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Practices, October 12 and 13

Numerical Simulation of a Heat Transfer Problem with ANSYS

Jörg Wolters, FZJ – ZEA-1

Contents

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Introduction
↳ Finite Element Method (FEM)

- Public known from e.g. crash simulations for automobile industry

Source: Institute for technical and numerical mechanics, University of Stuttgart

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Introduction

↳ Finite Element Method (FEM) – how does it work?

- The Finite Element Method (FEM) is a numerical method for solving problems (differential equations) of engineering and mathematical physics.
- Useful for problems with complex geometries, loadings, and material properties, for which analytical solutions are not available any more.
- Applicability: structural/stress analyses, heat transfer, electromagnetic fields, crash , fluid dynamics, fracture mechanics, acoustics …
- The whole domain is divided into small elements for which the field variables (e.g. displacements for mechanical problems) are interpolated from values at the corners (nodes) by approximating functions. The values of the field variable at the element nodes become the unknown of the problem, from which all other values can be derived (e.g. strains and stresses for structural analyses).

- Recombining all sets of element equations into a global system of equations, the problem can be solved for the whole domain.
- Important: The solution of a finite element analysis is not exact but only an approximation that strongly depends on the discretization and the approximating functions.

Introduction

↳ Finite Element Method (FEM) – what are the Benefits?

- identification of faulty designs and weak spots in the early development phase
- analysis of complex systems possible
- minimizing costly physical testing*
- results are available everywhere in the system
- fast and easy design optimization in terms of material stressing, weight, stiffness …
- assessment of lifetime

→

- enhanced product quality
- shortening of development phases
- reduction of development costs

*nevertheless, in most cases experiments are also indispensable in prototype development and only the combination of simulations and experiments will lead to optimal results

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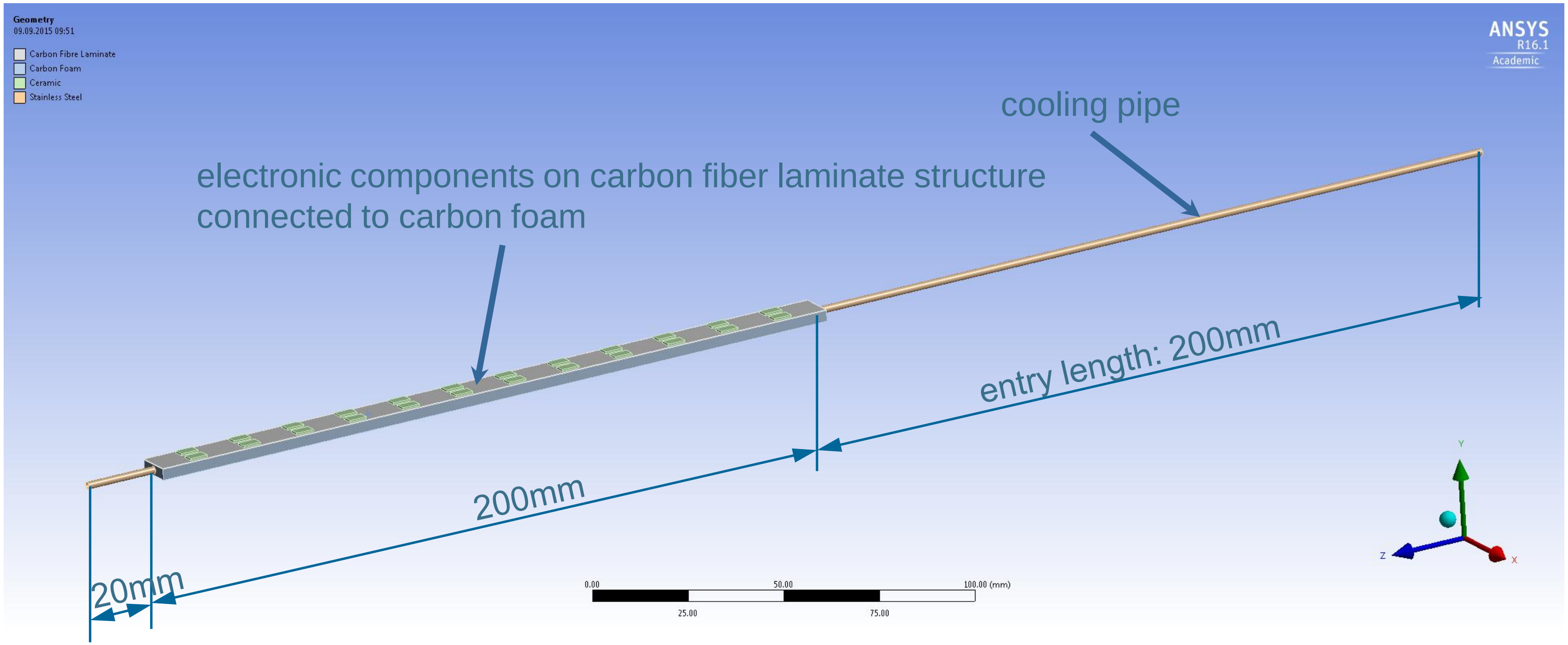
Exercise: Cooling of electronic components

↳ Exercise details

➢ Geometry



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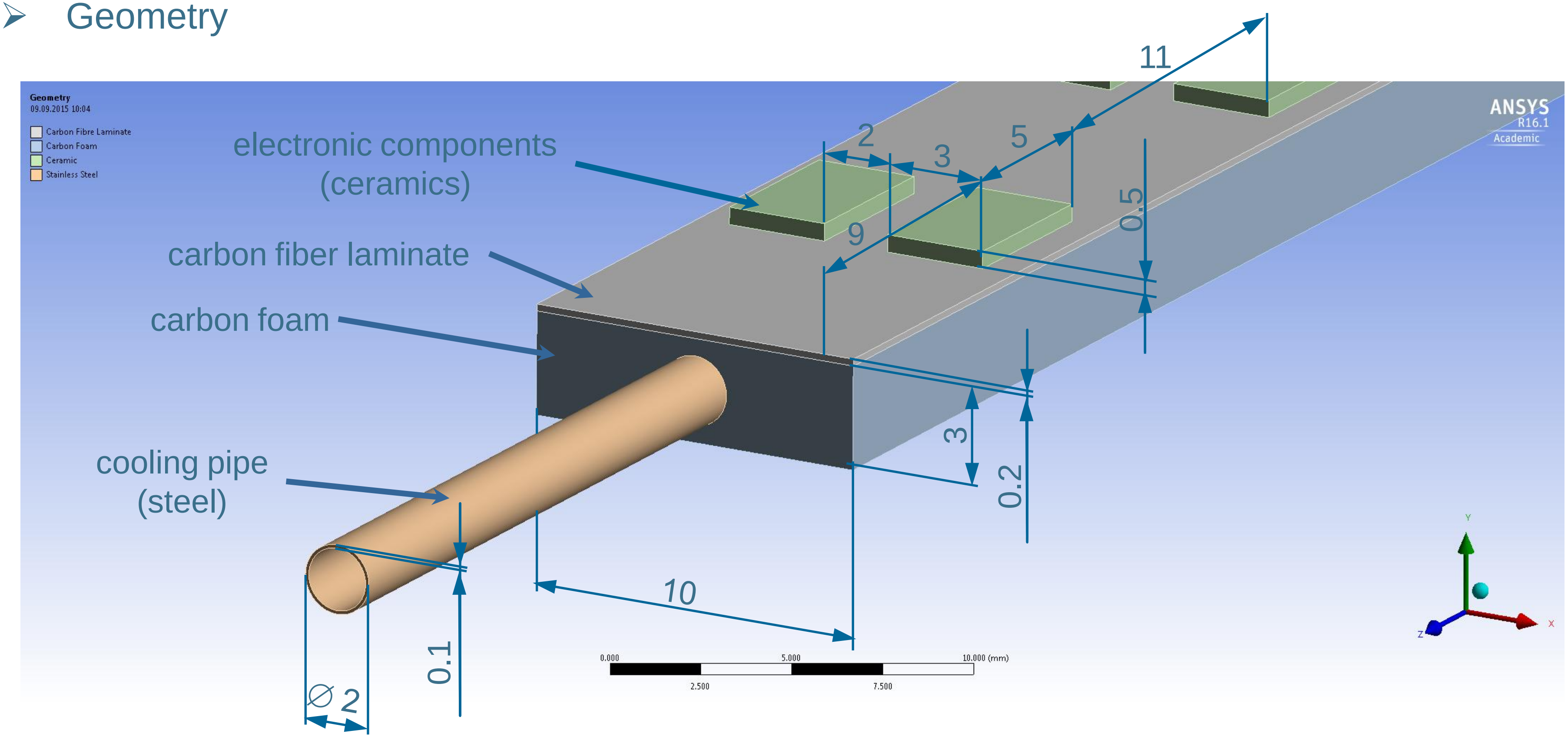
Exercise: Cooling of electronic components

↳ Exercise details

- Geometry



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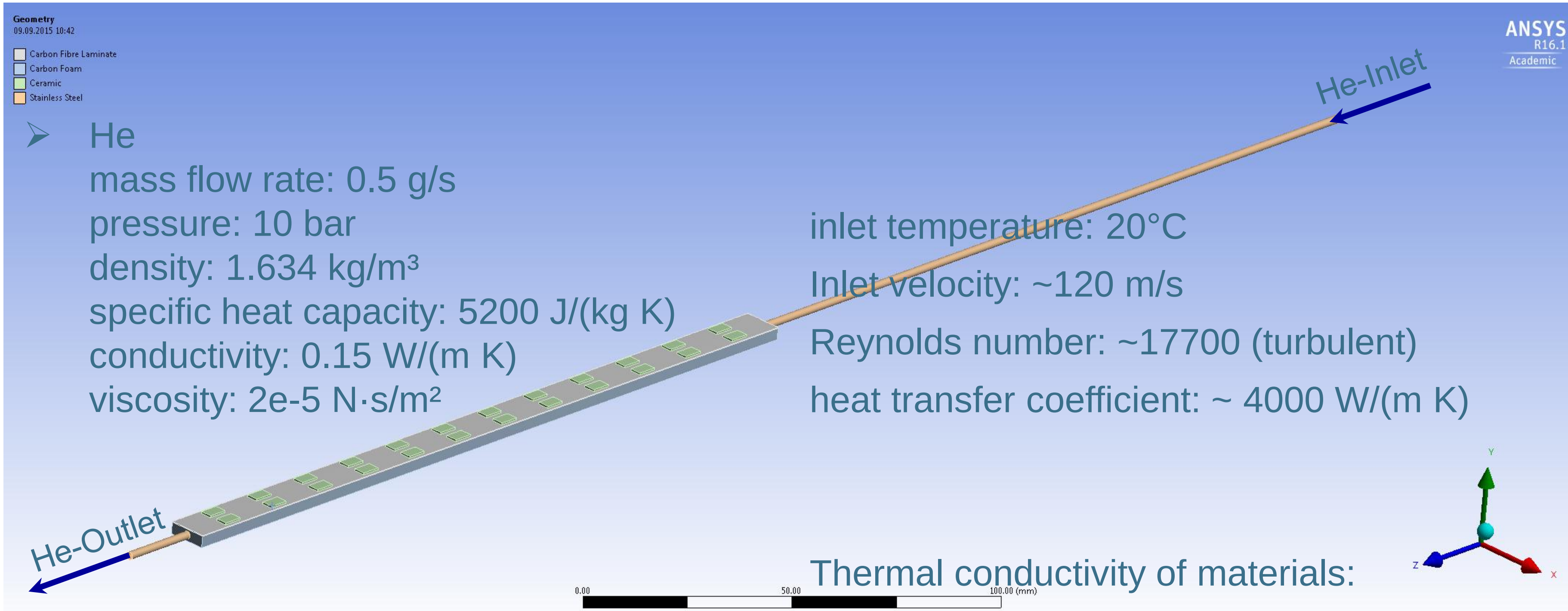
Exercise: Cooling of electronic components
↳ Exercise details

- Boundary Conditions



- He
  mass flow rate: 0.5 g/s
  pressure: 10 bar
  density: 1.634 kg/m³
  specific heat capacity: 5200 J/(kg K)
  conductivity: 0.15 W/(m K)
  viscosity: 2e-5 N·s/m²

inlet temperature: 20°C

Inlet velocity: ~120 m/s

Reynolds number: ~17700 (turbulent)

heat transfer coefficient: ~ 4000 W/(m K)

- Electronics
  heat generation:1.5 W per block
  total heat: 24·1.5 W = 36 W

Thermal conductivity of materials:

carbon foam: 70 W/(m K)
ceramics: 4.5 W/(m K)
steel: 15 W/(m K)
carbon fiber laminate:
  10 W/(m K) (in plane)
  0.5 W/(M K) (vertical)

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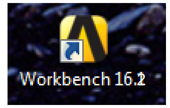
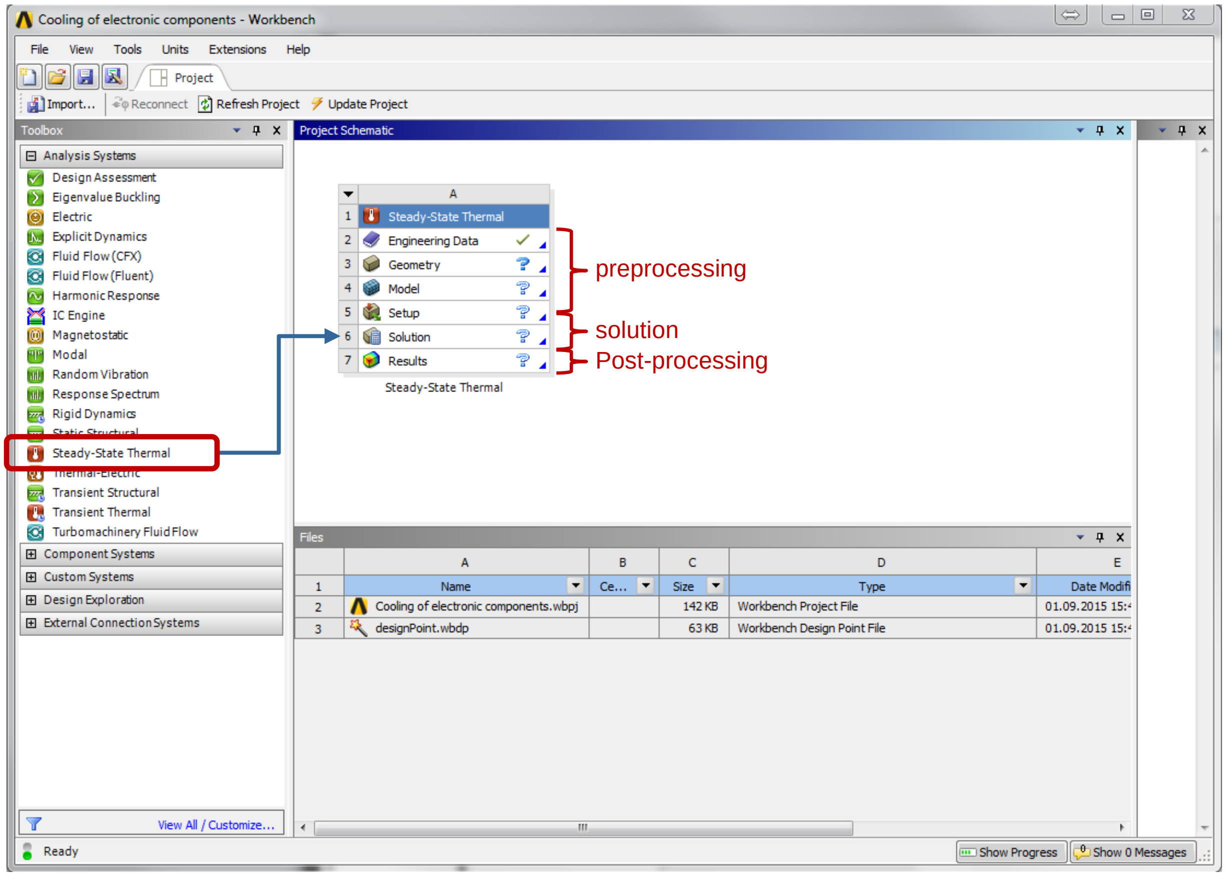
Exercise: Cooling of electronic components

↳ set up the simulation project

- Start WB16.2 from desktop



- Drag and Drop with LMB (left mouse button) ‘Steady-State Thermal’ to Project Schematic



- Main Menu => File => Save As… (choose directory and project name)

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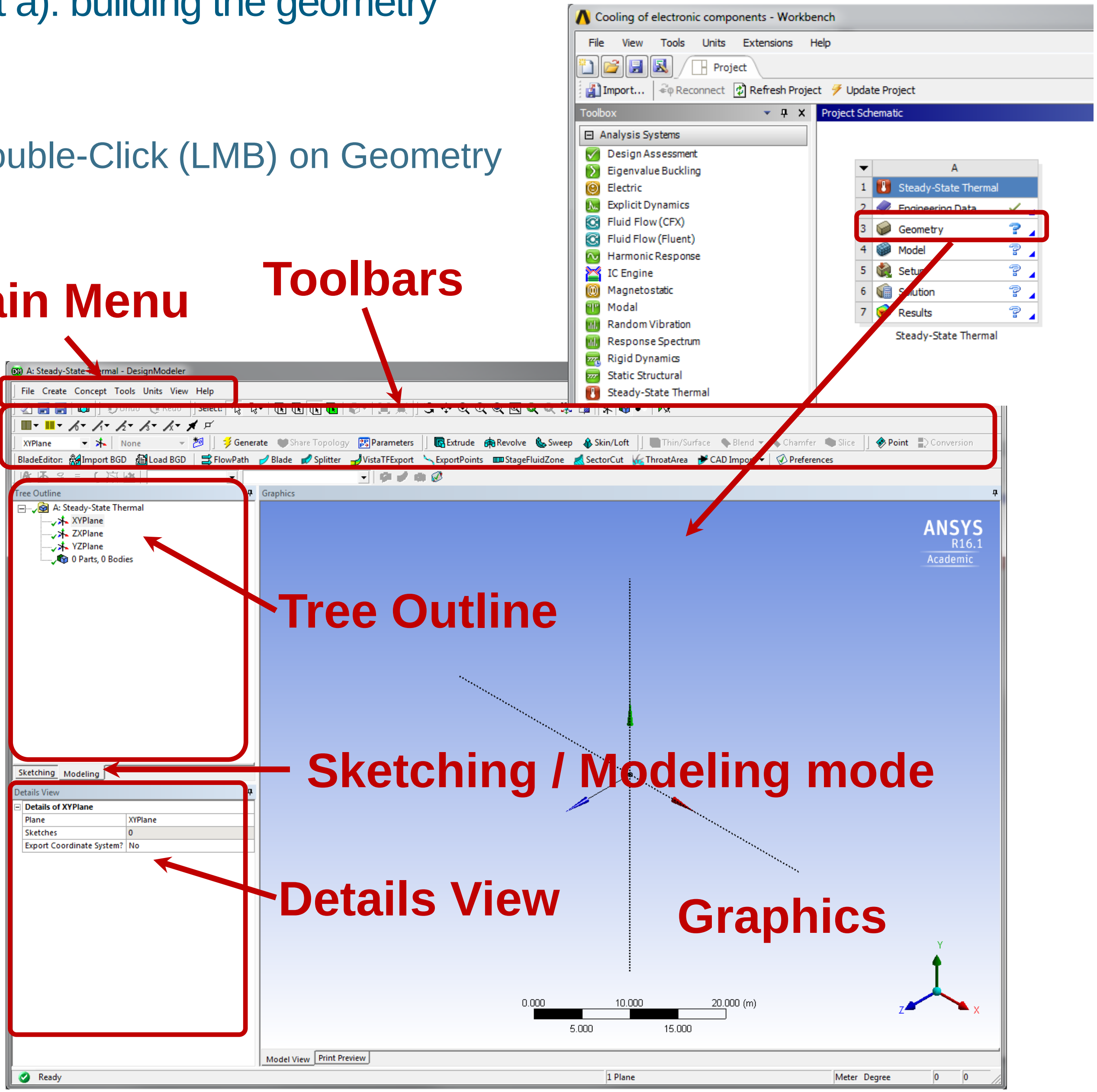
Exercise: Cooling of electronic components

↳ part a): building the geometry

➢ Double-Click (LMB) on Geometry



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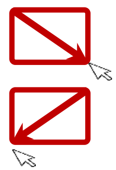
Exercise: Cooling of electronic components
↳ part a): building the geometry - toolbars

➢ Selection Tools:

Entity Selection Mode
- **New Selection**
- **Single Select**
- **Box Select**
- **Select Points**
- **Select Edges**
- **Select Faces**
- **Select Bodies**



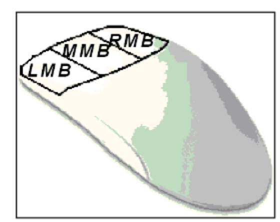
drag from left to right: items completely enclosed are selected

drag from right to left: items completely or **partially** enclosed are selected

➢ View options:

View Options can be accessed via toolbar
- **Rotate**
- **Pan**
- **Zoom**

- **Much quicker is Middle Mouse Button (MMB) with key changes**
  – Rotate
  – Shift + MMB : Zoom
  – Ctrl + MMB : Pan



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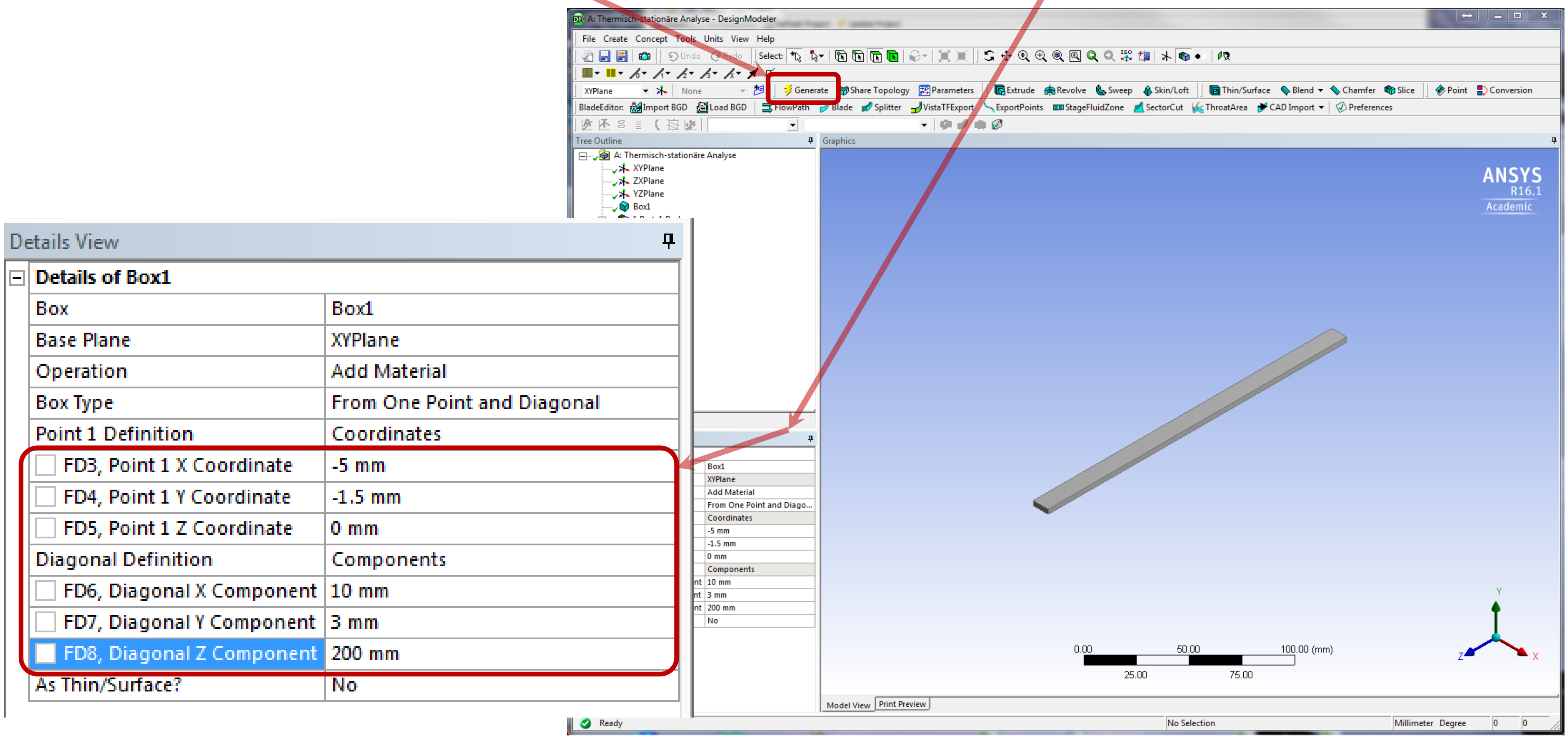
Exercise: Cooling of electronic components

part a): building the geometry – foam

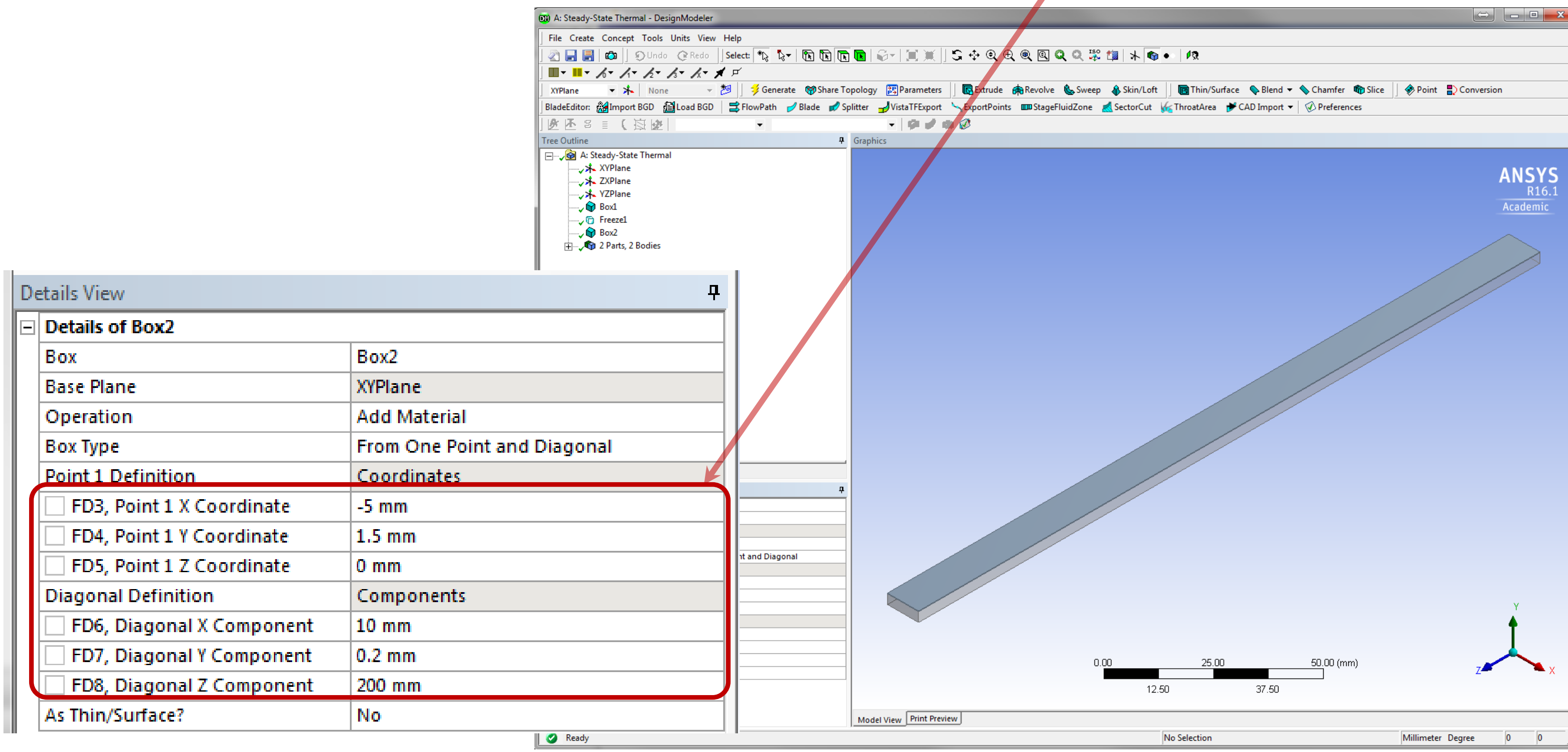
- Main Menu => Units => mm
- Main Menu => Create => Primitives => Box
- Details View: Enter dimensions (point 1: -5mm, -1.5mm,0mm; diagonal: 10mm, 3mm, 200mm)
- Toolbars => Generate (will create box)
- Main Menu => Tools => Freeze (protects body from being merged with other bodies)



Exercise: Cooling of electronic components

↳ part a): building the geometry – polyethylene layer

- Main Menu => Create => Primitives => Box
- Details View: Enter dimensions (point 1: -5mm, 1.5mm, 0mm; diagonal: 10mm, 0.2mm, 200mm)
- Toolbars => Generate
- Main Menu => Tools => Freeze
- Toolbars => (Zoom to fit / ‘F7’) and (Save Project / ‘Ctrl’ + ‘s’)



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Exercise: Cooling of electronic components

↳ part a): building the geometry – cooling pipe / outer dimension

- Main Menu => Create => Primitives => Cylinder
- Details View:

Details View

Details of Cylinder1	
Cylinder	Cylinder1
Base Plane	XYPlane
Operation	Add Material
Origin Definition	Coordinates
FD3, Origin X Coordinate	0 mm
FD4, Origin Y Coordinate	0 mm
FD5, Origin Z Coordinate	-200 mm
Axis Definition	Components
FD6, Axis X Component	0 mm
FD7, Axis Y Component	0 mm
FD8, Axis Z Component	420 mm
FD10, Radius (>0)	1 mm
As Thin/Surface?	No

- Toolbars => Generate
- Main Menu => Tools => Freeze

Exercise: Cooling of electronic components

↳ part a): building the geometry – cooling pipe / inner dimension

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- Main Menu => Create => Primitives => Cylinder
- Details View:

Details View

Details of Cylinder2	
Cylinder	Cylinder2
Base Plane	XYPlane
Operation	Add Material
Origin Definition	Coordinates
FD3, Origin X Coordinate	0 mm
FD4, Origin Y Coordinate	0 mm
FD5, Origin Z Coordinate	-200 mm
Axis Definition	Components
FD6, Axis X Component	0 mm
FD7, Axis Y Component	0 mm
FD8, Axis Z Component	420 mm
FD10, Radius (>0)	0.9 mm
As Thin/Surface?	No

- Toolbars => Generate
- Main Menu => Tools => Freeze
- Toolbars =>

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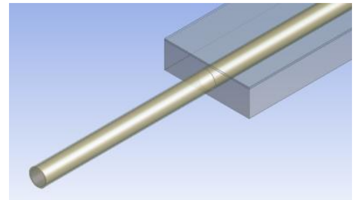
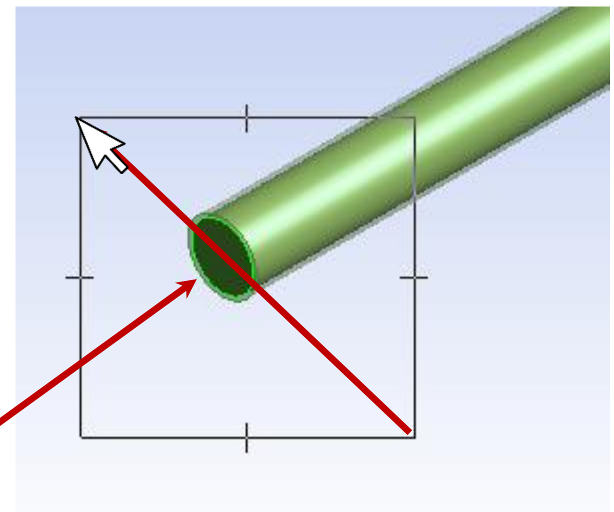
Exercise: Cooling of electronic components
↳ part a): building the geometry – intersect cylinders

- Toolbars => (Zoom in):



- Toolbars => (Select Bodies 'Ctrl' + 'B')
- Toolbars => (Box Select): Select both cylinders



- Main Menu => Create => Boolean
- Details View:

Details View

Details of Boolean1	
Boolean	Boolean1
Operation	Intersect
Tool Bodies	2 Bodies
Preserve Tool Bodies?	Yes, Sliced
Intersect Result	Intersection of All Bodies

- Toolbars => Generate

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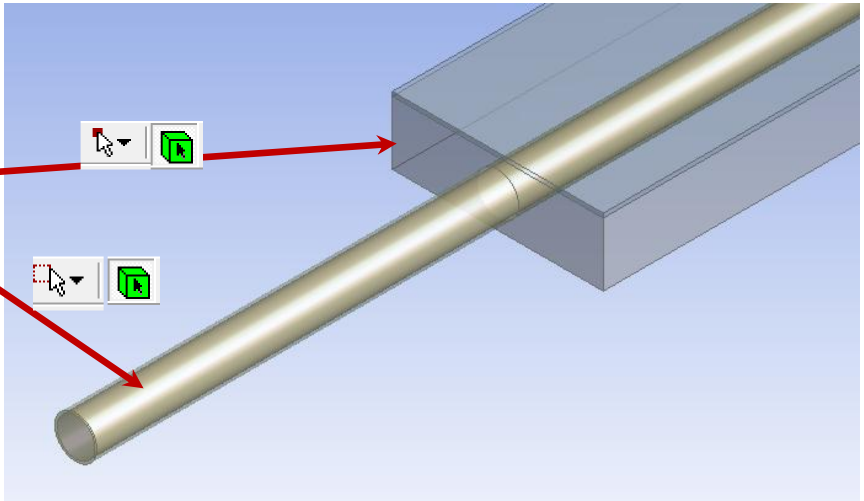
Exercise: Cooling of electronic components

↳ part a): building the geometry – subtract cylinders from foam

- Main Menu => Create => Boolean
- Details View:

Details View

Details of Boolean2	
Boolean	Boolean2
Operation	Subtract
Target Bodies	1 Body
Tool Bodies	2 Bodies
Preserve Tool Bodies?	Yes



- Toolbars => Generate

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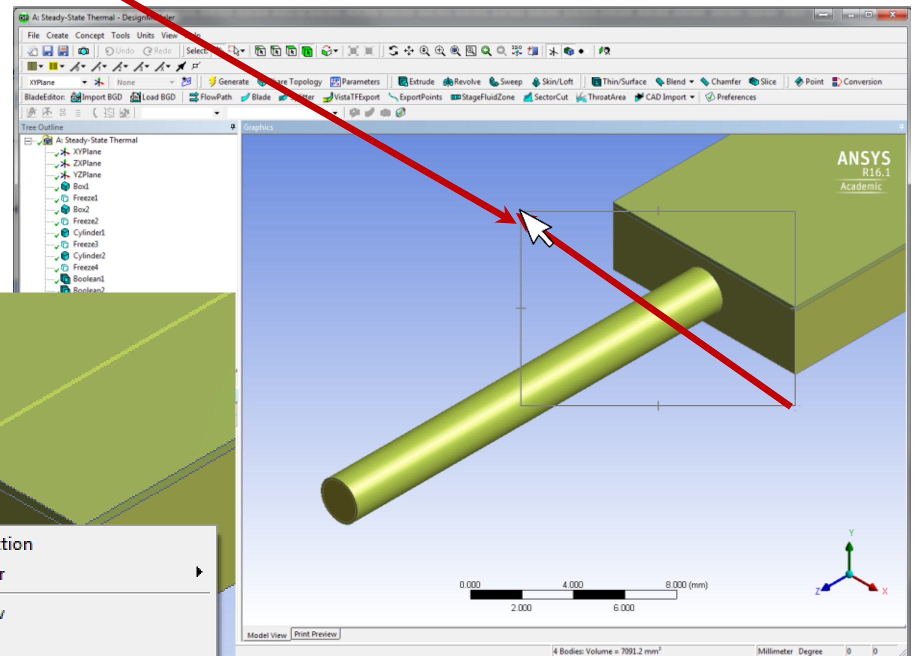
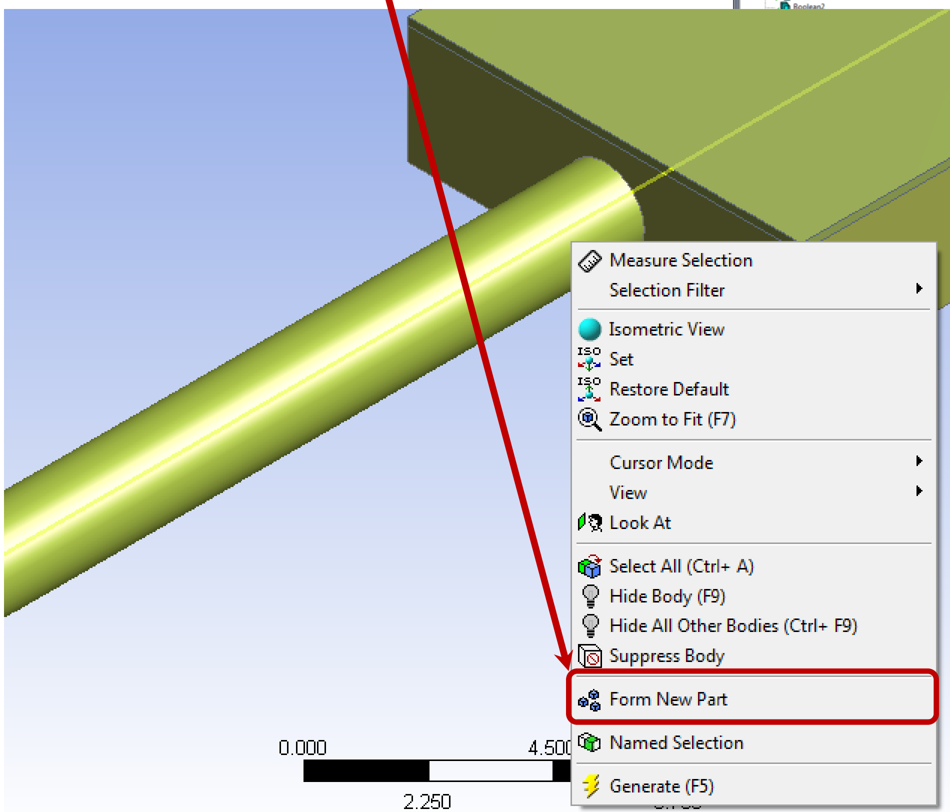
Exercise: Cooling of electronic components

↳ part a): building the geometry – generating parts

- Toolbars: => Select all bodies
- RMB: Form New Part





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Exercise: Cooling of electronic components

↳ part a): building the geometry – electronic components

- Main Menu => Create => Primitives => Box
- Details View:

Details View

Details of Box3	
Box	Box3
Base Plane	XYPlane
Operation	Add Material
Box Type	From One Point and Diago...
Point 1 Definition	Coordinates
FD3, Point 1 X Coordinate	1 mm
FD4, Point 1 Y Coordinate	1.7 mm
FD5, Point 1 Z Coordinate	10 mm
Diagonal Definition	Components
FD6, Diagonal X Component	3 mm
FD7, Diagonal Y Component	0.5 mm
FD8, Diagonal Z Component	5 mm
As Thin/Surface?	No

- Toolbars => Generate
- Main Menu => Tools => Freeze

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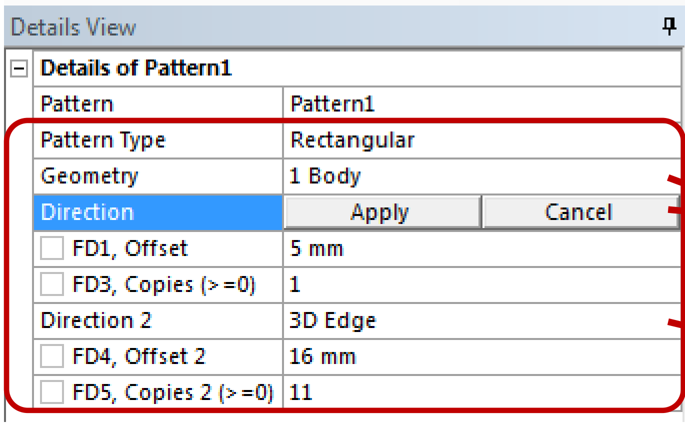
Exercise: Cooling of electronic components

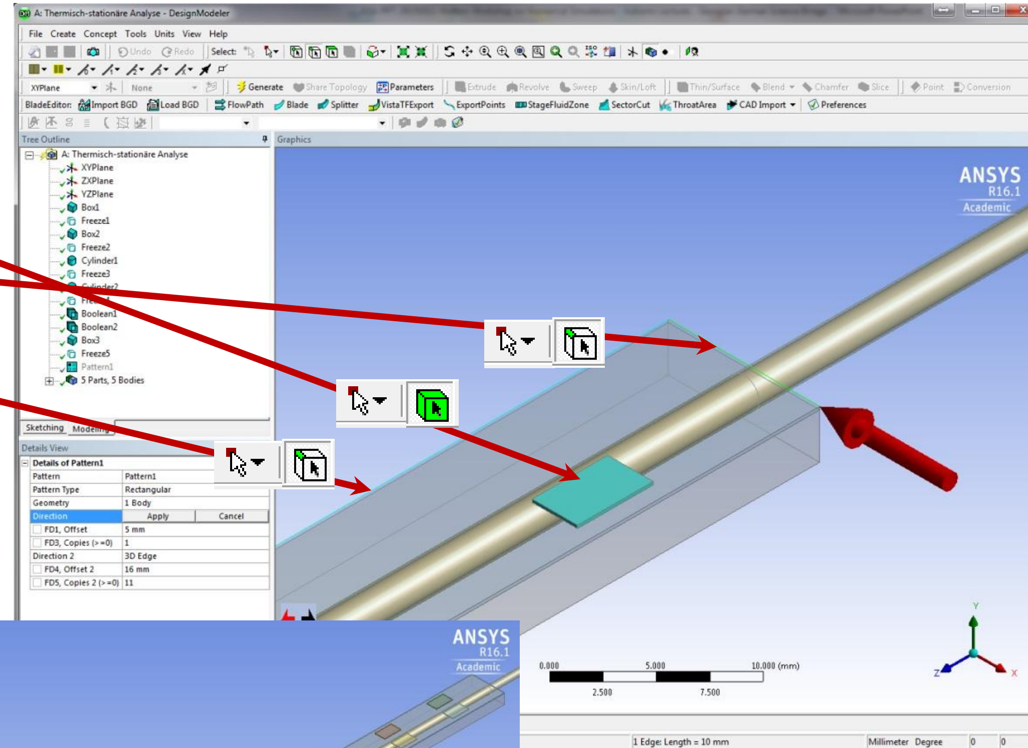
↳ part a): building the geometry – electronic components

