How to Model Lorentz Force in Solids and Magnetohydrodynamics

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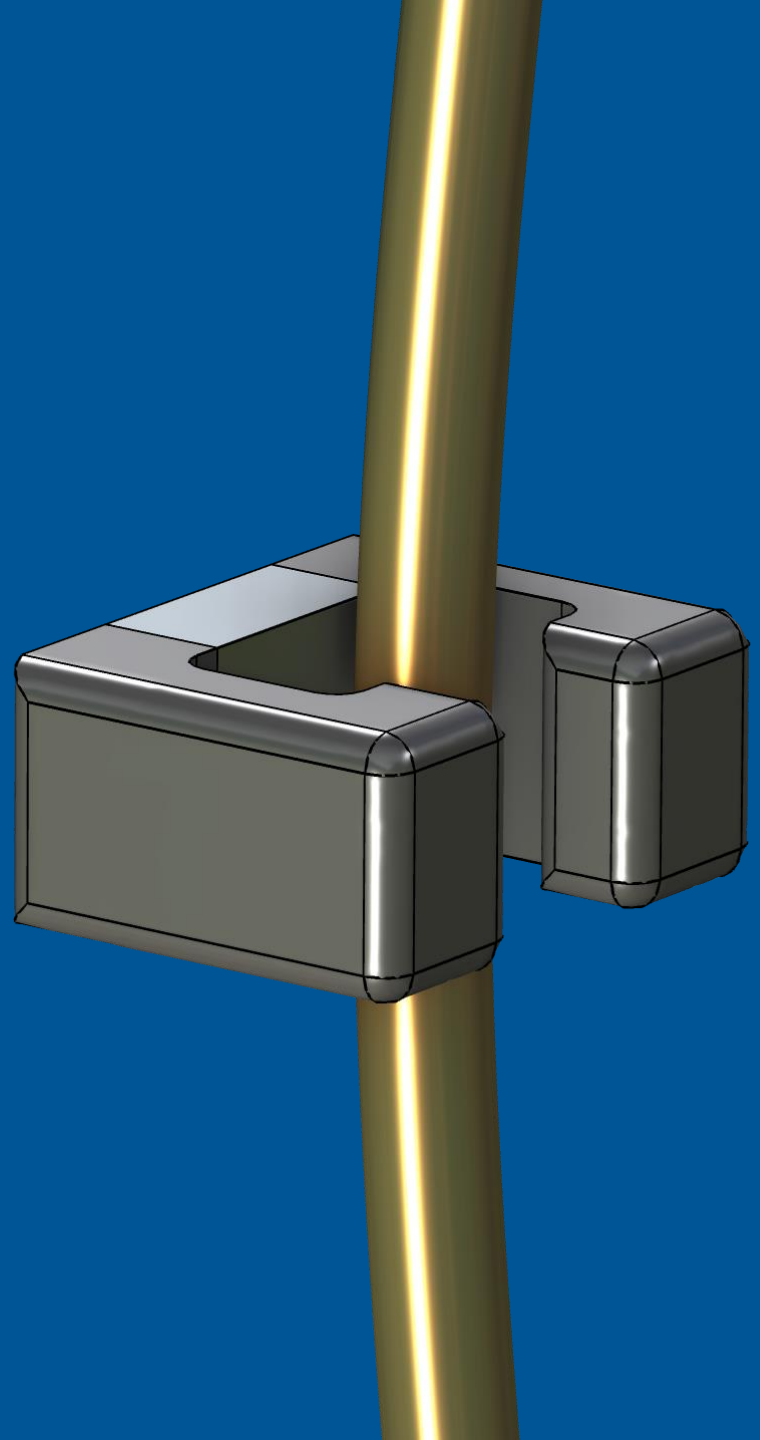
Schedule

1. ML: AC/DC Module Coupling Overview
2. ML: Magnetomechanics
3. ML: EM Force Demo Model
4. TV: Magnetohydrodynamics
5. TV: Demo Magnetohydrodynamics
6. TV: Experiment Magnetohydrodynamics

Magnetomechanics

Matouš Lorenc

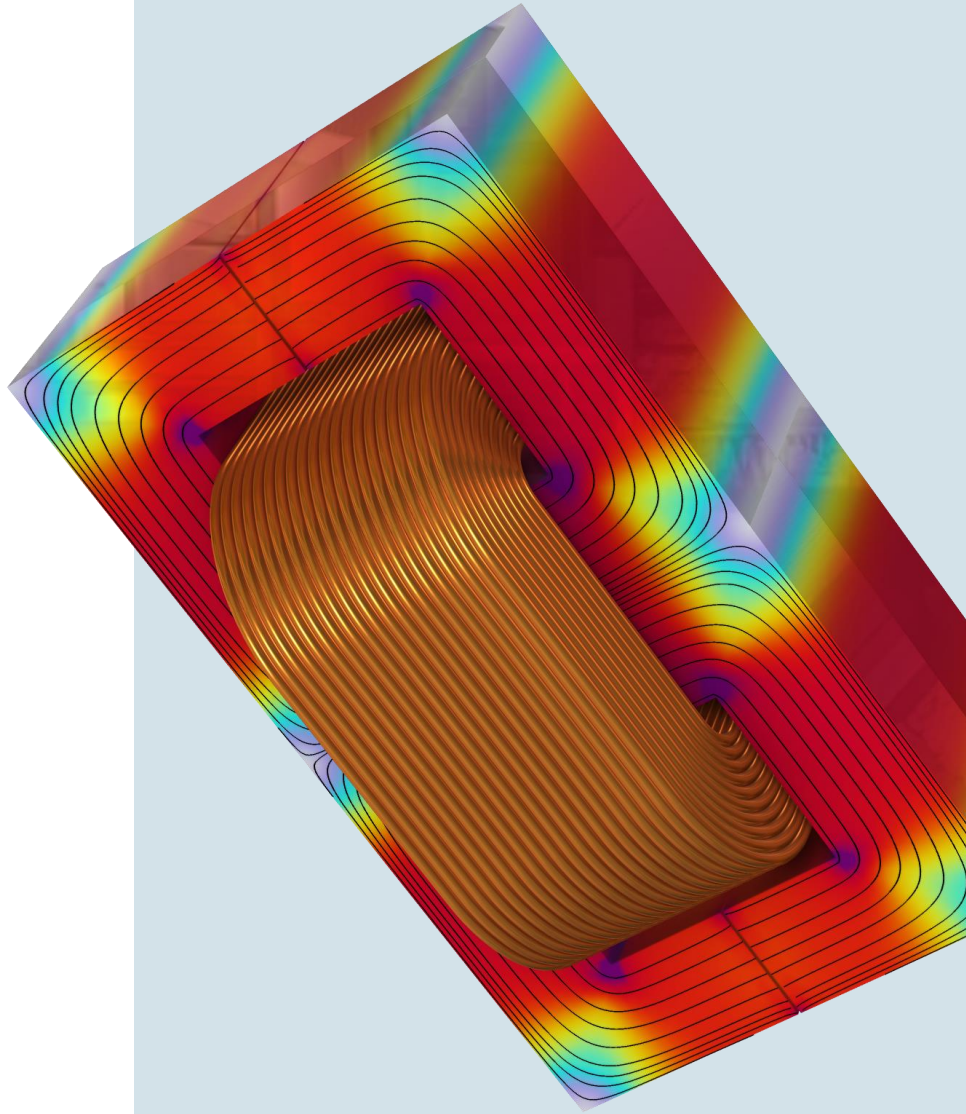


AC/DC Module:
Low Frequency Electromagnetics

- This is the frequency range where…
  - Resistive
  - Capacitive
  - Inductive

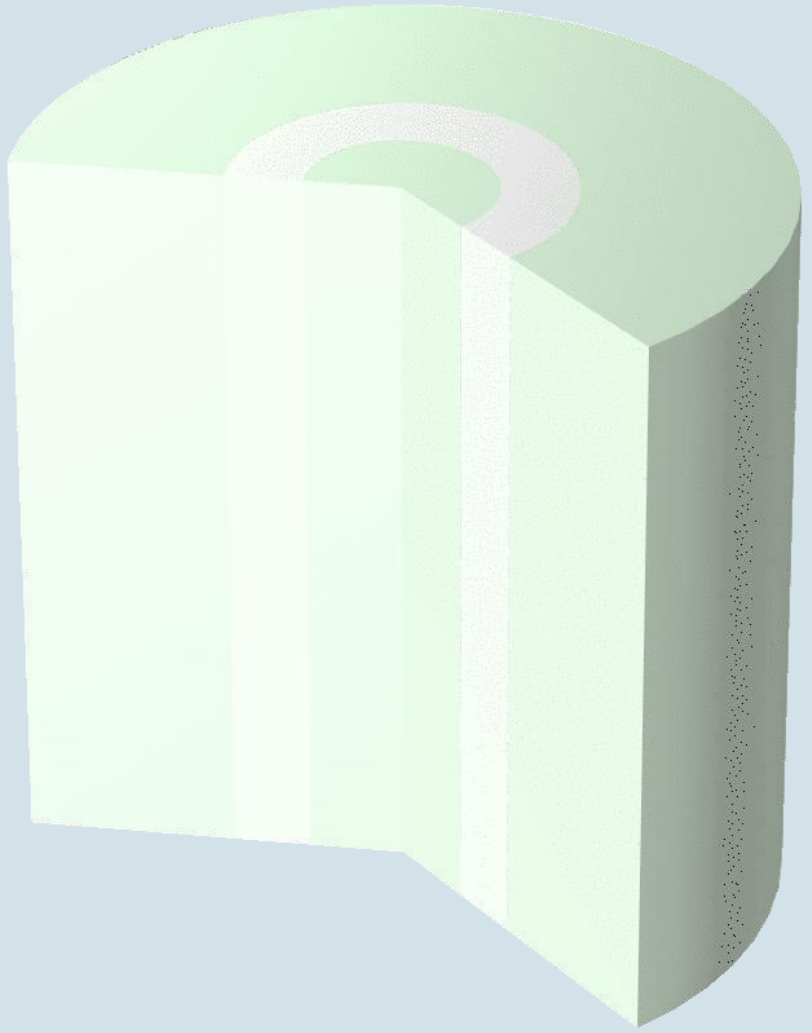
…effects are significant, but where wave phenomena are still negligible.

- Typical devices are: *heaters, busbars, transformers, motors, generators, cables, HV systems, power lines, circuit boards (PCB), switches, consumer electronics, automotive components, and superconductors*.



