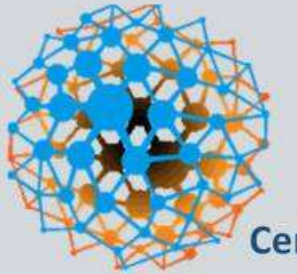


CEMMAC

Centro Multidisciplinario de Modelación Matemática y Computacional

3er WORKSHOP CEMMAC 2018

Modelación Matemática y sus Aplicaciones a la Medicina y Biología

27 y 28 de Septiembre Auditorio "Joaquín Ancona", FCFM-BUAP Puebla, México

BUAP

Facultad de Ciencias Físico Matemáticas

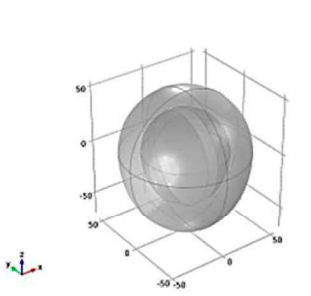
Centro Multidisciplinario de Modelación Matemática y Computacional

INVITA AL

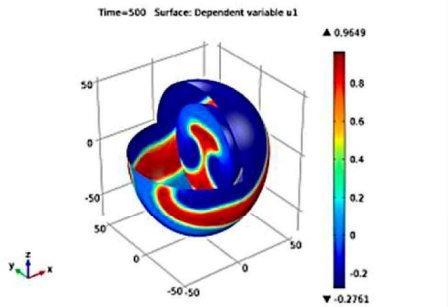
Taller 2:
Introducción a la Simulación usando COMSOL Multiphysics
3er WORKSHOP CEMMAC 2018

El objetivo de este taller es programar en COMSOL Multiphysics la ecuación de Poisson, la ecuación de calor y la ecuación de onda, las cuales son, en muchos casos, las bases de simulaciones de fenómenos físicos más complejos.

En este taller aprenderás las herramientas básicas para poder generar un dominio y su mallado; así como a programar las condiciones de frontera y condiciones iniciales que se requieran. Además, conocerás las diferentes opciones que COMSOL Multiphysics tiene para visualizar los resultados y podrás guardar las imágenes y videos de las simulaciones.



Model Geomtry: A heart is represented by two semispherical cavities.



Solution of the FitzHugh-Nagumo equations for the activation potential at time t = 500 seconds.

Introducción a la simulación usando COMSOL Multiphysics.

Dra. Beatriz Bonilla Capilla

Catedrática de CONACYT

Centro Multidisciplinario de Modelación Matemática y Computacional

Facultad de Ciencias Físico Matemáticas

Benemérita Universidad Autónoma de Puebla

Second order PDEs

$$a\frac{\partial^2 u}{\partial x^2} + 2b\frac{\partial^2 u}{\partial x \partial y} + c\frac{\partial^2 u}{\partial y^2} + d\frac{\partial u}{\partial x} + e\frac{\partial u}{\partial y} + fu = g.$$

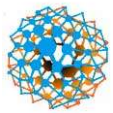
$$a\,u_{xx} + b\,u_{xy} + c\,u_{yy} + d\,u_x + e\,u_y + fu = g(x,y).$$

For the equation to be of second order, a, b, and c cannot all be zero. Define its *discriminant* to be $b^2 - 4ac$. The properties and behavior of its solution are largely dependent of its *type*, as classified below.

If $b^2 - 4ac > 0$, then the equation is called *hyperbolic*. The wave equation is one such example.

If $b^2 - 4ac = 0$, then the equation is called *parabolic*. The heat conduction equation is one such example.

If $b^2 - 4ac < 0$, then the equation is called *elliptic*. The Laplace equation is one such example.

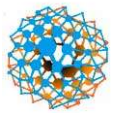


CEMAC

$$\alpha^2 u_{xx} = u_t \qquad \text{(one-dimensional heat conduction equation)}$$

$$a^2 u_{xx} = u_{tt} \qquad \text{(one-dimensional wave equation)}$$

$$u_{xx} + u_{yy} = 0 \qquad \text{(two-dimensional Laplace/potential equation)}$$



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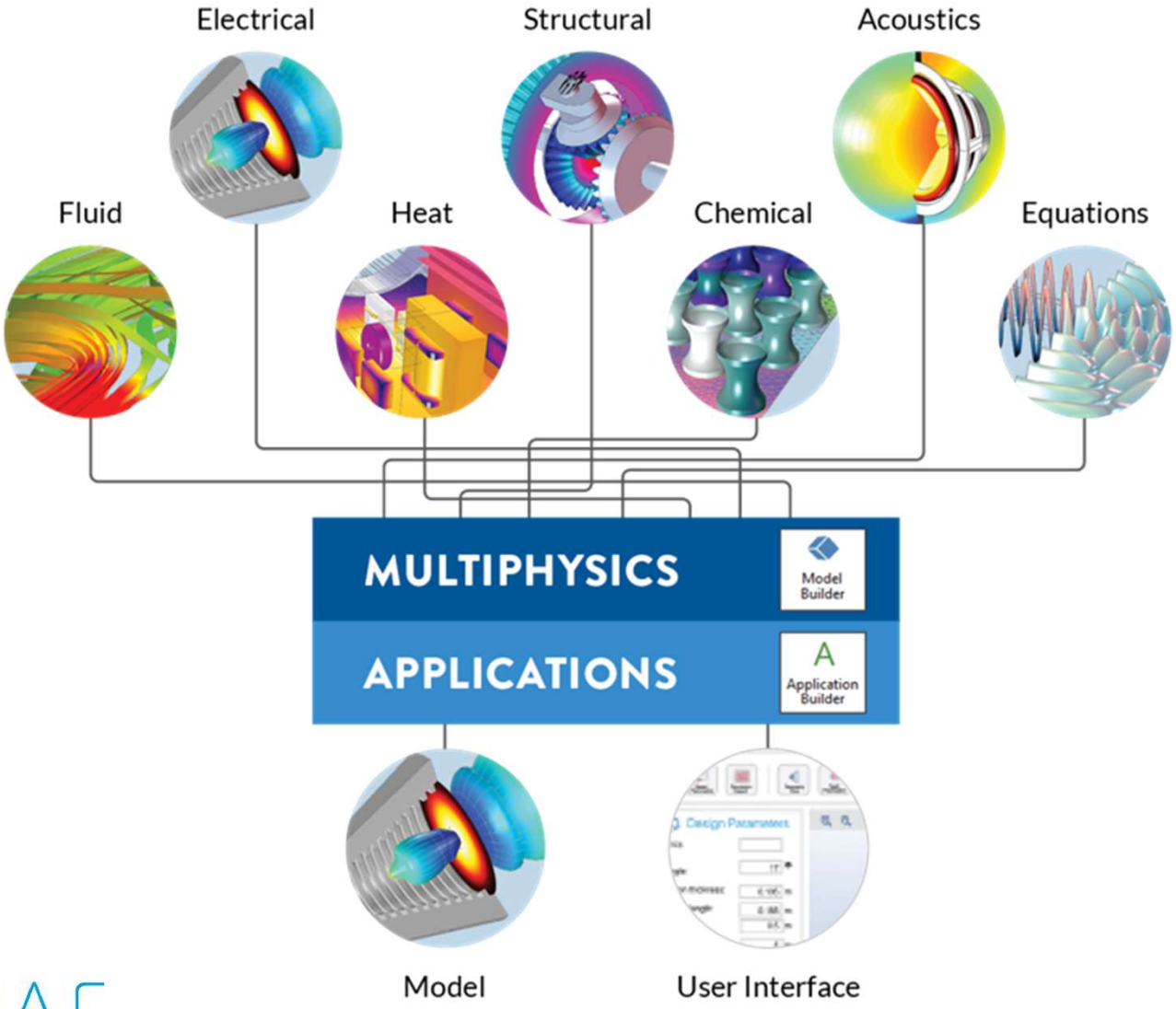
Ecuación Diferencial Parcial de segundo orden.

- Dominio

- Condiciones de Frontera:
  - Dirichlet
  - Newman

- Condiciones Iniciales

COMSOL Multiphysics



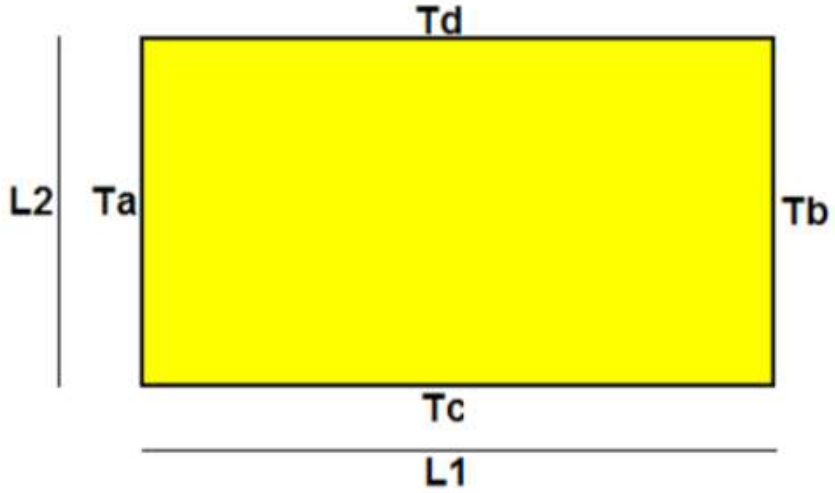
CEMAC

Ejemplo. *Resolver la ecuación de difusión en dos dimensiones:*

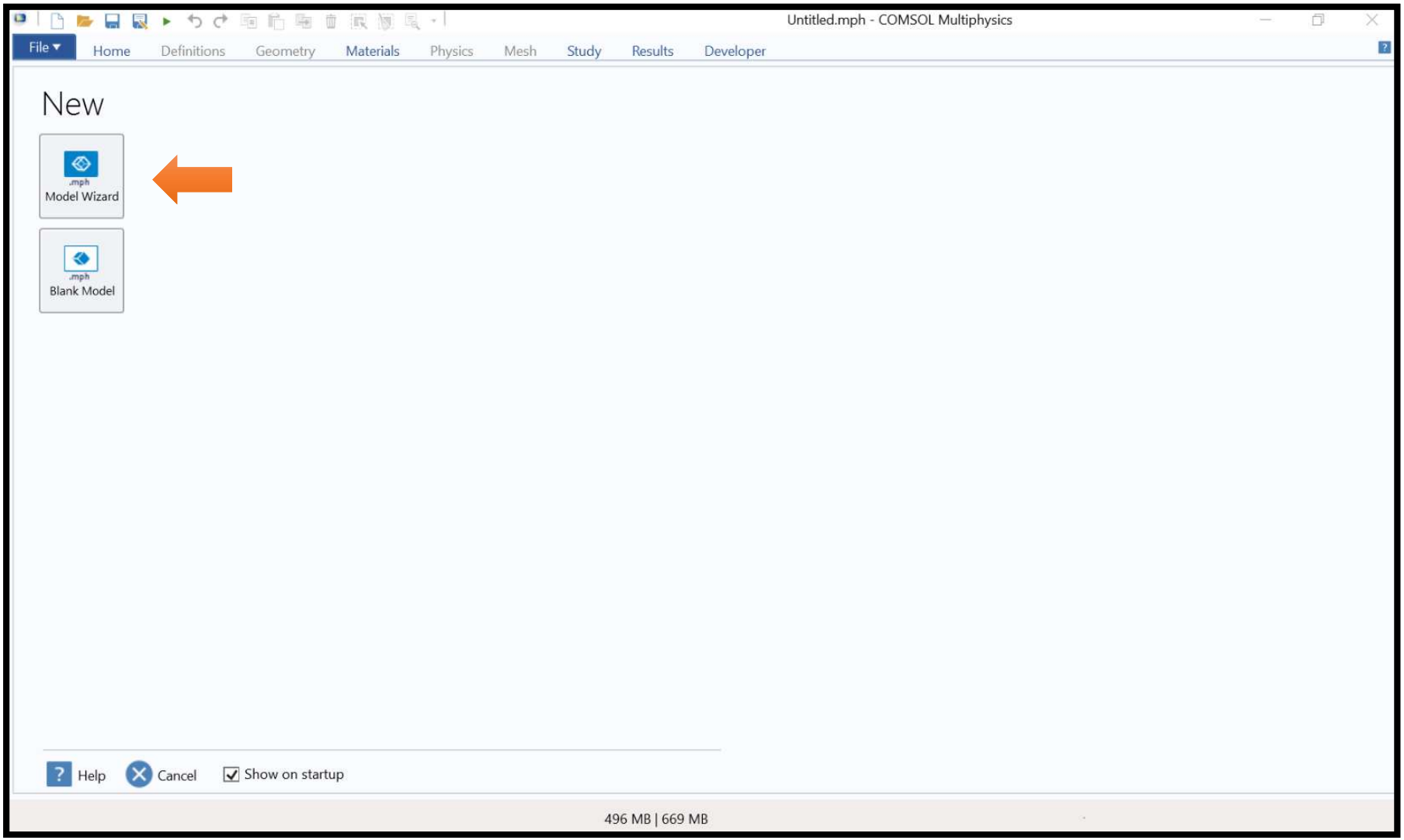
$$u(x,y): \quad \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = 0$$

Suponer que ***u*** *es una función que depende de* ***x, y,*** *en donde* ***u*** *representa valores de temperatura,* ***x, y*** *representan posición.*

