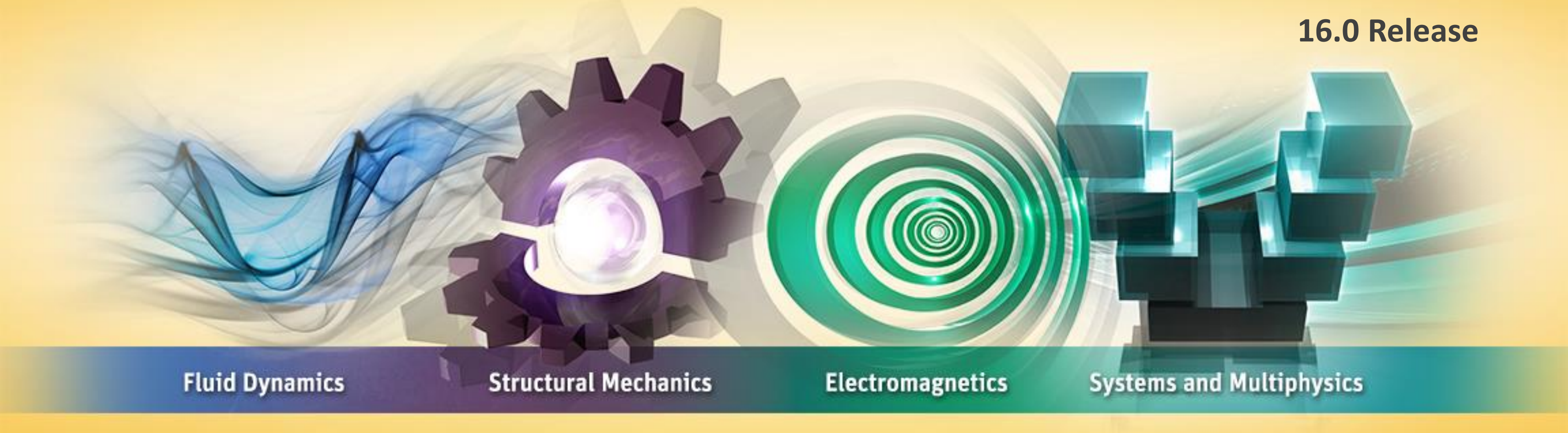
Lecture 9
Thermal Analysis

16.0 Release



Introduction to ANSYS Mechanical

Chapter Overview

In this chapter, performing steady-state thermal analyses in Mechanical will be covered:

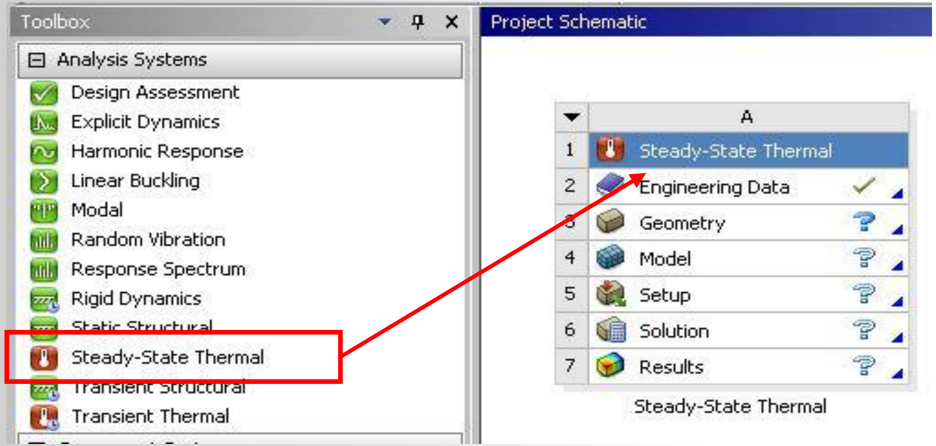
A. **Basics of Steady State Heat Transfer**
B. **Geometry**
C. **Material Properties**
D. **Thermal Contact**
E. **Thermal Boundary Conditions**
F. **Solution Options**
G. **Results and Postprocessing**
H. **Workshop 9.1 – Pump Housing**

Note: advanced topics including thermal transient analyses are covered in the ANSYS Mechanical Heat Transfer training course.

A. Basics of Steady-State Heat Transfer

The schematic setup for a steady-state (static) thermal analysis is shown here.

Later in this chapter we will shown the procedure for setting up a coupled thermal structural analysis.



. . . Basics of Steady-State Heat Transfer

For a steady-state (static) thermal analysis in Mechanical, the temperatures {T} are solved for in the matrix below:

$$[K(T)]\{T\} = \{Q(T)\}$$

Assumptions:

- No transient effects are considered in a steady-state analysis
- [K] can be constant or a function of temperature
- {Q} can be constant or a function of temperature
- Fixed temperatures represent constraints {T} on the system (like fixed displacements on structures).

It is important to remember these assumptions related to performing *thermal analyses* in Mechanical.

B. Geometry

In thermal analyses all body types are supported:

- **Solid, surface, and line bodies.**
  - ***Line bodies* cross-section and orientation is defined within DesignModeler or SpaceClaim.**
  - **A "Thermal Mass" feature is available for use in transient analysis (not covered in this course).**

Shell and line body assumptions:

