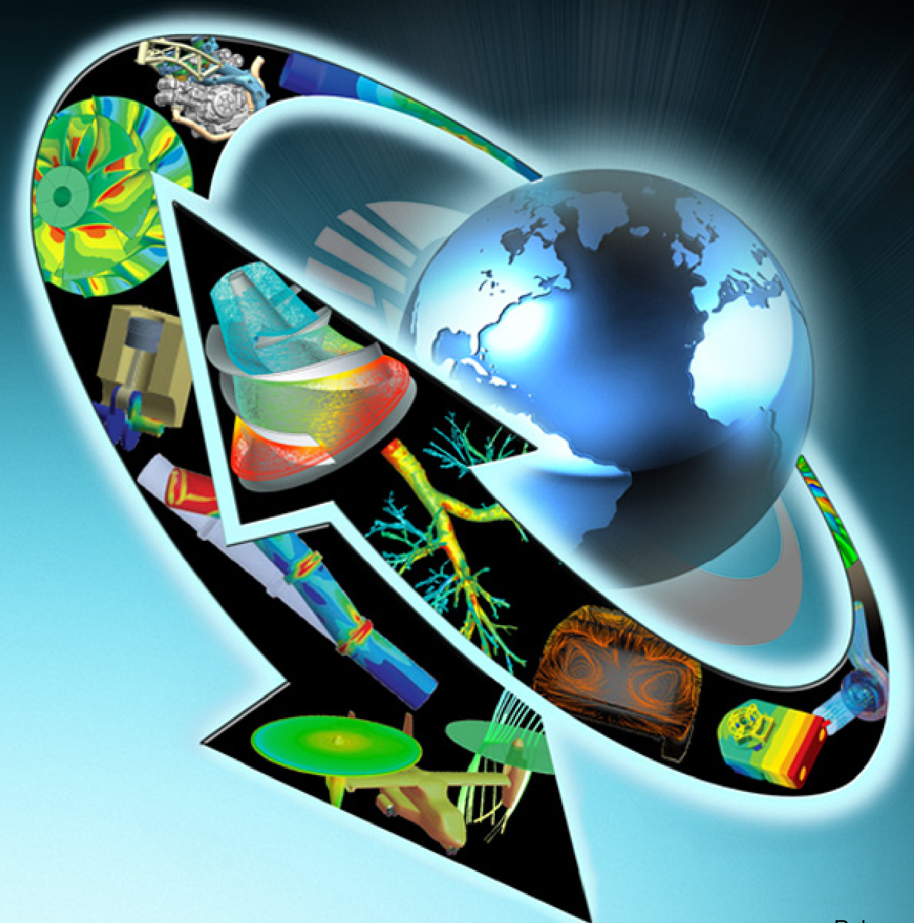
Customer Training Material

Appendix A

Advanced Heat Transfer Topics



ANSYS Mechanical Heat Transfer

Release 13.0
December 2010

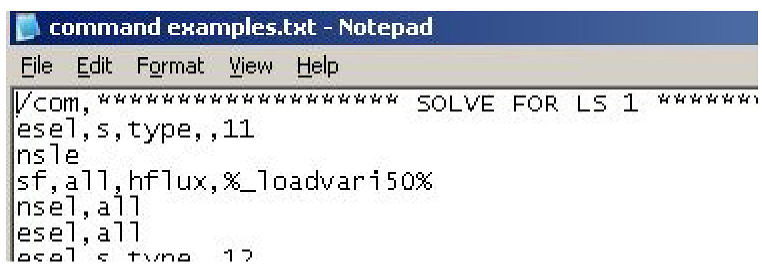
Contents

A. ANSYS APDL Command Language

- Despite the streamlined user interface the Mechanical application is command driven behind the scenes
- A series of sequential commands are submitted to the program as a result of various menu picks, however commands can be input directly
- In many cases very few commands are required to leverage additional features not currently available in the Workbench Mechanical interface
- Command Structure:
  - Commands are comma ‘,’ delimited
  - Extra spaces are unimportant (e.g. “N,1” is no different than “N,   1”)
  - Commands are not case sensitive (e.g. del = DeL)
    - Note: we will use caps here simply to differentiate the actual commands
  - The “ANSYS Mechanical APDL Command Reference” contains descriptions and syntax for all commands
  - Command files can be created, edited and viewed in simple text editors like Notepad

. . . ANSYS APDL Command Language

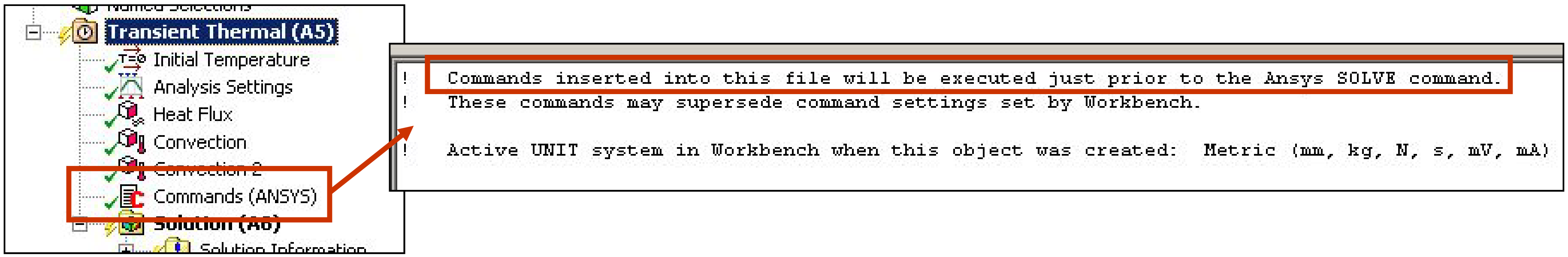
- **Command Structure:**
  - Let's look at the "N" command. This command is used to create a node.
  - From the commands manual we see the structure is:
    - N, NODE, X, Y, Z, THXY, THYZ, THZX:
      - N: the command name to create a node.
      - NODE: enter a number which will identify the node being created.
      - X, Y, Z: coordinate locations in the active coordinate system.
      - THXY, THYZ, THZX: rotations about active coordinate axes.
    - For example "N, 250, 10, 0, 15" would result in node number 250 being created at x=10, y=0 and z=15 in the active coordinate system (also note that no entry was required for rotations since none were desired).
- **When Mechanical executes a "solve" command, a batch input file containing commands is read. Example excerpt:**