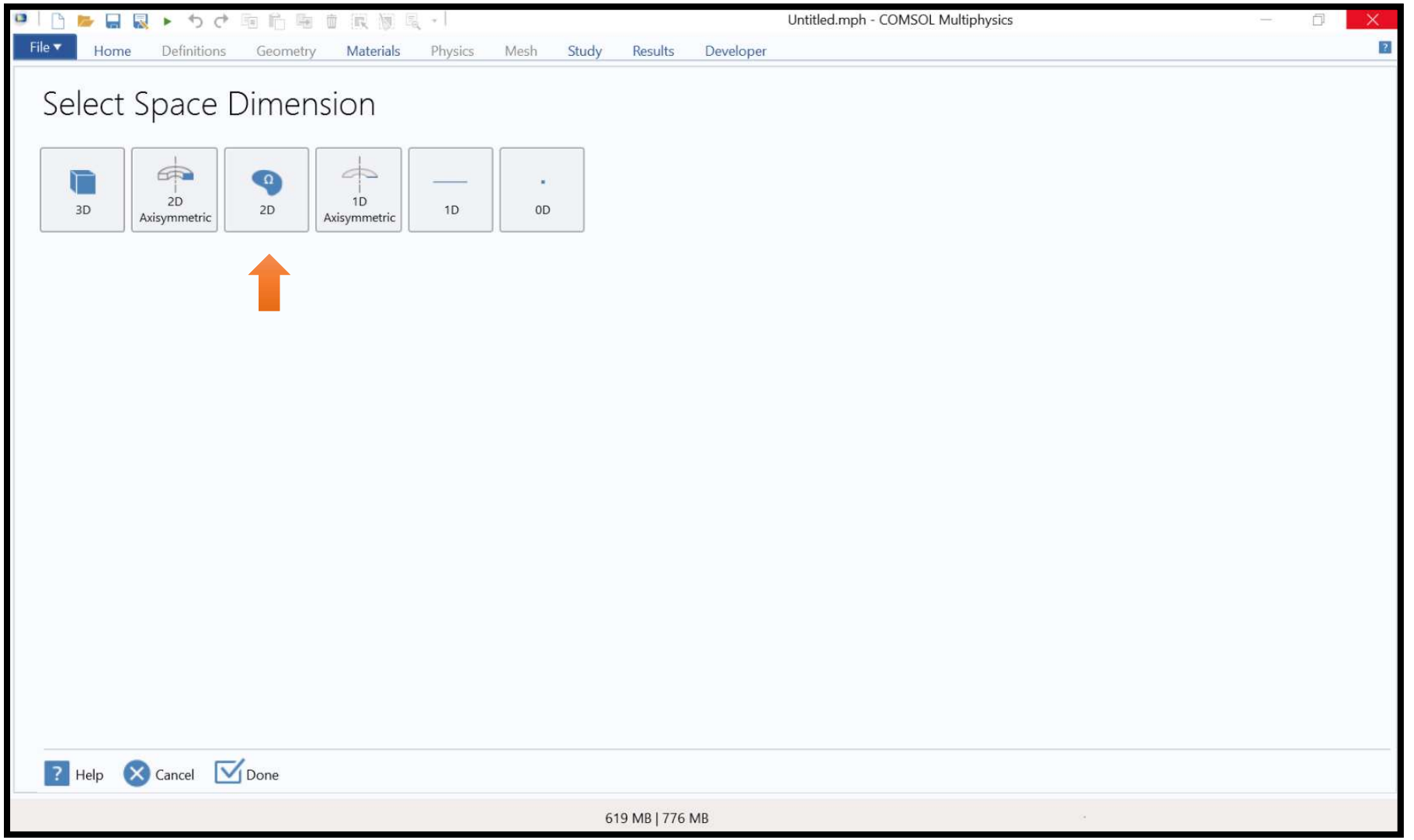
Esta ecuación se puede asociar al flujo de calor en una placa muy delgada aislada térmicamente en sus caras superior e inferior y sometida en los bordes a alguna condición. La solución representa la distribución final de temperaturas en la placa en cada punto **(x, y)**



Ta, Tb, Tc, Td son valores de temperatura, suponer constantes, de alguna fuente de calor aplicada en cada borde de la placa. **L1, L2** son las dimensiones de la placa.


Untitled.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
New
Model Wizard
Blank Model
Help
Cancel
Show on startup
496 MB | 669 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
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Physics
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Developer
Select Space Dimension
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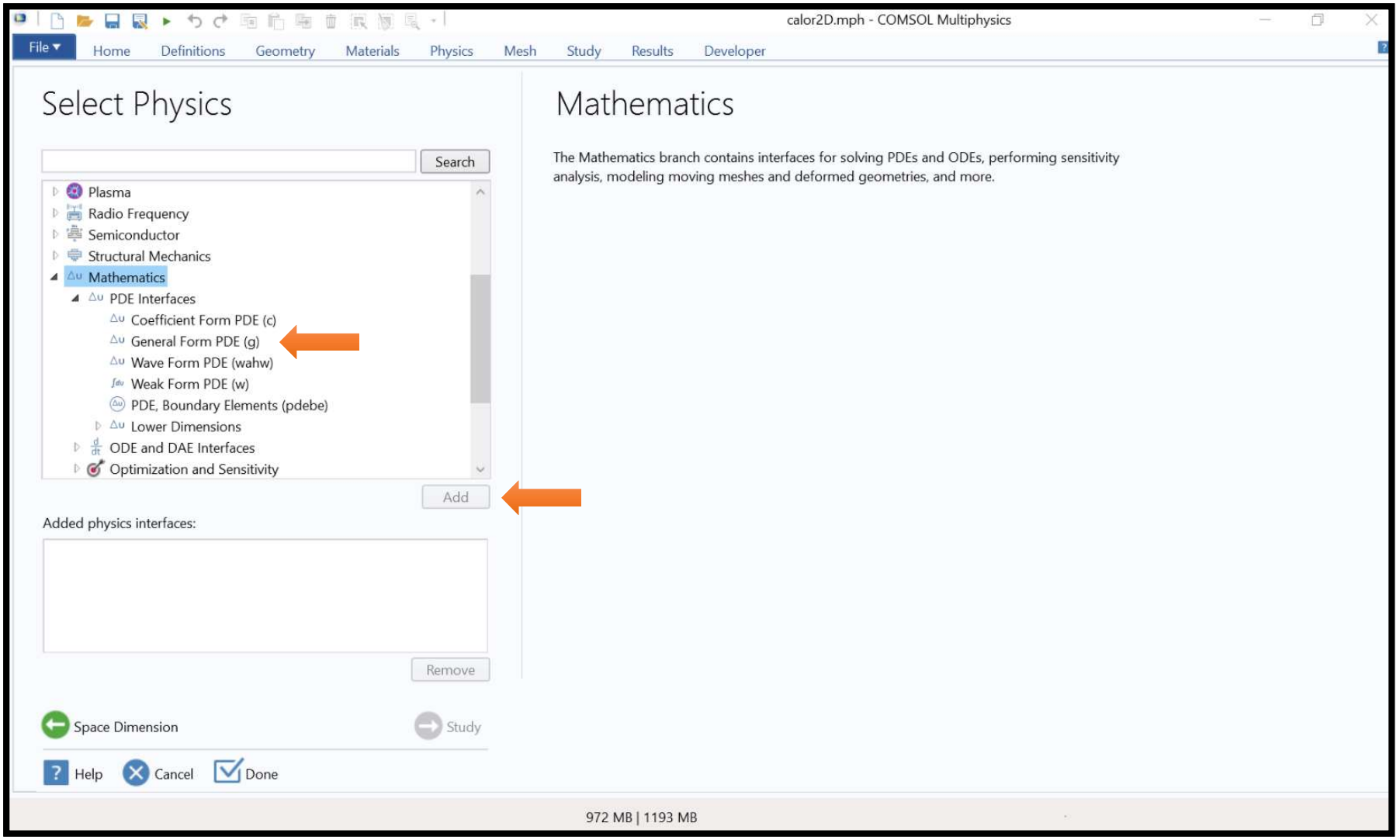
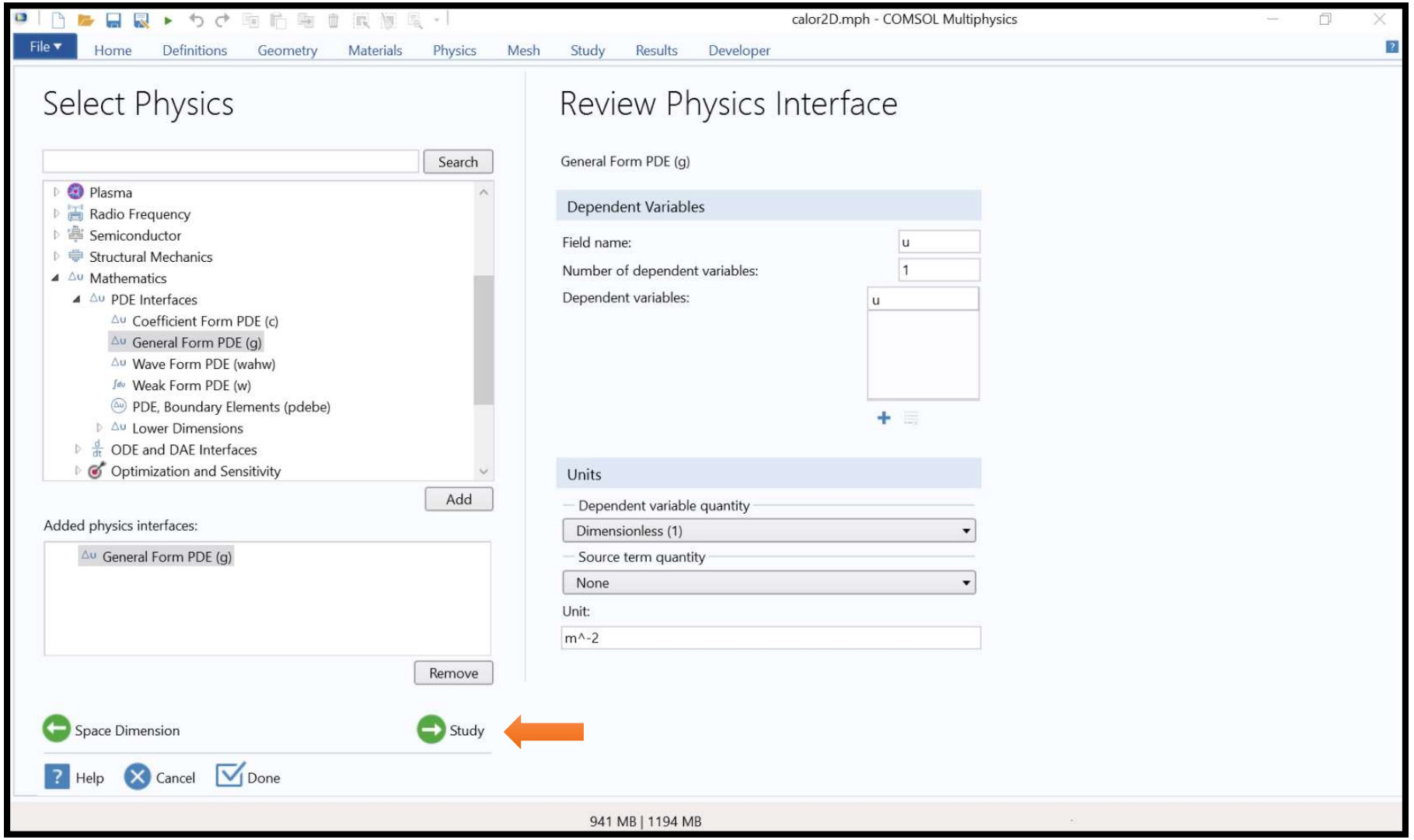
2D Axisymmetric
2D
1D Axisymmetric
1D
0D
Help
Cancel
Done
619 MB | 776 MB

CEMAC


calor2D.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
Select Physics
Search
Plasma
Radio Frequency
Semiconductor
Structural Mechanics
Mathematics
PDE Interfaces
Coefficient Form PDE (c)
General Form PDE (g)
Wave Form PDE (wahw)
Weak Form PDE (w)
PDE, Boundary Elements (pdebe)
Lower Dimensions
ODE and DAE Interfaces
Optimization and Sensitivity
Add
Added physics interfaces:
Remove
Space Dimension
Study
Help
Cancel
Done
Mathematics
The Mathematics branch contains interfaces for solving PDEs and ODEs, performing sensitivity analysis, modeling moving meshes and deformed geometries, and more.
972 MB | 1193 MB

