Tutorial Week 5

Transient Thermal Analysis
Investigation on Heating Up Steak

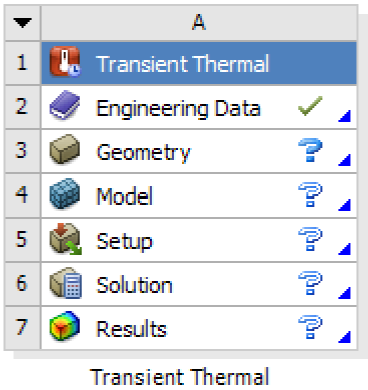
Introduction

This tutorial will introduce a different physics that can be solved through finite element analysis (FEA). We will be looking at a transient thermal analysis of heating up a T-bone steak on a pan. You will learn to:

- Create a geometry using the Design Modeler
- Perform an analysis using finite element methods in a physics that is not structural

Step 1: Getting Started

Open Workbench on your computer. Once the main window has loaded, double-click on **Transient Thermal** to add it to the Project Schematic.

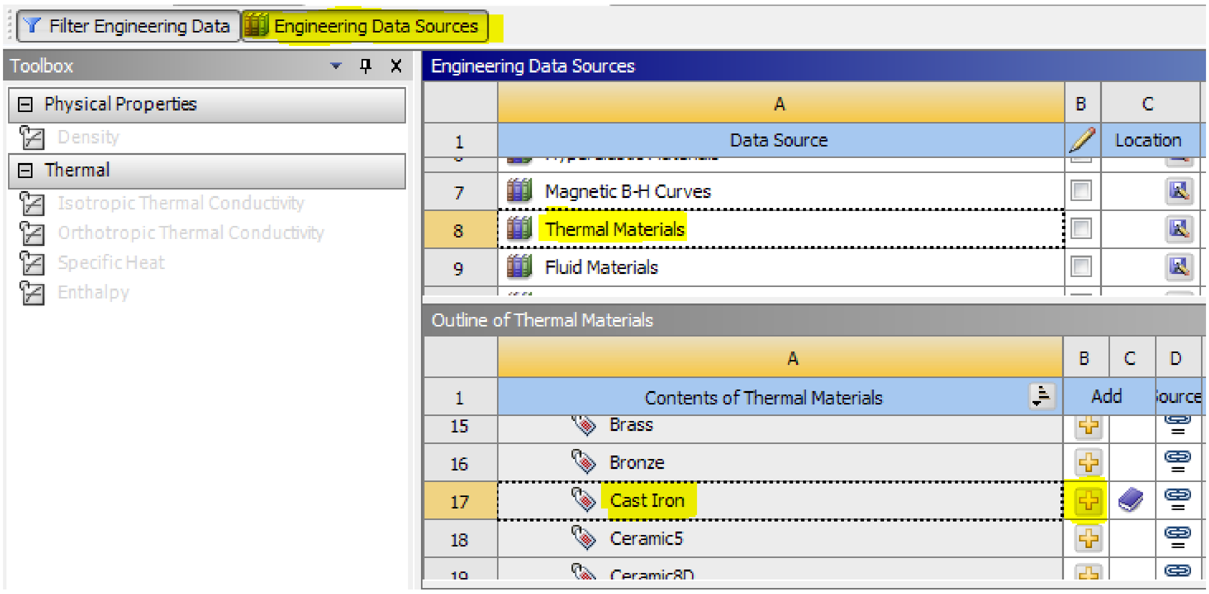


Double-click on **Engineering Data** to add the material properties. For the model of the T-bone steak, we need the properties for meat and bone. Right-click on the default material of **Structural Steel** to delete it. Add the materials **Meat** and **Bone** and define the following properties:

	Density (kg/m^3)	**Isotropic Thermal Conductivity (W/mK)**	**Specific Heat (J/kgK)**
Meat	881	0.4	3500
Bone	1420	0.5	1500

We will also add another material, **Cast Iron** for the frying pan, by adding it from the Engineering Materials Library. Click on **Engineering Data Sources** at the top of the screen. This should display a list of different materials. Click on **Thermal Materials** and select **Cast Iron** by clicking on the **+** symbol. Click on **Engineering Data Sources** again to close the library. You should now see three materials defined in your model.