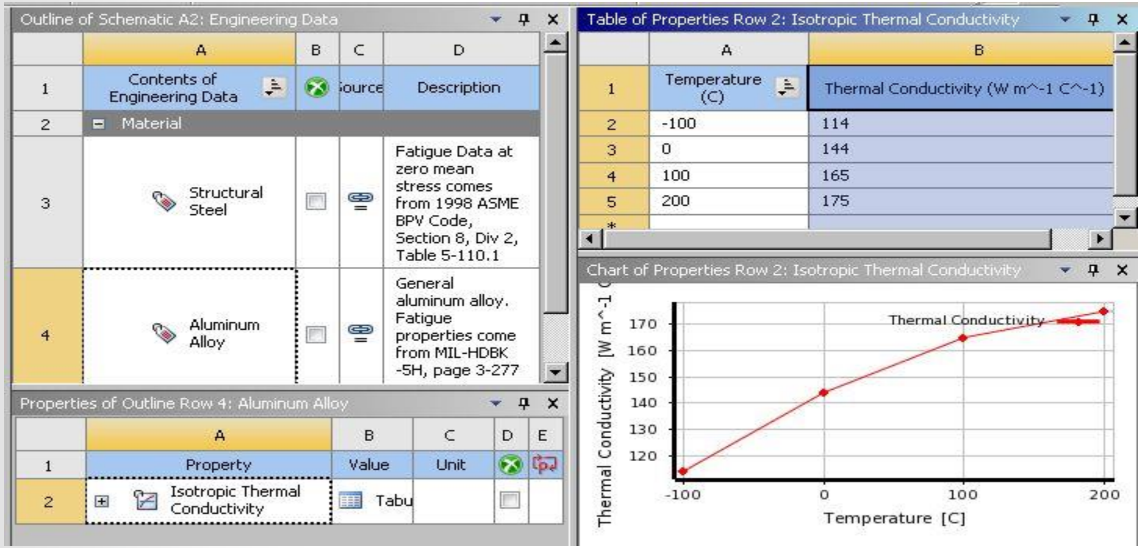
- **Shells: temperatures may vary over the surface (no through-thickness temperature variation)**
- **Line bodies: temperature may vary along the length of the beam (no variation across the cross section).**

C. Material Properties

- **The only required material property for steady state is thermal conductivity.**

- ***Thermal Conductivity* is input in the Engineering Data application**

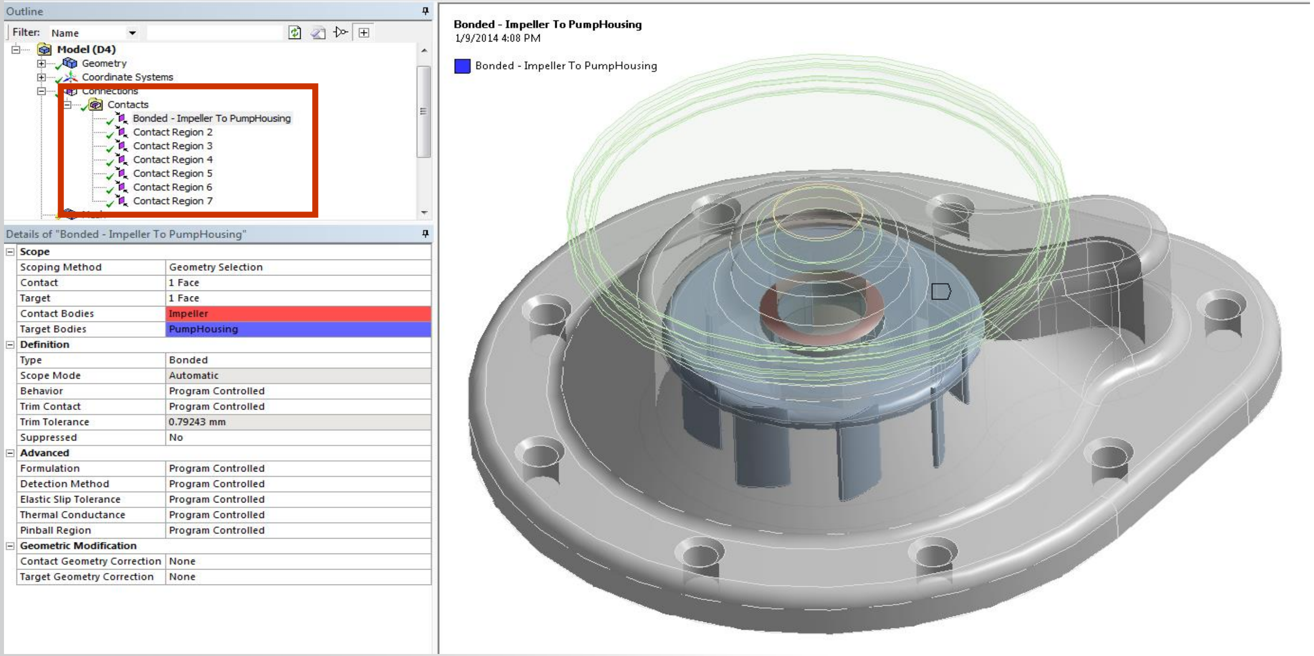
- **Temperature-dependent thermal conductivity is input as a table**



If any temperature-dependent material properties exist, this will result in a *nonlinear* solution.

D. Thermal Contact

As with structural analyses, contact regions are automatically created to enable heat transfer between parts in assemblies.



... Thermal Contact

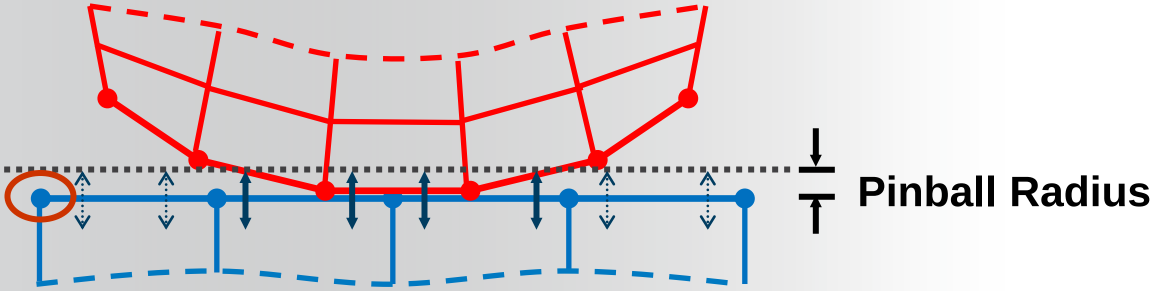
- When can heat flow across a contact region?