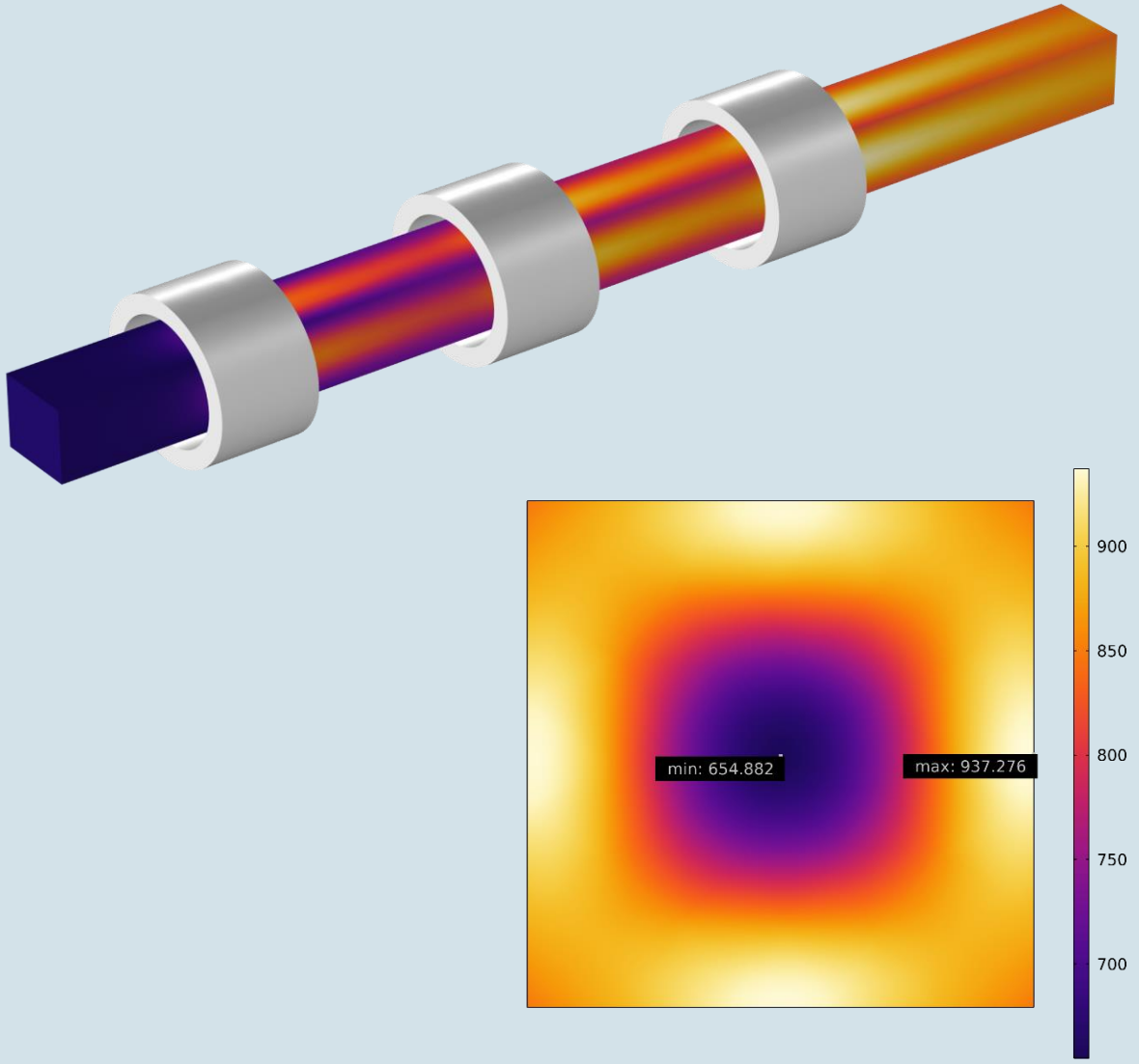
Multiphysics Couplings: CFD

- Magnetohydrodynamics



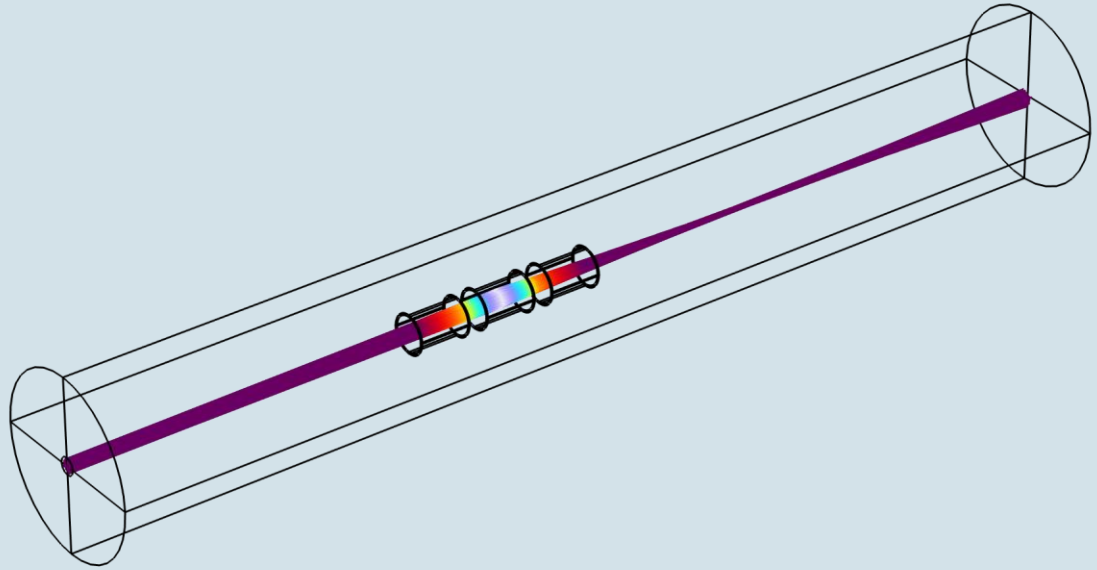
Multiphysics Couplings: Heat

- Joule Heating
  - Joule Heating with Thermal Expansion
- Inductive Heating
- Pyroelectricity



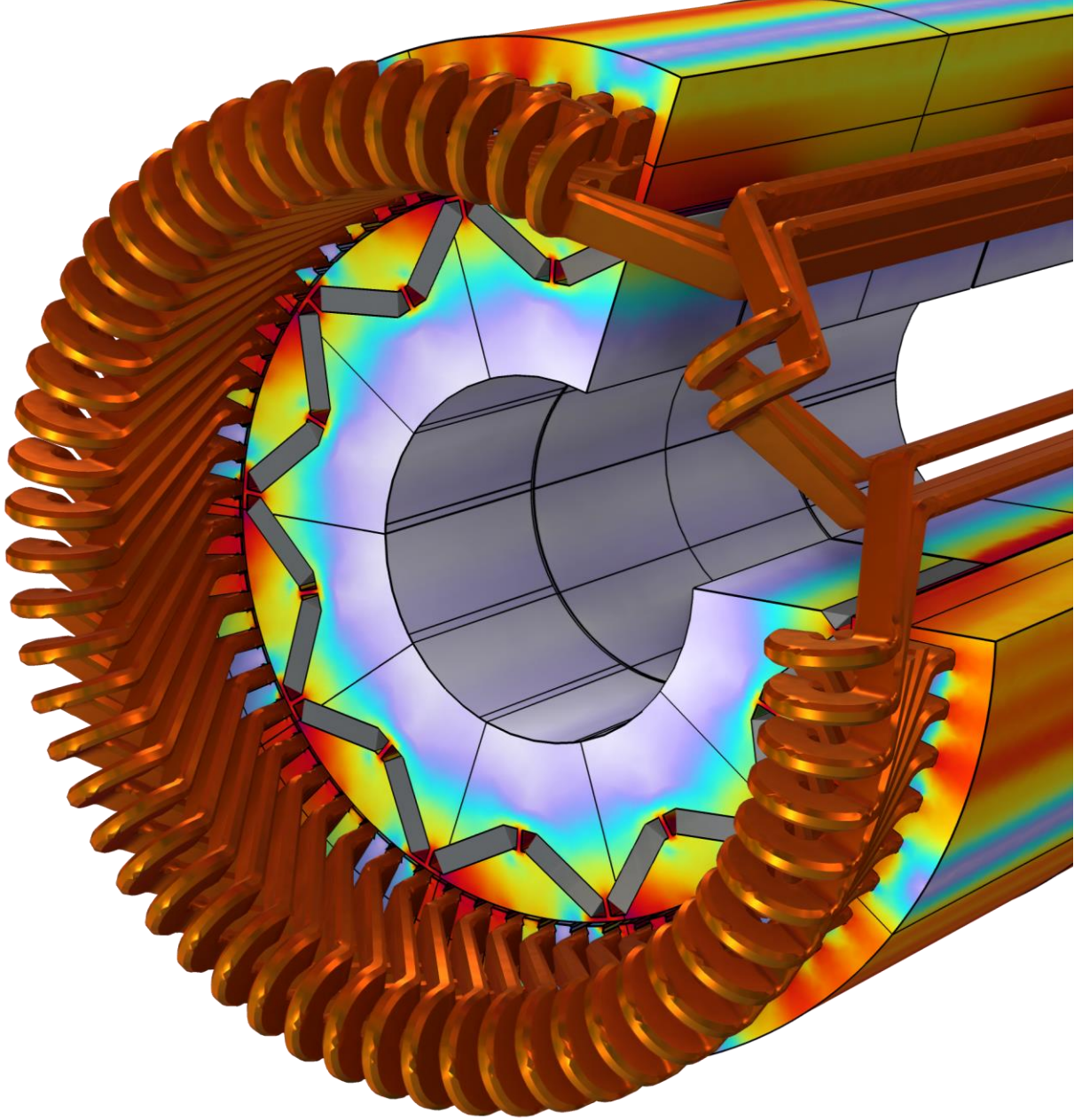
Multiphysics Couplings: Particle Tracing

- Charged Particle Tracing
- Particle-Field Interaction
  - Relativistic
  - Non-relativistic



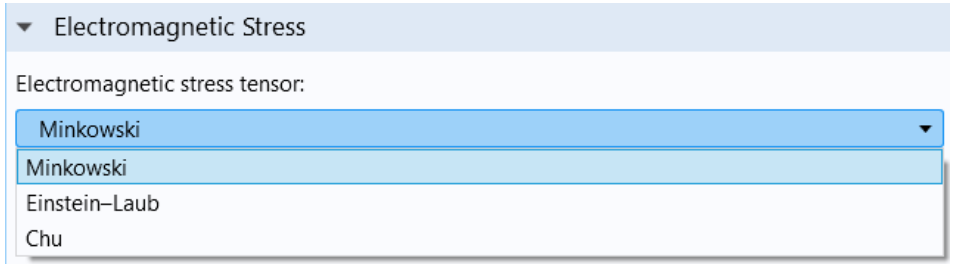
Multiphysics Couplings: Mechanics

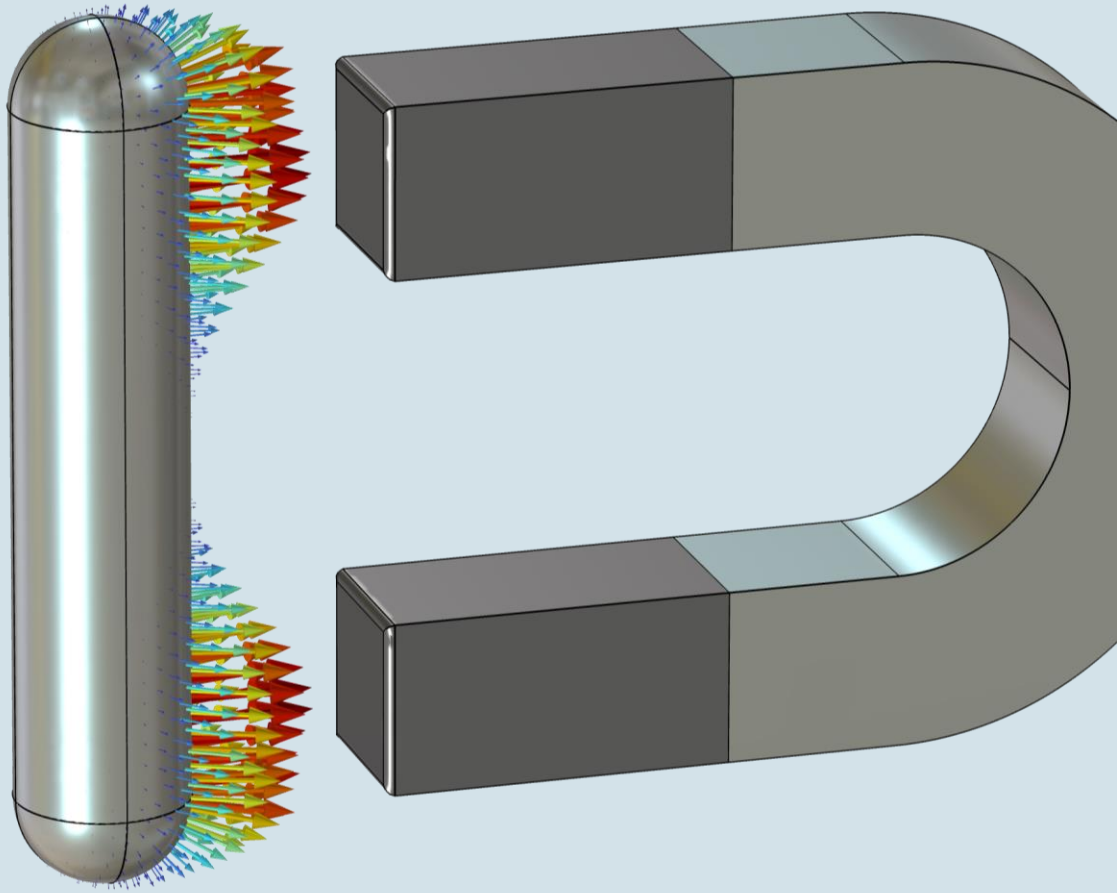
- Electromechanics
- Piezoelectricity
- Piezoresistivity
- Electrostriction
- Ferroelectricity
- Nonlinear Magnetostriction
- Piezomagnetism
- Rotating Machinery
- **Magnetomechanics**



Magnetomechanics

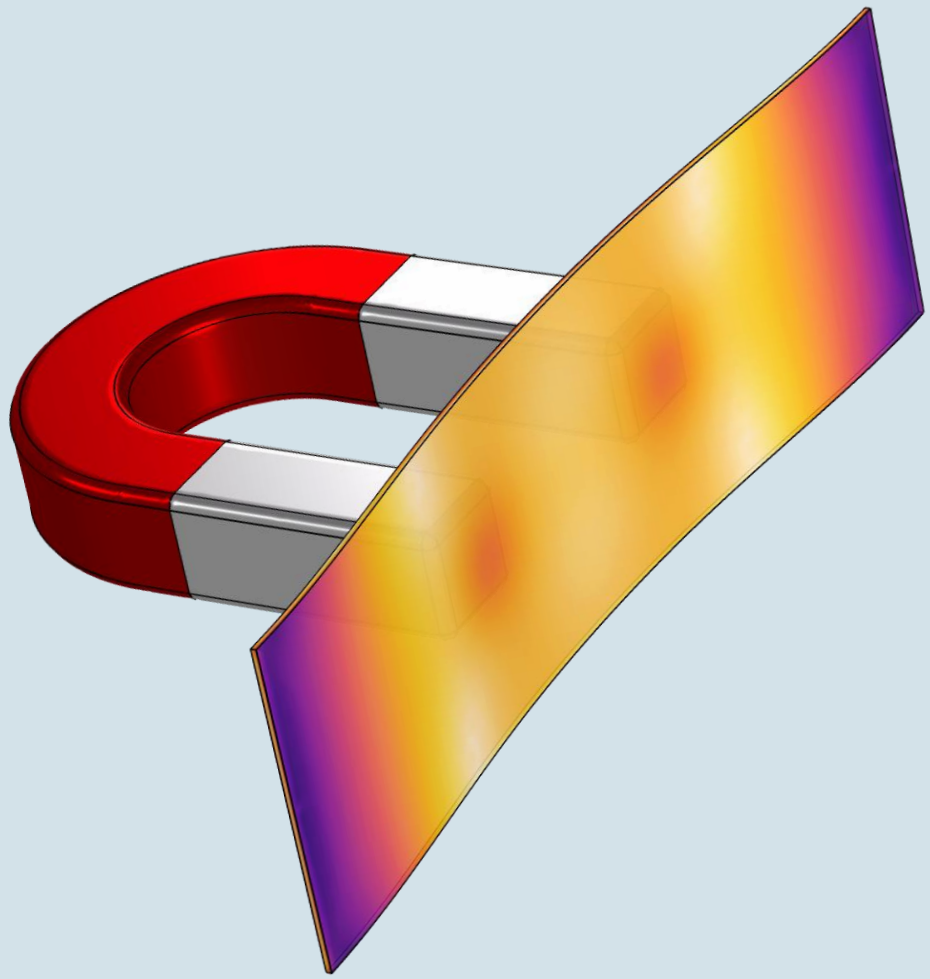
- Automatically coupling:
  - Moving Mesh
  - Solid Mechanics
  - Magnetic Fields (No Currents)
- Instead of surface integration of Maxwell stress tensor a volume integration of a **J x B** expression is performed – higher precision