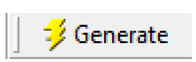
- Main Menu => Create => Pattern
- Details View:

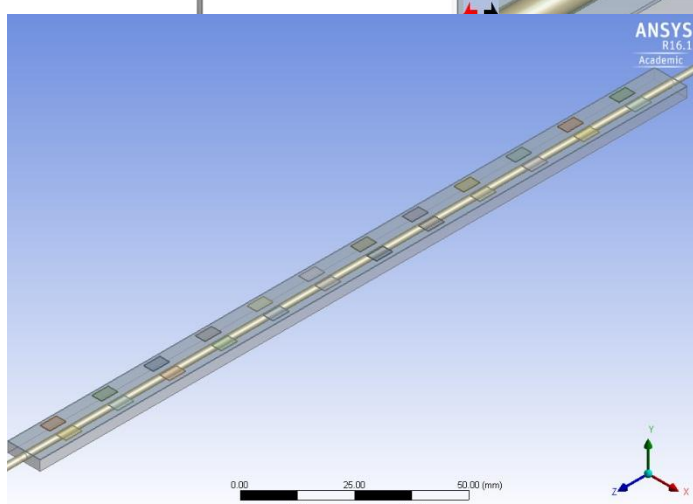


Details View

Details of Pattern1	
Pattern	Pattern1
Pattern Type	Rectangular
Geometry	1 Body
Direction	Apply / Cancel
FD1, Offset	5 mm
FD3, Copies (>=0)	1
Direction 2	3D Edge
FD4, Offset 2	16 mm
FD5, Copies 2 (>=0)	11



- Toolbars => 



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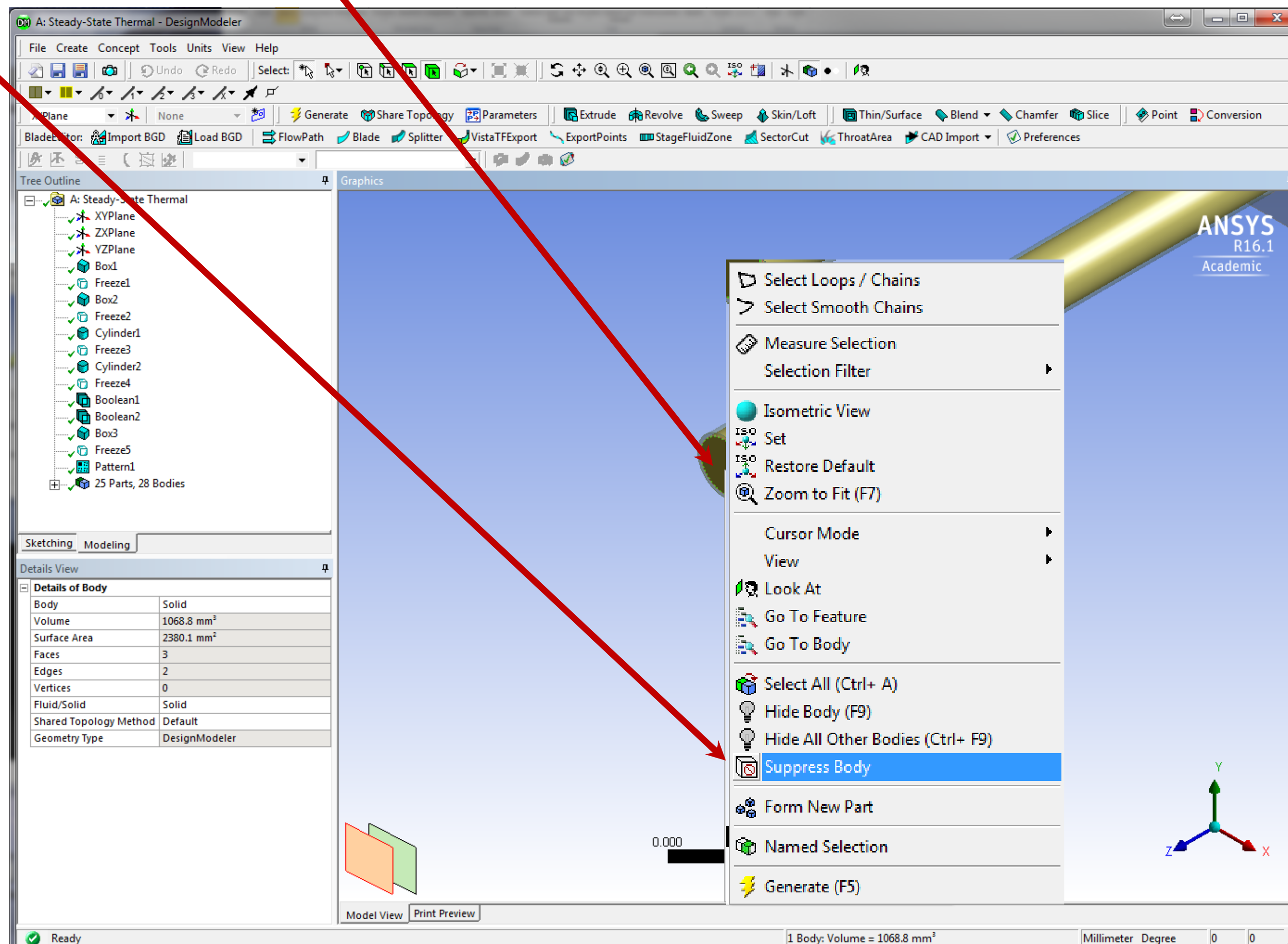
Exercise: Cooling of electronic components

part a): building the geometry – suppress fluid part of pipe

- Toolbars => (Zoom in)
- Toolbars => select inner part of pipe
- RMB: Suppress Body



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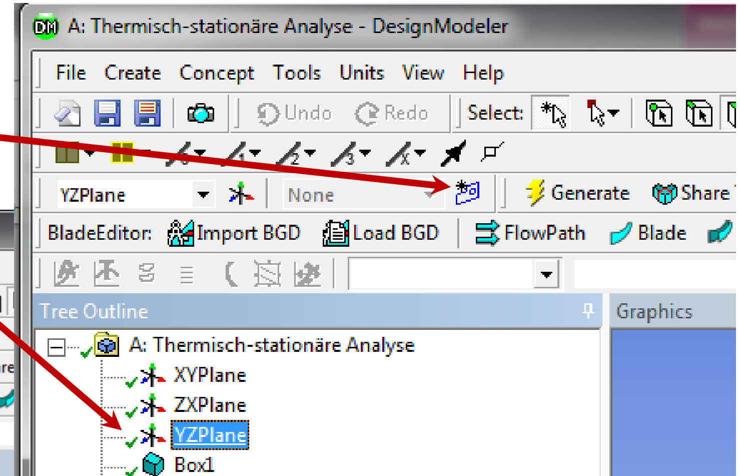
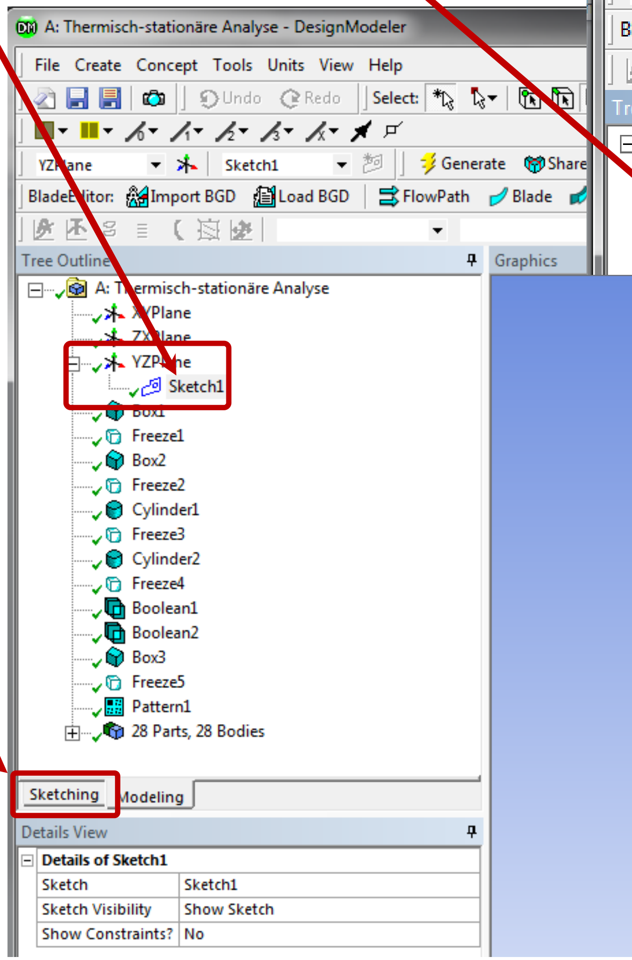
Exercise: Cooling of electronic components
↳ part a): building the geometry – centerline of cooling pipe

- Mark YZPlane (RMB)
- Toolbars => (New Sketch)
- Mark Sketch 1:





- 'Sketching' modus

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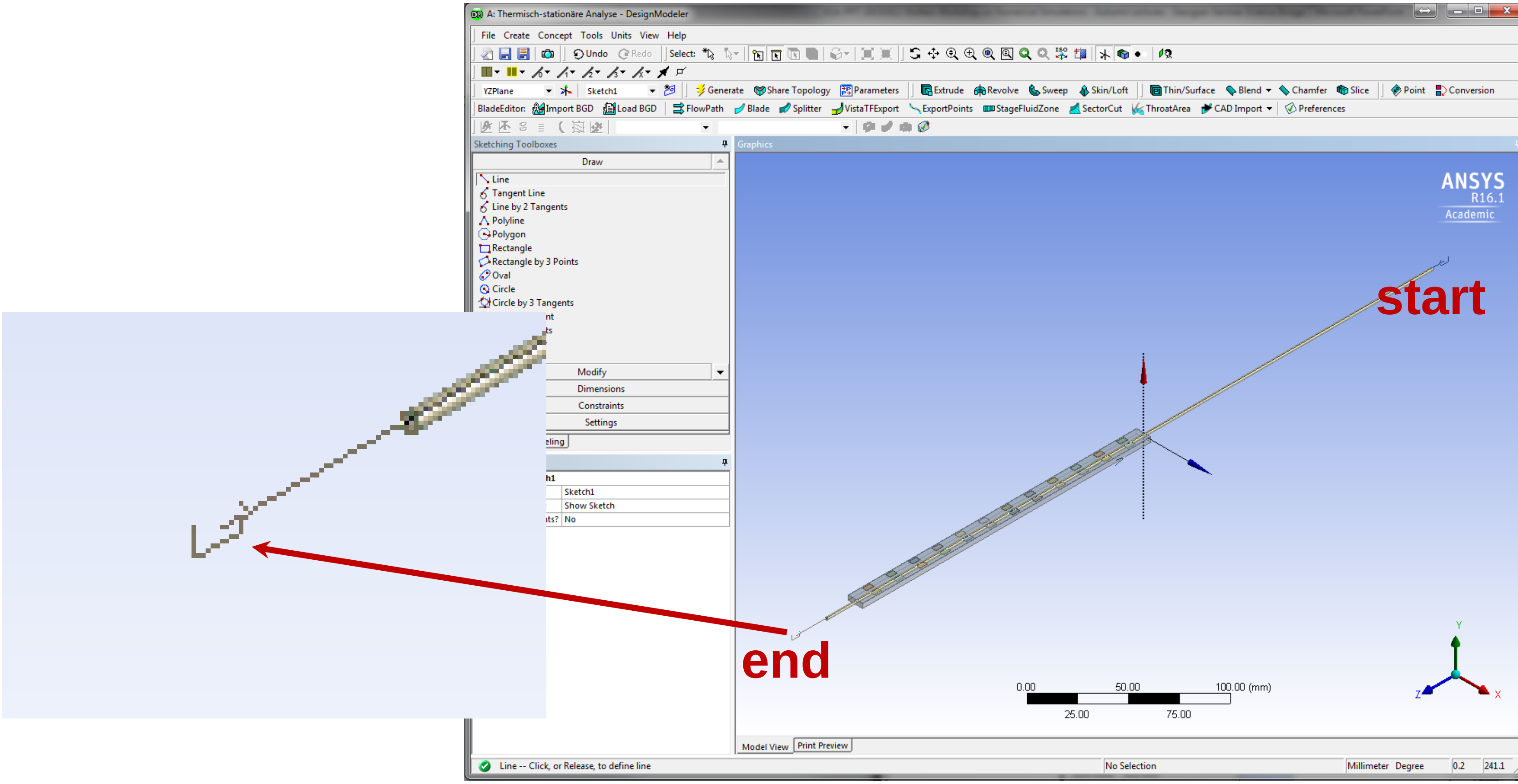
Exercise: Cooling of electronic components

↳ part a): building the geometry – centerline of cooling pipe

- Sketching Toolboxes => Draw => Line
- Draw line along pipe axis in Graphics Window
  Important:
  - C-Symbols must be visible when creating the start and end point of the line
  - the line should be slightly longer than the cooling pipe, so that end points can easily be selected



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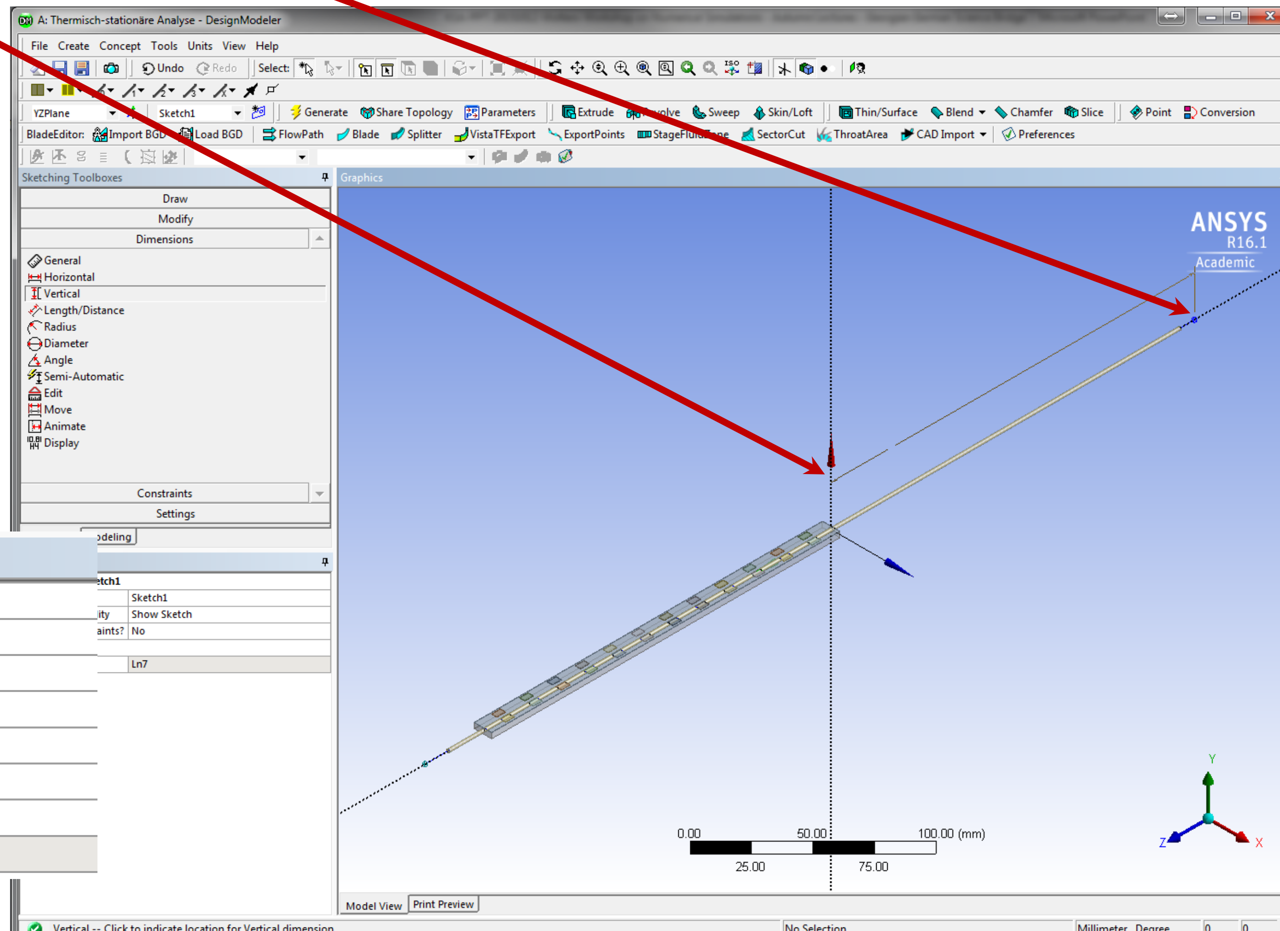
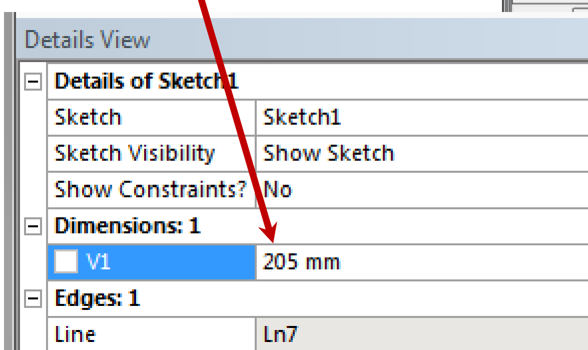
Exercise: Cooling of electronic components

↳ part a): building the geometry – centerline of cooling pipe

- Sketching Toolboxes => Dimensions => Vertical
- Click on red axis and next on starting point of line



- Details View:
  (enter exact distance)



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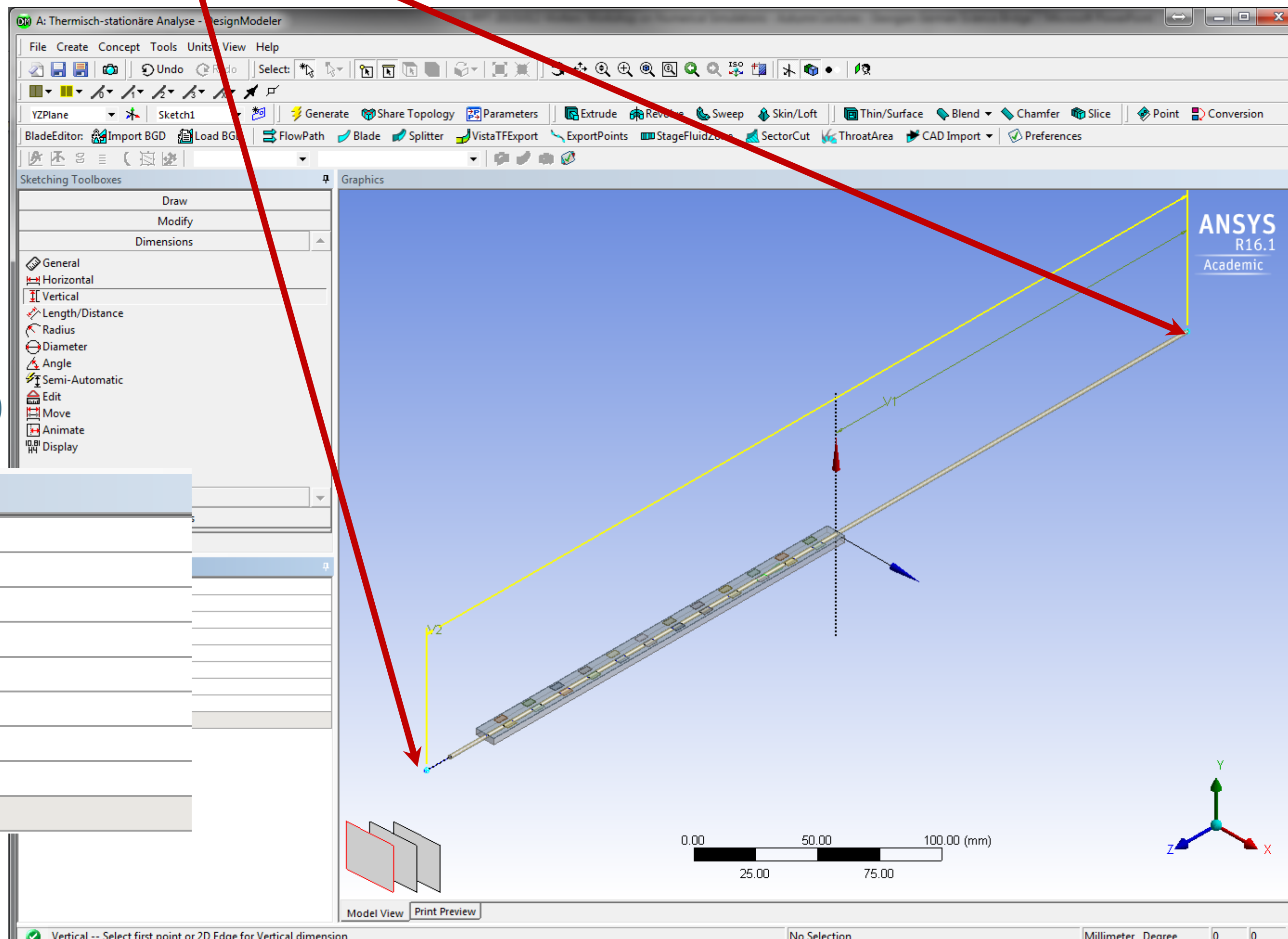
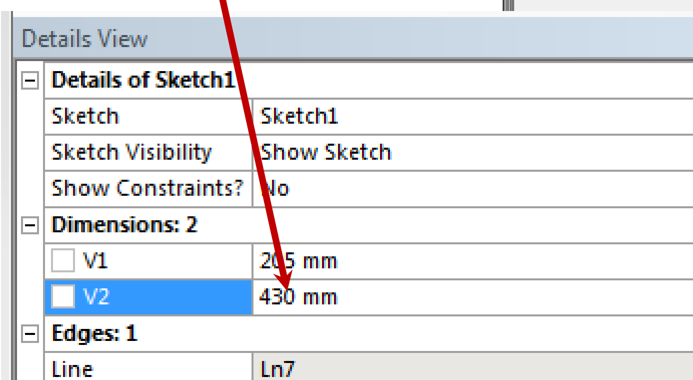
Exercise: Cooling of electronic components

↳ part a): building the geometry – centerline of cooling pipe

- Sketching Toolboxes => Dimensions => Vertical
- Click on both end points of line



- Details View:
  (enter exact distance)



- Toolbars =>

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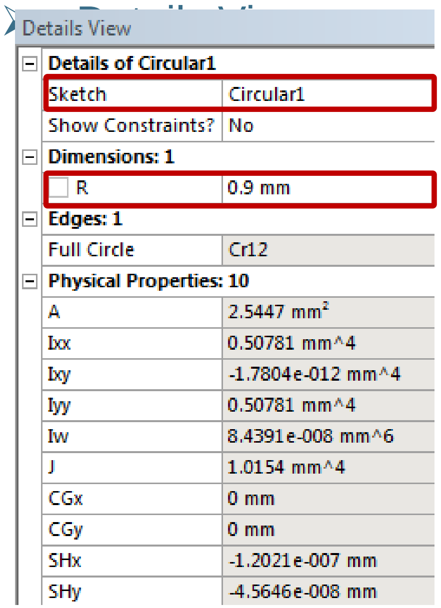
Exercise: Cooling of electronic components

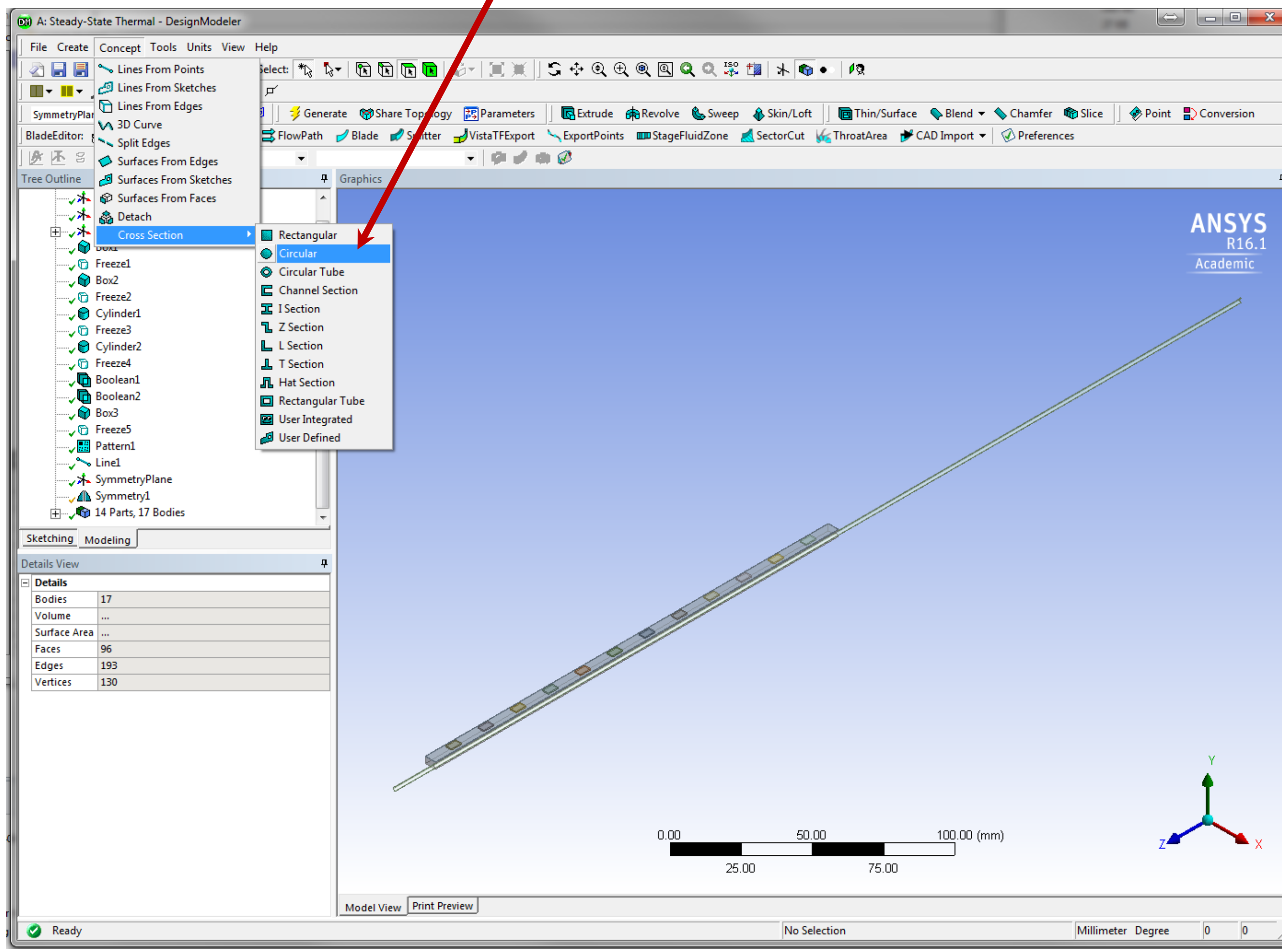
↳ part a): building the geometry – centerline of cooling pipe

- Main Menu => Concept => Cross Section => Circular (program will automatically leave the sketching modus)



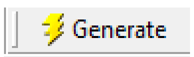
Details View

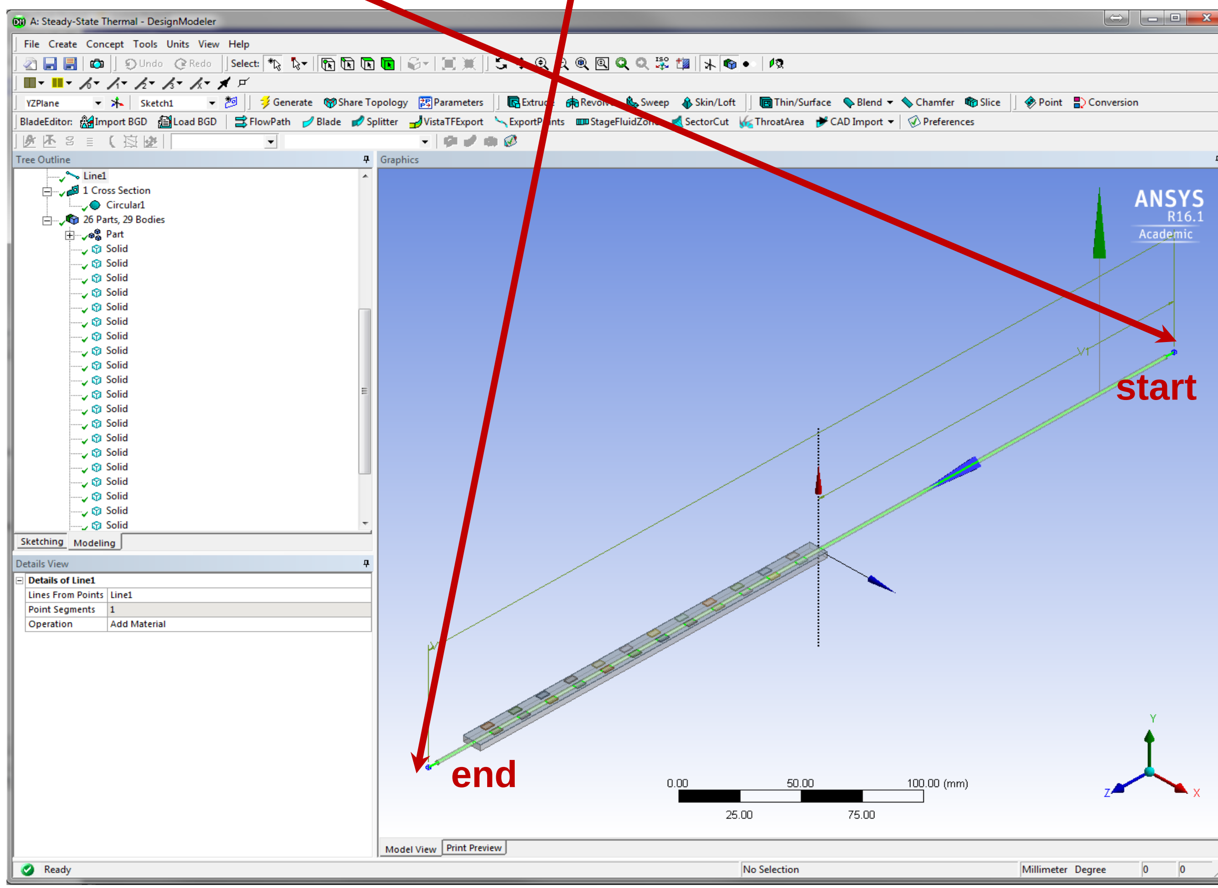
Details of Circular1	
Sketch	Circular1
Show Constraints?	No
Dimensions: 1	
R	0.9 mm
Edges: 1	
Full Circle	Cr12
Physical Properties: 10	
A	2.5447 mm²
Ixx	0.50781 mm^4
Ixy	-1.7804e-012 mm^4
Iyy	0.50781 mm^4
Iw	8.4391e-008 mm^6
J	1.0154 mm^4
CGx	0 mm
CGy	0 mm
SHx	-1.2021e-007 mm
SHy	-4.5646e-008 mm



Exercise: Cooling of electronic components

↳ part a): building the geometry – centerline of cooling pipe

- Main Menu => Concept => Line from points
- Details View:
  Point Segments: Select start point (LMB) ***and*** end point (‘Ctrl’ + LMB) from line sketch
  note: direction important
- Toolbars => 



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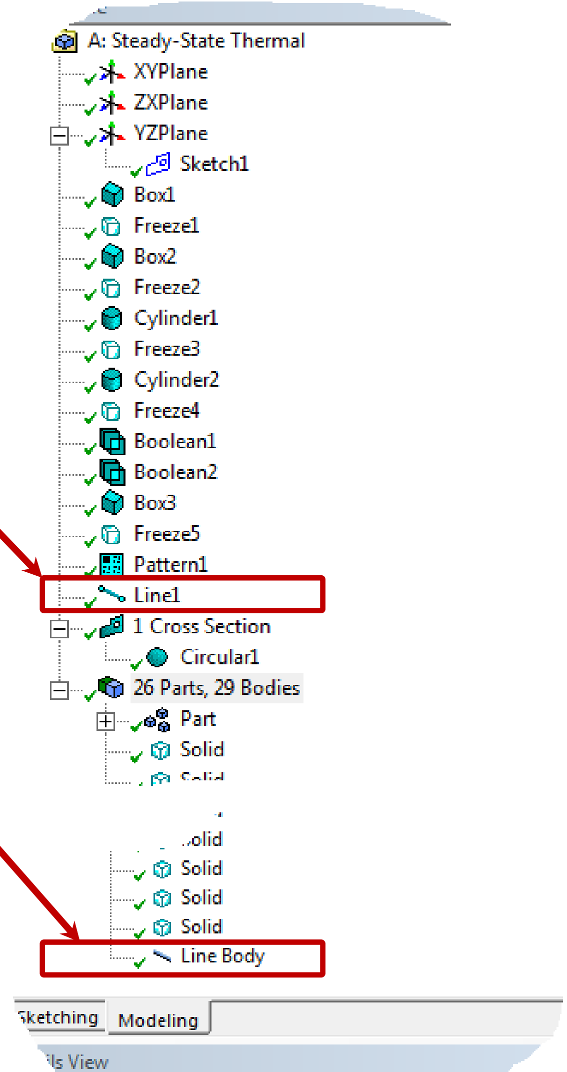
Exercise: Cooling of electronic components

part a): building the geometry – centerline of cooling pipe

- Tree Outline => Parts, Bodies
- => Line Body LMB
- Details View

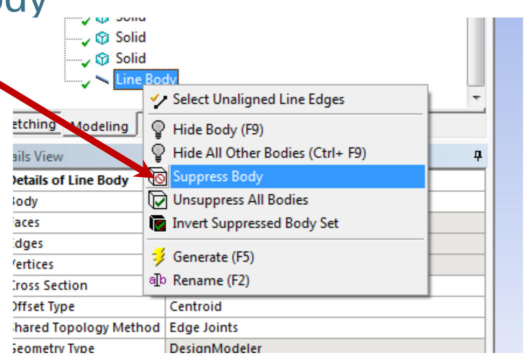
Details View	
Details of Line Body	
Body	Line Body
Faces	0
Edges	1
Vertices	2
Cross Section	Circular1
Offset Type	Centroid
Shared Topology Method	Edge Joints
Geometry Type	DesignModeler



Suppress line again, since not needed for first simulation

- Tree Outline => Line Body

  RMB => Suppress Body



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Exercise: Cooling of electronic components

↳ part a): building the geometry – using symmetry conditions

- Tree Outline => XYPlane (LMB)
- Main Menu => Create => New Plane
- Details View:

Details View

Details of SymmetryPlane	
Plane	SymmetryPlane
Sketches	0
Type	From Plane
Base Plane	XYPlane
Transform 1 (RMB)	Rotate about Y
FD1, Value 1	-90 °
Transform 2 (RMB)	None
Reverse Normal/Z-Axis?	No
Flip XY-Axes?	No
Export Coordinate System?	No

(rename)

- Toolbars => Generate

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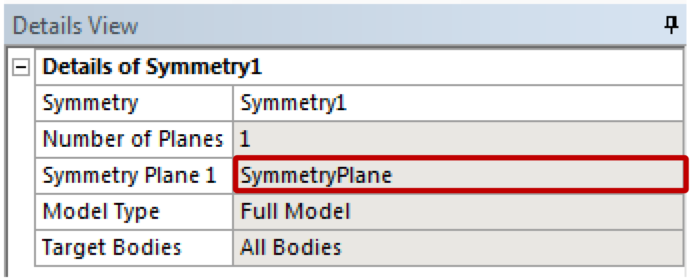
Exercise: Cooling of electronic components

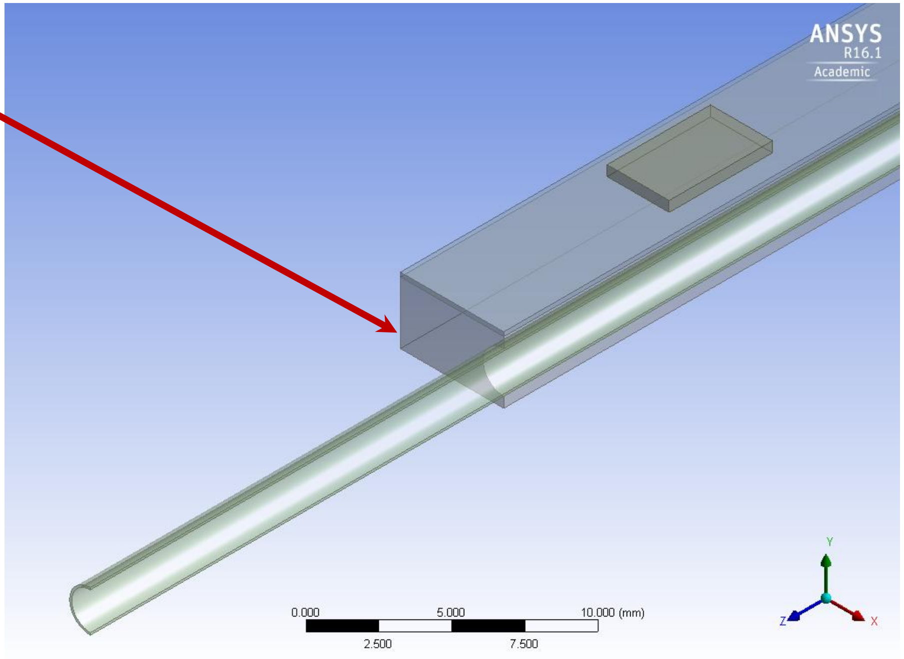
↳ part a): building the geometry – using symmetry conditions

- Main Menu => Tools => Symmetry
- Details View:



(select plane of previous step)

- Toolbars => Generate



- Toolbars =>
- Main Menu => File => Close DesignModeler

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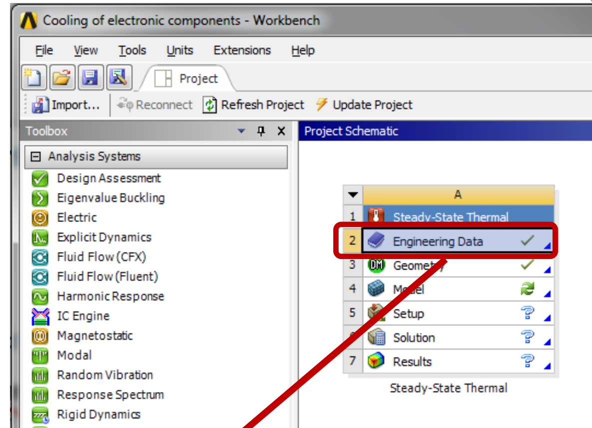
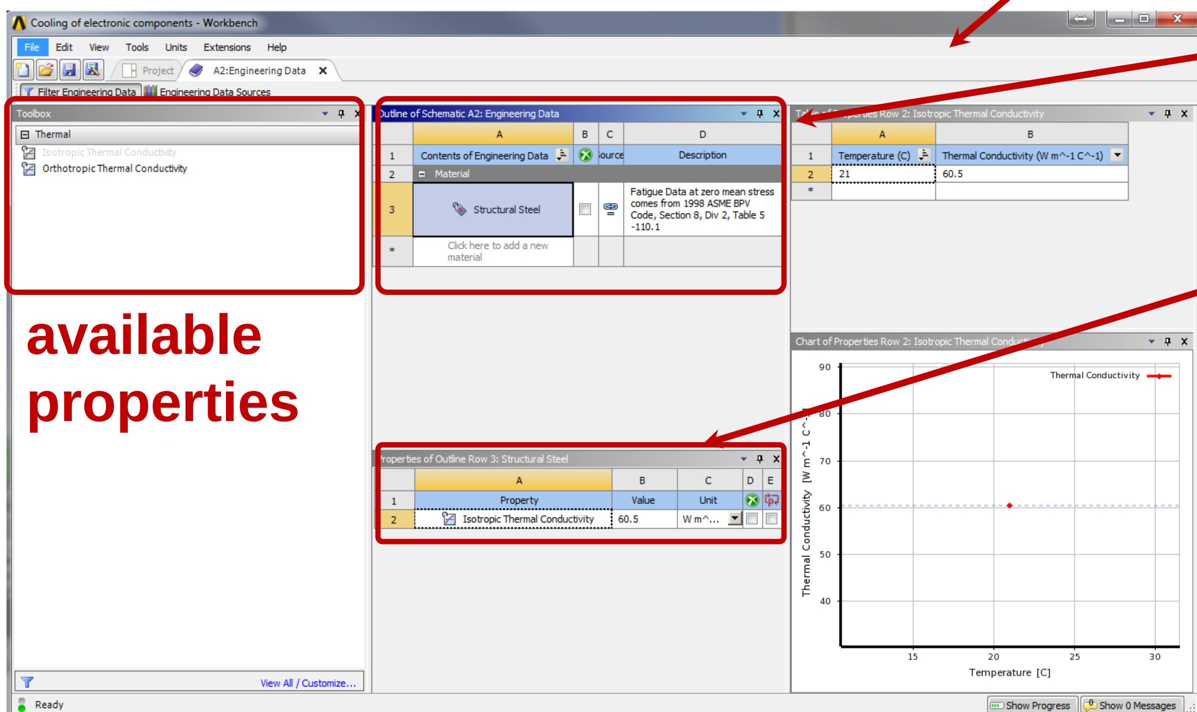
Exercise: Cooling of electronic components