Contact Type	Heat Transfer Between Parts in Contact Region?		
	Initially Touching	Inside Pinball Region	Outside Pinball Region
Bonded	Yes	Yes	No
No Separation	Yes	Yes	No
Rough	Yes	No	No
Frictionless	Yes	No	No
Frictional	Yes	No	No

- Thermal Contact Behavior:
  - If parts are in contact heat transfer can occur between them.
  - If parts are out of contact no heat transfer takes place.
    - For bonded and no separation the pinball can be expanded to allow heat transfer across a gap.

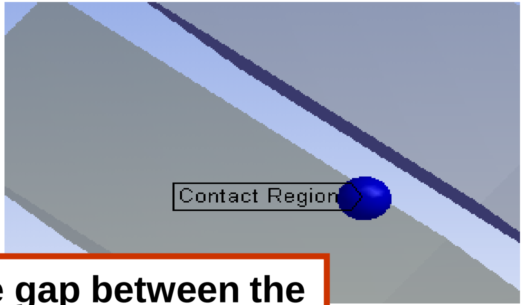
... Thermal Contact

If the contact is bonded or no separation, then heat transfer will occur when the surfaces are within the pinball radius.



Details of "Bonded - Impeller To PumpHousing"

Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	1 Face
Contact Bodies	Impeller
Target Bodies	PumpHousing
Definition	
Type	Bonded
Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	0.79243 mm
Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Elastic Slip Tolerance	Program Controlled
Thermal Conductance	Program Controlled
Pinball Region	Radius
Pinball Radius	0. mm
Geometric Modification	
Contact Geometry Correction	None
Target Geometry Correction	None



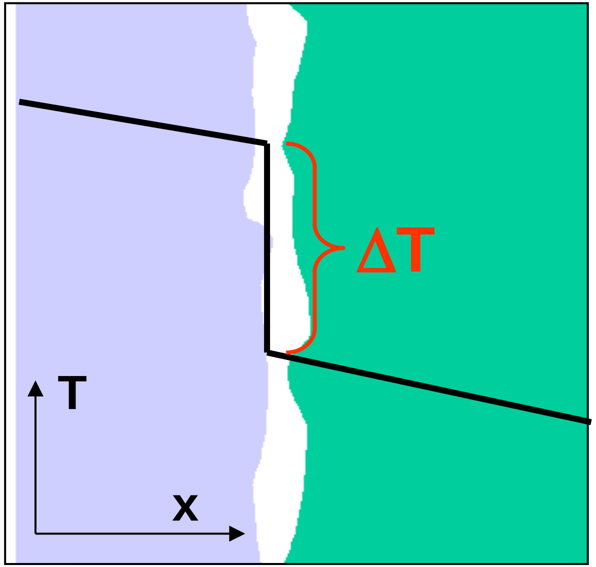
In this figure, the gap between the two parts is larger than the pinball region, so no heat transfer will occur between the parts.

… Thermal Contact

By default, perfect thermal contact is assumed, meaning no temperature drop occurs at the interface.

Numerous "real world" conditions can contribute to less than perfect contact conductance:

- **Surface roughness**
- **surface finish**
- **Oxides**
- **trapped fluids**
- **contact pressure**
- **surface temperature**
- **lubricants**
- **Etc . . . .**



Continued . . .

... Thermal Contact

The amount of heat flow across a contact interface is defined by the contact heat flux expression "*q*" shown here:

- $T_{contact}$ is the temperature of the contact surface and
- T_{target} is the temperature of the target surface.

$$q = TCC \cdot \left(T_{target} - T_{contact}\right)$$

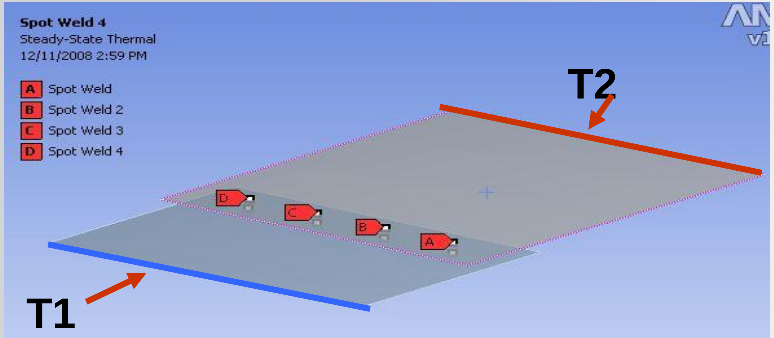
- By default, TCC (<u>T</u>hermal <u>C</u>ontact <u>C</u>onductivity) is set to a high value based on the size and material conductivities in the model. This essentially provides 'perfect' conductance between parts.
- A lower TCC value can be set in the contact details to provide a thermal resistance.

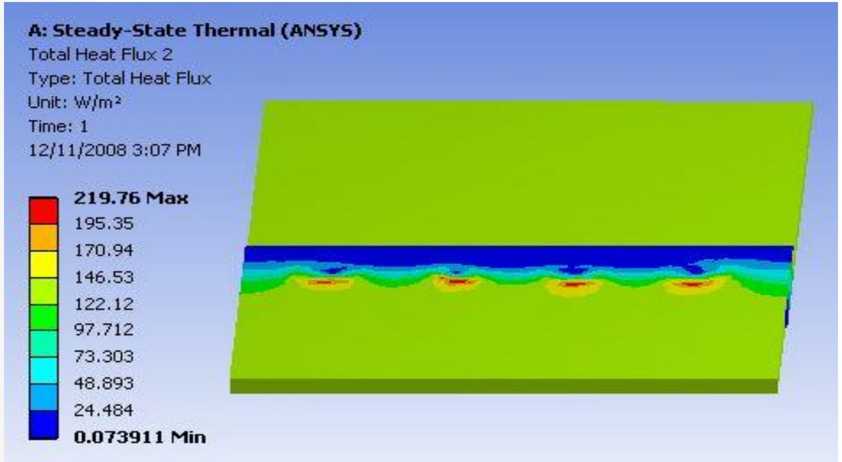
Details of "Bonded - Impeller To PumpHousing"

Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	1 Face
Contact Bodies	Impeller
Target Bodies	PumpHousing
Definition	
Type	Bonded
Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	0.79243 mm
Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Elastic Slip Tolerance	Program Controlled
Thermal Conductance	Manual
Thermal Conductance Value	0. $W/mm^2 \cdot {}^\circ C$
Pinball Region	Program Controlled
Geometric Modification	
Contact Geometry Correction	None
Target Geometry Correction	None

... Thermal Contact

Spot welds provide discrete contact locations where heat transfer can take place.