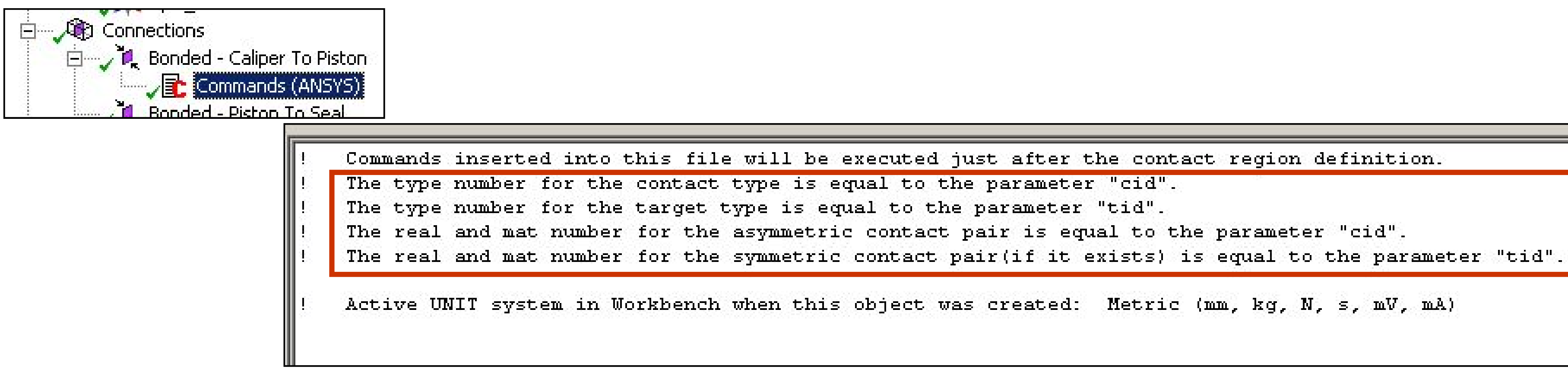

```
/com,******************** SOLVE FOR LS 1 *******
esel,s,type,,11
nsle
sf,all,hflux,%_loadvari50%
nsel,all
esel,all
esel,s,type,,12
```

B. Using Command Objects

- **When a command object is inserted in the Mechanical tree, the commands are executed in a specific order**
  - **Each command object indicates where it will be executed in its header**

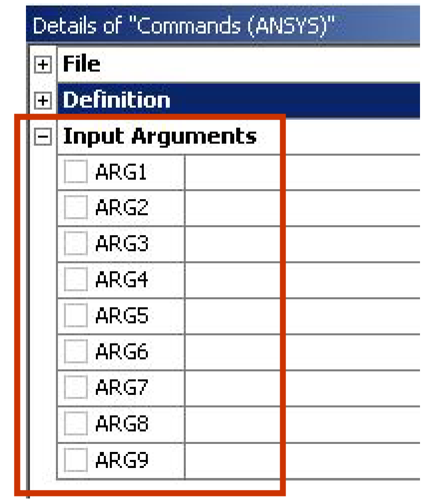


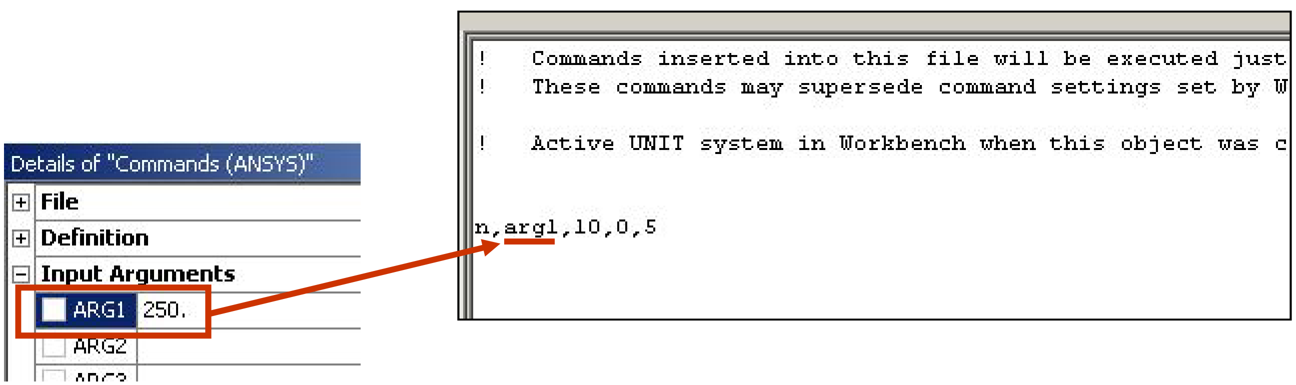
  - **In some cases local variables are available within a command object**
    - **Note a '!' symbol beginning a line denotes a comment**



. . . Using Command Objects

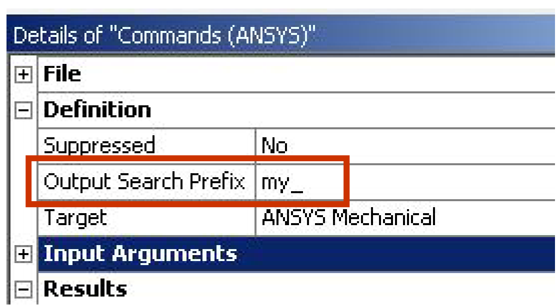
- Command objects can be parameterized via their details
- Up to 9 input arguments are available as local variables
- For example, “ARG1” is used to enter node number data into the “N” command below
- The value in the details for ARG1 is substituted in the expression in the command object