↳ part b): defining material properties

- Double-Click on ‘Engineering Data’
- Notice: Only thermal conductivity is needed for steady-state thermal analysis





defined materials

material property values

available properties

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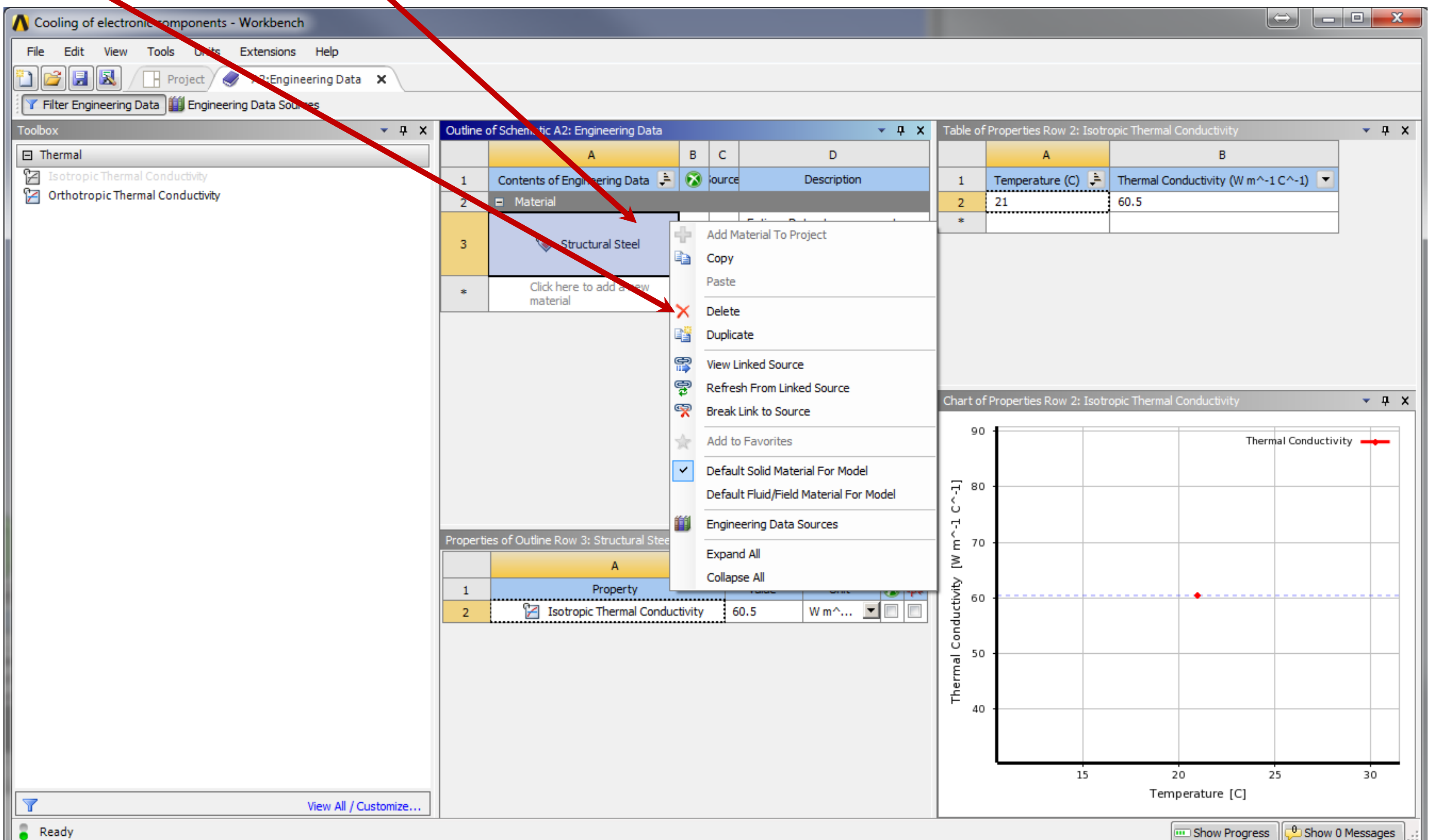
Exercise: Cooling of electronic components

↳ part b): defining material properties – delete standard material

- ➢ RMB on 'Structural Steel'
- ➢ Delete



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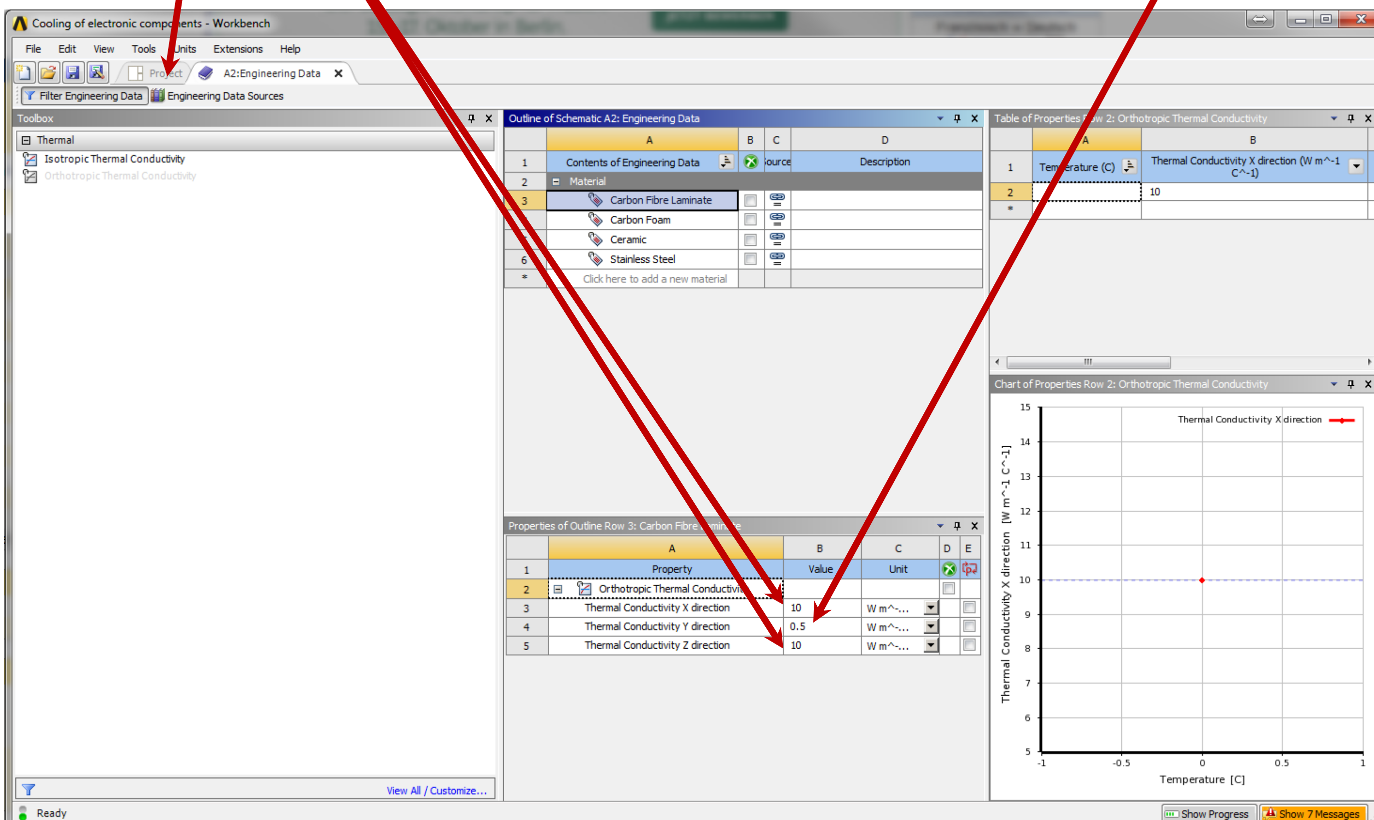
Exercise: Cooling of electronic components

↳ part b): defining material properties – import materials from xml-file

- Main Menu => File => Import Engineering Data …
- Select ‘Material Properties.xml’
- Notice that for Carbon Fiber Laminate an orthotropic thermal conductivity is selected => medium conductivity in fiber directions, low conductivity perpendicular to fiber directions
- Return to Project-Sheet:
- TB:



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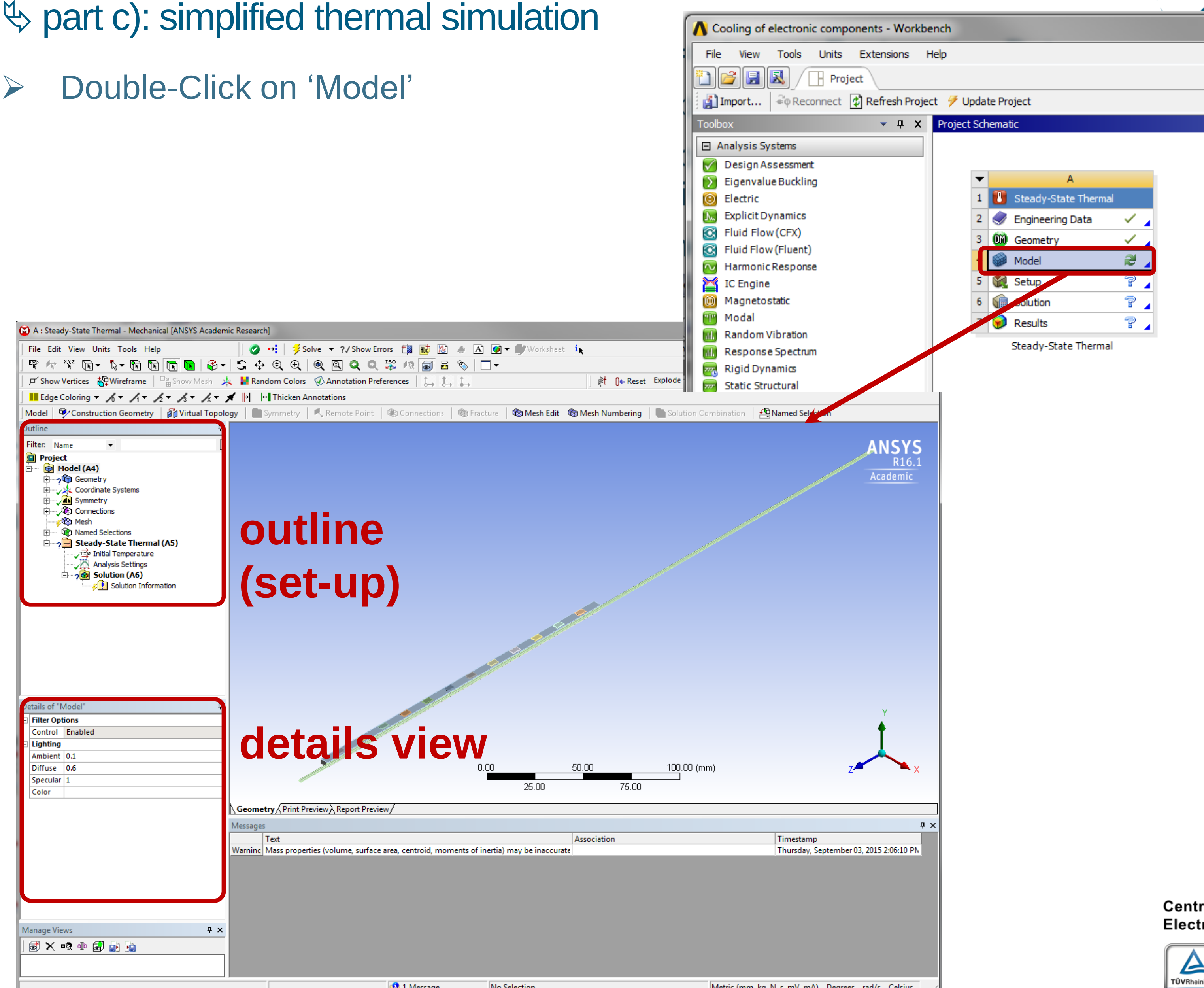
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation

- Double-Click on 'Model'



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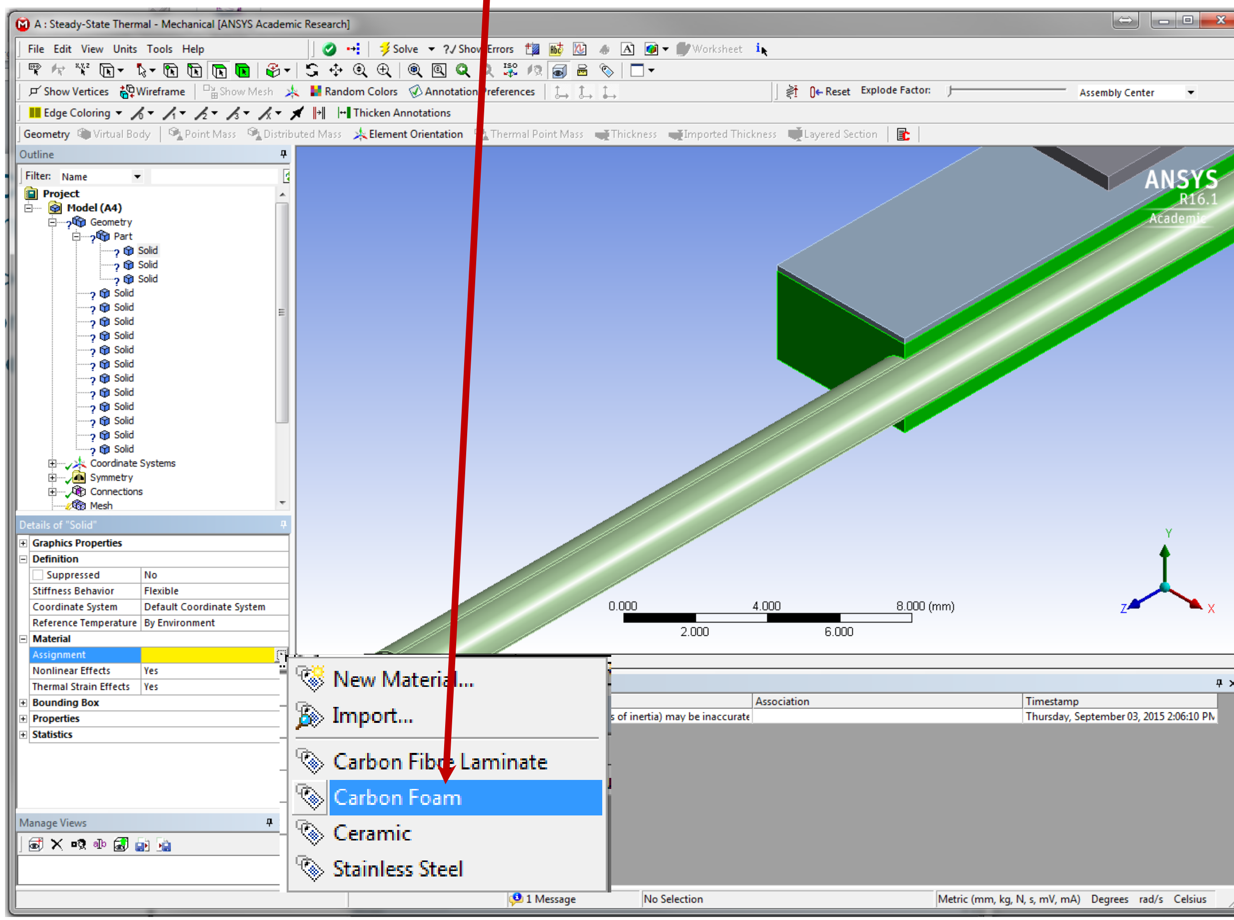
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – assigning materials

- Outline => Model => expand Geometry ⊞ Geometry
- LMB on one Solid (or mark all Solids with identical materials)
- Details View => Material => Assignment => choose material for marked solid(s)



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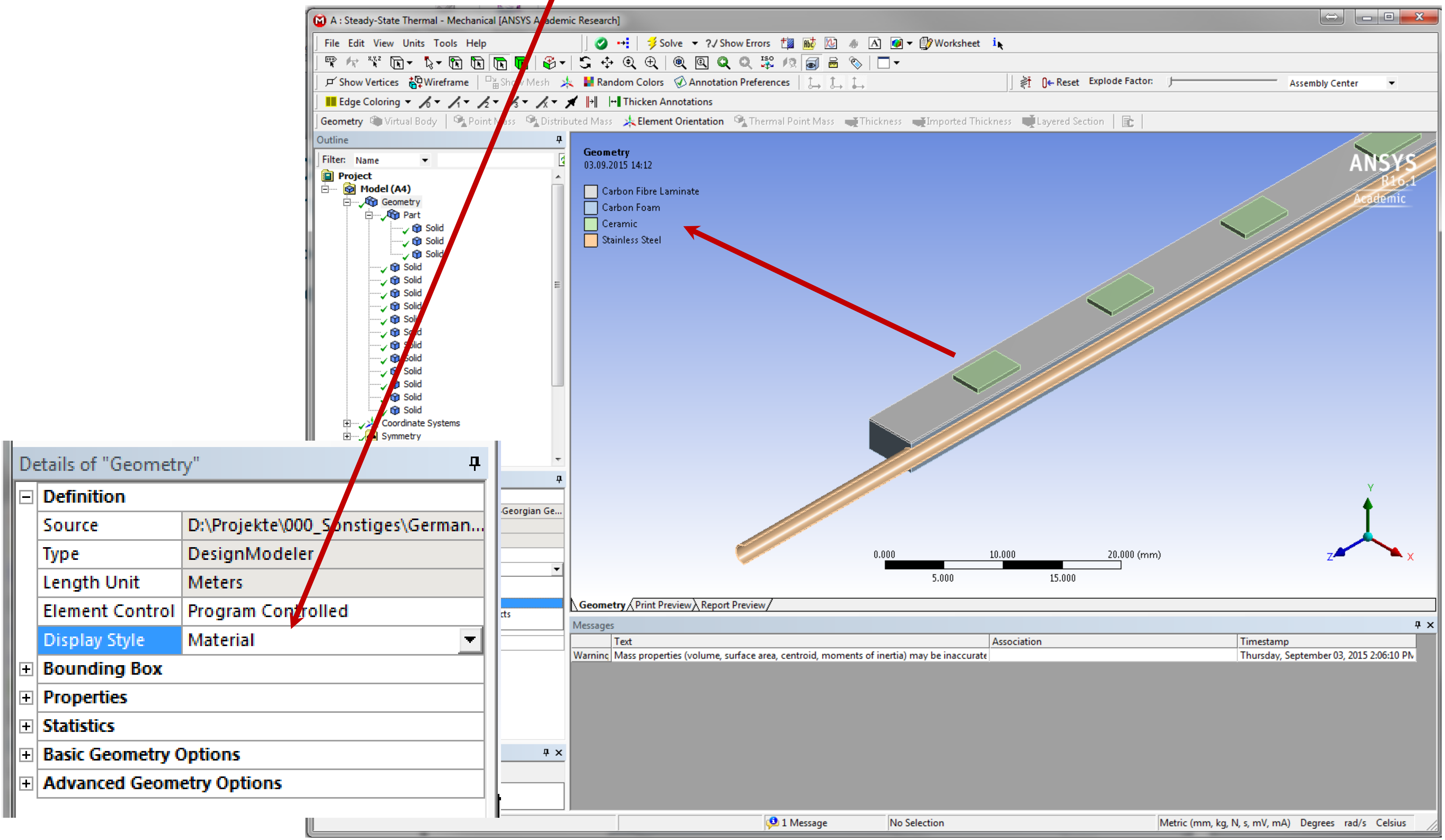
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – check assignment

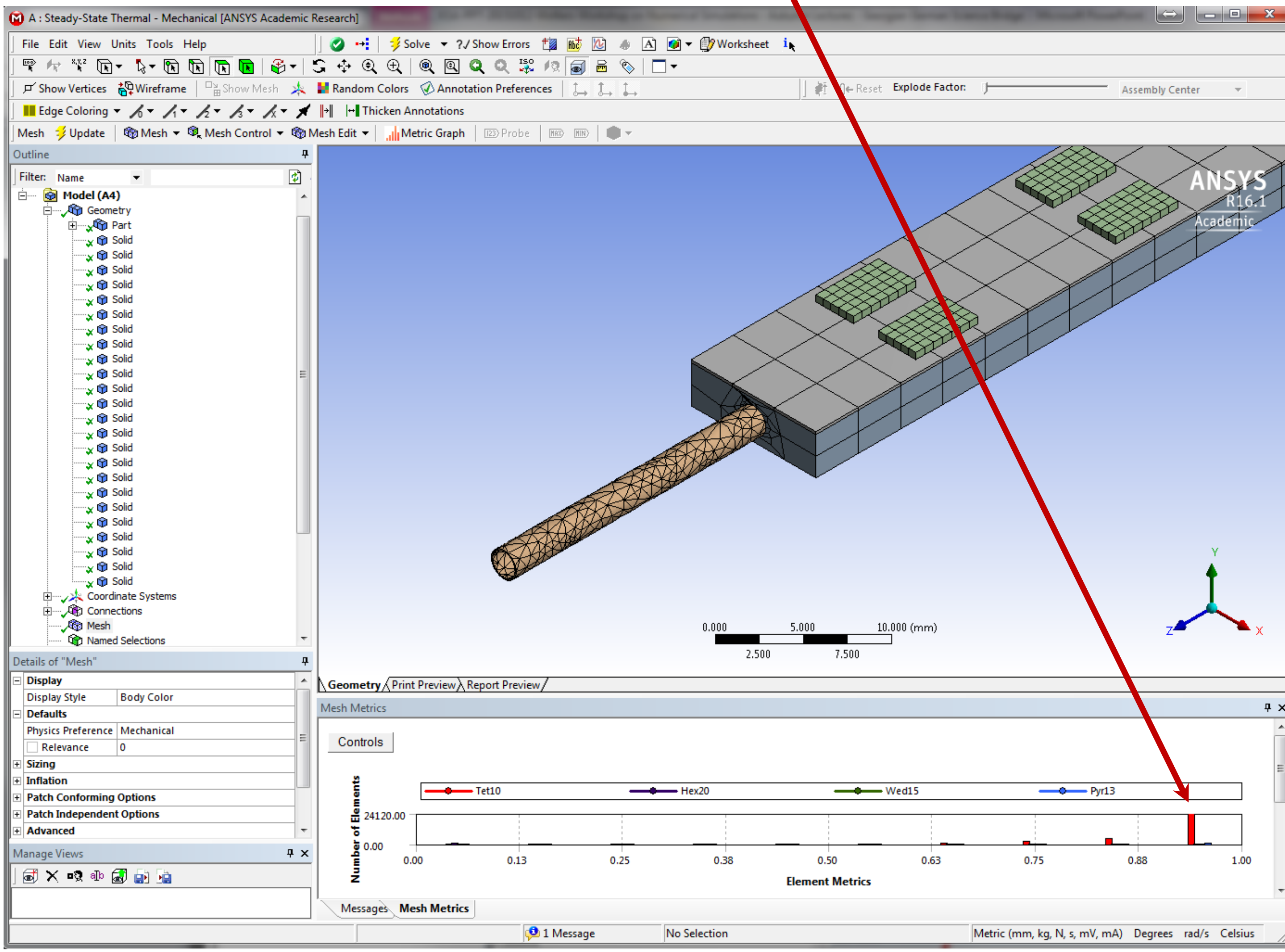
- Outline => Model => Geometry (LMB)
- Details View => Display Style => Material



Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – meshing remarks

- ➢ Notice: A good mesh quality is needed to obtain good results
- ➢ Meshing with standard values can lead to an insufficient mesh quality (here scewness for full model)



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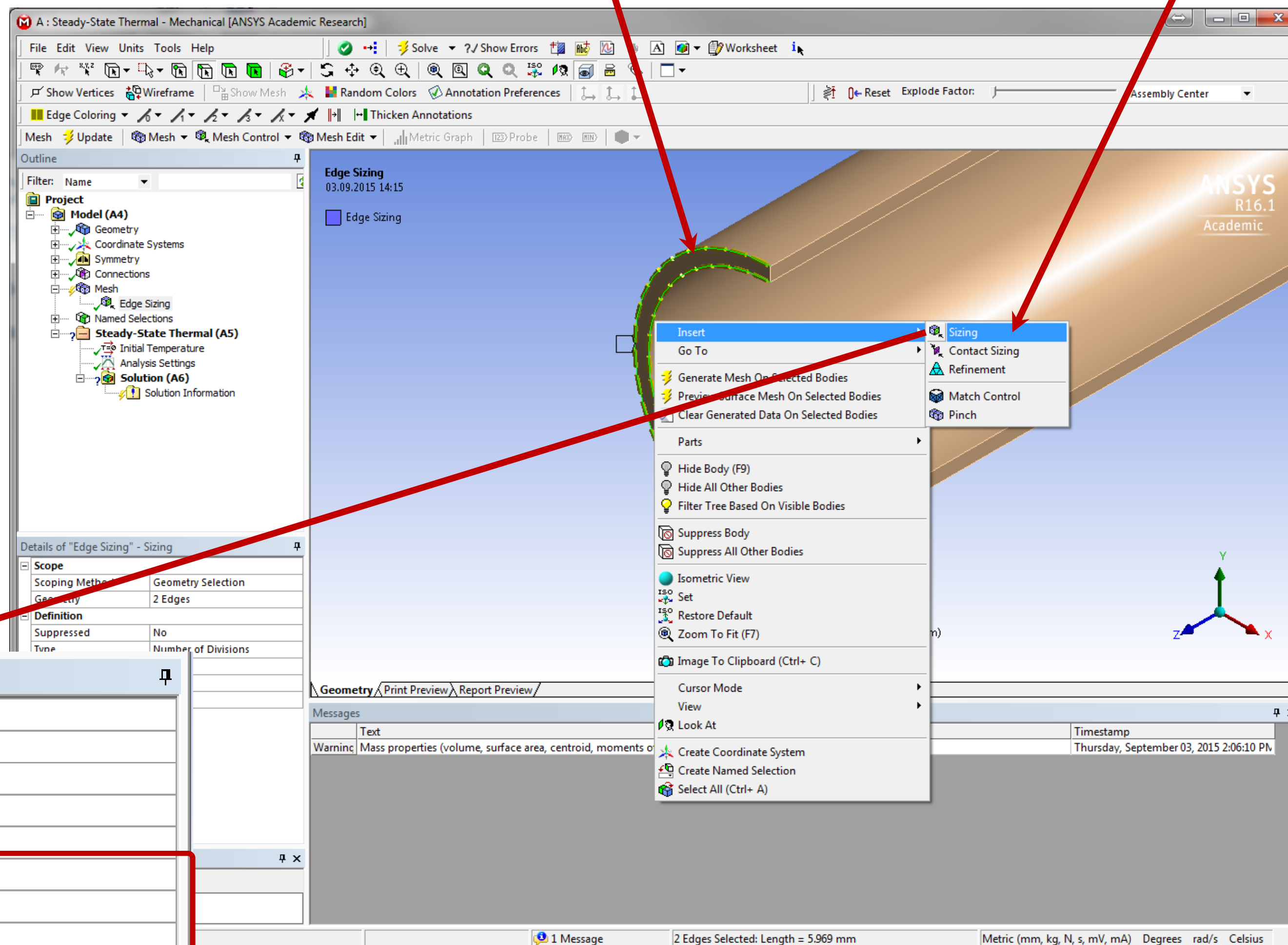
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – meshing

- ➢ Outline => Mesh
- ➢ Toolbars => : Select circumferential lines at end of pipe => RMB => Insert => Sizing



- ➢ Details View

Details of "Edge Sizing" - Sizing

Scope	
Scoping Method	Geometry Selection
Geometry	2 Edges
Definition	
Suppressed	No
Type	Number of Divisions
Number of Divisions	15
Behavior	Hard
Bias Type	No Bias

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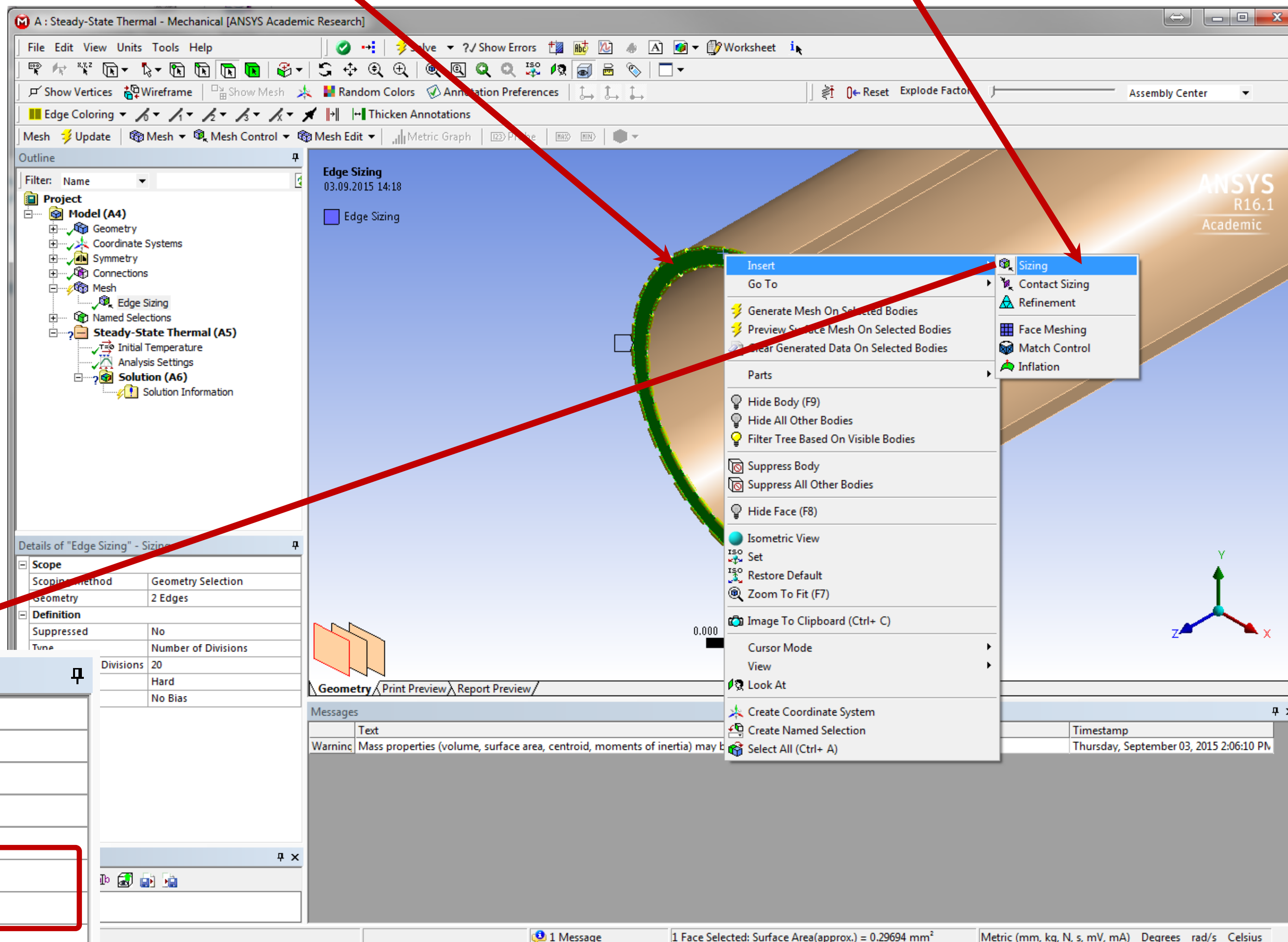
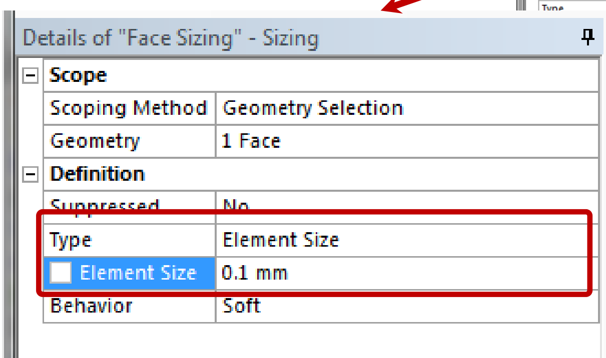
Exercise: Cooling of electronic components

part c): simplified thermal simulation – meshing

➢ Toolbars => : Select end face of pipe => RMB => Insert => Sizing



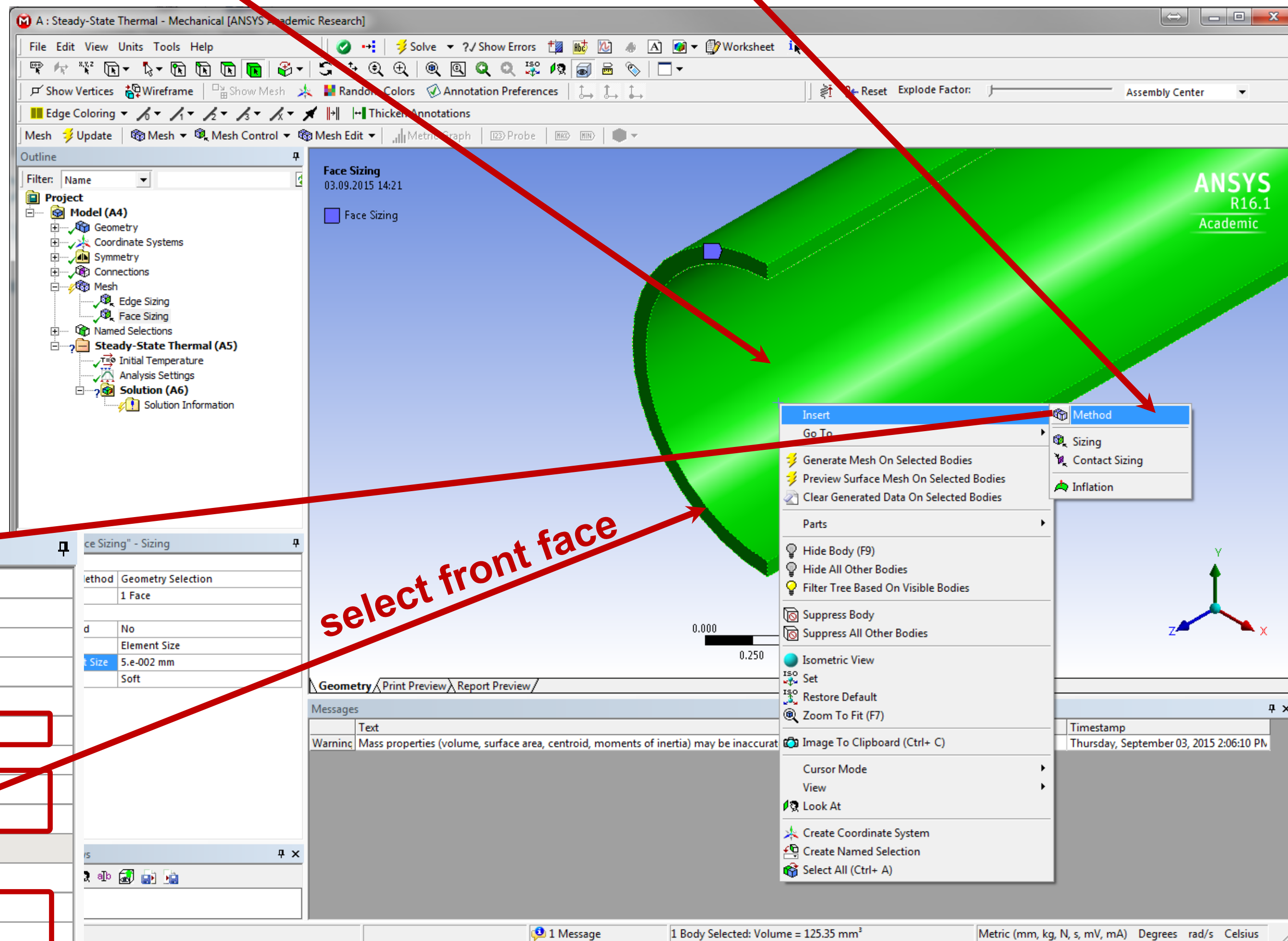
➢ Details View



Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – meshing

- Toolbars => : Select pipe body => RMB => Insert => Method



- Details View

Details of "Sweep Method" - Method

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Sweep
Element Midside Nodes	Use Global Setting
Src/Trg Selection	Manual Source
Source	1 Face
Target	Program Controlled
Free Face Mesh Type	Quad/Tri
Type	Element Size
Sweep Element Size	4. mm
Sweep Bias Type	No Bias
Element Option	Solid
Constrain Boundary	No

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Exercise: Cooling of electronic components

part c): simplified thermal simulation – meshing

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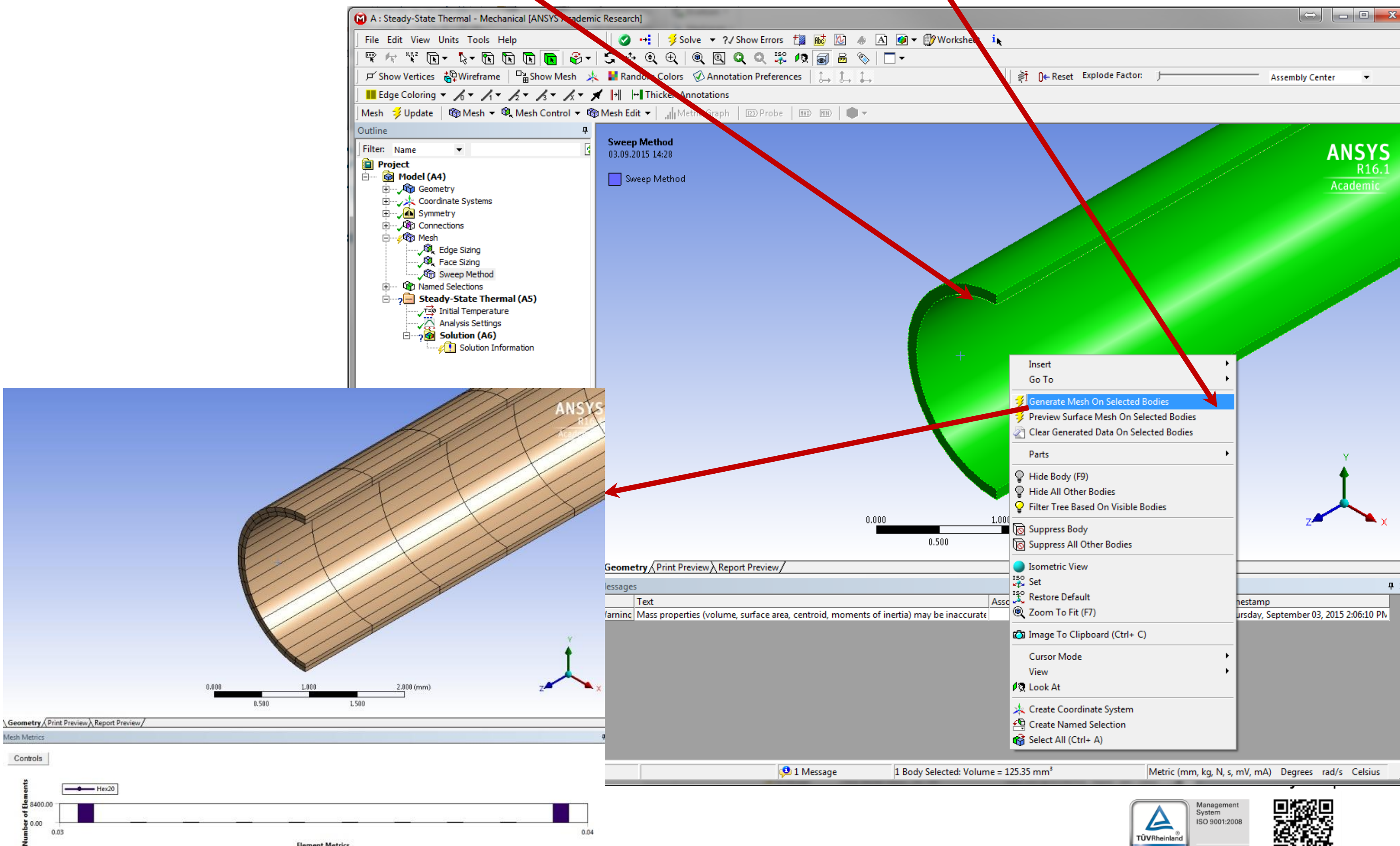
- Toolbars => : Select pipe => RMB => Generate Mesh on Selected Bodies