CEMAC


calor2D.mph - COMSOL Multiphysics
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Mesh
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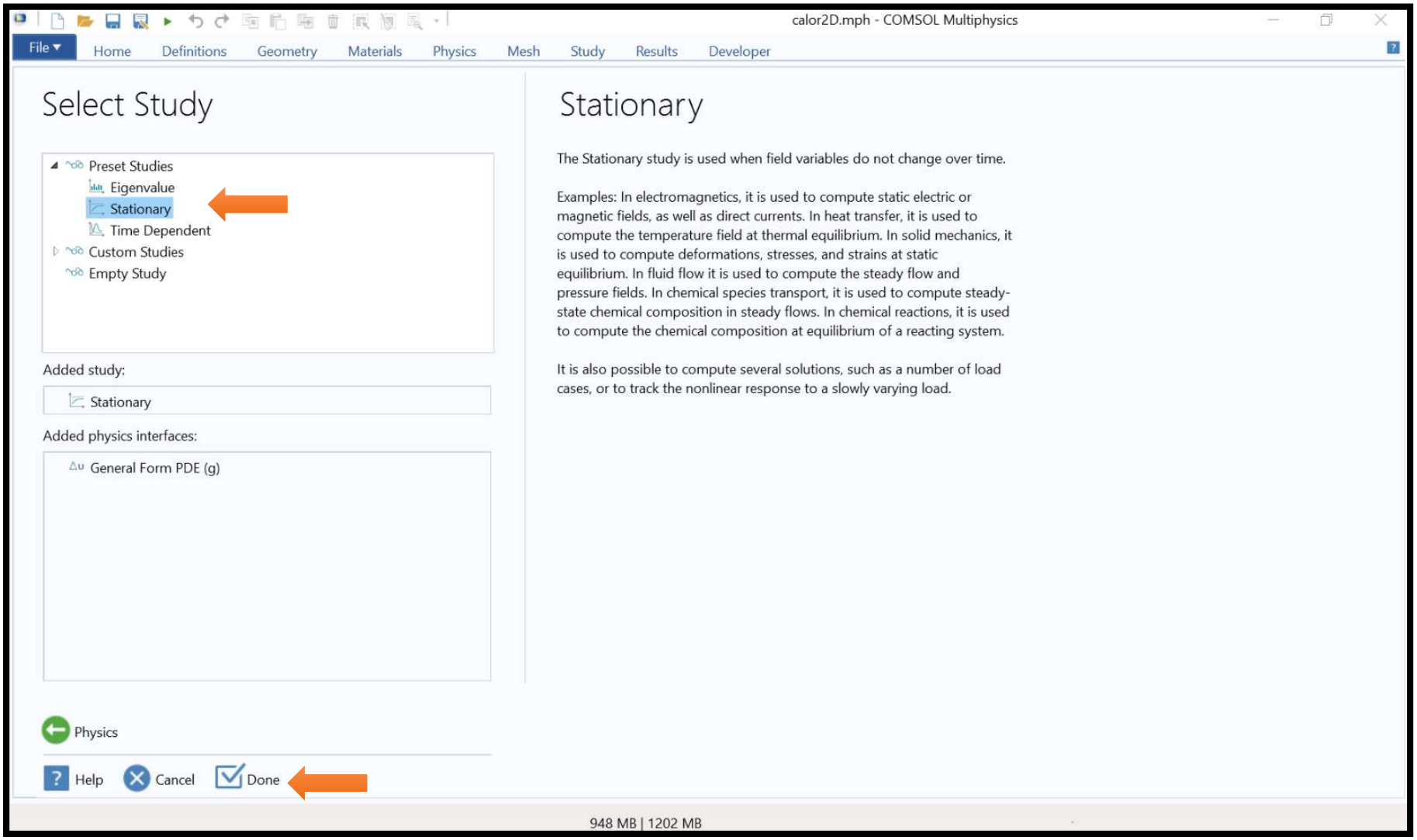
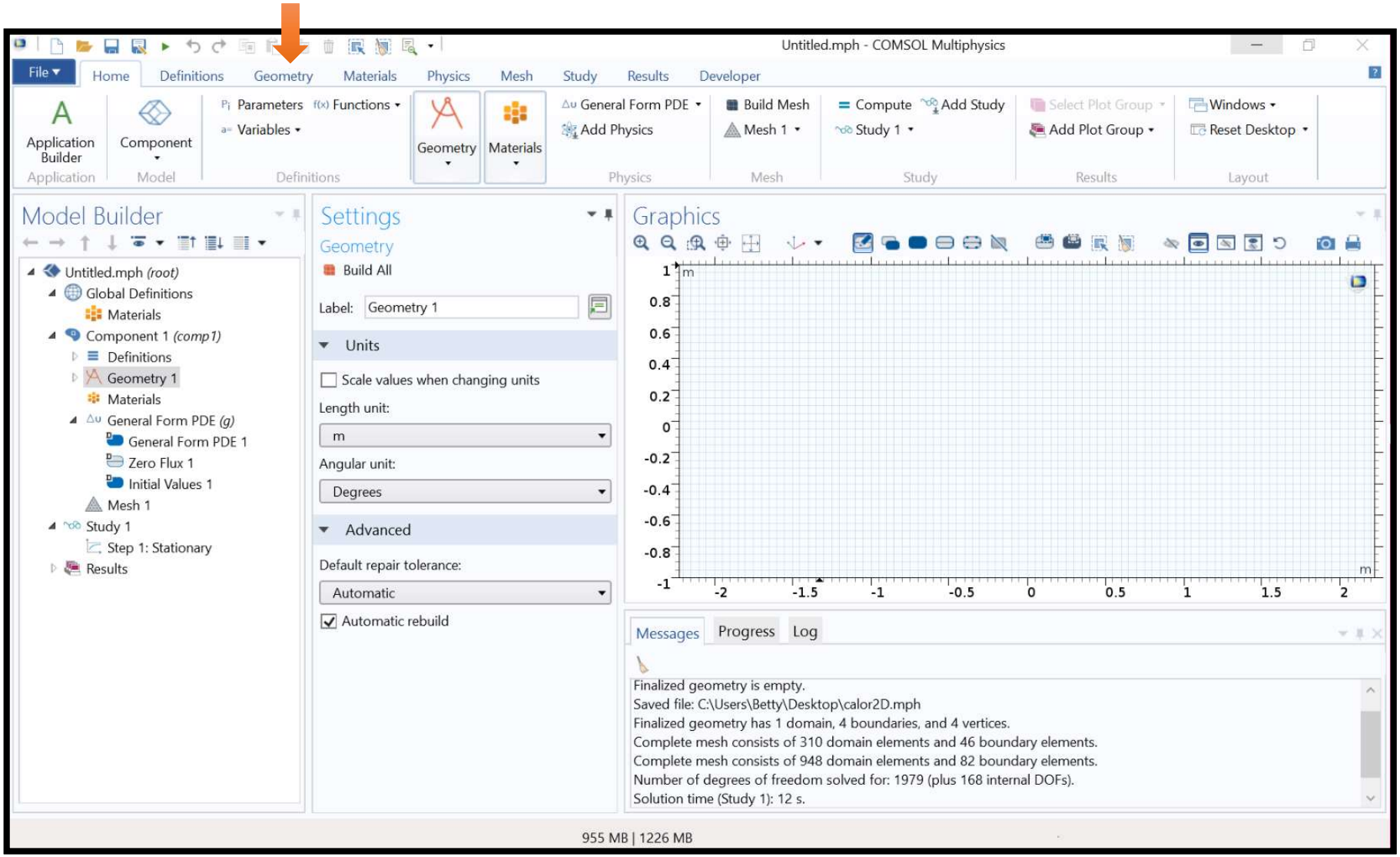
Results
Developer
Select Physics
Search
Plasma
Radio Frequency
Semiconductor
Structural Mechanics
Mathematics
PDE Interfaces
Coefficient Form PDE (c)
General Form PDE (g)
Wave Form PDE (wahw)
Weak Form PDE (w)
PDE, Boundary Elements (pdebe)
Lower Dimensions
ODE and DAE Interfaces
Optimization and Sensitivity
Add
Added physics interfaces:
General Form PDE (g)
Remove
Review Physics Interface
General Form PDE (g)
Dependent Variables
Field name:
u
Number of dependent variables:
1
Dependent variables:
u
Units
Dependent variable quantity
Dimensionless (1)
Source term quantity
None
Unit:
m^-2
Space Dimension
Study
Help
Cancel
Done
941 MB | 1194 MB

CEMAC


calor2D.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
Select Study
Preset Studies
Eigenvalue
Stationary
Time Dependent
Custom Studies
Empty Study
Added study:
Stationary
Added physics interfaces:
General Form PDE (g)
Physics
Help
Cancel
Done
Stationary
The Stationary study is used when field variables do not change over time.
Examples: In electromagnetics, it is used to compute static electric or magnetic fields, as well as direct currents. In heat transfer, it is used to compute the temperature field at thermal equilibrium. In solid mechanics, it is used to compute deformations, stresses, and strains at static equilibrium. In fluid flow it is used to compute the steady flow and pressure fields. In chemical species transport, it is used to compute steady-state chemical composition in steady flows. In chemical reactions, it is used to compute the chemical composition at equilibrium of a reacting system.
It is also possible to compute several solutions, such as a number of load cases, or to track the nonlinear response to a slowly varying load.
948 MB | 1202 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
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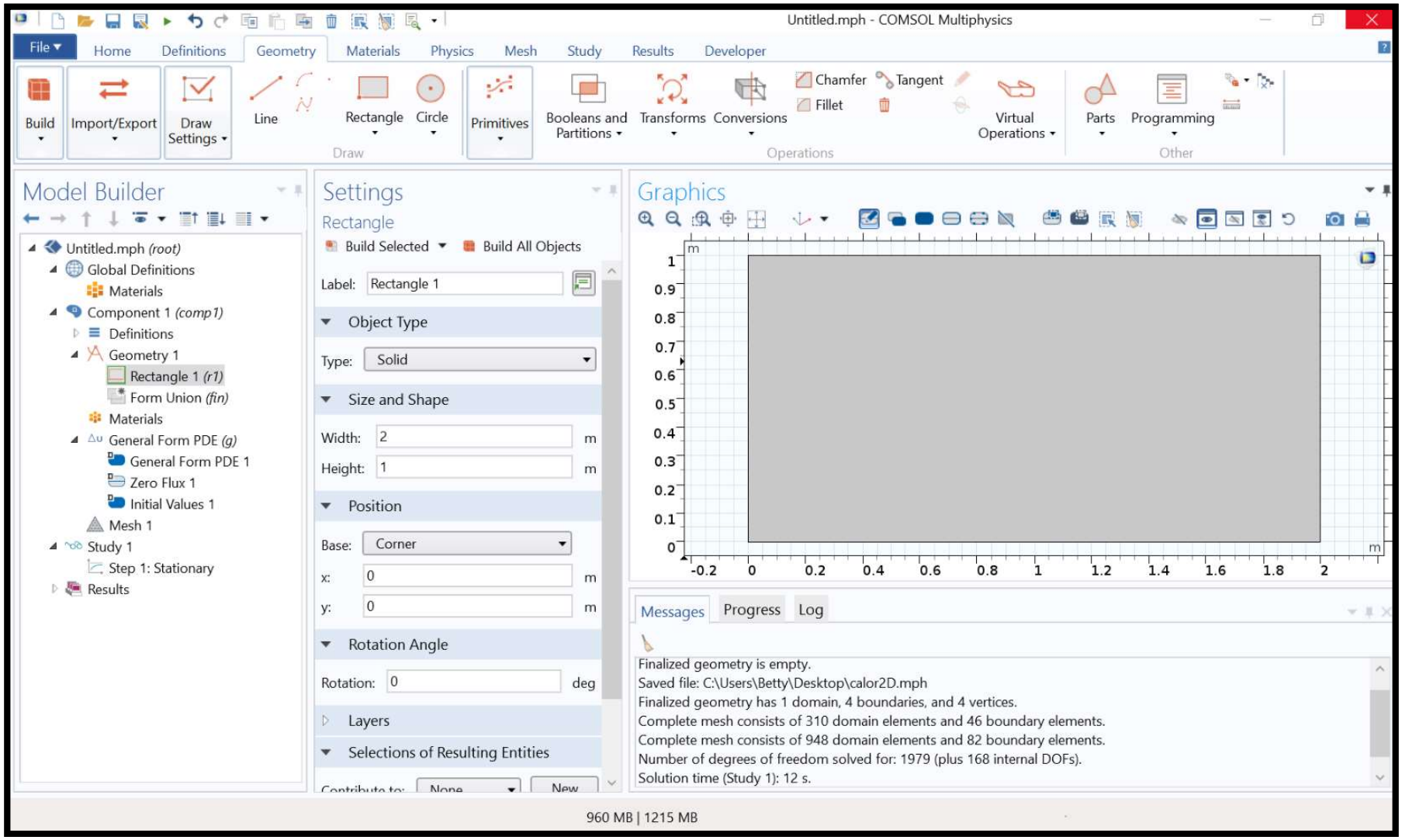
Physics
Mesh
Study
Results
Developer
Application Builder
Component
Parameters
Functions
Variables
Geometry
Materials
General Form PDE
Add Physics
Build Mesh
Mesh 1
Compute
Add Study
Study 1
Select Plot Group
Add Plot Group
Windows
Reset Desktop
Application
Model
Definitions
Physics
Mesh
Study
Results
Layout
Model Builder
Untitled.mph (root)
Global Definitions
Materials
Component 1 (comp1)
Definitions
Geometry 1
Materials
General Form PDE (g)
General Form PDE 1
Zero Flux 1
Initial Values 1
Mesh 1
Study 1
Step 1: Stationary
Results
Settings
Geometry
Build All
Label: Geometry 1
Units
Scale values when changing units
Length unit:
m
Angular unit:
Degrees
Advanced
Default repair tolerance:
Automatic
Automatic rebuild
Graphics
Messages
Progress
Log
Finalized geometry is empty.
Saved file: C:\Users\Betty\Desktop\calor2D.mph
Finalized geometry has 1 domain, 4 boundaries, and 4 vertices.
Complete mesh consists of 310 domain elements and 46 boundary elements.
Complete mesh consists of 948 domain elements and 82 boundary elements.
Number of degrees of freedom solved for: 1979 (plus 168 internal DOFs).
Solution time (Study 1): 12 s.
955 MB | 1226 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
File
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Physics
Mesh
Study
Results
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Build
Import/Export
Draw Settings
Line
Rectangle
Circle
Primitives
Draw
Booleans and Partitions
Transforms
Conversions
Chamfer
Fillet
Tangent
Virtual Operations
Operations
Parts
Programming
Other
Model Builder
Untitled.mph (root)
Global Definitions
Materials
Component 1 (comp1)
Definitions
Geometry 1
Rectangle 1 (r1)
Form Union (fin)
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General Form PDE (g)
General Form PDE 1
Zero Flux 1
Initial Values 1
Mesh 1
Study 1
Step 1: Stationary
Results
Settings
Rectangle
Build Selected
Build All Objects
Label: Rectangle 1
Object Type
Type: Solid
Size and Shape
Width: 2 m
Height: 1 m
Position
Base: Corner
x: 0 m
y: 0 m
Rotation Angle
Rotation: 0 deg
Layers
Selections of Resulting Entities
Graphics
Messages
Progress
Log
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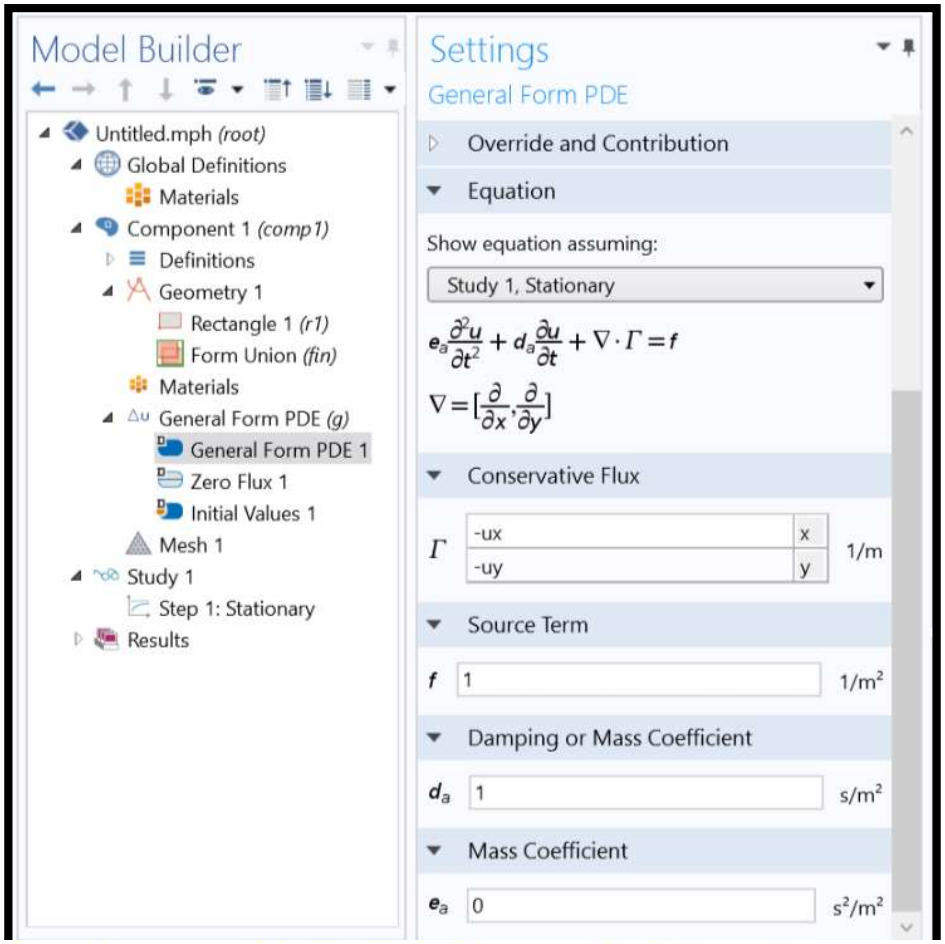
Number of degrees of freedom solved for: 1979 (plus 168 internal DOFs).
Solution time (Study 1): 12 s.
960 MB | 1215 MB