E. Thermal Boundary Conditions

Heat Flow:

- A heat flow rate can be applied to a vertex, edge, or surface.
- Heat flow has units of energy/time.

Heat Flux:

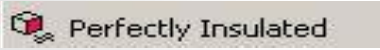
- Heat flux can be applied to surfaces only (edges in 2D).
- Heat flux has units of energy/time/area.

Internal Heat Generation:

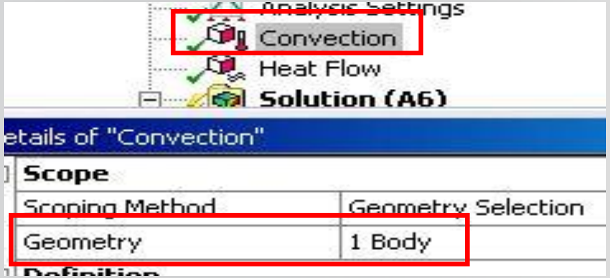
- An internal heat generation rate can be applied to bodies only.
- Heat generation has units of energy/time/volume.

A positive value for heat load will add energy to the system.

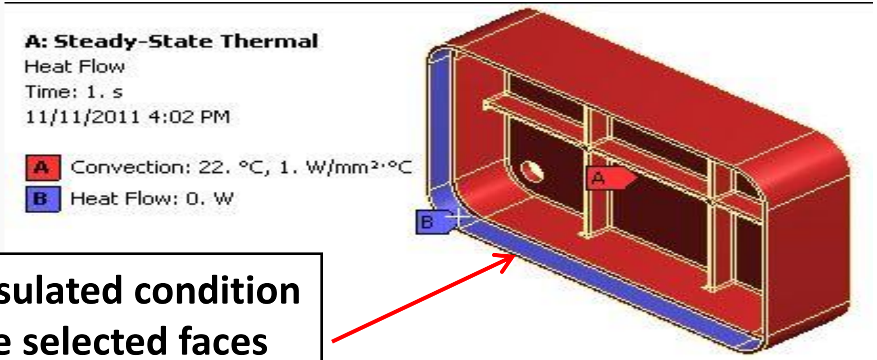
ANSYS ... Thermal Boundary Conditions

Perfectly insulated (heat flow = 0): 

- Remove part of an applied boundary condition.



A convection load is scoped to the entire body.



A perfectly insulated condition removes the selected faces from the convection

NOTE: adiabatic (perfectly insulated) is the default condition where no boundary condition is applied. Therefore, Perfectly Insulated is ONLY necessary to remove part of a previously applied BC or to define a symmetry region.

… Thermal Boundary Conditions

Temperature, Convection and Radiation:

– At least one type of thermal condition containing temperature {T} should be present to bound the problem (prevent the thermal equivalent of rigid body motion).

Temperature: Temperature

$$\{T\}$$

- Imposes a temperature on vertices, edges, surfaces or bodies.

$$q_c = hA\left(T_{surface} - T_{ambient}\right)$$

Convection: Convection

- Ambient temperature

$$q_R = \sigma\varepsilon FA\left(T_{surface}^4 - T_{ambient}^4\right)$$

Radiation: Radiation

- Ambient temperature

… Thermal Boundary Conditions

Convection: Convection

- Applied to surfaces only (edges in 2D analyses).
- Convection *q* is defined by a film coefficient *h*, the surface area *A*, and the difference in the surface temperature $T_{surface}$ & ambient temperature $T_{ambient}$

$$q_c = hA\left(T_{surface} - T_{ambient}\right)$$

- "*h*" and "$T_{ambient}$" are user input values.
- The film coefficient *h* can be constant, temperature or spatially dependent (only temperature dependent is covered in this course).

Details of "Convection"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Type	Convection
Film Coefficient	3. W/m²·°C (ramped)
Ambient Temperature	22. °C (ramped)
Convection Matrix	Program Controlled
Suppressed	No

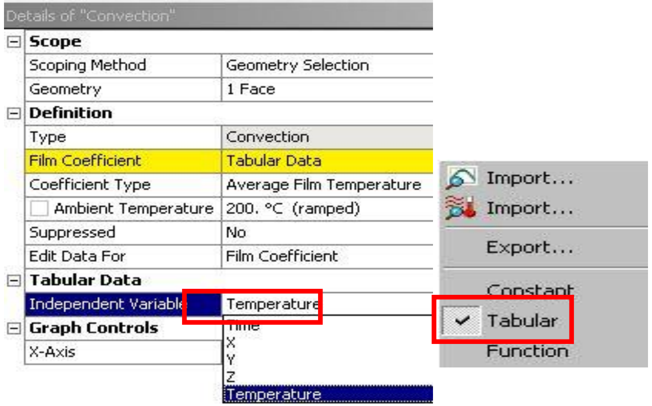
Details of "Convection"