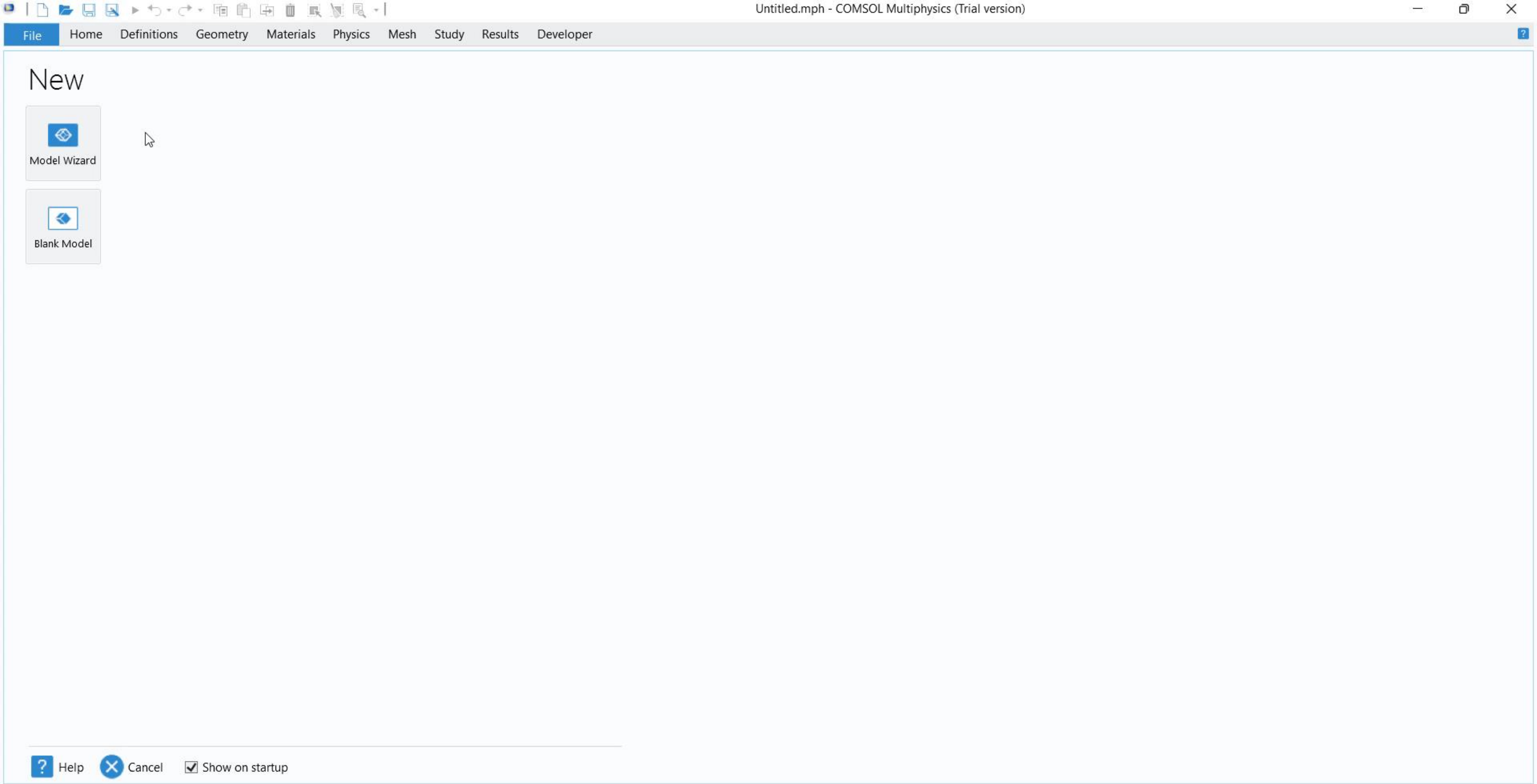




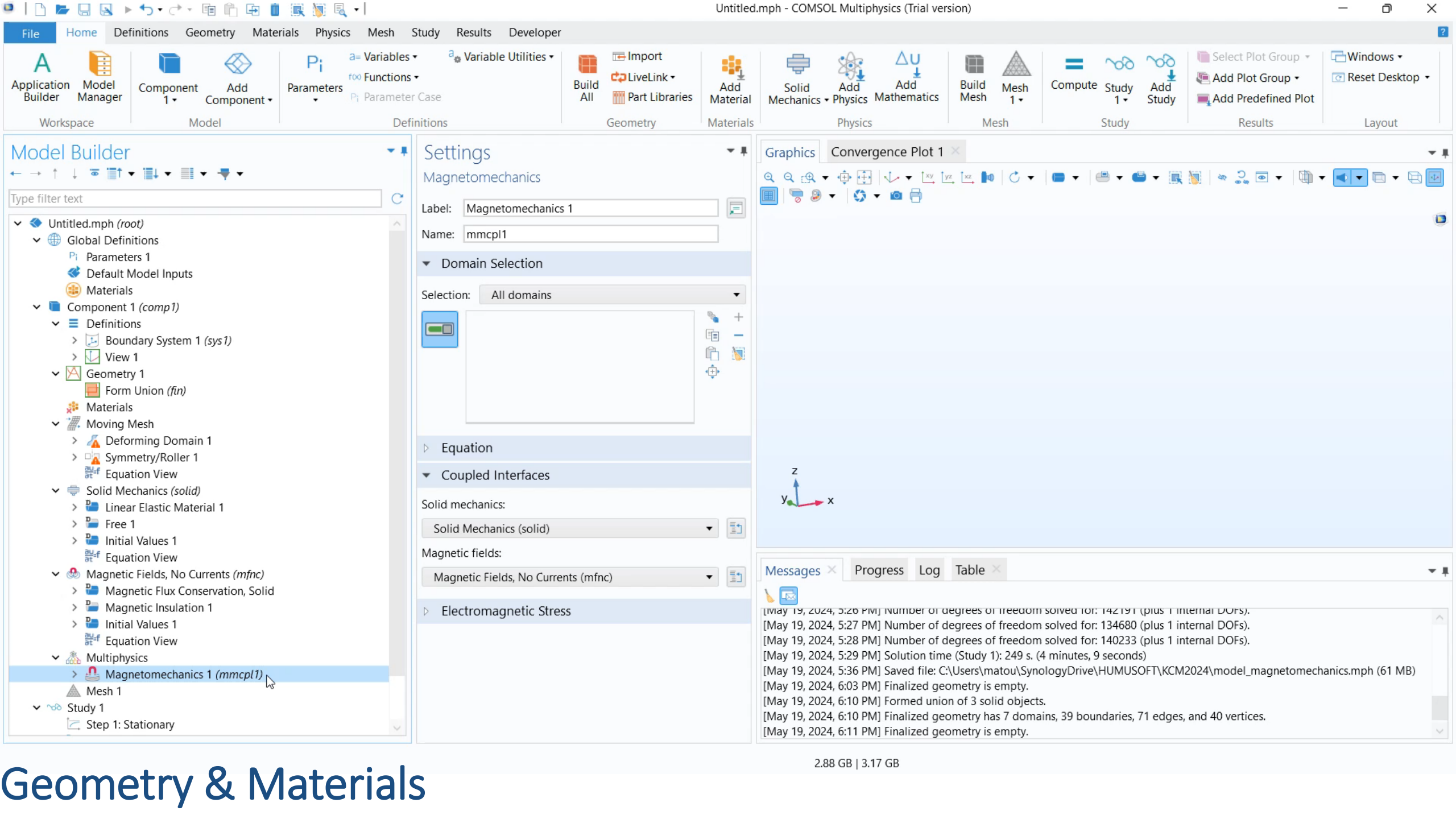
DEMO:
Plate Deflected by Magnet

- A strong permanent magnet positioned close to permeable thin iron plate
- Magnetic force calculated by Force calculation interface and compared to reaction forces calculated by the Solid Mechanics interface
  - Force calculation: Maxwell tensor integration
- Exploring different symmetry modes





Model Initialization



Geometry & Materials

Untitled.mph - COMSOL Multiphysics (Trial version)

File | Home | Definitions | Geometry | Materials | Physics | Mesh | Study | Results | Developer

Application Builder | Model Manager | Component 1 | Add Component | Parameters | Variables | Functions | Parameter Case | Variable Utilities | Build All | Import | LiveLink | Part Libraries | Add Material | Solid Mechanics | Add Physics | Add Mathematics | Build Mesh | Mesh 1 | Compute | Study 1 | Add Study | Select Plot Group | Add Plot Group | Add Predefined Plot | Windows | Reset Desktop

Workspace | Model | Definitions | Geometry | Materials | Physics | Mesh | Study | Results | Layout

Model Builder

Type filter text

- Untitled.mph *(root)*
  - Global Definitions
    - Parameters 1
    - Default Model Inputs
    - Materials
  - Component 1 *(comp1)*
    - Definitions
      - Boundary System 1 *(sys1)*
      - View 1
    - Geometry 1
      - Work Plane 1 *(wp1)*
        - Extrude 1 *(ext1)*
        - Block 1 *(blk1)*
        - Block 2 *(blk2)*
        - Form Union *(fin)*
    - Materials
      - Air *(mat1)*
      - Soft Iron (Without Losses) *(mat2)*
      - N35 (Sintered NdFeB) *(mat3)*
    - Moving Mesh
      - Deforming Domain 1
      - Symmetry/Roller 1
      - Equation View
    - Solid Mechanics *(solid)*
      - Linear Elastic Material 1
      - Free 1
      - Initial Values 1
      - Equation View
    - Magnetic Fields, No Currents *(mfnc)*
      - Magnetic Flux Conservation, Solid
      - Magnetic Insulation 1

Settings

Material

Label: Air

Name: mat1

Geometric Entity Selection

Geometric entity level: Domain

Selection: All domains

1
2
3 (overridden)
4
5 (overridden)
6 (overridden)

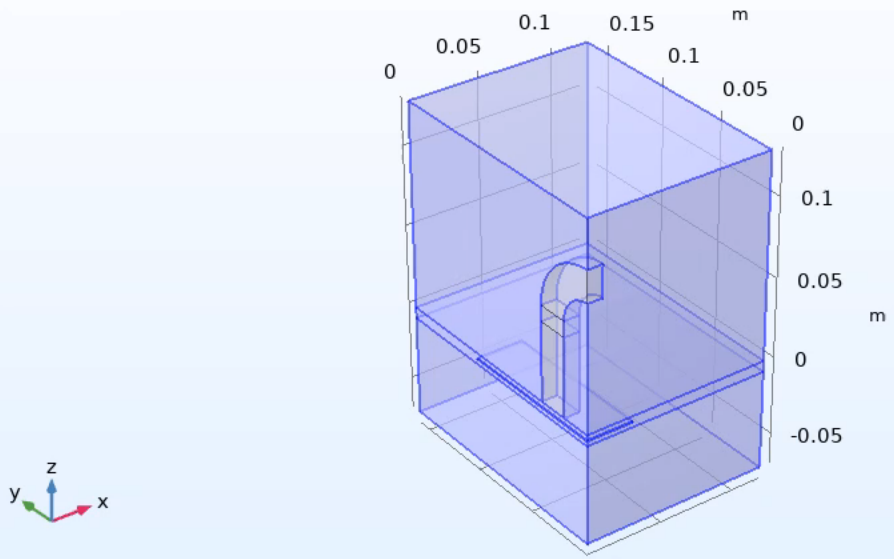
Override

Material Properties

Material Contents

Property	Variable	Value
Young's modulus	E	
Poisson's ratio	nu	
Relative permeability	mur_is...	1
Density	rho	rho(pA,T)
Coefficient of thermal expansi...	alpha_...	alpha_p...
Mean molar mass	Mn	0.02897[.
Bulk viscosity	muB	muB(T)
Relative permittivity	epsilo...	1
Dynamic viscosity	mu	eta(T)