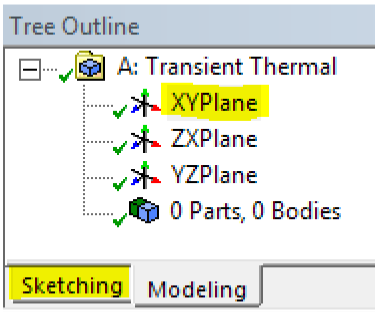
Once complete, close the Engineering Data tab to return to the main window.



Step 2: Geometry

Double-click on **Geometry** to open the Design Modeler window. Here we will draw a T-bone steak.

Right-click on **XYPlane** in the Tree Outline and select **Look at**. Click on **Sketching** at the bottom of the Tree Outline to see the available sketching tools.

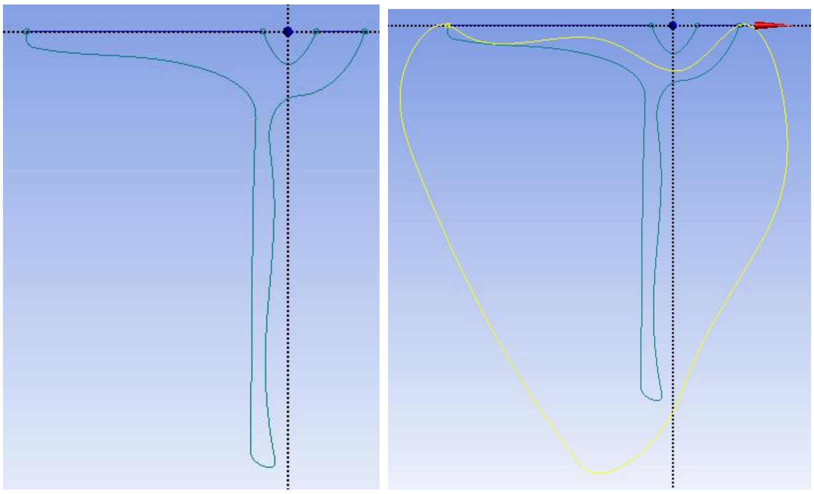


Zoom in using the **Zoom** tool to get to the appropriate zoom level (you should not be drawing a 20 m steak!). It may be easier to change the units from metres to centimetres in the **Units** menu.

Try your best to draw the following:

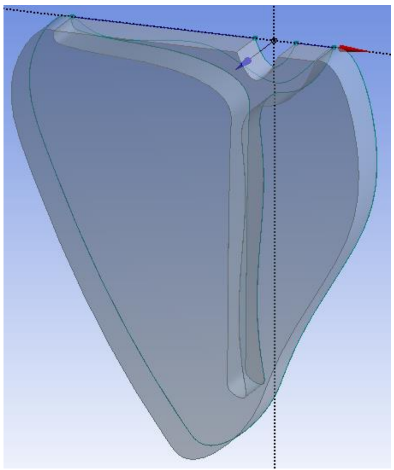
The best approach would be to draw the bone first using a combination of the **Line** tool and the **Spline** tool. When using the spline tool, if you want to end the spline, right-click and select **Open End**.

Click on **New Sketch**.



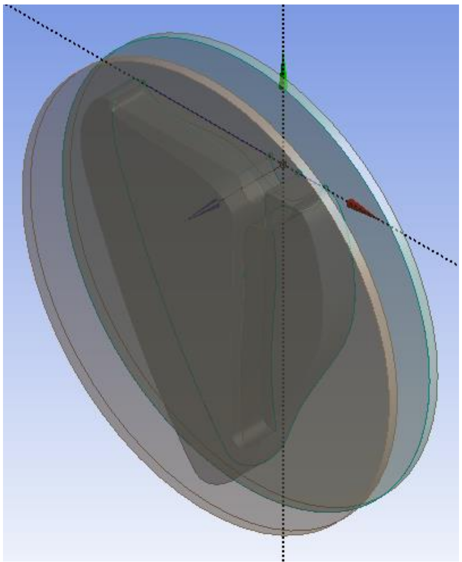
Now draw the meat part by using the **Spline** tool. To end the spline, right-click and select **Closed End**. Do not make the meat go beyond the bone at the top. See figure above (right). This will ensure a clean Boolean subtraction in the next step.

