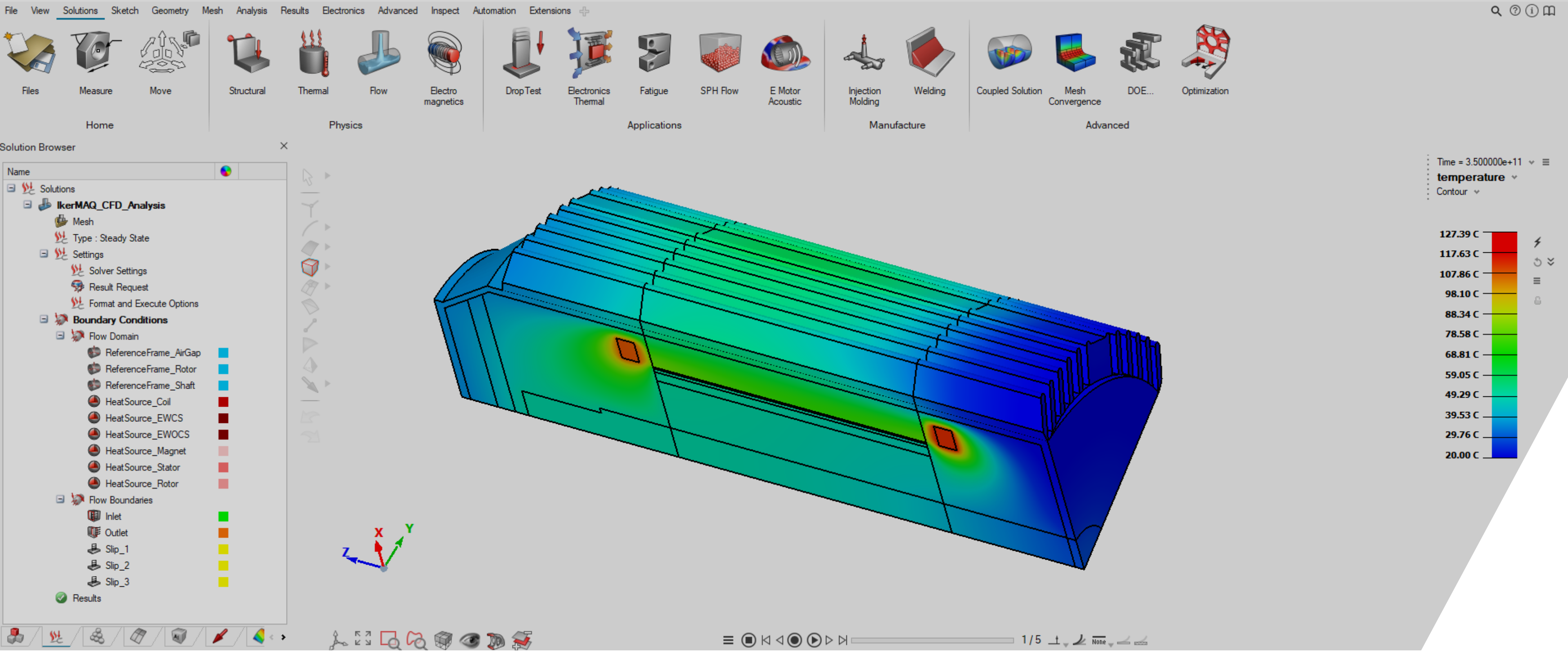


E-MOTOR CFD ANALYSIS: IKERMAQ MOTOR

FLUX-ACUSOLVE COUPLING APPLICATION (VIA SIMLAB)

June 2022, Altair Engineering Inc.

TUTORIAL OUTLINE

I. Introduction

II. 2D Electromagnetic Analysis (Flux)

- II.1: Loss computation

III. 3D CFD Analysis (SimLab / AcuSolve)

- III.1: eMotor CFD meshing
- III.2: CFD solution setup

IV. Conclusion

INTRODUCTION

INTRODUCTION

Application Case: IkerMAQ Motor

- About the machine: IkerMAQ[1]
  - **P**ermanent **M**agnet **S**ynchronous **M**achine
  - Performance study
    - Transient magnetic analysis
    - NVH analysis
      - Vibration analysis
      - Acoustic analysis
    - Thermal analysis

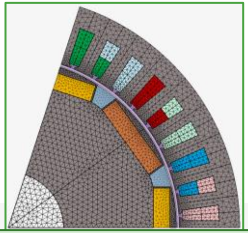
Parameter	IkerMAQ
Power	75 kW
Speed	1080 rpm
Torque	700 Nm
EMF (phase)	293 V_{rms}
Current (phase)	87 A_{rms}
External stator radius	0.188 m
Effective length	0.31 m
Pole pairs number	5
Slots number	45
Internal stator radius	0.139 m
Airgap	2.5 mm

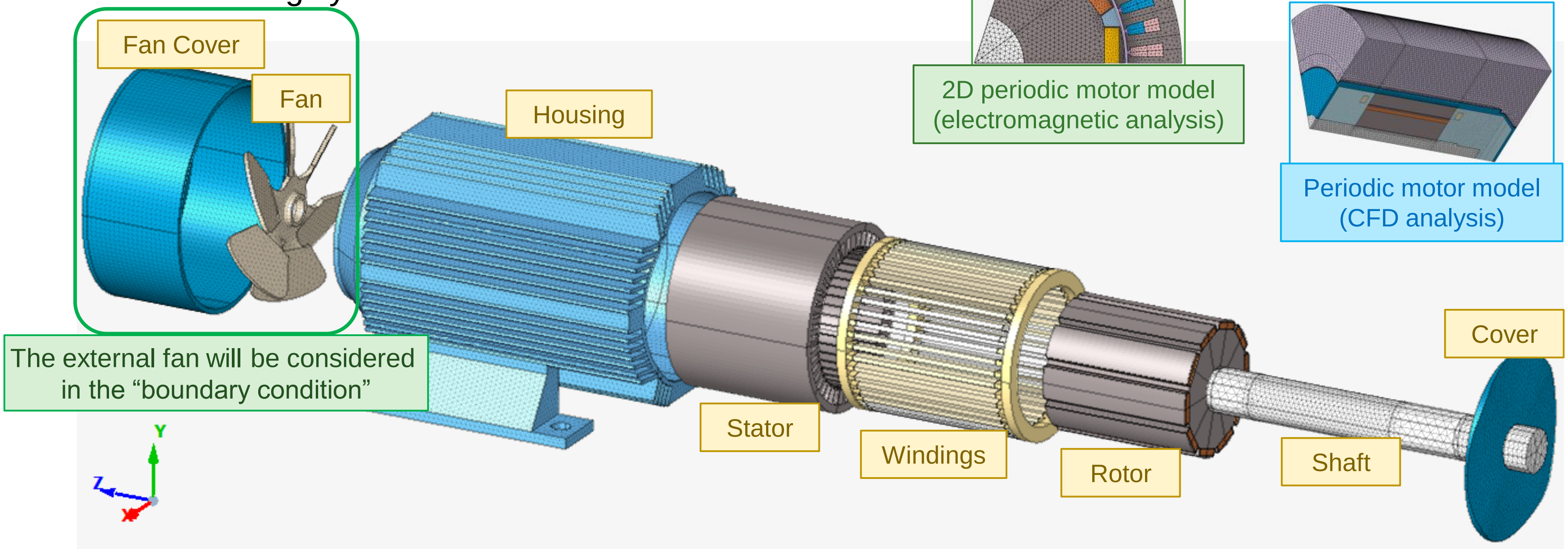
[1]*IkerMAQ PMSM has been designed by the technological center IK4-Ikerlan.*

INTRODUCTION

Application Case: IkerMAQ Motor

- CFD model illustration in SimLab
    - Air cooling system





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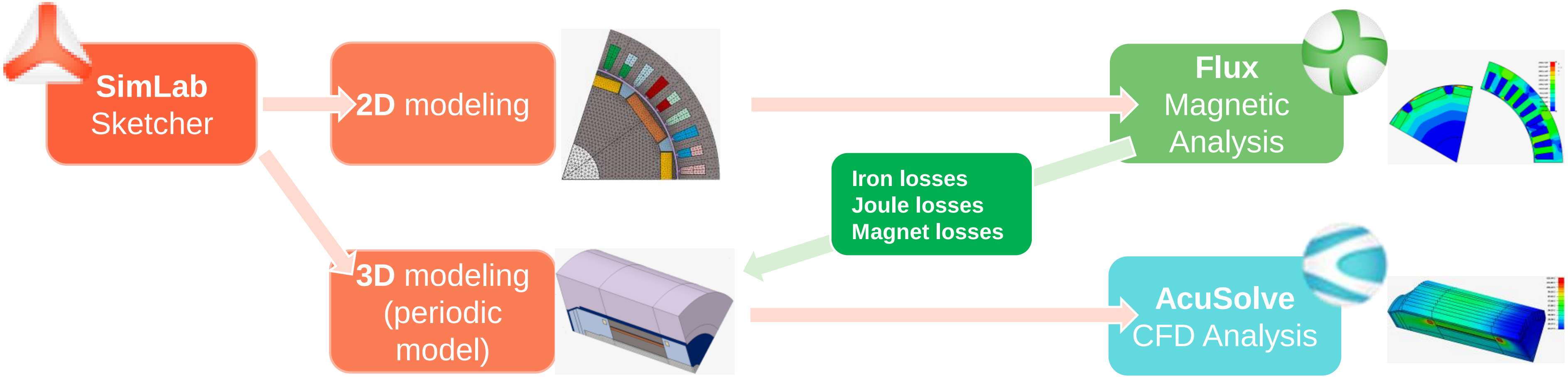
INTRODUCTION

E-Motors CFD Analysis with SimLab

- Analysis workflow (Flux-AcuSolve one way coupling application)



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2D ELECTROMAGNETIC ANALYSIS (FLUX)

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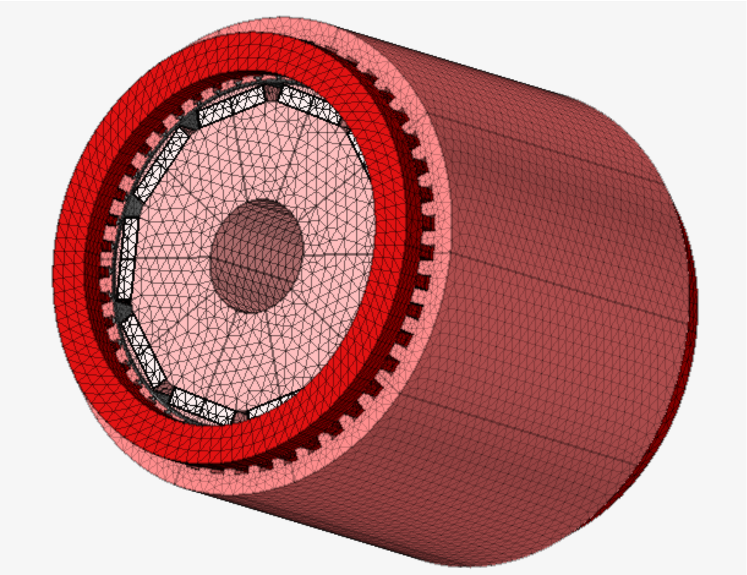
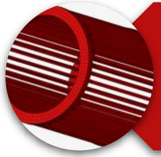
LOSS COMPUTATION

2D ELECTROMAGNETIC ANALYSIS

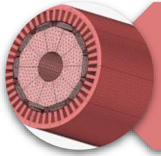
Loss Computation

- Loss distribution inside an eMotor
  - Generally, it can be divided into the following three cases

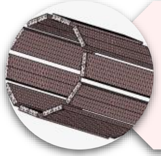




Coil losses (**Joule** loss)



Stator / Rotor losses (**iron** loss)

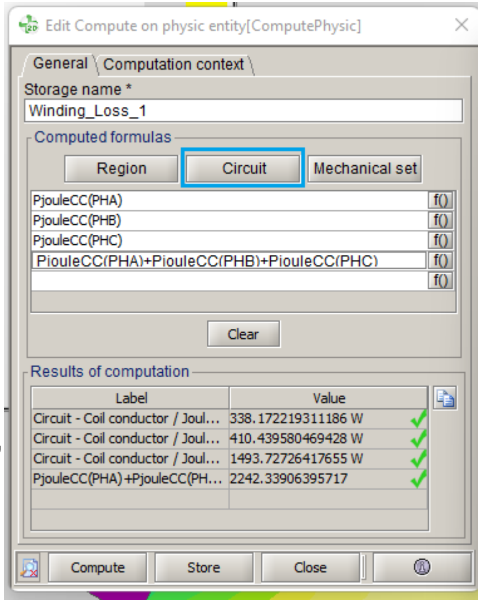


Magnet losses (**Joule** loss)

2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Total Value Method

- Loss distribution inside an eMotor
  - The losses insides an eMotor will be defined as **Heat Sources** in SimLab for AcuSolve.

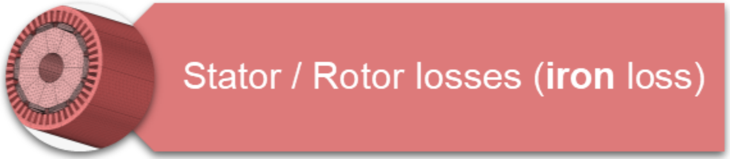


- As the temperature distribution in coil regions (both straight parts and the end-windings) and magnet regions is quite homogeneous, the Heat Source of the coil and magnet bodies can be defined using the **total loss value**.

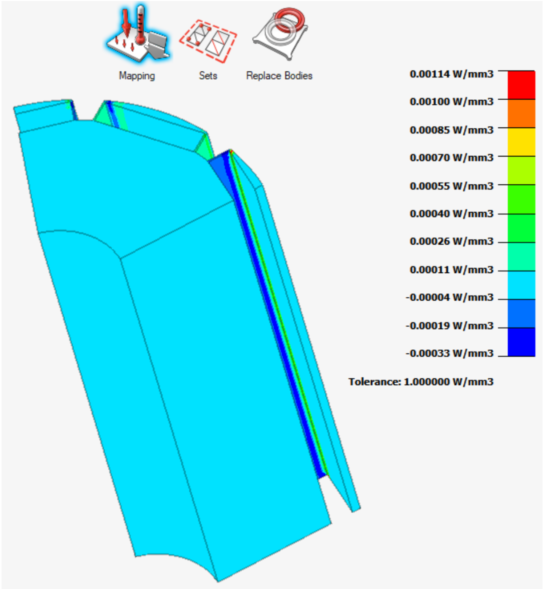
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Nodal Mapping Method

- Loss distribution inside an eMotor
  - The losses insides an eMotor will be defined as **Heat Sources** in SimLab for AcuSolve.



- As iron loss distributions in the stator region and the rotor region are not homogeneous, the Heat Source of the stator / rotor bodies is better to be defined using the **nodal mapping method.**



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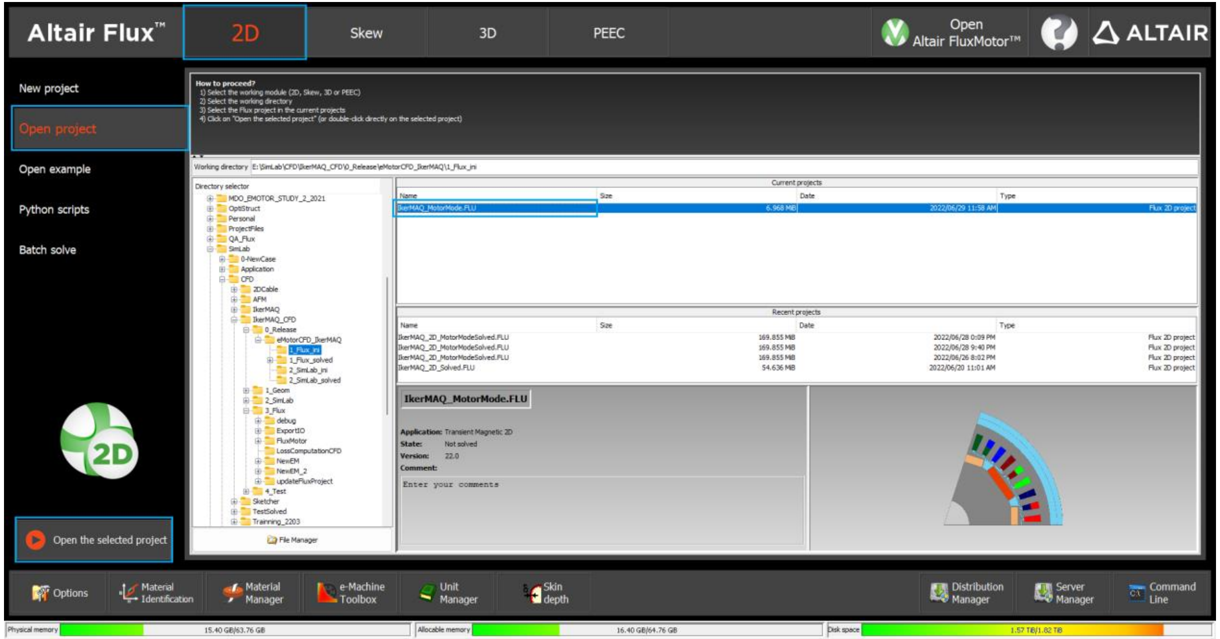
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Flux Initiation

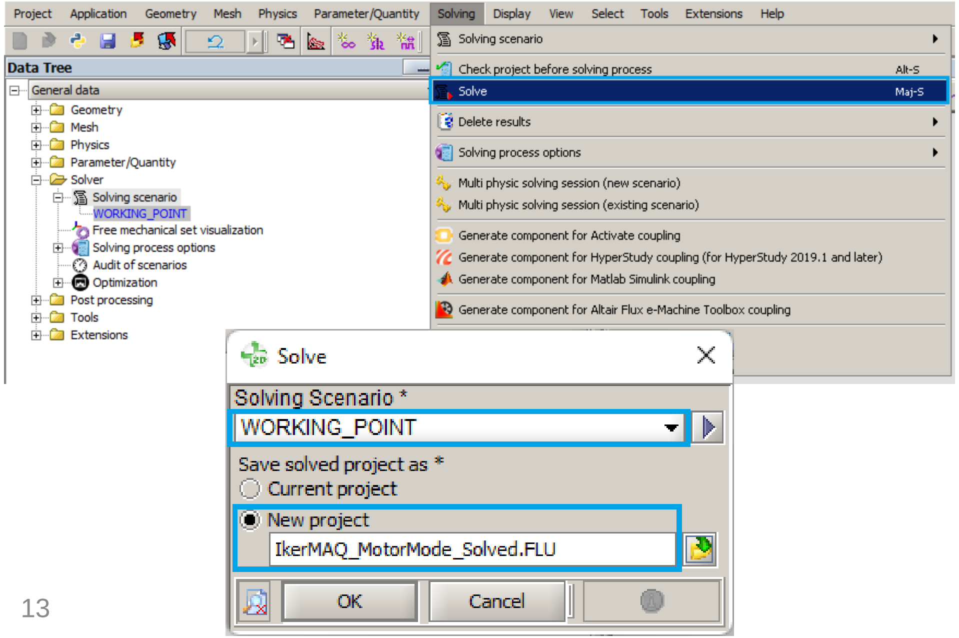
- Run the predefined 2D electromagnetic analysis (in motor mode)
    - Open the project “IkerMAQ_MotorMode.FLU” in Flux

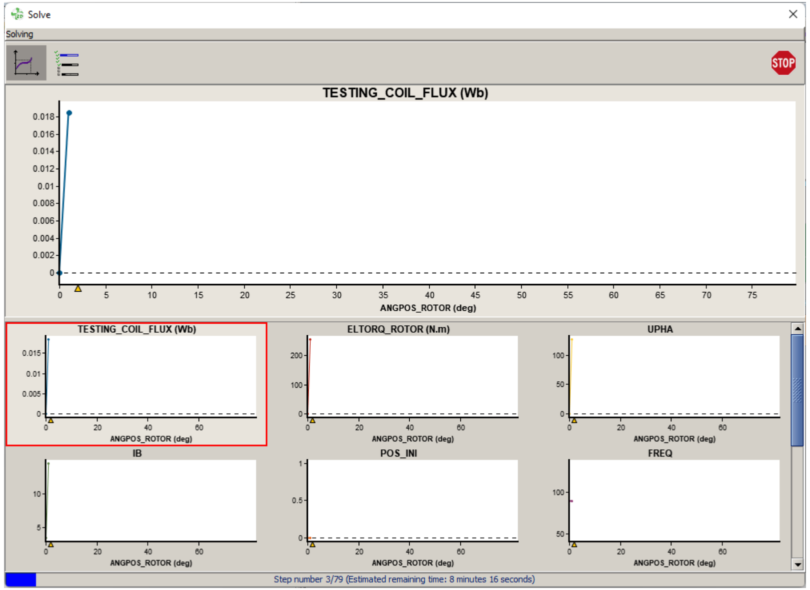


2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Flux Initiation

- Run the predefined 2D electromagnetic analysis (in motor mode)
  - [Solving] – [Solve] (as a new project “IkerMAQ_MotorMode_Solved.FLU”)





