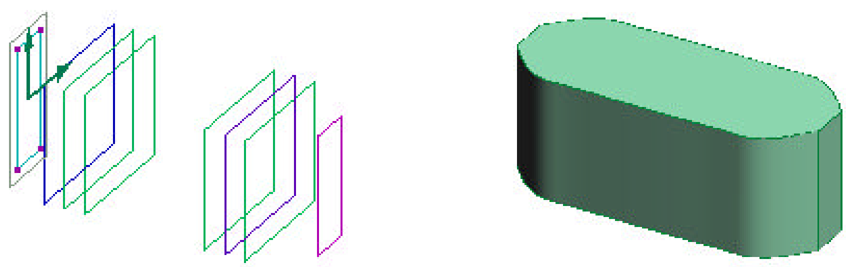


Straight sides

Transitions between curved and flat surfaces are tricky.

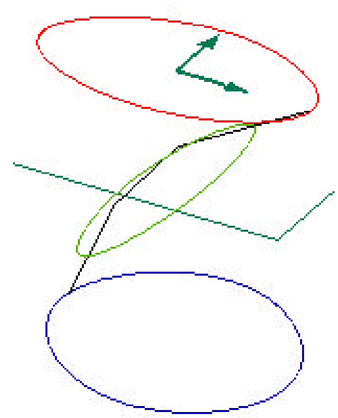


Several closely spaced profiles may be needed before a flat surface will result.



Splines

Splines can be used as profile sketches when creating lofted solids but you will not be offered drag handles to control connecting nodes.

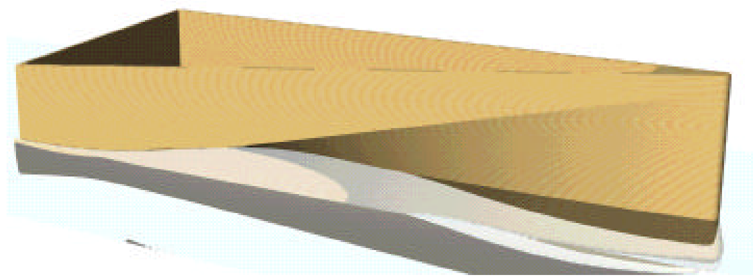


Lofting is a very powerful feature and will produce complex curved surfaces. It is useful wherever a surface/skin shape is required.

Boat hulls

As you have seen hull shapes are easily produced.

Consider making model boat hulls for different types of craft such as yachts, canoes, planing hull speed boats or even a new style wave cutting design.



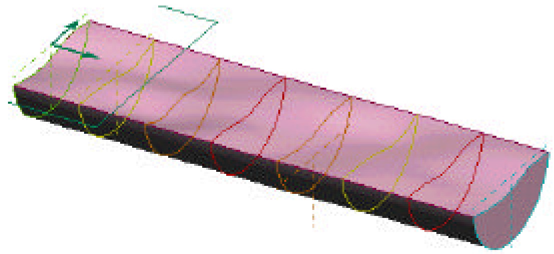
Aircraft wings and fuselage

Lofting also lends itself to creating fuselage and wing shapes for aircraft models. Many factors determine whether a model will fly including center of gravity, center of lift, thrust and drag.

Wings have to have 'washout' to make the aircraft stable and easier to fly. You might also want to research this.

Liquids and the surface of fluids

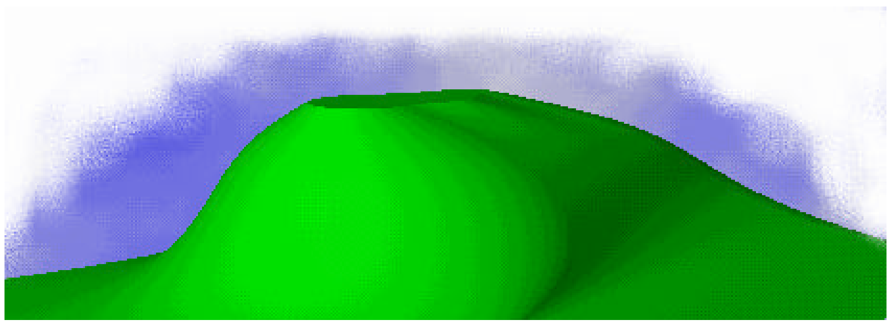
The surface of fluids and fabric effects are difficult to reproduce in Pro/DESKTOP but reasonable results can be gained from using the loft feature across several profiles.



You could redesign your room creating patterned fabrics for curtains and soft furnishings.

Landscapes

These could be produced in a similar way to water and fabrics.



Why not make a topographical model of the plot your home stands on? You might also create a Pro/DESKTOP model of your house and create a virtual tour for the web!

Containers

With the power of loft you can create any number of wild and wacky containers.

These could be moneyboxes, shampoo bottles, soda drinks. Don't be limited by the shapes you see in the store.