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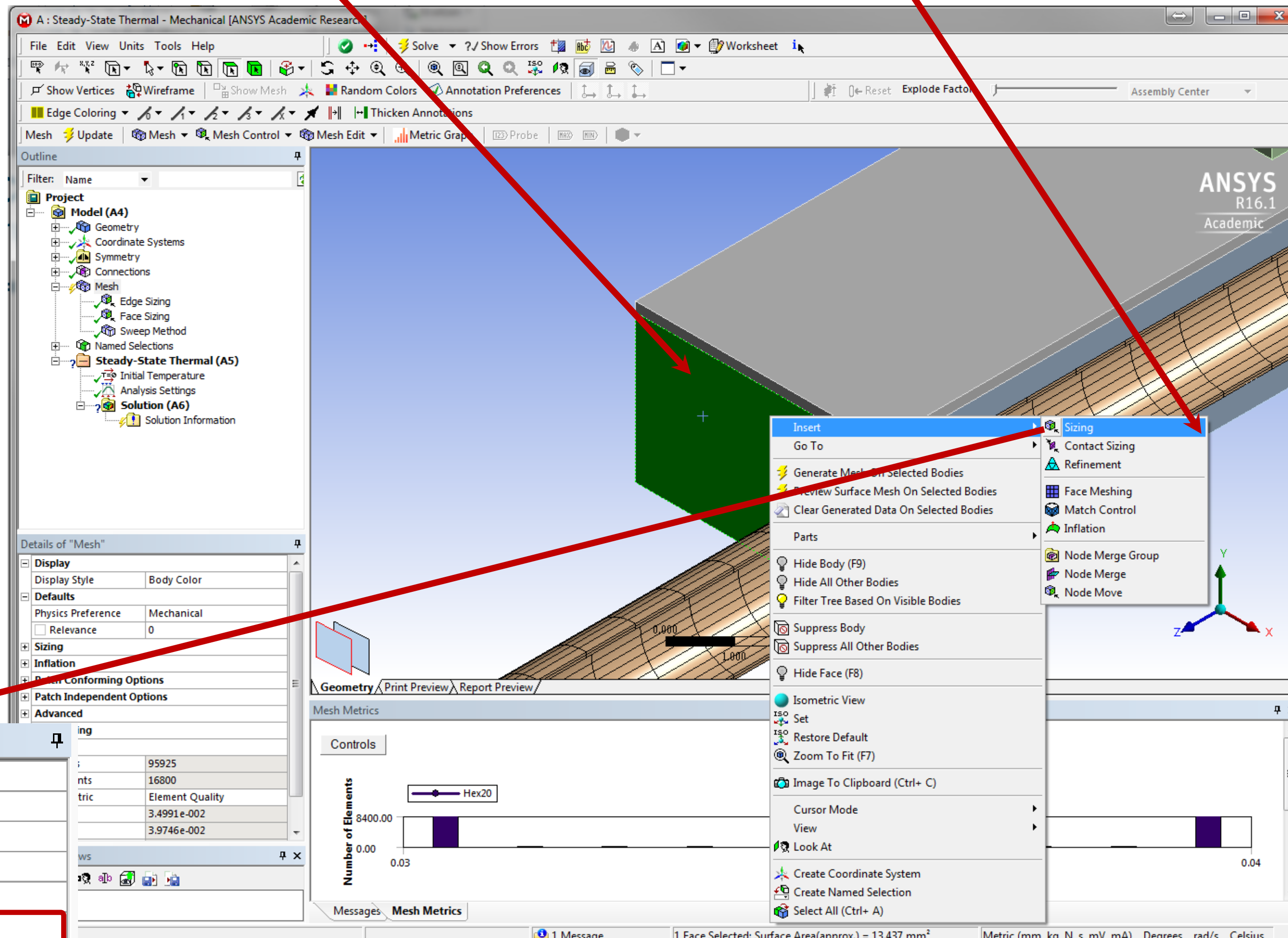
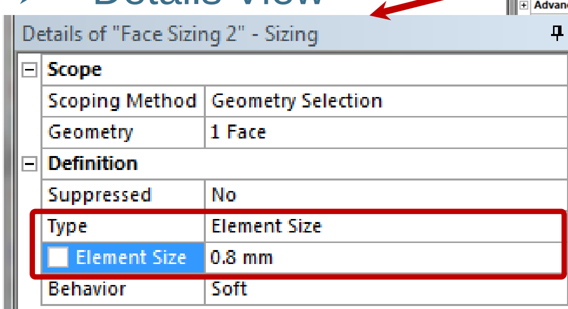
Exercise: Cooling of electronic components

part c): simplified thermal simulation – meshing

➢ Toolbars => : Select front face of foam => RMB => Insert => Sizing



➢ Details View



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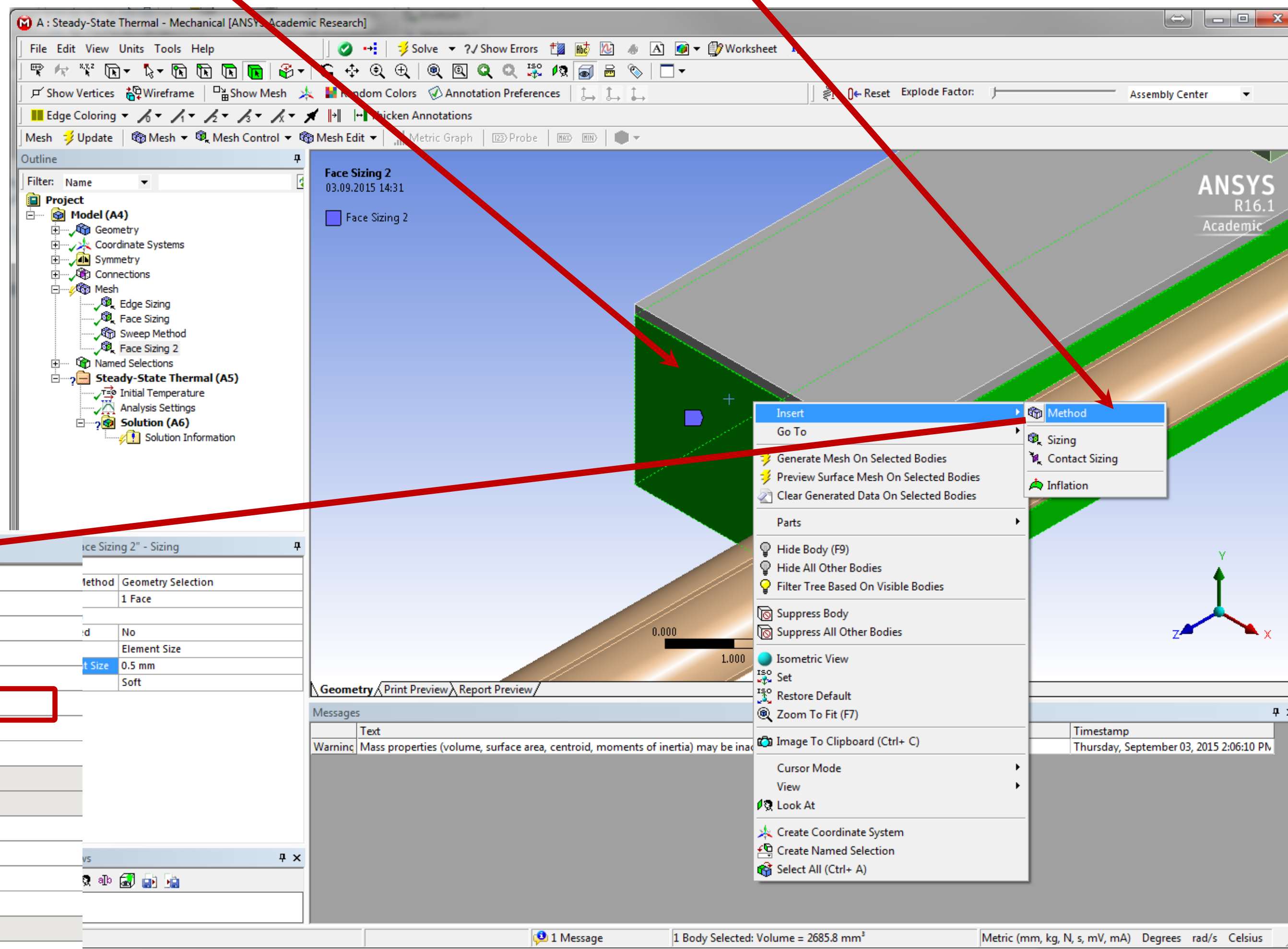
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – meshing

➢ Toolbars => : Select foam => RMB => Insert => Method



➢ Details View

Details of "Sweep Method 2" - Method

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Sweep
Element Midside Nodes	Use Global Setting
Src/Trg Selection	Automatic
Source	Program Controlled
Target	Program Controlled
Free Face Mesh Type	Quad/Tri
Type	Number of Divisions
Sweep Num Divs	Default
Sweep Bias Type	No Bias
Element Option	Solid
Constrain Boundary	No

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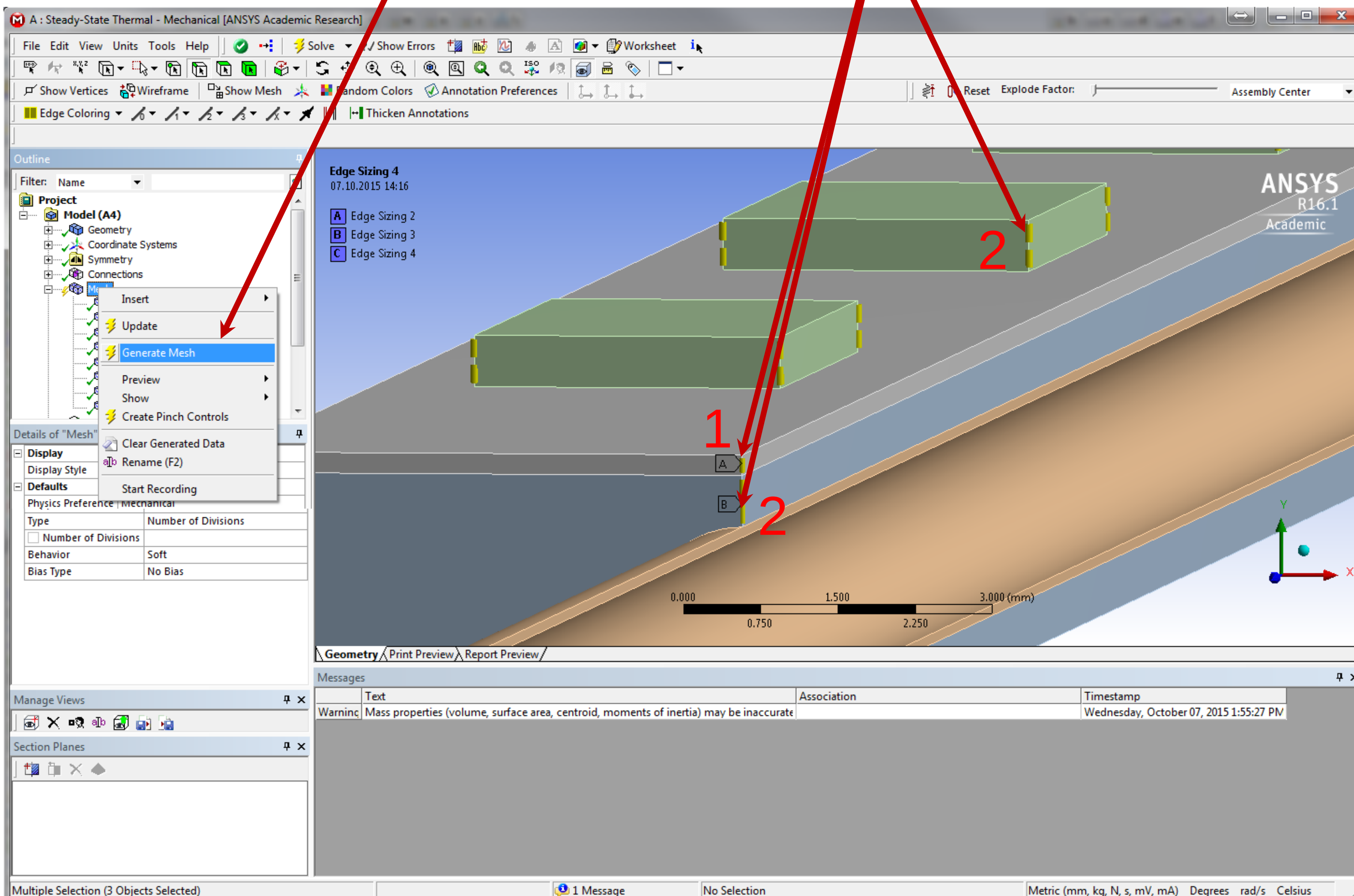
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – meshing

- ➢ Try to modify number of elements along vertical lines by your own ☺
- ➢ Outline => Mesh => RMB => Generate Mesh



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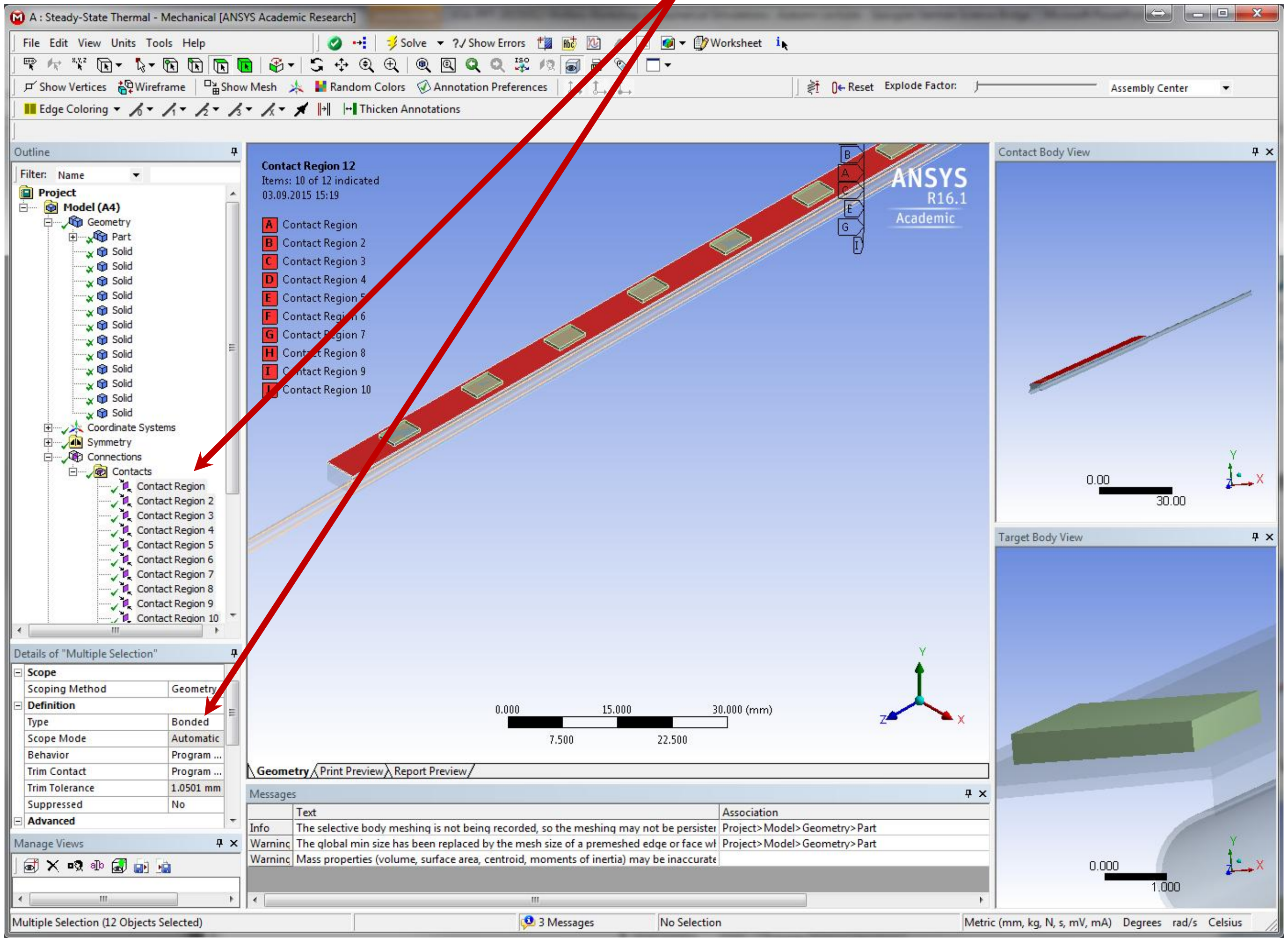
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – meshing

- Note: All bodies in a part are automatically connected and share nodes at the interface
- The mesh of the electronic components is different from the mesh of the subjacent laminate, here the software automatically generates contact elements (bonded contact)



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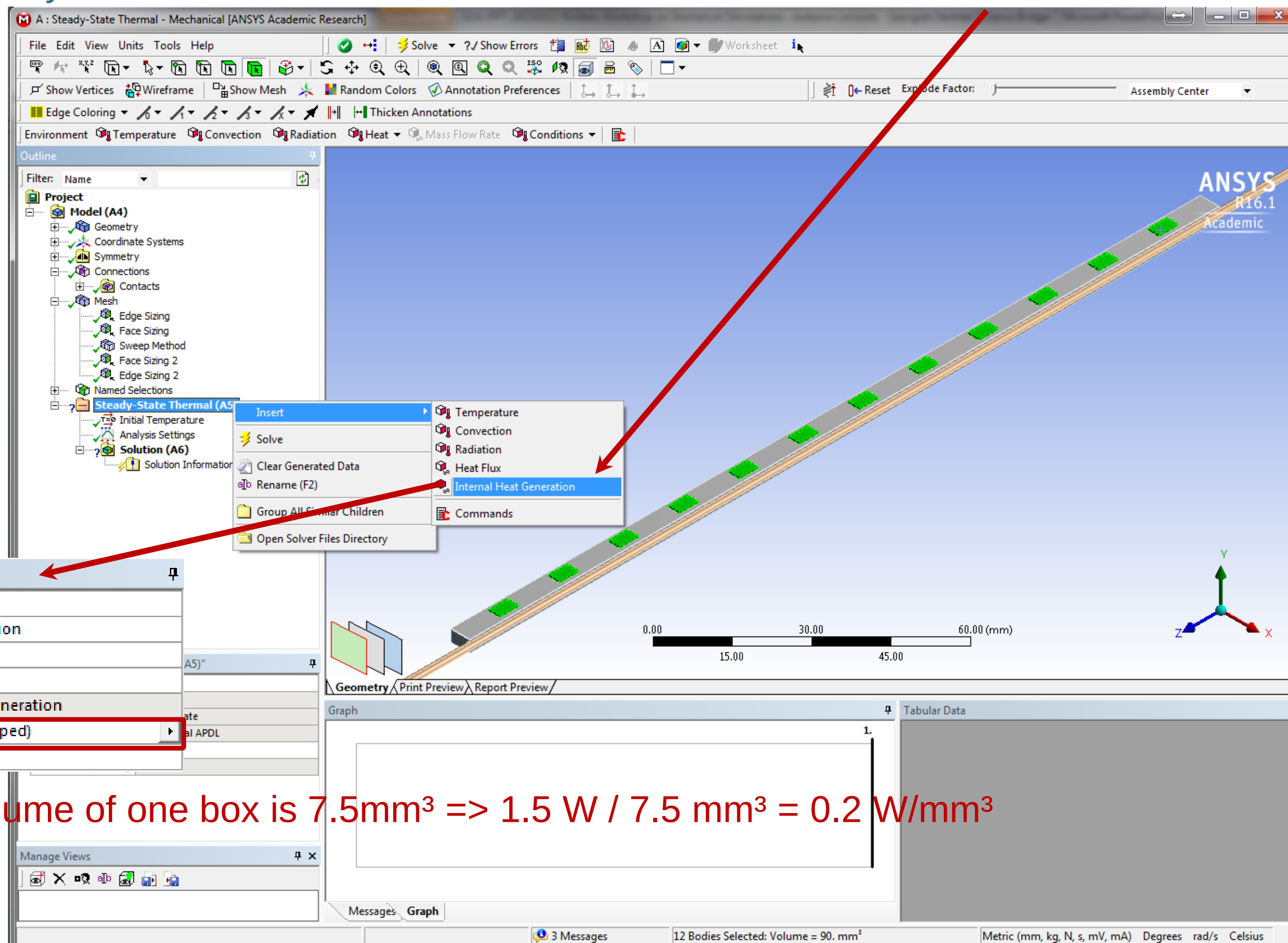
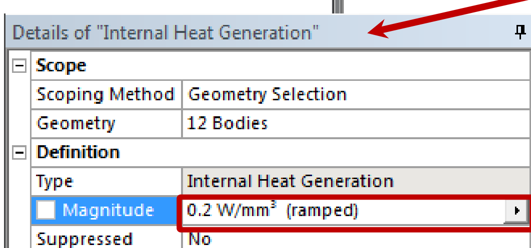
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – boundary conditions

- Toolbars => => select all electronic components (use 'Ctrl' & select each box)
- Outline => Steady-State Thermal => RMB => Insert => Internal Heat Generation



- Details View



- Notice: the volume of one box is 7.5mm³ => 1.5 W / 7.5 mm³ = 0.2 W/mm³

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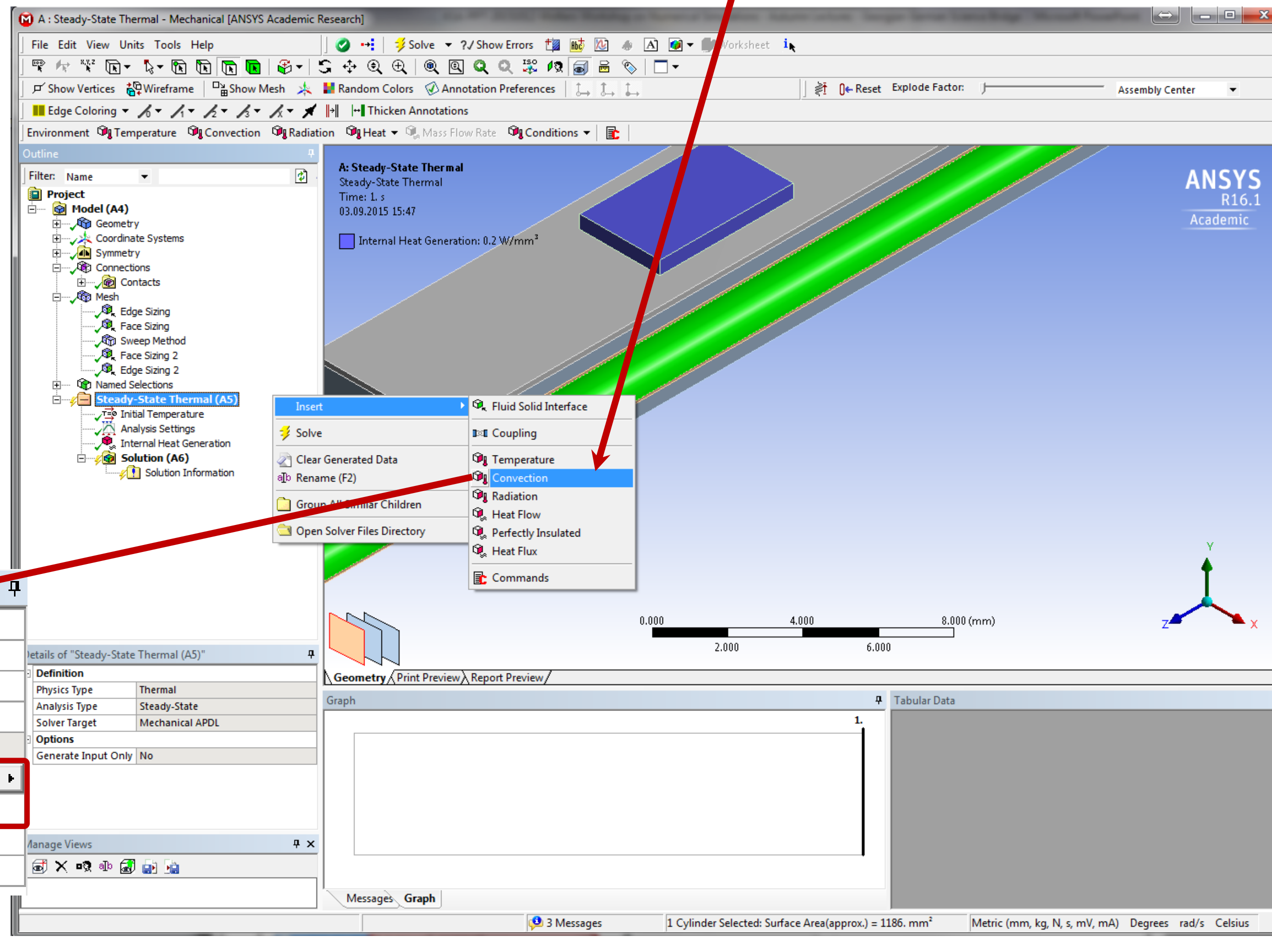
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – boundary conditions and solution

- Toolbars => => select inner surface of pipe
- Outline => Steady-State Thermal => RMB => Insert => Convection



- Details View

Details of "Convection"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Type	Convection
Film Coefficient	4.e-003 W/mm²·°C (ramped)
Ambient Temperature	20. °C (ramped)
Convection Matrix	Program Controlled
Suppressed	No

- Toolbars => Solve
-

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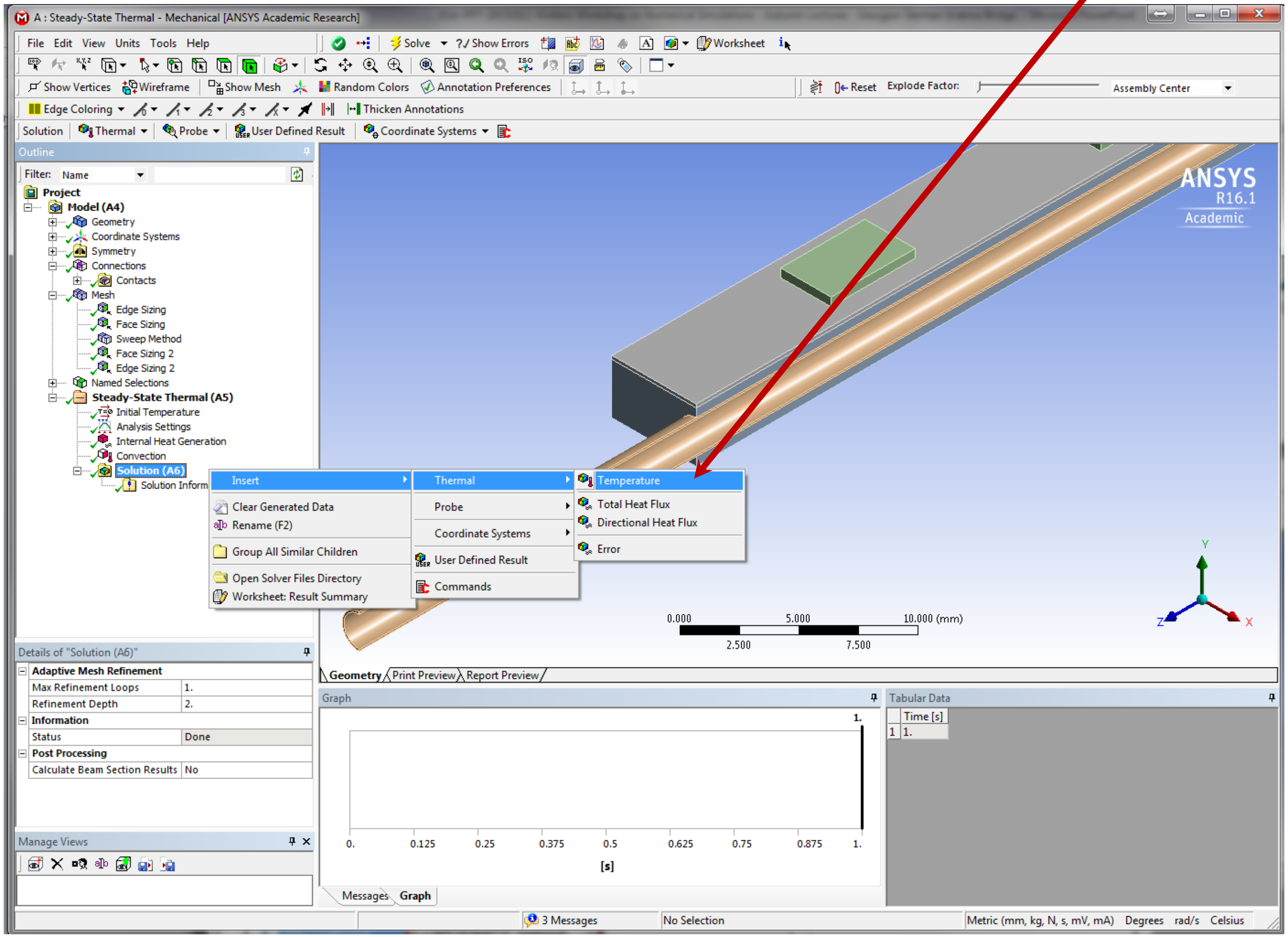
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – post-processing

- Outline => Steady-State Thermal => Solution => RMB => Insert => Thermal =>Temperatures



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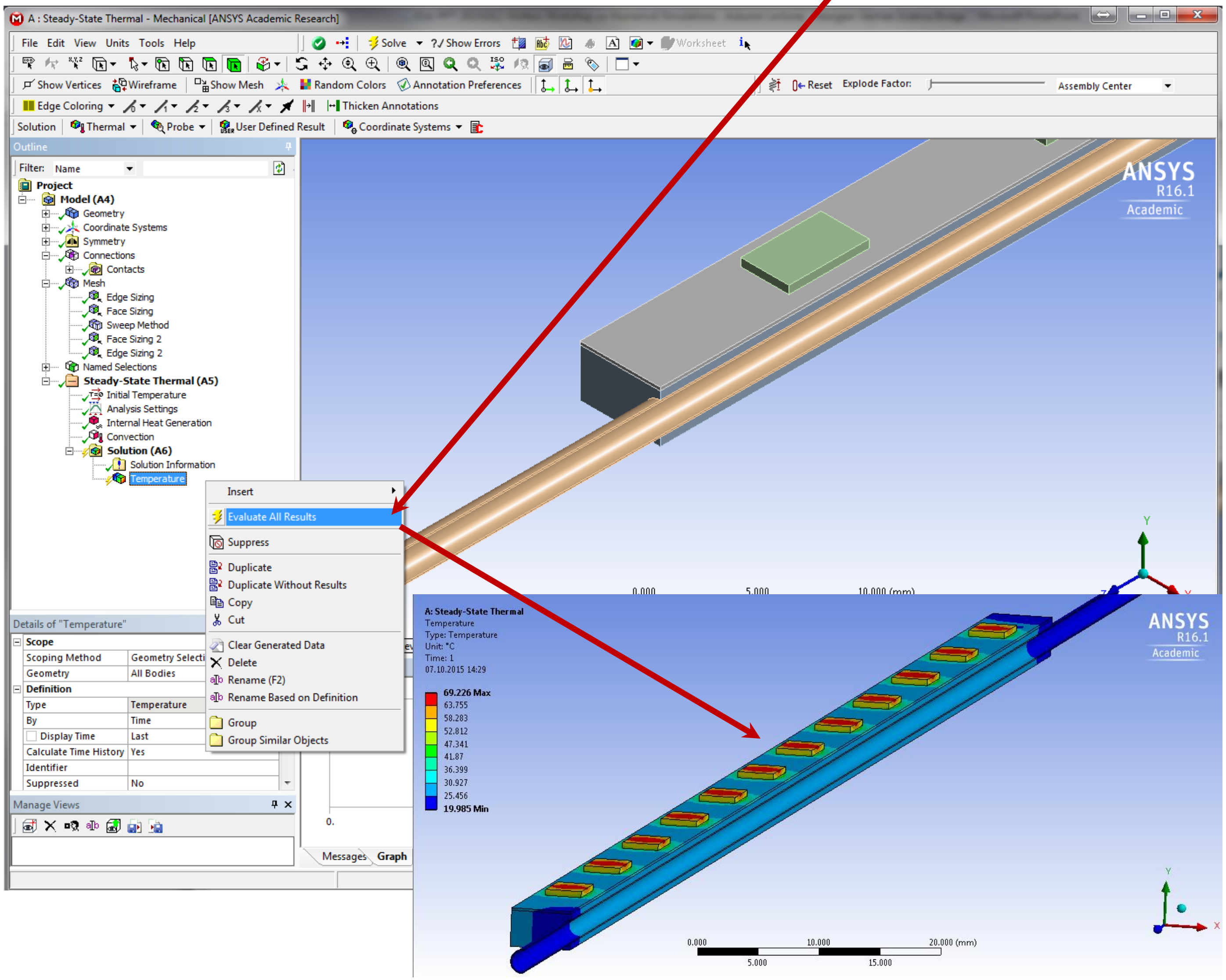
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – post-processing

- Outline => Steady-State Thermal => Solution => RMB Evaluate All Results



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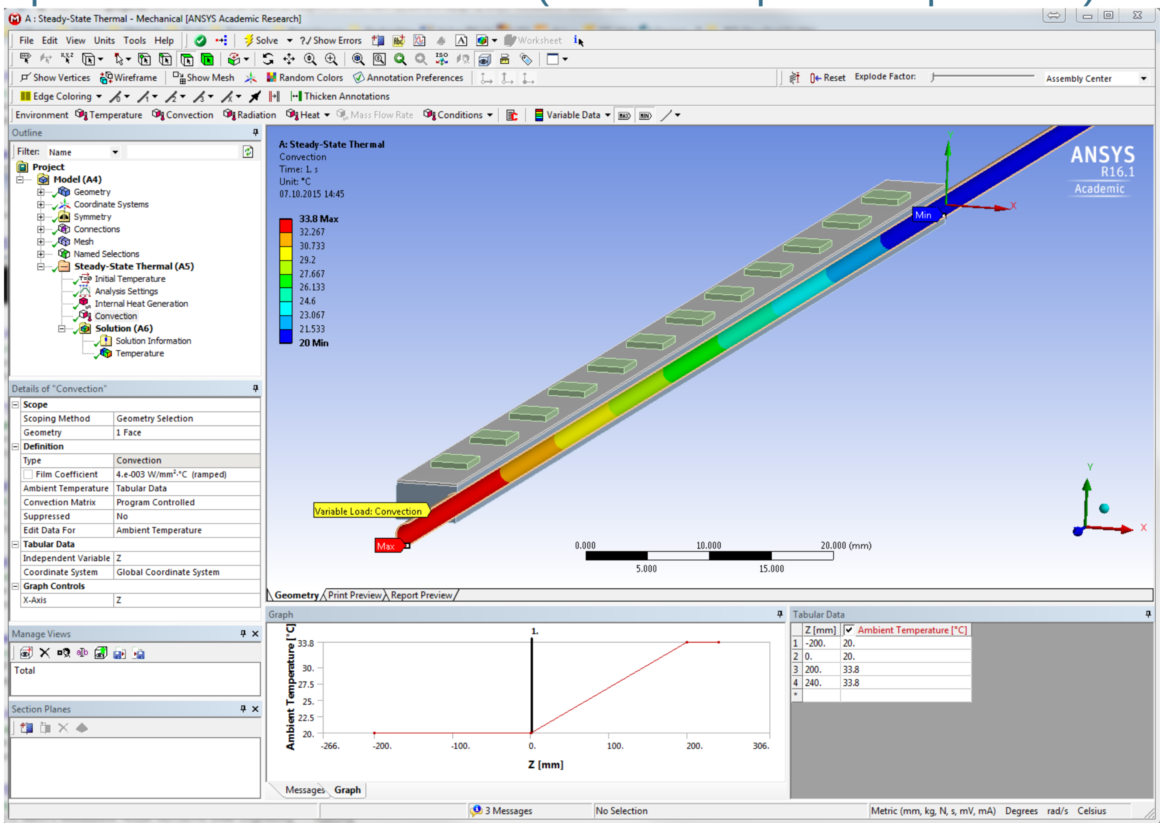
Exercise: Cooling of electronic components

↳ part c): simplified thermal simulation – adapted boundary conditions

- Main problem of current solution:
  heating up of helium while passing the pipe is not considered but is important in this case!
- Possible options:
  => modify ambient temperature in convection boundary condition by analytically assessing the temperature rise in the helium (for this simple case possible)



or

=> d) more precise simulation using fluid elements

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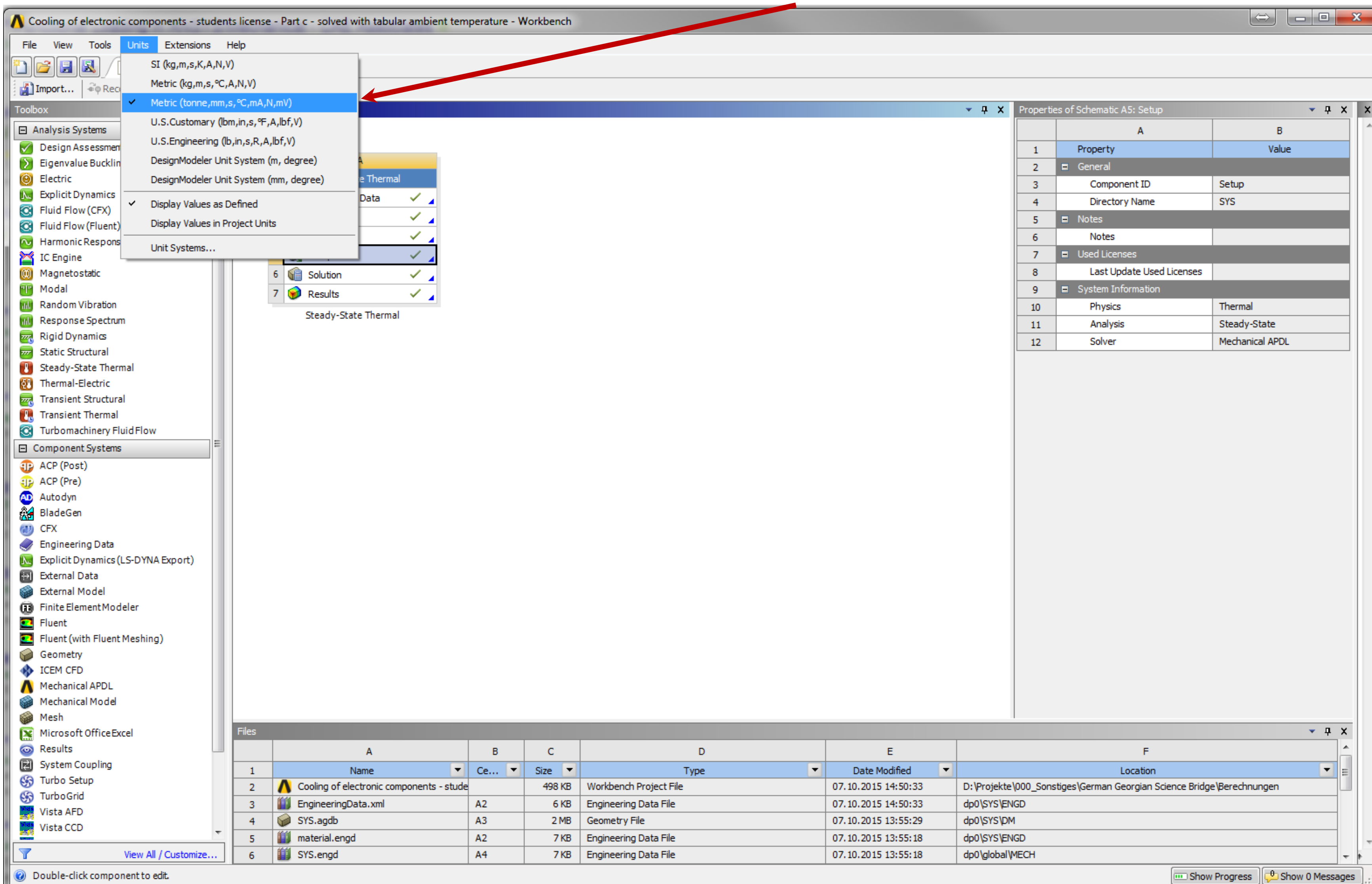
Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements – solver units

- Main Menu => Units => select ‘Metric (tonne,mm,s,°C,mA,N,mV)’