Go back to the **Modeling** tab. You should see the two sketches listed under the XYPlane. Click on **Extrude** and select Sketch1 (bone). Give the steak a thickness/depth of 2 cm. Change the **Operation** from Add Material to **Add Frozen**. This will allow us to create two separate bodies. Click on **Generate**. Create another **Extrude** and repeat the process for Sketch2 (meat). Create the subtraction by adding a **Boolean Subtract** from the **Create** menu. Select the meat as the **Target Body** and the bone as the **Tool Body**. Change the **Preserve Tool Bodies** option to **Yes**. Then click **Generate**. Your model should look something like this.



Add a third sketch in the XY Plane. Draw a **circle** that completely surrounds the steak. This circle will form the surface of the pan where the heat will be applied. Extrude this circle by selecting **Add Frozen** in the **Reverse Direction** by 0.5 cm. and click **Generate**.

As you may know from experience, cooking a steak on one side is not ideal. We would usually flip the steak over after a few minutes to make the heat travel through the meat more evenly. Unfortunately, flipping a body mid-simulation is not easy. Instead, we will create a second pan on the other side of the steak and turn these pans on and off during the simulation. Create a **Translation Body Transformation** using the top menu. Translate the body (with **Preserve Bodies** set to **Yes**) by 2.5 cm. You will need to define the direction of the translation. You can do this by selecting one of the edges of the bone lining up with the Y axis. Ensure that the direction is correct, then click **Generate**. You should have the following.



Close the window to exit the Design Modeler.

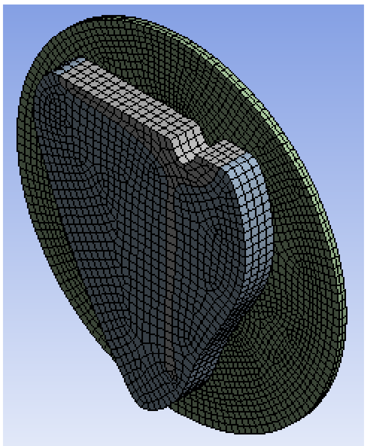
Step 3: Model Setup

Back in the Project Schematic, double click on **Model**.

In the **Transient Thermal Mechanical** window, we need to work through each component to set up the model.

- Expand **Geometry** in the Outline Tree to reveal four Solids. Assign the correct material for each of these bodies. Use the **Rotate** tool to help with visualisation of what you are selecting.
- Expand **Connections** in the Outline Tree and check to see if the contact regions are correctly defined. The blue and red regions indicate the contacting surfaces between the two bodies. Workbench has set the **Definition Type** of the contact to be **Bonded**, indicating that the two bodies are glued together and will not separate. Click on this to reveal other types of contact definitions,

including frictional (with a friction coefficient), and frictionless (smooth contact with no losses). For this tutorial, we will leave this as Bonded.



- Right-click on **Mesh** in the Outline Tree to generate a mesh. You will see that a very coarse mesh is produced, with at most 2 elements along the thickness of the steak. To get a more accurate solution, we will need more elements. Expand the **Sizing** options in the bottom panel and define the **Element Size** to be 0.5 cm. **Update** the mesh.
- Click on **Initial Temperature** under **Transient Thermal**. The initial temperature of 22 degrees (room temperature) will be the temperature of all the bodies in our simulation. If you wish to change it, this is where you would do it.
- We need to define the analysis. In our model, we will have 3 stages of heating: (1) heating on the first side for 3 minutes, (2) heating on the second side for 3 minutes, and (3) no heating for 4 minutes (total 10 minutes). Click on **Analysis Settings** under **Transient Thermal**. Set the **Number of Steps** to be 3. On the right side, a small table shows the end time for each of these steps. Define the end times for these steps to be 180, 360, and 600 seconds. You will have to do this in reverse because Workbench won't allow the first step to end at 180 seconds if the second step ends at 2 seconds, etc.