CEMAC



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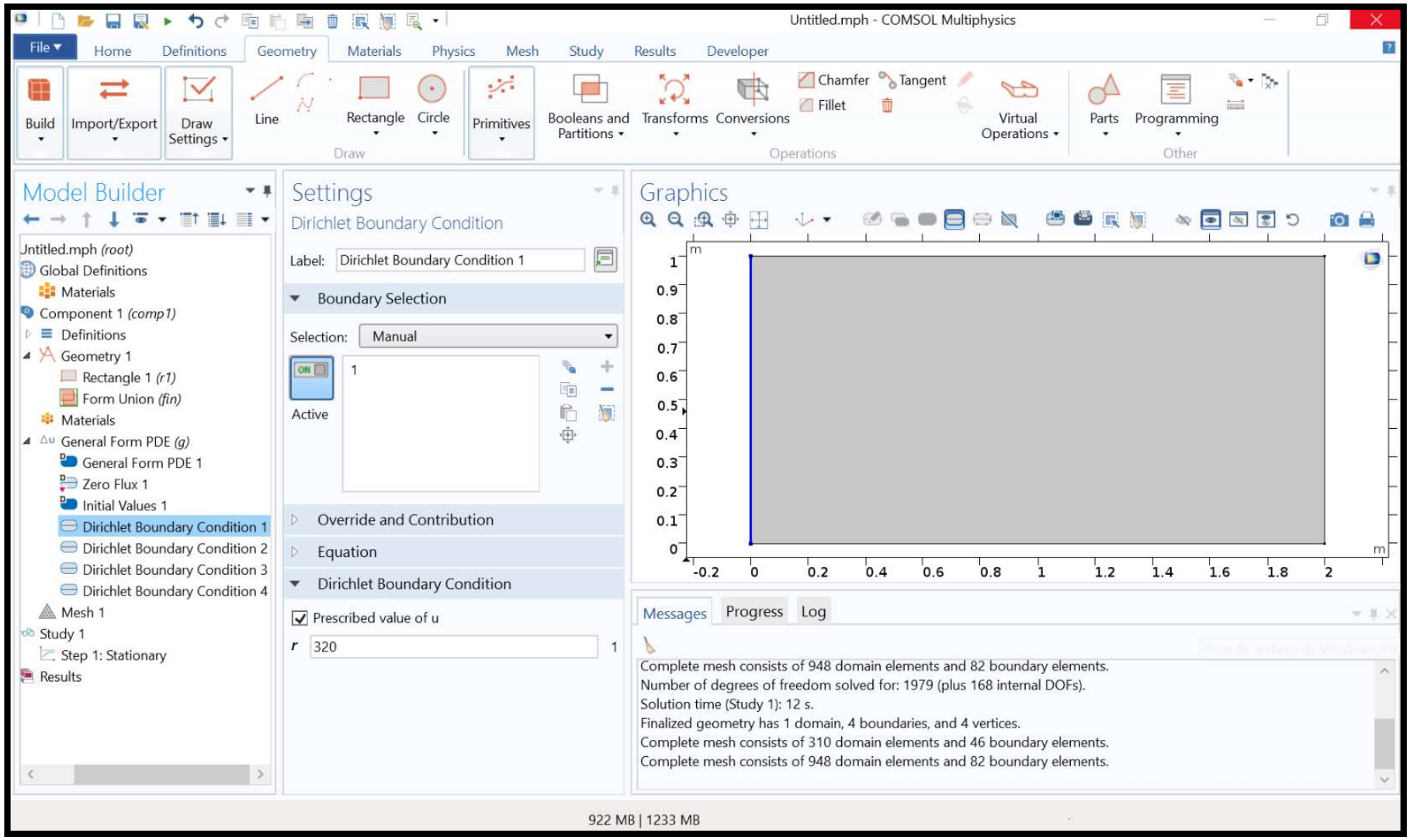
CEMAC