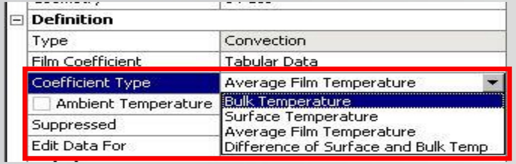
Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Type	Convection
Film Coefficient	Tabular Data
Coefficient Type	Average Film Temperature
Ambient Temperature	22. °C (ramped)
Convection Matrix	Program Controlled
Suppressed	No
Edit Data For	Film Coefficient
Tabular Data	
Independent Variable	Temperature
Graph Controls	
X-Axis	Temperature

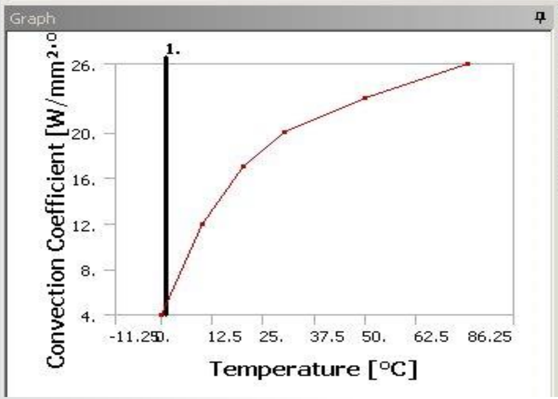
… Thermal Boundary Conditions

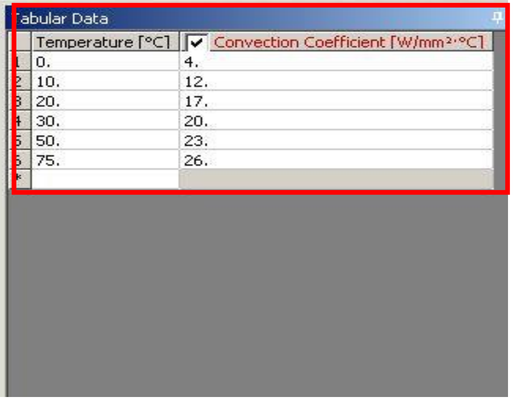
To define temperature dependent convection:

- **Select "Tabular" for the film coefficient.**
- **Set the independent variable to "temperature".**
- **Enter coefficient vs temperature tabular data.**
- **In the "Coefficient Type" field, specify how temperature from the table is to be interpreted.**





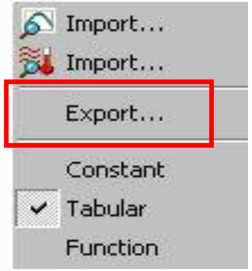




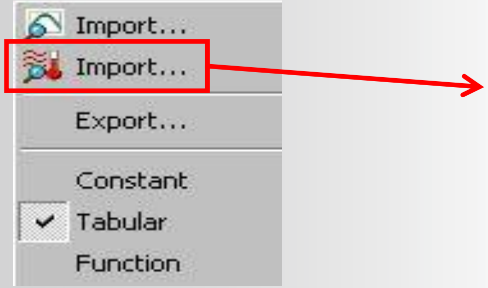
Note: as shown (above right), other independent variables are available for tabular data. These are not covered in this course.

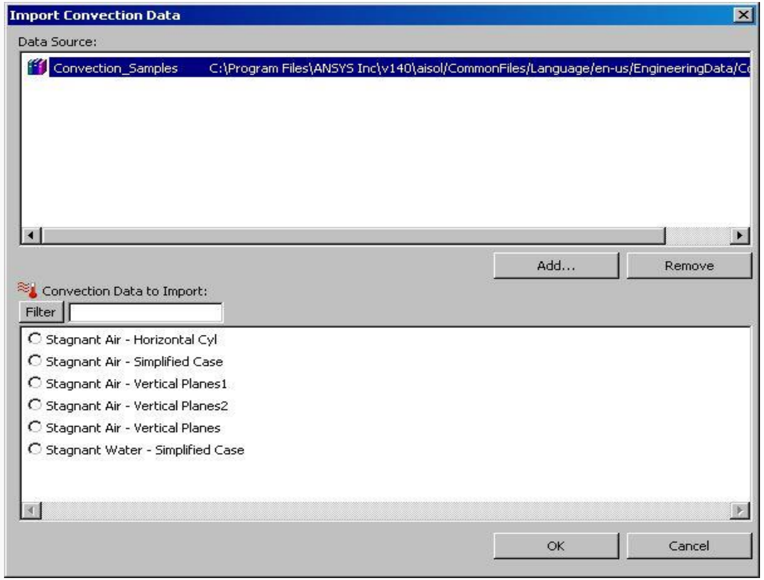
... Thermal Boundary Conditions

- **Once defined convection correlations can be exported to a convection library for reuse.**



- **Several common “text book” correlations are available to import from a Workbench sample library.**





… Thermal Boundary Conditions

Radiation: Radiation

- Applied to surfaces (edges in 2D analyses)

$$q_R = \sigma \varepsilon F A \left(T_{surface}^4 - T_{ambient}^4 \right)$$

- Where:
  - σ = Stefan-Boltzman constant
  - ε = Emissivity
  - A = Area of radiating surface
  - F = Form factor

- Correlations:
  - <u>To ambient</u> (form factor assumed to be 1)

  OR

  - <u>Surface to surface</u> (view factors calculated).