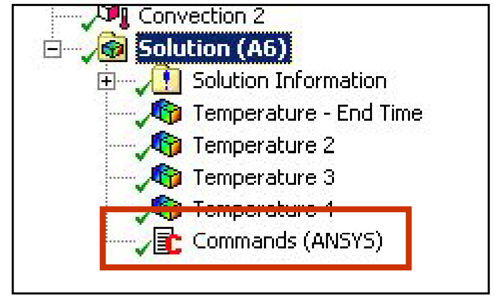
. . . Using Command Objects

- **Command objects may be used to retrieve information as well**
- **Data is extracted using the *GET command (see the "ANSYS Parametric Design Language Guide" for full details)**
  - ***GET retrieves information assigns a parameter name to the values**
  - **Thus: *GET, *parameter name*, . . .**
- **An output search prefix allows users to retrieve this parametric data to a command object (default is "my_" but is user controlled)**
  - **For example "MY_temperature" could be included in a command object and the result would be retrieved (see next slide)**
  - **The search prefix is not case sensitive**



. . . Using Command Objects

- In this example a command object is included in the Solution branch
- The *GET command is written to retrieve the temperature at node number 250
- That value is to be returned in a parameter called “MY_temperature”

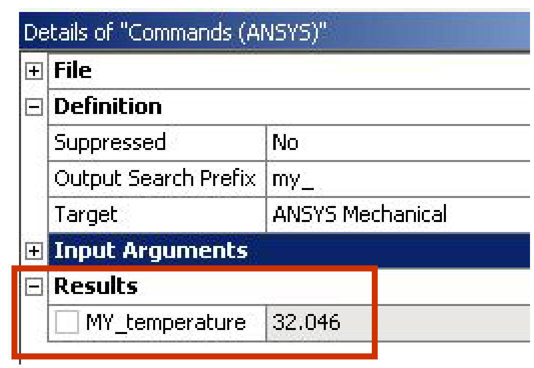



```
!   Commands inserted into this file will be executed immediately after the Ansys /POST1 command.

!   Active UNIT system in Workbench when this object was created:  Metric (mm, kg, N, s, mV, mA)

*GET, MY_temperature, node, 250, temp
```

- The result is returned to the details of the command object

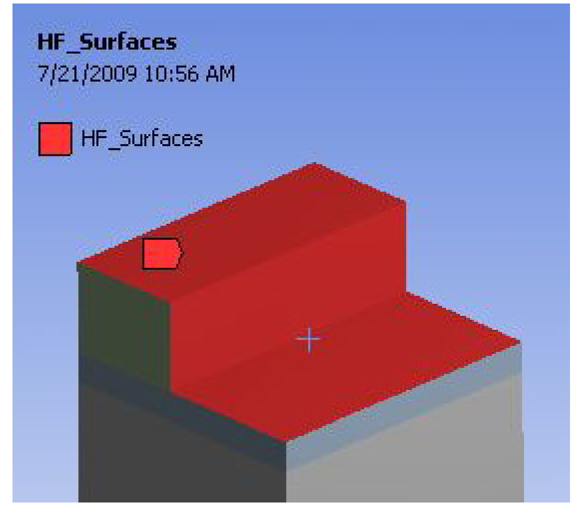


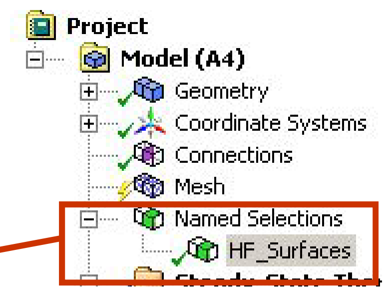
C. Named Selection Control

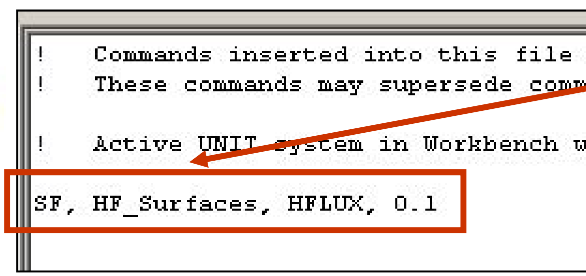
- **Workbench Mechanical:**
  - Named selections are groups of entities (e.g vertices, surfaces, etc.) which are related to one another by a common name
  - A named selection allows users to control all related entities as a group rather than individually
  - In addition to the common Workbench Mechanical uses above, a named selection is "recognized" by the ANSYS APDL solver in special ways
- **Mechanical APDL:**
  - In ANSYS APDL groups like named selections are referred to as "components"
  - A named selection created in Workbench Mechanical will become a component (of the same name) within ANSYS Mechanical APDL
  - Named Selection to Component transfer:
    - Vertex, Line or Surface NS = Nodal component
    - Body NS = Element component

. . . Named Selection Control

- A named selection provides a "bridge" from Workbench to APDL for identifying parts of a model
- Example: we would like to use the "SF" command to apply a heat flux using a command branch
  - First the surfaces where the heat flux will be applied are grouped as a named selection
  - The "name" is then used in the APDL command

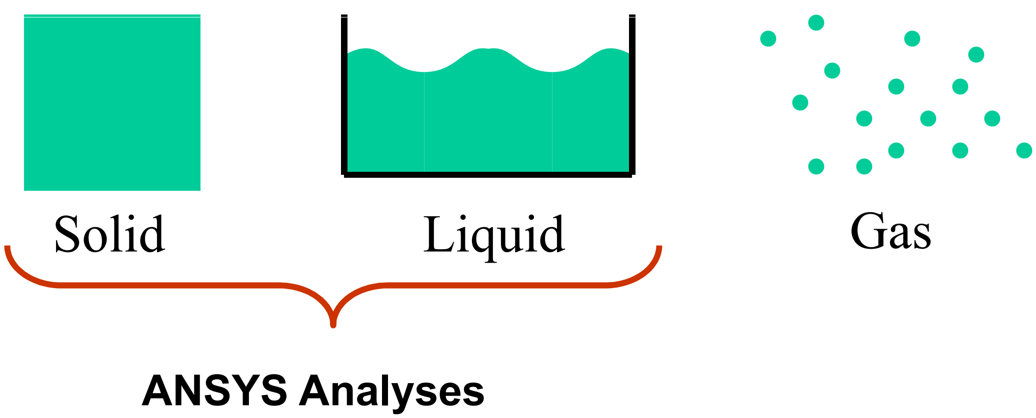






D. Phase Change

- **Phase Change - A change of energy to a system (either added or taken away) causes a substance to change phase**
  - **The Common phase change processes are called freezing, melting, vaporization, or condensation**
- **Phase - A distinct molecular structure of a substance, homogeneous throughout**
  - **There are three principal phases:**