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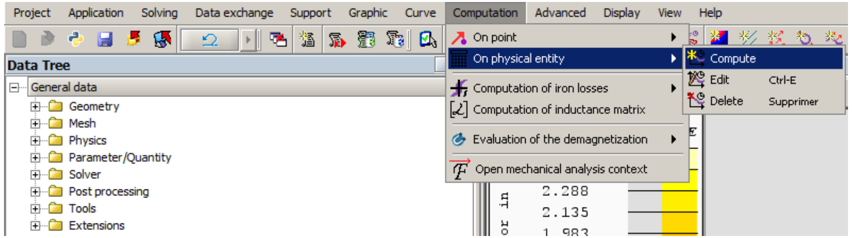
LOSS COMPUTATION: TOTAL VALUE

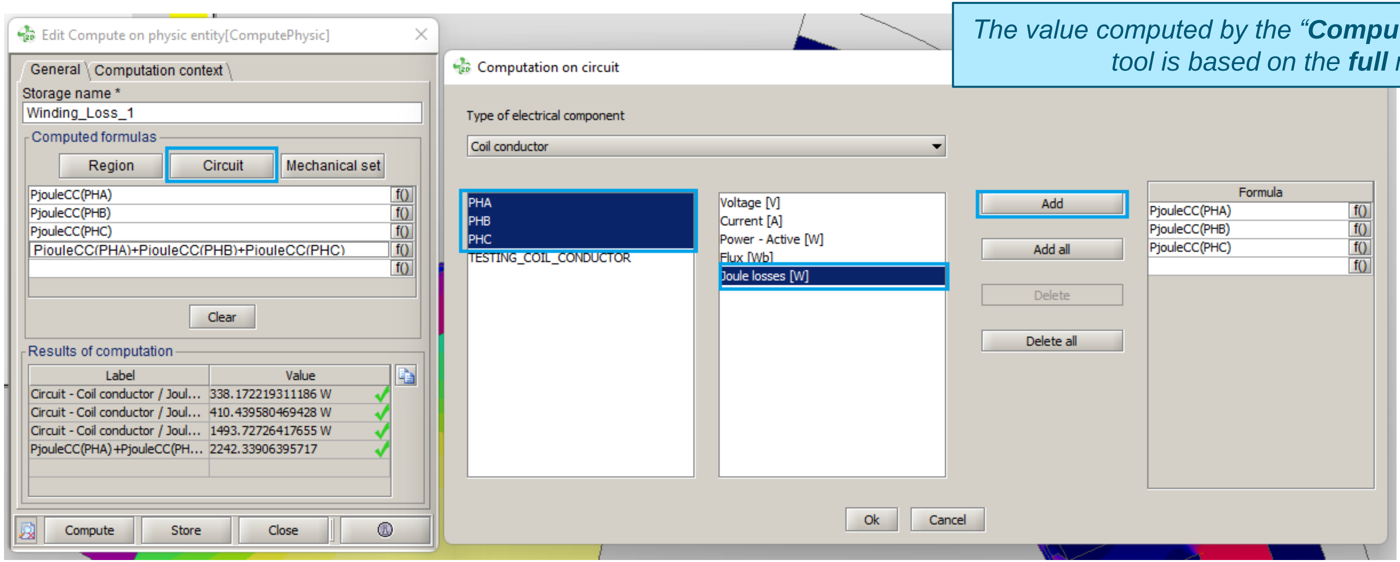
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Total Value Method

- Winding Joule losses
  - [Computation] – [On physical entity] – [Compute]



*The value computed by the “**Computation on circuit**” tool is based on the **full** model*



Formula to compute total Joule losses on winding area:
PjouleCC(PHA)+PjouleCC(PHB)+PjouleCC(PHC)

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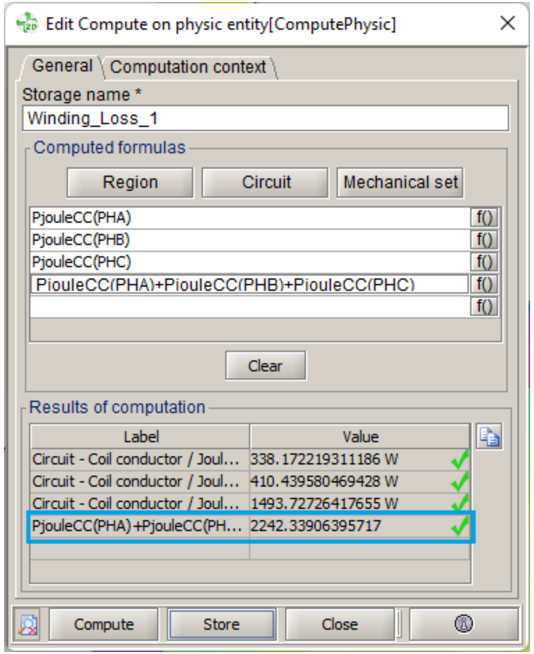
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Total Value Method

- Winding Joule losses
  - Straight part: 2242.34 W



Overview | Current

Winding and Magnet characteristics

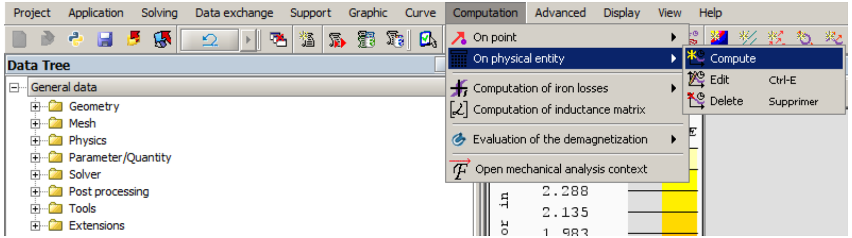
Winding					
Winding connection	Wye	Winding resistance factor	1.0		
Winding temperature (°C)	20.0				
Phase resistance (Ω)	5.365 E-2	Line-Line resistance (Ω)	1.073 E-1	End winding resistance (Ω)	2.916 E-2
In slot winding (°C)	20.0	C.S. end winding (°C)	20.0	O.C.S. end winding (°C)	20.0
Winding straight part resistance (Ω)	2.45 E-2	C.S. end winding resistance (Ω)	1.737 E-2	O.C.S. end winding resistance (Ω)	1.179 E-2
Magnets					
Magnet name	Magnet_1	Material name	USER.N48SH-I...	Material reference temp. Tref (°C)	20.0
Remanent induction at Tref (T)	1.27	Intrinsic coercive field at Tref (A/m)	1.512 E6	Relative permeability at Tref	1.05
Magnet temperature Tmag (°C)	20.0				
Remanent induction at Tmag (T)	1.27	Intrinsic coercive field at Tmag (A/m)	1.512 E6	Relative permeability at Tmag	1.05

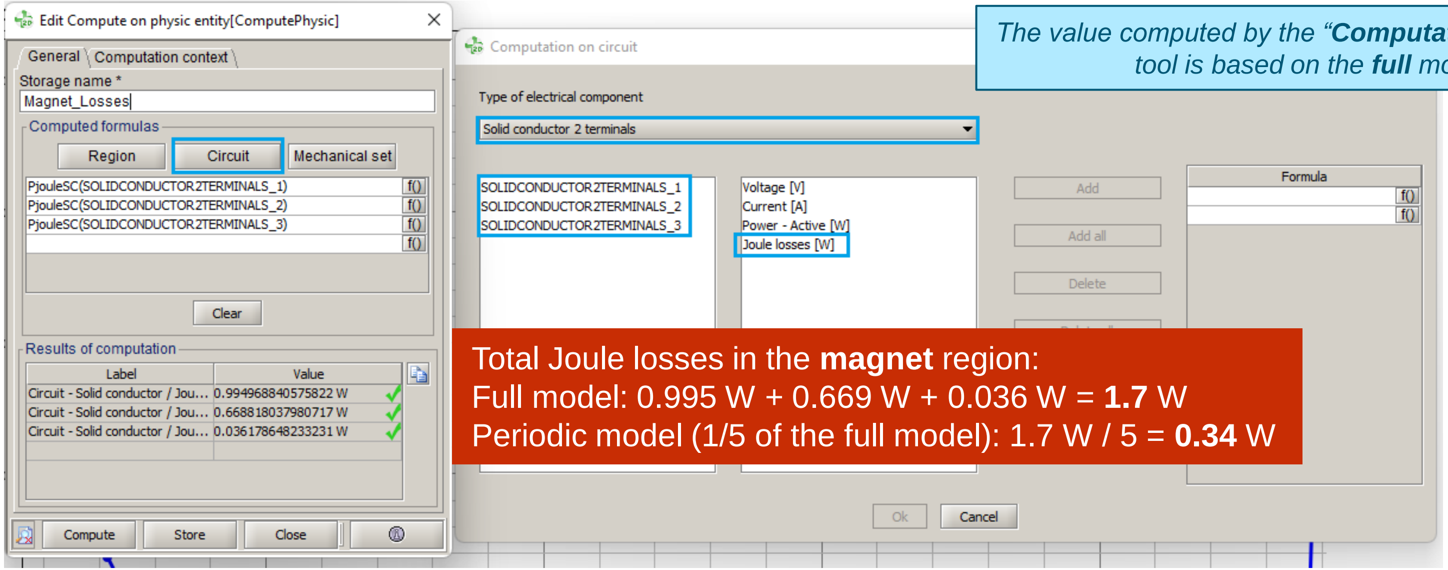
	R / Ohms	Loss (full model) / W	Loss (periodic model) / W
Straight part	0.0245	2242.34	448.47
C.S. end windings	0.0173	1583.37	316.67
O.C.S. end windings	0.0117	1070.83	214.17

2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Total Value Method

- Magnet losses
  - [Computation] – [On physical entity] – [Compute]





*The value computed by the "**Computation on circuit**" tool is based on the **full** model*

Total Joule losses in the **magnet** region:
Full model: 0.995 W + 0.669 W + 0.036 W = **1.7** W
Periodic model (1/5 of the full model): 1.7 W / 5 = **0.34** W

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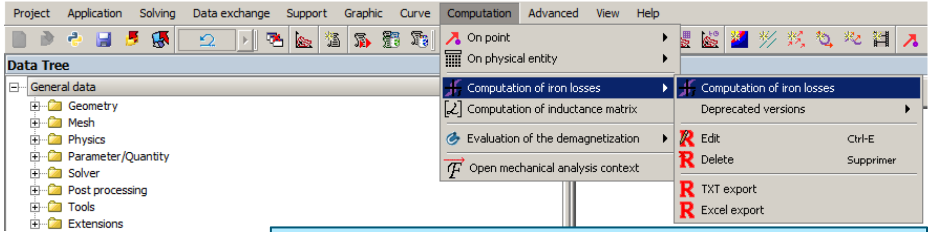
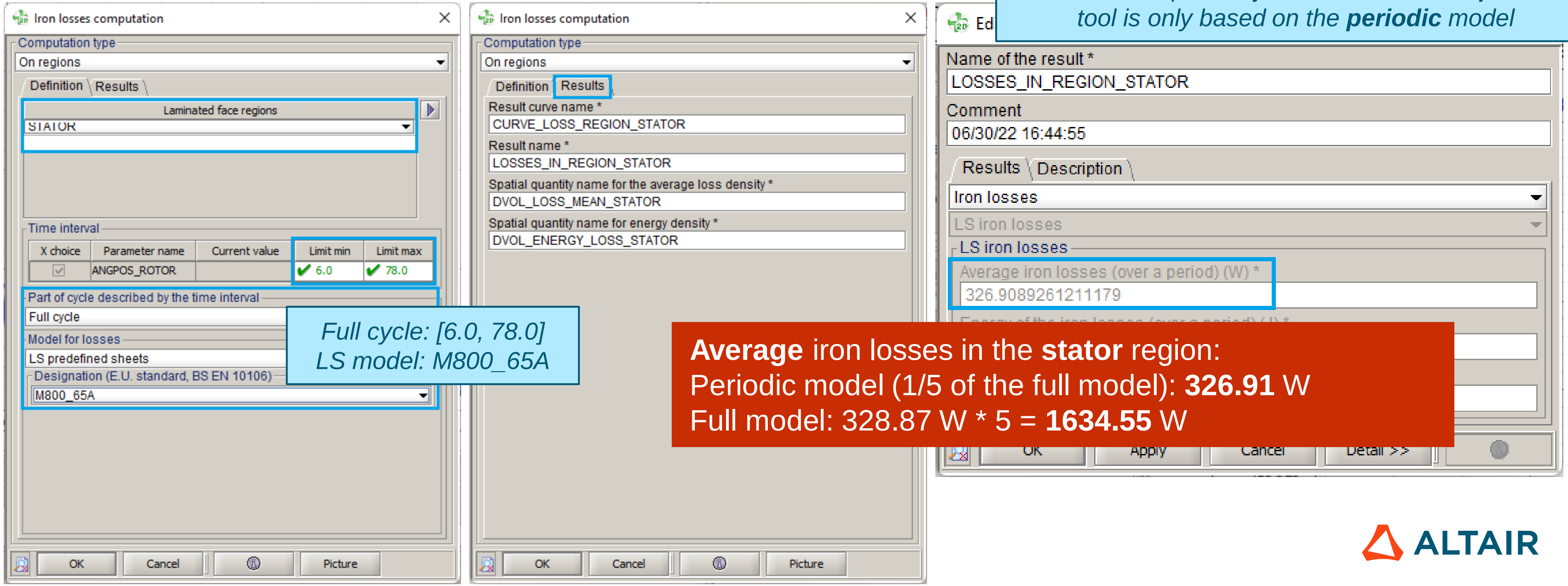
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Total Value Method

- Iron losses: stator
  - [Computation] – [Computation of iron losses]



*The value computed by the "**Iron loss computation**" tool is only based on the **periodic** model*



Full cycle: [6.0, 78.0]
LS model: M800_65A

Average iron losses in the **stator** region:
Periodic model (1/5 of the full model): **326.91** W
Full model: 328.87 W * 5 = **1634.55** W

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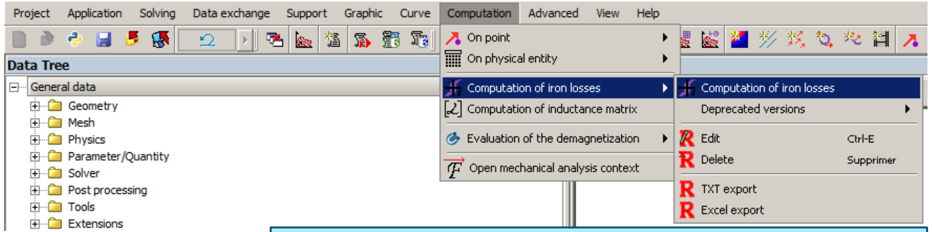
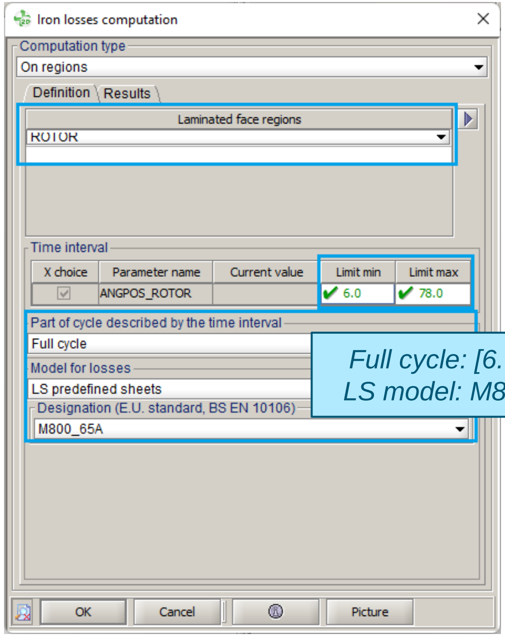
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Total Value Method

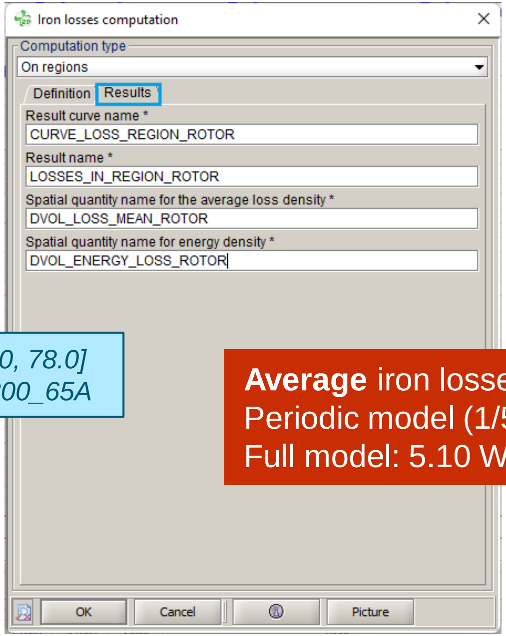
- Iron losses: **rotor**
  - [Computation] – [Computation of iron losses]

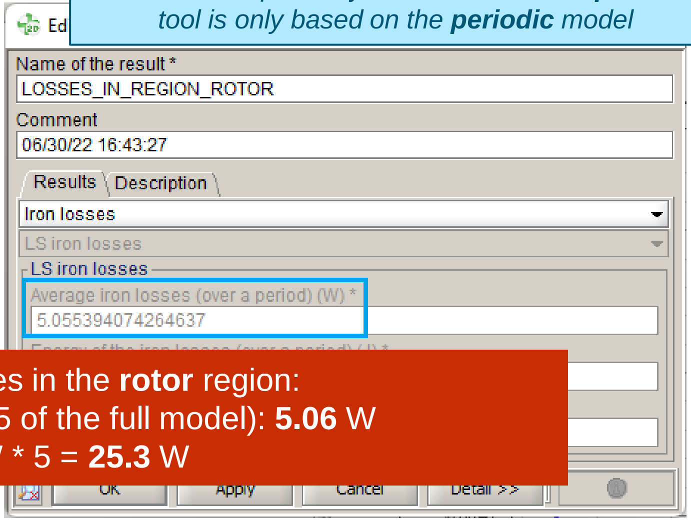


*The value computed by the "**Iron loss computation**" tool is only based on the **periodic** model*



Full cycle: [6.0, 78.0]
LS model: M800_65A





Average iron losses in the **rotor** region:
Periodic model (1/5 of the full model): **5.06** W
Full model: 5.10 W * 5 = **25.3** W

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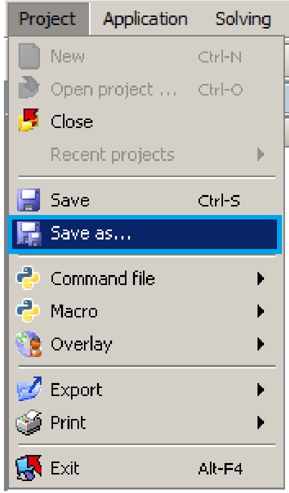
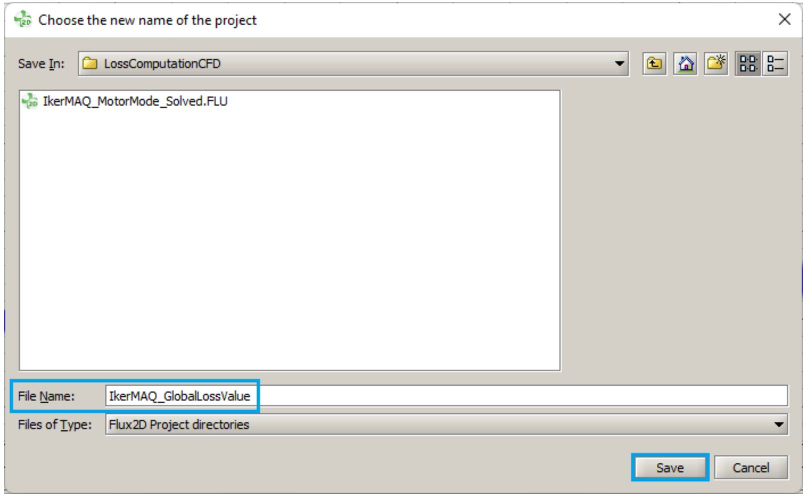
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Total Value Method

- Loss computation in Flux: total value method
  - Save the project as “IkerMAQ_GlobalLossValue.FLU”





LOSS COMPUTATION: NODAL MAPPING

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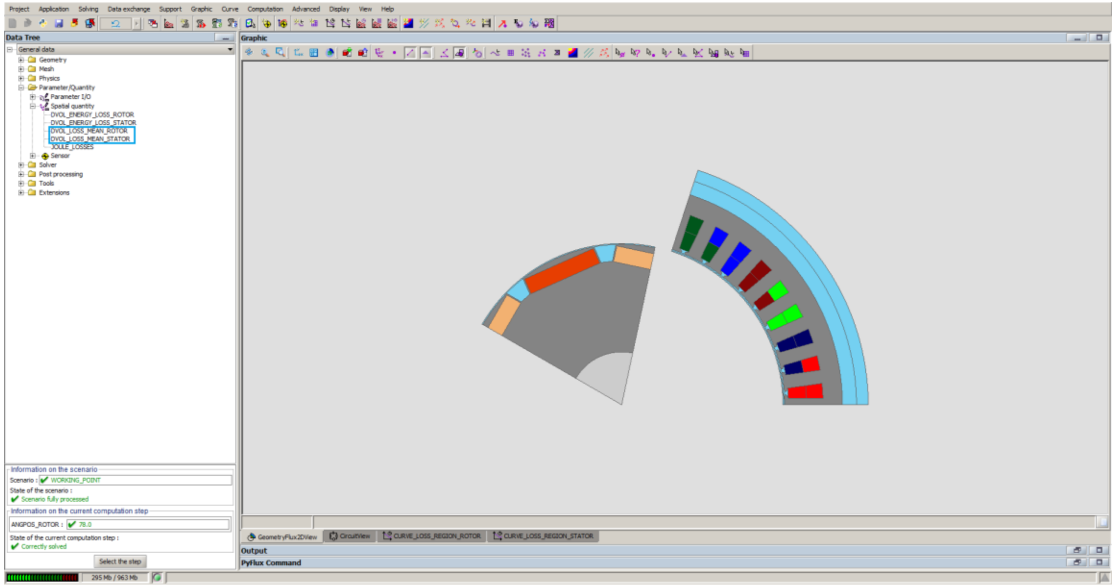
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Nodal Mapping Method