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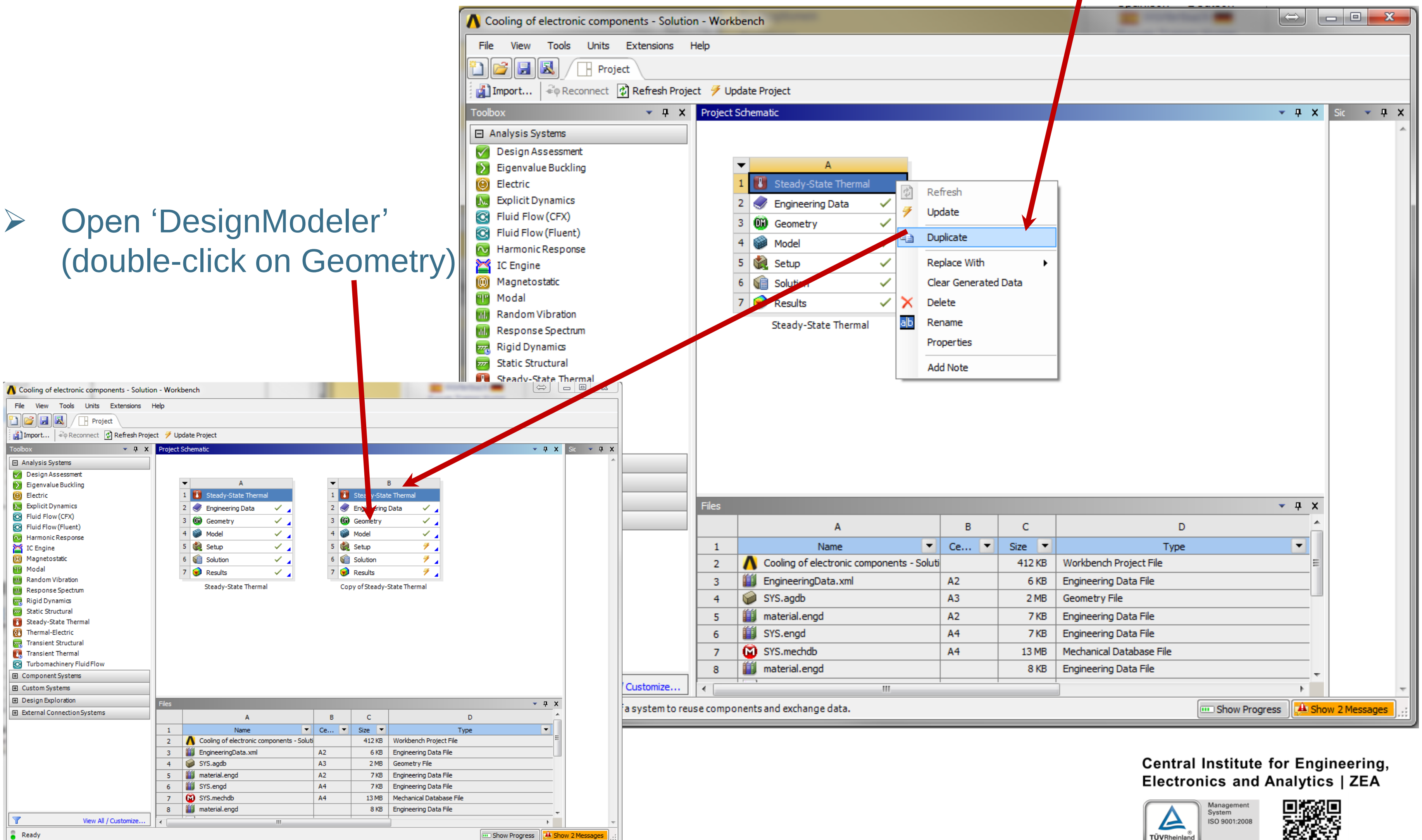
Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements – new project

- Project Schematic => Project A: Steady-State Thermal => RMB => Duplicate

- Open ‘DesignModeler’ (double-click on Geometry)



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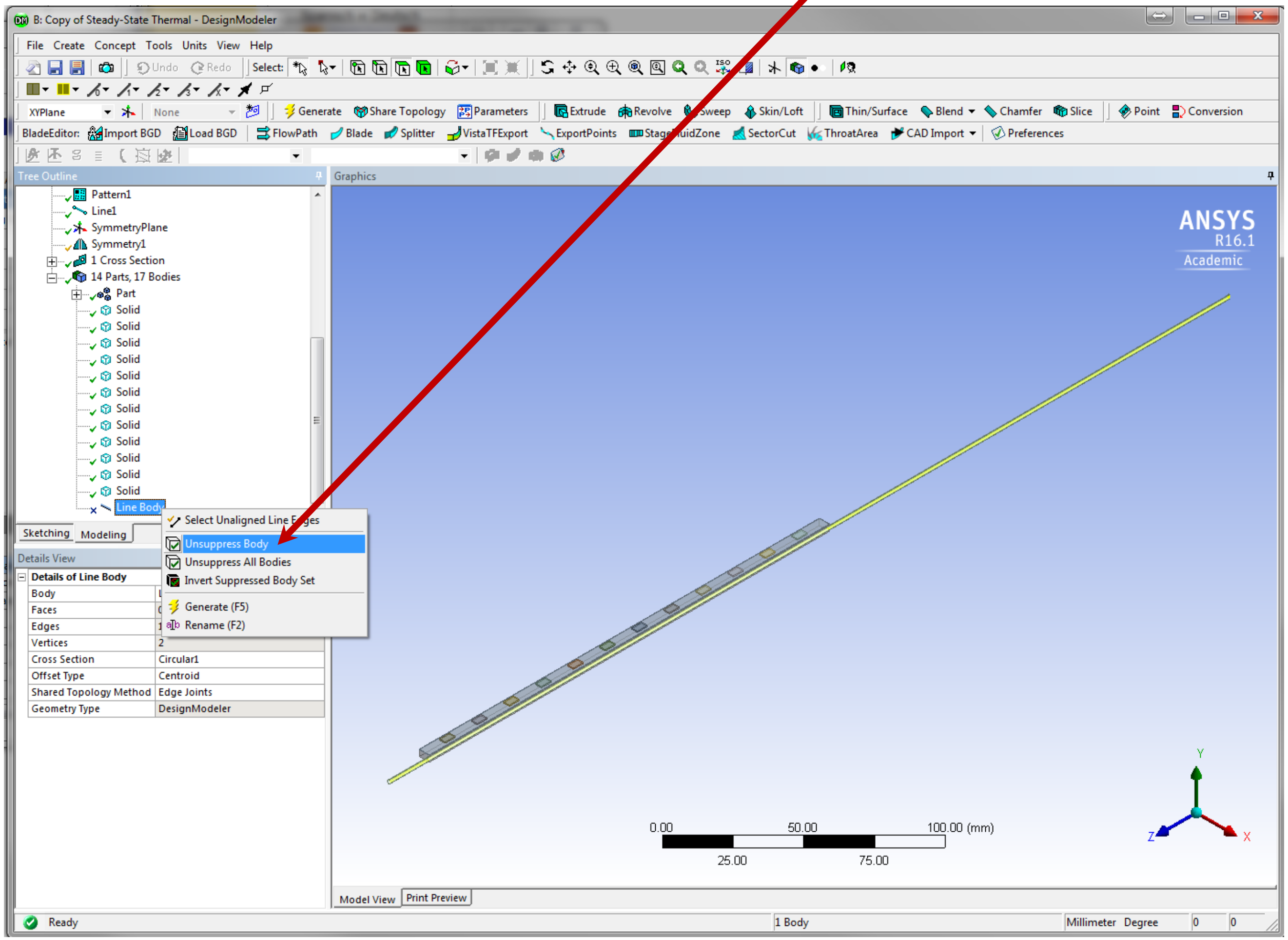
Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements – activate center line of pipe

- ➤ Tree Outline => Parts, Bodies => Line Body => RMB => Unsuppress Body
- ➤ Main Menu =>
  File =>
  Close Design Modeler



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Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements – activate center line of pipe

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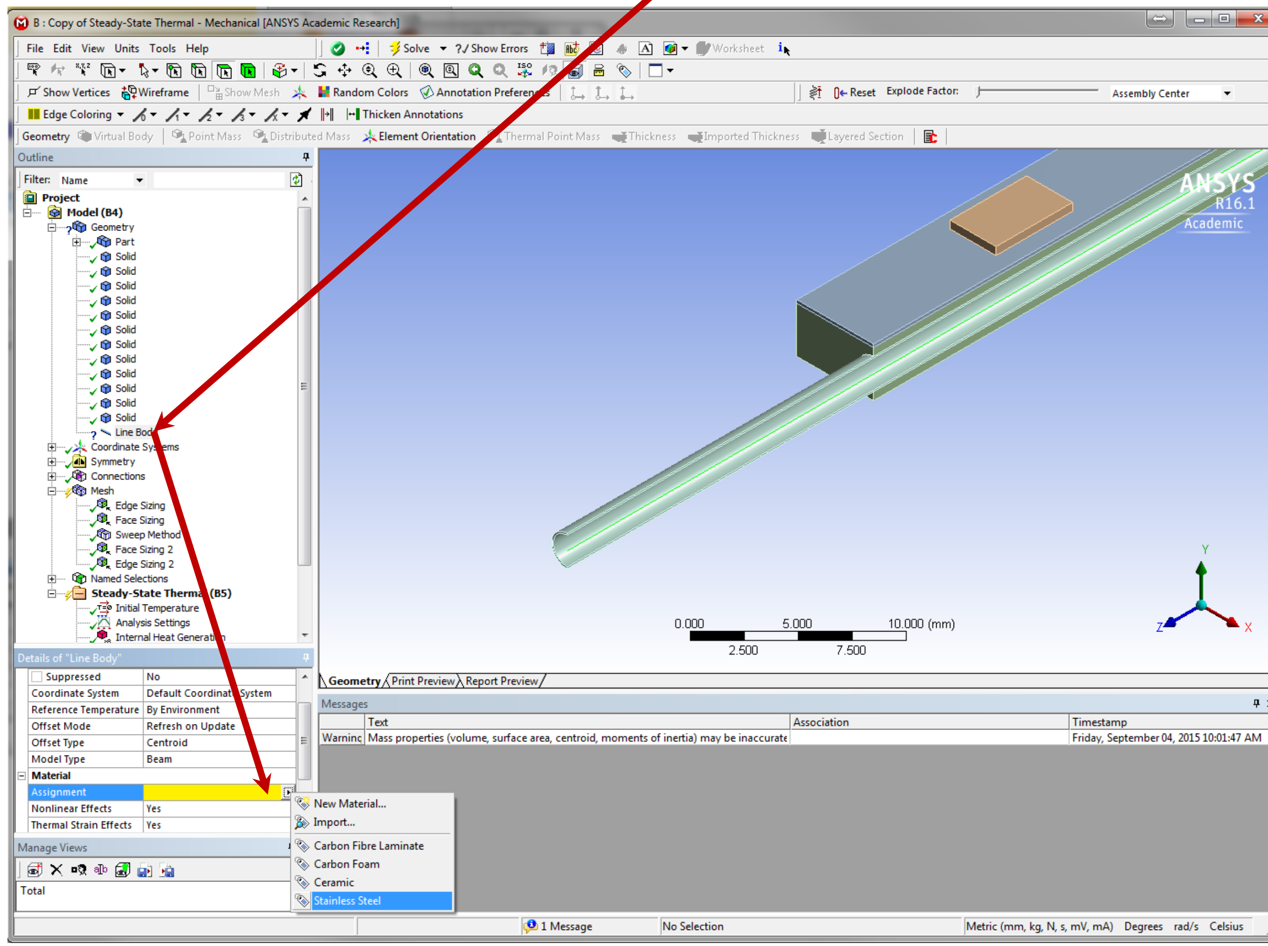
- Project Schematic => Project B => double-click on ‘Model’
- Outline => Project => Model => Geometry => Line Body => LMB
- Details View

Details of "Line Body"

+ Graphics Properties	
− Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Offset Mode	Refresh on Update
Offset Type	Centroid
Model Type	Beam
− Material	
Assignment	Stainless Steel
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
+ Bounding Box	
+ Properties	
+ Statistics	

(Note: Assignment not important for calculation but a material has to be selected)



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Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements – meshing

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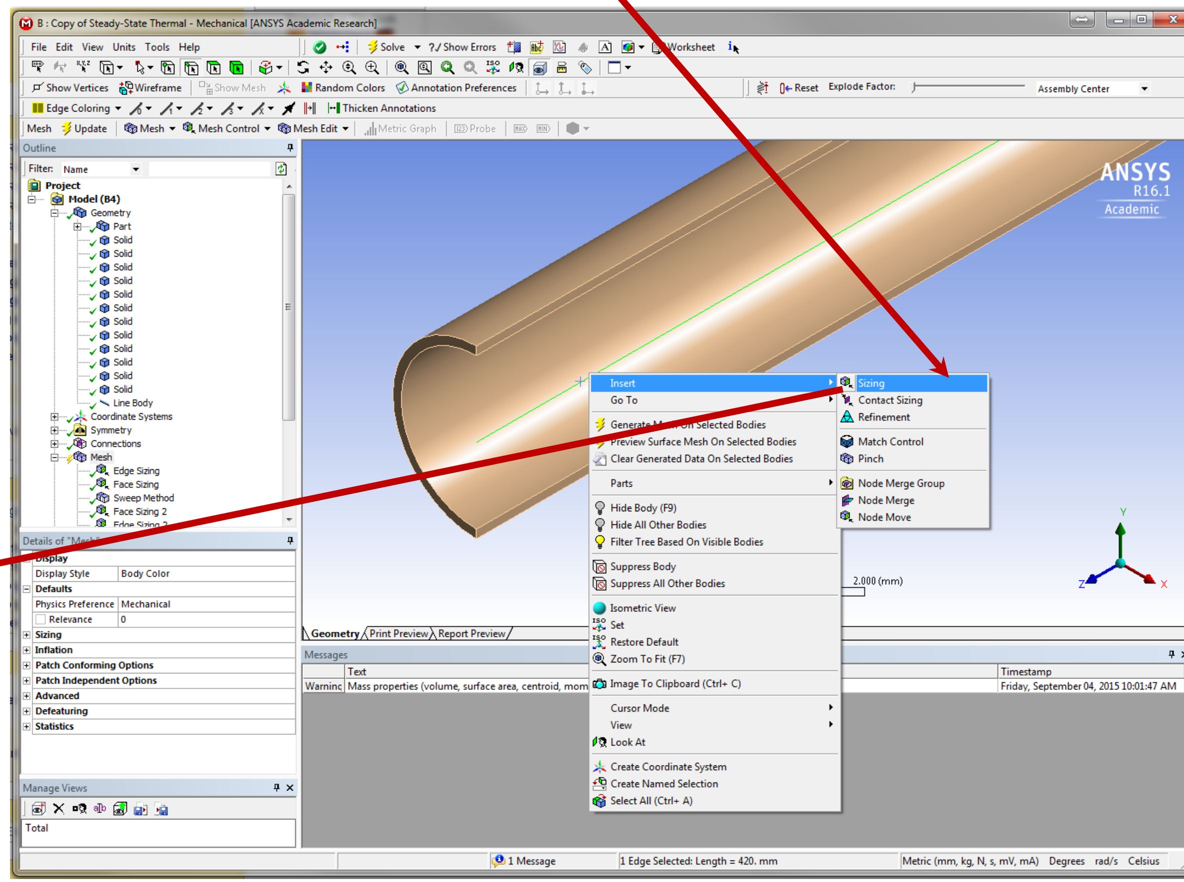
- ➢ Outline Mesh
- ➢ Toolbars => select center line => RMB => Insert => Sizing



- ➢ Details View:

Details of "Edge Sizing 5" - Sizing

Scope	
Scoping Method	Geometry Selection
Geometry	1 Edge
Definition	
Suppressed	No
Type	Element Size
Element Size	2. mm
Behavior	Soft
Bias Type	No Bias

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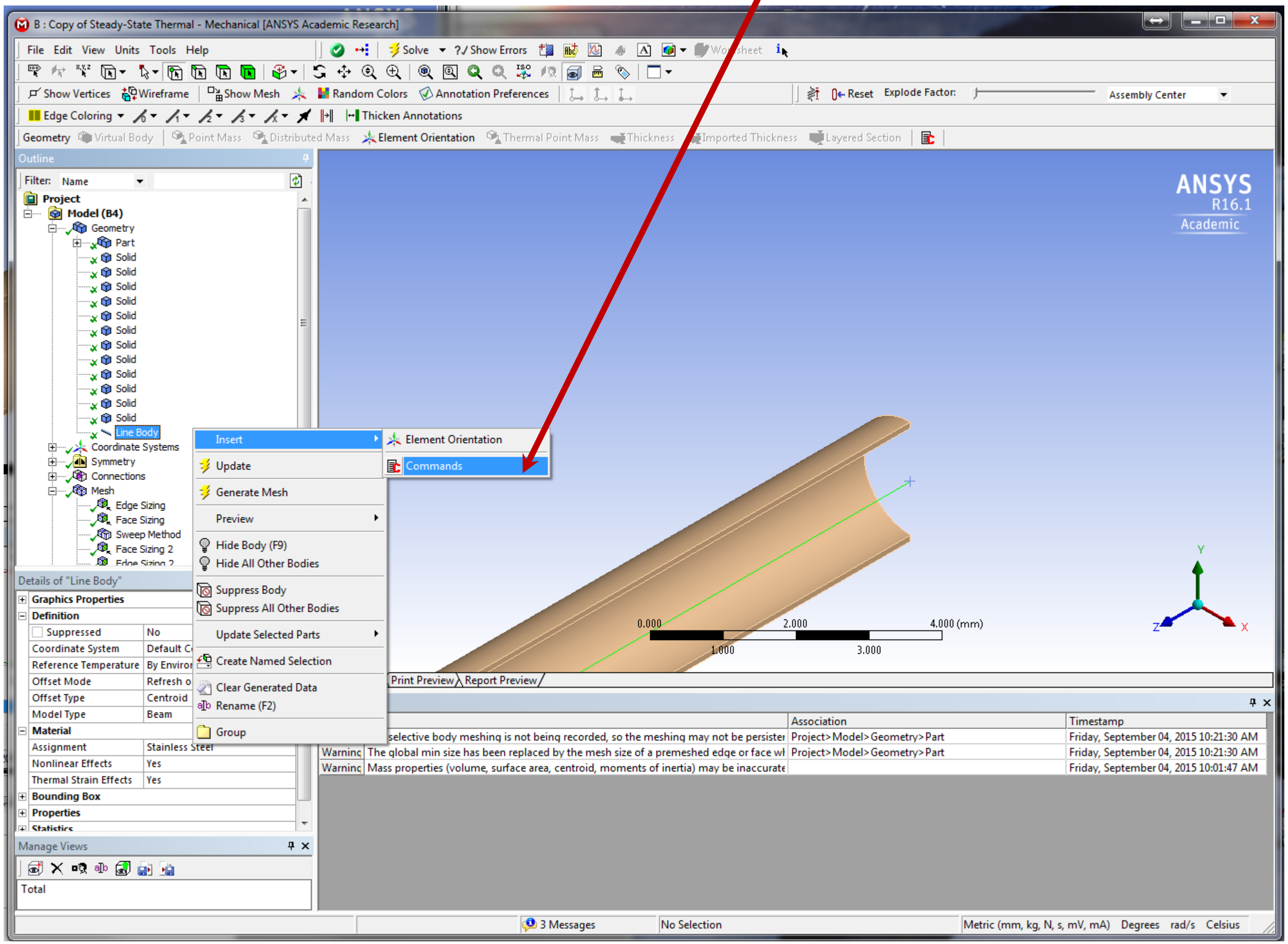
Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements - commands

Meshing the center line of pipe with fluid elements and assigning material properties:

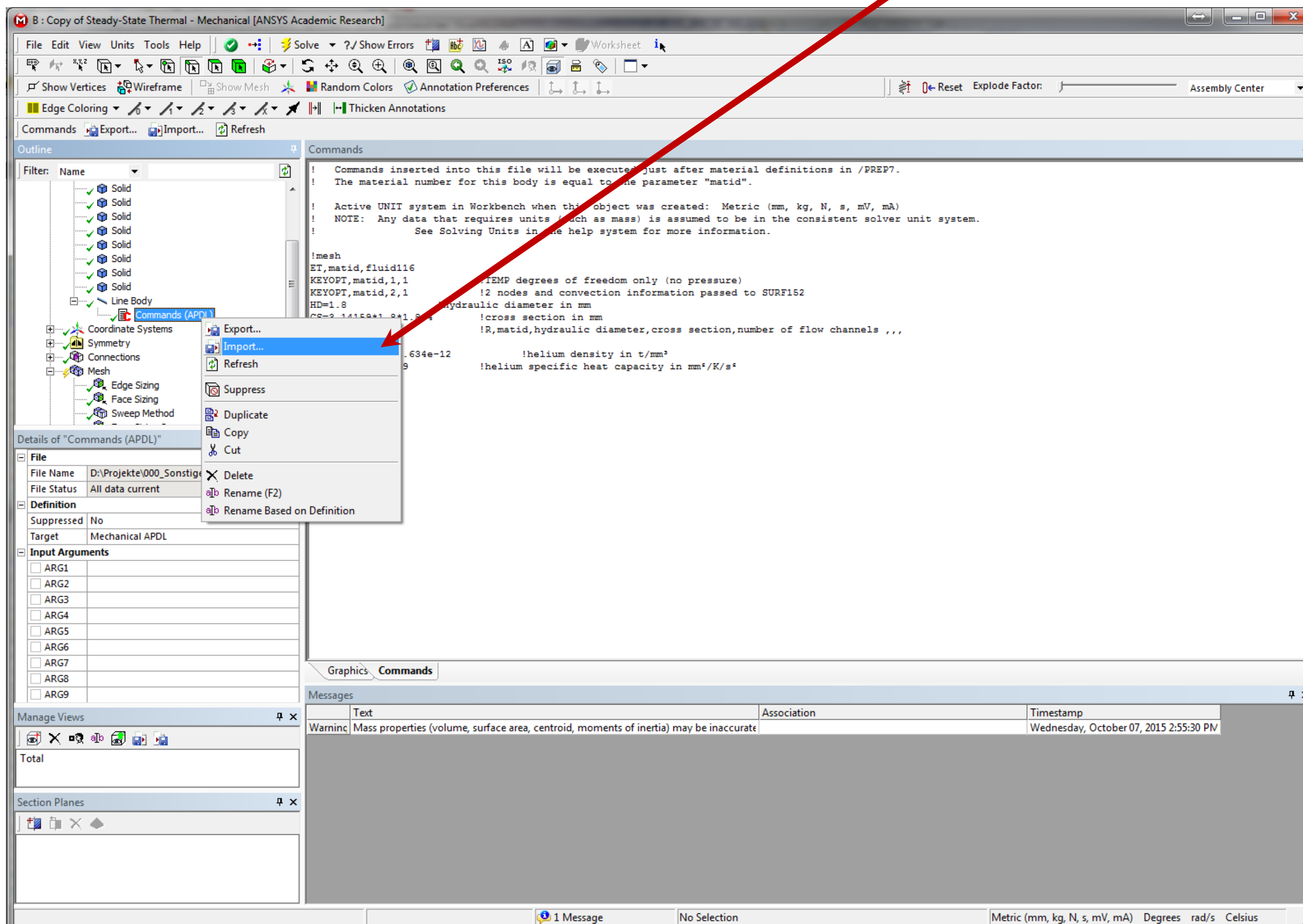
➢ Outline => Geometry => Line Body => RMB => Insert => Command



Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements - commands

- Outline => Geometry => Line Body => Commands (APDL) => RMB => Import … => 'LineBody-Commands.txt'



Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements - commands

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the following commands were imported:

```
!mesh
ET,matid,fluid116
KEYOPT,matid,1,1                  !TEMP degrees of freedom only (no pressure)
KEYOPT,matid,2,1                  !2 nodes and convection information passed to SURF152
HD=1.8                            !hydraulic diameter in mm
CS=3.14159*1.8*1.8/4              !cross section in mm
R,matid,HD,CS,1                   !R,matid,hydraulic diameter,cross section,number of flow channels ,,,
! material
mp,dens,matid,1.634e-12           !helium density in t/mm³
mp,c,matid,5.2e9                  !helium specific heat capacity in mm²/K/s²
```

Notice: In principle ANSYS Workbench will consider units – but when using commands in Workbench the user is responsible to enter all values in the correct unit system!

If you run the same simulation using the SI-Unit-System (m, kg, s, V …) in Workbench you will get incorrect results.

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Exercise: Cooling of electronic components
↳ part d): simulation with fluid elements – meshing

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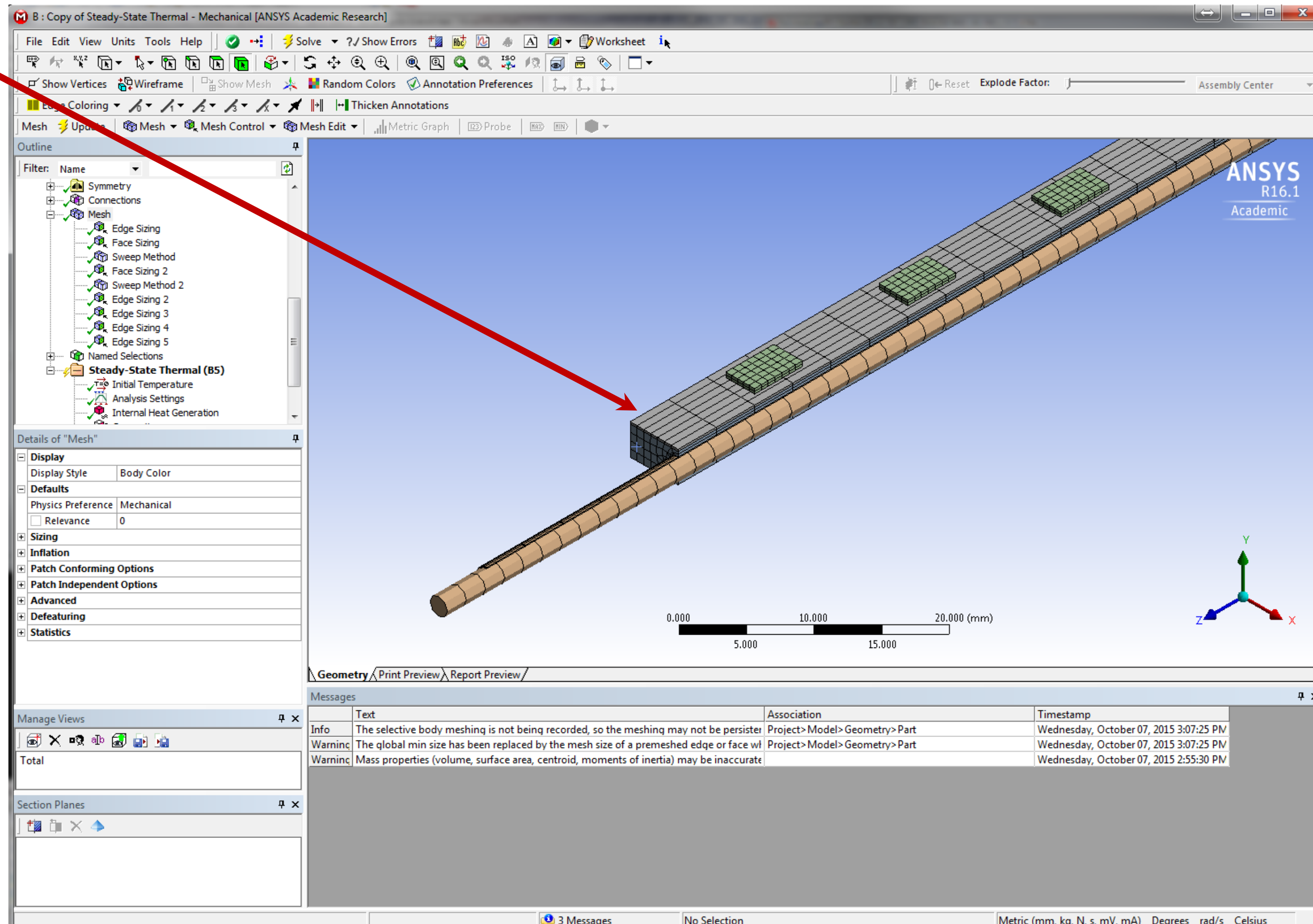
➢ Mesh geometry
sequence like in part c)
- first mesh pipe
- then mesh foam
- then generate complete mesh



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Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements – boundary conditions

Convective heat transfer boundary conditions are not needed here:

- Outline => Steady-State Thermal => Convection => RMB => Suppress

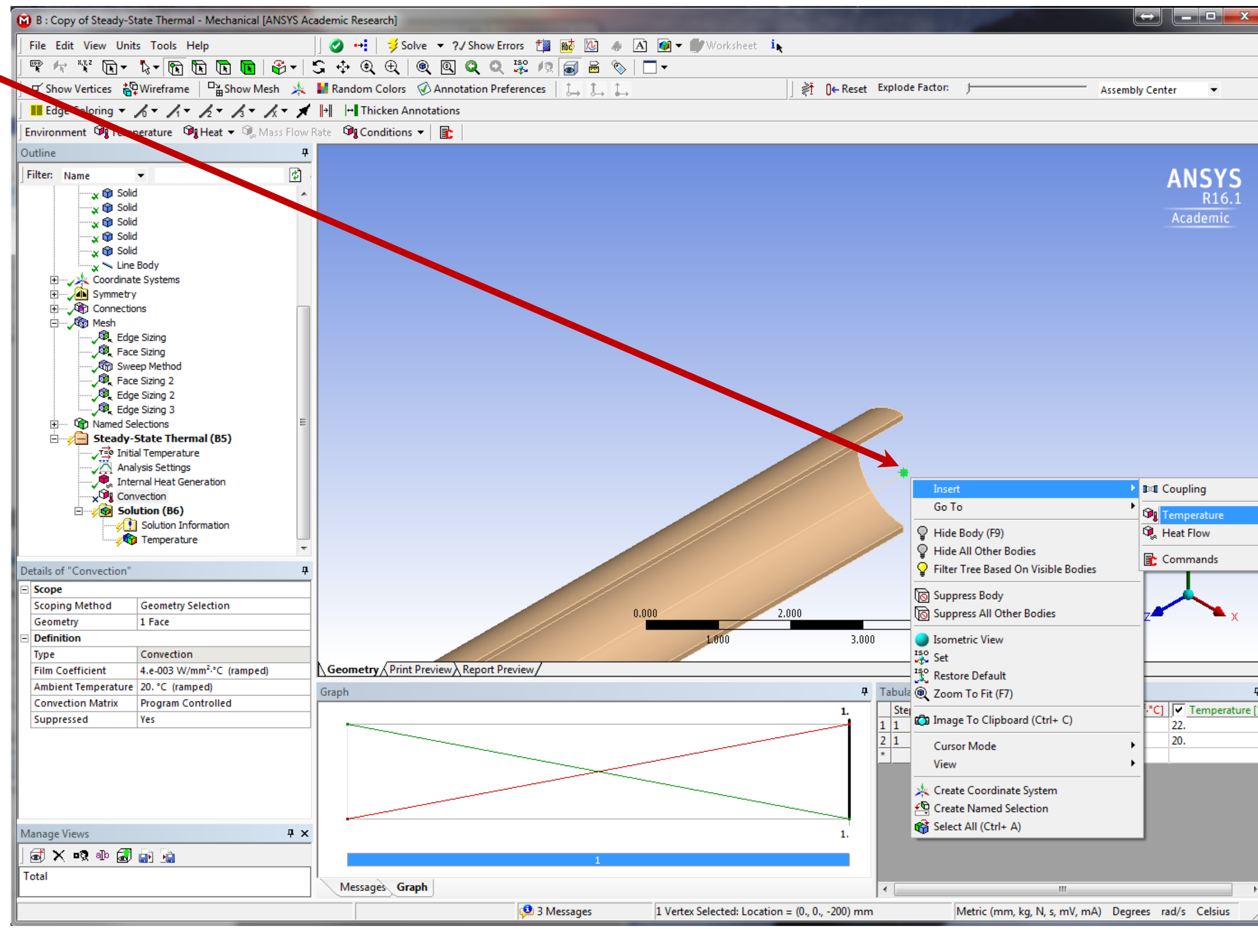
Specify fluid inlet temperature:

- Toolbars => select start point of centerline => RMB => Insert => Temperature

- Details View:

Details of "Temperature"

Scope	
Scoping Method	Geometry Selection
Geometry	1 Vertex
Definition	
Type	Temperature
Magnitude	20. °C (ramped)
Suppressed	No



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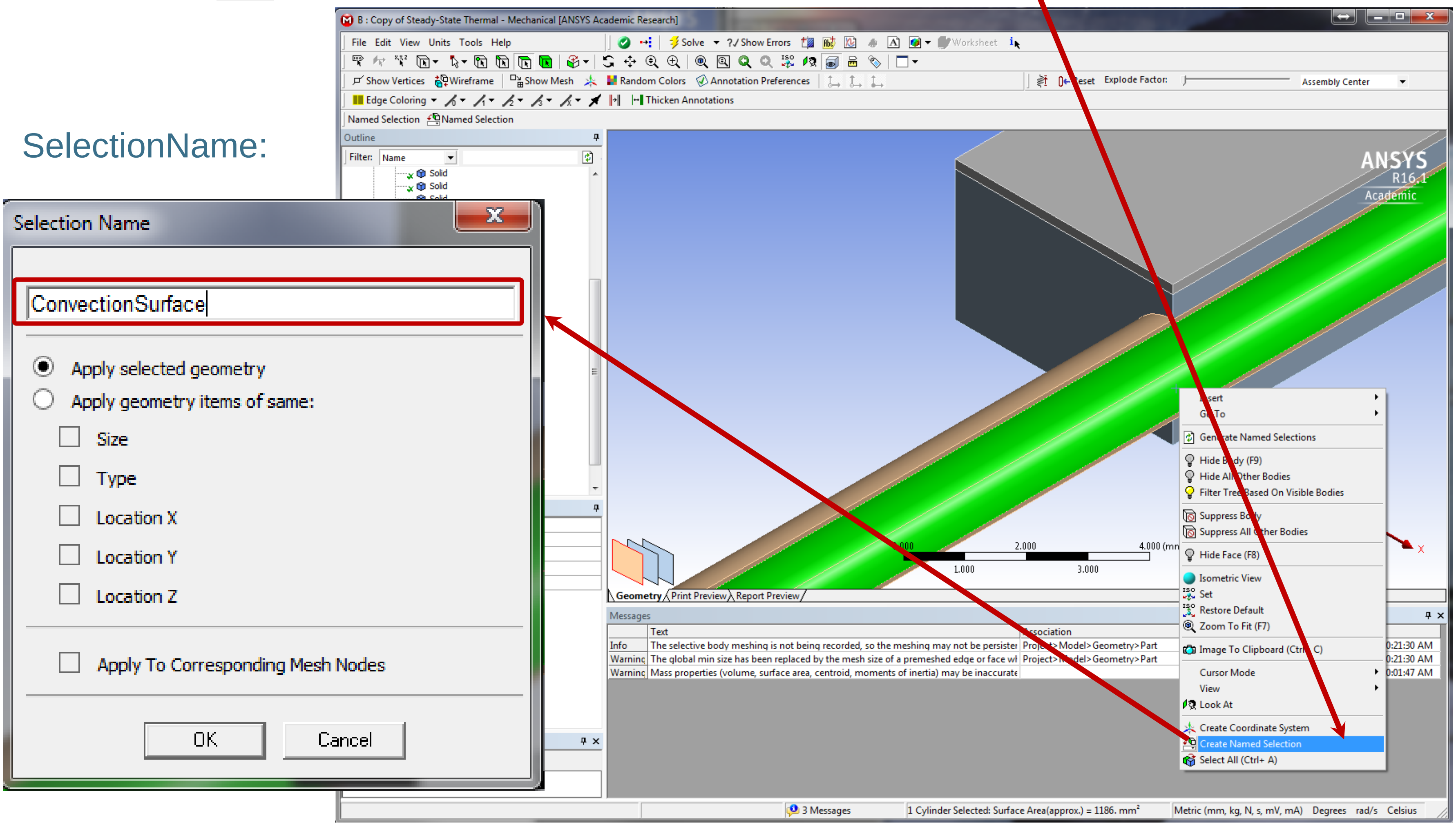
Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements – boundary conditions

Heat transfer from pipe to fluid elements has to be defined:

- ➢ Outline => Named Selections => LMB
- ➢ Toolbars => select inner surface of pipe => RMB => Create Named Selection
- ➢ SelectionName:



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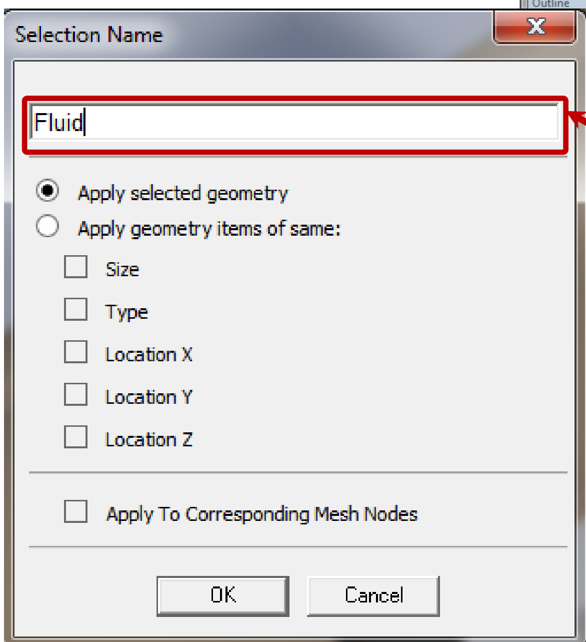
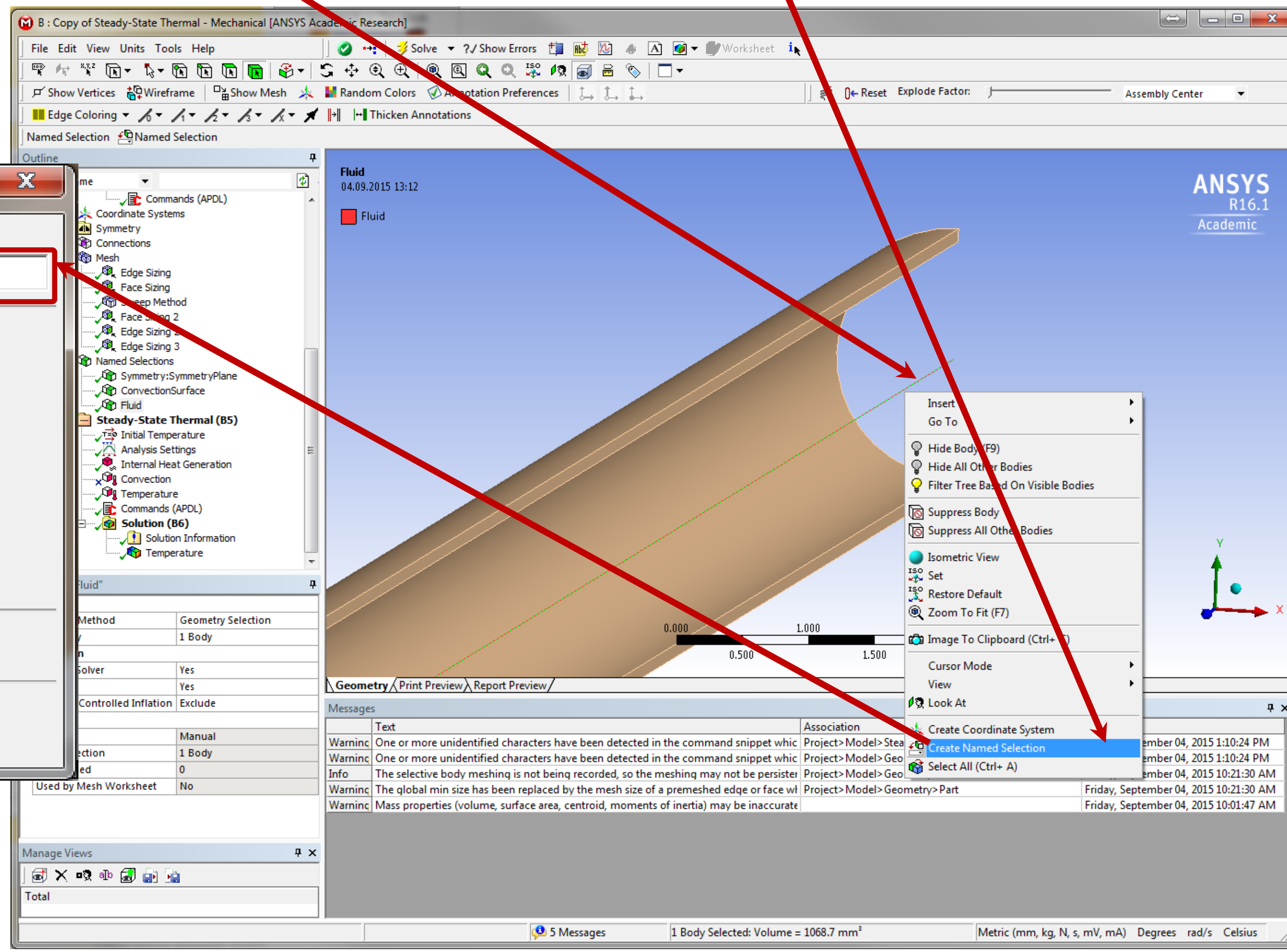
Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements – boundary conditions

- Outline => Named Selections => LMB
- Toolbars => select center line **body** => RMB => Create Named Selection (important)
- Selection Name:





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Exercise: Cooling of electronic components

↳ part d): simulation with fluid elements – boundary conditions

- Outline => Steady-State Thermal => RMB => Insert => Command
- Outline => Steady-State Thermal => Commands (APDL) => RMB => Import => 'SteadyStateThermal-Commands.txt'

the following commands were imported::

```
finish
/PREP7
!----
! surface effect elements
et,200,152
keyopt,200,8,2                    !Hf at average T
type,200
! generate surface elements on existing mesh of pipe with closest fluid element node
ndsurf,'ConvectionSurface','Fluid',3
!boundary conditions
cmsel,s,Fluid
sfe,all,,hflux,,2.5e-7 !mass flow rate in t/s (due to symmetry only 1/2 of total mass flow rate)
esel,s,type,,200
sfe,all,,conv,,4 !heat transfer coefficient in t/K/s³
!----
alls
fini
/solu
```