. . . Phase Change

- **Latent Heat:**
  - **When a substance changes phase, the temperature remains constant or nearly constant throughout the change.**
  - **For example, solid ice at 0 °C is ready to melt:**
    - **Heat is added to the ice and it becomes liquid water.**
    - **When the ice has just become completely liquid, it is still 0 °C.**
  - ***Where did the heat energy go, if there was no temperature change?***
    - **The heat energy is absorbed by changes in the molecular structure of the substance.**
    - **The energy required for the substance to change phase is called its *latent heat*.**
  - **A phase change analysis must account for the latent heat of the material.**
  - **Latent heat is related using the enthalpy property which varies with temperature. Therefore, a thermal phase change analysis is non-linear.**

Enthalpy, H, is related to density (ρ), specific heat (c), and temperature (T) according to:

$$H = \int \rho c dT$$

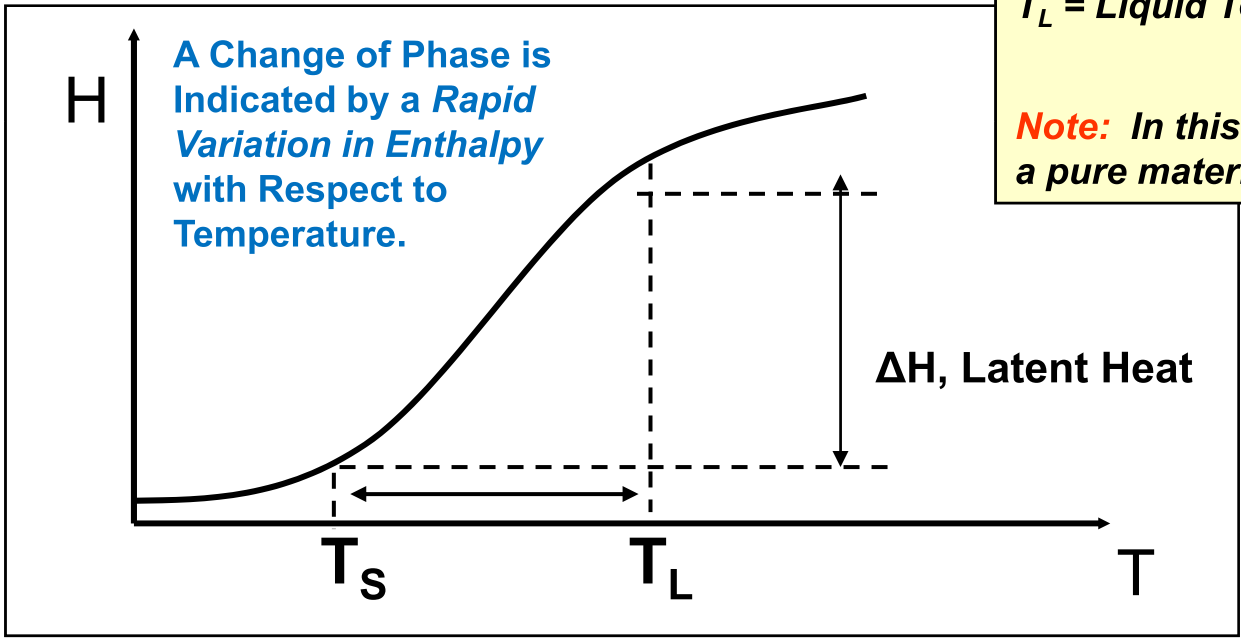
. . . Phase Change

- **During phase change, a small temperature range exists where both the solid and liquid phases exist together.**
  - **The temperature at which the substance is completely liquid (the liquidus temperature) is $T_{L.}$**
  - **The temperature at which the substance is completely solid (the solidus temperature) is $T_{S.}$**

T_S = Solid Temperature

T_L = Liquid Temperature

Note: In this diagram, T_L - T_S is small. For a pure material, T_L - T_S would be zero.



. . . Phase Change

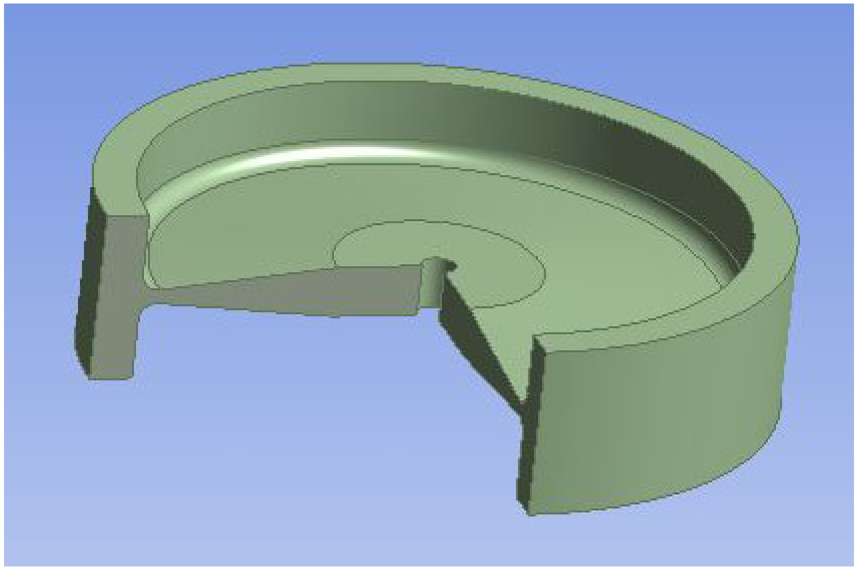
- **Applications involving phase change which can be approached using ANSYS Mechanical products are:**
  - **The freezing (or solidification) of a liquid.**
  - **The melting of a solid.**
- **A phase change analysis must be solved as a thermal transient analysis.**
- **Phase change analysis recommendations:**
  - **Transient analysis type.**
  - **A small initial and minimum time step sizes.**
  - **Use automatic time stepping.**
  - **Generally the "Line Search" solution option is preferred.**
  - **ANSYS enthalpy data (material property) must be specified in units of energy/volume.**
    - **NOTE: the enthalpy material property is not available in Workbench Mechanical Engineering Data. This property must be added via a command object.**