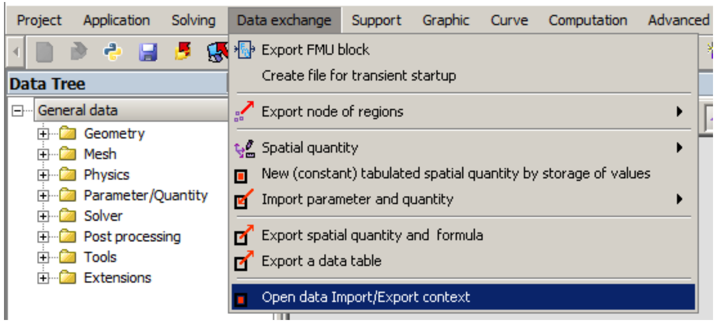
- Loss computation in Flux: nodal mapping method
  - Need the spatial quantities created in the previous step
    - Continue to work on the project “IkerMAQ_GlobalLossValue” in Flux

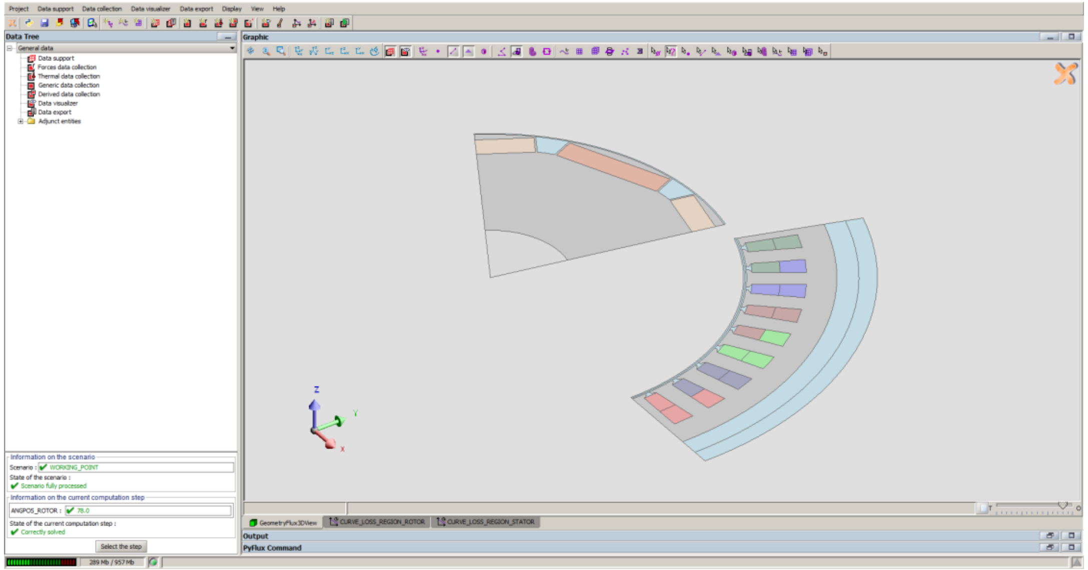


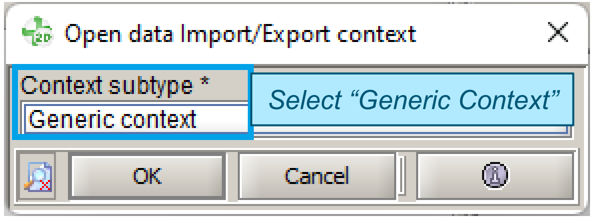
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Nodal Mapping Method

- Iron loss export from Flux
  - Export the nodal loss values from Flux to AcuSolve
    - [Data exchange] – [Open data Import/Export context]



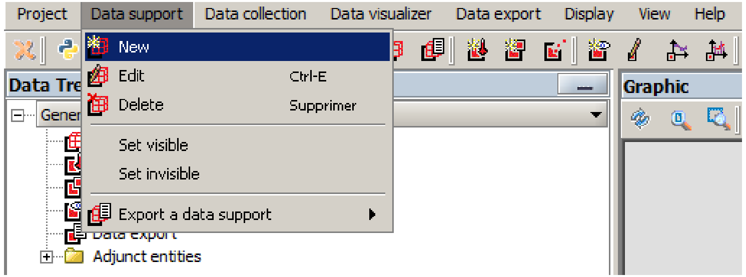


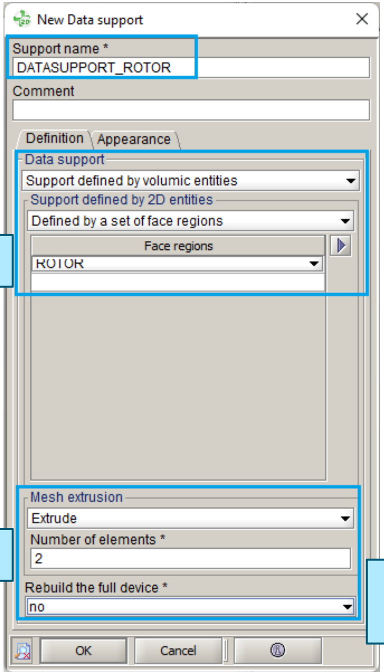


2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Nodal Mapping Method

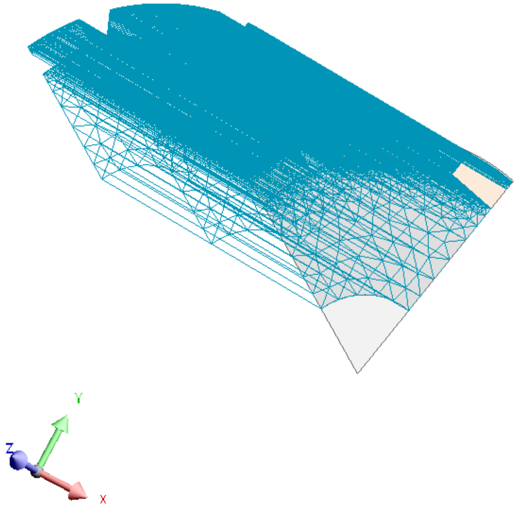
- Iron loss export from Flux
  - Create data support: **ROTOR**
    - [Data support] – [New]

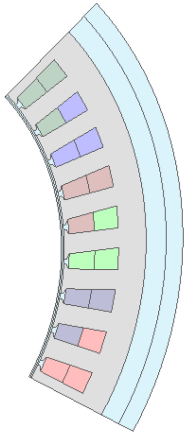




*Select the region **ROTOR***

Extrude with 2 elements





No need to rebuild the full device for the CFD analysis on a periodic model

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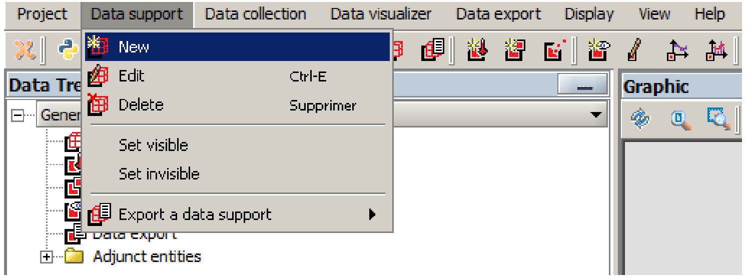
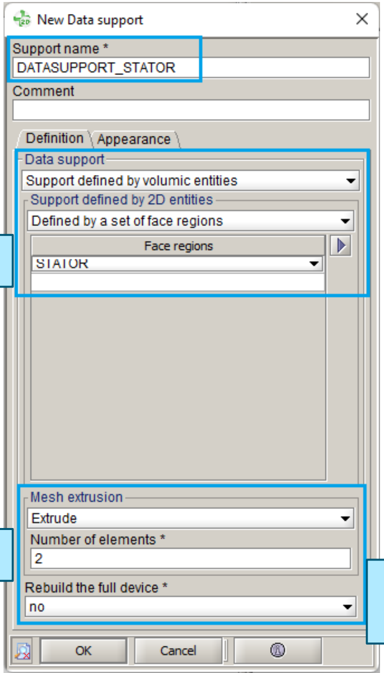
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Nodal Mapping Method

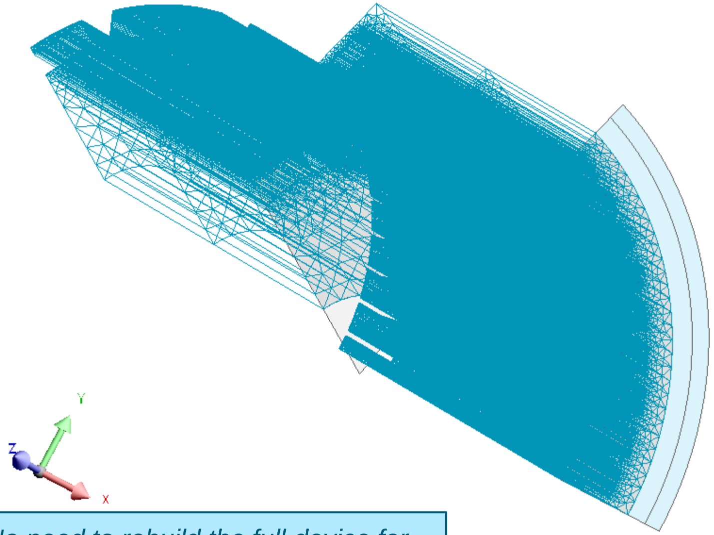
- Iron loss export from Flux
  - Create data support: **STATOR**
    - [Data support] – [New]





*Select the region **STATOR***

Extrude with 2 elements



No need to rebuild the full device for the CFD analysis on a periodic model

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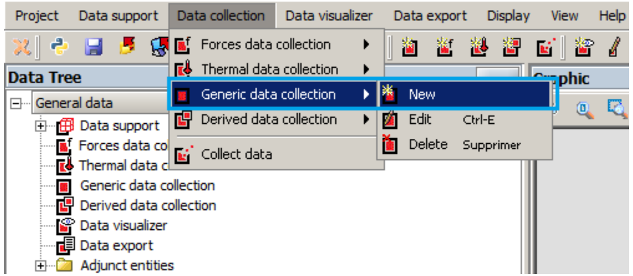
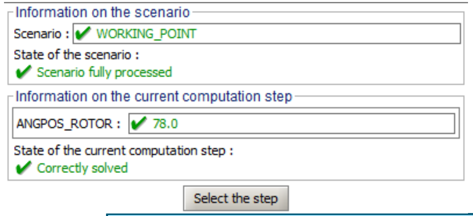
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Nodal Mapping Method

- Iron loss export from Flux
  - Create generic data collection
    - [Data collection] – [Generic data collection] – [New]



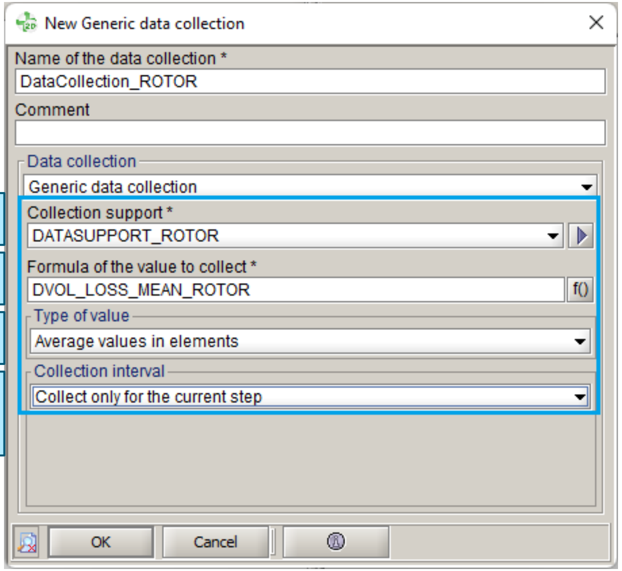


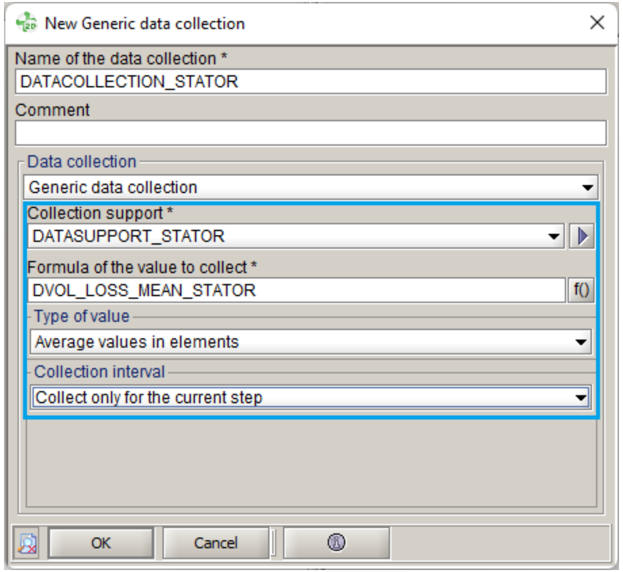
Select the created DataSupport

Select the dedicated spatial quantity formula

Select "Average values in elements"

Collect the data only for the current step (the last EM solution step)





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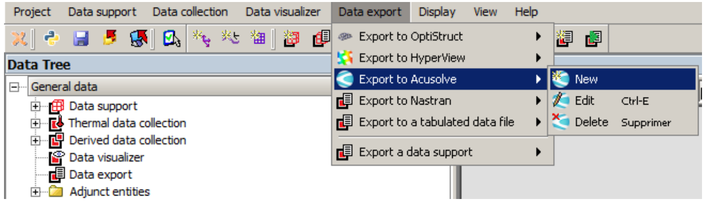
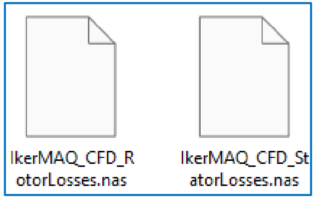
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Nodal Mapping Method



- Iron loss export from Flux
  - Create data export
    - [Data export] – [Export to AcuSolve] – [New]

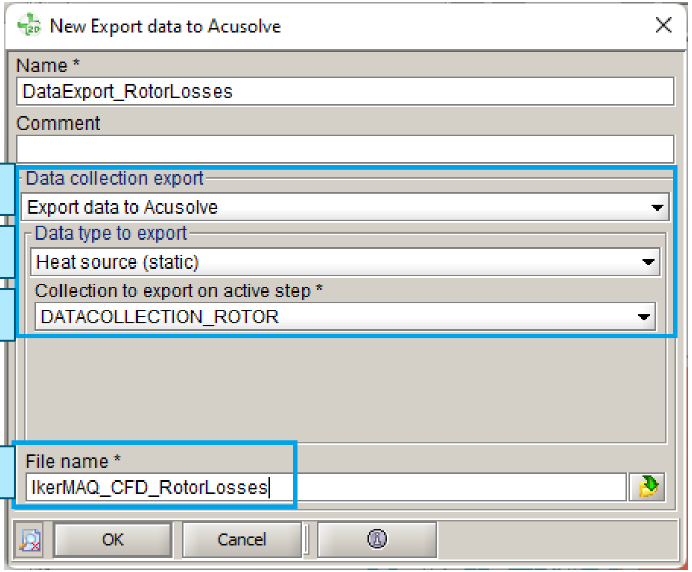


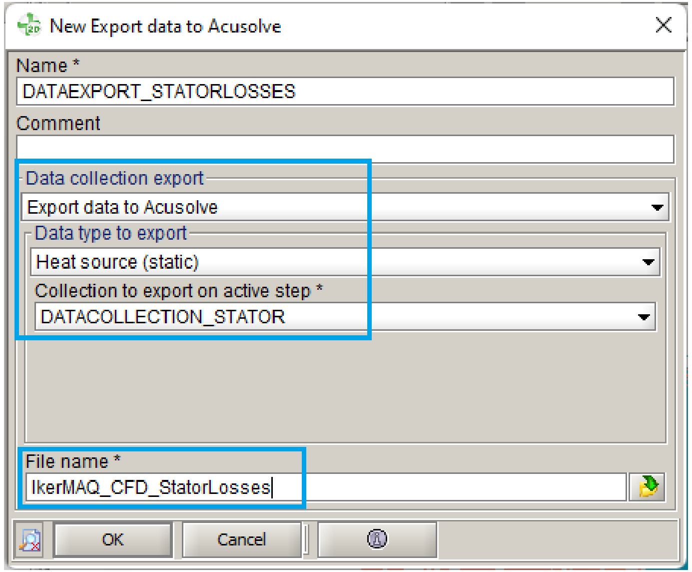
Select “Export data to AcuSolve”

Select “Heat source (static)”

Select the defined DataCollection

Define the export file name





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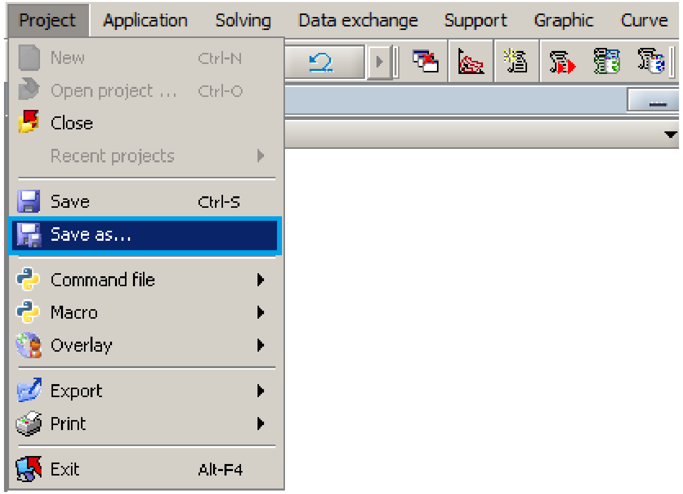
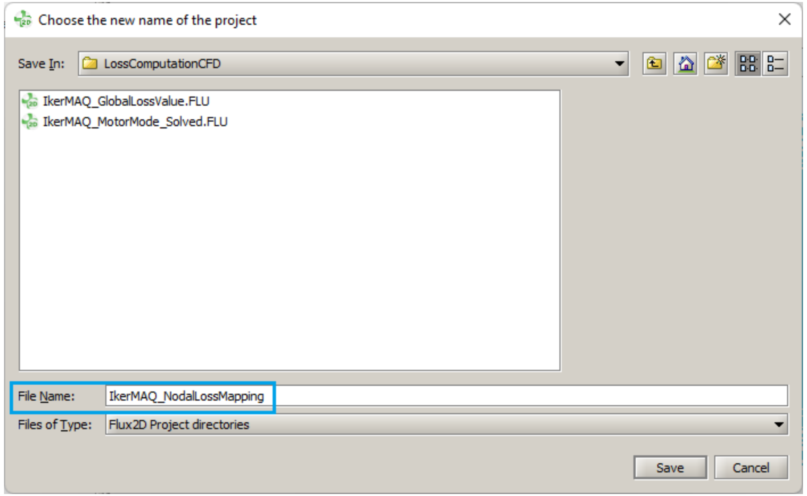
2D ELECTROMAGNETIC ANALYSIS

Loss Computation: Nodal Mapping Method

- Loss distribution inside an eMotor
  - Loss computation in Flux[1]
    - Save the project as “IkerMAQ_NodalLossMapping.FLU”





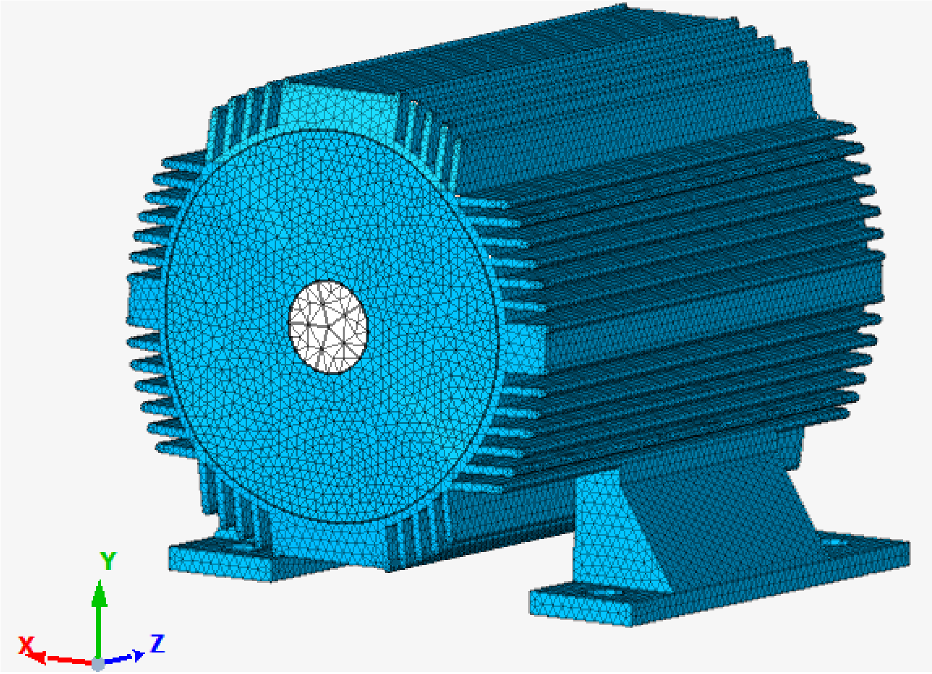
3D CFD ANALYSIS (SIMLAB / ACUSOLVE)