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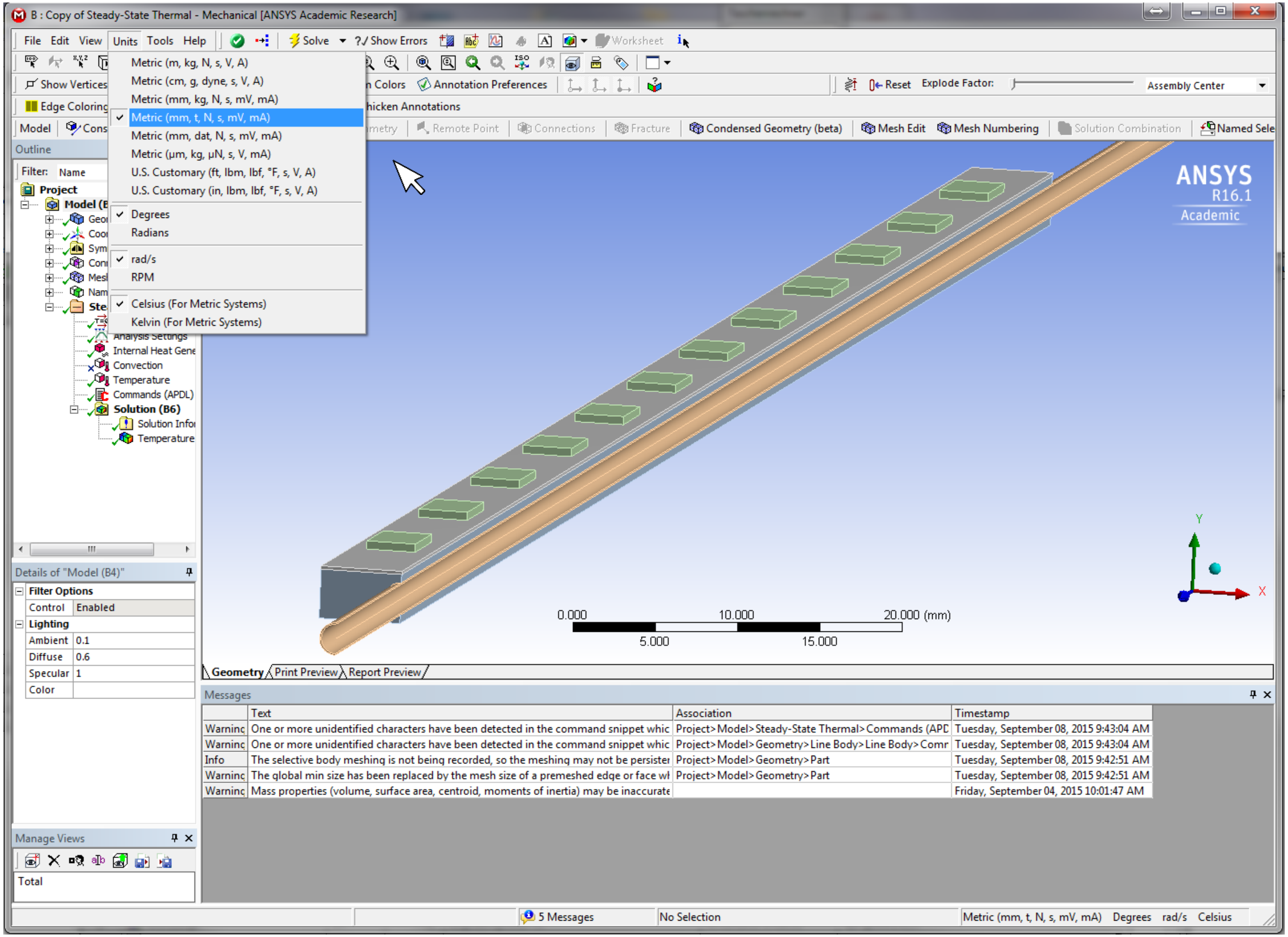
Exercise: Cooling of electronic components
↳ part d): simulation with fluid elements – boundary conditions

- Main Menu => Units => Metric (mm, t, N, s, mV, mA) => LMB



	Text	Association	Timestamp
Warning	One or more unidentified characters have been detected in the command snippet whic	Project>Model>Steady-State Thermal>Commands (APD	Tuesday, September 08, 2015 9:43:04 AM
Warning	One or more unidentified characters have been detected in the command snippet whic	Project>Model>Geometry>Line Body>Line Body>Comr	Tuesday, September 08, 2015 9:43:04 AM
Info	The selective body meshing is not being recorded, so the meshing may not be persister	Project>Model>Geometry>Part	Tuesday, September 08, 2015 9:42:51 AM
Warning	The global min size has been replaced by the mesh size of a premeshed edge or face wi	Project>Model>Geometry>Part	Tuesday, September 08, 2015 9:42:51 AM
Warning	Mass properties (volume, surface area, centroid, moments of inertia) may be inaccurate		Friday, September 04, 2015 10:01:47 AM

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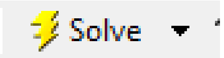
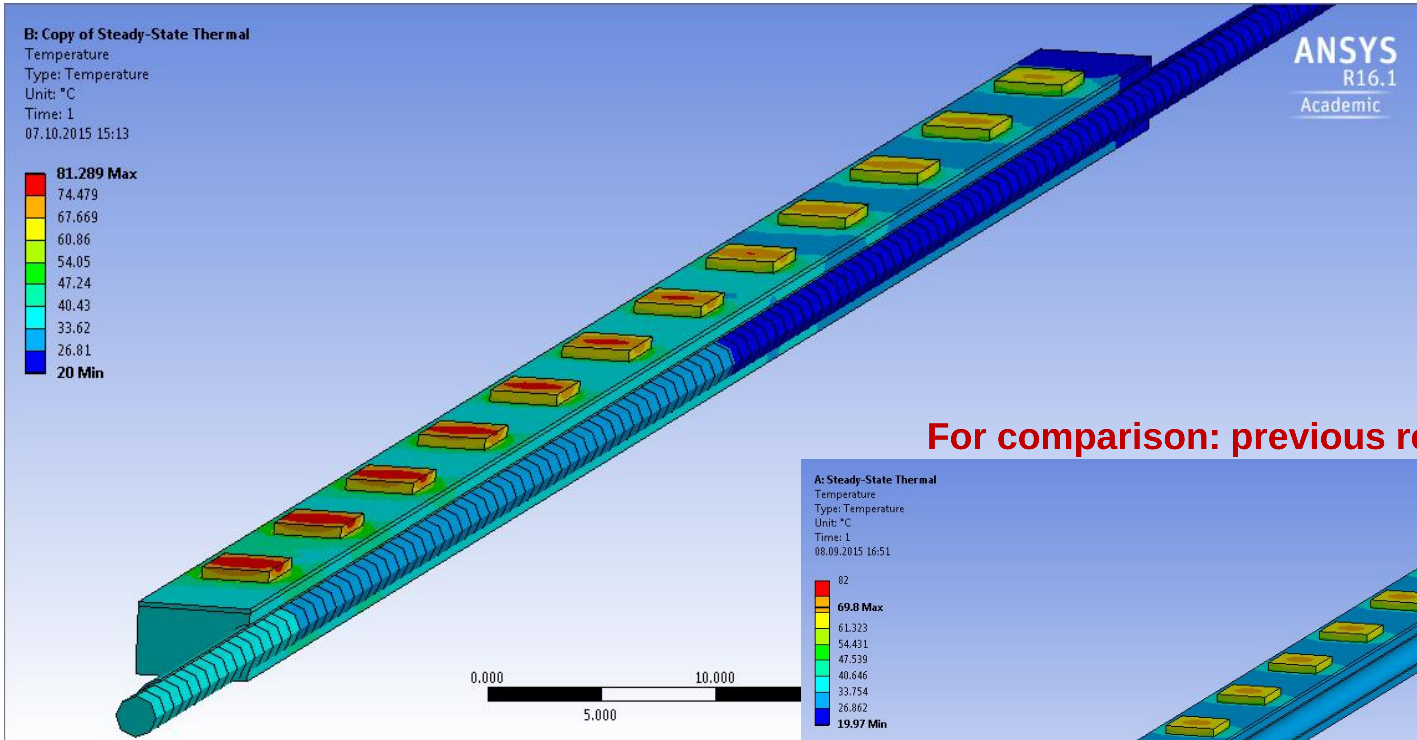
Exercise: Cooling of electronic components

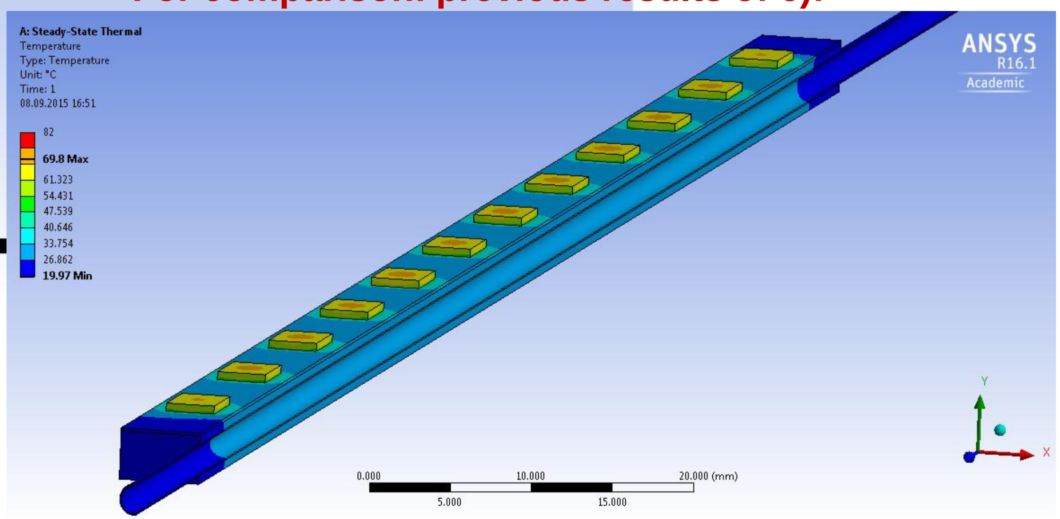
↳ part d): simulation with fluid elements – solving and post-processing

- Toolbars => 

- Outline => Steady-State Thermal => Solution => Temperature => LMB



For comparison: previous results of c):



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- Numerical method for solving partial differential equations representing conservation laws for mass, momentum and energy for fluid flows.
- Domain is discretized into a finite set of control volumes or cells. The discretized domain is called the “grid” or the “mesh.” The most commonly used method for CFD is the Finite-Volume-Method.
- Control volume balance for a general flow variable ϕ can be expressed by:
rate of change = net flux due to convection + net flux due to diffusion + net rate of creation
- The Navier-Stokes equations are the general form of the equation of motion for a viscous fluid.
- Typical numerical methods to consider flow turbulence:
  - DNS (direct numerical simulation): all eddies are resolved by a very fine mesh
    => this method is time consuming and requires huge computational resources
  - RANS (Reynolds-Averaged Navier-Stokes): a turbulence model describes all effects of turbulence on the flow
    => this is the most commonly used method for technical applications; stationary analyses are possible and computational costs are low
  - LES (large eddy simulations): only the largest eddies are resolved by the mesh and smaller eddies are considered by a turbulence model
    => compromise between DNS and RANS

Exercise: Cooling of electronic components

↳ part e): CFD simulation – CFX project

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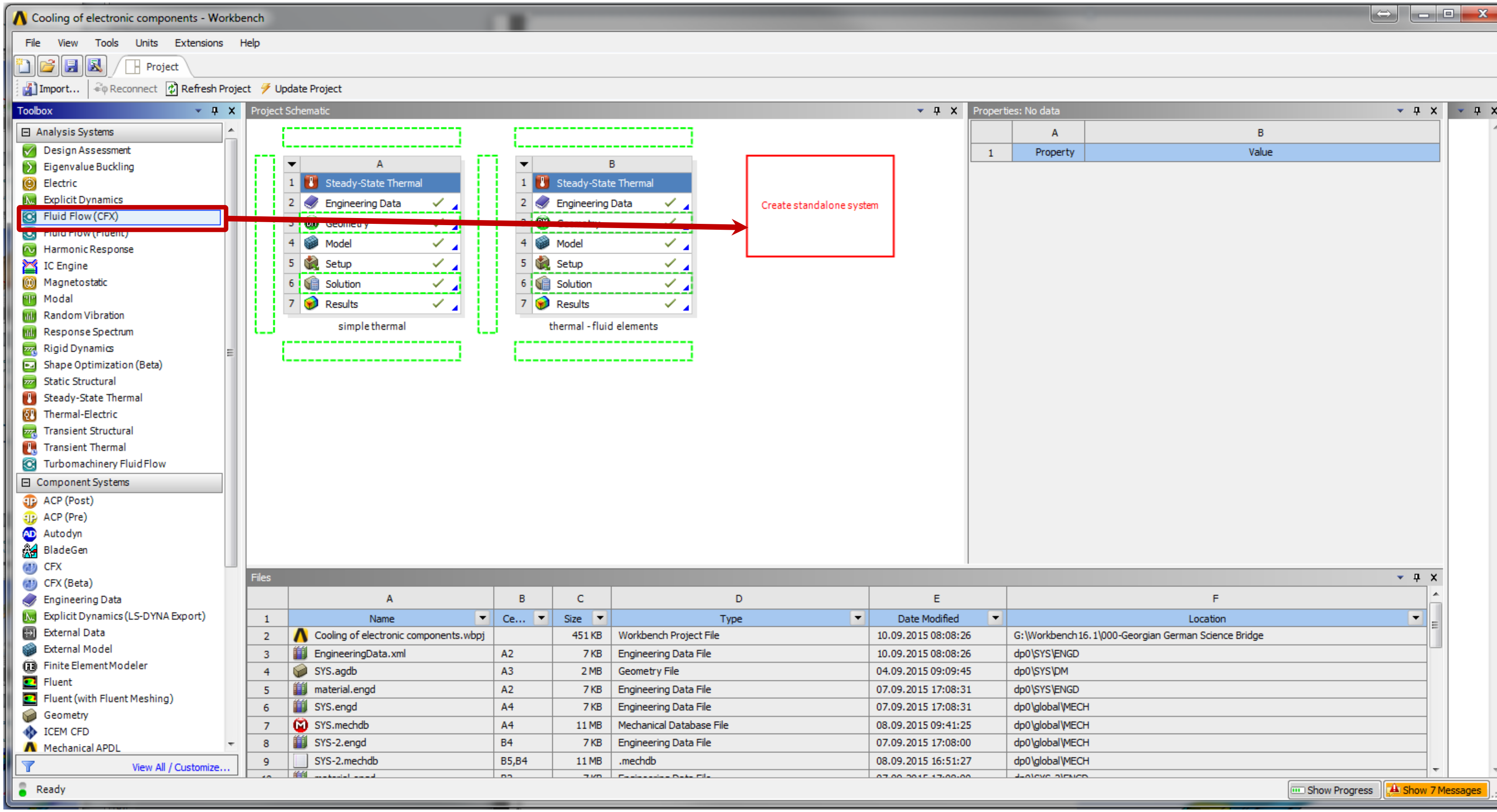
➢ Project => Toolbox => Analysis Systems => Fluid Flow (CFX) => drag and drop (LMB) to Project Schematic



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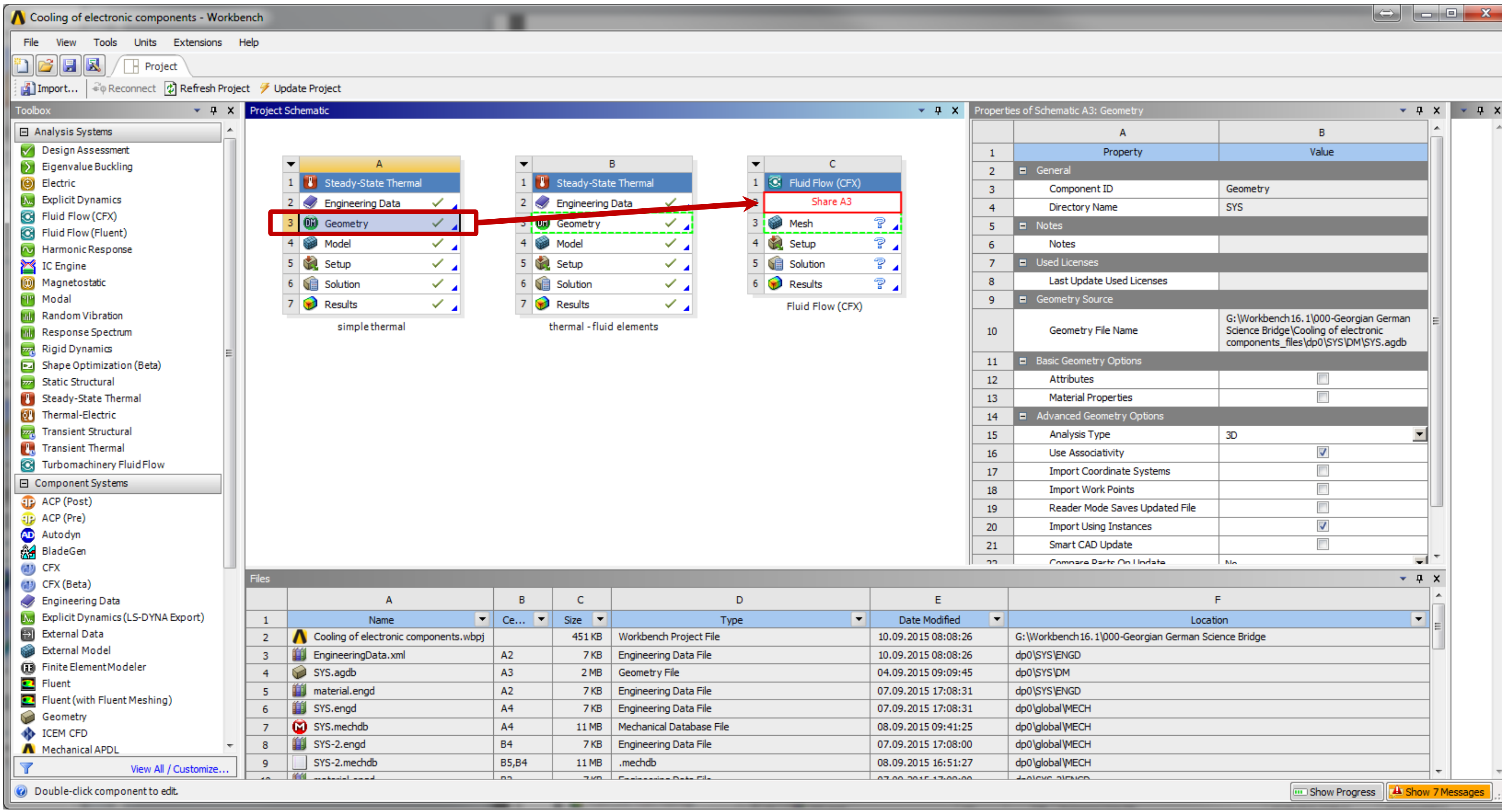
Exercise: Cooling of electronic components

↳ part e): CFD simulation – CFX project

➢ Project => Project Schematic => Project A => Geometry => drag and drop (LMB) to Project C Geometry



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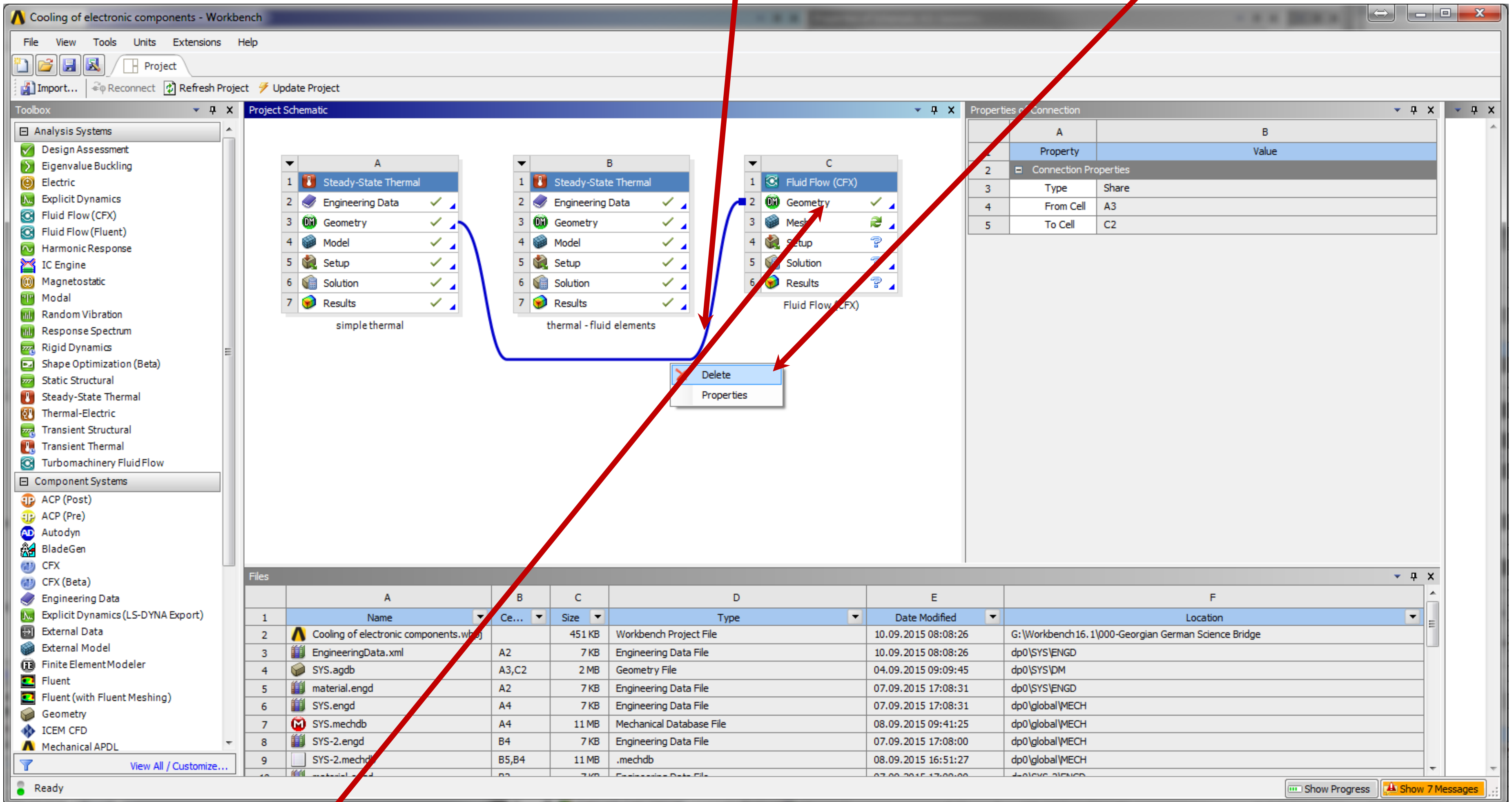
Exercise: Cooling of electronic components

↳ part e): CFD simulation – CFX project

- Project => Project Schematic => Geometry Connection => RMB => Delete



- Open Geometry (double click LMB)

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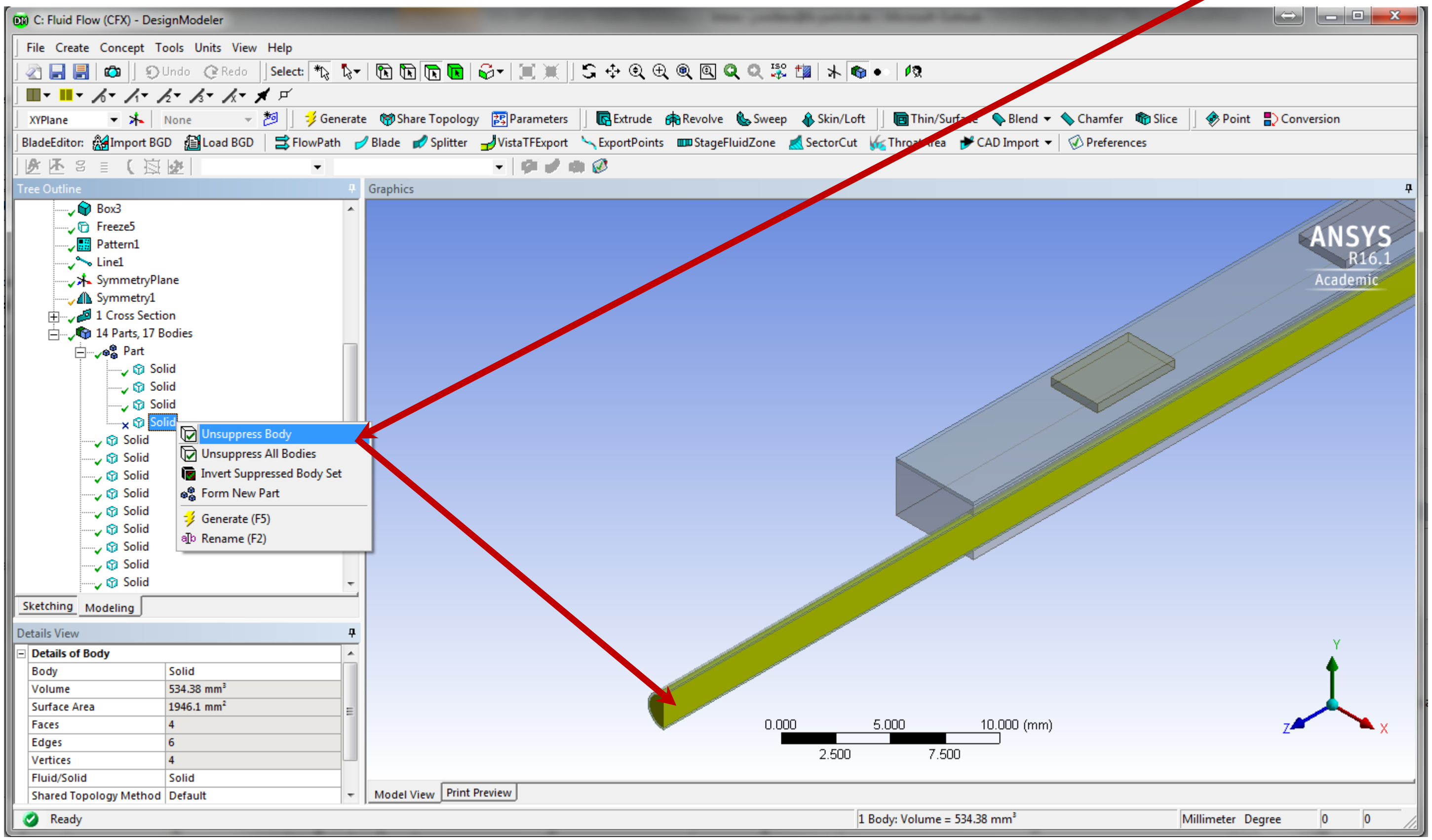
Exercise: Cooling of electronic components

↳ part e): CFD simulation – geometry: activate fluid region

➢ Tree Outline => Parts, Bodies => Part => Solid RMB => Unsuppress Body



➢ Main Manu => File => Close DesignModeler

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Exercise: Cooling of electronic components

↳ part e): CFD simulation – meshing

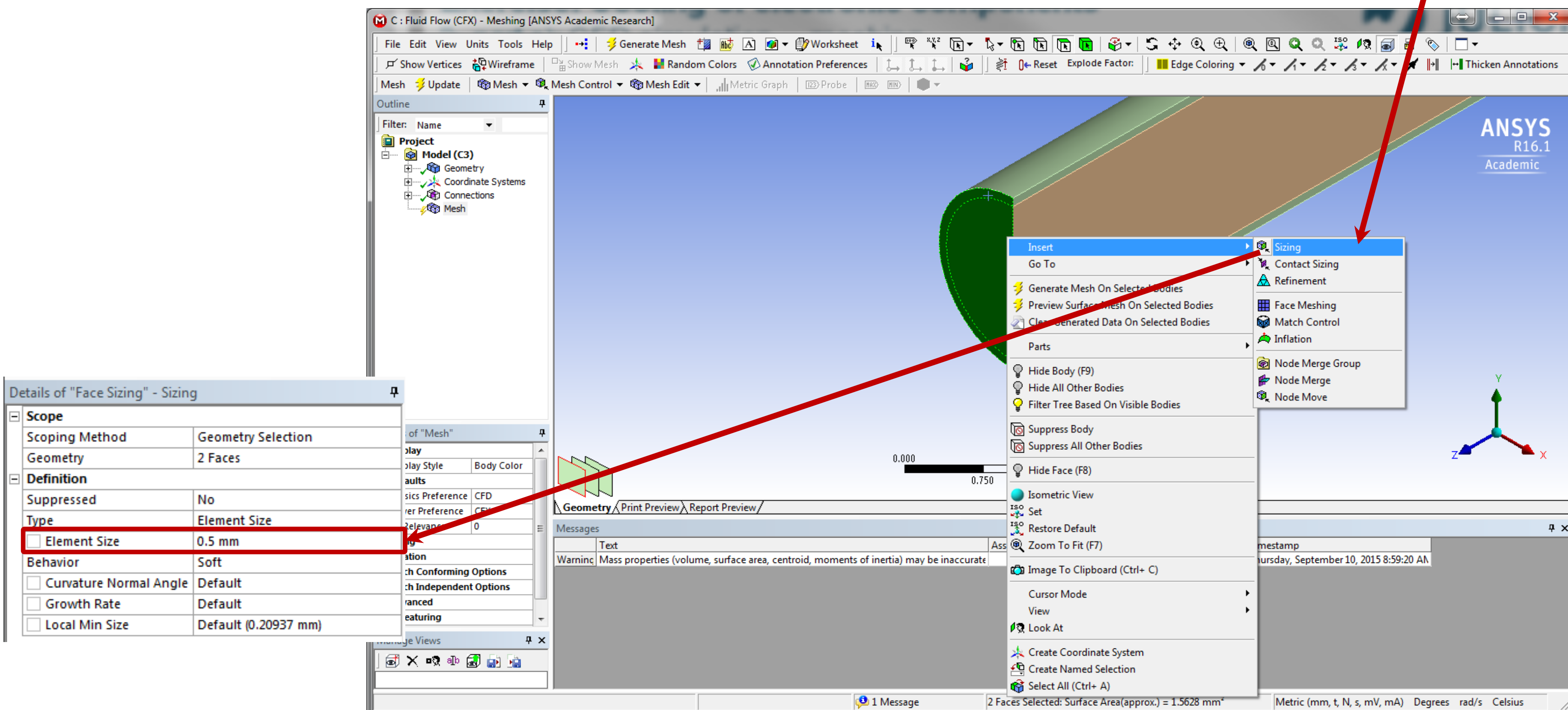
Open Meshing:

➢ Project => Project Schematic => Project C => Mesh (double click LMB)

Element Size on end faces of fluid and pipe

➢ Outline => Project => Mesh => LMB

➢ Toolbars => => select faces (second face with ‘Ctrl’) => RMB => Insert => Sizing



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↳ part e): CFD simulation – meshing

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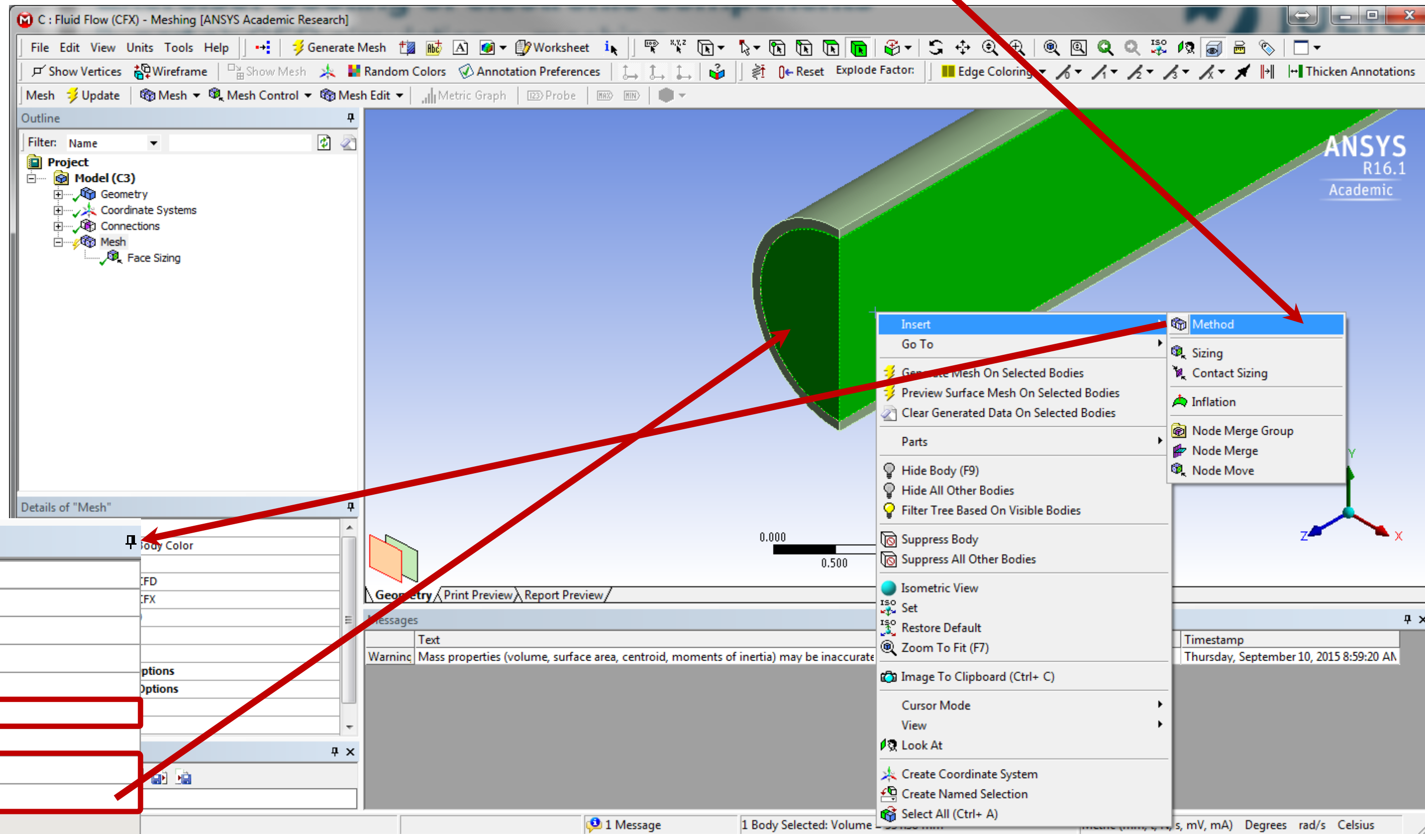
➢ Toolbars => => select fluid body => RMB => Insert => Method



➢ Details View

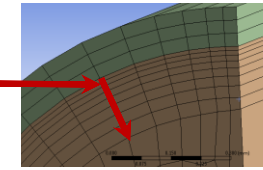
Details of "Sweep Method" - Method

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Sweep
Element Midside Nodes	Use Global Setting
Src/Trg Selection	Manual Source
Source	1 Face
Target	Program Controlled
Free Face Mesh Type	Quad/Tri
Type	Element Size
Sweep Element Size	1. mm
Sweep Bias Type	No Bias
Element Option	Solid
Constrain Boundary	No

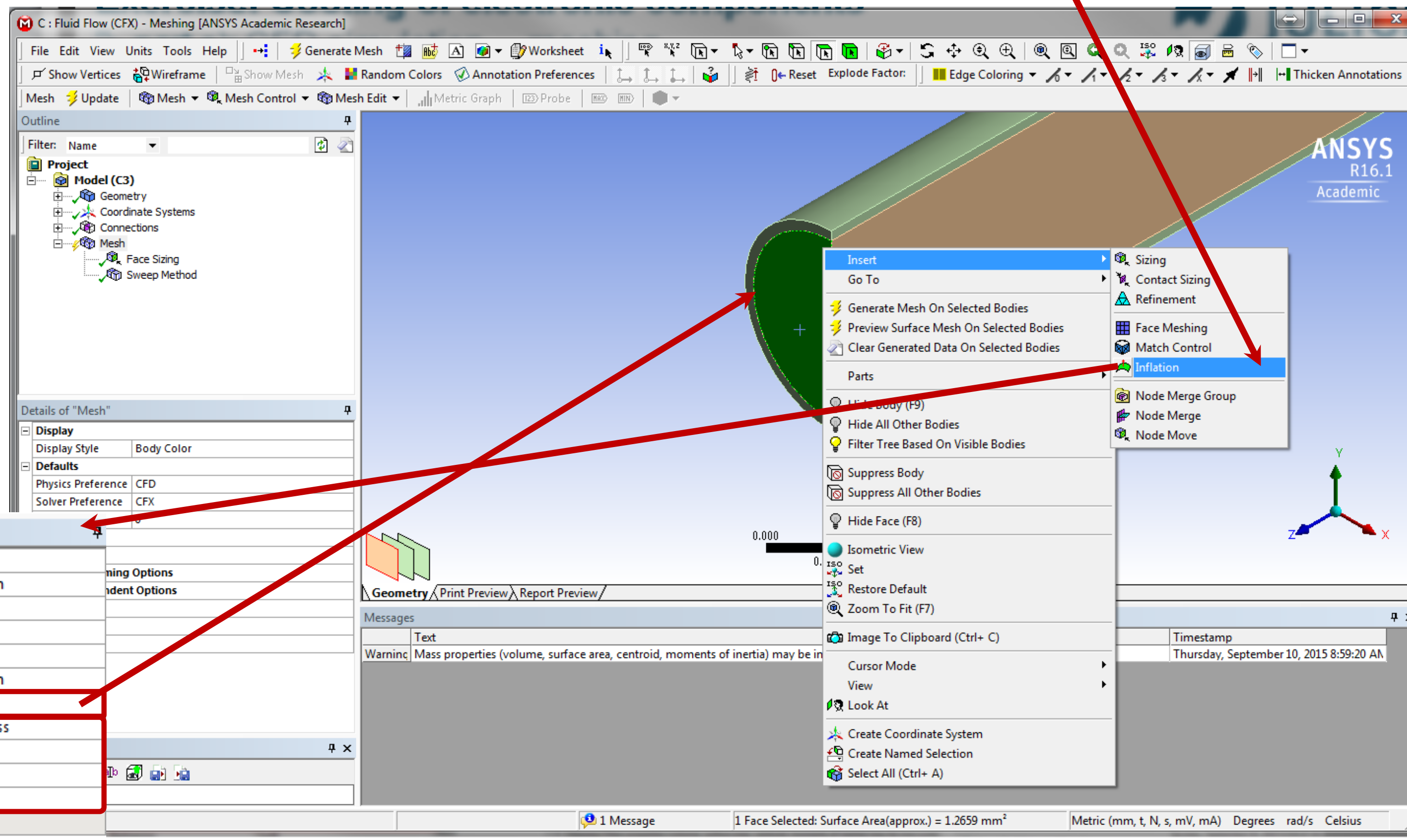
Exercise: Cooling of electronic components

↳ part e): CFD simulation – meshing

For the heat transfer calculation a fine mesh at the fluid-solid interface is needed – here a mesh inflation is used at the end face



- Toolbars => => select fluid end faces => RMB => Insert => Inflation



- Details View

Details of "Inflation" - Inflation

Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Suppressed	No
Boundary Scoping Method	Geometry Selection
Boundary	1 Edge
Inflation Option	First Layer Thickness
First Layer Height	1.e-002 mm
Maximum Layers	8
Growth Rate	1.2
Inflation Algorithm	Pre

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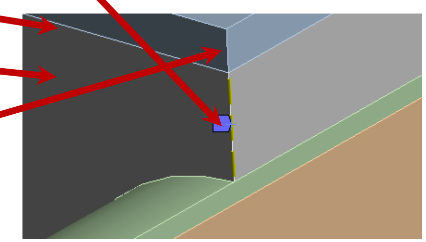
Exercise: Cooling of electronic components

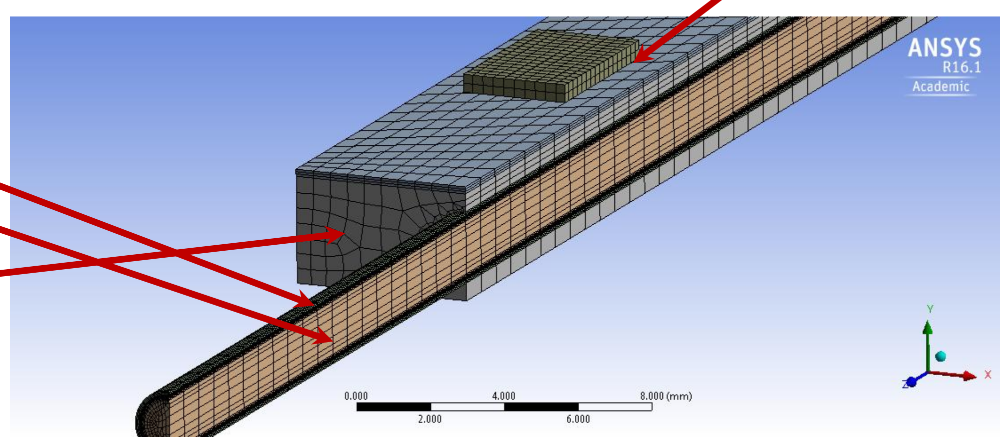
↳ part e): CFD simulation – meshing

Try yourself:

- Sweep method for pipe body with manual source (end surface) and 1mm element size in sweep direction
- RMB on end surface of pipe => ‘Face Meshing’ with default values (=> mapped mesh)
- Number of element divisions (element size) for pipe wall thickness: 3 (behavior: ‘hard’)
- Number of element divisions for circumferential lines of pipe: 25 (‘hard’)
- Number of element divisions in foam body between pipe and laminate: 3 (‘hard’)
- Number of element divisions in width direction: 10 (‘hard’)
- Element size on end surface of foam: 0.4 mm
- Sweep method for foam (default settings in Details View)
- Element size on bodies of electronic components: 0.3 mm
- Number of element divisions for laminate thickness: 3 (‘hard’)
- Number of element divisions for thickness of electronic components: 2