. . . Phase Change

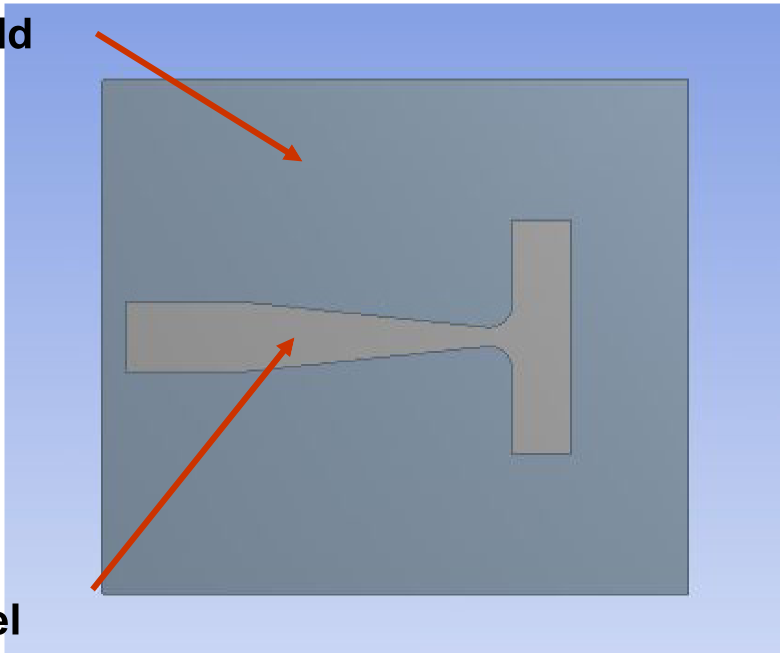
- **Enthalpy Definitions/Calculations (reference):**
  - Equations 1 through 7 can be used to calculate enthalpy values to enter as material properties
    1. $C_{avg} = (C_S + C_L)/2$: Average specific heat
    2. $C^* = C_{avg} + (L / (T_L – T_S))$: Specific heat for transition
    3. $H_- = p^*C (T – T_0)$: Enthalpy below solid temperature
    4. $H_S = p\ C_S (T_S – T_0)$: Enthalpy at solid temperature
    5. $H_{TR} = H_S + pC (T_L – T_S)$: Enthalpy between solid/liquid temperatures
    6. $H_L = H_S + pC^* (T_L – T_S)$: Enthalpy at liquid temperature
    7. $H_+ = H_L + pC_L (T – T_L)$: Enthalpy above liquid temperature
  - C_S: specific heat of solid
  - C_L: specific heat of liquid
  - P: density
  - T_S: solidus temperature
  - T_L: liquidus temperature
  - L: latent heat

. . . Phase Change

- **Example: solidification of an aluminum flywheel casting contained in a sand mold**
  - **A 2D axisymmetric model is used to represent the 3D one shown below on left**



3D Wheel Model with Cutaway

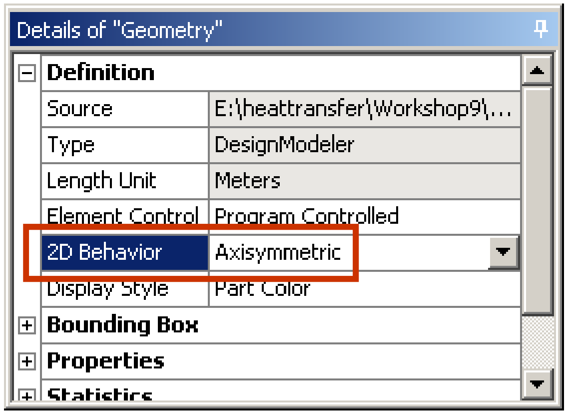


2D Axisymmetric Model with Sand Mold

. . . Phase Change

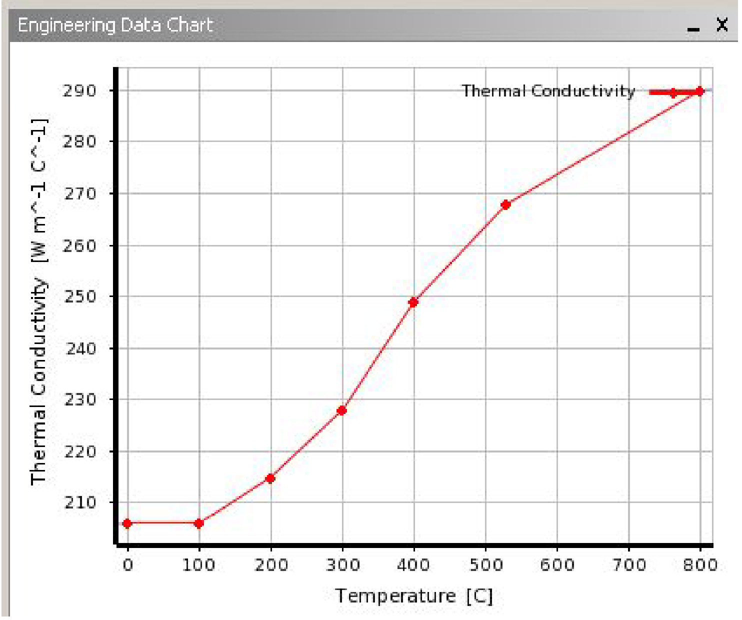
- **Description:**
  - **The molten aluminum is introduced into the mold at 800° C**
  - **The ambient temperature and the mold are initially at 30° C**
  - **The top and side faces of the mold exchange heat with the environment by free convection**
  - **Axisymmetric behavior is assumed for sand mold and aluminum casting**
  - **Thermal material properties are assumed constant for the sand, but vary with temperature for the aluminum**
  - **Specific heat and density will be replaced by enthalpy for the aluminum**
  - **The end time for the analysis will be 25 minutes (1500 seconds)**