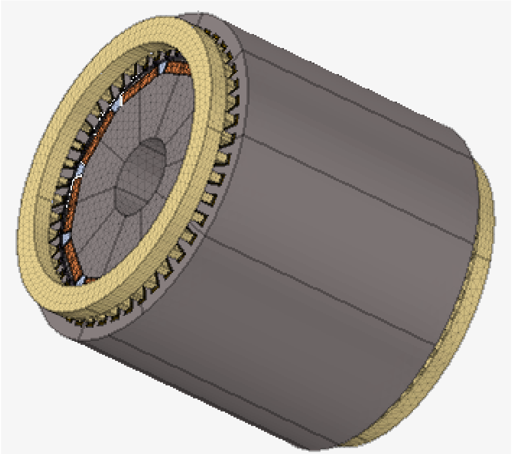
EMOTOR CFD MESHING

3D CFD ANALYSIS

eMotor CFD Meshing

- Full motor modeling for thermal analysis





Motor model (with end-windings)

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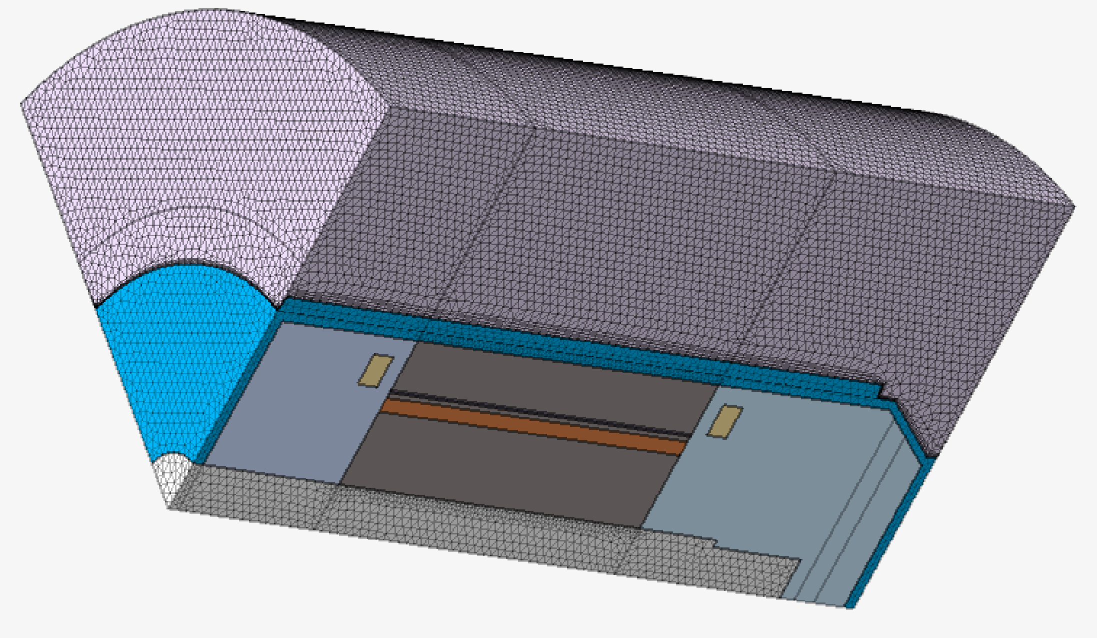
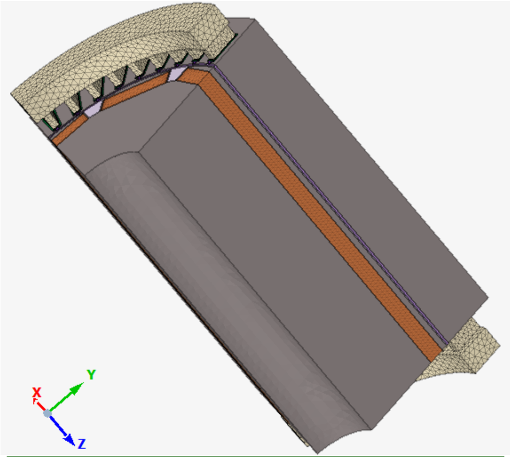
3D CFD ANALYSIS

eMotor CFD Meshing

- Periodic modeling (axisymmetric model) for CFD analysis
  - With outside air fluid region



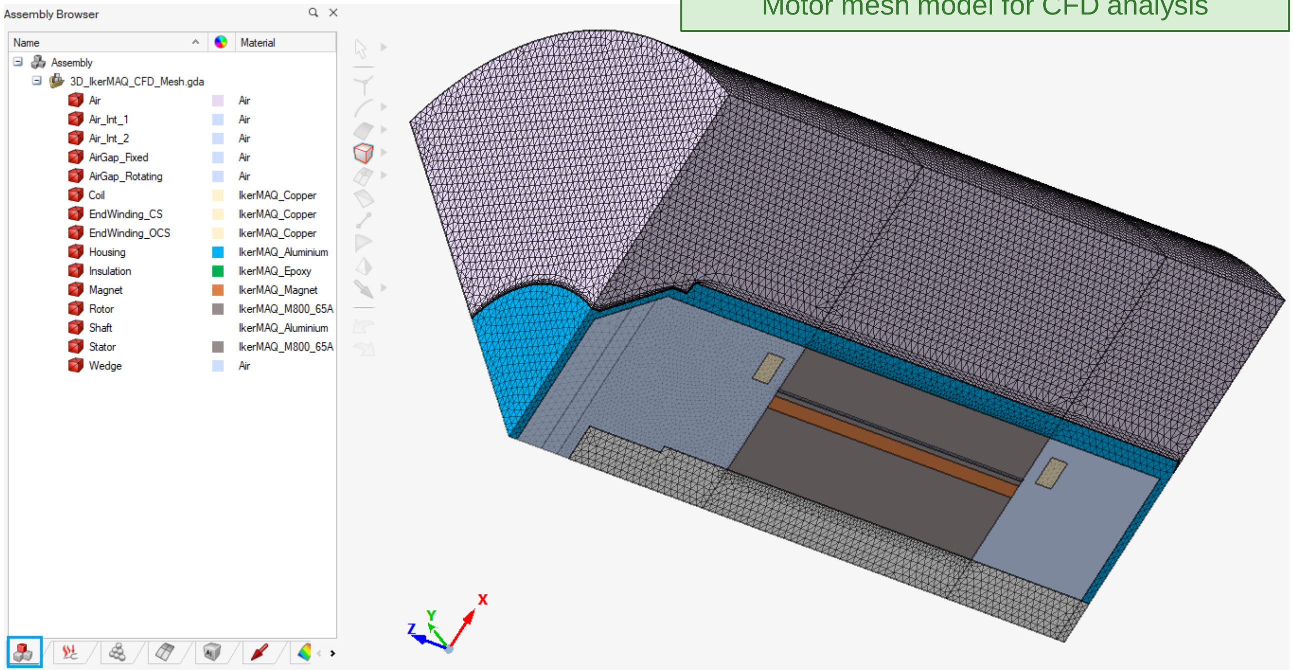


Motor model (with end-windings)

3D CFD ANALYSIS

eMotor CFD Meshing

- Periodic modeling (axisymmetric model) for CFD analysis
  - Open the project “IkerMAQ_CFD_Mesh.slb”

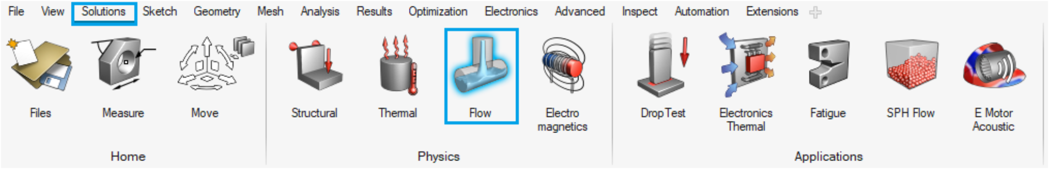


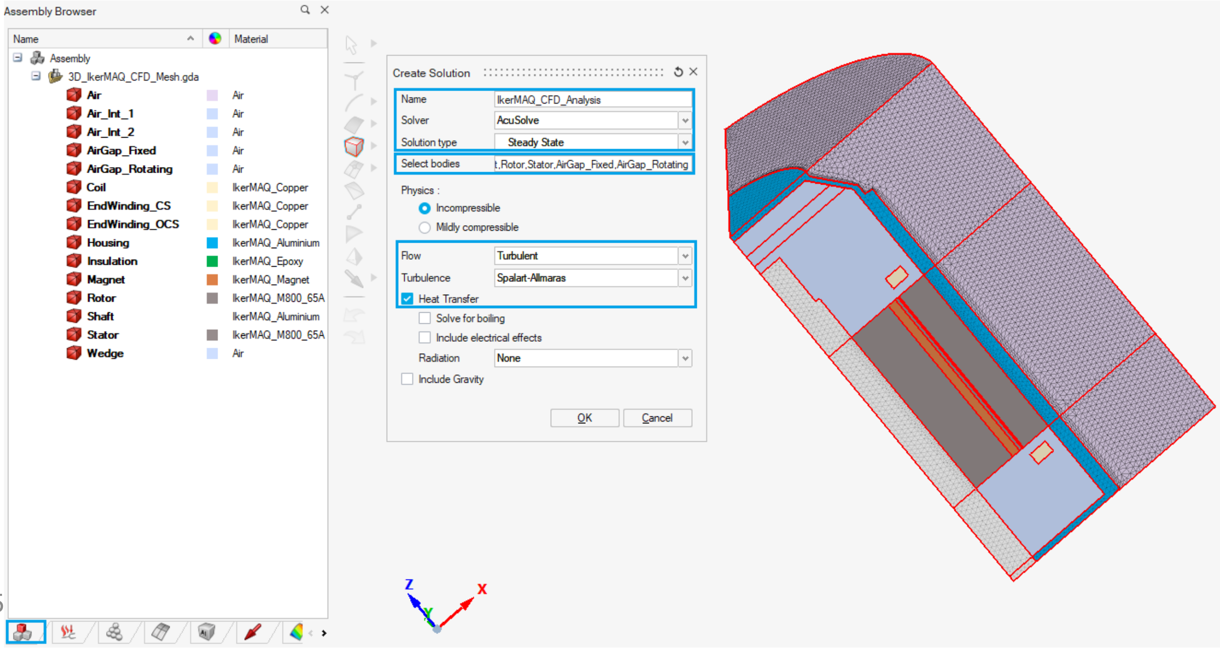
CFD SOLUTION SETUP

3D CFD ANALYSIS

CFD Solution Setup

- Create a **Solution** for CFD analysis
  - [Solutions] – [Flow]





Parameter	Type / value
Name	IkerMAQ_CFD_Analysis
Solver	AcuSolve
Solution type	Steady State
Physics	Incompressible
Flow	Turbulent
Turbulence	Spalart-Allmaras

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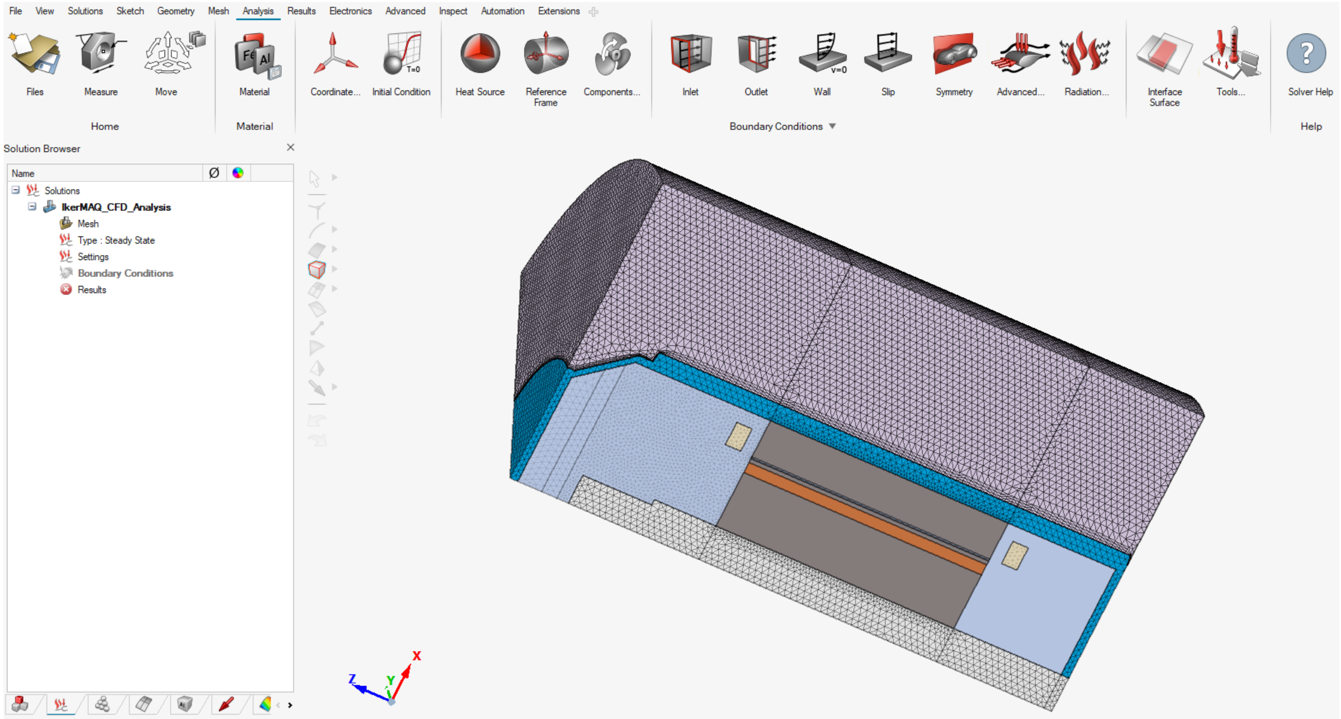
3D CFD ANALYSIS

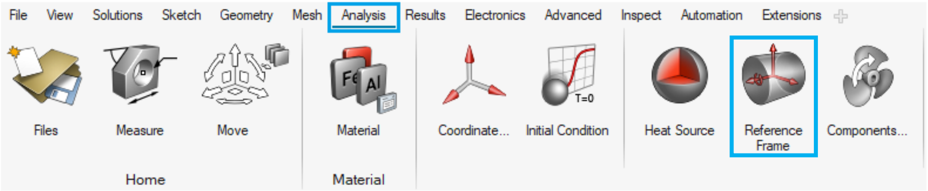
CFD Solution Setup

- Create a **Solution** for CFD analysis

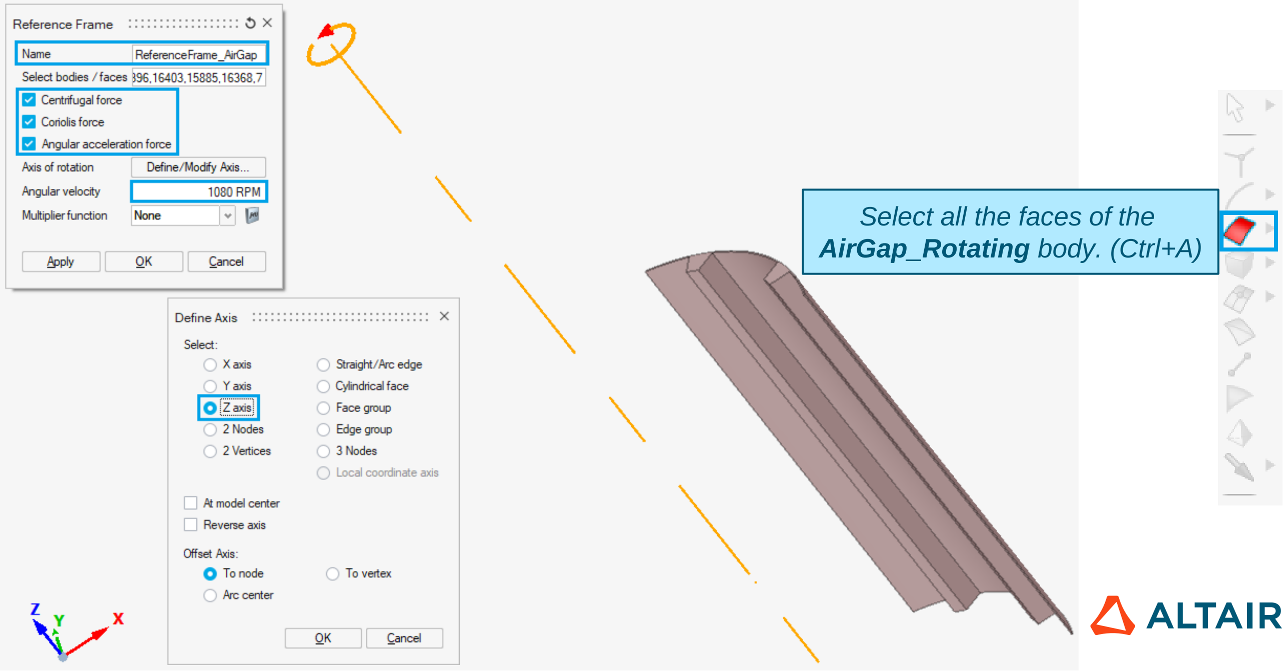


3D CFD ANALYSIS

CFD Solution Setup

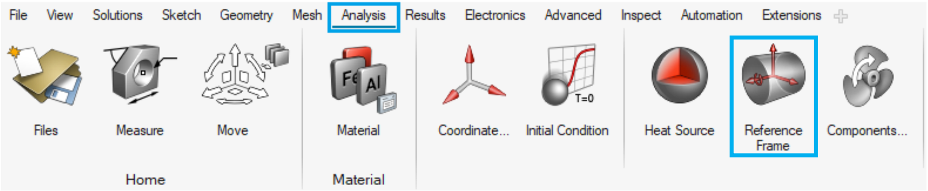


- Define **Flow Domain:** *Reference Frame*
  - [Analysis] – [Reference Frame]
    - AirGap_Rotating

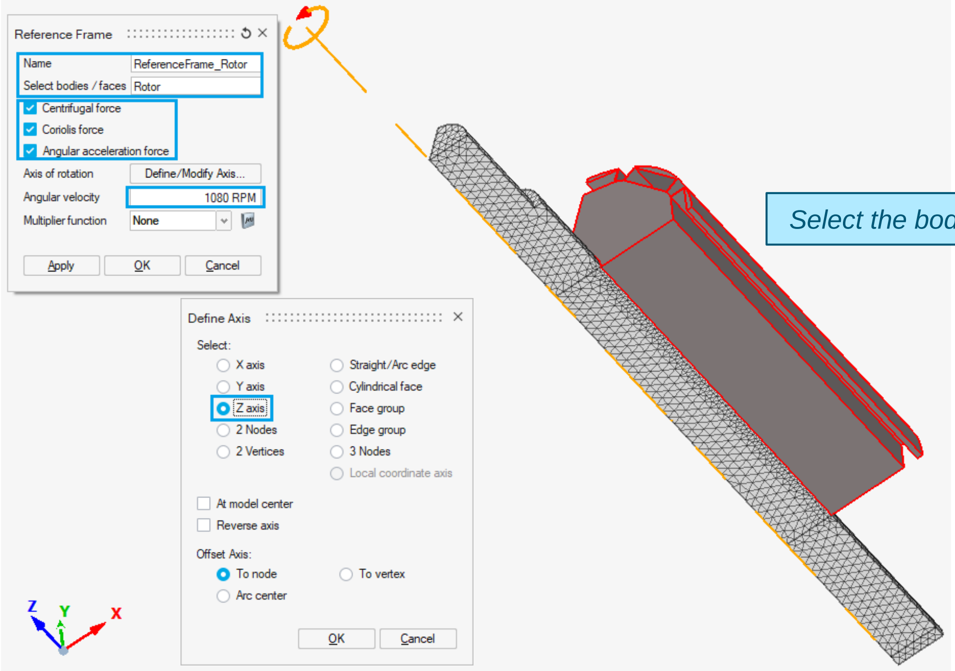


3D CFD ANALYSIS

CFD Solution Setup



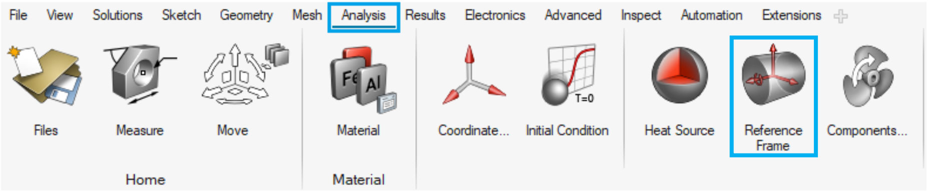
- Define **Flow Domain:** *Reference Frame*
  - [Analysis] – [Reference Frame]
    - Rotor