Graphics | Convergence Plot 1

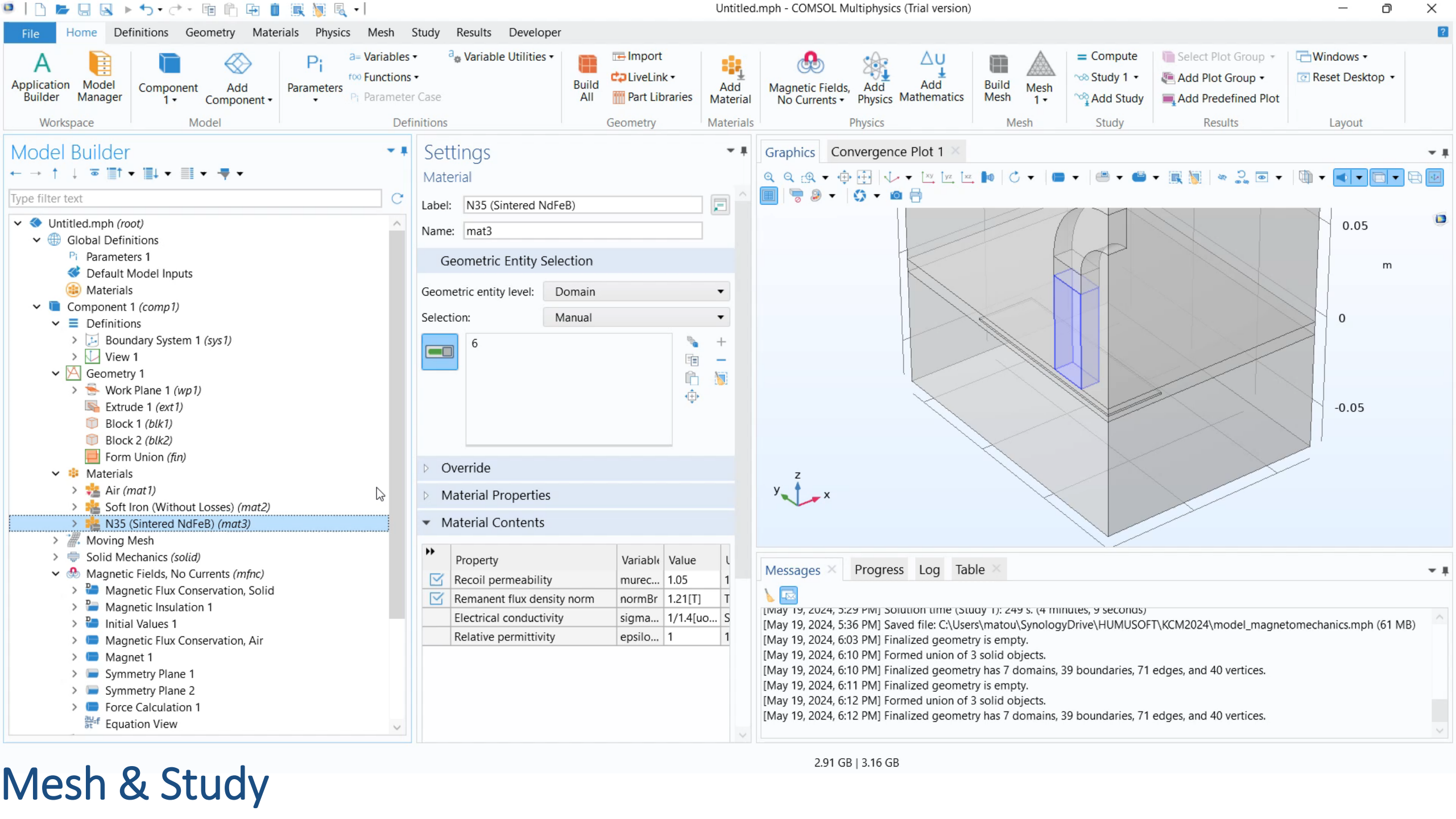


Messages | Progress | Log | Table

[May 19, 2024, 5:29 PM] Solution time (Study 1): 249 s. (4 minutes, 9 seconds)
[May 19, 2024, 5:36 PM] Saved file: C:\Users\matou\SynologyDrive\HUMUSOFT\KCM2024\model_magnetomechanics.mph (61 MB)
[May 19, 2024, 6:03 PM] Finalized geometry is empty.
[May 19, 2024, 6:10 PM] Formed union of 3 solid objects.
[May 19, 2024, 6:10 PM] Finalized geometry has 7 domains, 39 boundaries, 71 edges, and 40 vertices.
[May 19, 2024, 6:11 PM] Finalized geometry is empty.
[May 19, 2024, 6:12 PM] Formed union of 3 solid objects.
[May 19, 2024, 6:12 PM] Finalized geometry has 7 domains, 39 boundaries, 71 edges, and 40 vertices.

2.9 GB | 3.17 GB

Physics


Untitled.mph - COMSOL Multiphysics (Trial version)
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
Application Builder
Model Manager
Component 1
Add Component
Parameters
Variables
Functions
Parameter Case
Variable Utilities
Build All
Import
LiveLink
Part Libraries
Add Material
Magnetic Fields, No Currents
Add Physics
Add Mathematics
Build Mesh
Mesh 1
Compute
Study 1
Add Study
Select Plot Group
Add Plot Group
Add Predefined Plot
Windows
Reset Desktop
Workspace
Model
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Layout
Model Builder
Type filter text
Untitled.mph (root)
Global Definitions
Parameters 1
Default Model Inputs
Materials
Component 1 (comp1)
Definitions
Boundary System 1 (sys1)
View 1
Geometry 1
Work Plane 1 (wp1)
Extrude 1 (ext1)
Block 1 (blk1)
Block 2 (blk2)
Form Union (fin)
Materials
Air (mat1)
Soft Iron (Without Losses) (mat2)
N35 (Sintered NdFeB) (mat3)
Moving Mesh
Solid Mechanics (solid)
Magnetic Fields, No Currents (mfnc)
Magnetic Flux Conservation, Solid
Magnetic Insulation 1
Initial Values 1
Magnetic Flux Conservation, Air
Magnet 1
Symmetry Plane 1
Symmetry Plane 2
Force Calculation 1
Equation View
Settings
Material
Label: N35 (Sintered NdFeB)
Name: mat3
Geometric Entity Selection
Geometric entity level: Domain
Selection: Manual
6
Override
Material Properties
Material Contents
Property
Variable
Value
Recoil permeability
murec...
1.05
Remanent flux density norm
normBr
1.21[T]
Electrical conductivity
sigma...
1/1.4[uo...
Relative permittivity
epsilo...
1
Graphics
Convergence Plot 1
0.05
m
0
-0.05
z
y
x
Messages
Progress
Log
Table
[May 19, 2024, 5:36 PM] Saved file: C:\Users\matou\SynologyDrive\HUMUSOFT\KCM2024\model_magnetomechanics.mph (61 MB)
[May 19, 2024, 6:03 PM] Finalized geometry is empty.
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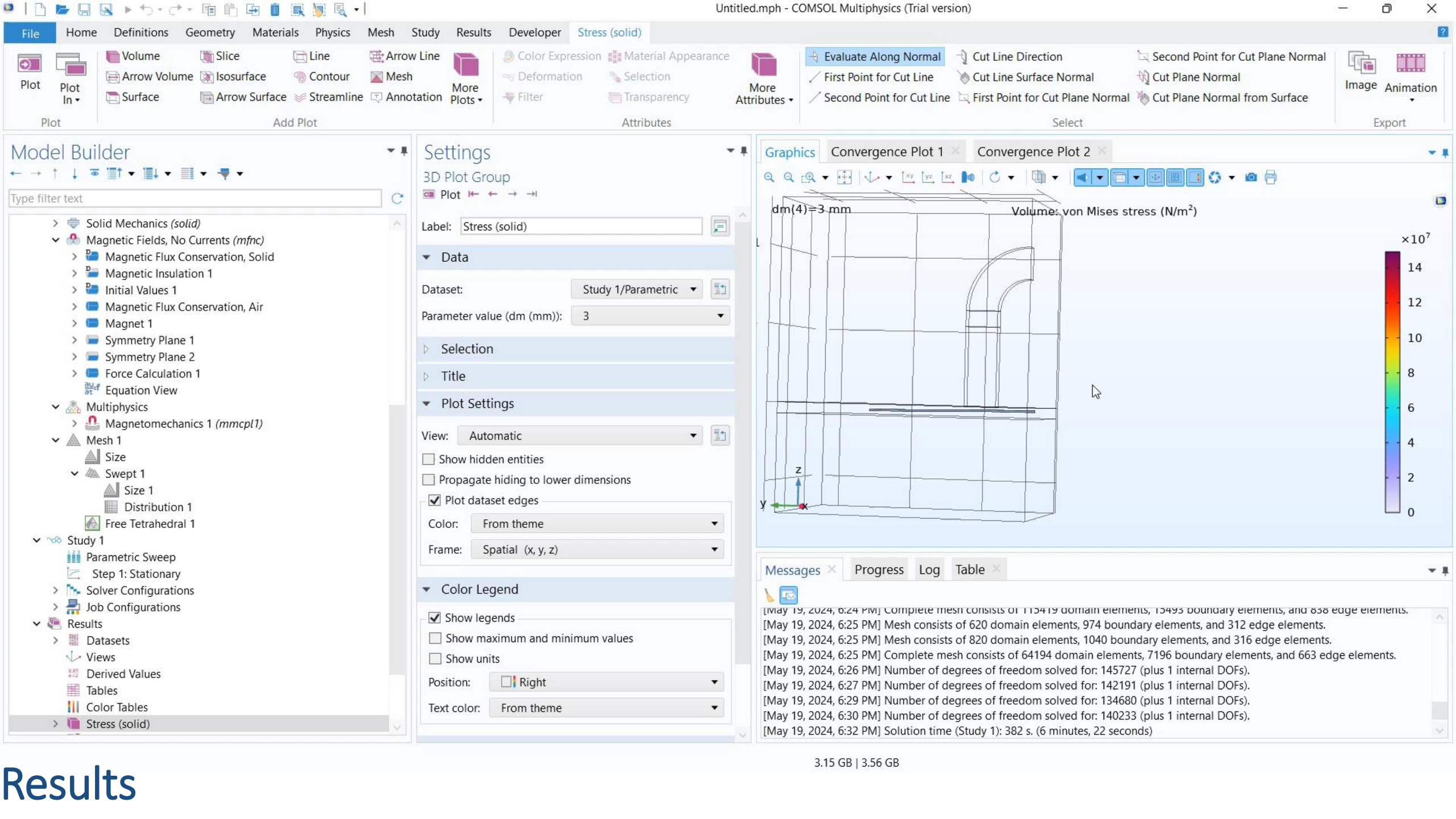
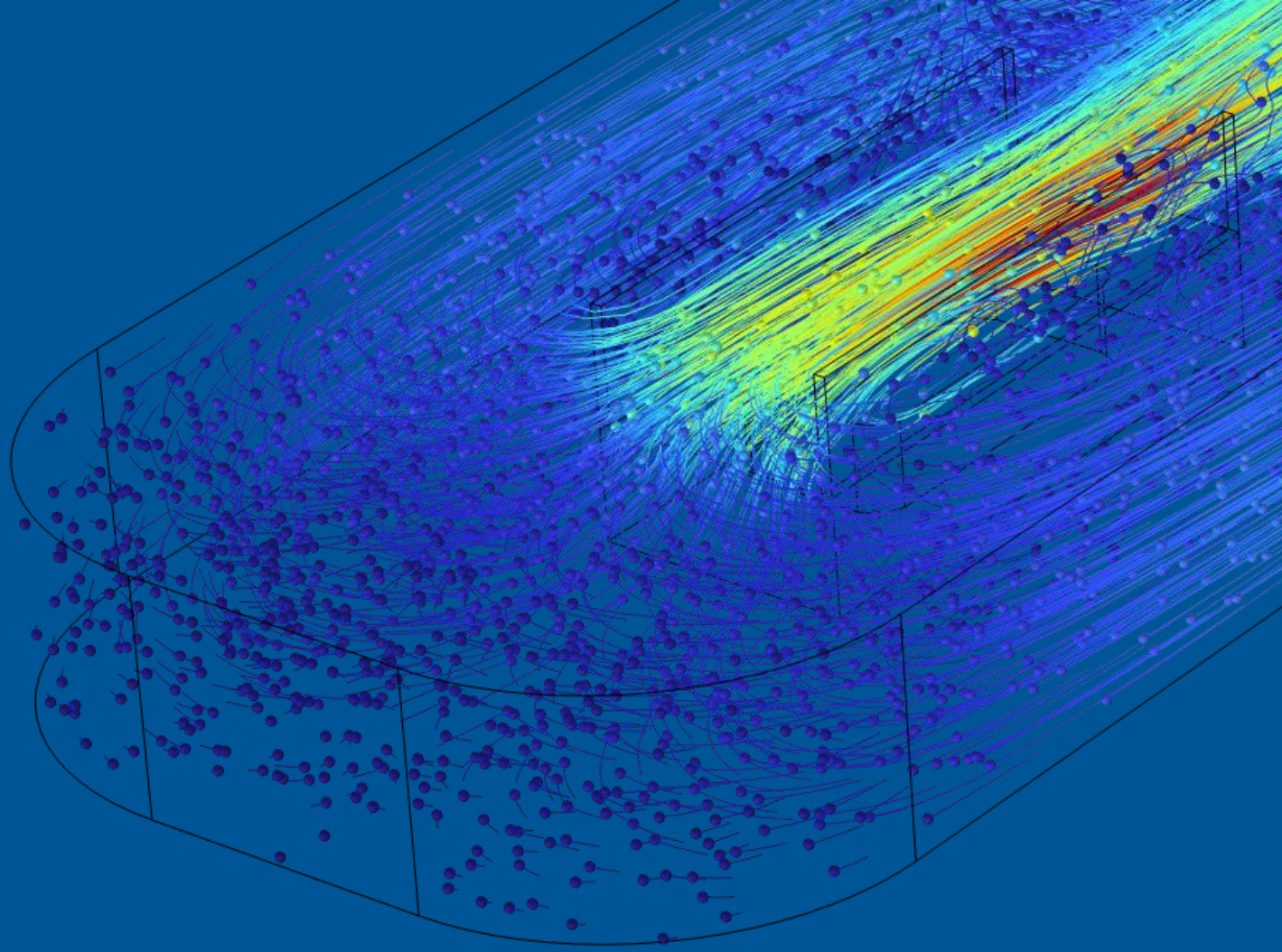
[May 19, 2024, 6:12 PM] Formed union of 3 solid objects.
[May 19, 2024, 6:12 PM] Finalized geometry has 7 domains, 39 boundaries, 71 edges, and 40 vertices.
2.91 GB | 3.16 GB