. . . Phase Change



- **Set "Axisymmetric" as the 2D behavior**
- **Material Properties:**
  - **Sand:**
    - **Thermal conductivity : 0.346 W/m-°C**
    - **Density : 1520 kg/m3**
    - **Specific Heat : 816 J/kg-°C**
  - **Aluminum:**
    - **Thermal Conductivity as a function of Temperature**

Temperature Deg. C	Thermal Conductivity (W/(m*C))
0	206
100	208
200	215
300	228
400	249
530	268
800	290



. . . Phase Change

- **The enthalpy data for aluminum is not given however we can use the properties below to calculate enthalpy:**
  - **Choose T_S = 695° C and T_L = 697° C (giving a 2 degree transition zone between liquid and solid phases)**

Property	Value
Melting Point	696 °C
Density	2707 kg/m^3
C_s, Solid Specific Heat	896 J/kg-°C
C_l, Liquid Specific Heat	1050 J/kg-°C
L, Latent Heat	395440 J/kg
(or from L x Density)	1.0704e9 J/m^3

Temp (C)	Enthalpy (J/m3)	Value	Equation Number (p 7-19)
0	0	H_0	-
695	1.6857E9	H_S	4
697	2.7614E9	H_L	6
1000	3.6226E9	H_+	7

. . . Phase Change

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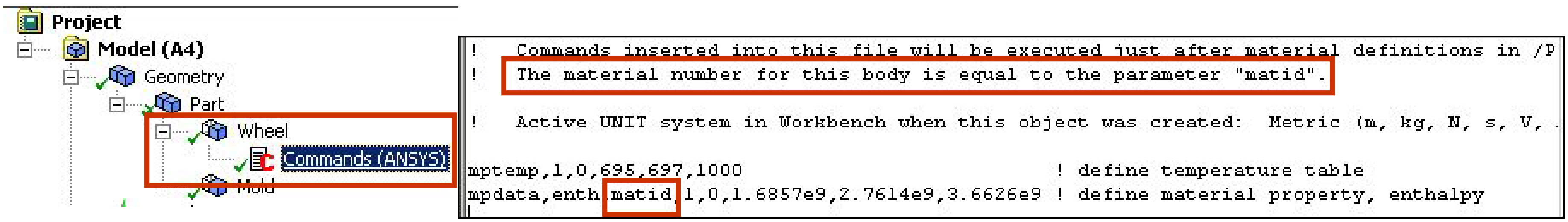
- **Using these enthalpy calculations a command object containing 2 commands is used to enter the values.**
  - **By associating the commands to the “Wheel” part, the local parameter “matid” can be used to specify the material number in the command.**



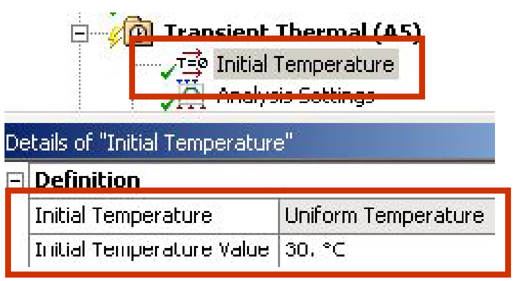
  - **Since the enthalpy property is derived from both density and specific heat, those properties are overwritten in engineering data.**

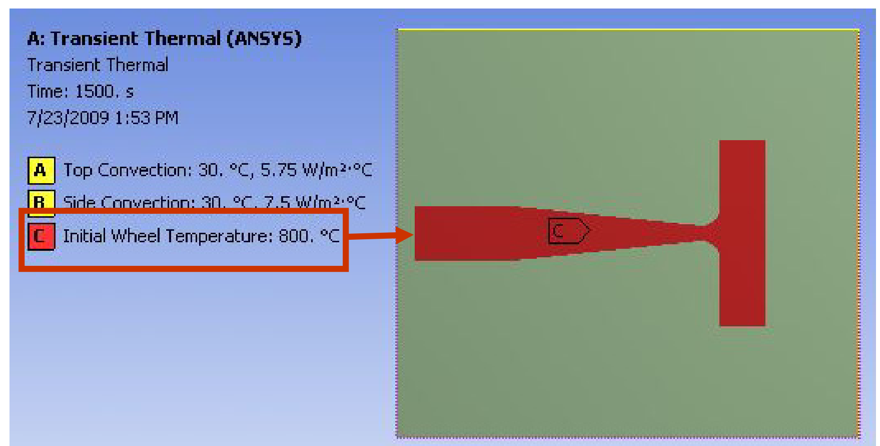
. . . Phase Change

- **Given the nature of the loading we choose 2 load steps in the analysis settings**
  - **The initial step (0.1 s) is used to establish the initial temperature for the liquid aluminum (800º C)**
  - **The second step (1500 s) represents the transient cooling/solidification of the aluminum**
  - **The "Initial Temperature" branch accounts for the mold's initial 30º C**

Analysis Settings

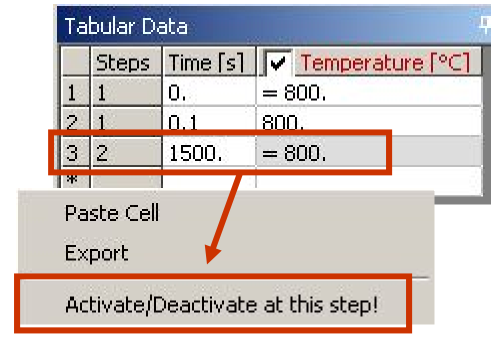
Properties	Step 1	Step 2
Step Controls		
Step End Time	0.1	1500.
Auto Time Stepping	On	On
Define By	Time	Time
Carry Over Time Step	N/A	Off
Initial Time Step	1.e-003	1.e-003
Minimum Time Step	1.e-003	1.e-004
Maximum Time Step	0.1	5.
Time Integration	On	On
Nonlinear Controls		
Heat Convergence	Program Controlled	Program Controlled
Temperature Convergence	Program Controlled	Program Controlled
Line Search	On	On
Output Controls		
Calculate Thermal Flux	Yes	Yes
Calculate Results At	All Time Points	All Time Points