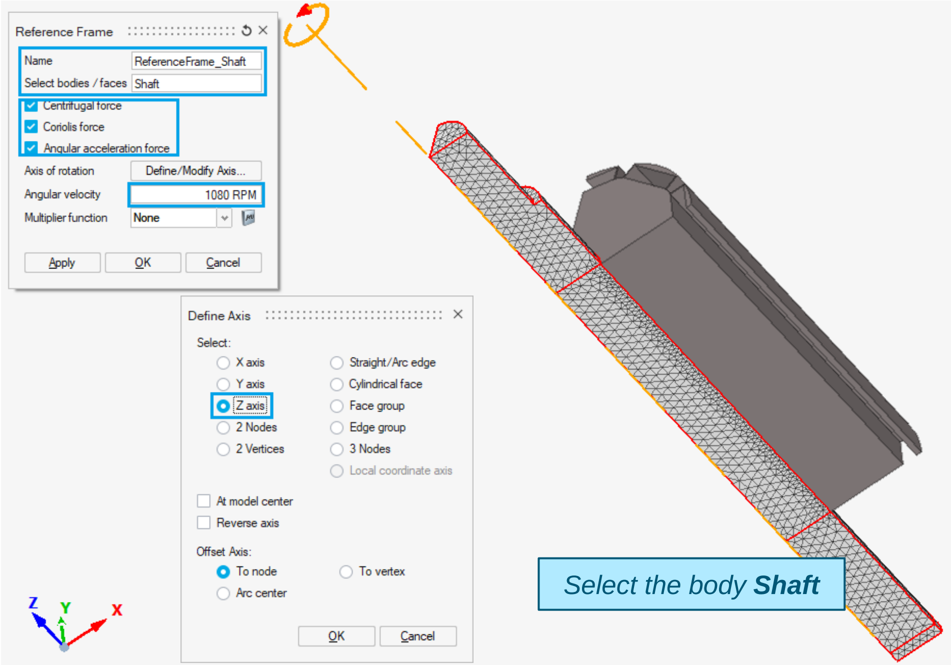
Select the body ***Rotor***

3D CFD ANALYSIS

CFD Solution Setup

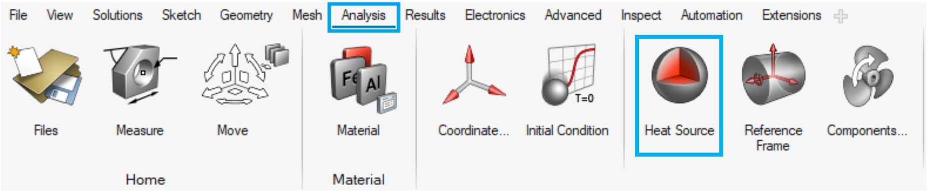


- Define **Flow Domain:** *Reference Frame*
  - [Analysis] – [Reference Frame]
    - Shaft



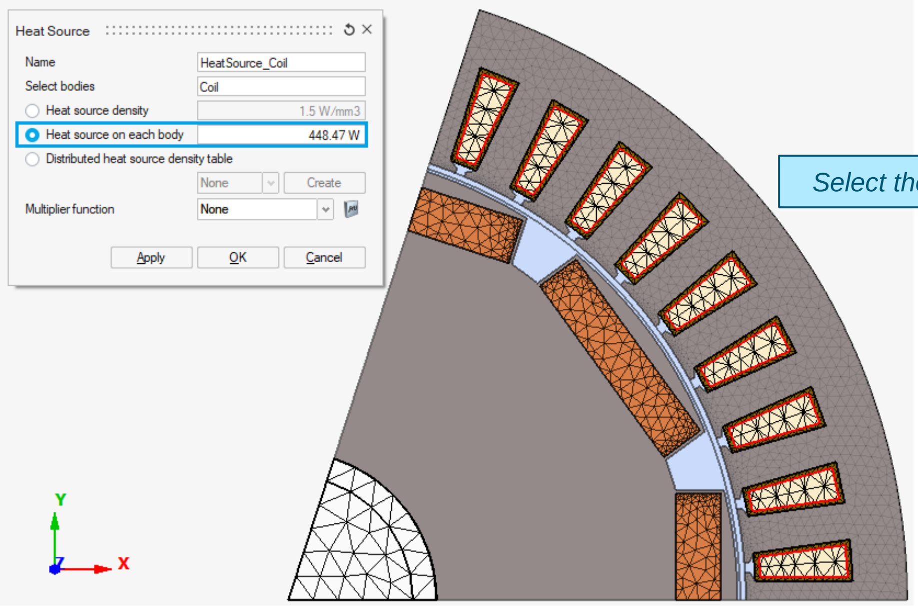
3D CFD ANALYSIS

CFD Solution Setup



- Define **Flow Domain:** *Heat Source (total loss value)*
  - [Analysis] – [Heat Source]
    - Winding loss (straight part): 448.47 W

Please refer to the pages 15-16 for the winding loss (Joule loss) computation



*Select the body **Coil***

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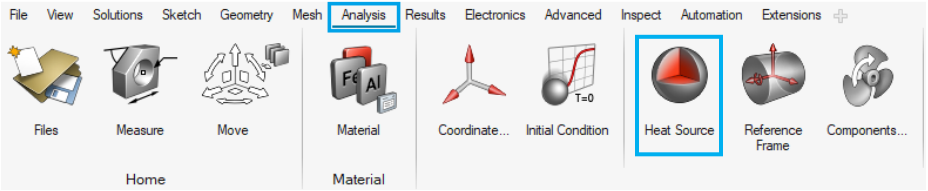
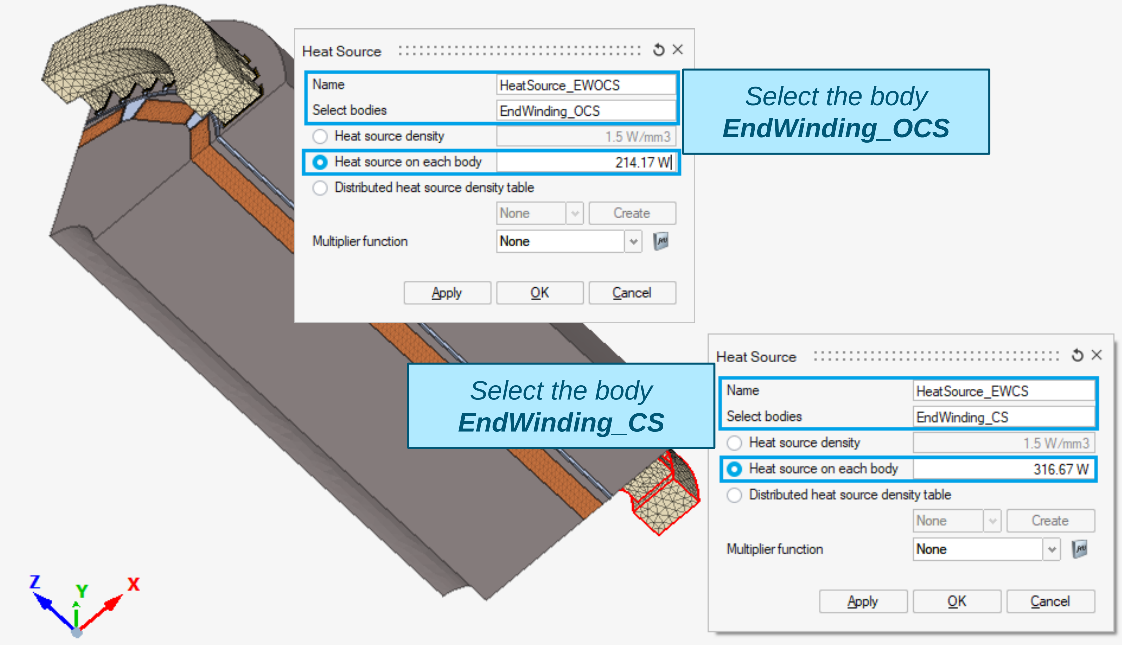
3D CFD ANALYSIS

CFD Solution Setup



- Define **Flow Domain:** *Heat Source (total loss value)*
  - [Analysis] – [Heat Source]
    - Winding loss (end windings)
      - C.S.: 316.67 W
      - O.C.S.: 214.17 W

Please refer to the pages 15-16 for the winding loss (Joule loss) computation



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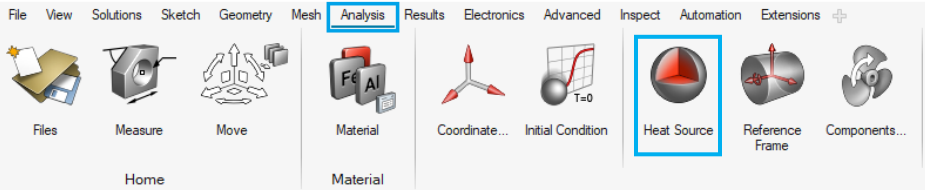
3D CFD ANALYSIS

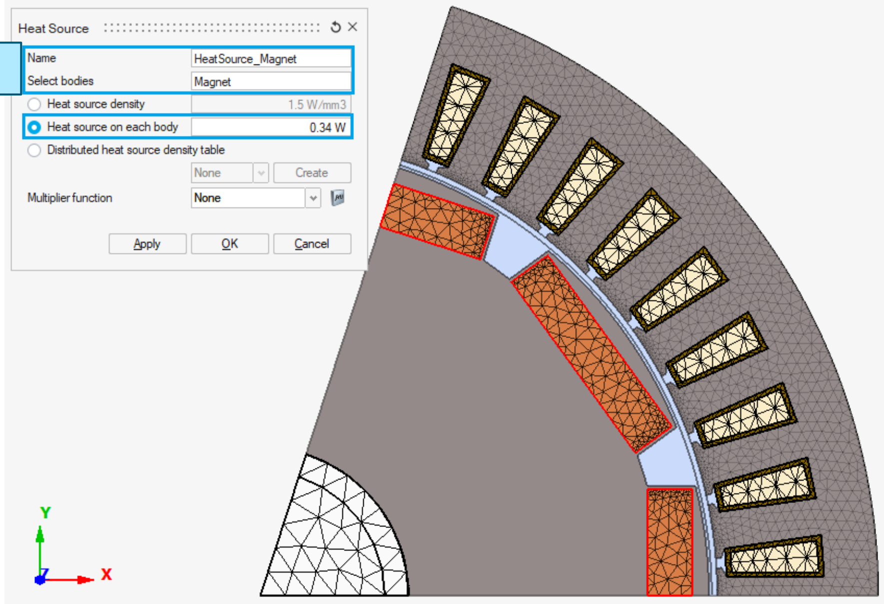
CFD Solution Setup



- Define **Flow Domain:** *Heat Source (total loss value)*
  - [Analysis] – [Heat Source]
    - Magnet: 0.34 W

Please refer to the page 17 for the magnet loss (Joule loss) computation

Select the body ***Magnet***



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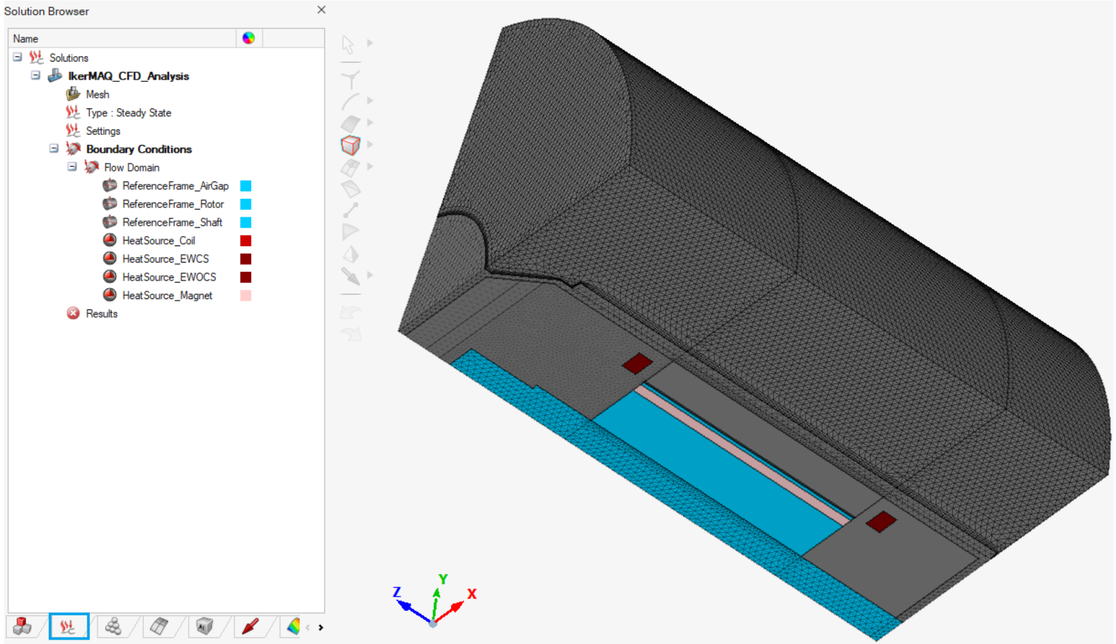
3D CFD ANALYSIS

CFD Solution Setup

- Define **Flow Domain**
  - *Reference Frames + Heat Sources (total loss value)*



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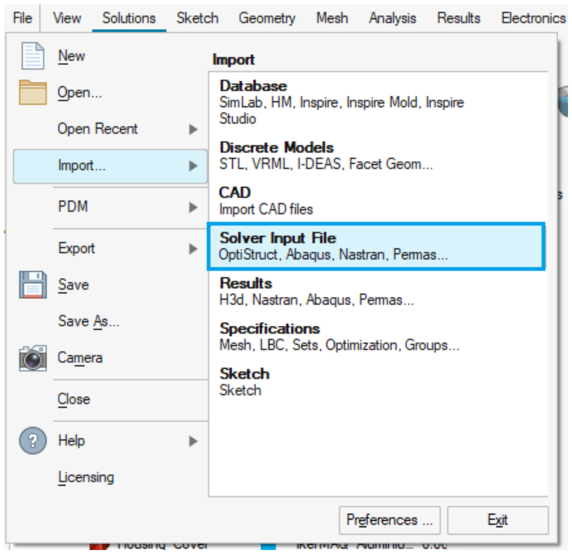
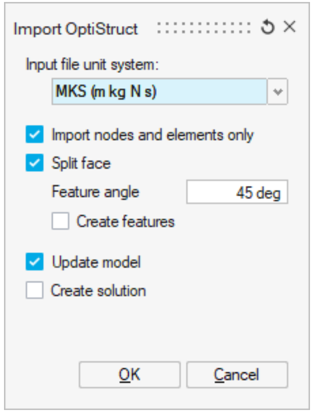
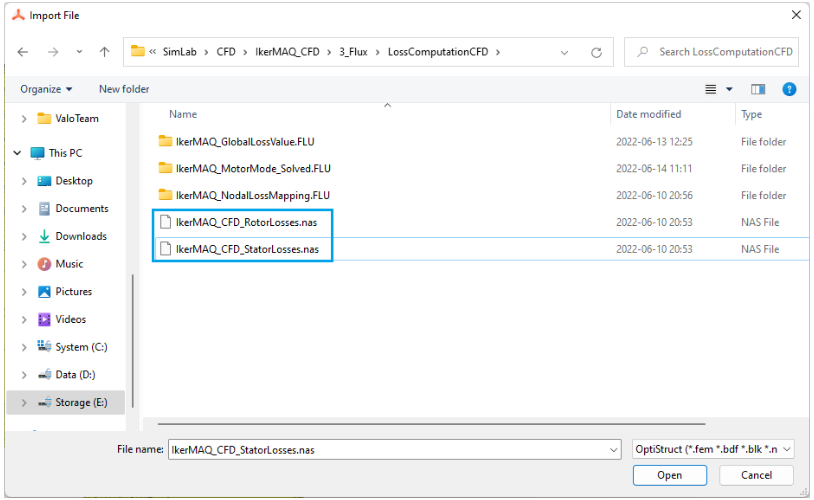
3D CFD ANALYSIS

CFD Solution Setup

- Define **Flow Domain:** *Heat Source (nodal mapping)*
  - Loss import: stator and rotor losses
    - [File] – [Import] – [Solver Input File]







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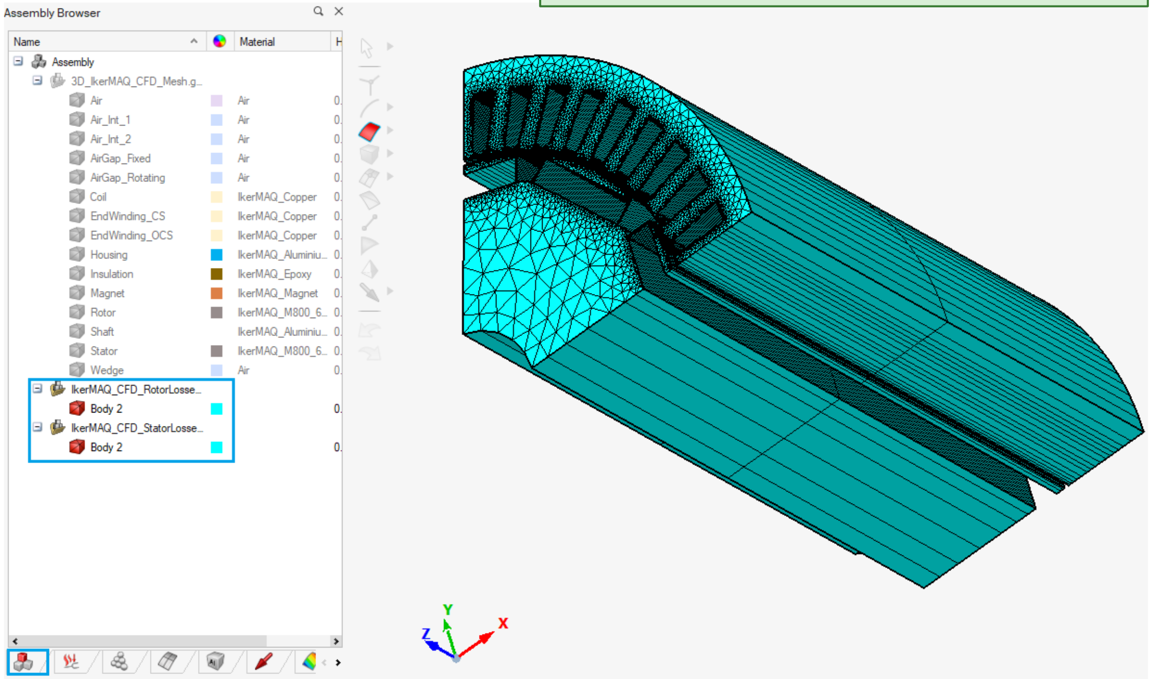
3D CFD ANALYSIS

CFD Solution Setup

- Define **Flow Domain:** *Heat Source (nodal mapping)*
  - Loss import: stator and rotor losses

Imported meshed models for iron losses



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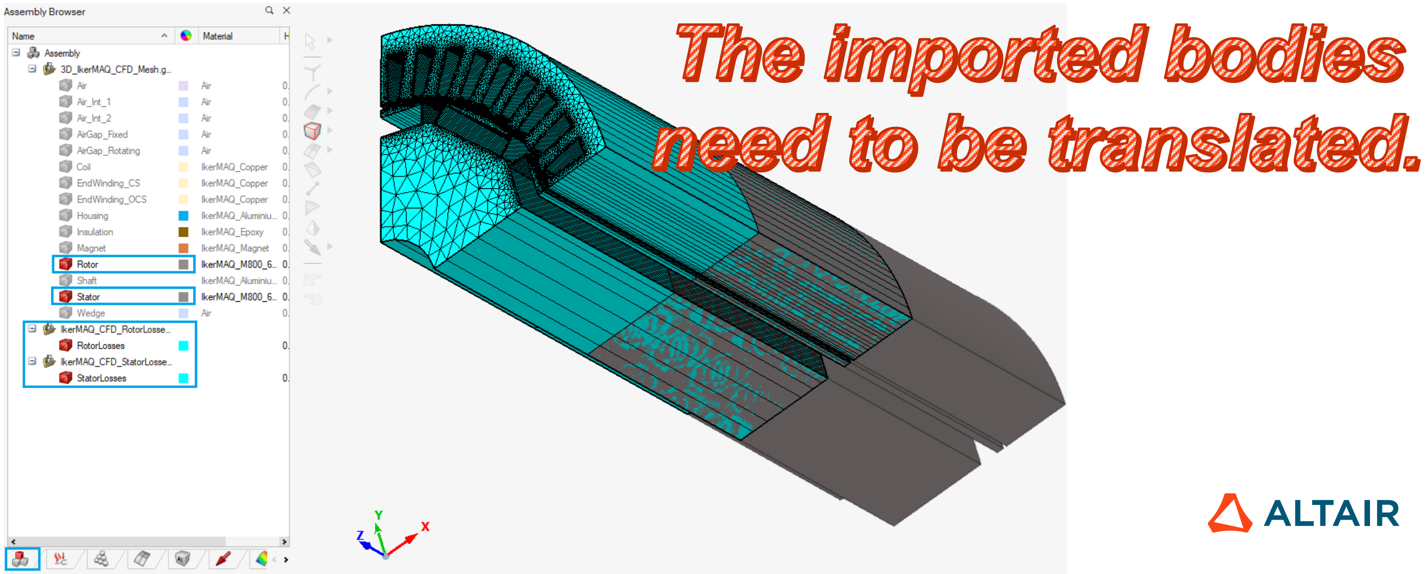
3D CFD ANALYSIS

CFD Solution Setup

- Define **Flow Domain:** *Heat Source (nodal mapping)*
  - Loss import: stator and rotor losses
    - Visualize both the import bodies (stator and rotor losses) and the original bodies to check if the bodies are well covered