- Meshing sequence:
  - pipe wall
  - fluid body
  - complete mesh



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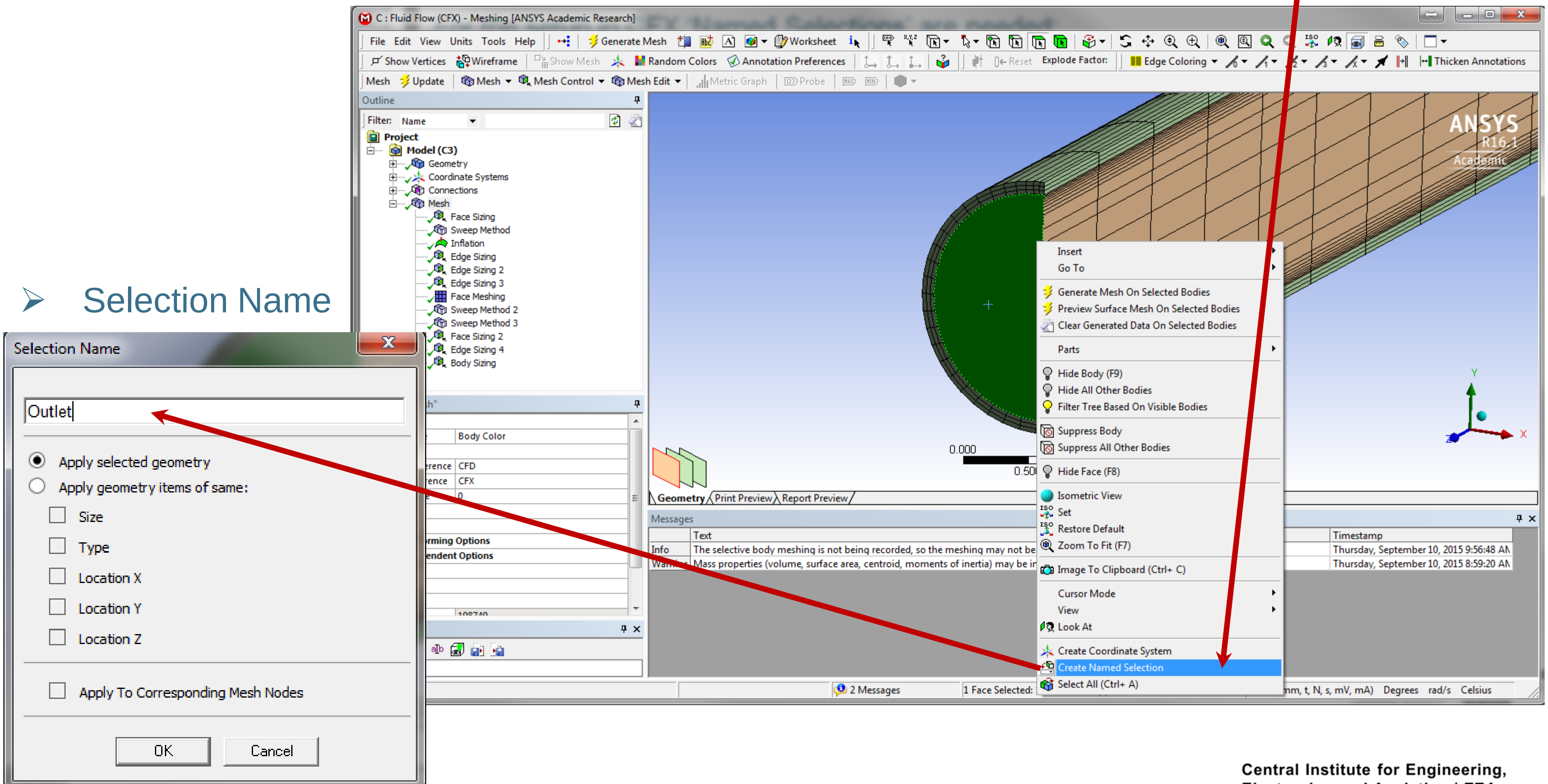
Exercise: Cooling of electronic components

↳ part e): CFD simulation – meshing

For the setup in CFX ‘Named Selections’ are needed:

- Toolbars => select end surface of fluid => RMB => Create Named Selection

- Selection Name



Exercise: Cooling of electronic components

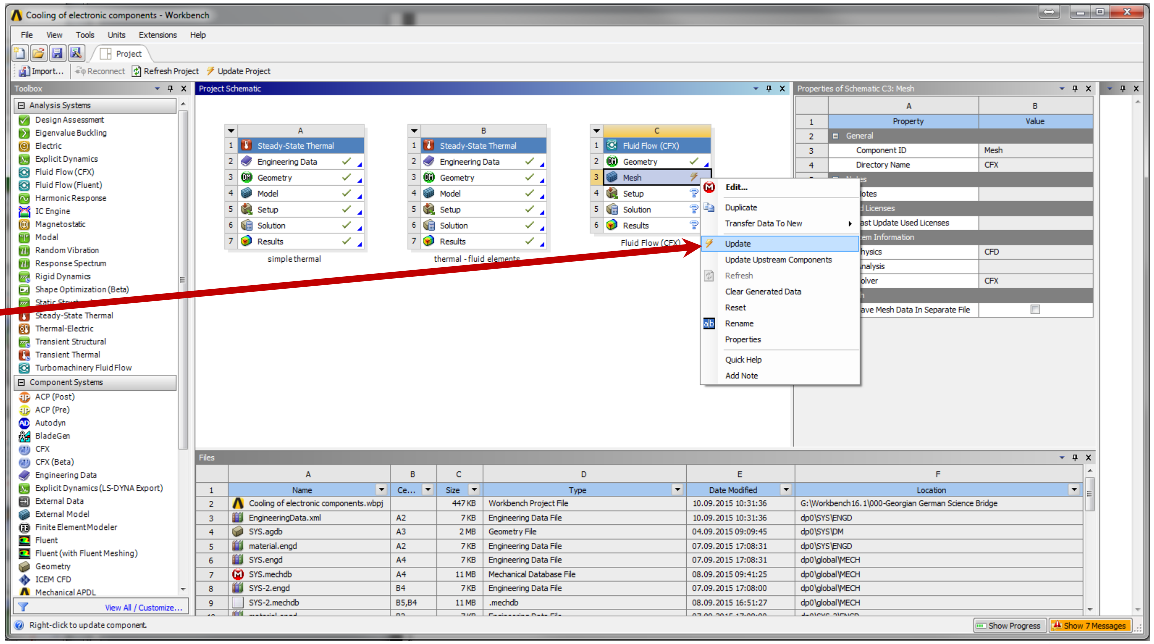
↳ part e): CFD simulation – meshing

Try yourself:

- Front surface of fluid body => Named Selection ‘Inlet’
- Symmetry face of fluid body => Named Selection ‘Symmetry’
- Fluid body => Named Selection ‘Fluid’
- Pipe body => Named Selection ‘Pipe’
- Foam body => Named Selection ‘Foam’
- Carbon fiber laminate body => Named Selection ‘Laminate’
- Electronic components => Named Selection ‘Electronics’

- Main Menu => File => Close Meshing

- Project Schematic => Project C => Mesh => RMB => Update



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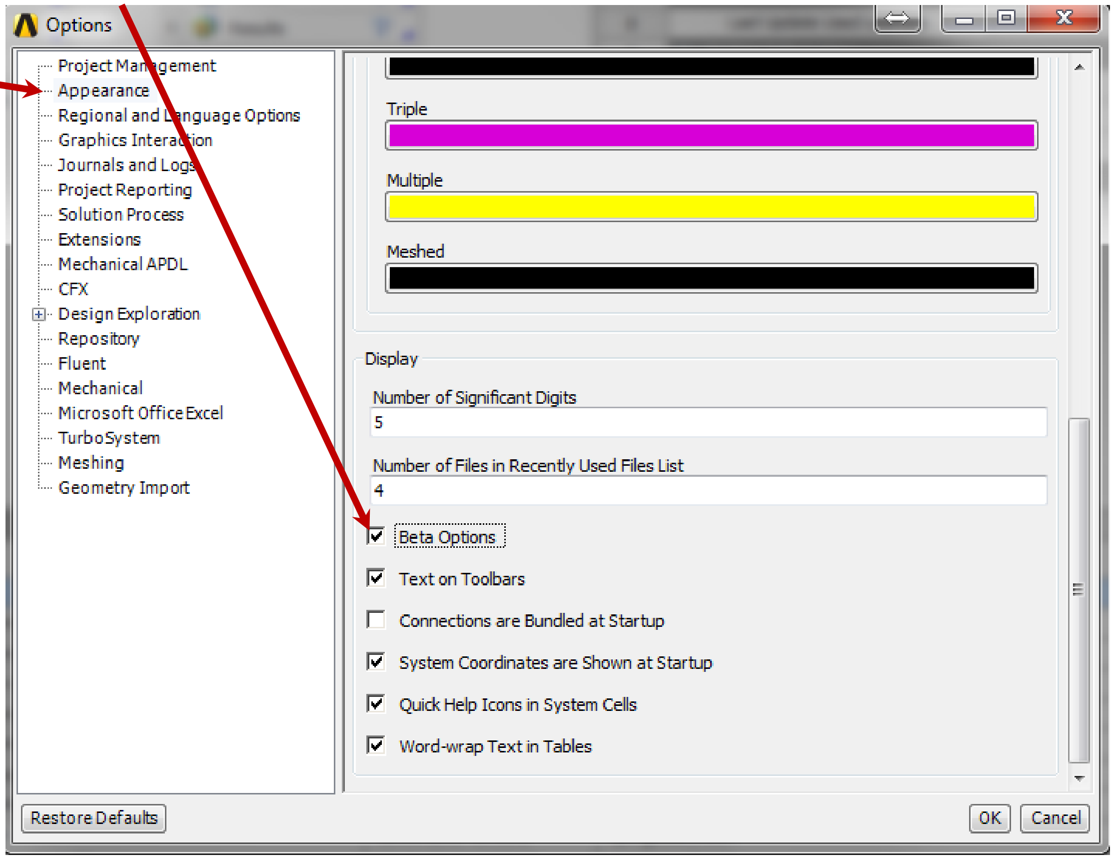
Exercise: Cooling of electronic components

↳ part e): CFD simulation – activate beta options (needed later on)

Project Overview:

- Main Menu => Tools => Options => Appearance => Beta Options => activate



Start Setup:

- Project Schematics => Project C => Setup => double click LMB

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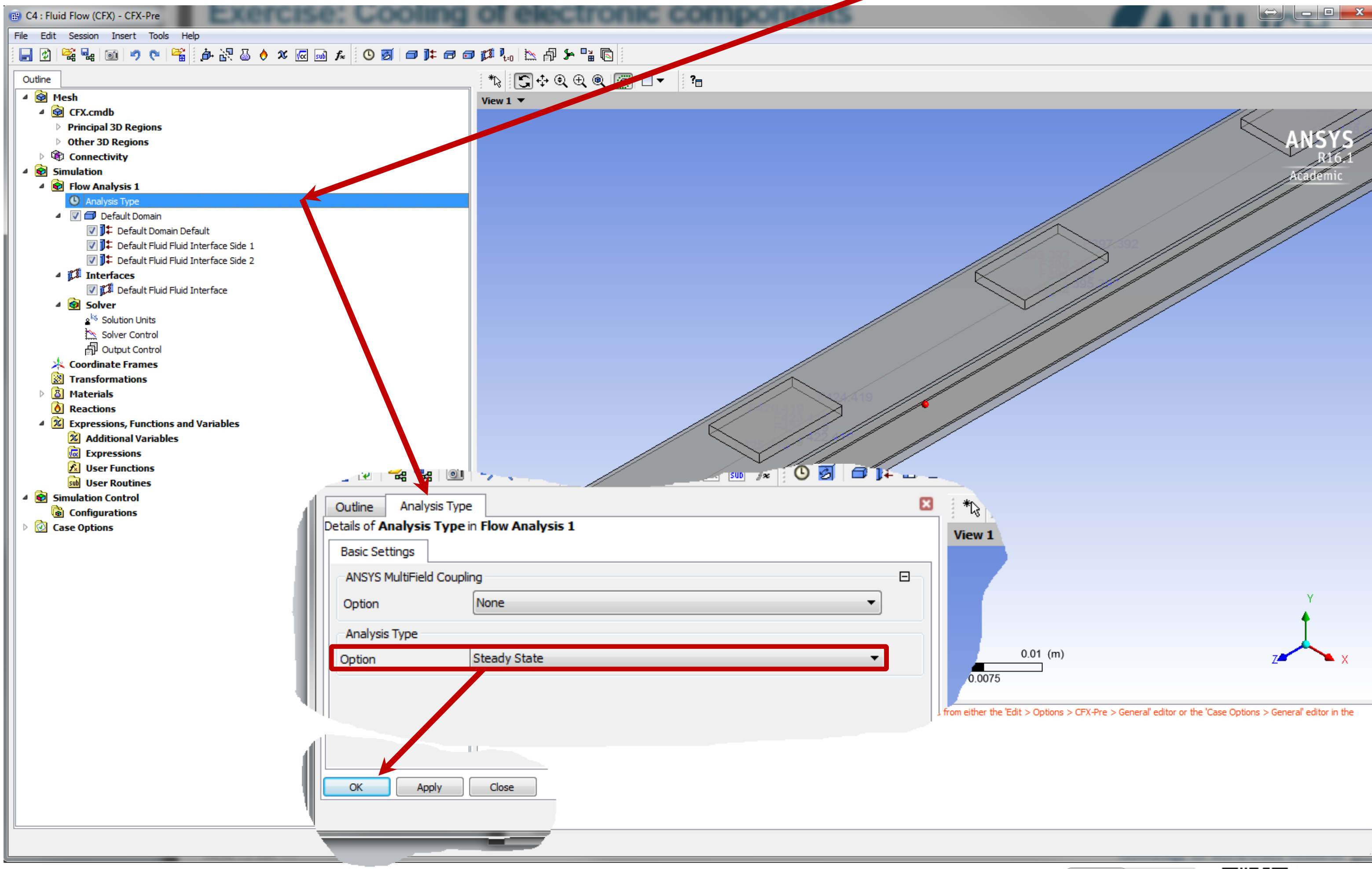
➢ Outline => Simulation => Flow Analysis 1 => Analysis Type => double click LMB



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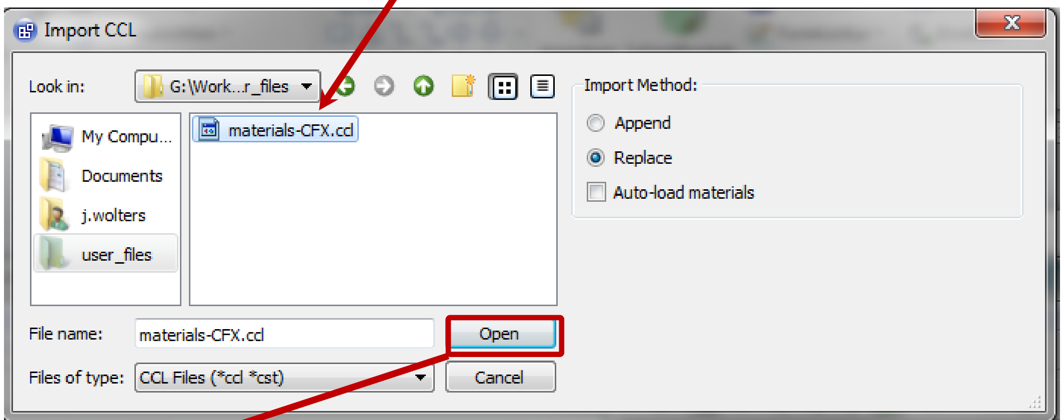
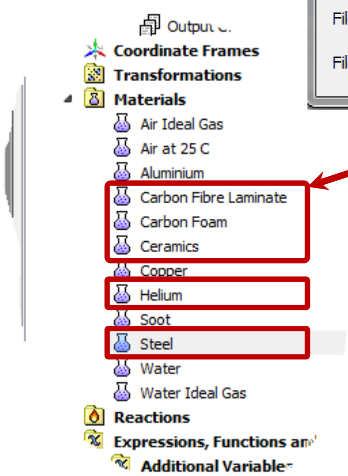
Exercise: Cooling of electronic components

↳ part e): CFD simulation – setup materials

Import material properties from file

- Main Menu => File => Import => CCL … (choose directory with materials-CFX.ccl file)





Notice:

- thermal conductivity is important for all solids, but orthotropic values for the laminate can not be defined in the GUI (workaround available)
- material properties like density and heat capacity have to be defined for solids but are not important for the results of a steady-state calculation.
- for Helium all thermodynamic and transport properties are important for the flow simulation

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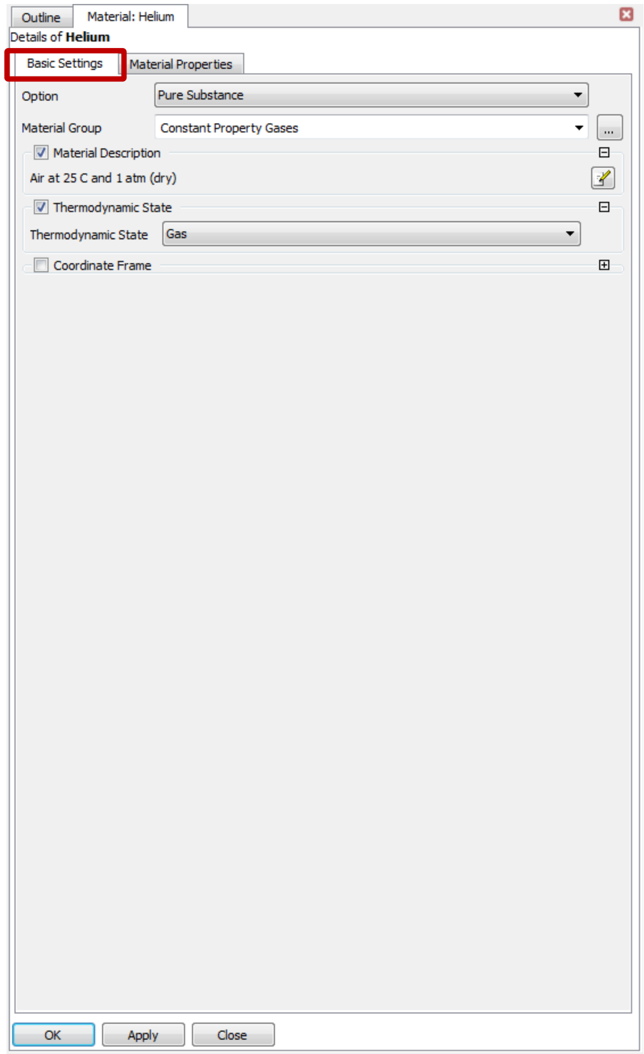
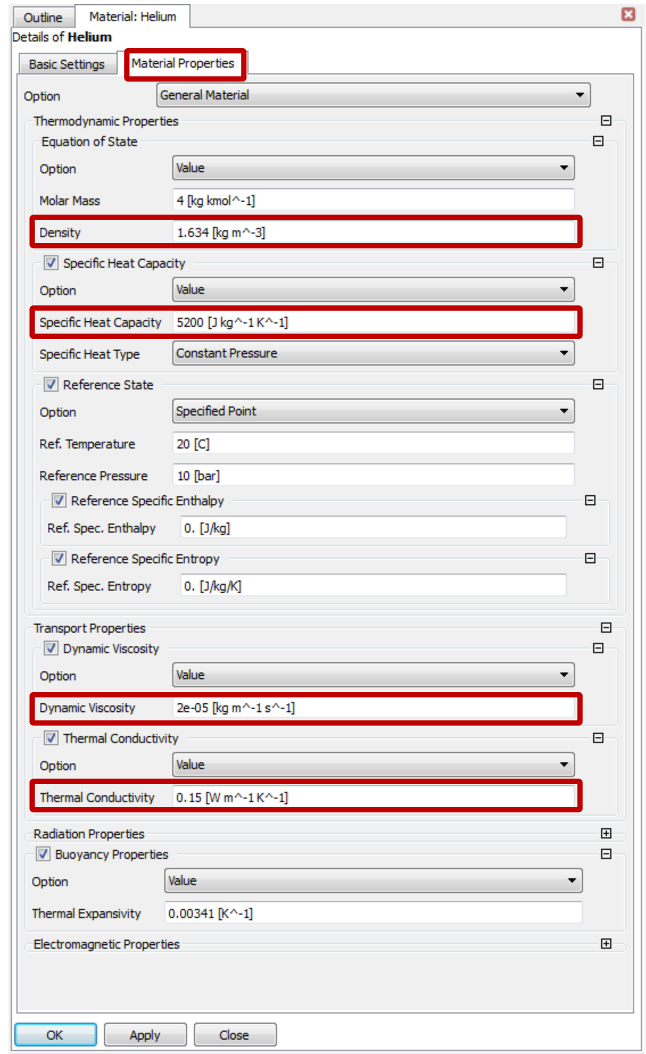
Exercise: Cooling of electronic components

↳ part e): CFD simulation – setup materials

Check properties for helium @ 10 bar

➢ Outline => Simulation => Materials => Helium => double click LMB





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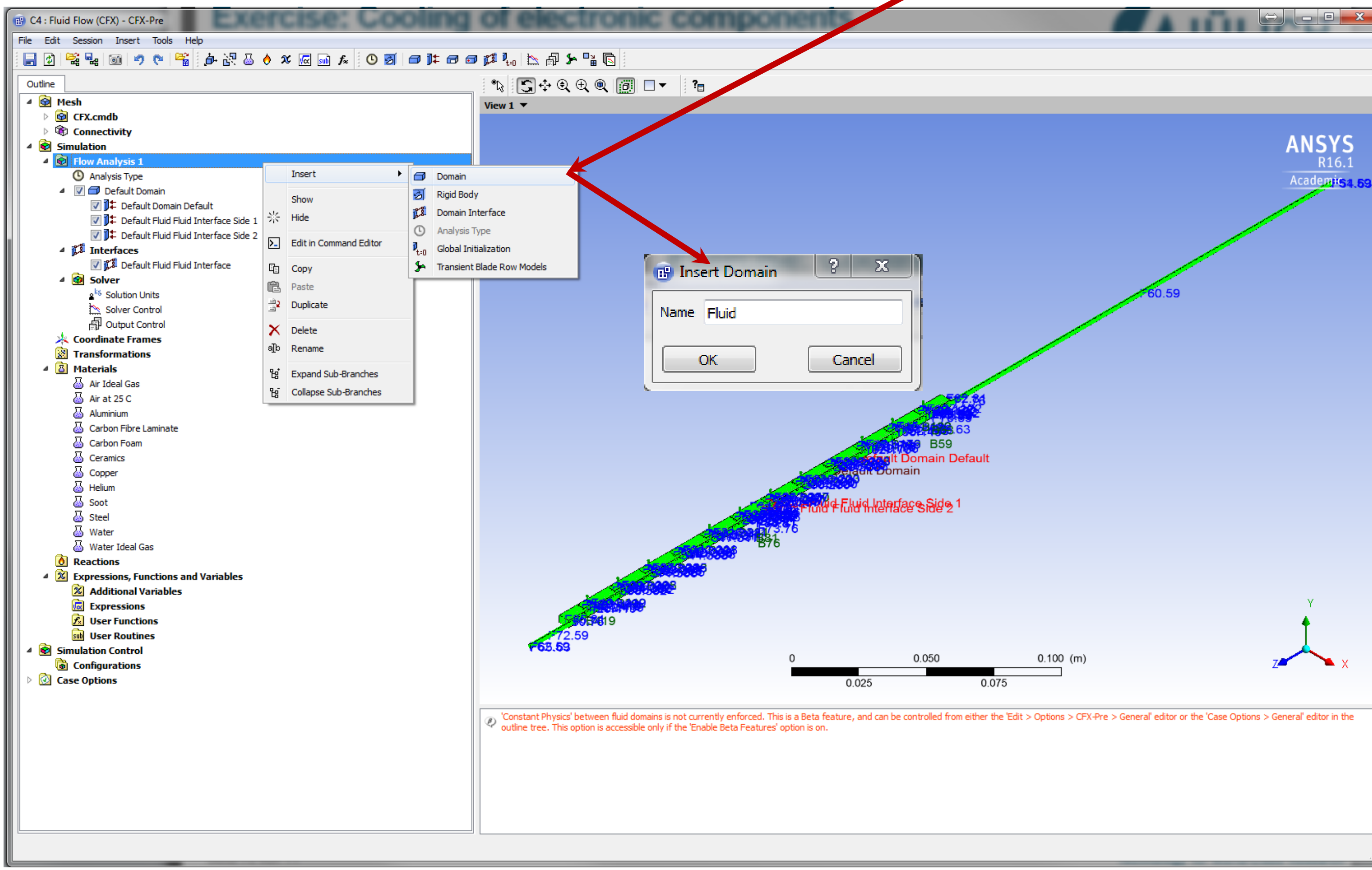
Exercise: Cooling of electronic components

↳ part e): CFD simulation – setup domains

For each material a domain has to be defined. Domain interfaces will be generated automatically

- Outline => Simulation => Flow Analysis 1 => RMB => Insert => Domain



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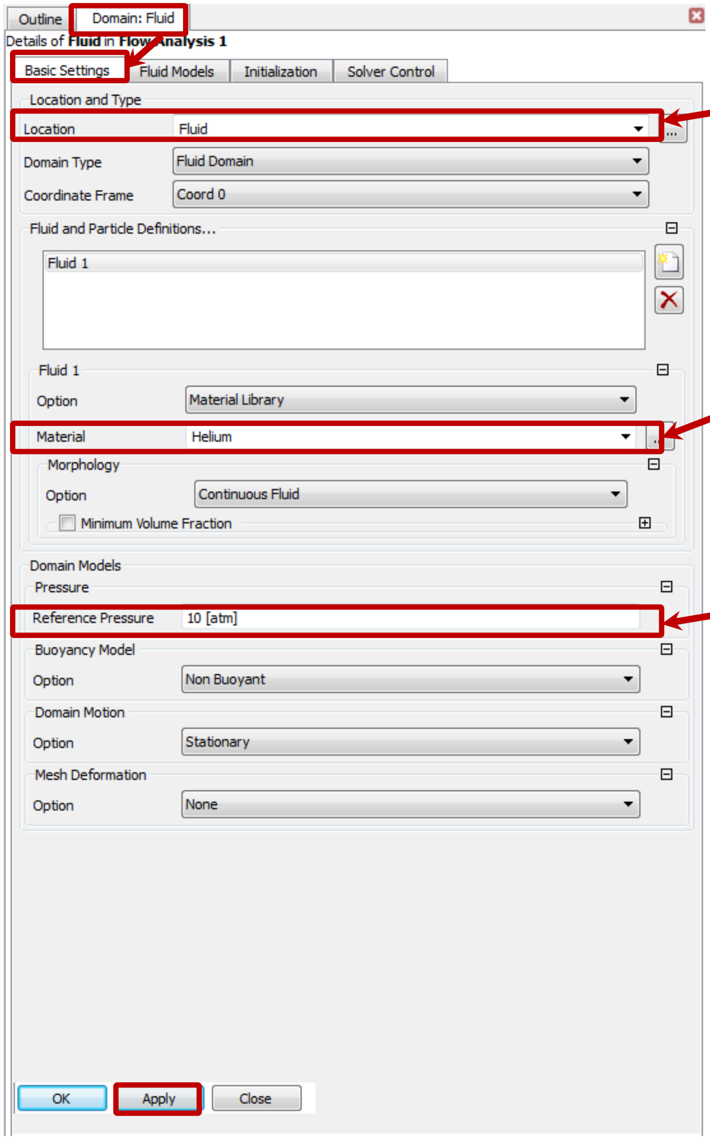
Exercise: Cooling of electronic components

↳ part e): CFD simulation – setup domains

Fluid domain settings – Basic Settings (will automatically open):



Notice:

- If a 'named selection' is found with the same name, this will be pre-selected as location (here the fluid volume mesh).
- Here a domain material has to be selected from the material library
- Fluid pressure

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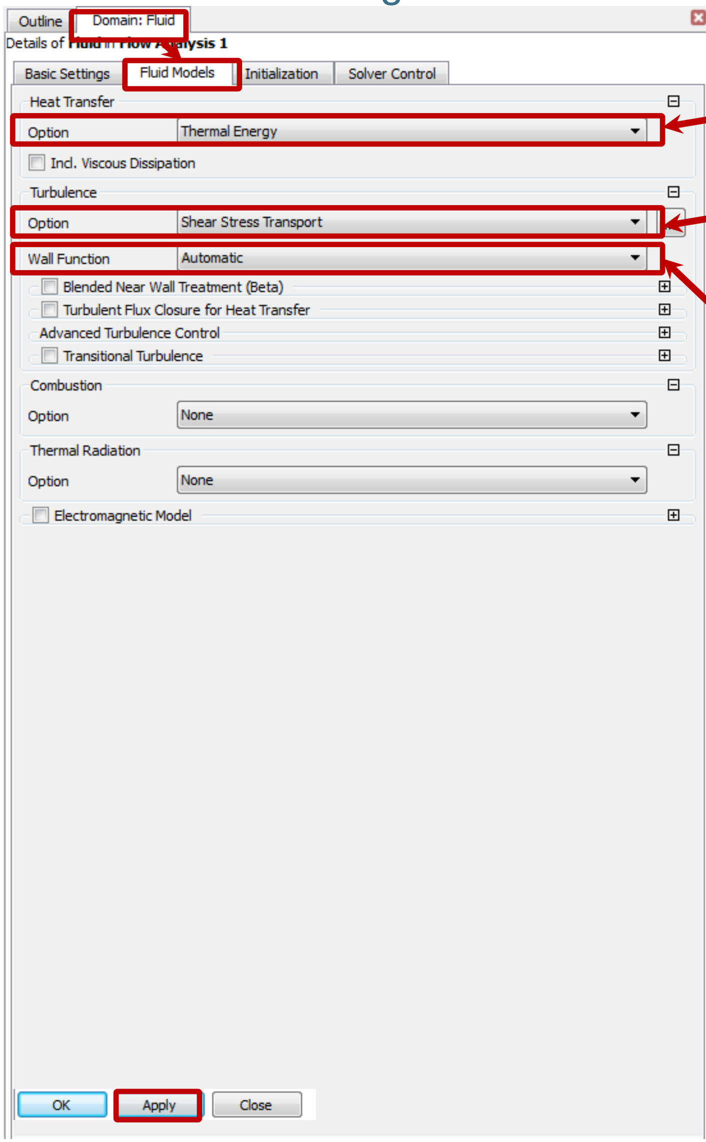
↳ part e): CFD simulation – setup domains

Fluid domain settings – Fluid Models:



Notice:

- Since temperatures should be calculated the option ‘thermal energy’ has to be chosen.
- Since the Reynolds number is greater then 10000 we will habe a fully turbulent flow – so a turbulence model has to be activated (SST is the preferred one)
- Wall functions will consider the viscous boundary layer near the walls, if the mesh is not fine enough.

Exercise: Cooling of electronic components

part e): CFD simulation – setup domains

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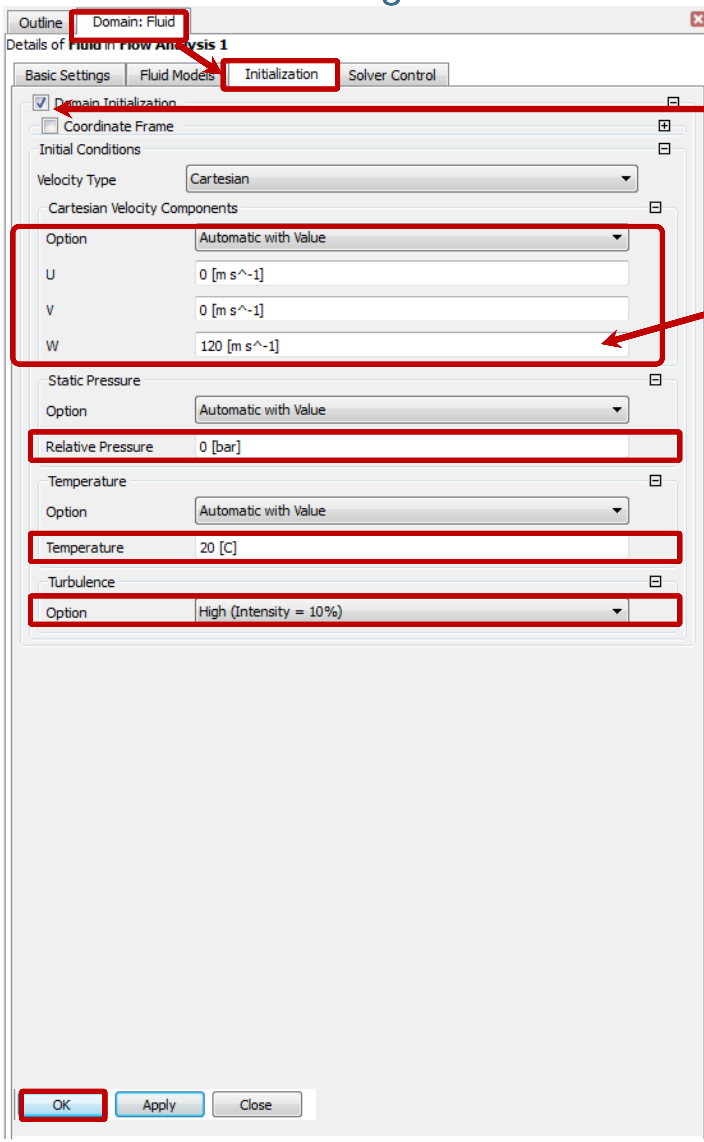
Fluid domain settings - initialization:



Notice:

- Setting realistic initial conditions may improve convergency
- Mean flow velocity

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Exercise: Cooling of electronic components

↳ part e): CFD simulation – setup domains

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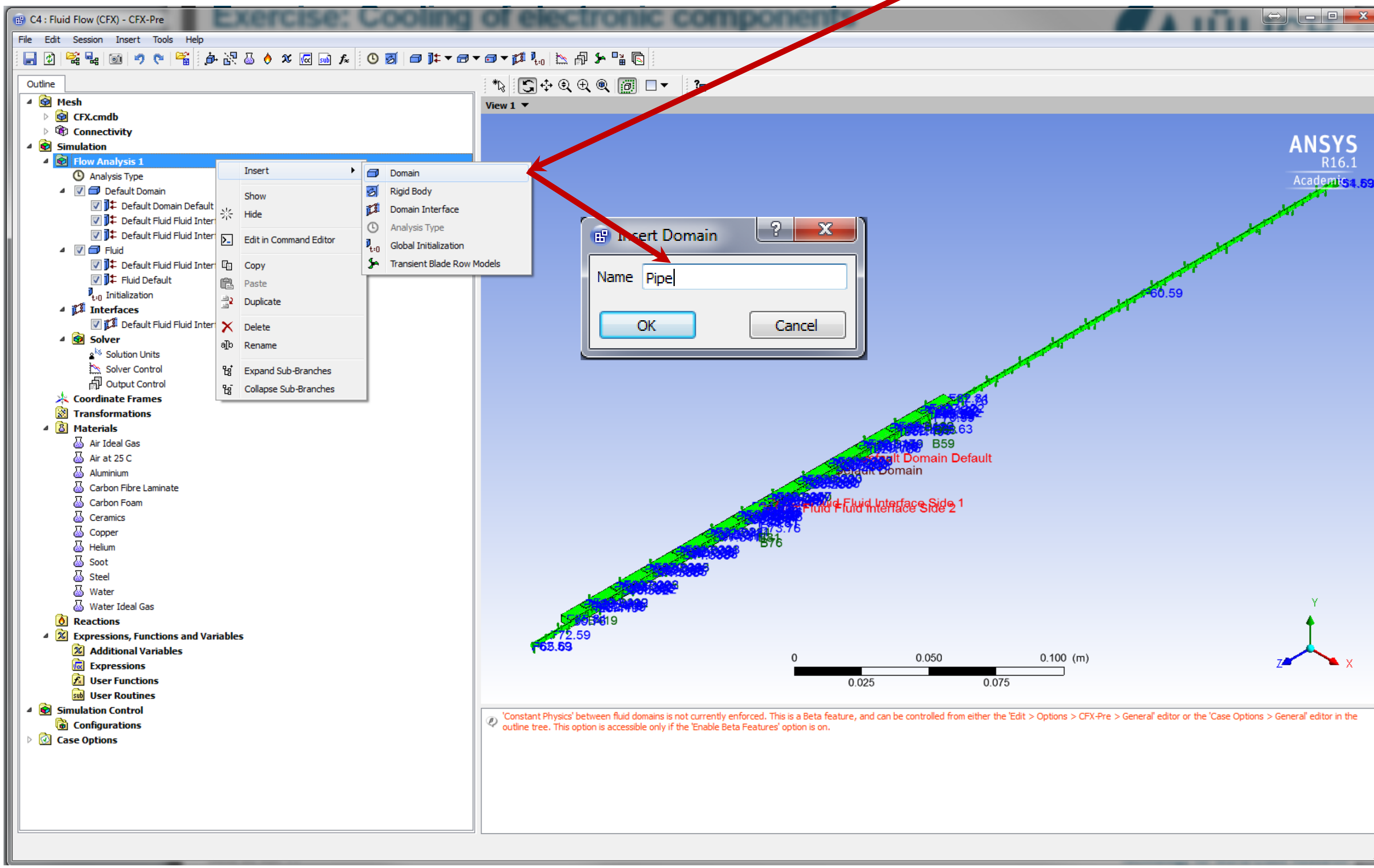
Define Solid Domains

- ➢ Outline => Simulation => Flow Analysis 1 => RMB => Insert => Domain



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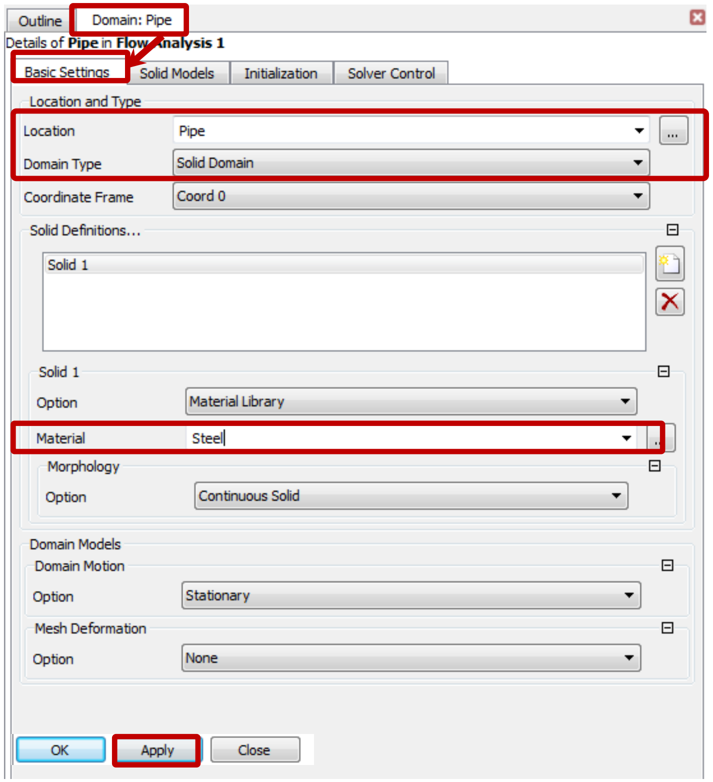
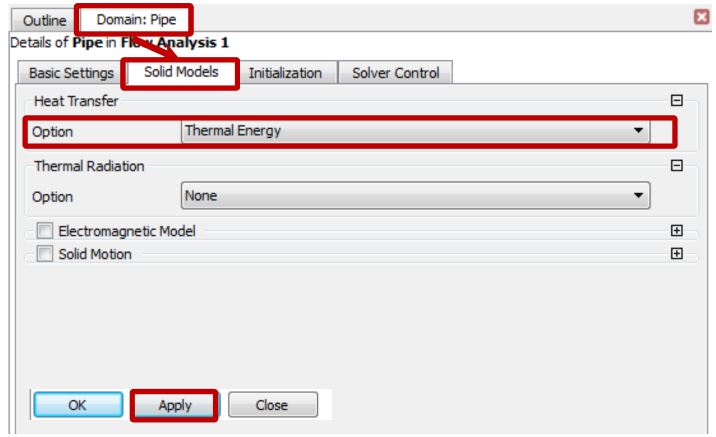
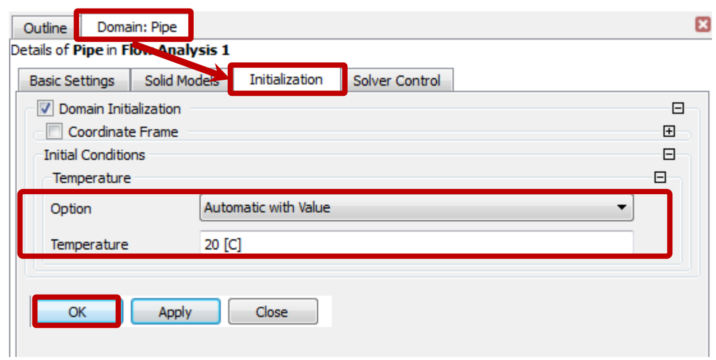
Exercise: Cooling of electronic components

↳ part e): CFD simulation – setup domains

Solid domain settings (Pipe) – Basic Settings (will automatically open):







Try yourself to set up domains for:
- Foam
- Laminate
- Electronics

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↳ part e): CFD simulation – boundary conditions