Untitled.mph - COMSOL Multiphysics
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Rectangle 1 (r1)
Form Union (fin)
Materials
General Form PDE (g)
General Form PDE 1
Zero Flux 1
Initial Values 1
Dirichlet Boundary Condition 1
Dirichlet Boundary Condition 2
Dirichlet Boundary Condition 3
Dirichlet Boundary Condition 4
Mesh 1
Study 1
Step 1: Stationary
Results
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Dirichlet Boundary Condition
Label: Dirichlet Boundary Condition 1
Boundary Selection
Selection: Manual
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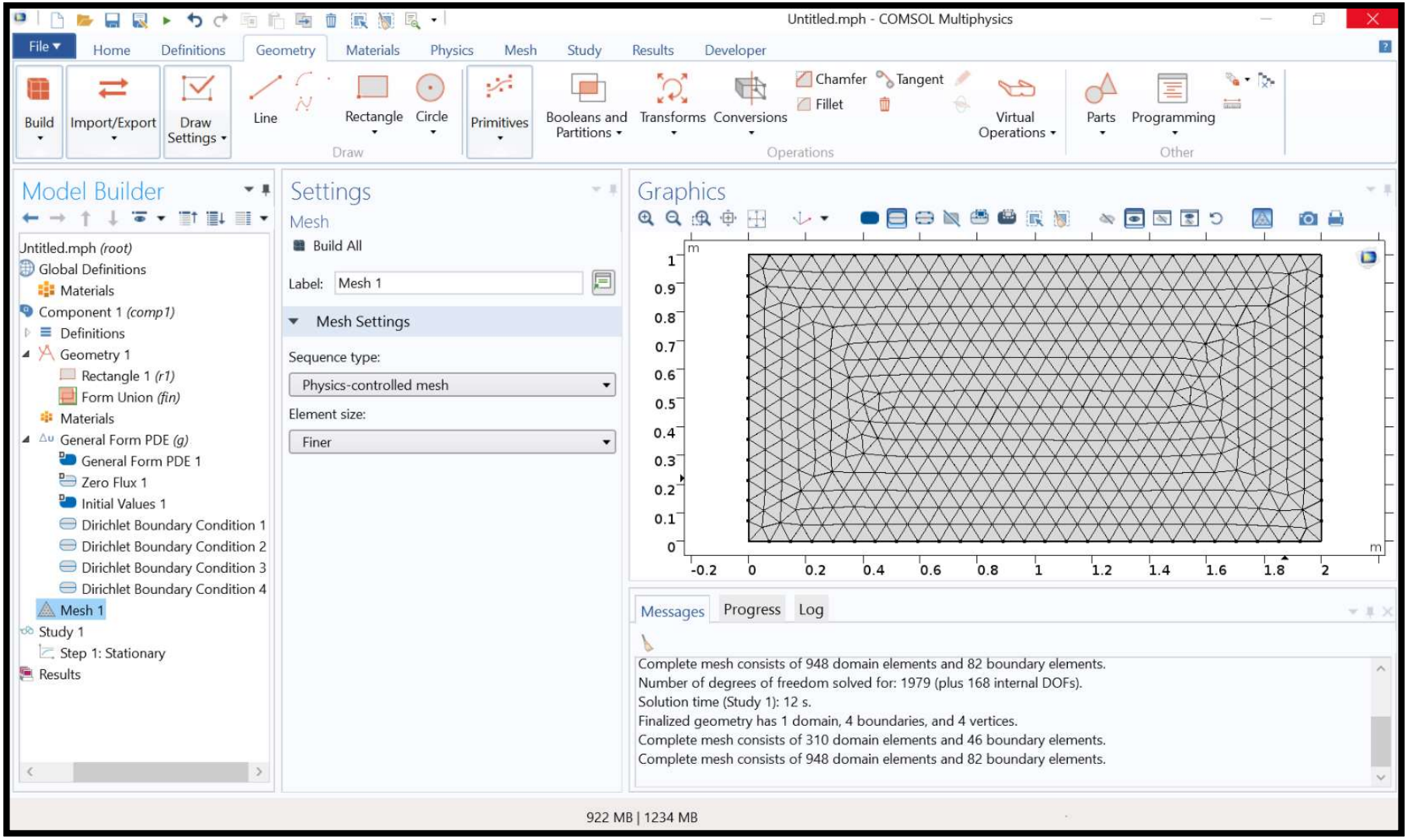
Messages
Progress
Log
Complete mesh consists of 948 domain elements and 82 boundary elements.
Number of degrees of freedom solved for: 1979 (plus 168 internal DOFs).
Solution time (Study 1): 12 s.
Finalized geometry has 1 domain, 4 boundaries, and 4 vertices.
Complete mesh consists of 310 domain elements and 46 boundary elements.
Complete mesh consists of 948 domain elements and 82 boundary elements.
922 MB | 1233 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
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Line
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Rectangle 1 (r1)
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General Form PDE (g)
General Form PDE 1
Zero Flux 1
Initial Values 1
Dirichlet Boundary Condition 1
Dirichlet Boundary Condition 2
Dirichlet Boundary Condition 3
Dirichlet Boundary Condition 4
Mesh 1
Study 1
Step 1: Stationary
Results
Settings
Mesh
Build All
Label: Mesh 1
Mesh Settings
Sequence type:
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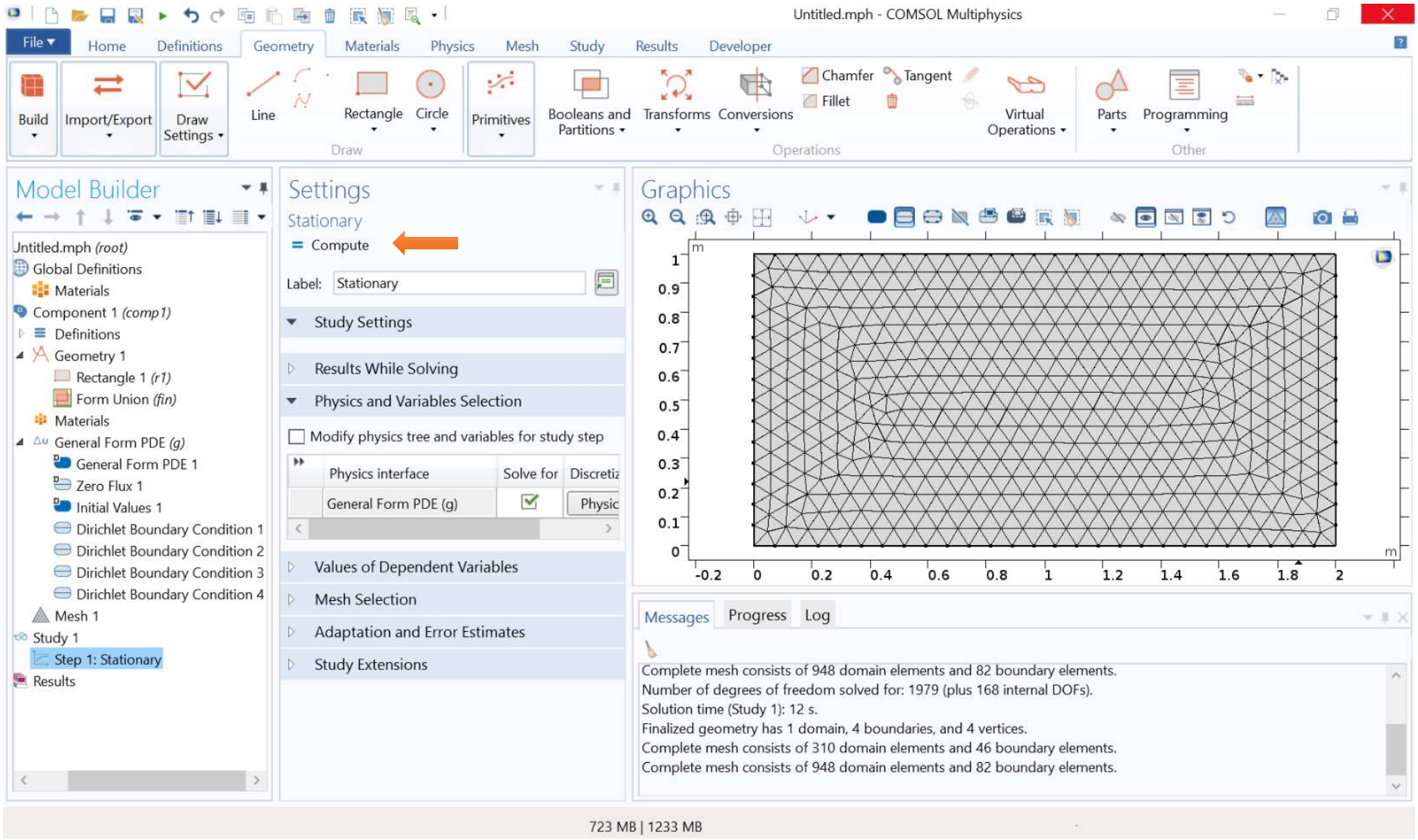
922 MB | 1234 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
File
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Definitions
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Import/Export
Draw Settings
Line
Rectangle
Circle
Primitives
Booleans and Partitions
Transforms
Conversions
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Virtual Operations
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Programming
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Model Builder
Untitled.mph (root)
Global Definitions
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Component 1 (comp1)
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Geometry 1
Rectangle 1 (r1)
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General Form PDE (g)
General Form PDE 1
Zero Flux 1
Initial Values 1
Dirichlet Boundary Condition 1
Dirichlet Boundary Condition 2
Dirichlet Boundary Condition 3
Dirichlet Boundary Condition 4
Mesh 1
Study 1
Step 1: Stationary
Results
Settings
Stationary
Compute
Label: Stationary
Study Settings
Results While Solving
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Physics interface
Solve for
Discretiz
General Form PDE (g)
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Values of Dependent Variables
Mesh Selection
Adaptation and Error Estimates
Study Extensions
Graphics
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Messages
Progress
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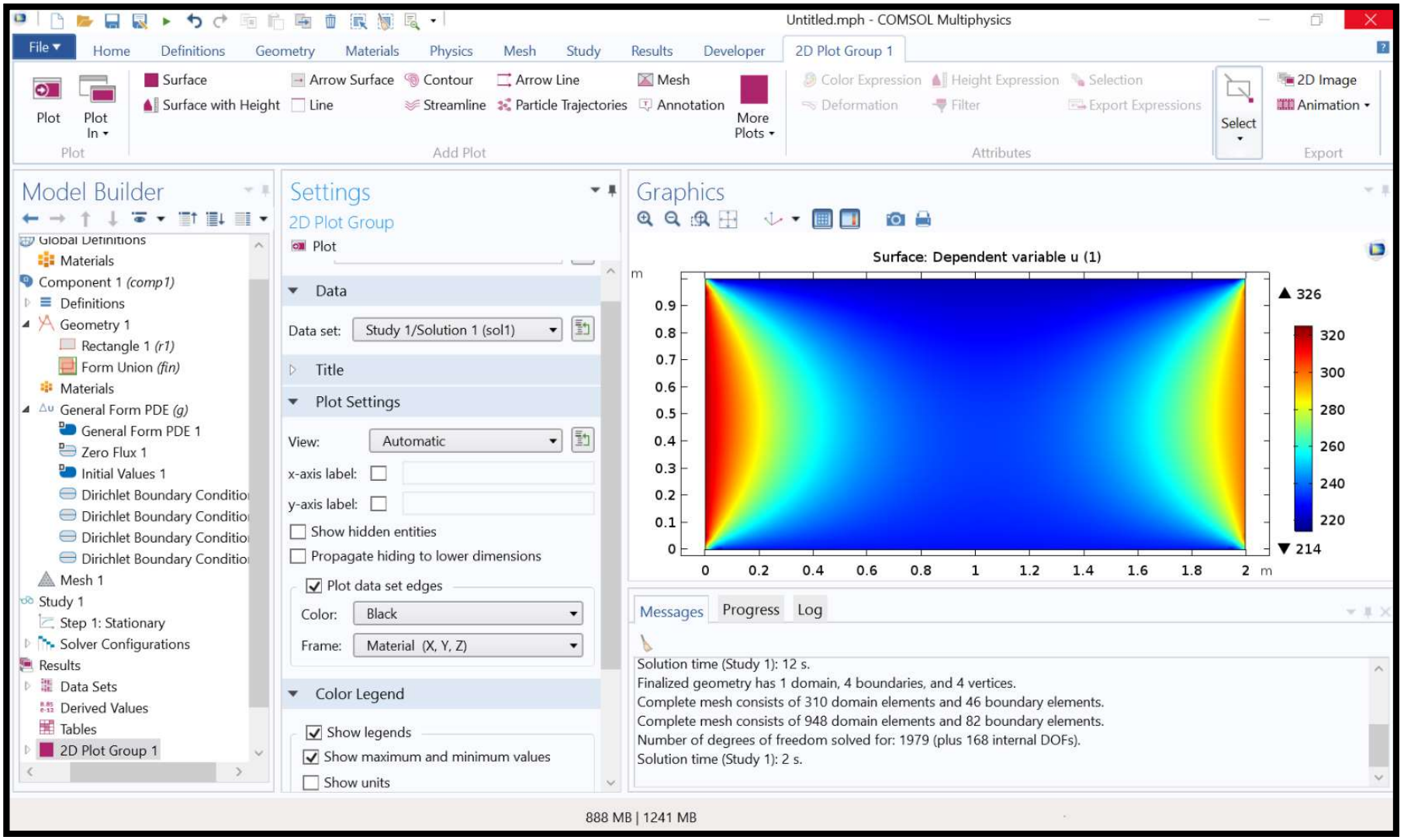
723 MB | 1233 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
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Physics
Mesh
Study
Results
Developer
2D Plot Group 1
Plot
Plot In
Surface
Surface with Height
Arrow Surface
Line
Contour
Streamline
Arrow Line
Particle Trajectories
Mesh
Annotation
More Plots
Color Expression
Deformation
Height Expression
Filter
Selection
Export Expressions
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2D Image
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General Form PDE (g)
General Form PDE 1
Zero Flux 1
Initial Values 1
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Study 1
Step 1: Stationary
Solver Configurations
Results
Data Sets
Derived Values
Tables
2D Plot Group 1
Settings
2D Plot Group
Plot
Data
Data set: Study 1/Solution 1 (sol1)
Title
Plot Settings
View: Automatic
x-axis label:
y-axis label:
Show hidden entities
Propagate hiding to lower dimensions
Plot data set edges
Color: Black
Frame: Material (X, Y, Z)
Color Legend
Show legends
Show maximum and minimum values
Show units
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Surface: Dependent variable u (1)
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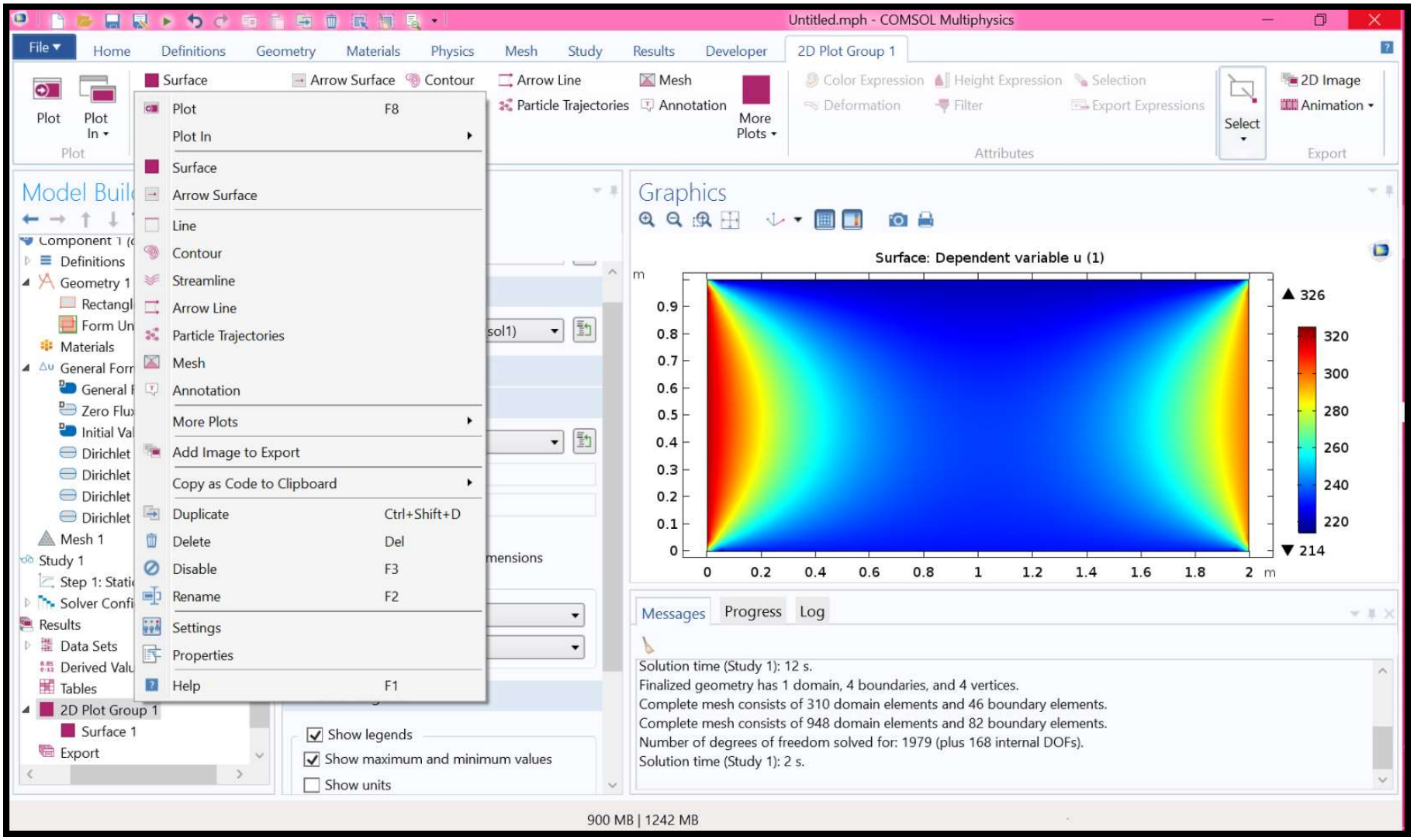
Messages
Progress
Log
Solution time (Study 1): 12 s.
Finalized geometry has 1 domain, 4 boundaries, and 4 vertices.
Complete mesh consists of 310 domain elements and 46 boundary elements.
Complete mesh consists of 948 domain elements and 82 boundary elements.
Number of degrees of freedom solved for: 1979 (plus 168 internal DOFs).
Solution time (Study 1): 2 s.
888 MB | 1241 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
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Plot In
Surface
Arrow Surface
Contour
Arrow Line
Particle Trajectories
Mesh
Annotation
More Plots
Color Expression
Height Expression
Selection
Deformation
Filter
Export Expressions
Select
2D Image
Animation
Attributes
Export
Model Builder
Component 1
Definitions
Geometry 1
Materials
Mesh 1
Study 1
Results
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Surface 1
Export
Plot F8
Plot In
Surface