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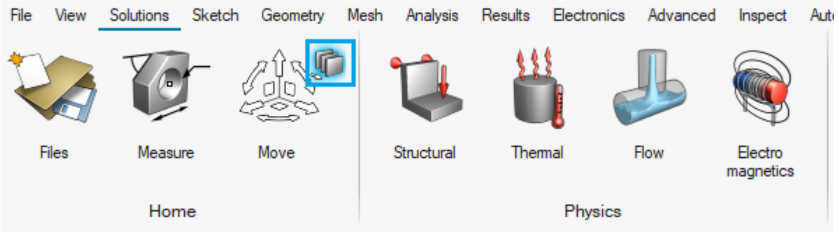
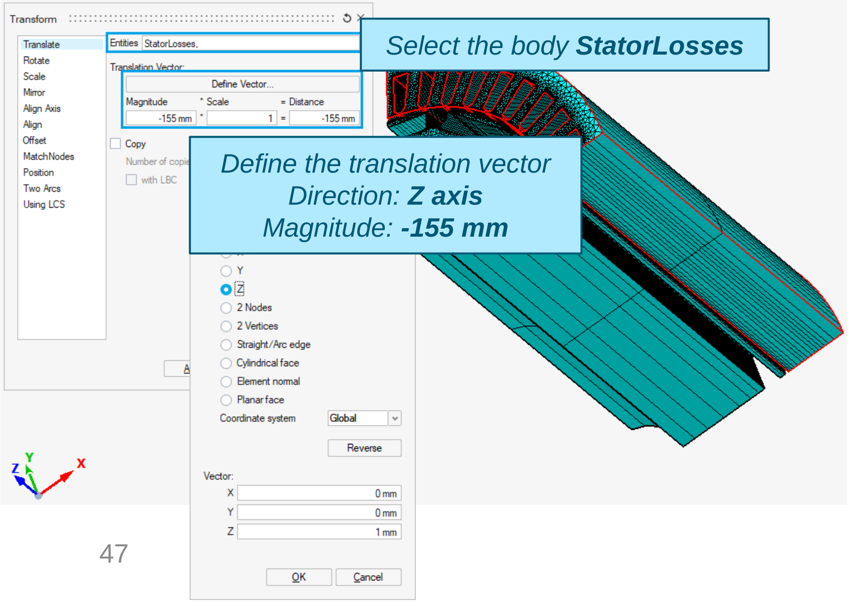
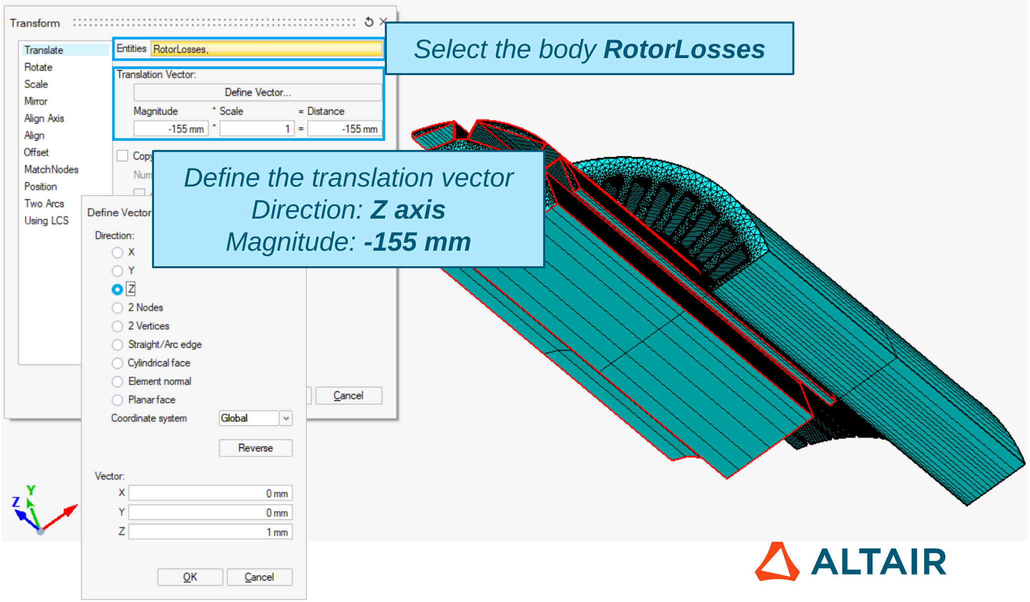
3D CFD ANALYSIS

CFD Solution Setup



- Define **Flow Domain:** *Heat Source (nodal mapping)*
  - Loss import: stator and rotor losses
    - Translate respectively the imported bodies (stator and rotor losses)

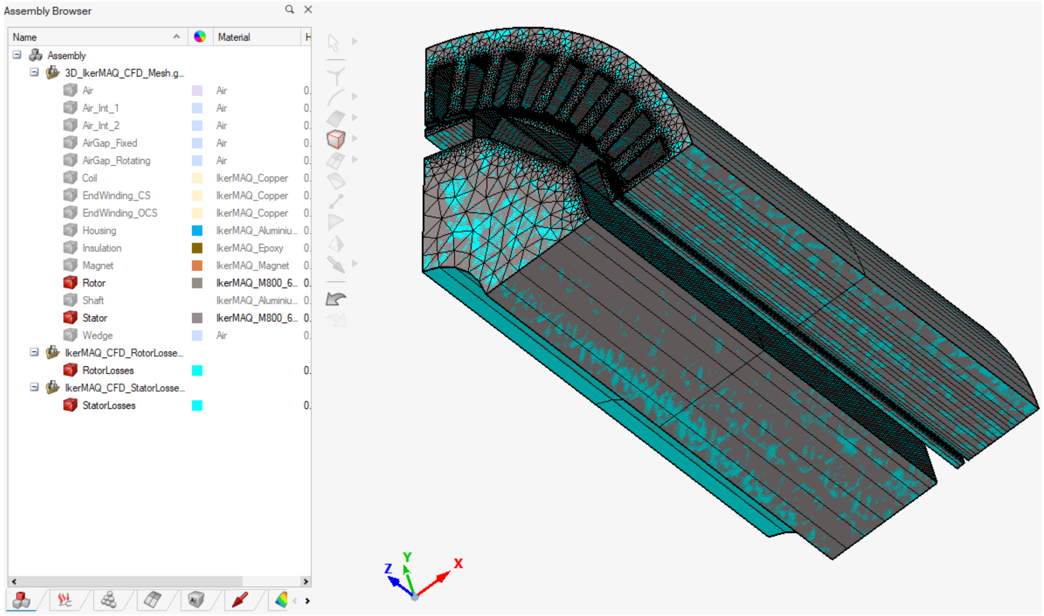




3D CFD ANALYSIS

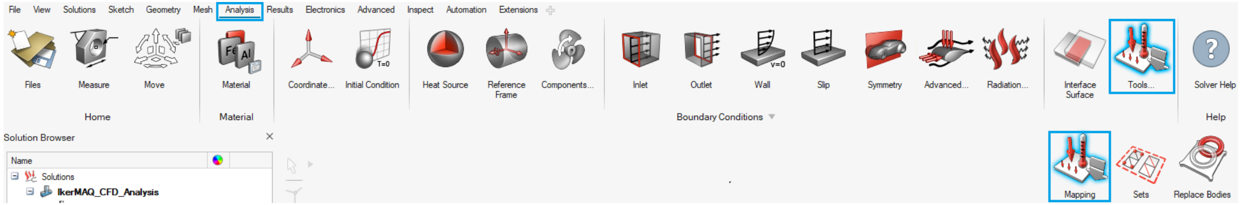
CFD Solution Setup

- Define **Flow Domain:** *Heat Source (nodal mapping)*
  - Loss import: stator and rotor losses
    - Translate respectively the imported bodies (stator and rotor losses)

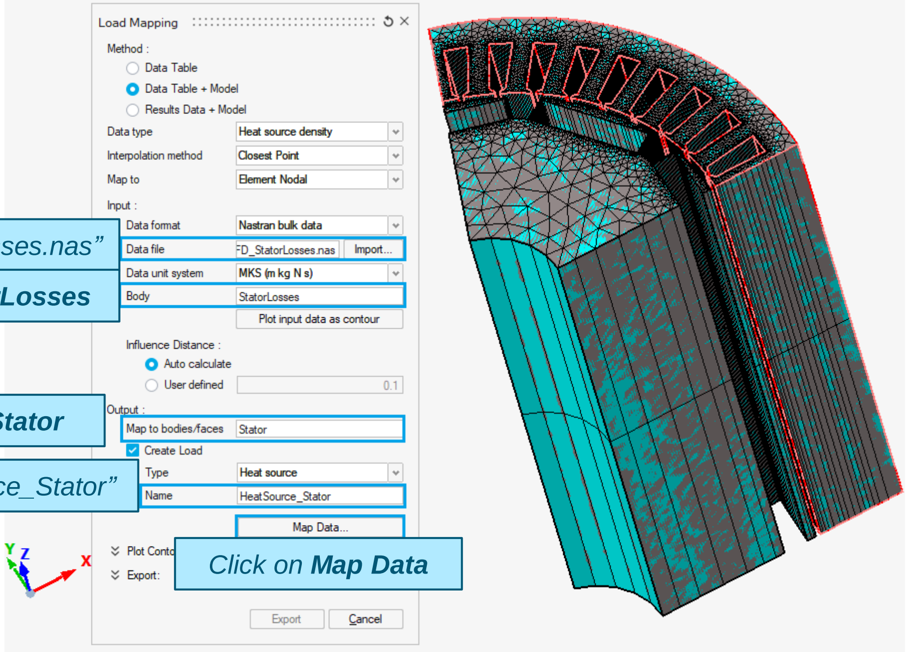


3D CFD ANALYSIS

CFD Solution Setup



- Define **Flow Domain:** *Heat Source (nodal mapping)*
  - Loss mapping: stator losses
    - [Analysis] – [Tools] – [Mapping]



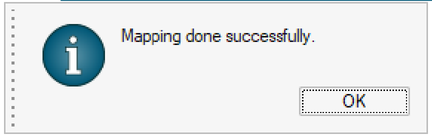
Select the loss file "IkerMAQ_CFD_StatorLosses.nas"

Select the imported body ***StatorLosses***

Select the body to be mapped: ***Stator***

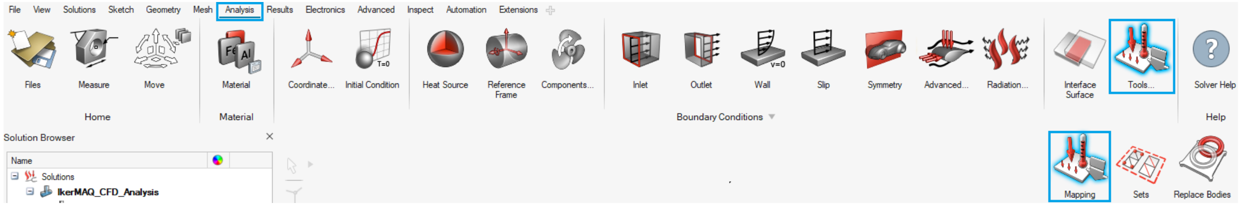
Define the generated result name: "HeatSource_Stator"

Click on ***Map Data***



3D CFD ANALYSIS

CFD Solution Setup



- Define **Flow Domain:** *Heat Source (nodal mapping)*
  - Loss mapping: rotor losses
    - [Analysis] – [Tools] – [Mapping]

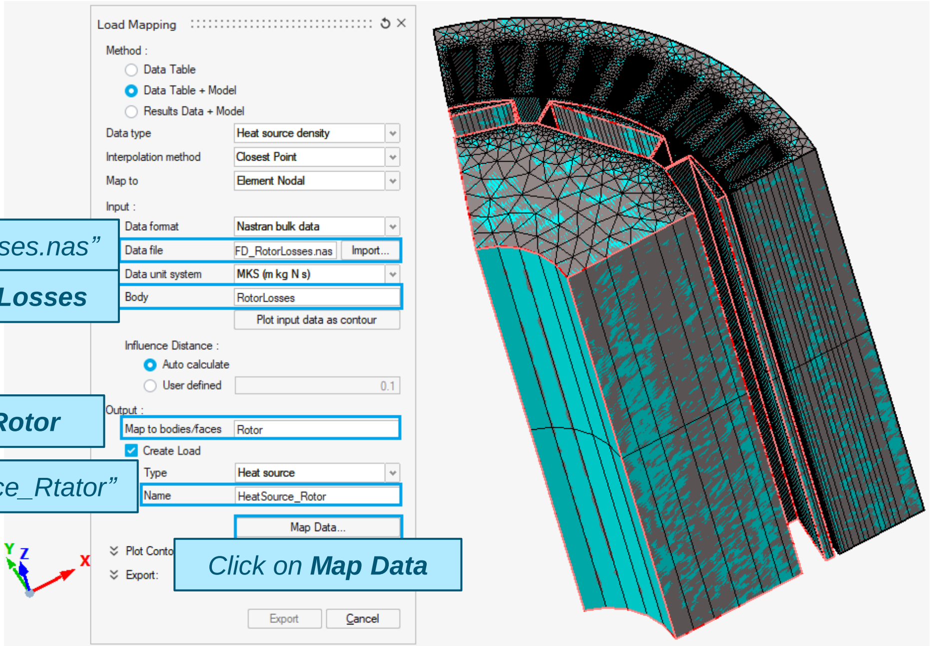
Select the loss file "IkerMAQ_CFD_RotorLosses.nas"

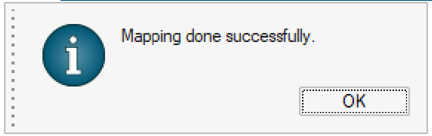
*Select the imported body **RotorLosses***

*Select the body to be mapped: **Rotor***

Define the generated result name: "HeatSource_Rtator"

*Click on **Map Data***

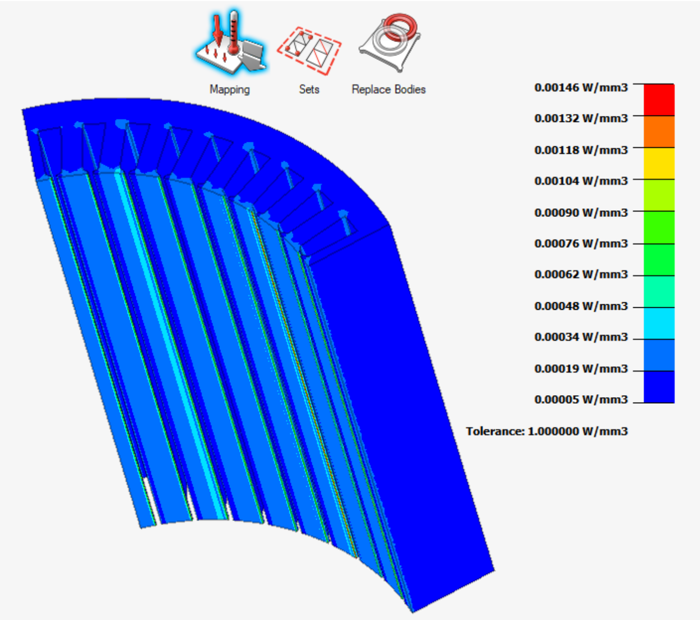


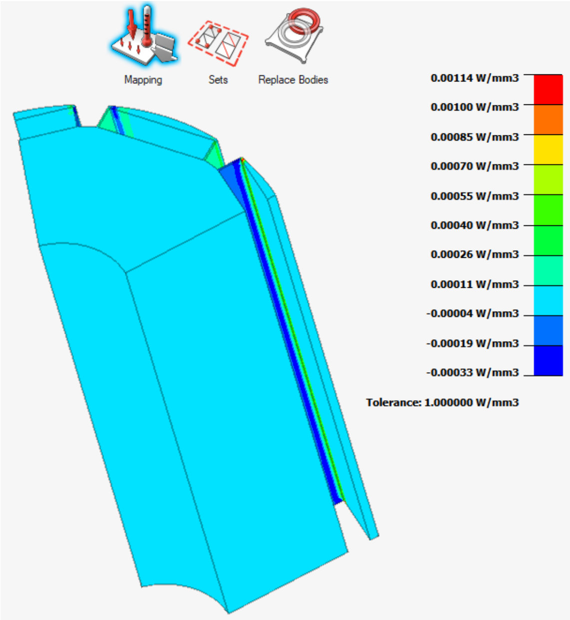


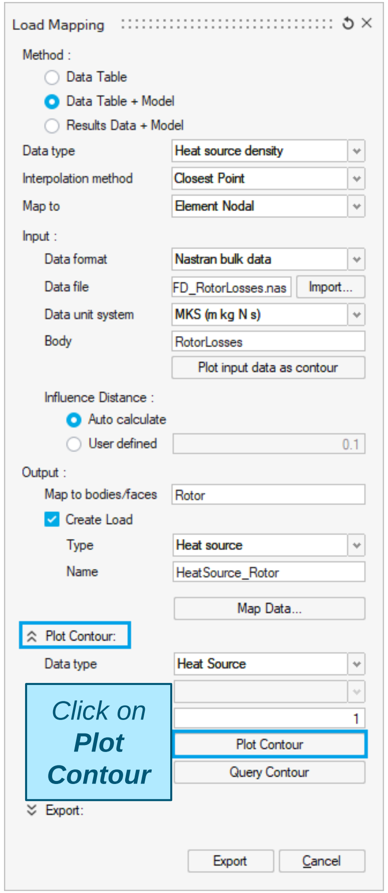
3D CFD ANALYSIS

CFD Solution Setup

- Define **Flow Domain:** *Heat Source (nodal mapping)*
  - Loss mapping: stator and rotor losses
    - Visualize mapping results



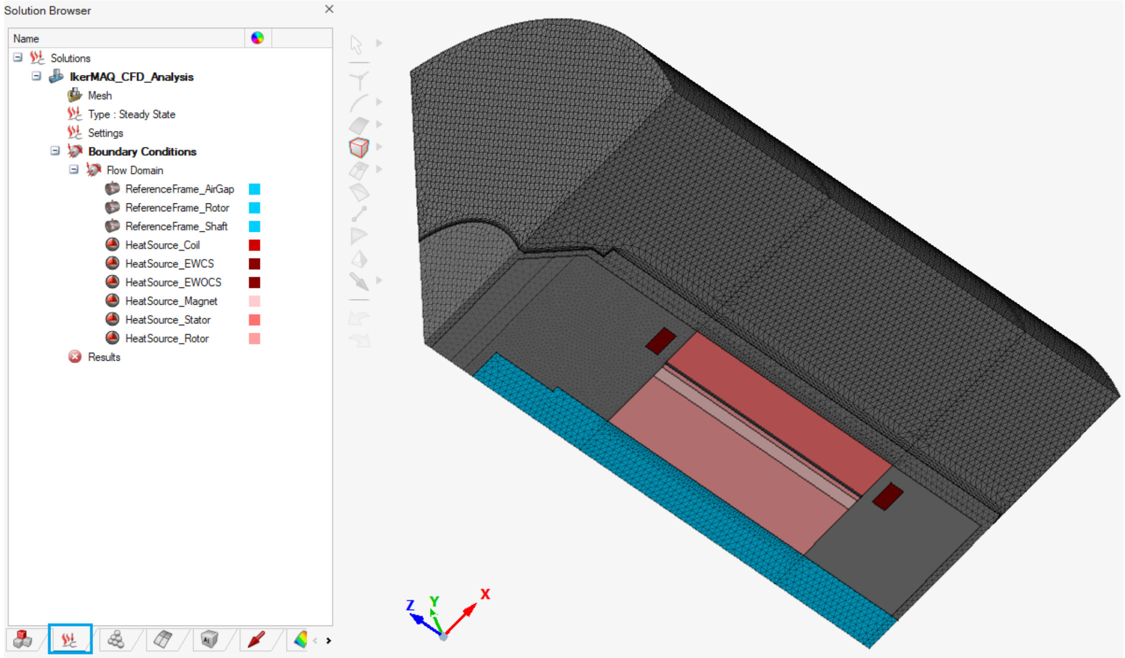




3D CFD ANALYSIS

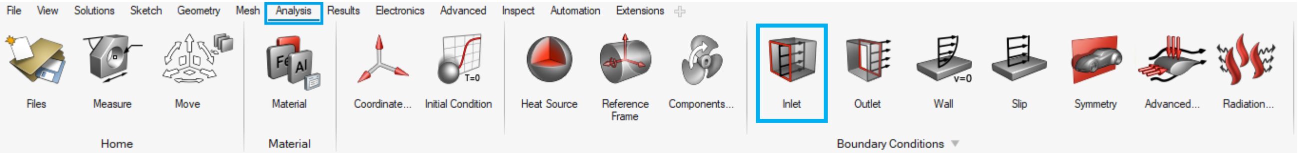
CFD Solution Setup

- Define **Flow Domain**
  - *Reference Frames + Heat Sources (total loss value + nodal mapping)*