Mesh & Study


Untitled.mph - COMSOL Multiphysics (Trial version)
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
Stress (solid)
Plot
Plot In
Volume
Arrow Volume
Surface
Slice
Isosurface
Arrow Surface
Line
Contour
Streamline
Arrow Line
Mesh
Annotation
More Plots
Color Expression
Deformation
Filter
Material Appearance
Selection
Transparency
More Attributes
Evaluate Along Normal
First Point for Cut Line
Second Point for Cut Line
Cut Line Direction
Cut Line Surface Normal
First Point for Cut Plane Normal
Second Point for Cut Plane Normal
Cut Plane Normal
Cut Plane Normal from Surface
Image
Animation
Plot
Add Plot
Attributes
Select
Export
Model Builder
Type filter text
Solid Mechanics (solid)
Magnetic Fields, No Currents (mfnc)
Magnetic Flux Conservation, Solid
Magnetic Insulation 1
Initial Values 1
Magnetic Flux Conservation, Air
Magnet 1
Symmetry Plane 1
Symmetry Plane 2
Force Calculation 1
Equation View
Multiphysics
Magnetomechanics 1 (mmcpl1)
Mesh 1
Size
Swept 1
Size 1
Distribution 1
Free Tetrahedral 1
Study 1
Parametric Sweep
Step 1: Stationary
Solver Configurations
Job Configurations
Results
Datasets
Views
Derived Values
Tables
Color Tables
Stress (solid)
Settings
3D Plot Group
Plot
Label: Stress (solid)
Data
Dataset: Study 1/Parametric
Parameter value (dm (mm)): 3
Selection
Title
Plot Settings
View: Automatic
Show hidden entities
Propagate hiding to lower dimensions
Plot dataset edges
Color: From theme
Frame: Spatial (x, y, z)
Color Legend
Show legends
Show maximum and minimum values
Show units
Position: Right
Text color: From theme
Graphics
Convergence Plot 1
Convergence Plot 2
dm(4)=3 mm
Volume: von Mises stress (N/m²)
×10⁷
14
12
10
8
6
4
2
0
z
y
x
Messages
Progress
Log
Table
[May 19, 2024, 6:24 PM] Complete mesh consists of 115419 domain elements, 15493 boundary elements, and 838 edge elements.
[May 19, 2024, 6:25 PM] Mesh consists of 620 domain elements, 974 boundary elements, and 312 edge elements.
[May 19, 2024, 6:25 PM] Mesh consists of 820 domain elements, 1040 boundary elements, and 316 edge elements.
[May 19, 2024, 6:25 PM] Complete mesh consists of 64194 domain elements, 7196 boundary elements, and 663 edge elements.
[May 19, 2024, 6:26 PM] Number of degrees of freedom solved for: 145727 (plus 1 internal DOFs).
[May 19, 2024, 6:27 PM] Number of degrees of freedom solved for: 142191 (plus 1 internal DOFs).
[May 19, 2024, 6:29 PM] Number of degrees of freedom solved for: 134680 (plus 1 internal DOFs).
[May 19, 2024, 6:30 PM] Number of degrees of freedom solved for: 140233 (plus 1 internal DOFs).
[May 19, 2024, 6:32 PM] Solution time (Study 1): 382 s. (6 minutes, 22 seconds)
3.15 GB | 3.56 GB

Results



Magnetohydrodynamics

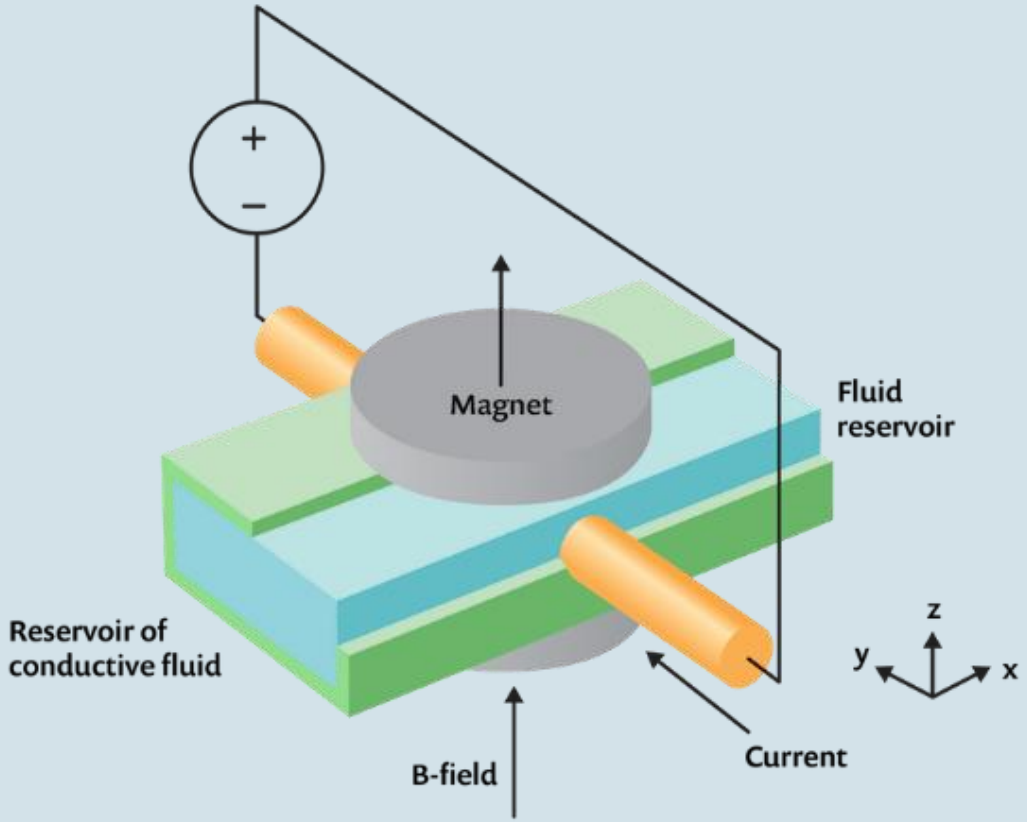
Magnetohydrodynamics

- Multiphysics interface coupling magnetic fields interfaces with CFD
- Passes Lorentz force to CFD…

$$\mathbf{F} = \mathbf{J} \times \mathbf{B}$$

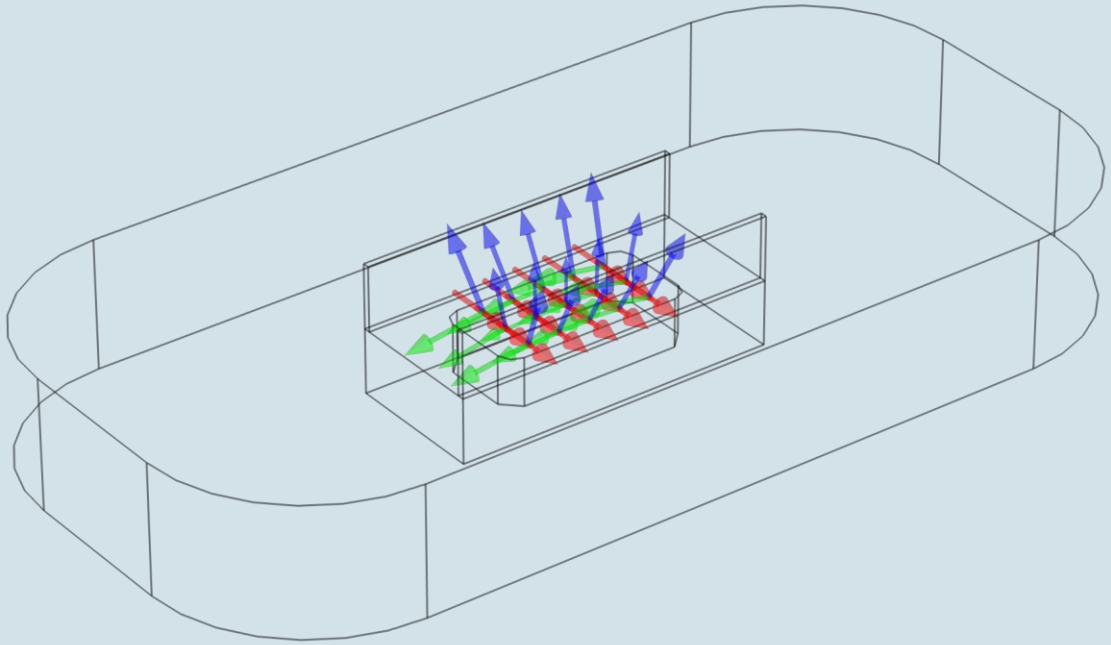
- …and the electromotive force (the induced electric field) back to electromagnetics

$$\mathbf{E} = \boldsymbol{v} \times \mathbf{B}$$



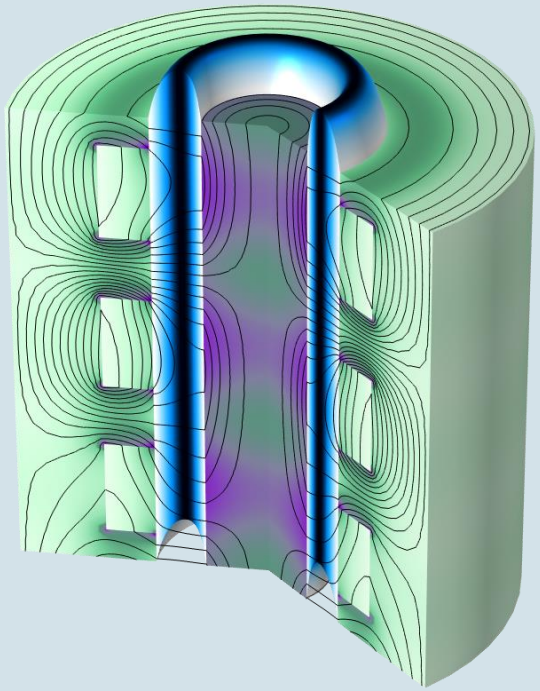
But How Does the Water Move?

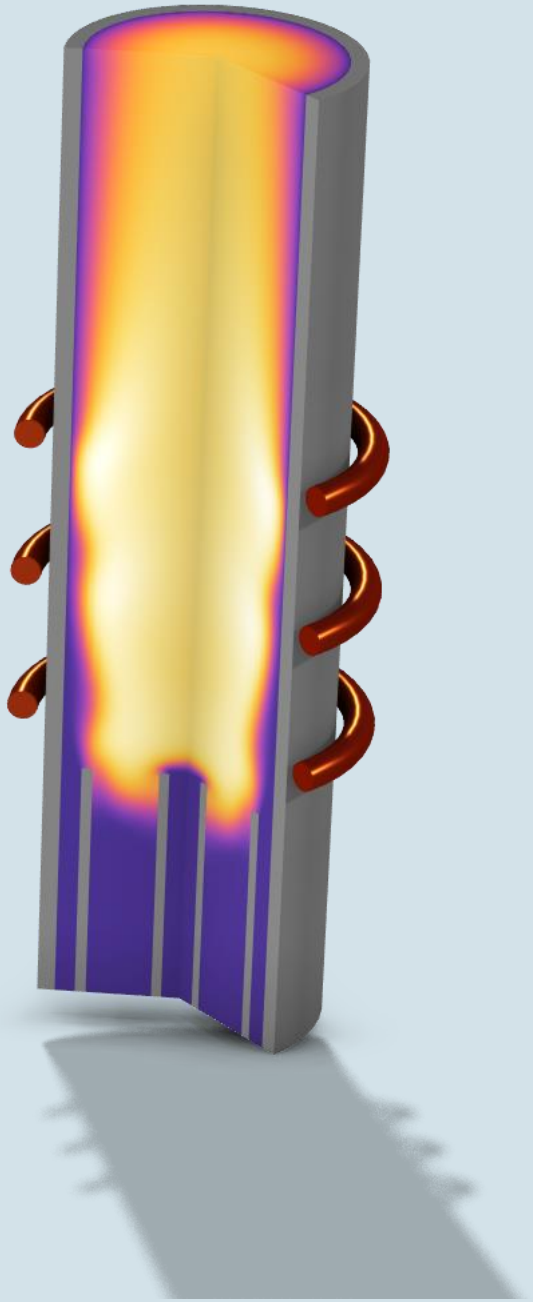
- Permanent magnet generates a strong static magnetic field
- Two electrodes generate static electric field causing electrolytic effect in the saline solution
- Conducting liquid is accelerated in a direction of Lorentz force perpendicular both to magnetic and electric field vectors