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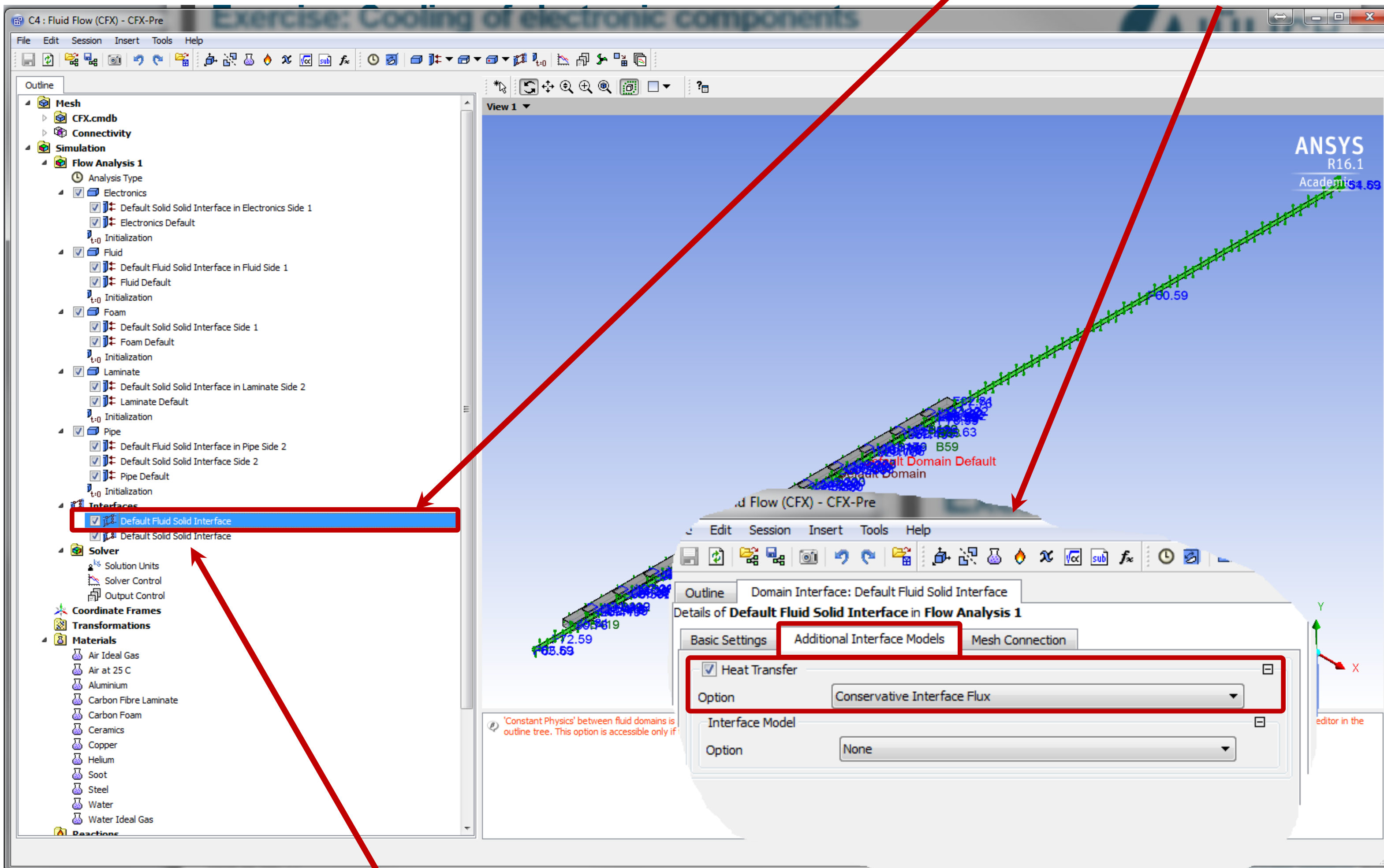
Heat transfer for interfaces

- Outline => Simulation => Interfaces => Default Fluid Solid Interface => double click LMB



- Same for 'Default Solid Solid Interface'

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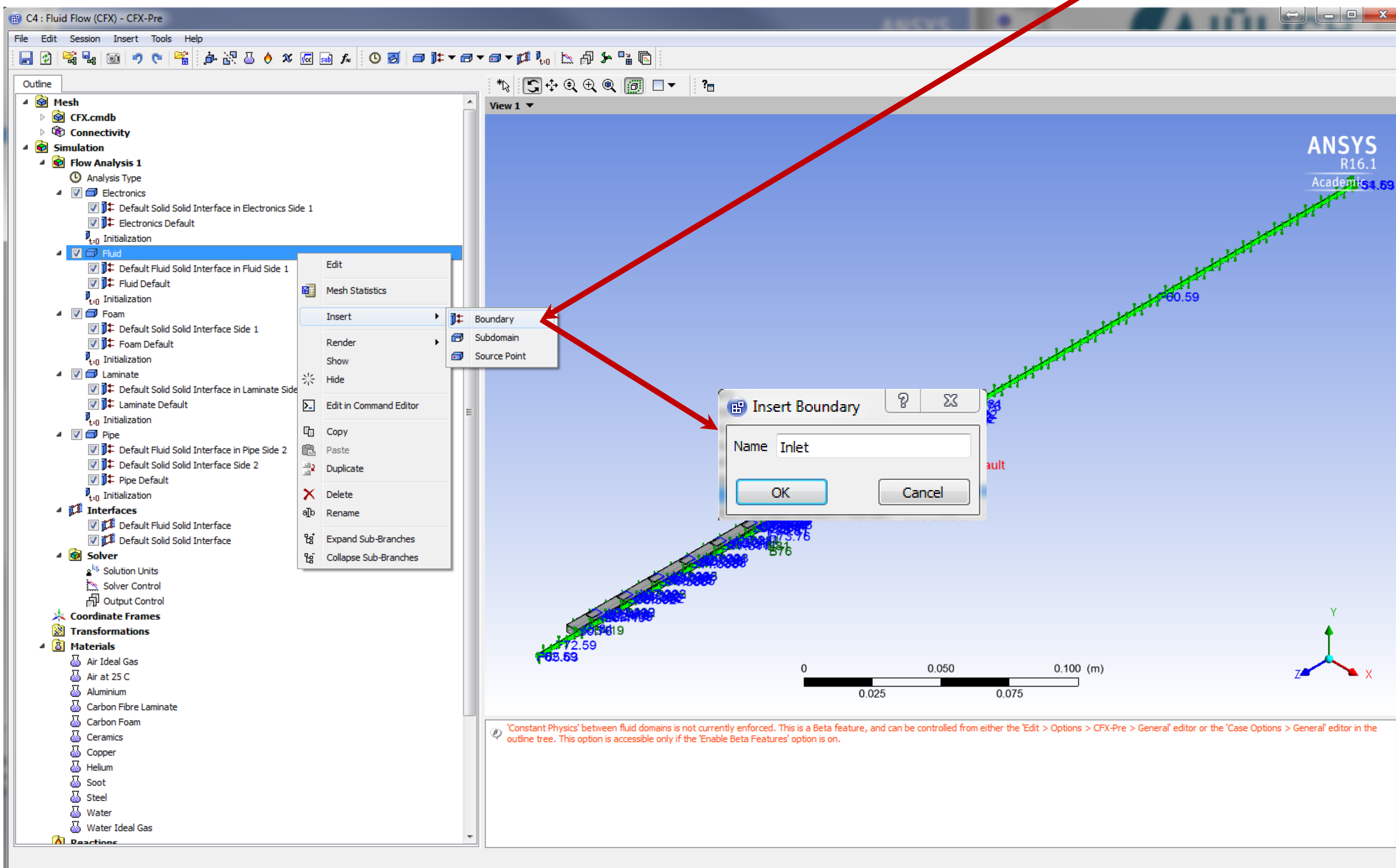
↳ part e): CFD simulation – boundary conditions

Flow conditions

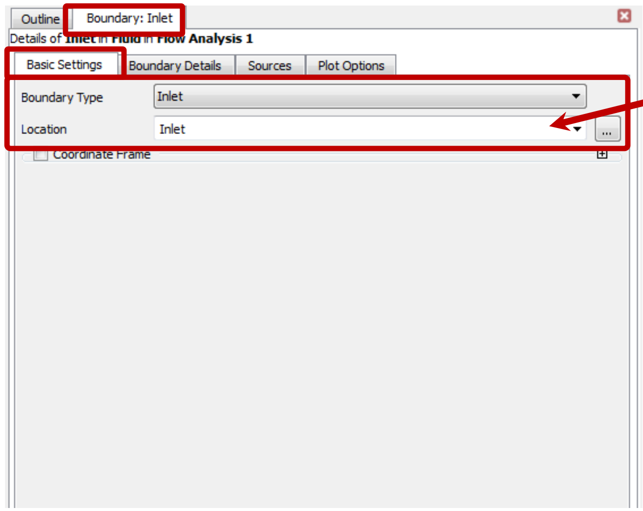
- Outline => Simulation => Flow Analysis 1 => Fluid => RMB => Insert => Boundary



Exercise: Cooling of electronic components

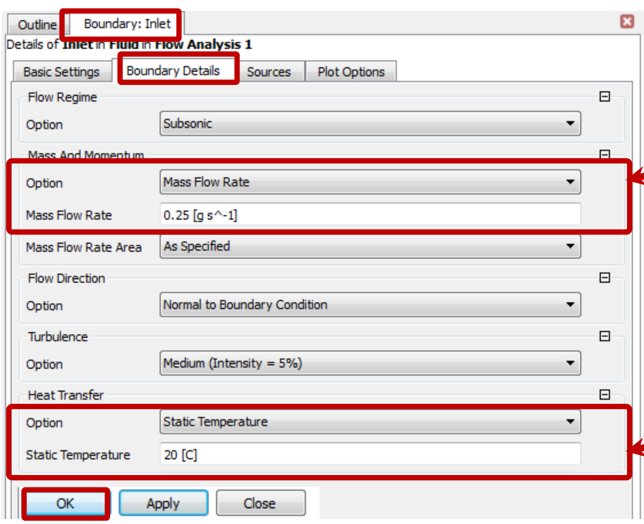
↳ part e): CFD simulation – boundary conditions

Inlet conditions for helium flow



Notice:

- If a 'named selection' is found with the same name, this will be pre-selected as location (here the inlet face mesh).



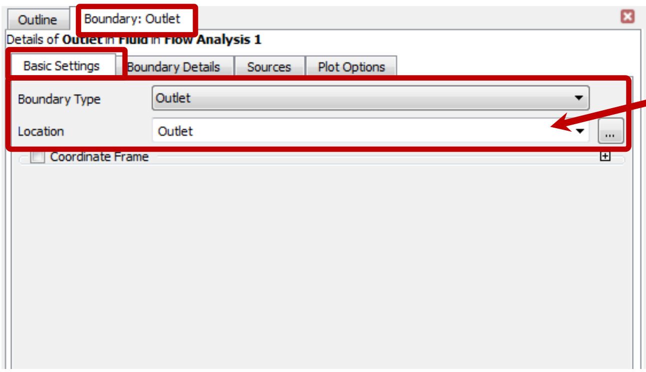
- Since the calculation is done for a half-model only half of the total mass flow rate is considered here.
  Select units [g s^-1] from drop down list at end of text field (visible during editing text field).

- Inlet temperature

Exercise: Cooling of electronic components

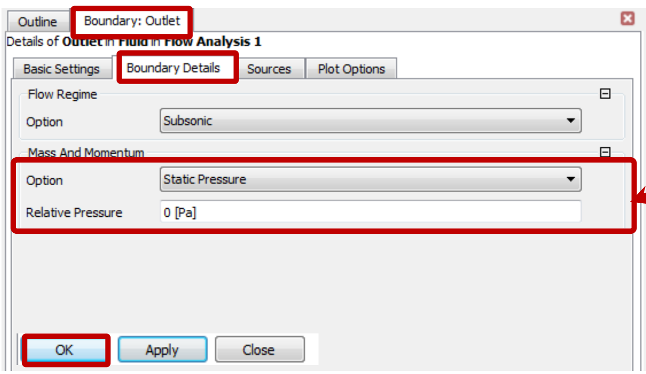
↳ part e): CFD simulation – boundary conditions

- Outline => Simulation => Flow Analysis 1 => Fluid => RMB => Insert => Boundary
  Boundary name: ‘Outlet’



Notice:

- If a ‘named selection’ is found with the same name, this will be pre-selected as location (here the inlet face mesh).



- Relative static outlet pressure is based on the system pressure of 10 bar defined before
  => absolute outlet pressure is 10bar

- Outline => Simulation => Flow Analysis 1 => Fluid => RMB => Insert => Boundary
  Boundary name: ‘Symmetry’ => location ‘Symmetry’
  (no further settings needed)

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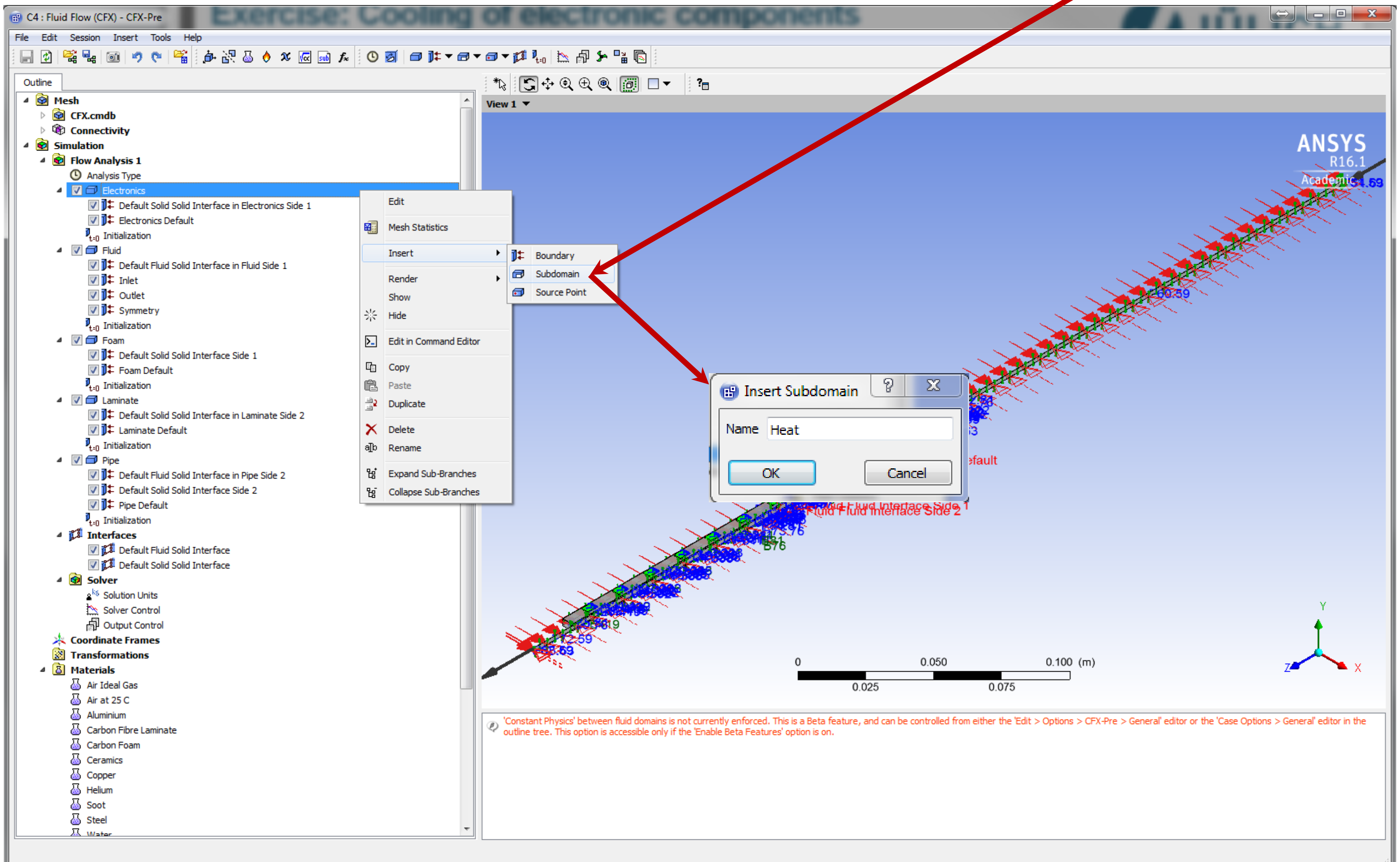
Exercise: Cooling of electronic components

↳ part e): CFD simulation – boundary conditions

Heat generation

➢ Outline => Simulation => Flow Analysis 1 => Electgronics => RMB => Insert => Subdomain



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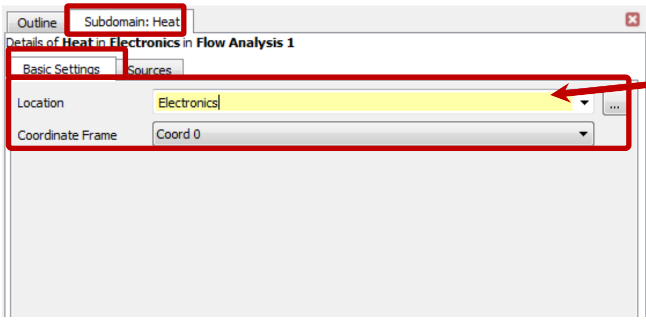
Exercise: Cooling of electronic components

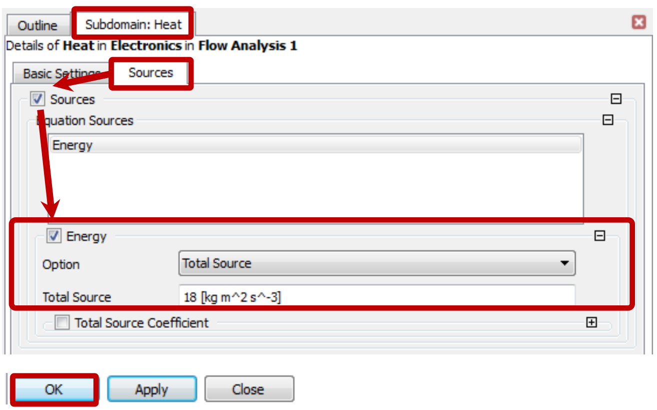
↳ part e): CFD simulation – boundary conditions

Inlet conditions for helium flow



Notice:

- The heat is generated on all domain bodies
=> Named Selection 'Electronics' can be selected here again



- Since the calculation is done for a half-model only half of the total heat generation (1/2 of 36 W) is considered

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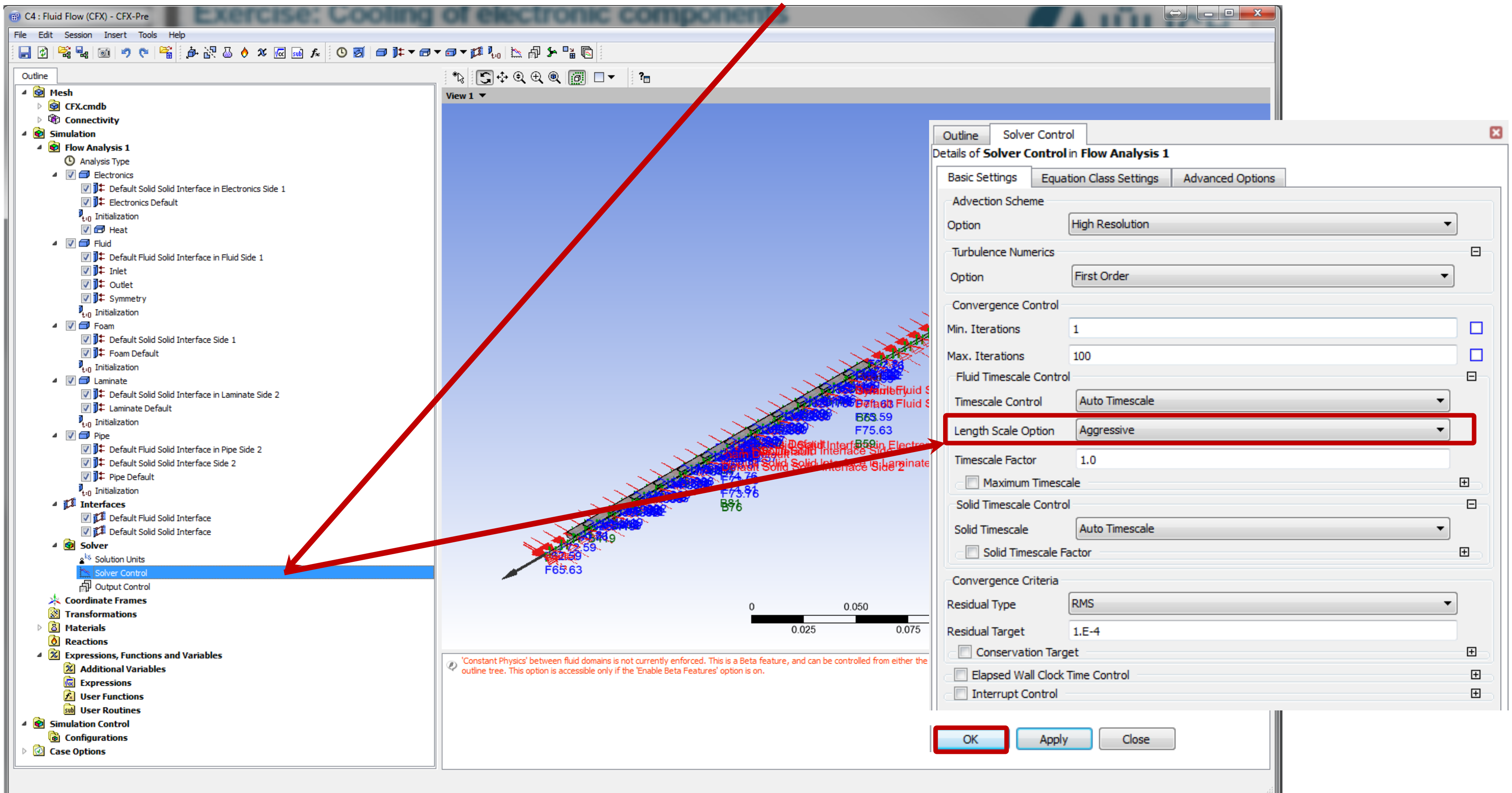
Exercise: Cooling of electronic components

↳ part e): CFD simulation – solution control

Increase convergency by an aggressive 'Length Scale Option'

➢ Outline => Simulation => Flow Analysis 1 => Solver => Solver Control => double click LMB



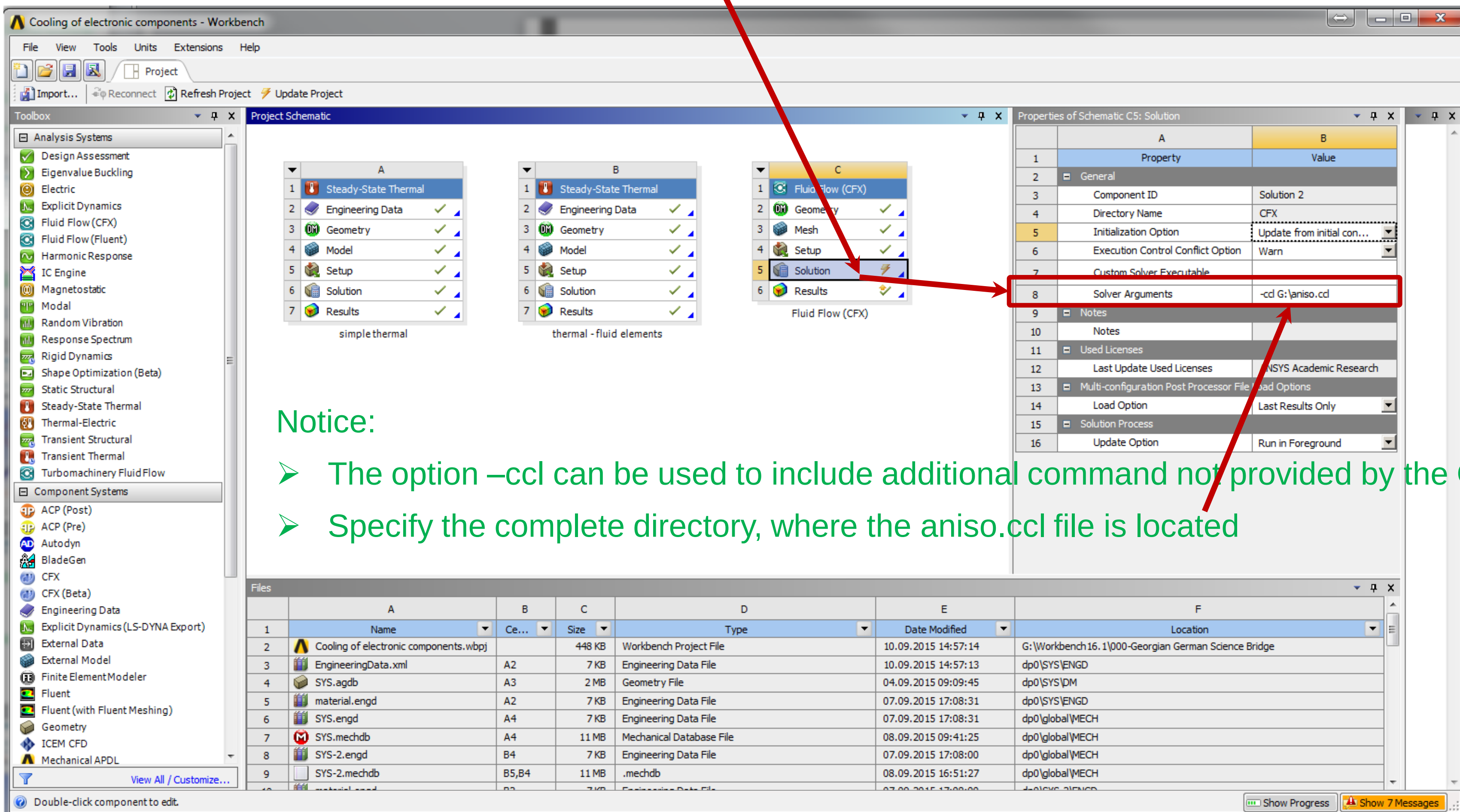
Leave Pre-Processor

➢ Main Menu => Close CFX-Pre

Exercise: Cooling of electronic components

↳ part e): CFD simulation – solve problem

- Main Menu => View => Properties (must be activated)
- Project Schematic => Project C => Solution => LMB

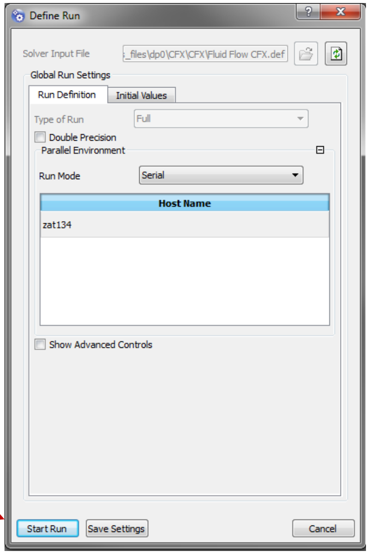


Notice:

- The option –ccl can be used to include additional command not provided by the GUI
- Specify the complete directory, where the aniso.ccl file is located

Exercise: Cooling of electronic components

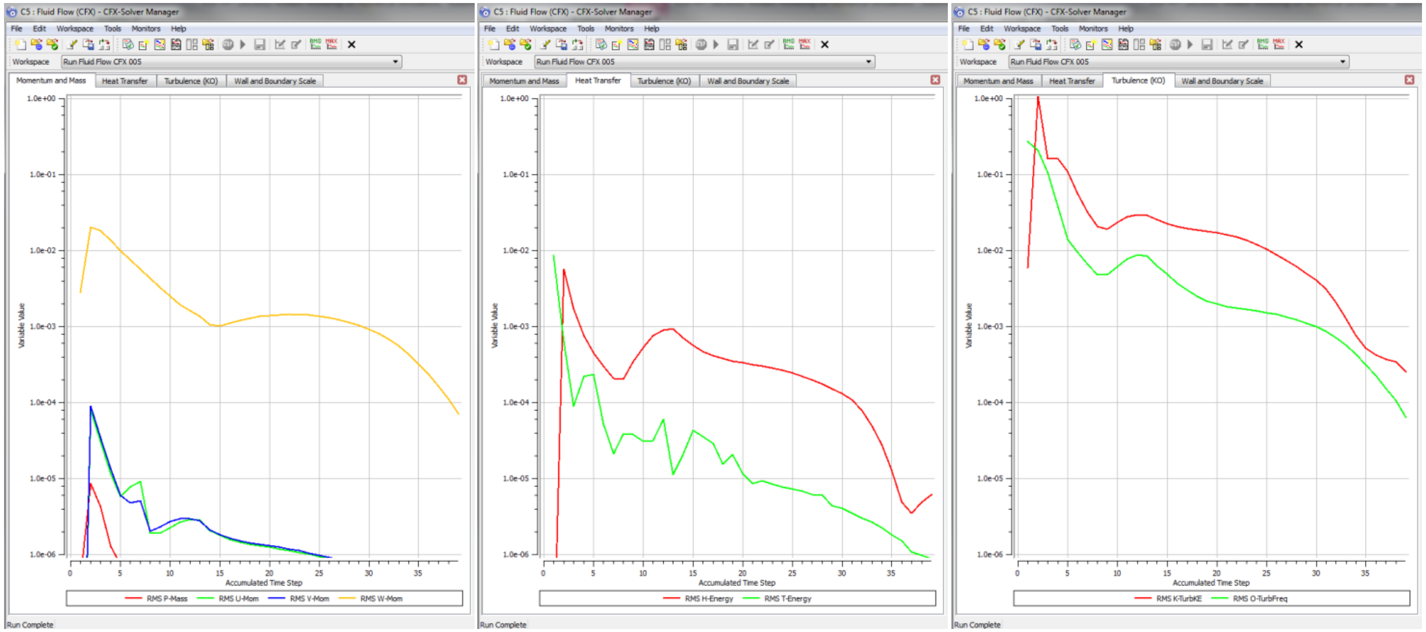
↳ part e): CFD simulation – solve problem



Start simulation

- Project Schematic => Project C => Solution => double click LMB => Define Run => Start Run

- Convergency control:



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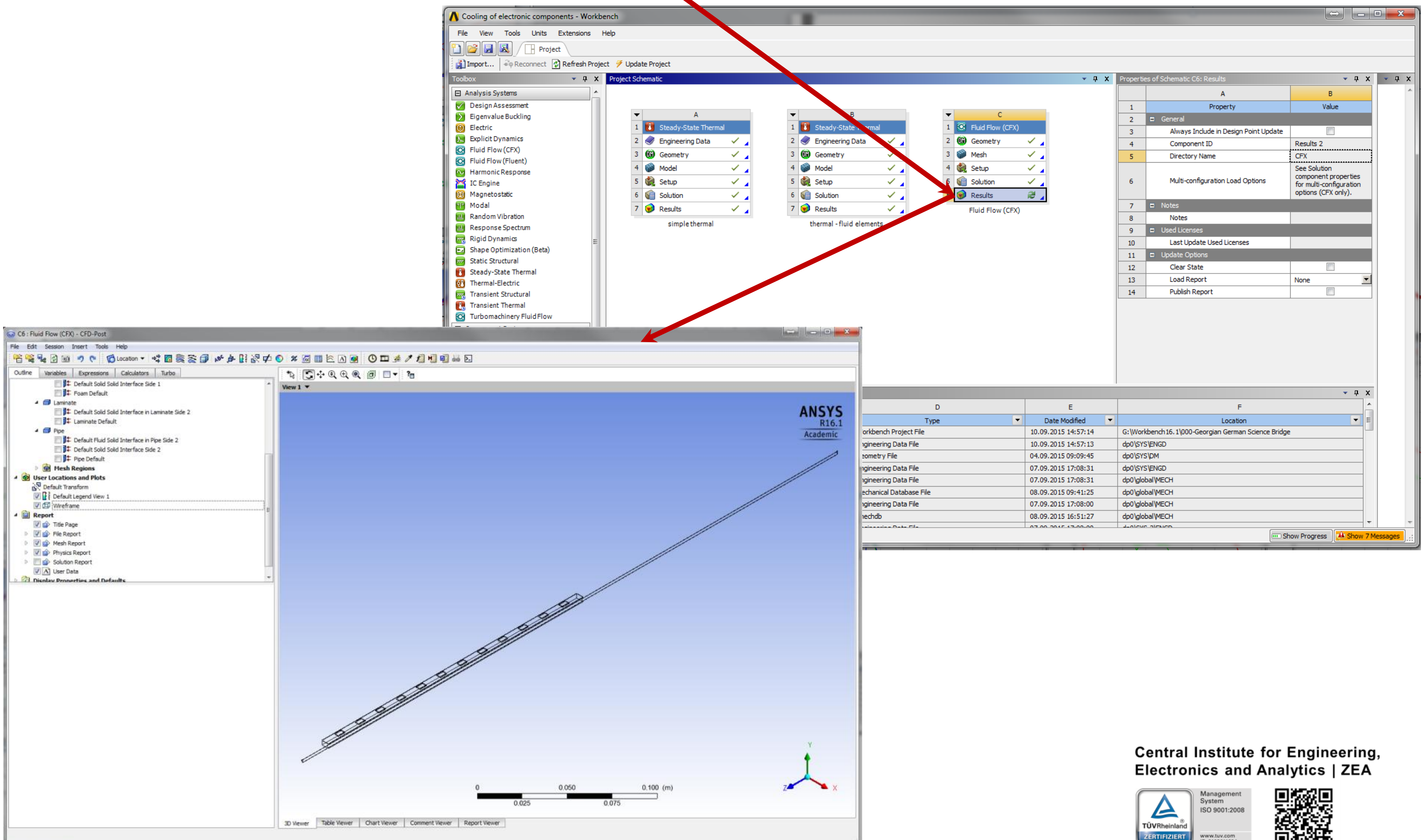
Exercise: Cooling of electronic components

↳ part e): CFD simulation – post-processing results

➢ Project Schematic => Project C => Results => double click LMB



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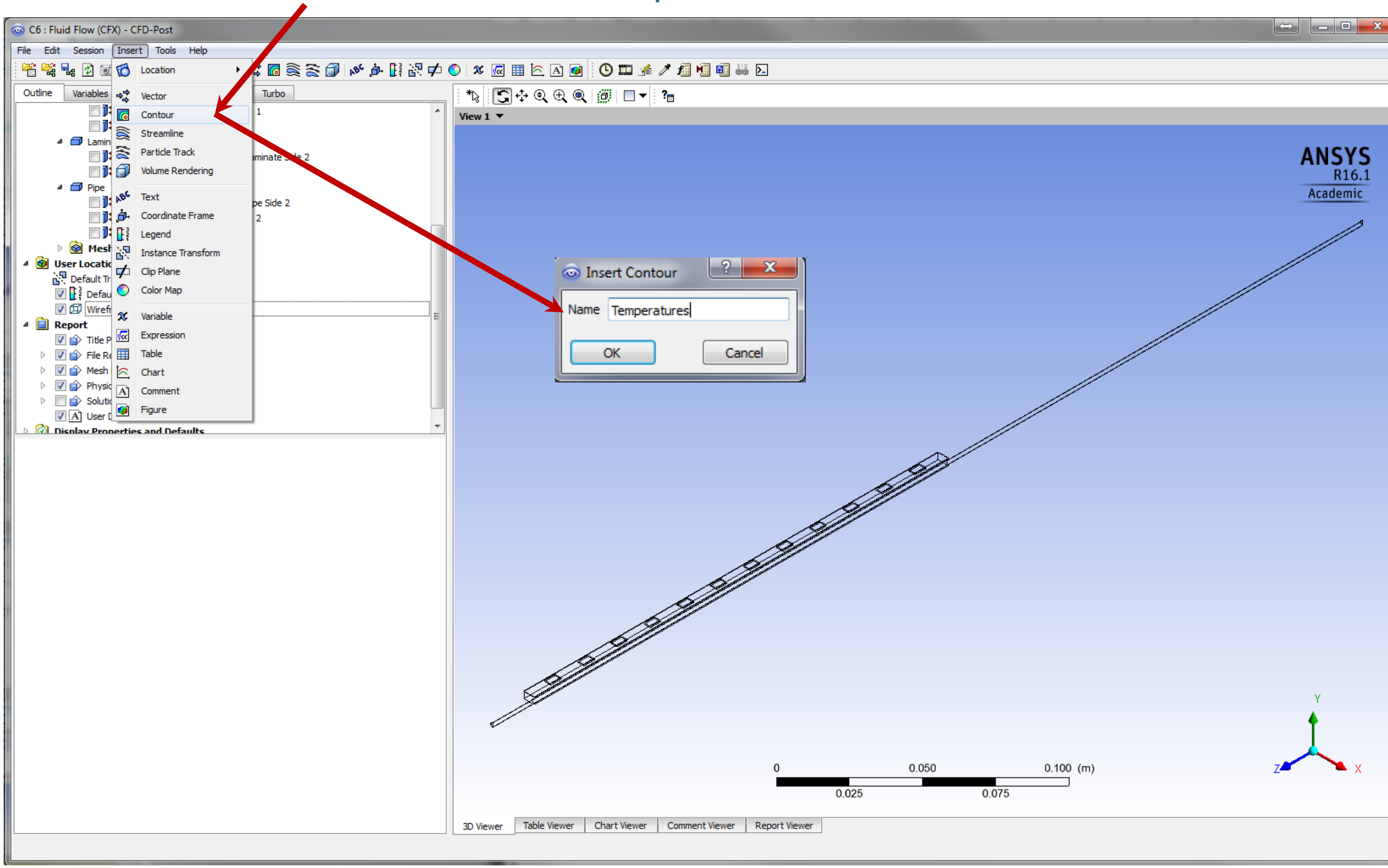
Exercise: Cooling of electronic components

↳ part e): CFD simulation – post-processing results

- Main Menu => Insert => Contour => Name: ‘Temperatures’



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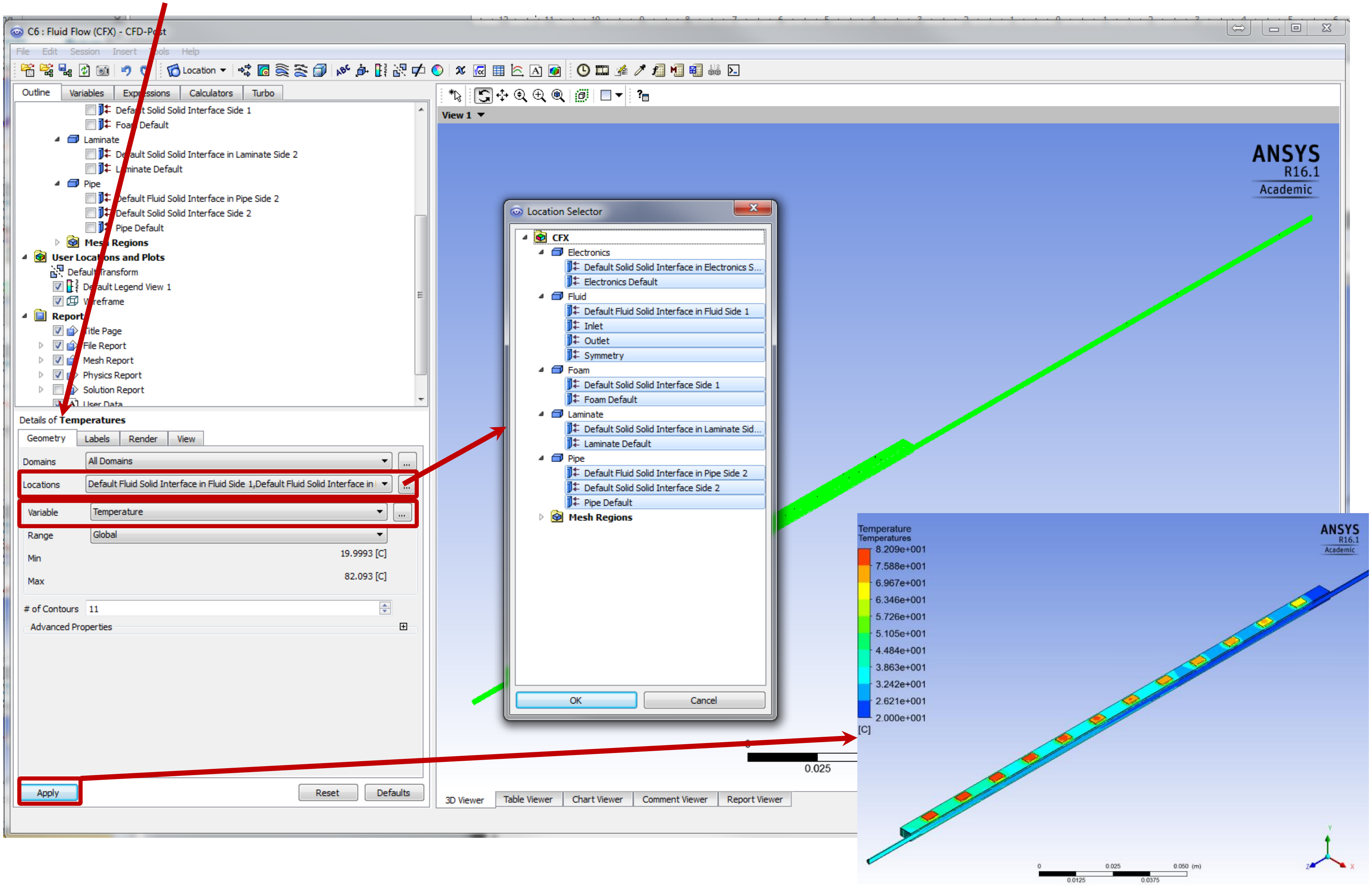
Exercise: Cooling of electronic components

↳ part e): CFD simulation – post-processing results

➢ Details View



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Thank you for your participation & attention!

Any questions ...?

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