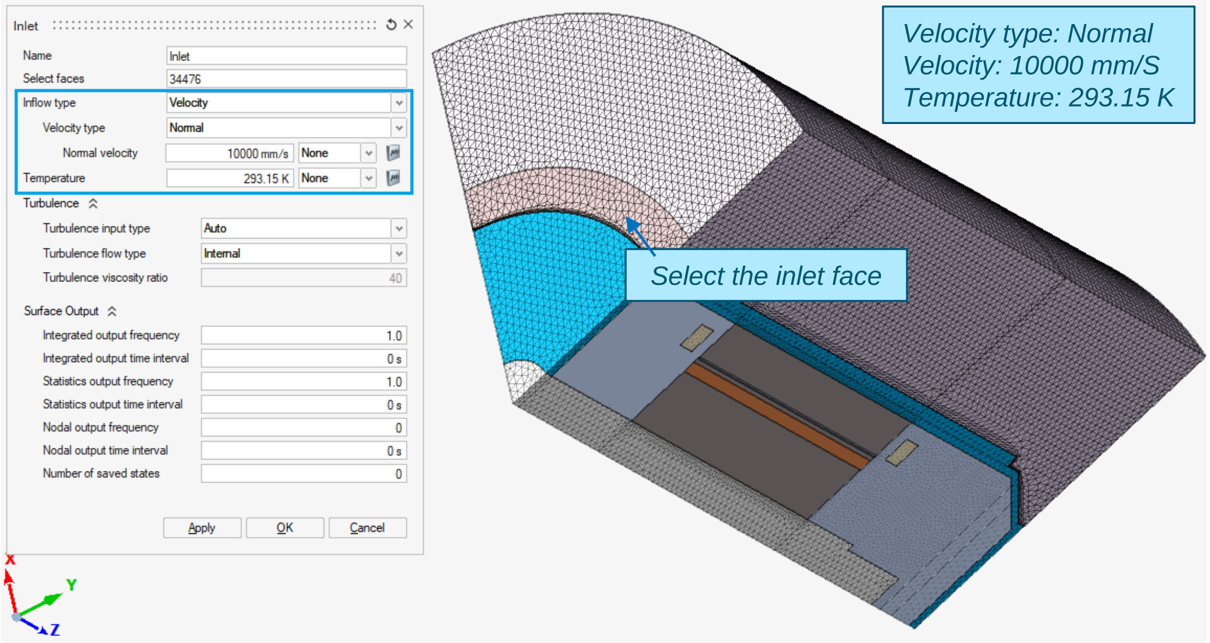


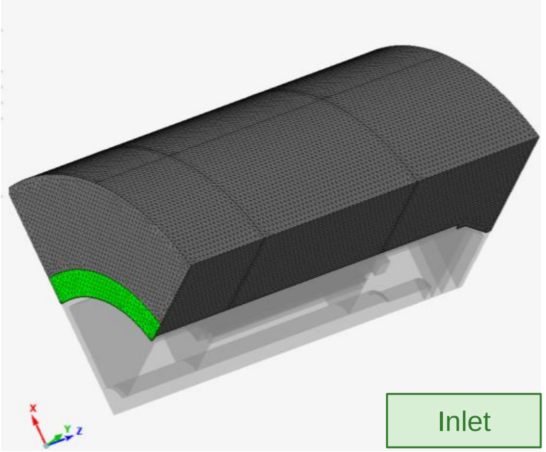
3D CFD ANALYSIS

CFD Solution Setup



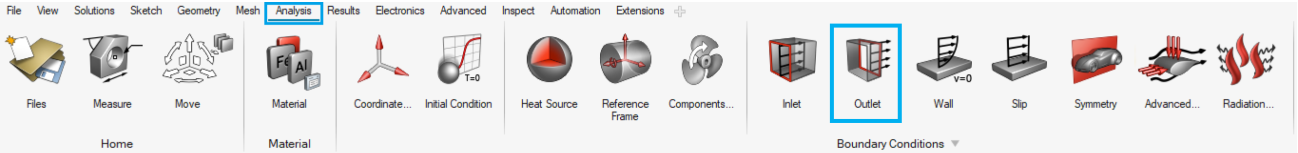
- Define **Flow Boundaries:** *Inlet*
  - [Analysis] – [Inlet]



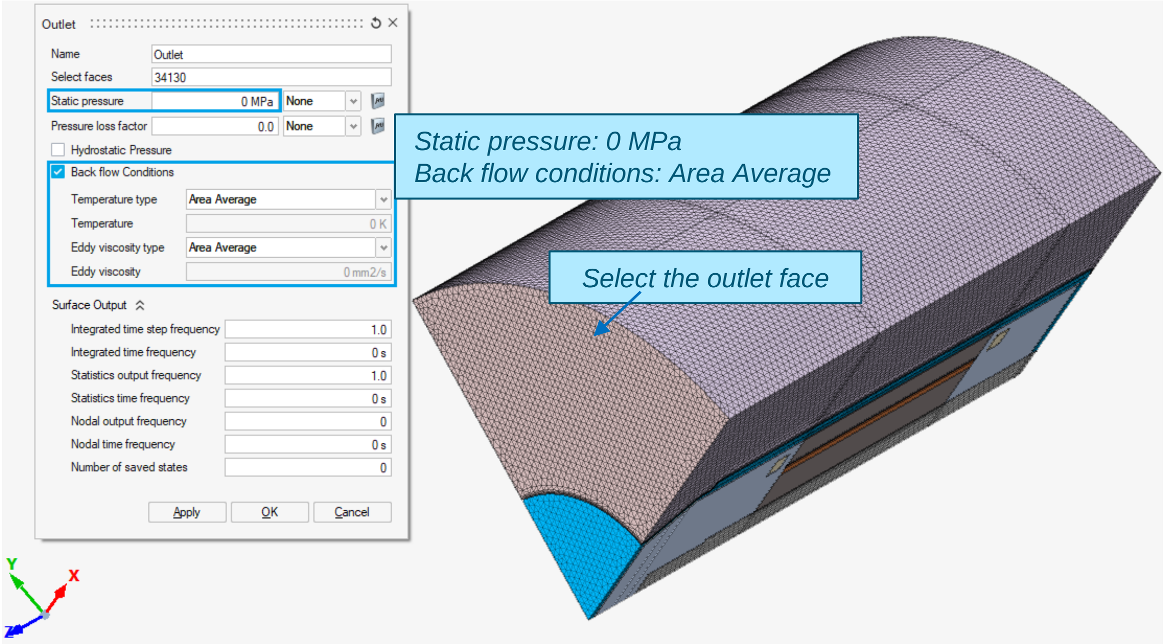


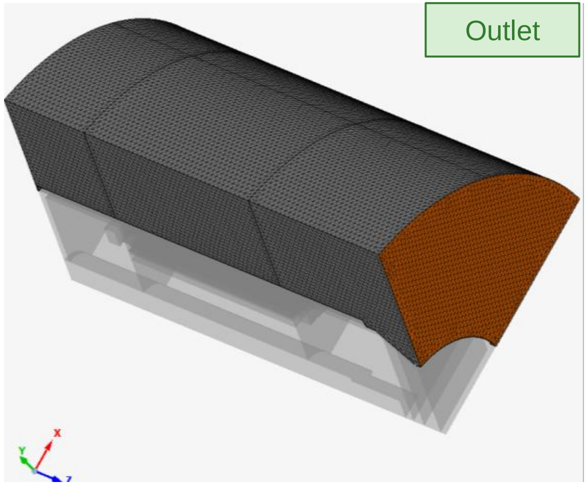
3D CFD ANALYSIS

CFD Solution Setup



- Define **Flow Boundaries:** *Outlet*
  - [Analysis] – [*Outlet*]





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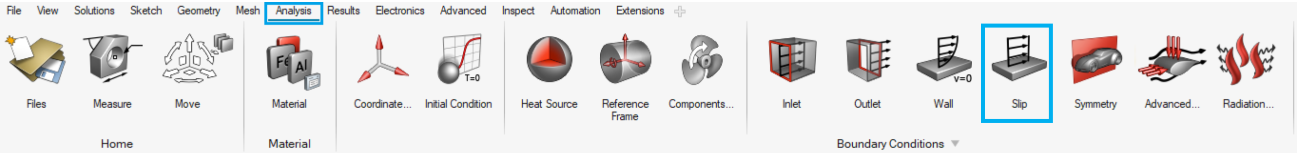
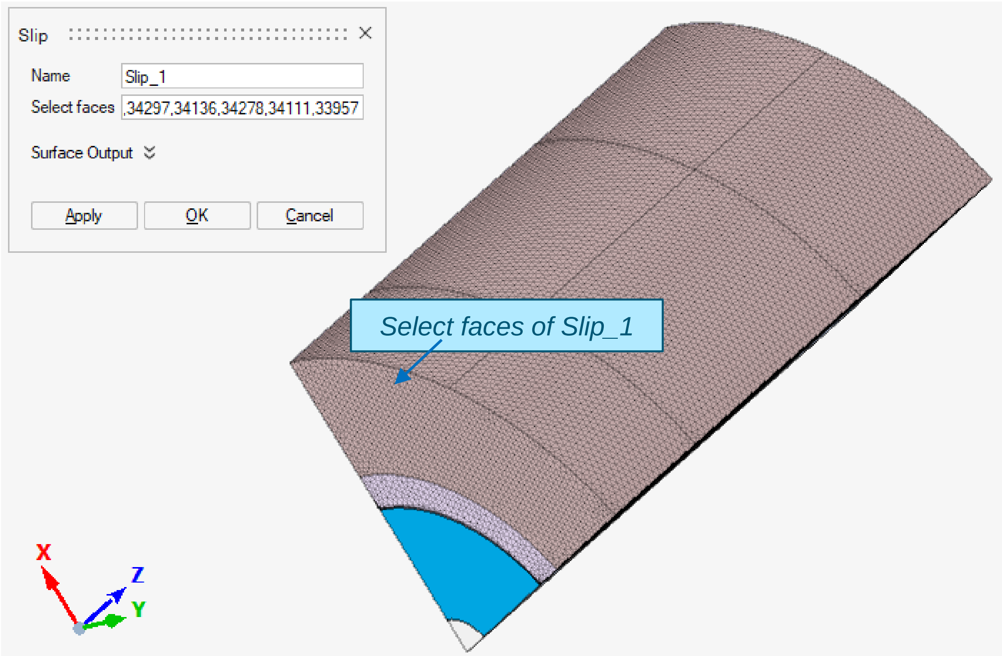
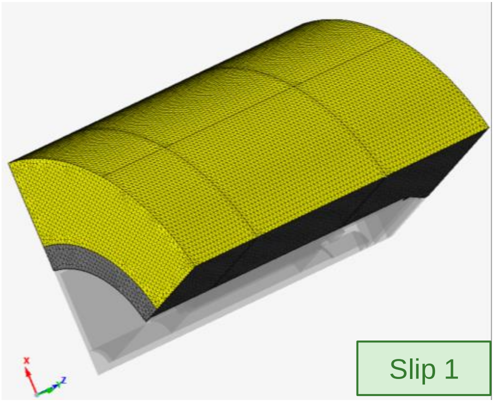
3D CFD ANALYSIS

CFD Solution Setup



- Define **Flow Boundaries:** *Slip*
  - [Analysis] – [*Slip*]
    - Slip 1





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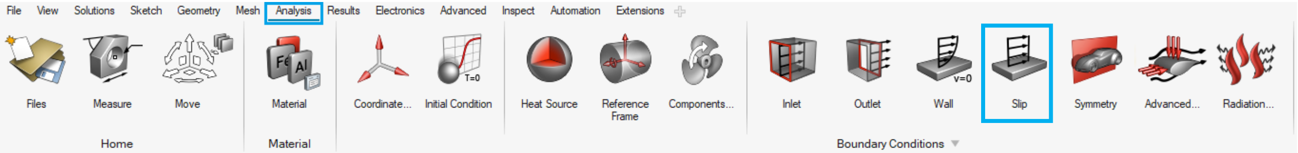
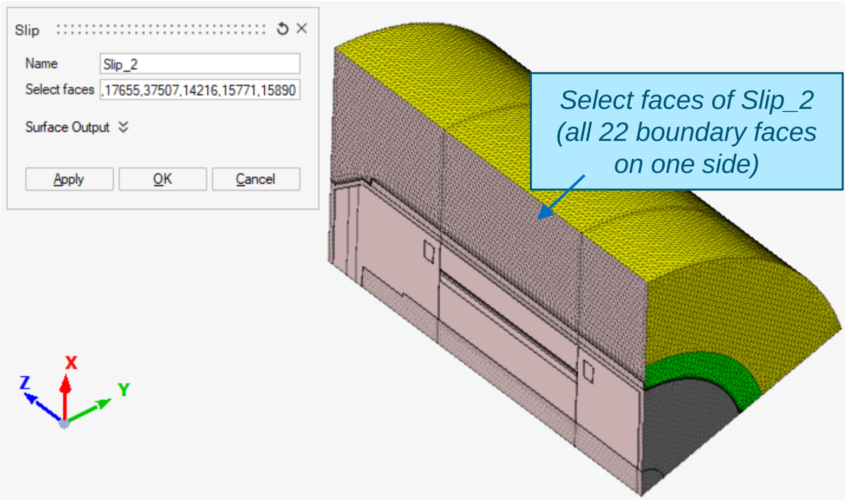
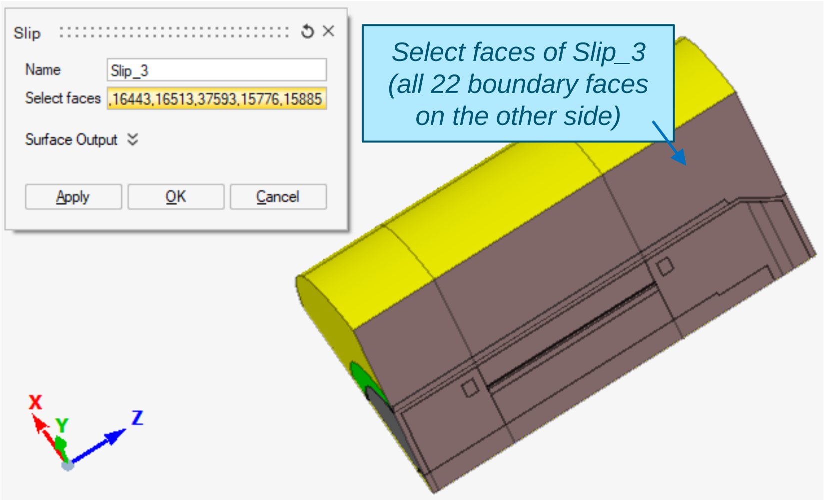
3D CFD ANALYSIS

CFD Solution Setup



- Define **Flow Boundaries:** *Slip*
  - [Analysis] – [*Slip*]
    - Slip 2 and 3





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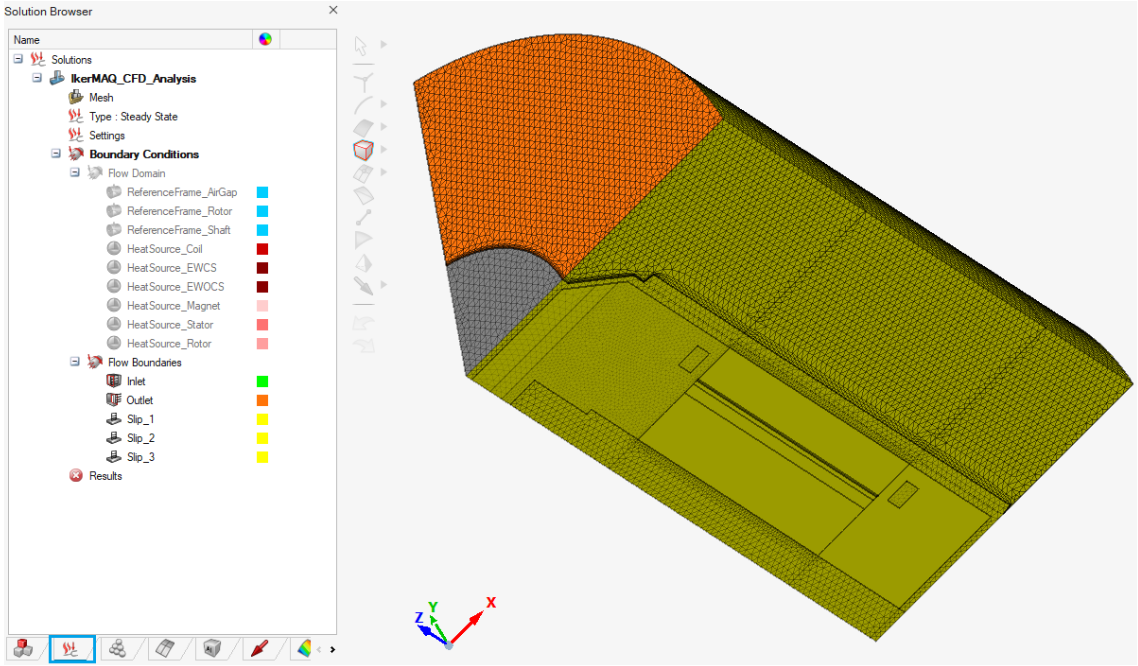
3D CFD ANALYSIS

CFD Solution Setup

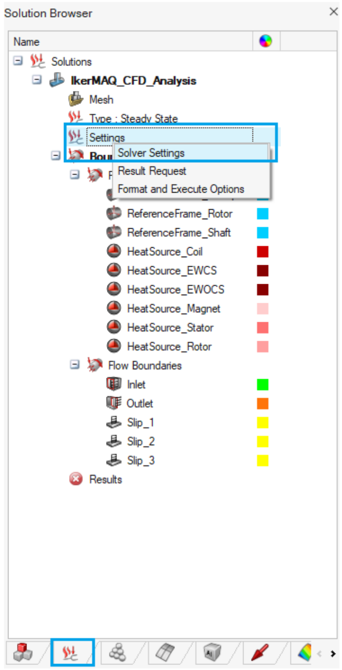
- Define **Flow Boundaries**
  - *Inlet + Outlet + Slip*