Arrow Surface
Line
Contour
Streamline
Arrow Line
Particle Trajectories
Mesh
Annotation
More Plots
Add Image to Export
Copy as Code to Clipboard
Duplicate Ctrl+Shift+D
Delete Del
Disable F3
Rename F2
Settings
Properties
Help F1
Show legends
Show maximum and minimum values
Show units
Graphics
Surface: Dependent variable u (1)
m
0.9
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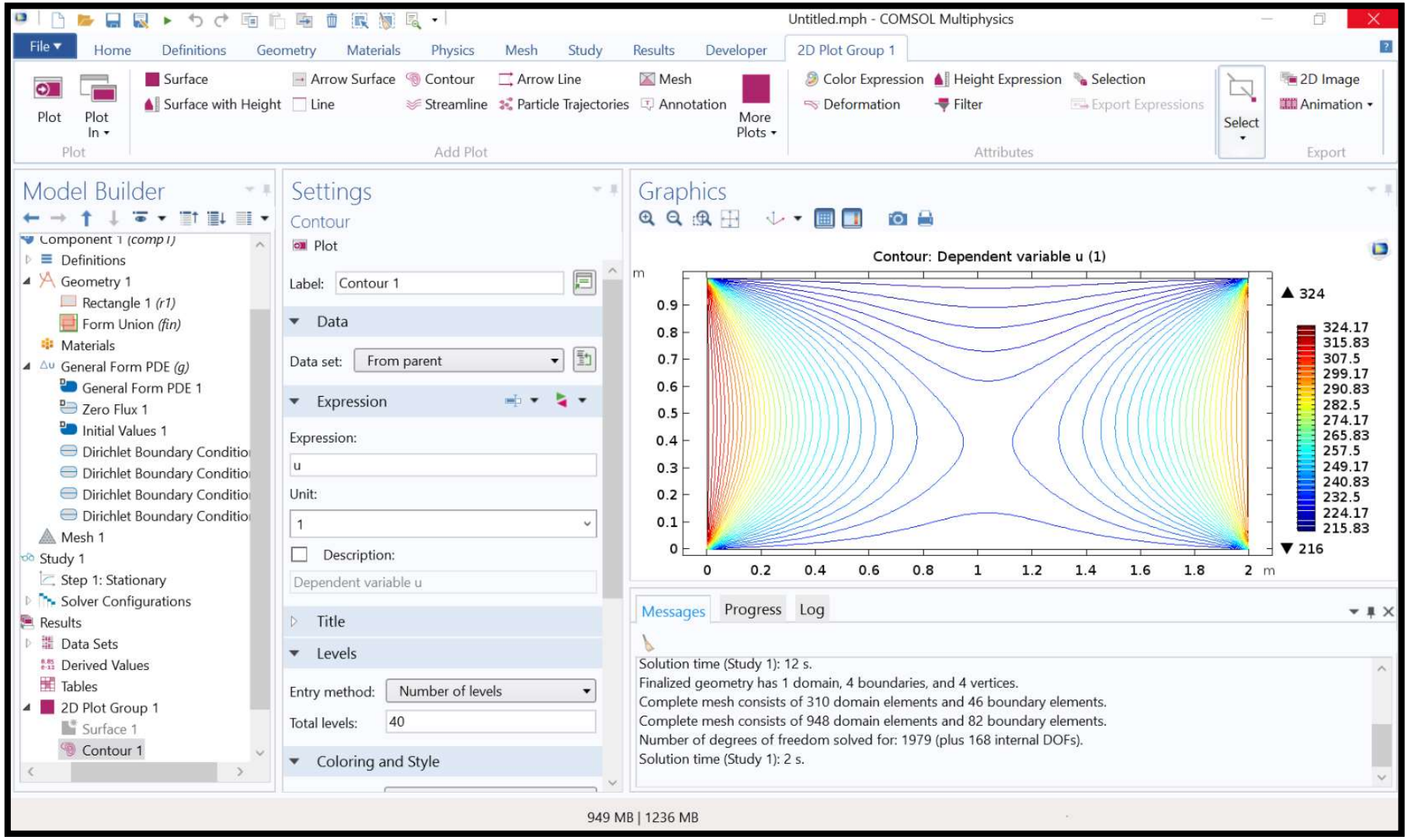
0
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 m
▲ 326
320
300
280
260
240
220
▼ 214
Messages
Progress
Log
Solution time (Study 1): 12 s.
Finalized geometry has 1 domain, 4 boundaries, and 4 vertices.
Complete mesh consists of 310 domain elements and 46 boundary elements.
Complete mesh consists of 948 domain elements and 82 boundary elements.
Number of degrees of freedom solved for: 1979 (plus 168 internal DOFs).
Solution time (Study 1): 2 s.
900 MB | 1242 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
2D Plot Group 1
Plot
Plot In
Surface
Surface with Height
Arrow Surface
Line
Contour
Streamline
Arrow Line
Particle Trajectories
Mesh
Annotation
More Plots
Color Expression
Deformation
Height Expression
Filter
Selection
Export Expressions
Select
2D Image
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Form Union (fin)
Materials
General Form PDE (g)
General Form PDE 1
Zero Flux 1
Initial Values 1
Dirichlet Boundary Condition
Dirichlet Boundary Condition
Dirichlet Boundary Condition
Dirichlet Boundary Condition
Mesh 1
Study 1
Step 1: Stationary
Solver Configurations
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Derived Values
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2D Plot Group 1
Surface 1
Contour 1
Settings
Contour
Plot
Label: Contour 1
Data
Data set: From parent
Expression
Expression:
u
Unit:
1
Description:
Dependent variable u
Title
Levels
Entry method: Number of levels
Total levels: 40
Coloring and Style
Graphics
Contour: Dependent variable u (1)
m
0.9
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0.8
1
1.2
1.4
1.6
1.8
2
m
▲ 324
324.17
315.83
307.5
299.17
290.83
282.5
274.17
265.83
257.5
249.17
240.83
232.5
224.17
215.83
▼ 216
Messages
Progress
Log
Solution time (Study 1): 12 s.
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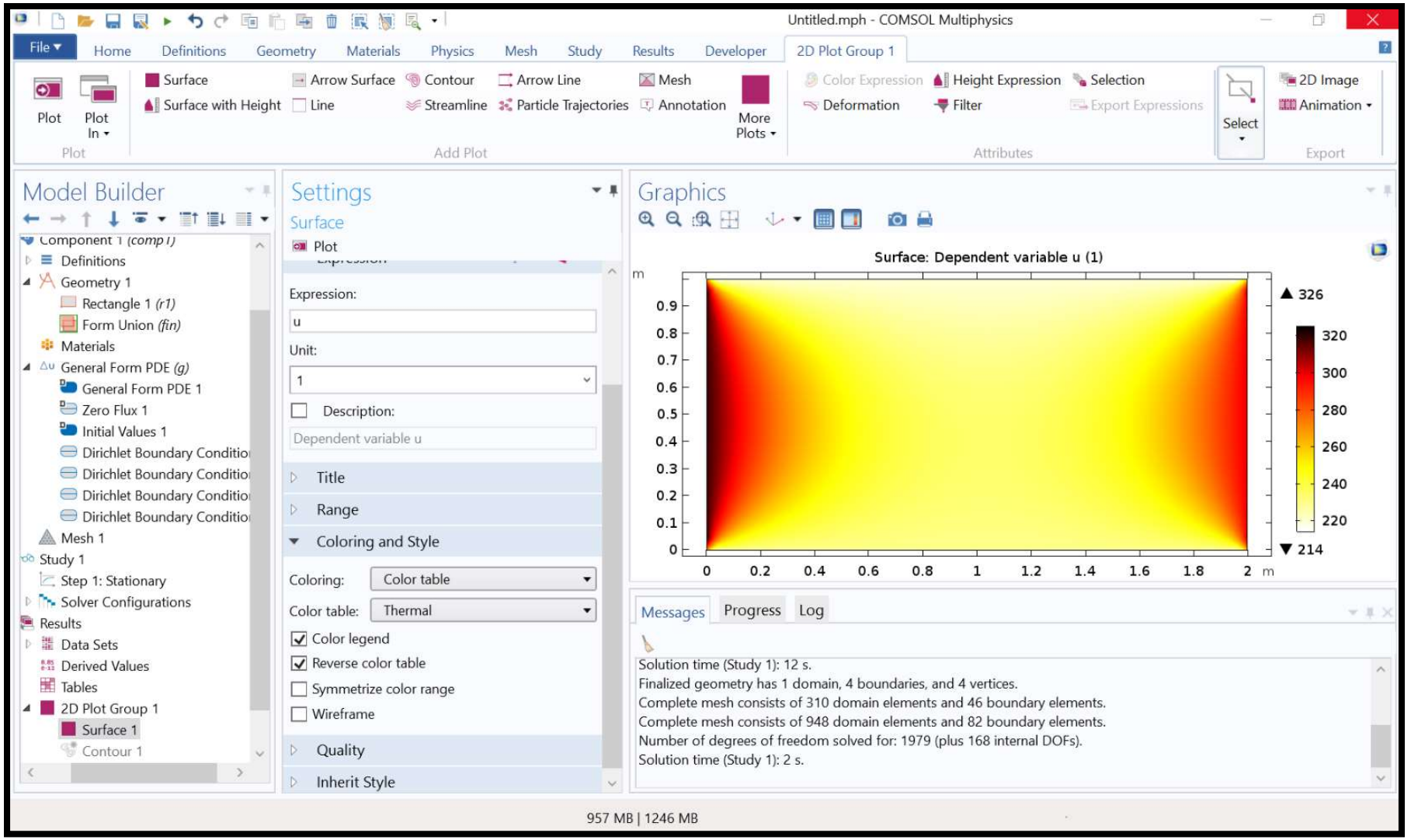
Complete mesh consists of 948 domain elements and 82 boundary elements.
Number of degrees of freedom solved for: 1979 (plus 168 internal DOFs).
Solution time (Study 1): 2 s.
949 MB | 1236 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
File
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Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
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Plot In
Surface
Surface with Height
Arrow Surface
Line
Contour
Streamline
Arrow Line
Particle Trajectories
Mesh
Annotation
More Plots
Color Expression
Deformation
Height Expression
Filter
Selection
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Plot
Add Plot
Attributes
Export
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Geometry 1
Rectangle 1 (r1)
Form Union (fin)
Materials
General Form PDE (g)
General Form PDE 1
Zero Flux 1
Initial Values 1
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Solver Configurations
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Data Sets
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2D Plot Group 1
Surface 1
Contour 1
Settings
Surface
Plot
Expression:
u
Unit:
1
Description:
Dependent variable u
Title
Range
Coloring and Style
Coloring:
Color table
Color table:
Thermal
Color legend
Reverse color table
Symmetrize color range
Wireframe
Quality
Inherit Style
Graphics
Surface: Dependent variable u (1)
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0.3
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0.2
0.4
0.6
0.8
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1.2
1.4
1.6
1.8
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▼ 214
Messages
Progress
Log
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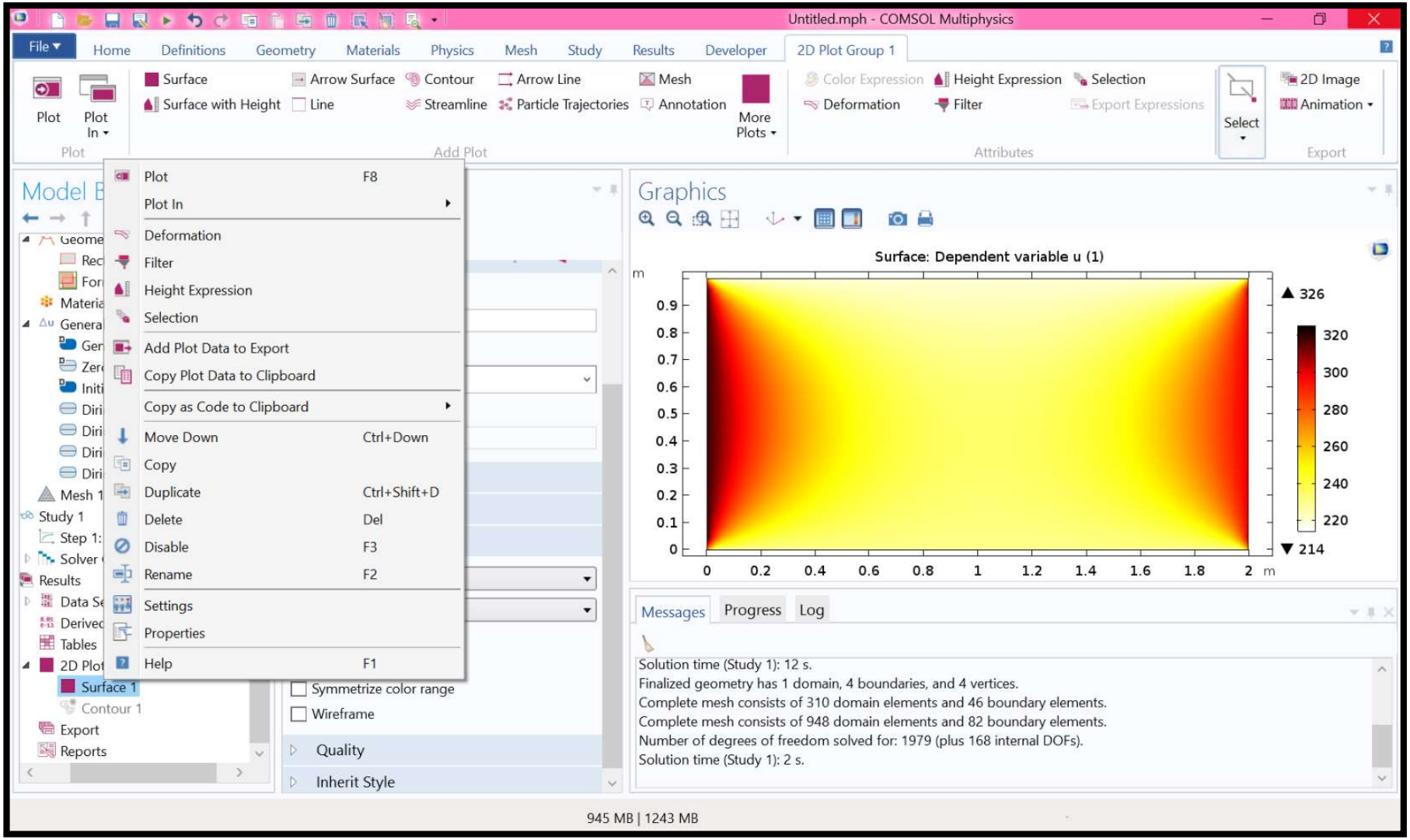
Complete mesh consists of 948 domain elements and 82 boundary elements.
Number of degrees of freedom solved for: 1979 (plus 168 internal DOFs).
Solution time (Study 1): 2 s.
957 MB | 1246 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
2D Plot Group 1
Plot
Plot In
Surface
Surface with Height
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More Plots
Color Expression
Deformation
Height Expression
Filter
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Export Expressions
Select
2D Image
Animation
Plot
Add Plot
Attributes
Export
Plot F8
Plot In
Deformation
Filter
Height Expression
Selection
Add Plot Data to Export
Copy Plot Data to Clipboard
Copy as Code to Clipboard
Move Down Ctrl+Down
Copy
Duplicate Ctrl+Shift+D
Delete Del
Disable F3
Rename F2
Settings
Properties
Help F1
Graphics
Surface: Dependent variable u (1)
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0.7
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▼ 214
Messages
Progress
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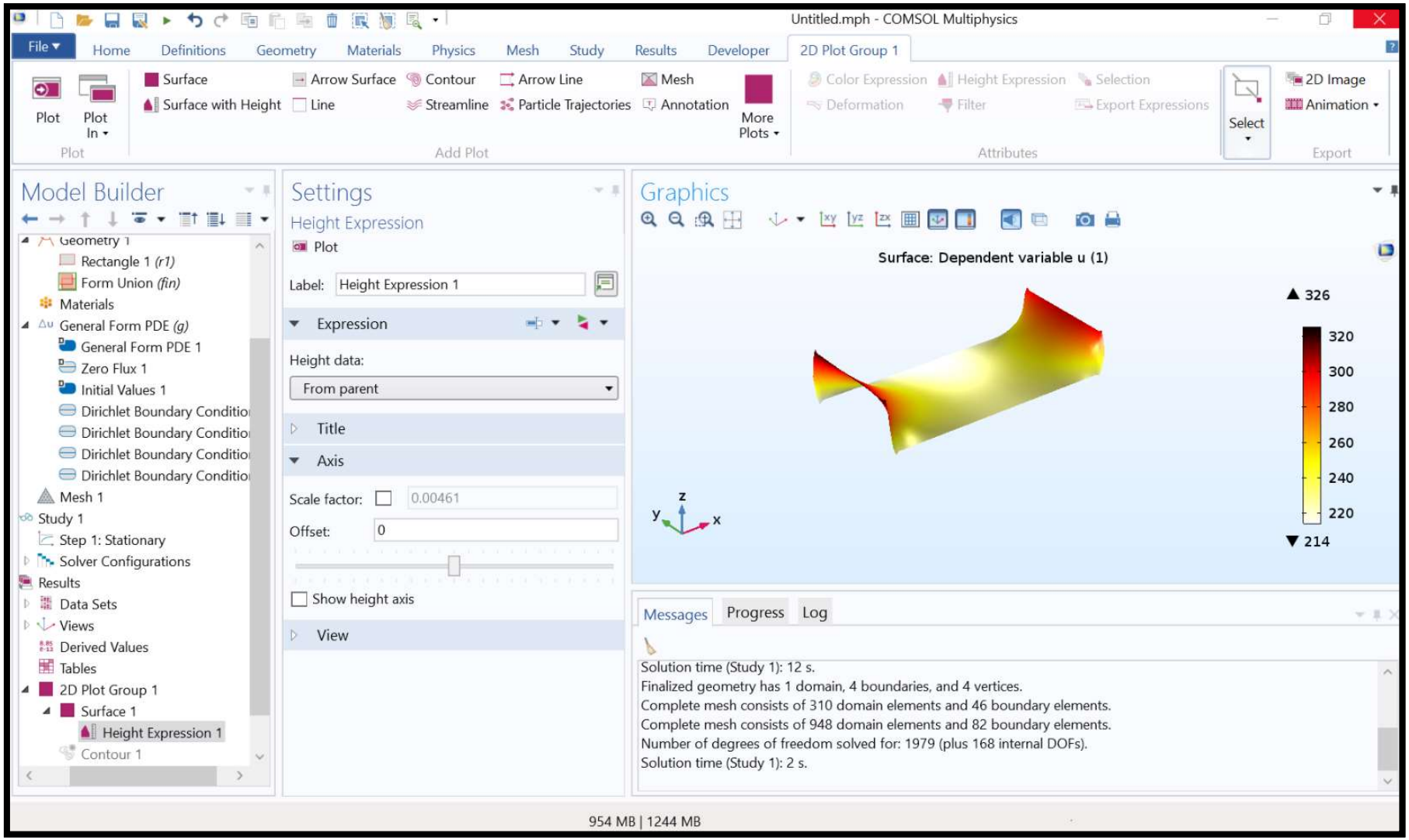
Solution time (Study 1): 2 s.
Mesh 1
Study 1
Step 1:
Solver
Results
Data Se
Derived
Tables
2D Plot
Surface 1
Contour 1
Export
Reports
Symmetrize color range
Wireframe
Quality
Inherit Style
945 MB | 1243 MB