- Stefan Boltzman constant is set automatically based on the active unit system

Details of "Outer Surface Radiation"

Scope	
Scoping Method	Named Selection
Named Selection	NS_RadSurf_1
Definition	
Type	Radiation
Correlation	To Ambient
Emissivity	0.7
Ambient Temperature	25. °C (ramped)
Suppressed	No

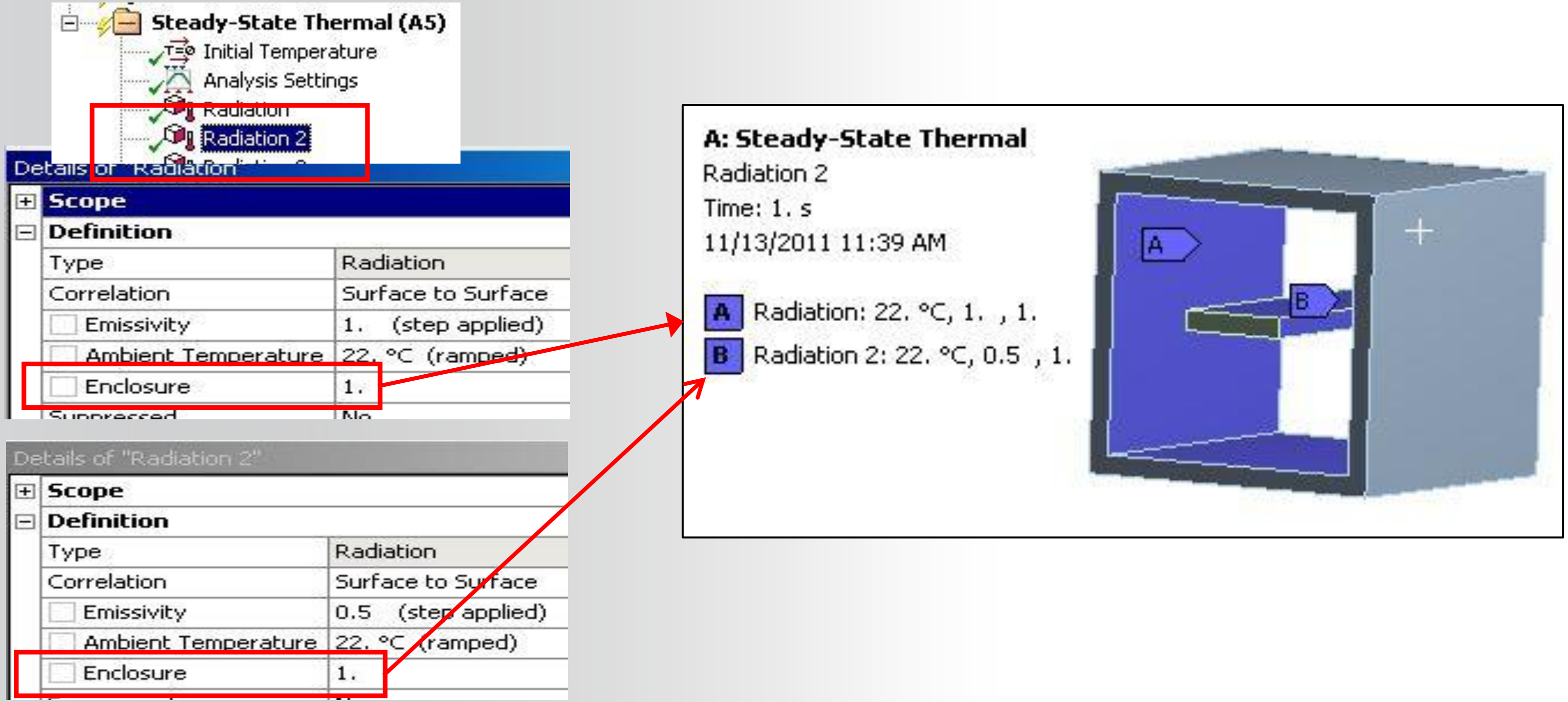
Details of "Radiation 2"

Scope	
Scoping Method	Geometry Selection
Geometry	5 Faces
Definition	
Type	Radiation
Correlation	Surface to Surface
Emissivity	1. (step applied)
Ambient Temperature	22. °C (ramped)
Enclosure	1.
Suppressed	No

… Thermal Boundary Conditions

Surface to Surface radiation is related by "Enclosure" number.

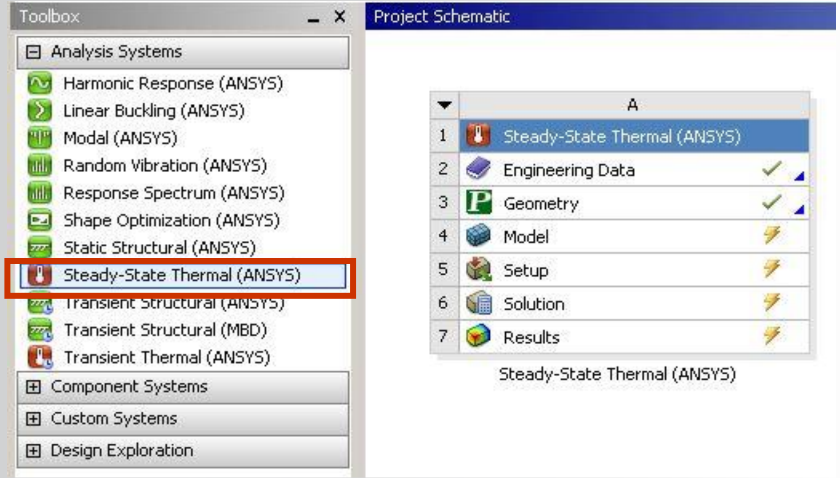
- **In the example shown, 2 radiation boundaries are defined with different emissivity. By sharing a common enclosure number, view factors will be calculated for all surfaces.**

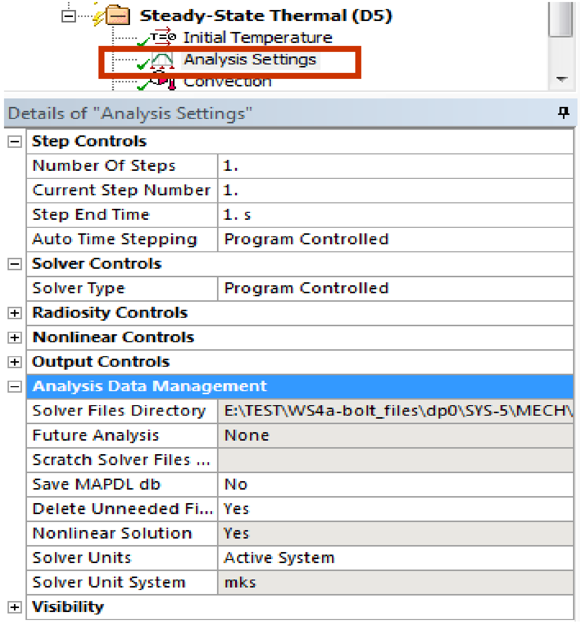


F. Solution Options

As with all analysis types in Mechanical the "Analysis Settings" can be used to set solution options.