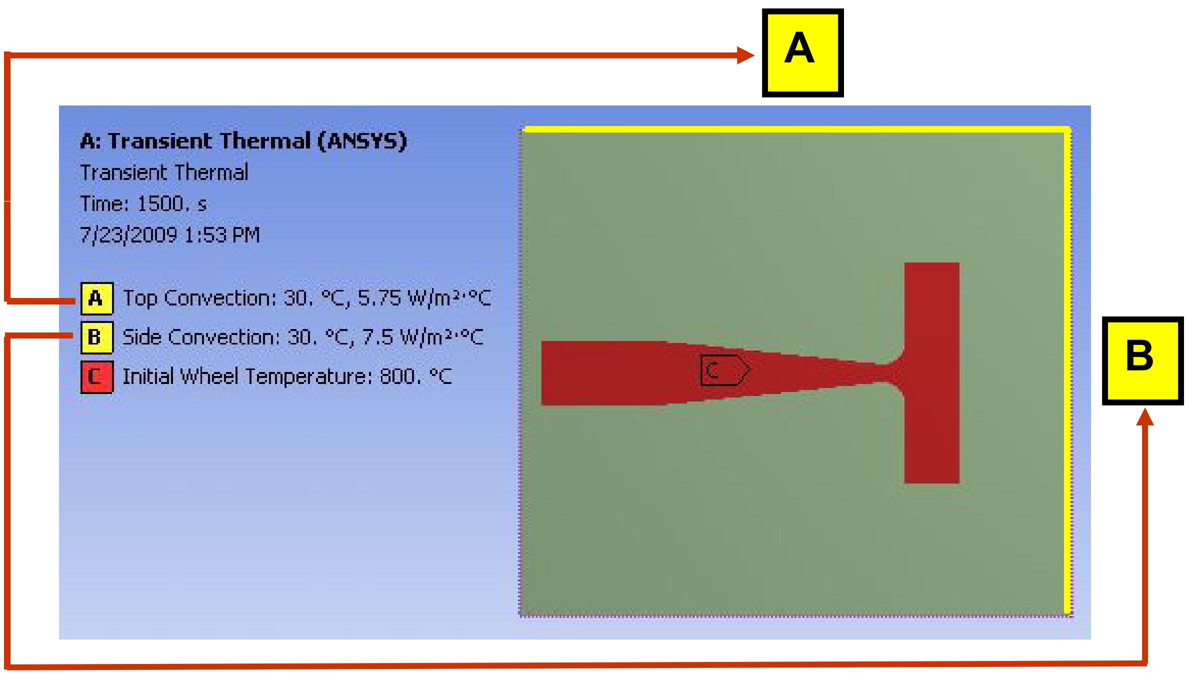




. . . Phase Change

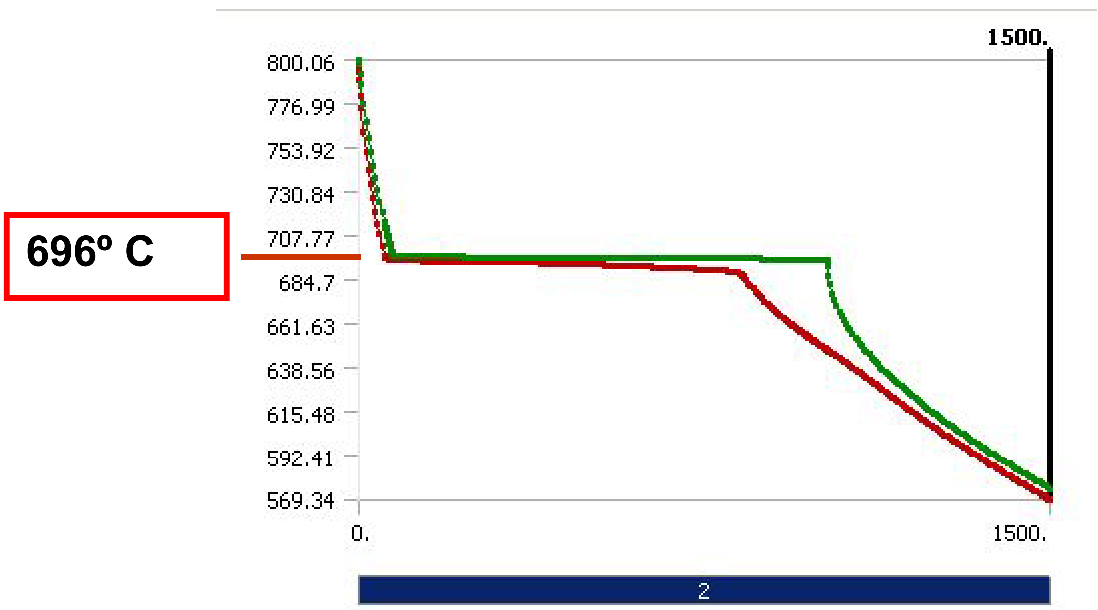
- **From the tabular data for the temperature load, the load is deactivated for step 2**
  - **Note the load must be deactivated not simply set to zero**
- **Convection loads are applied as shown below**