CEMAC


Untitled.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
2D Plot Group 1
Plot
Plot In
Surface
Surface with Height
Arrow Surface
Line
Contour
Streamline
Arrow Line
Particle Trajectories
Mesh
Annotation
More Plots
Color Expression
Height Expression
Selection
Deformation
Filter
Export Expressions
Select
2D Image
Animation
Plot
Add Plot
Attributes
Export
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Geometry 1
Rectangle 1 (r1)
Form Union (fin)
Materials
General Form PDE (g)
General Form PDE 1
Zero Flux 1
Initial Values 1
Dirichlet Boundary Conditio
Dirichlet Boundary Conditio
Dirichlet Boundary Conditio
Dirichlet Boundary Conditio
Mesh 1
Study 1
Step 1: Stationary
Solver Configurations
Results
Data Sets
Views
Derived Values
Tables
2D Plot Group 1
Surface 1
Height Expression 1
Contour 1
Settings
Height Expression
Plot
Label: Height Expression 1
Expression
Height data:
From parent
Title
Axis
Scale factor: 0.00461
Offset: 0
Show height axis
View
Graphics
Surface: Dependent variable u (1)
▲ 326
320
300
280
260
240
220
▼ 214
z
y
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Messages
Progress
Log
Solution time (Study 1): 12 s.
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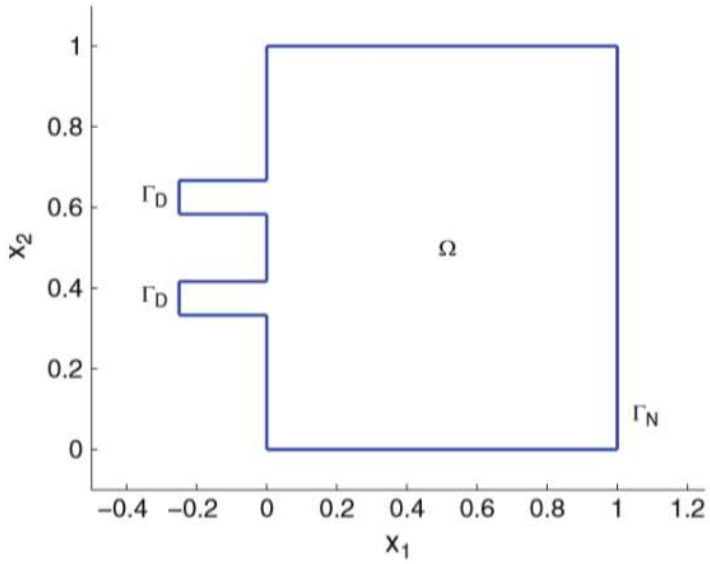
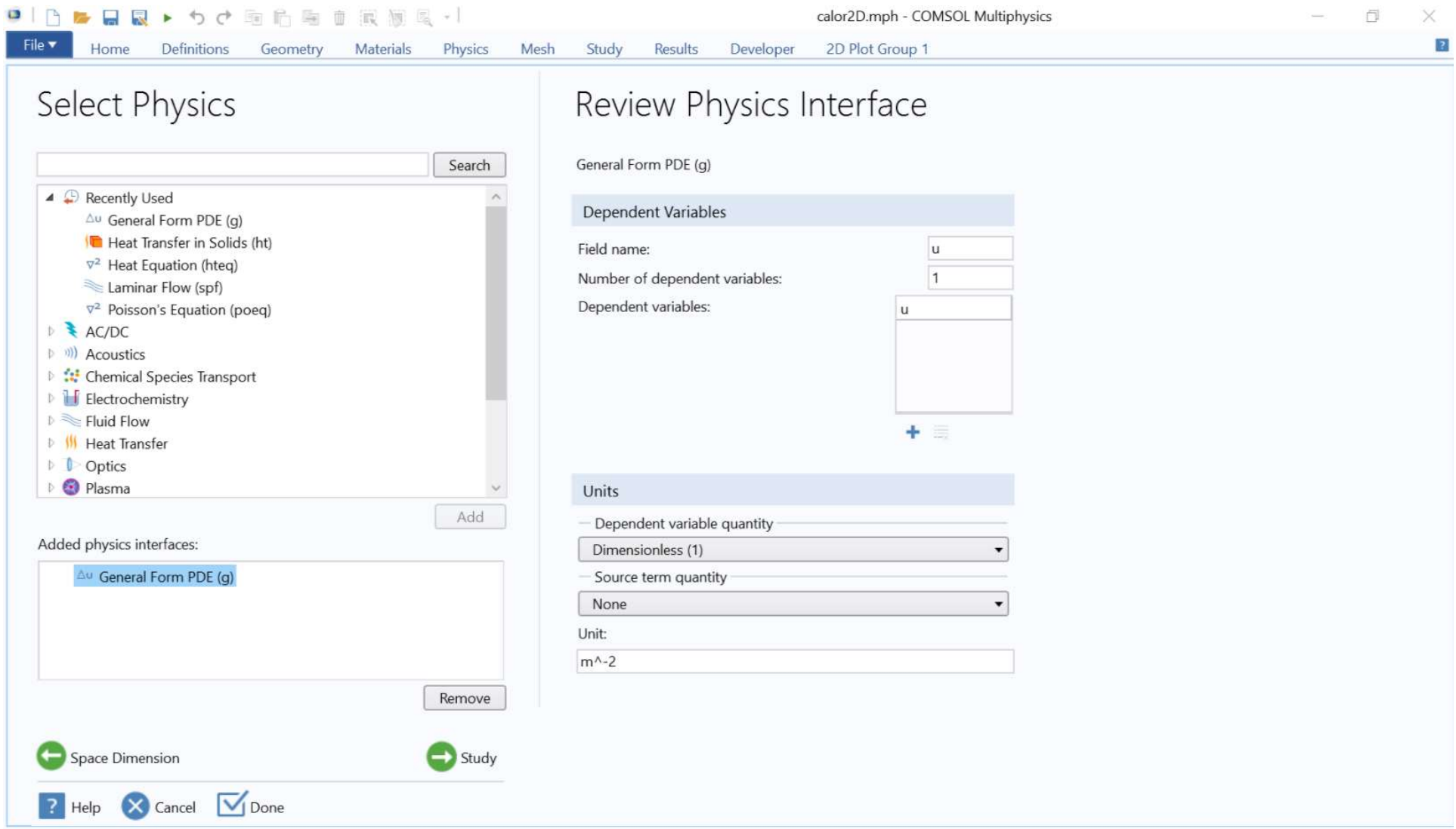
Complete mesh consists of 948 domain elements and 82 boundary elements.
Number of degrees of freedom solved for: 1979 (plus 168 internal DOFs).
Solution time (Study 1): 2 s.
954 MB | 1244 MB

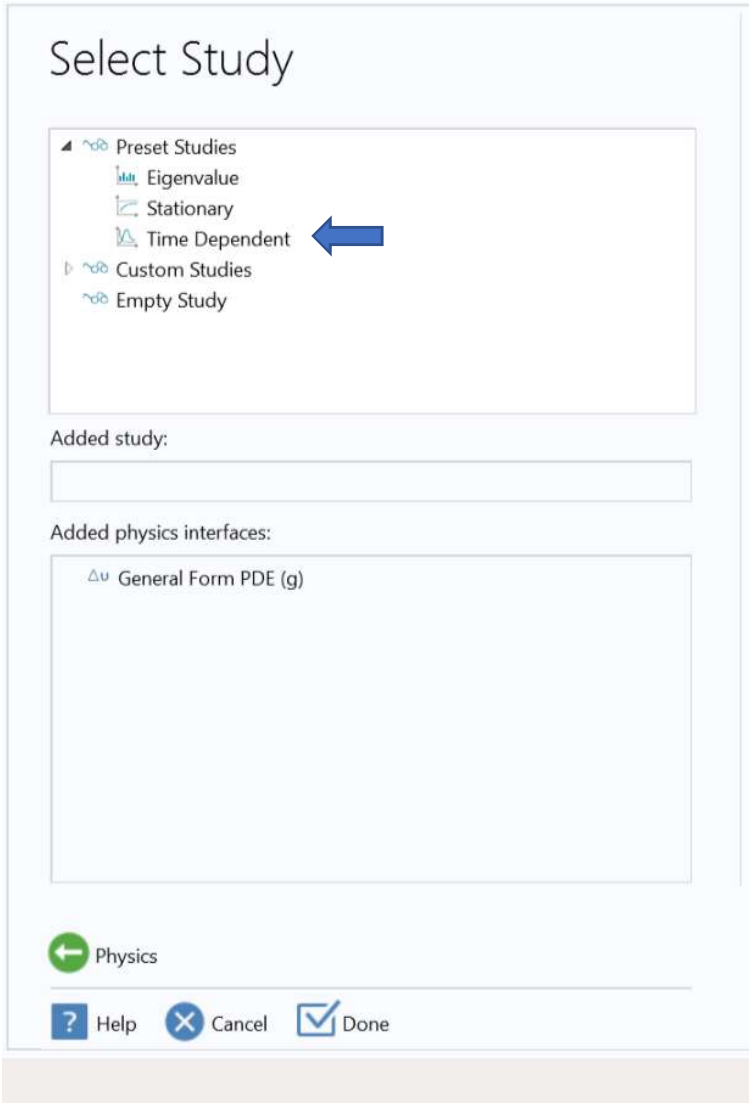
CEMAC



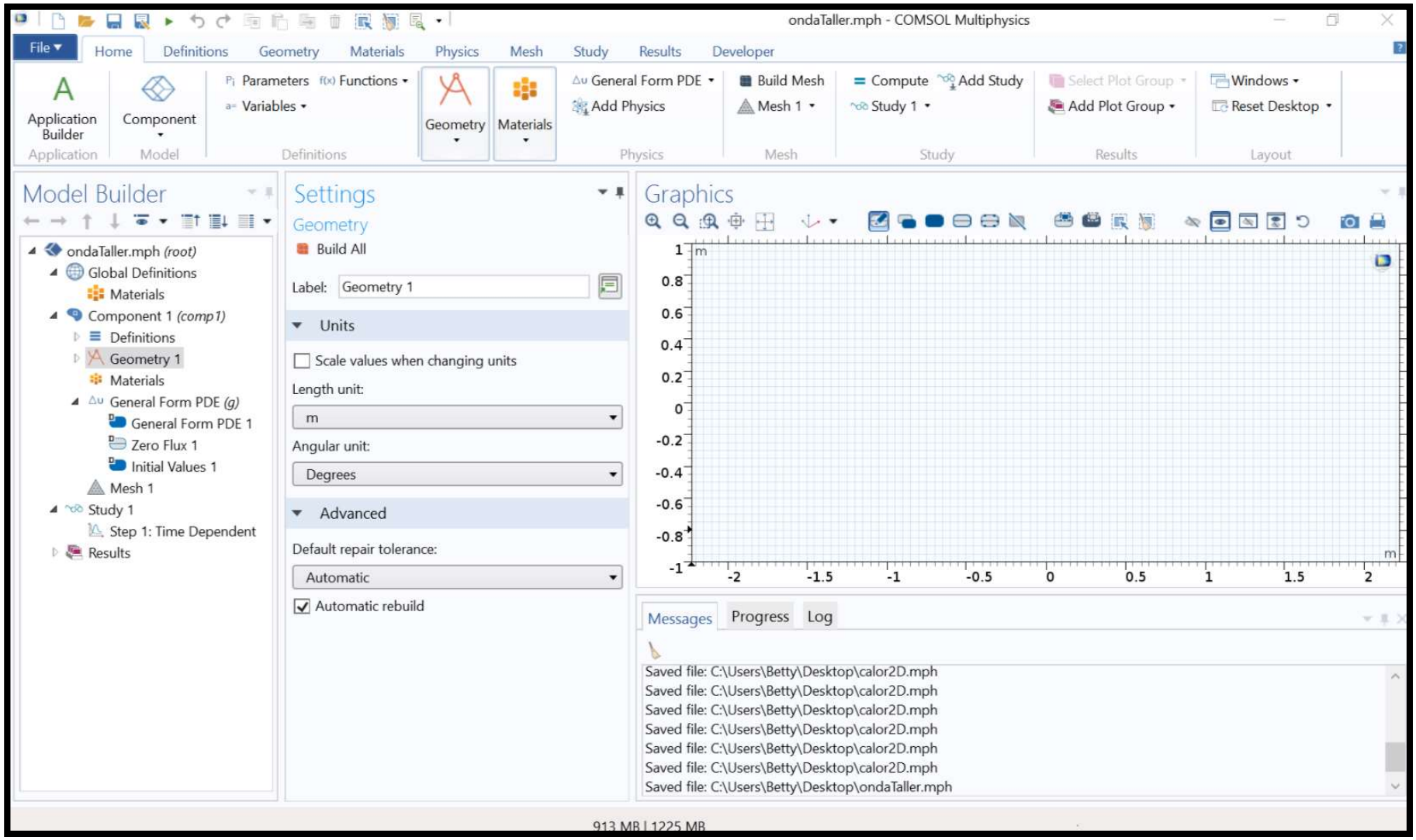
A MATLAB code for solving the Wave equation is given below. The problem under consideration is $\ddot{u} - \Delta u = 0$ in a domain Ω composed of a square with two smaller rectangular strips added on one side. This domain is shown in Fig. 5.3. The boundary conditions are $u = 0.1\sin(8\pi t)$ on the line segments $\Gamma_D = \{x : x_1 = -0.25\}$, and $n \cdot \nabla u = 0$ on the rest of the boundary Γ_N. Thus, we have both Dirichlet and Neumann boundary conditions. The initial condition u_0 is zero.