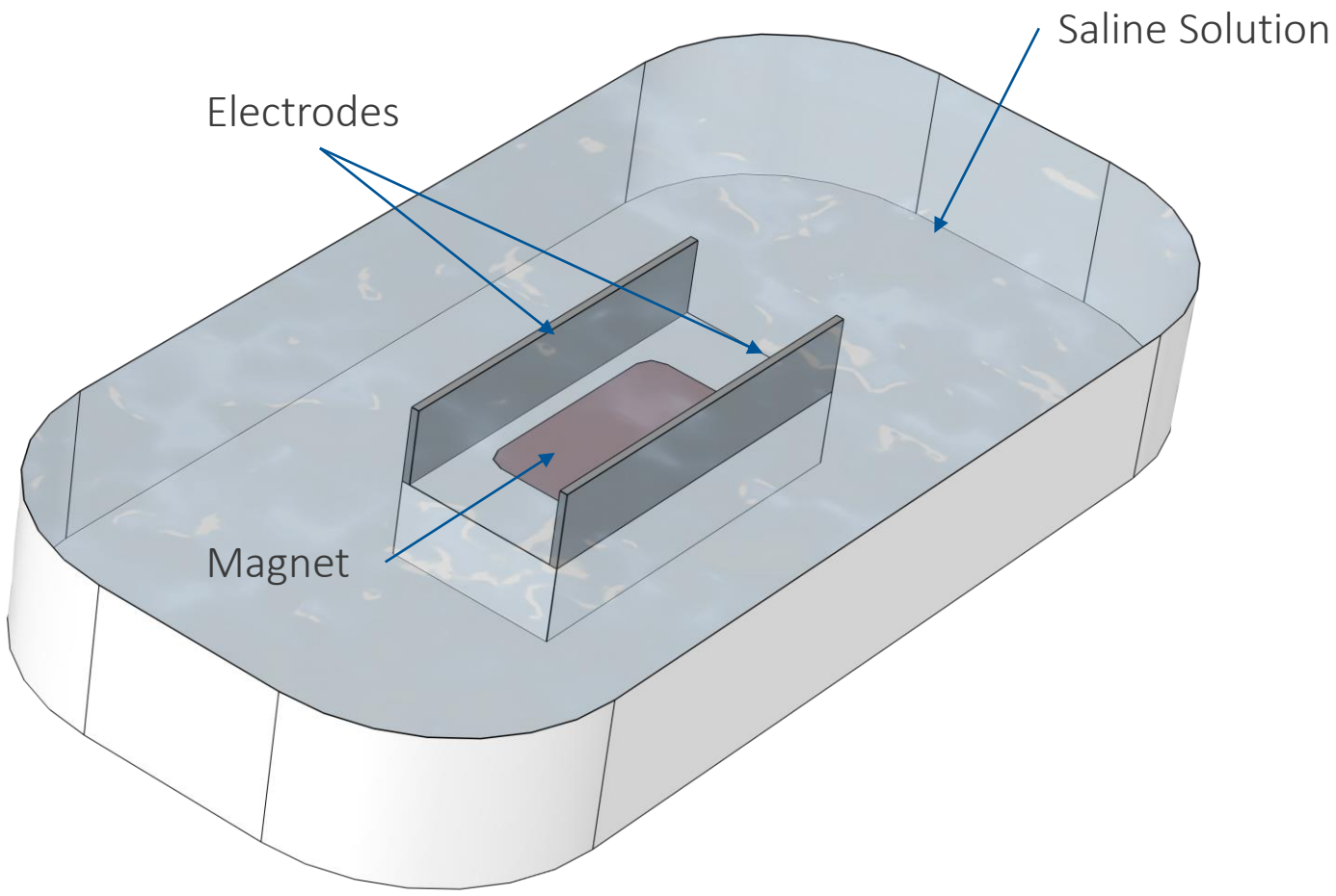
Application of Magnetohydrodynamics

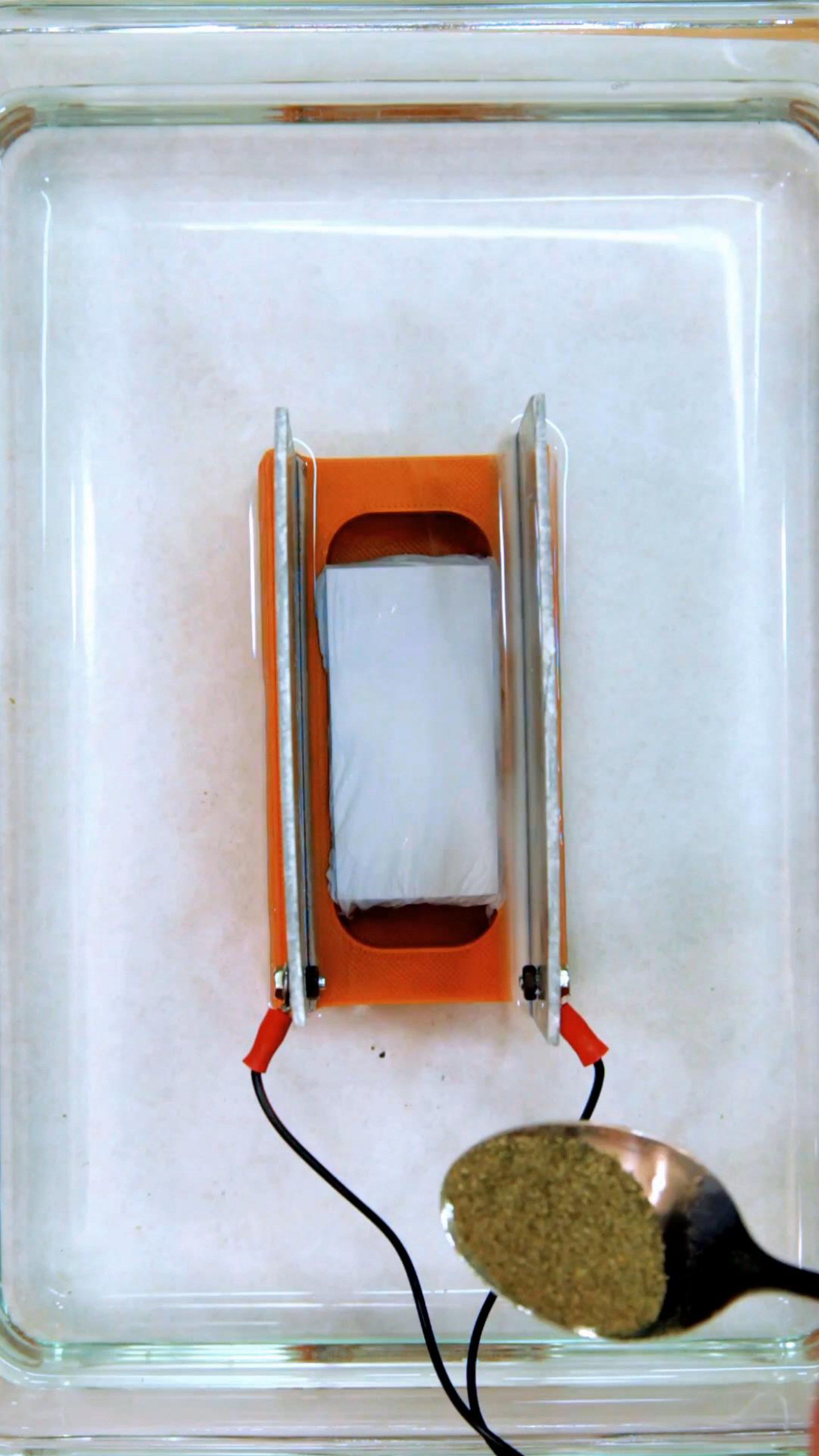
- Magnetohydrodynamics pump
- Inductively Coupled Plasma (ICP) Torch
- Fluid stirring
- Flow meters for molten metals





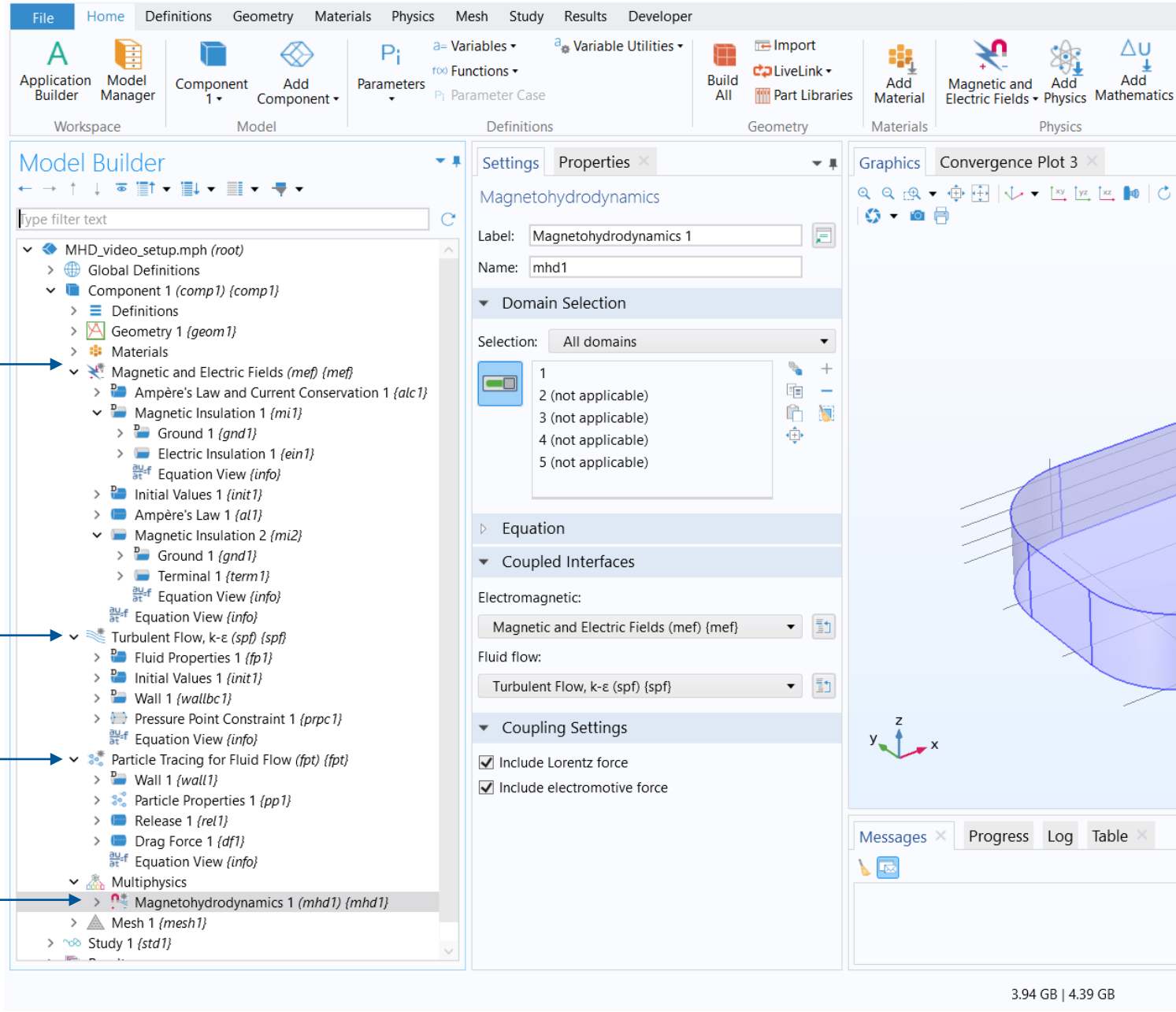
Model Setup

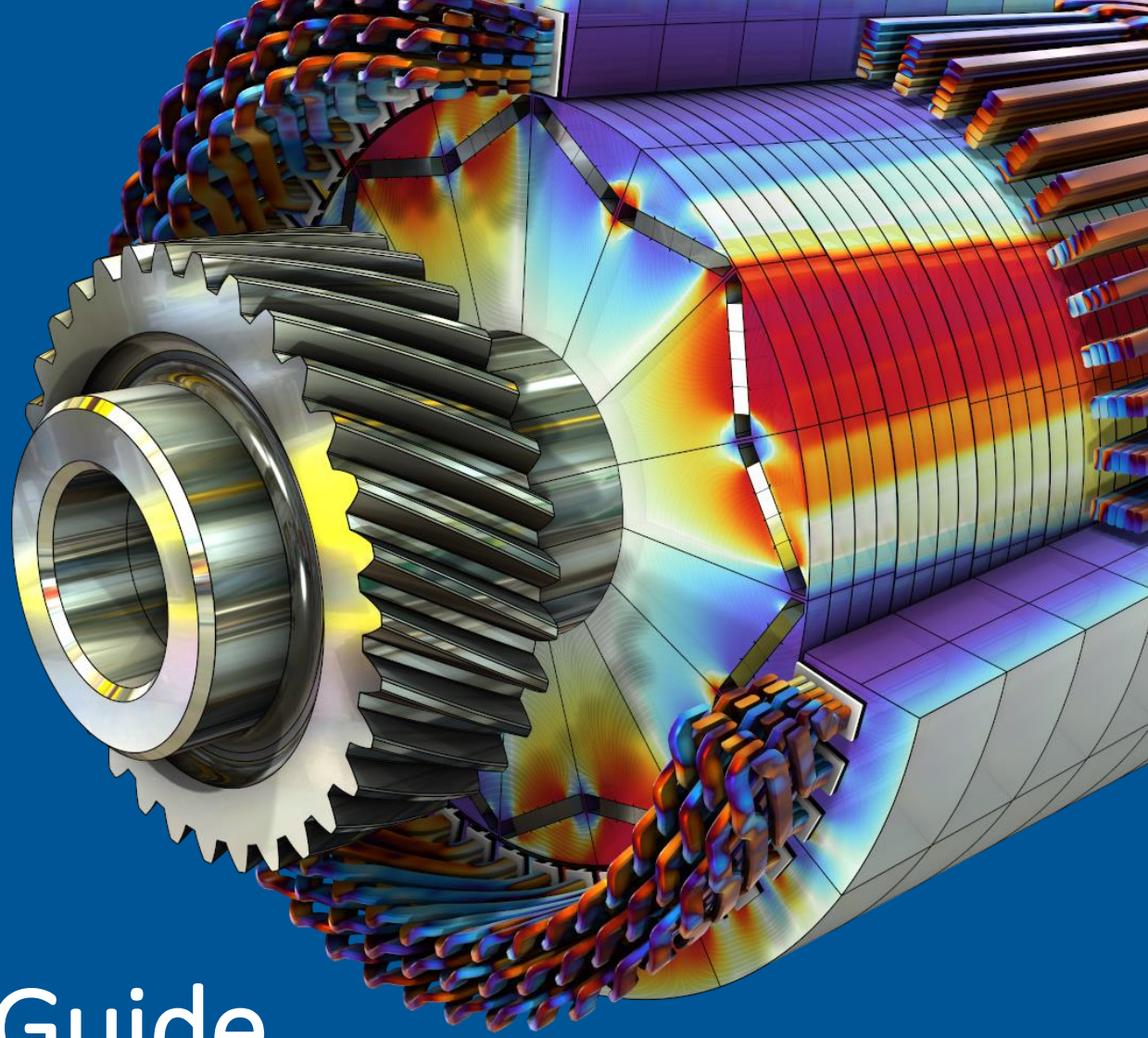




COMSOL Multiphysics

- Magnetic and Electric Fields
- Turbulent Flow
- Particle Tracing for Fluid Flow
- Magnetohydrodynamics