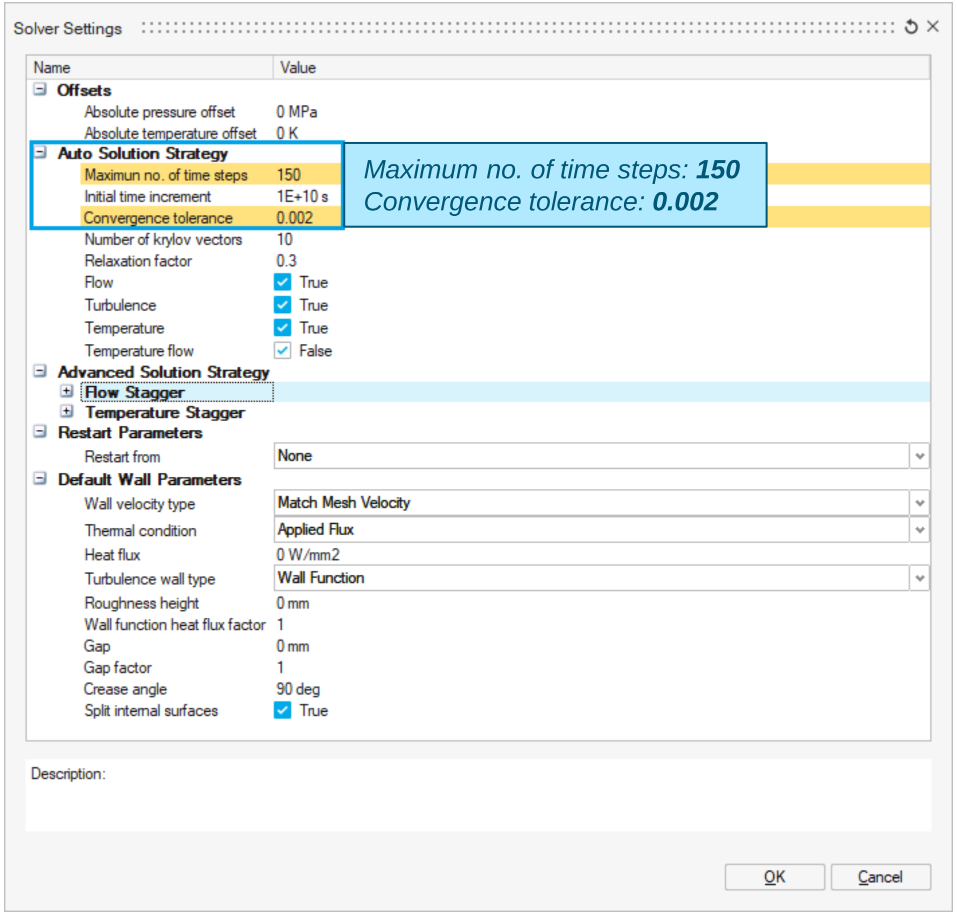


3D CFD ANALYSIS

CFD Solution Setup

- Define **Solution Settings**
  - Define **Solver Settings**

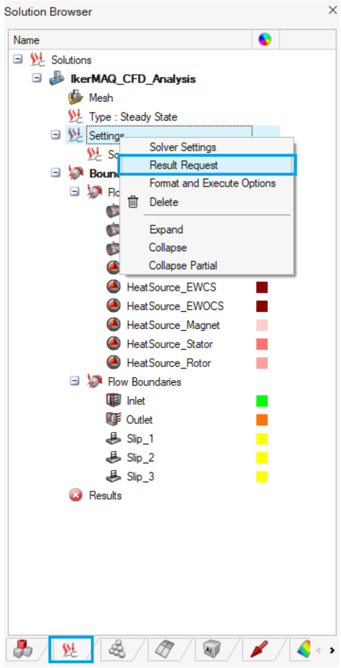


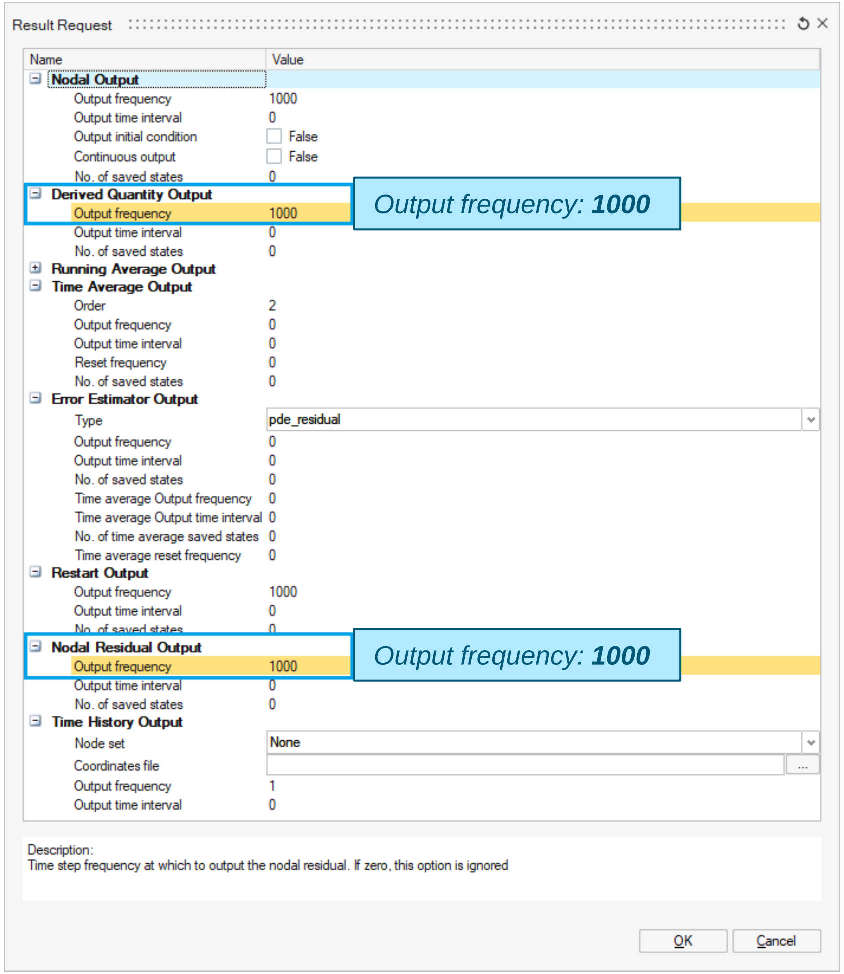


3D CFD ANALYSIS

CFD Solution Setup

- Define **Solution Settings**
  - Define **Result Request**

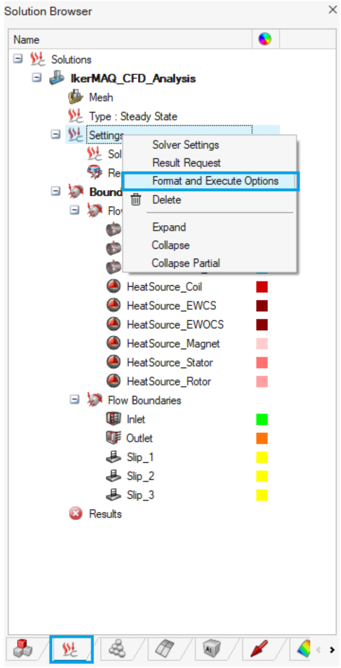


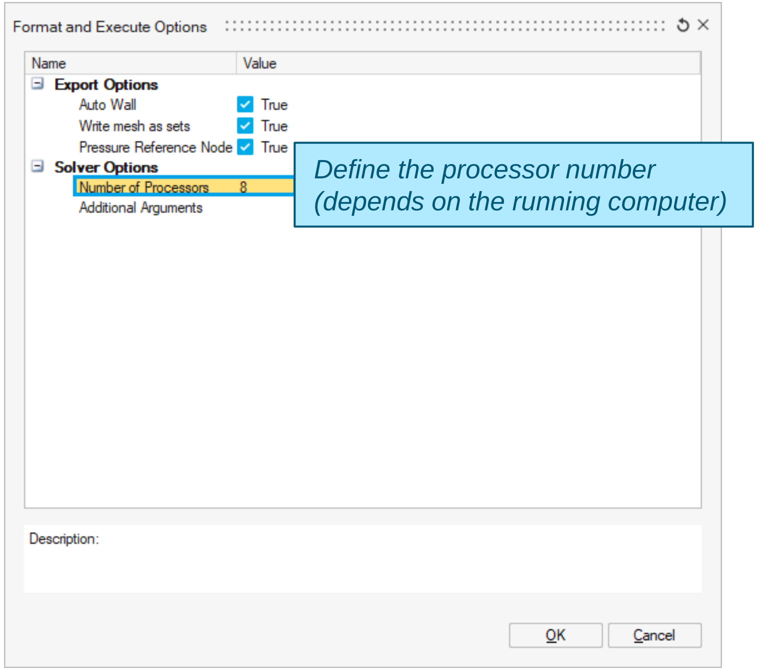


3D CFD ANALYSIS

CFD Solution Setup

- Define **Solution Settings**
  - Define **Format and Execute Options**

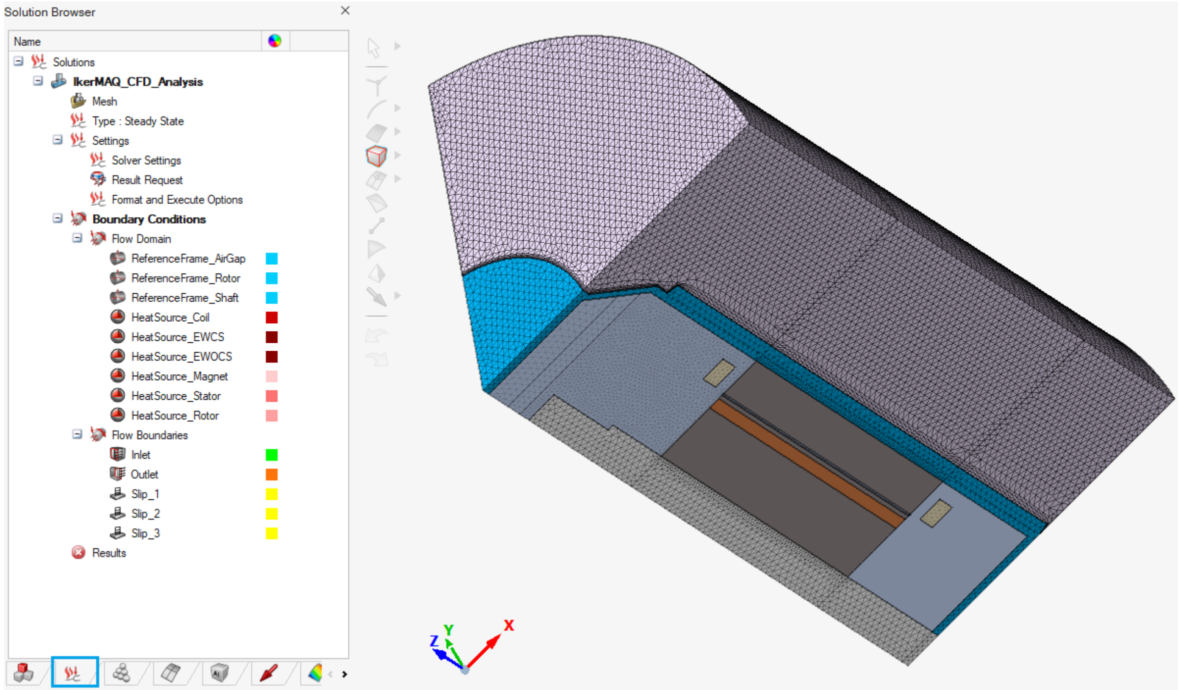




3D CFD ANALYSIS

CFD Solution Setup

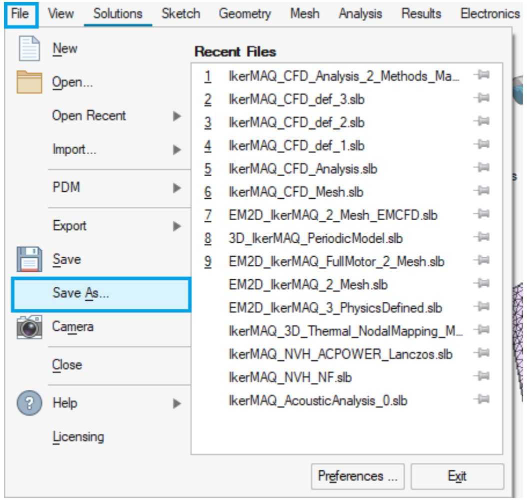
- Final CFD solution setup
  - *Flow Domain + Flow Boundaries + Solver Settings*

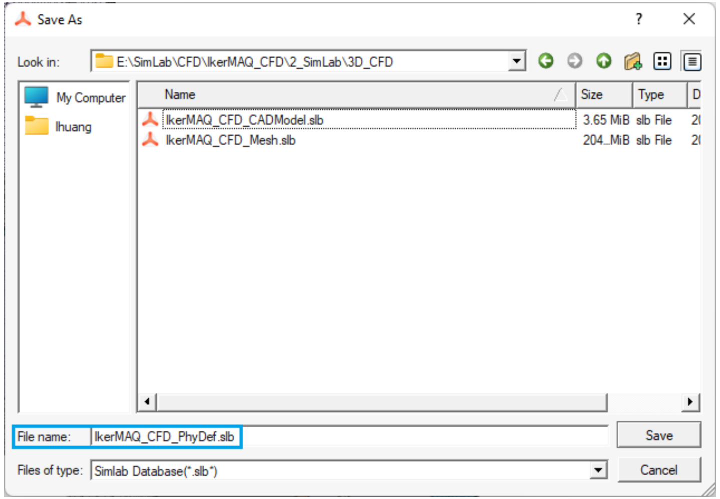


3D CFD ANALYSIS

CFD Solution Setup

- Final CFD solution setup
  - Save the project [File] – [Save As]
    - Save the project as “IkerMAQ_CFD_PhyDef”





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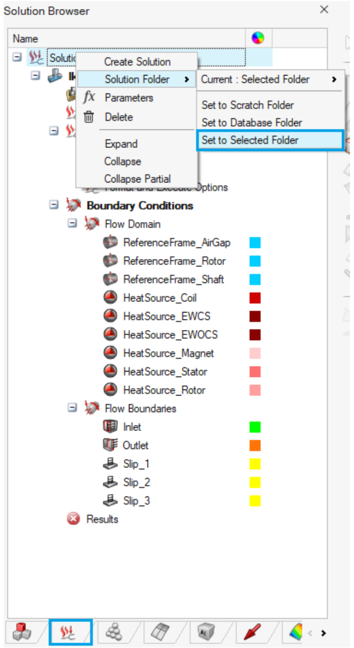
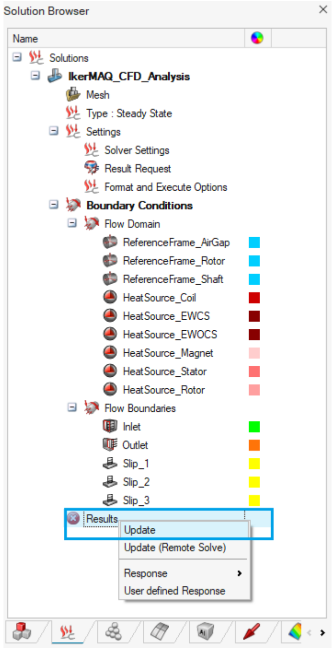
3D CFD ANALYSIS

CFD Solution Setup

- Solve the CFD simulation project
  - Right click on the “Solutions” and select the solving folder for AcuSolve





☞Notes:

The solving process takes about 45 min depending on the computer on which it is run.

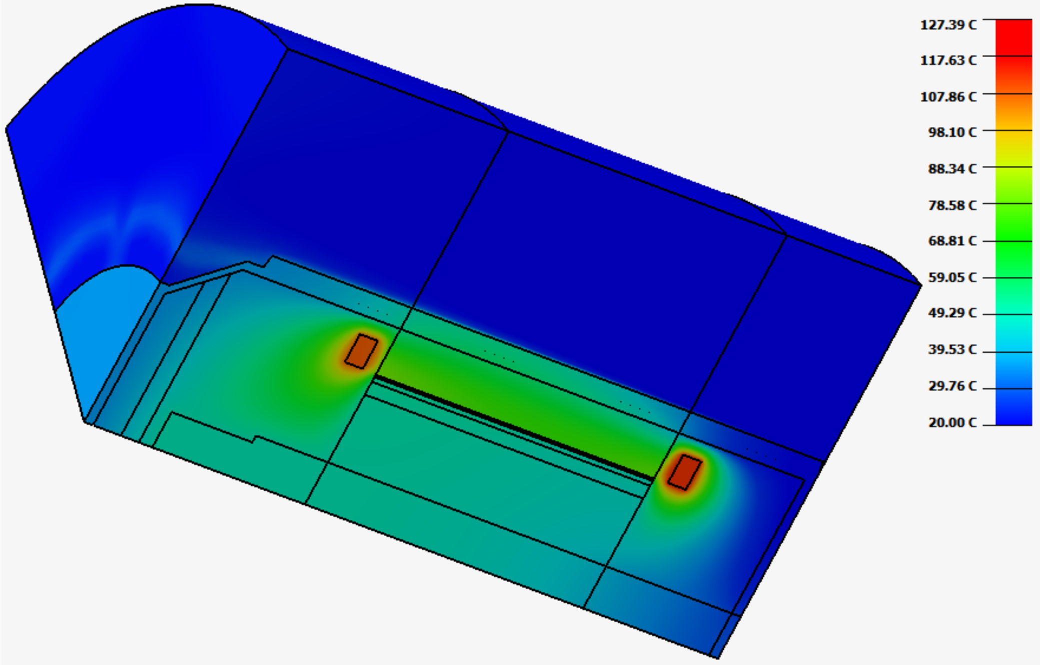
Results means that the solving process is completed

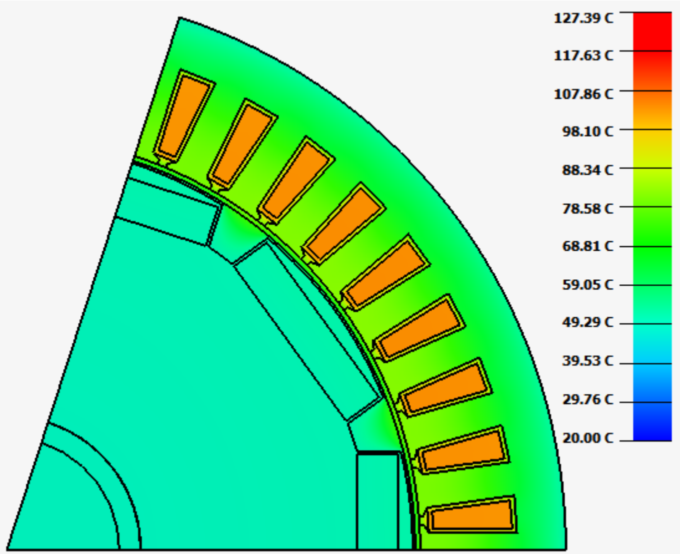
Results means that the solving process is in progress

3D CFD ANALYSIS

CFD Solution Setup

- Solve the CFD simulation project
  - Temperature distribution





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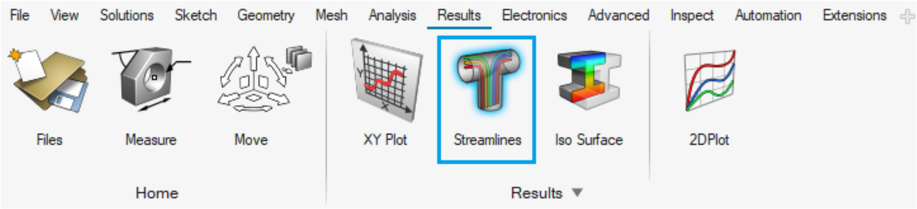
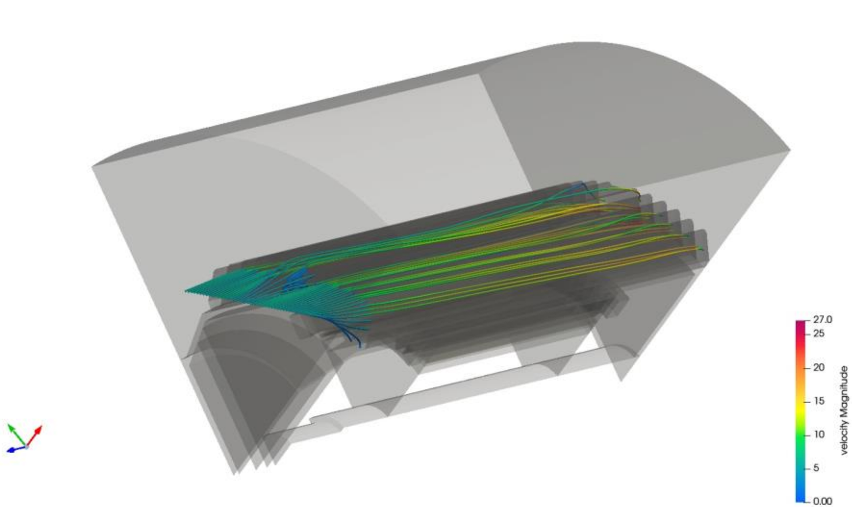
3D CFD ANALYSIS

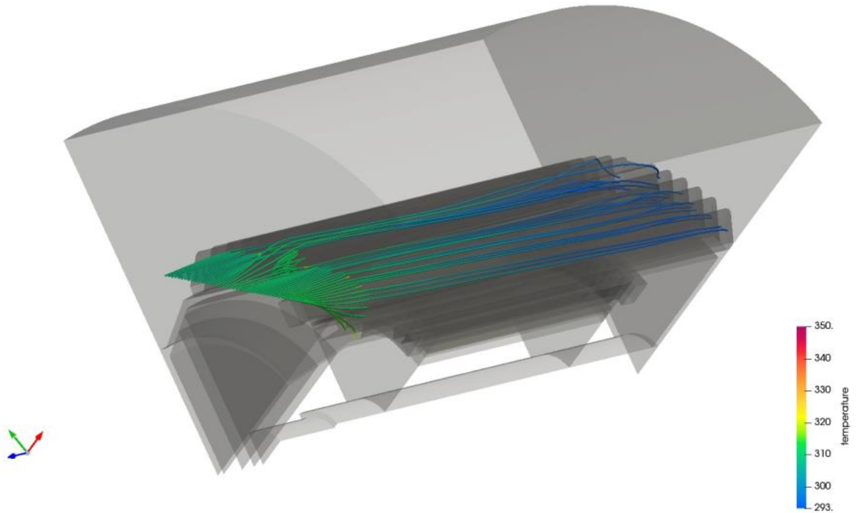
CFD Solution Setup

- Solve the CFD simulation project
  - Streamline results





Flow velocity



Temperature

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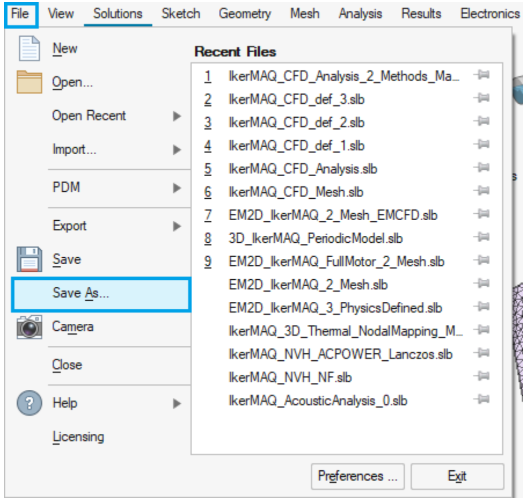
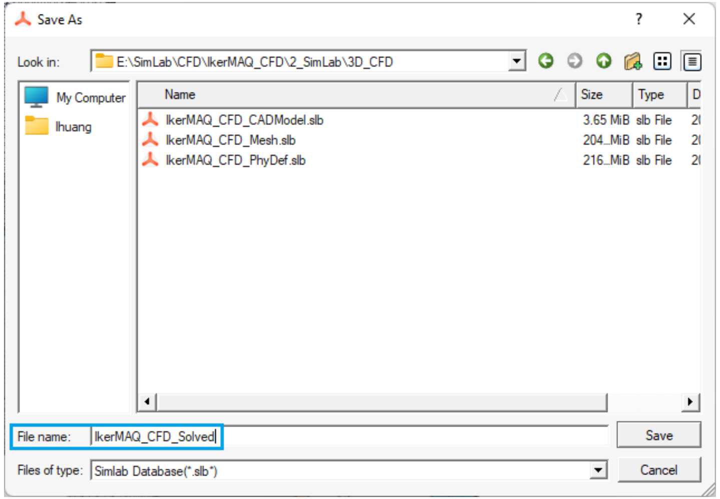
3D CFD ANALYSIS

CFD Solution Setup

- Solve the CFD simulation project
  - Save the project [File] – [Save As]
    - Save the project as “IkerMAQ_CFD_Solved”





CONCLUSION

CONCLUSION

- In this application case, a **P**ermanent **M**agnet **S**ynchronous **M**achine (IkerMAQ motor) is modeled in **Flux** for 2D electromagnetic analysis.
- All the eMotor loss information computed by **Flux** serve as Heat Source in **AcuSolve** to run CFD analysis.
- The eMotor CFD analysis is simulated with **AcuSolve** (via **SimLab**) .Preliminary CFD analysis results are reasonable. The temperature simulation results are close to the actual values.

THANK YOU

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