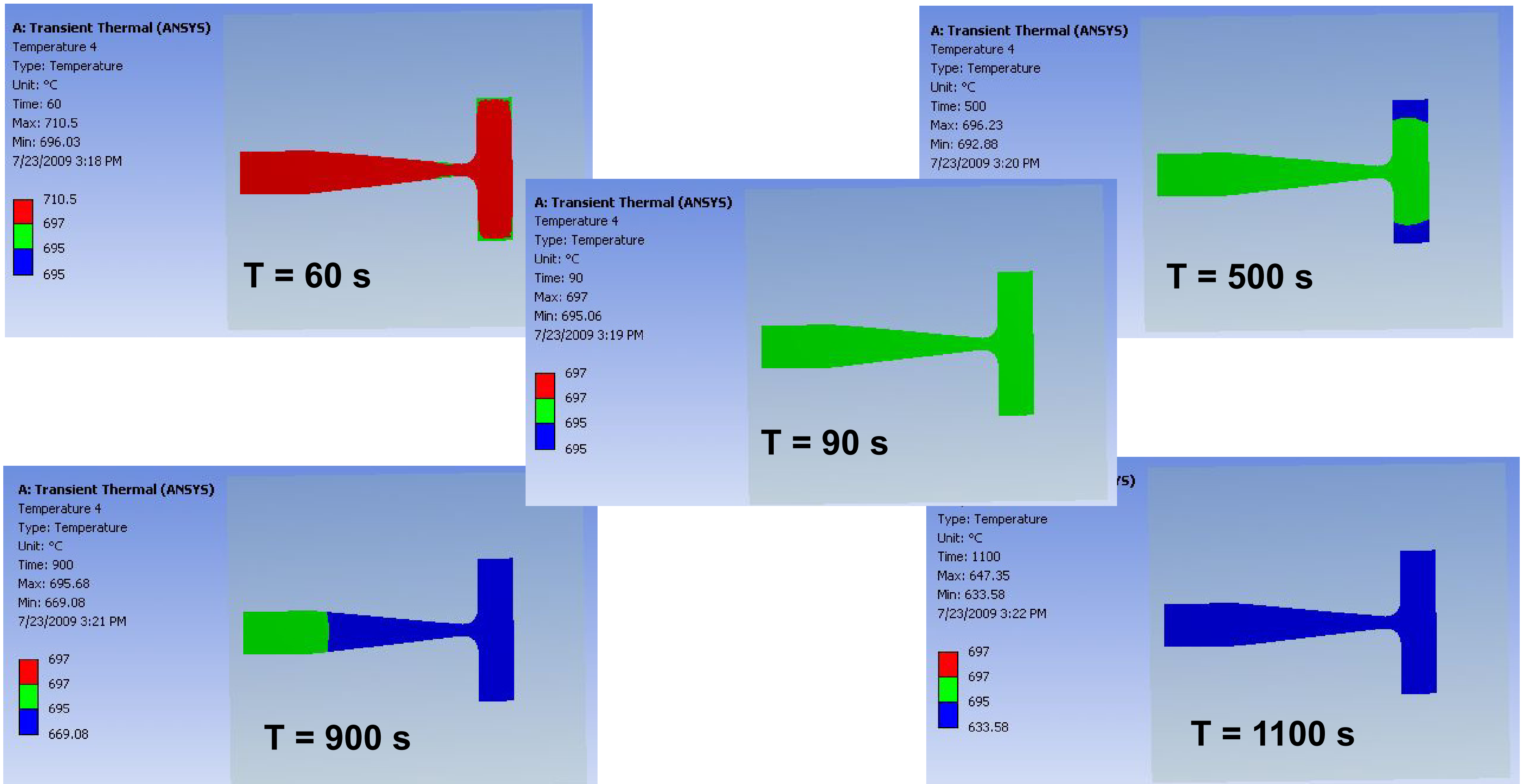
. . . Phase Change

- **When the solution is complete a plot of temperature vs time show temperatures leveling off near the material's transition region (695-697º C) as solidification occurs**



. . . Phase Change

- Temperature plots at discreet time points illustrate the progress of solidification (red = liquid; green = transition; blue = solid)



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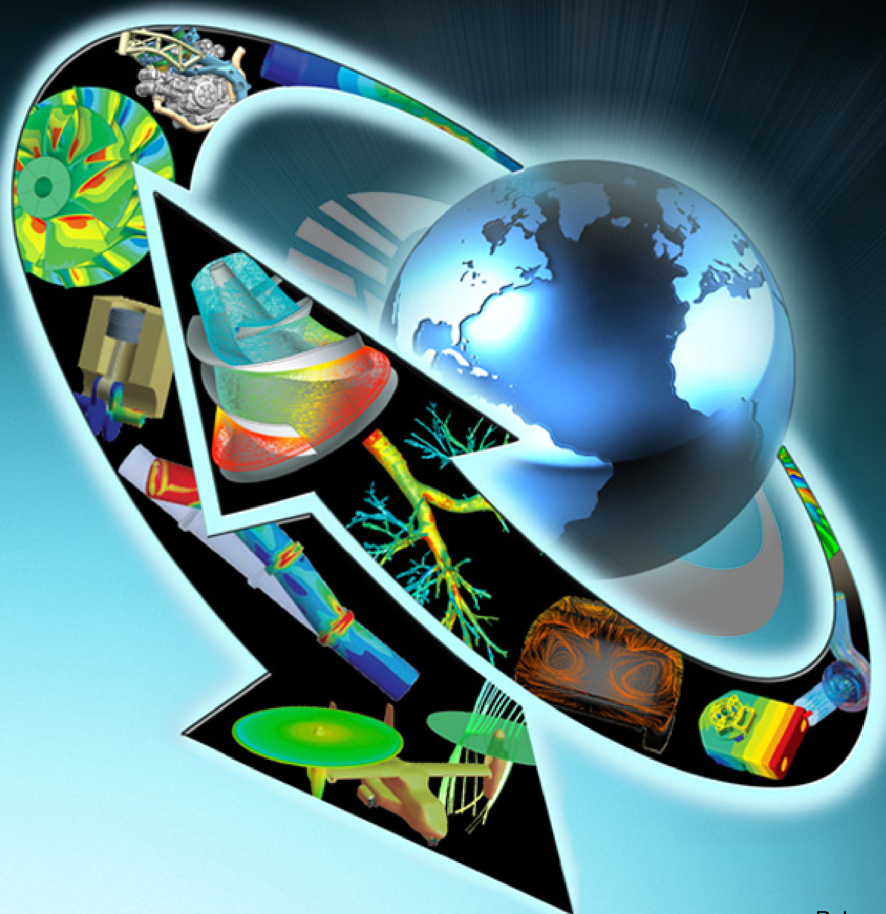
Workshop (Appendix)

Phase Change



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