Step-by-Step Modeling Guide

Geometry

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

New

Model Wizard

Blank Model

Help Cancel Show on startup

1.09 GB | 1.38 GB

Materials

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Build All | Import | Export | Insert Sequence | Defeaturing and Repair | Remove Details | Virtual Operations | Block | Cone | Cylinder | Sphere | Torus | Helix | More Primitives | Select Work Plane | Work Plane | Extrude | Revolve | Sweep | Loft | Booleans and Partitions | Transforms | Conversions | Editing | Extract | Delete | Part Libraries | Create Part | Load Part | Part Instance | Selections | Selection List | Colors | Programming | Measure | Measurements | Clear Sequence

Build | Import/Export | Cleanup | Primitives | Work Plane | Operations | Parts | Selections | Programming | Evaluate | Clear

Model Builder

Type filter text

- Untitled.mph *(root)*
  - Global Definitions
    - Parameters 1 *{default}*
    - Materials
  - Component 1 *(comp1) {comp1}*
    - Definitions
    - Geometry 1 *{geom1}*
      - Block 1 - water *(blk1) {blk1}*
      - Block 2 - magnet *(blk2) {blk2}*
      - Block 3 - holder *(blk3) {blk3}*
      - Block 4 - electrode *(blk4) {blk4}*
      - Mirror 1 *(mir1) {mir1}*
      - Fillet 1 *(fil1) {fil1}*
      - Fillet 2 *(fil2) {fil2}*
      - Difference 1 *(dif1) {dif1}*
      - Difference 2 *(dif2) {dif2}*
      - Form Union *(fin) {fin}*
    - Materials
    - Magnetic and Electric Fields *(mef) {mef}*
      - Ampère's Law and Current Conservation 1 *{alc1}*
      - Magnetic Insulation 1 *{mi1}*
        - Ground 1 *{gnd1}*
        - Equation View *{info}*
      - Initial Values 1 *{init1}*
      - Equation View *{info}*
    - Laminar Flow *(spf) {spf}*
      - Fluid Properties 1 *{fp1}*
      - Initial Values 1 *{init1}*
      - Wall 1 *{wallbc1}*
      - Equation View *{info}*
    - Particle Tracing for Fluid Flow *(fpt) {fpt}*
      - Wall 1 *{wall1}*
      - Particle Properties 1 *{pp1}*
      - Equation View *{info}*
    - Multiphysics
      - Magnetohydrodynamics 1 *(mhd1) {mhd1}*
    - Mesh 1 *{mesh1}*
  - Results

Settings / Properties

Difference

Build Selected | Build All Objects

Label: Difference 2

Difference

Objects to add: blk3

Objects to subtract: fil1

- [ ] Keep objects to add
- [x] Keep objects to subtract
- [x] Keep interior boundaries

Repair tolerance: Automatic

Selections of Resulting Entities

- [ ] Resulting objects selection

Show in physics: Domain selection

Color: None

Cumulative selection

Contribute to: None | New

Selections on Input Objects

- [x] Propagate selections to resulting objects

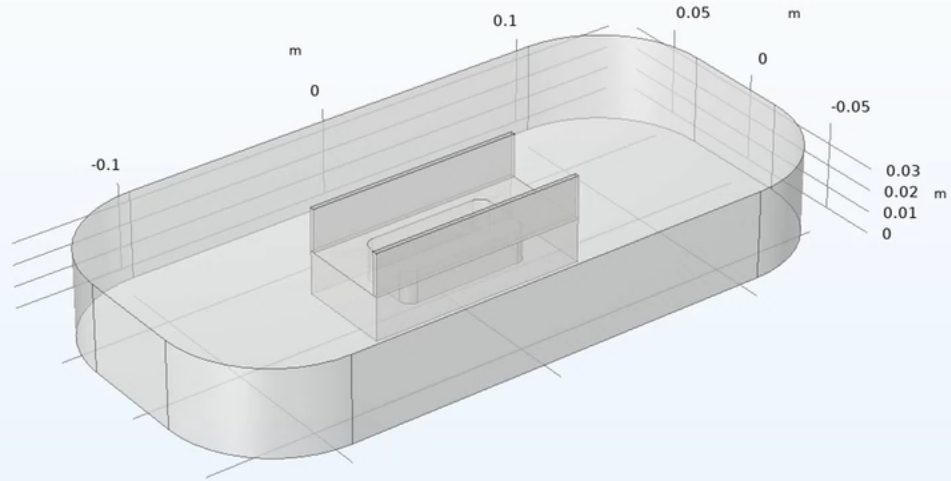
Assigned Attributes

Construction geometry: Inherit from input

Information

Last build time: < 1 second

Graphics



Messages / Progress / Log / Table

COMSOL Multiphysics 6.2.0.339

Setting physics

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Build All | Import Export Insert Sequence | Defeaturing and Repair Remove Details Virtual Operations | Block Cone Cylinder Sphere Torus Helix More Primitives | Select Work Plane Work Plane | Extrude Revolve Sweep Loft | Booleans and Partitions Transforms Conversions Editing Extract Delete | Part Libraries Create Part Load Part Part Instance | Selections Selection List Colors | Programming | Measure Measurements | Clear Sequence

Build | Import/Export | Cleanup | Primitives | Work Plane | Operations | Parts | Selections | Programming | Evaluate | Clear

Model Builder

Type filter text

- Untitled.mph *(root)*
  - Global Definitions
    - Parameters 1 *{default}*
    - Default Model Inputs *{cminpt}*
    - Materials
  - Component 1 *(comp1) {comp1}*
    - Definitions
    - Geometry 1 *{geom1}*
      - Block 1 - water *(blk1) {blk1}*
      - Block 2 - magnet *(blk2) {blk2}*
      - Block 3 - holder *(blk3) {blk3}*
      - Block 4 - electrode *(blk4) {blk4}*
      - Mirror 1 *(mir1) {mir1}*
      - Fillet 1 *(fil1) {fil1}*
      - Fillet 2 *(fil2) {fil2}*
      - Difference 1 *(dif1) {dif1}*
      - Difference 2 *(dif2) {dif2}*
      - Form Union *(fin) {fin}*
    - Materials
      - N38 (Sintered NdFeB) *(mat1) {mat1}*
      - Aluminum *(mat2) {mat2}*
      - Silicon *(mat3) {mat3}*
      - Seawater [liquid,S = 35 g/kg] *(mat4) {mat4}*
    - Magnetic and Electric Fields *(mef) {mef}*
      - Ampère's Law and Current Conservation 1 *{alc1}*
      - Magnetic Insulation 1 *{mi1}*
        - Ground 1 *{gnd1}*
        - Equation View *{info}*
      - Initial Values 1 *{init1}*
      - Equation View *{info}*
    - Laminar Flow *(spf) {spf}*
      - Fluid Properties 1 *{fp1}*
      - Initial Values 1 *{init1}*
      - Wall 1 *{wallbc1}*
      - Equation View *{info}*
    - Particle Tracing for Fluid Flow *(fpt) {fpt}*
      - Wall 1 *{wall1}*
      - Particle Properties 1 *{pp1}*
      - Equation View *{info}*
    - Multiphysics
      - Magnetohydrodynamics 1 *(mhd1) {mhd1}*
    - Mesh 1 *{mesh1}*
  - Results

Settings | Properties

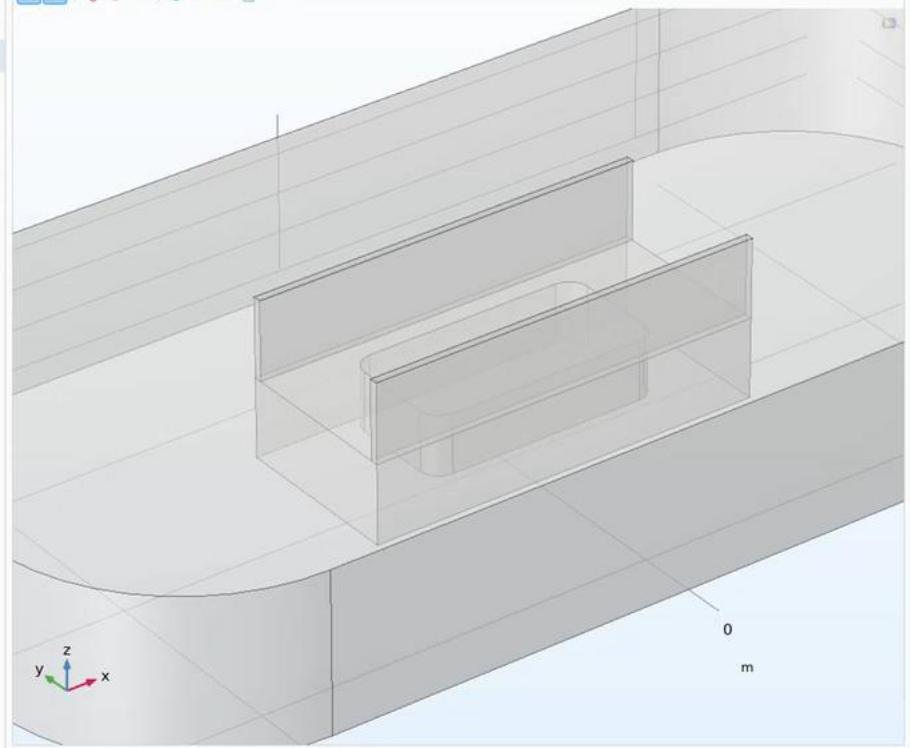
Materials

Label: Materials

Material Overview

Material	Selection
N38 (Sintered NdFeB) (mat1) {ma...	Domain 5
Aluminum (mat2) {mat2}	Domains 3–4
Silicon (mat3) {mat3}	Domain 2
Seawater [liquid,S = 35 g/kg] (ma...	Domain 1

Graphics



Add Material

Add to Global Materials | Add to Component

seawater | Search

- Recent Materials
- Material Library
  - Other Materials
    - Seawater
      - Seawater [liquid]
        - Seawater [liquid,S = 35 g/kg]
        - Seawater [liquid,S = 10 g/kg]
        - Seawater [liquid,S = 30 g/kg]
        - Seawater [liquid,S = 38 g/kg]
        - Seawater [liquid,S = 80 g/kg]
        - Seawater [liquid,S = 120 g/kg]
      - Seawater [liquid, natural bodies of water]
        - Seawater [liquid, natural bodies of water,An
        - Seawater [liquid, natural bodies of water,Ba
        - Seawater [liquid, natural bodies of water,Bla
        - Seawater [liquid, natural bodies of water,Me
        - Seawater [liquid, natural bodies of water,Wh
        - Seawater [liquid, natural bodies of water,Yel
        - Seawater [liquid, natural bodies of water,ave
      - Seawater [liquid, dilute synthetic seawater]
        - Seawater [liquid, dilute synthetic seawater,0.
        - Seawater [liquid, dilute synthetic seawater,0.
        - Seawater [liquid, dilute synthetic seawater,0.
        - Seawater [liquid, dilute synthetic seawater,0.
        - Seawater [liquid, dilute synthetic seawater,0.
        - Seawater [liquid, dilute synthetic seawater,0.
        - Seawater [liquid, dilute synthetic seawater,1.
        - Seawater [liquid, dilute synthetic seawater,1.
        - Seawater [liquid, dilute synthetic seawater,2.
      - Seawater [salinity of 10 k ppm]
        - Seawater [salinity of 10 k ppm,tested at 15 °

Messages | Progress | Log | Table

1.39 GB | 1.65 GB

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Build All | Import Export Insert Sequence | Defeaturing and Repair Remove Details Virtual Operations | Block Cone Cylinder Sphere Torus Helix More Primitives | Select Work Plane Work Plane | Extrude Revolve Sweep Loft Booleans and Partitions Transforms Conversions Editing Extract Delete | Part Libraries Create Part Load Part Part Instance | Selections Selection List Colors | Programming | Measure Measurements | Clear Sequence

Build | Import/Export | Cleanup | Primitives | Work Plane | Operations | Parts | Selections | Programming | Evaluate | Clear

Model Builder

Type filter text

- Parameters 1 *{default}*
- Default Model Inputs *{cminpt}*
- Materials
- Component 1 *(comp1) {comp1}*
  - Definitions
  - Geometry 1 *{geom1}*
    - Block 1 - water *(blk1) {blk1}*
    - Block 2 - magnet *(blk2) {blk2}*
    - Block 3 - holder *(blk3) {blk3}*
    - Block 4 - electrode *(blk4) {blk4}*
    - Mirror 1 *(mir1) {mir1}*
    - Fillet 1 *(fil1) {fil1}*
    - Fillet 2 *(fil2) {fil2}*
    - Difference 1 *(dif1) {dif1}*
    - Difference 2 *(dif2) {dif2}*
    - Form Union *(fin) {fin}*
  - Materials
    - N38 (Sintered NdFeB) *(mat1) {mat1}*
    - Aluminum *(mat2) {mat2}*
    - Silicon *(mat3) {mat3}*
    - Seawater [liquid,S = 35 g/kg] *(mat4) {mat4}*
  - Magnetic and Electric Fields *(mef) {mef}*
    - Ampère's Law and Current Conservation 1 *{alc1}*
    - Magnetic Insulation 1 *{mi1}*
      - Ground 1 *{gnd1}*
      - Electric Insulation 1 *{ein1}*
      - Equation View *{info}*
    - Initial Values 1 *{init1}*
    - Ampère's Law 1 *{al1}*
    - Magnetic Insulation 2 *{mi2}*
      - Ground 1 *{gnd1}*
      - Terminal 1 *{term1}*
      - Equation View *{info}*
    - Equation View *{info}*
  - Turbulent Flow, k-ε *(spf) {spf}*
    - Fluid Properties 1 *{fp1}*
    - Initial Values 1 *{init1}*
    - Wall 1 *{wallbc1}*
    - Pressure Point Constraint 1 *{prpc1}*
    - Equation View *{info}*
  - Particle Tracing for Fluid Flow *(fpt) {fpt}*
    - Wall 1 *{wall1}*
    - Particle Properties 1 *{pp1}*
    - Equation View *{info}*
  - Multiphysics
    - Magnetohydrodynamics 1 *(mhd1) {mhd1}*
  - Mesh 1 *{mesh1}*
- Results