Tabular Data

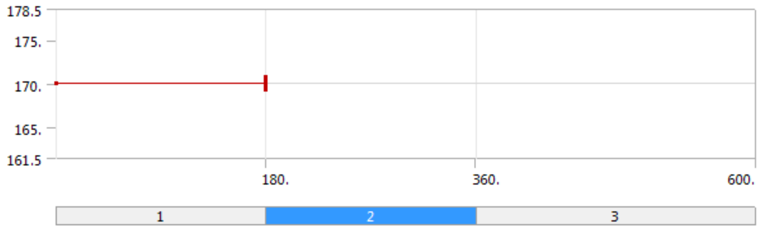
	Steps	End Time [s]
1	1	180.
2	2	360.
3	3	600.
*		

- Right click on **Transient Thermal** to insert a **Convection** boundary condition. The convection boundary condition is the definition of the heat dissipating into the surrounding air. Select all the bodies for this definition. Define the **Film Coefficient** to be 20 W/m^2.K. Make sure the ambient temperature is 22 degrees.
- Right click on **Transient Thermal** to insert a **Temperature** boundary condition. Select the first frying pan body for this boundary condition and change the **Application** from the External Faces to the **Entire Body**. On the right side, the small table shows the temperature of the body for each of the steps. Manually set the temperature of the first step (at 0 and 180 seconds) to be **170 degrees**. This will automatically change all the other entries as well. We do not want the steak to be cooking on this side for the entire 10 minutes. Click on the second step (360 seconds), then right click and **deactivate** it. This will grey out the row.

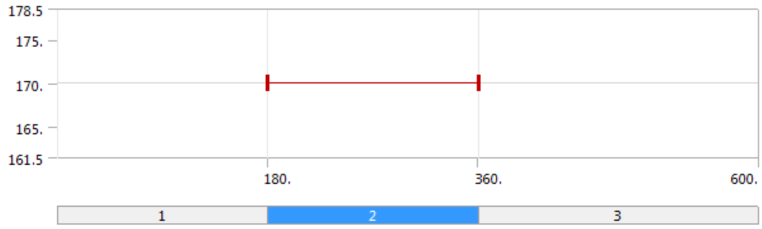
Tabular Data

	Steps	Time [s]	☑ Temperature [°C]
1	1	0.	170.
2	1	180.	170.
3	2	360.	= 170.
4	3	600.	= 170.
*			

Repeat this for the third step (600 seconds). The graph will show what the applied temperature will be for the different stages.



- Create another **Temperature** boundary condition. Repeat the process as before, except you will need to select the other frying pan body. You will also need to set it so that the temperature is only applied during the second step (180-360 seconds).

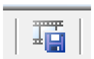


- Right click on **Solution** and insert a **Temperature** for only the meat and bone bodies.

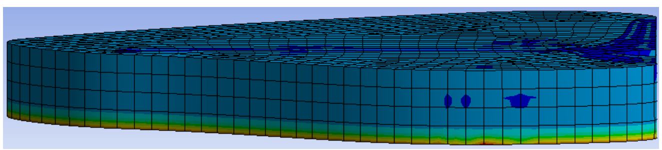
Step 4: Solving and Results

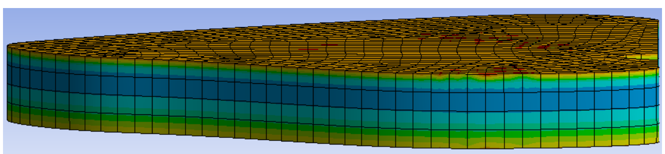
Click on **Solve** to find a solution. This should take several minutes.

Once complete, click on the **Temperature** result. You can watch an animation of the temperature of your steak over the duration of the heating process. Change the number of frames to be 100 and the animation to be 10 seconds. Press play. You can save the video by clicking on the **Export** button.



If you look at the variation of temperature over time in the graph at the bottom, you will notice that there may be odd temperatures (higher than 170, and lower than 22 degrees). This is due to inaccuracies in the mesh and concentrations in the temperature at various points.

Stage 1


Stage 2


Stage 3