- **Note, the same Analysis Data Management options discussed in chapter 4 regarding static analyses are available in thermal analysis.**

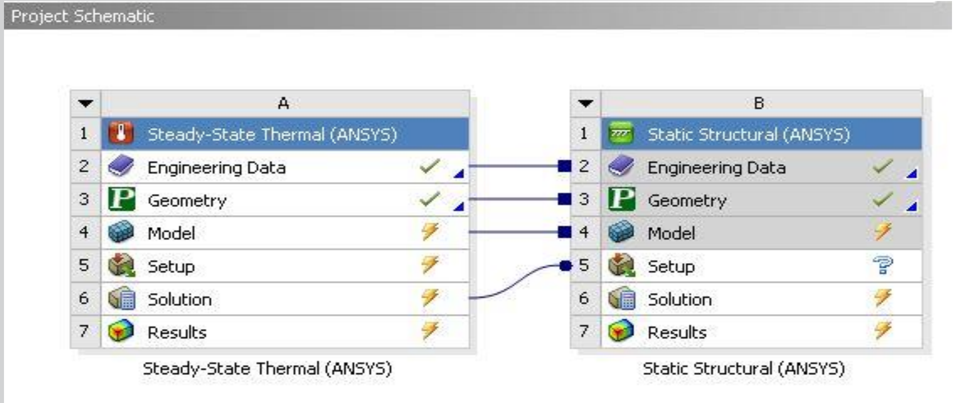


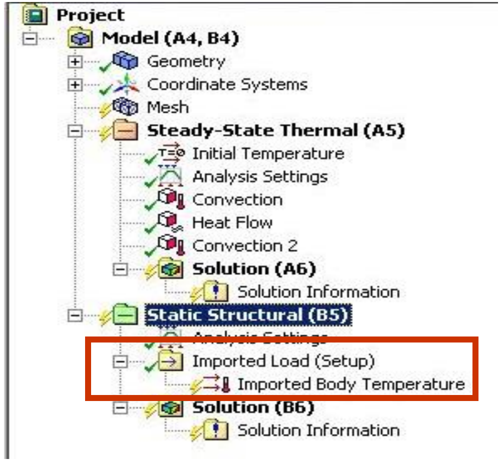


… Solution Options

To perform a thermal-stress solution link a structural analysis to the thermal model at the Solution level.

An "imported load" branch is inserted in the Static Structural branch along with any applied structural loads and supports

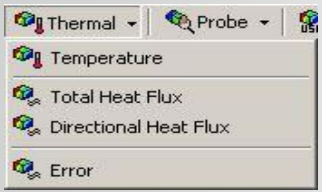


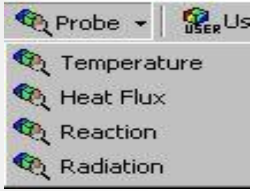


G. Results and Postprocessing

Various results are available for postprocessing:

- **Temperature**
- **Heat Flux**
- **“Reaction” Heat Flow Rate**
- **User defined results**





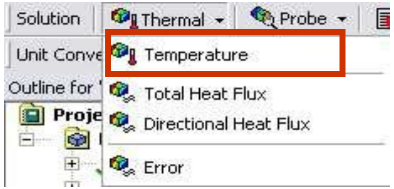
In Mechanical, results can be requested before or after solving.

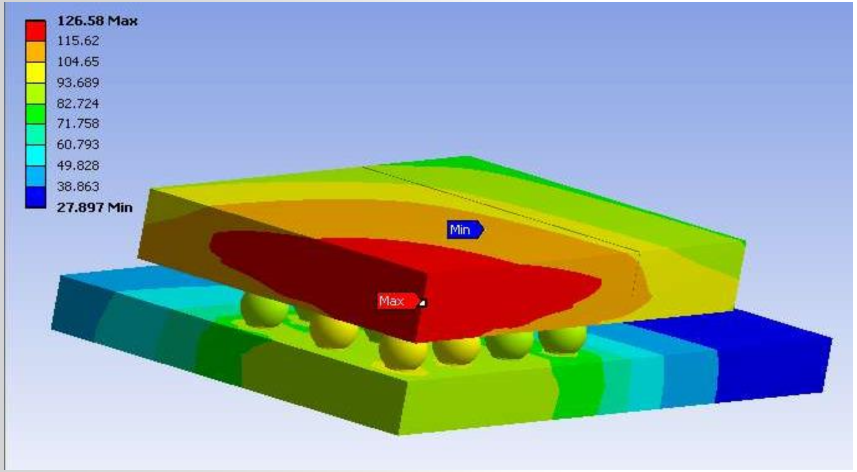
- **A new solution is not required when retrieving new results from a solved model.**

… Temperature

Temperature:

- **Temperature is a scalar quantity and has no direction associated with it.**



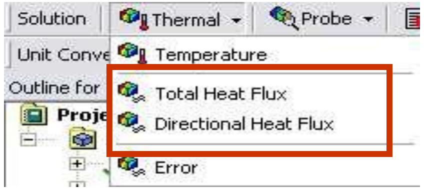


… Heat Flux

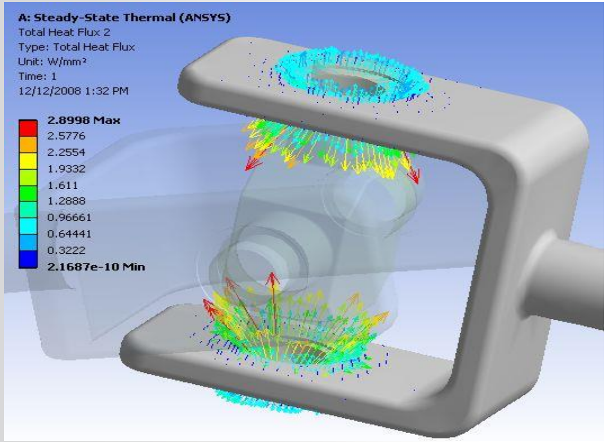
Heat flux contour or vector plots are available:

- **Heat flux *q* is defined as:**

$$q = -KXX \cdot \nabla T$$



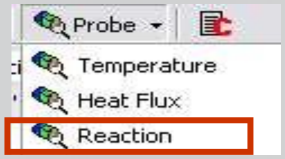
- **"Total Heat Flux" and "Directional Heat Flux" can be requested**
  - **The magnitude & direction can be plotted as vectors by activating vector mode**



… Reaction Heat Flow Rate

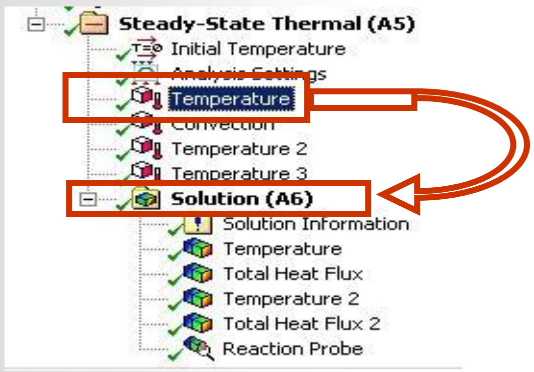
Reaction heat flow rates are available for Temperature, convection or radiation boundary conditions:

- **Reaction heat flow rate is requested by inserting a reaction probe.**
- **A short cut is to drag and drop a boundary condition onto the Solution branch.**

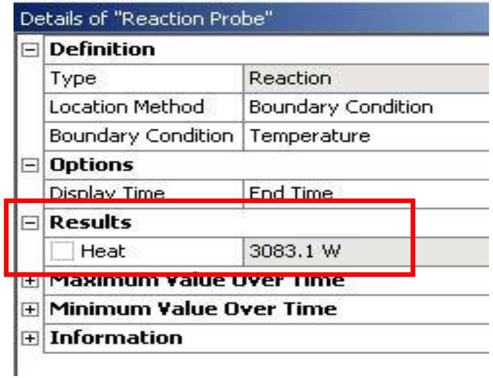


Select from Probe menu

OR



Drag and drop boundary condition



… Thermal equilibrium

When the solution is finished it's good practice to check the validity of the solution. Thermal equilibrium can be checked.

From the First Law of Thermodynamics, the steady-state heat balance can be expressed simply as:

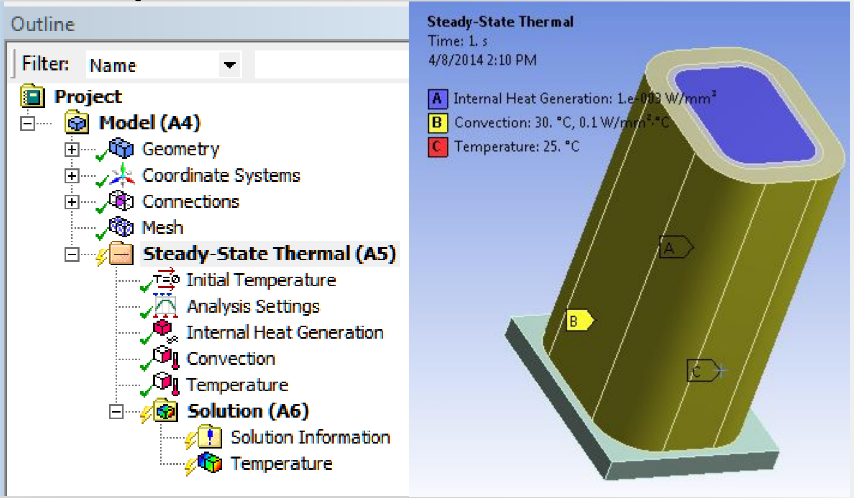
Energy in - Energy out = 0

Reaction probes are used to check heat transfer induced by each boundary condition.

Example next slide …

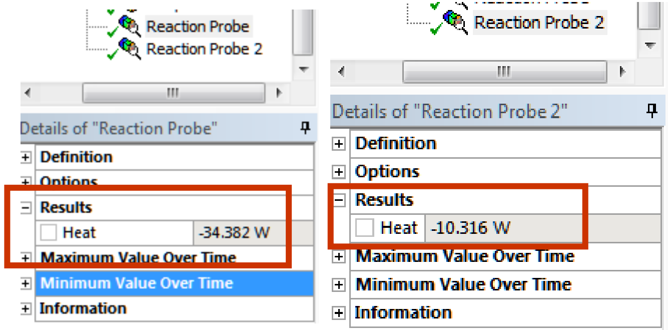
… Thermal equilibrium

Example:



Heat balance:

- **Heat generation load 0.001: W/mm^3. Total heat generated : + 44.698 W**
- **Reaction of temperature load: -34.382 W**
- **Reaction of convection BC: -10.316 W**



By summing the probe results we find good agreement:

$$H_{gen} - R_{temp} - R_{conv} = 0$$

$$44.698 - 10.316 - 34.382 = 0.000$$

Having verified an energy balance we can proceed to postprocess other results.

H. Workshop 9.1

- **Workshop 9.1 – Steady State Thermal Analysis**
- **Goal:**
  – **Analyze the pump housing shown below for its heat transfer characteristics.**