Settings | Properties

Pressure Point Constraint

Label: Pressure Point Constraint 1

Point Selection

Selection: Manual

5

Override and Contribution

Equation

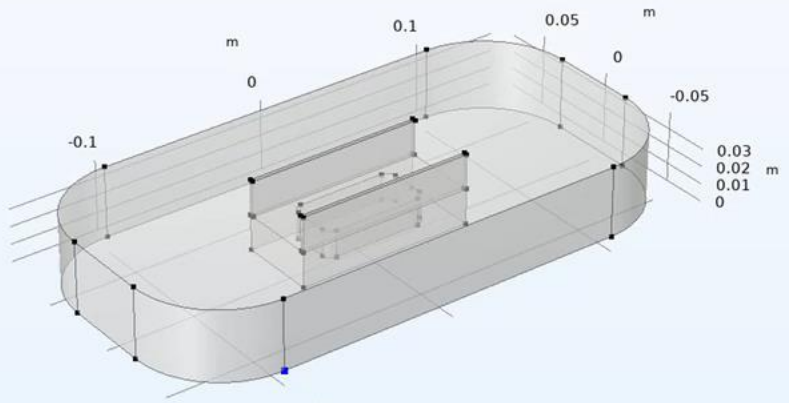
Pressure Constraint

Pressure:

p_0 0 Pa

Constraint Settings

Graphics



Messages | Progress | Log | Table

1.43 GB | 1.75 GB

Study + Postprocessing

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Build All | Import Export Insert Sequence | Defeaturing and Repair | Remove Details | Virtual Operations | Block Cone Cylinder Sphere Torus Helix More Primitives | Select Work Plane | Work Plane | Extrude Revolve Sweep Loft | Booleans and Partitions | Transforms | Conversions | Editing | Extract Delete | Part Libraries | Create Part Load Part Part Instance | Selections | Selection List | Colors | Programming | Measure | Measurements | Clear Sequence

Build | Import/Export | Cleanup | Primitives | Work Plane | Operations | Parts | Selections | Programming | Evaluate | Clear

Model Builder

Type filter text

- Materials
- Component 1 (comp1) (comp1)
  - Definitions
  - Geometry 1 (geom1)
    - Block 1 - water (blk1) (blk1)
    - Block 2 - magnet (blk2) (blk2)
    - Block 3 - holder (blk3) (blk3)
    - Block 4 - electrode (blk4) (blk4)
    - Mirror 1 (mir1) (mir1)
    - Fillet 1 (fil1) (fil1)
    - Fillet 2 (fil2) (fil2)
    - Difference 1 (dif1) (dif1)
    - Difference 2 (dif2) (dif2)
    - Form Union (fin) (fin)
  - Materials
    - N38 (Sintered NdFeB) (mat1) (mat1)
    - Aluminum (mat2) (mat2)
    - Silicon (mat3) (mat3)
    - Seawater [liquid,S = 35 g/kg] (mat4) (mat4)
  - Magnetic and Electric Fields (mef) (mef)
    - Ampère's Law and Current Conservation 1 (alc1)
    - Magnetic Insulation 1 (mi1)
      - Ground 1 (gnd1)
      - Electric Insulation 1 (ein1)
      - Equation View (info)
    - Initial Values 1 (init1)
    - Ampère's Law 1 (al1)
    - Magnetic Insulation 2 (mi2)
      - Ground 1 (gnd1)
      - Terminal 1 (term1)
      - Equation View (info)
    - Equation View (info)
  - Turbulent Flow, k-ε (spf) (spf)
    - Fluid Properties 1 (fp1)
    - Initial Values 1 (init1)
    - Wall 1 (wallbc1)
    - Pressure Point Constraint 1 (prpc1)
    - Equation View (info)
  - Particle Tracing for Fluid Flow (fpt) (fpt)
    - Wall 1 (wall1)
    - Particle Properties 1 (pp1)
    - Release 1 (rel1)
    - Drag Force 1 (df1)
    - Equation View (info)
  - Multiphysics
    - Magnetohydrodynamics 1 (mhd1) (mhd1)
  - Mesh 1 (mesh1)
- Results

Settings | Properties

Mesh

Build All

Label: Mesh 1

Sequence Type

Physics-controlled mesh

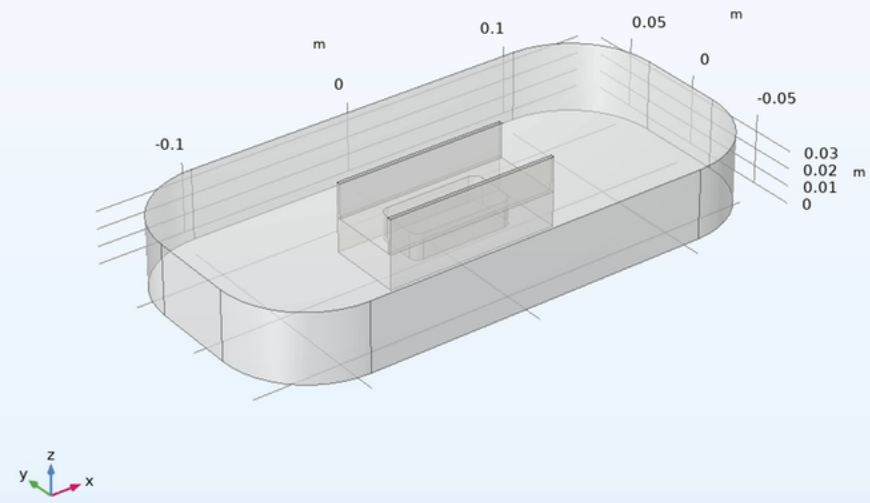
Physics-Controlled Mesh

Element size:

Coarser

Contributor	Use
Magnetic and Electric Fields (mef) (mef)	☑
Turbulent Flow, k-ε (spf) (spf)	☑
Particle Tracing for Fluid Flow (fpt) (fpt)	☑
Magnetohydrodynamics 1 (mhd1) (mhd1)	☑

Graphics



Messages | Progress | Log | Table

1.44 GB | 1.76 GB

Creation of the application

File | Home | Definitions | Geometry | Materials | Physics | Mesh | Study | Results | Developer | Particle Trajectories (fpt)

Plot | Plot In | Volume | Arrow Volume | Surface | Slice | Isosurface | Arrow Surface | Line | Contour | Streamline | Arrow Line | Mesh | Annotation | More Plots | Color Expression | Deformation | Filter | Material Appearance | Selection | Transparency | More Attributes | Evaluate Along Normal | First Point for Cut Line | Second Point for Cut Line | Cut Line Direction | Cut Line Surface Normal | First Point for Cut Plane Normal | Second Point for Cut Plane Normal | Cut Plane Normal | Cut Plane Normal from Surface | Image | Animation

Plot | Add Plot | Attributes | Select | Export

Model Builder

Type filter text

- Seawater [liquid,S = 35 g/kg] *(mat4) {mat4}*
- Magnetic and Electric Fields *(mef) {mef}*
  - Ampère's Law and Current Conservation 1 *{alc1}*
  - Magnetic Insulation 1 *{mi1}*
    - Ground 1 *{gnd1}*
    - Electric Insulation 1 *{ein1}*
    - Equation View *{info}*
  - Initial Values 1 *{init1}*
  - Ampère's Law 1 *{al1}*
  - Magnetic Insulation 2 *{mi2}*
    - Ground 1 *{gnd1}*
    - Terminal 1 *{term1}*
    - Equation View *{info}*
  - Equation View *{info}*
- Turbulent Flow, k-ε *(spf) {spf}*
  - Fluid Properties 1 *{fp1}*
  - Initial Values 1 *{init1}*
  - Wall 1 *{wallbc1}*
  - Pressure Point Constraint 1 *{prpc1}*
  - Equation View *{info}*
- Particle Tracing for Fluid Flow *(fpt) {fpt}*
  - Wall 1 *{wall1}*
  - Particle Properties 1 *{pp1}*
  - Release 1 *{rel1}*
  - Drag Force 1 *{df1}*
  - Equation View *{info}*
- Multiphysics
  - Magnetohydrodynamics 1 *(mhd1) {mhd1}*
- Mesh 1 *{mesh1}*
- Study 1 *{std1}*
  - Step 1: Stationary *{stat}*
  - Step 2: Time Dependent *{time}*
  - Solver Configurations
  - Job Configurations
- Results
  - Datasets
  - Views
  - Derived Values
  - Tables
  - Color Tables
  - Magnetic Flux Density Norm (mef) *{pg1}*
  - Electric Potential (mef) *{pg2}*
  - Velocity (spf) *{pg3}*
    - Slice *{slc1}*
  - Pressure (spf) *{pg4}*
  - Wall Resolution (spf) *{pg5}*
  - Particle Trajectories (fpt) *{pg6}*
    - Particle Trajectories 1 *{traj1}*
  - Export

Settings | Properties

3D Plot Group

Plot

Label: Particle Trajectories (fpt)

Data

Dataset: Particle 1 (part1)

Time (s): 31.75

Title

Plot Settings

View: Automatic

- [ ] Show hidden entities
- [ ] Propagate hiding to lower dimensions
- [x] Plot dataset edges

Color: From theme

Frame: Material (x, y, z)

Color Legend

- [x] Show legends
- [ ] Show maximum and minimum values
- [ ] Show units

Position: Right

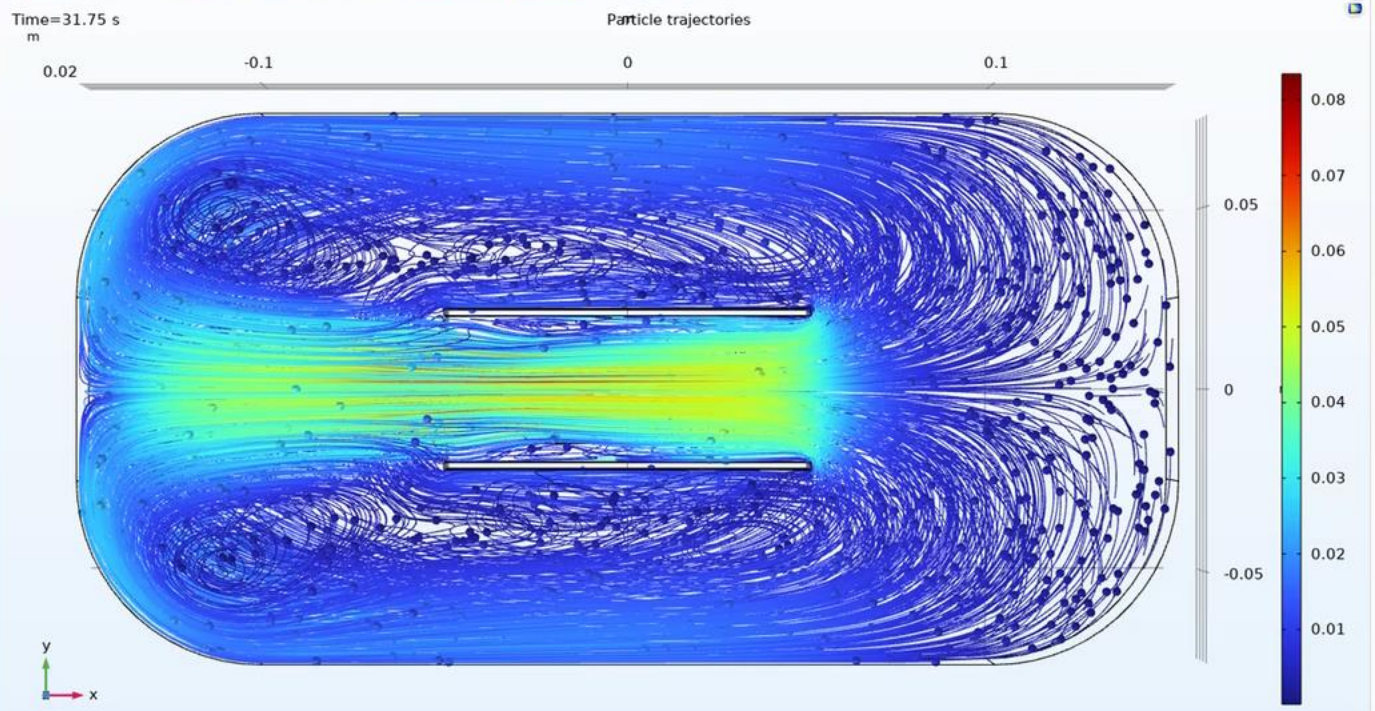
Text color: From theme

Number Format

Plot Array

Window Settings

Graphics | Convergence Plot 1 | Convergence Plot 2 | Convergence Plot 3



Messages | Progress | Log | Table

3.36 GB | 3.89 GB

Come to see the experiment!

COMSOL CONFERENCE 2024 FLORENCE

October 22-24

Connect with industry leaders at the modeling and simulation event of the year.