calor2D.mph - COMSOL Multiphysics
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
2D Plot Group 1
Select Physics
Search
Recently Used
General Form PDE (g)
Heat Transfer in Solids (ht)
Heat Equation (hteq)
Laminar Flow (spf)
Poisson's Equation (poeq)
AC/DC
Acoustics
Chemical Species Transport
Electrochemistry
Fluid Flow
Heat Transfer
Optics
Plasma
Add
Added physics interfaces:
General Form PDE (g)
Remove
Space Dimension
Study
Help
Cancel
Done
Review Physics Interface
General Form PDE (g)
Dependent Variables
Field name:
u
Number of dependent variables:
1
Dependent variables:
u
Units
Dependent variable quantity
Dimensionless (1)
Source term quantity
None
Unit:
m^-2
665 MB | 1233 MB

CEMAC


Select Study
Preset Studies
Eigenvalue
Stationary
Time Dependent
Custom Studies
Empty Study
Added study:
Added physics interfaces:
General Form PDE (g)
Physics
Help
Cancel
Done

CEMAC


ondaTaller.mph - COMSOL Multiphysics
File
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Definitions
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Study
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Application Builder
Component
Parameters
Functions
Variables
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Materials
General Form PDE
Add Physics
Build Mesh
Mesh 1
Compute
Add Study
Study 1
Select Plot Group
Add Plot Group
Windows
Reset Desktop
Application
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General Form PDE 1
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Build All
Label: Geometry 1
Units
Scale values when changing units
Length unit:
m
Angular unit:
Degrees
Advanced
Default repair tolerance:
Automatic
Automatic rebuild
Graphics
Messages
Progress
Log
Saved file: C:\Users\Betty\Desktop\calor2D.mph
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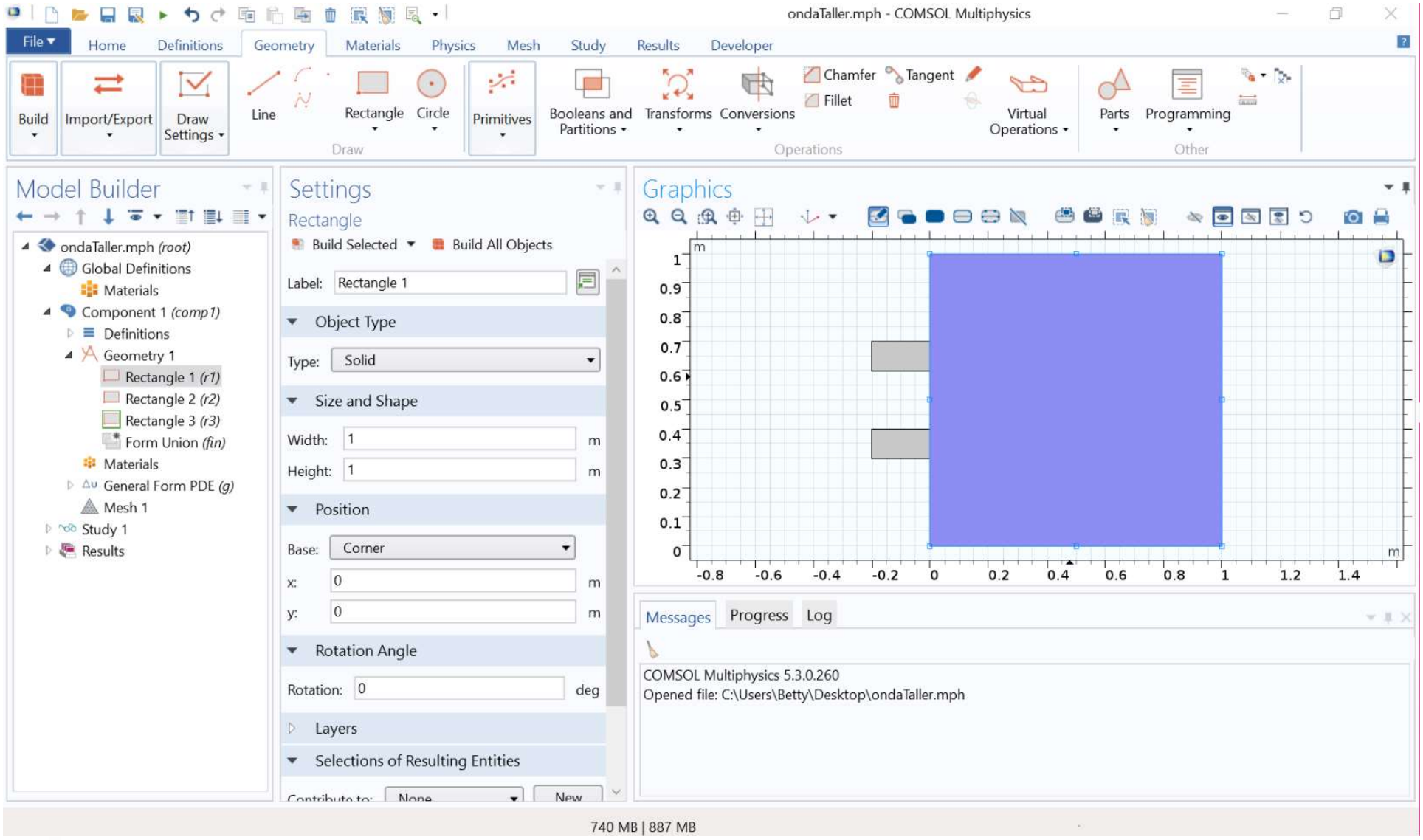
913 MB | 1225 MB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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Rectangle 2 (r2)
Rectangle 3 (r3)
Form Union (fin)
Materials
General Form PDE (g)
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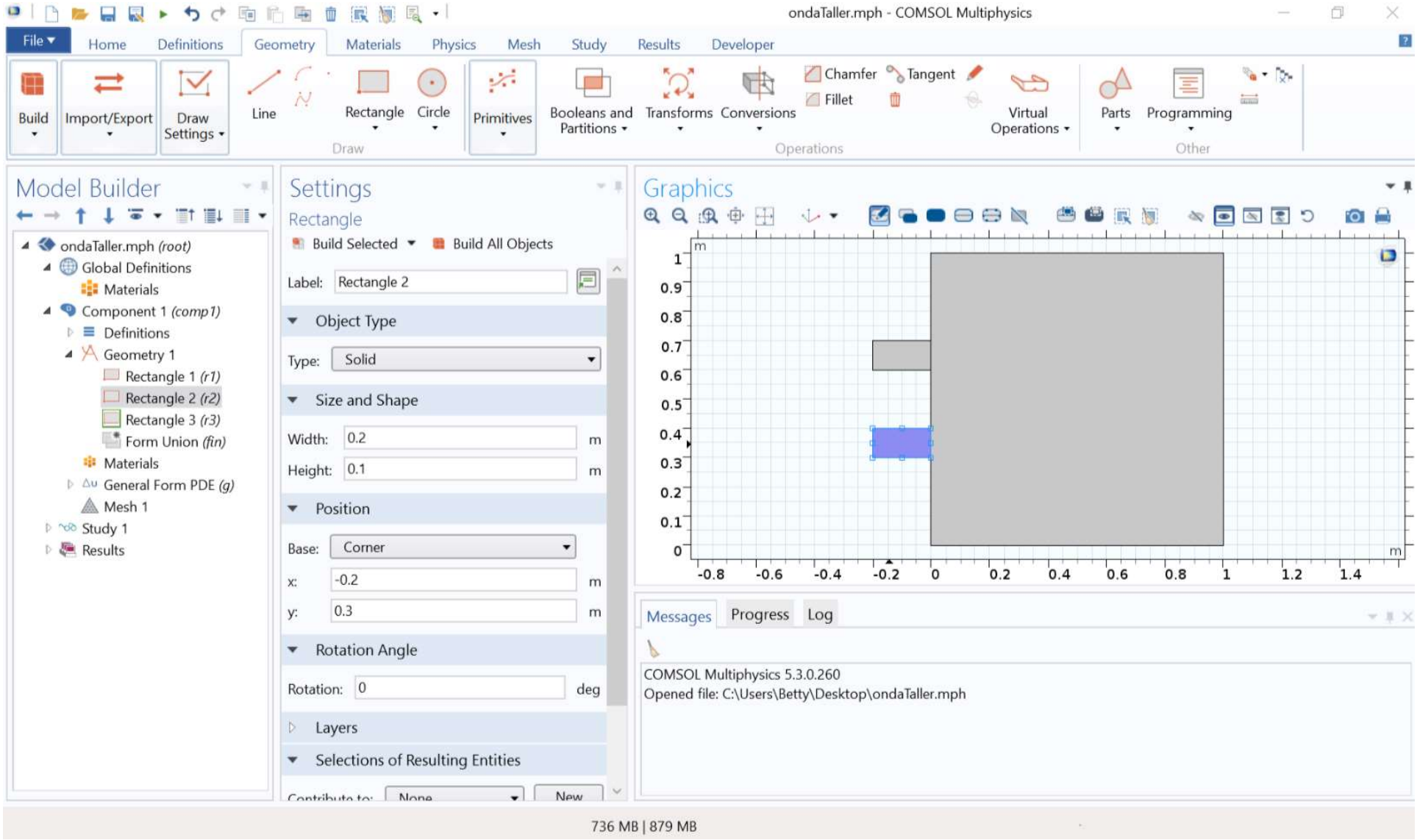
Study 1
Results
Settings
Rectangle
Build Selected
Build All Objects
Label: Rectangle 1
Object Type
Type: Solid
Size and Shape
Width: 1 m
Height: 1 m
Position
Base: Corner
x: 0 m
y: 0 m
Rotation Angle
Rotation: 0 deg
Layers
Selections of Resulting Entities
Graphics
Messages
Progress
Log
COMSOL Multiphysics 5.3.0.260
Opened file: C:\Users\Betty\Desktop\ondaTaller.mph
740 MB | 887 MB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
File
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Rectangle 2 (r2)
Rectangle 3 (r3)
Form Union (fin)
Materials
General Form PDE (g)
Mesh 1
Study 1
Results
Settings
Rectangle
Build Selected
Build All Objects
Label: Rectangle 2
Object Type
Type: Solid
Size and Shape
Width: 0.2 m
Height: 0.1 m
Position
Base: Corner
x: -0.2 m
y: 0.3 m
Rotation Angle
Rotation: 0 deg
Layers
Selections of Resulting Entities
Graphics
Messages
Progress
Log
COMSOL Multiphysics 5.3.0.260
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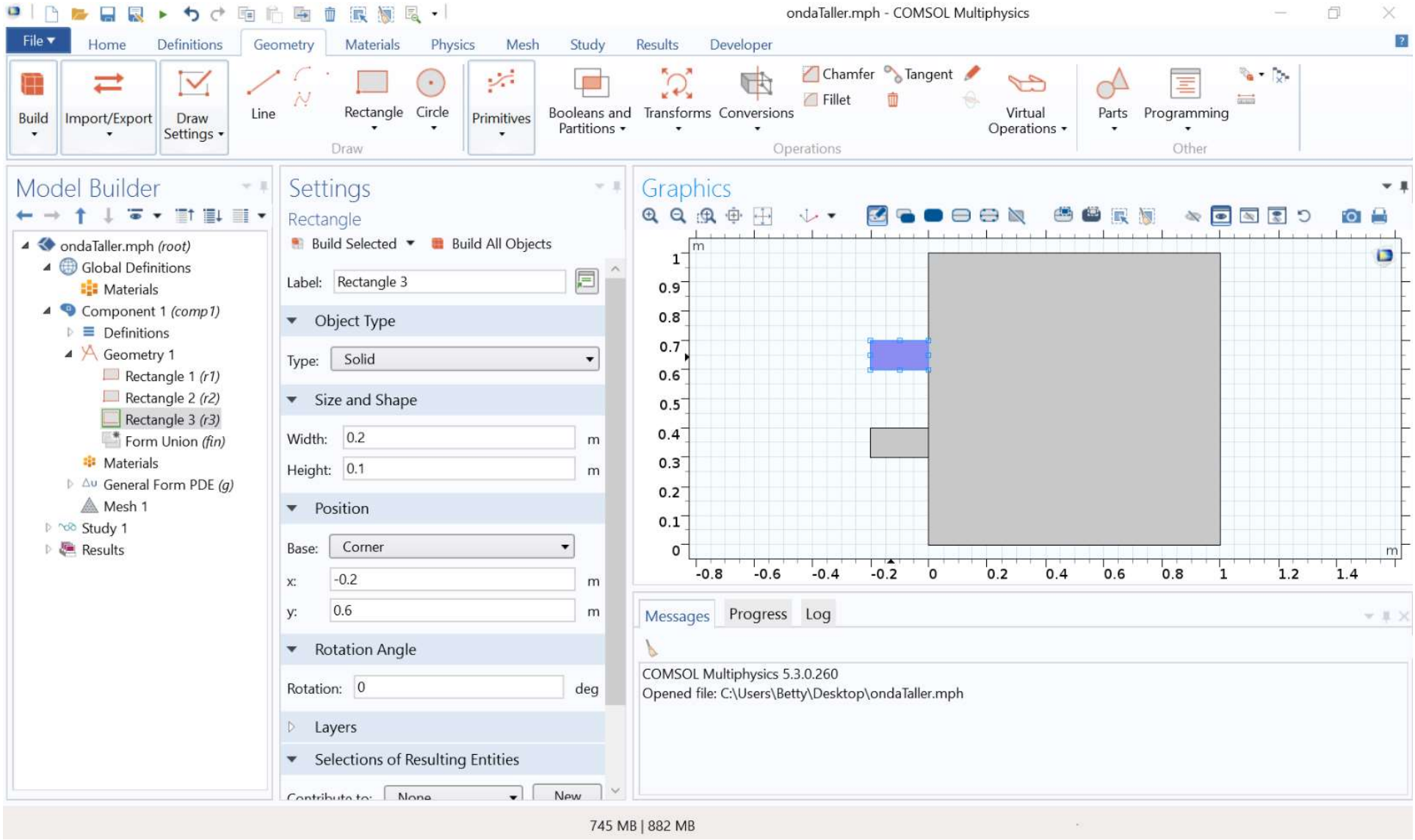
736 MB | 879 MB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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Rectangle 2 (r2)
Rectangle 3 (r3)
Form Union (fin)
Materials
General Form PDE (g)
Mesh 1
Study 1
Results
Settings
Rectangle
Build Selected
Build All Objects
Label: Rectangle 3
Object Type
Type: Solid
Size and Shape
Width: 0.2 m
Height: 0.1 m
Position
Base: Corner
x: -0.2 m
y: 0.6 m
Rotation Angle
Rotation: 0 deg
Layers
Selections of Resulting Entities
Graphics
Messages
Progress
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COMSOL Multiphysics 5.3.0.260
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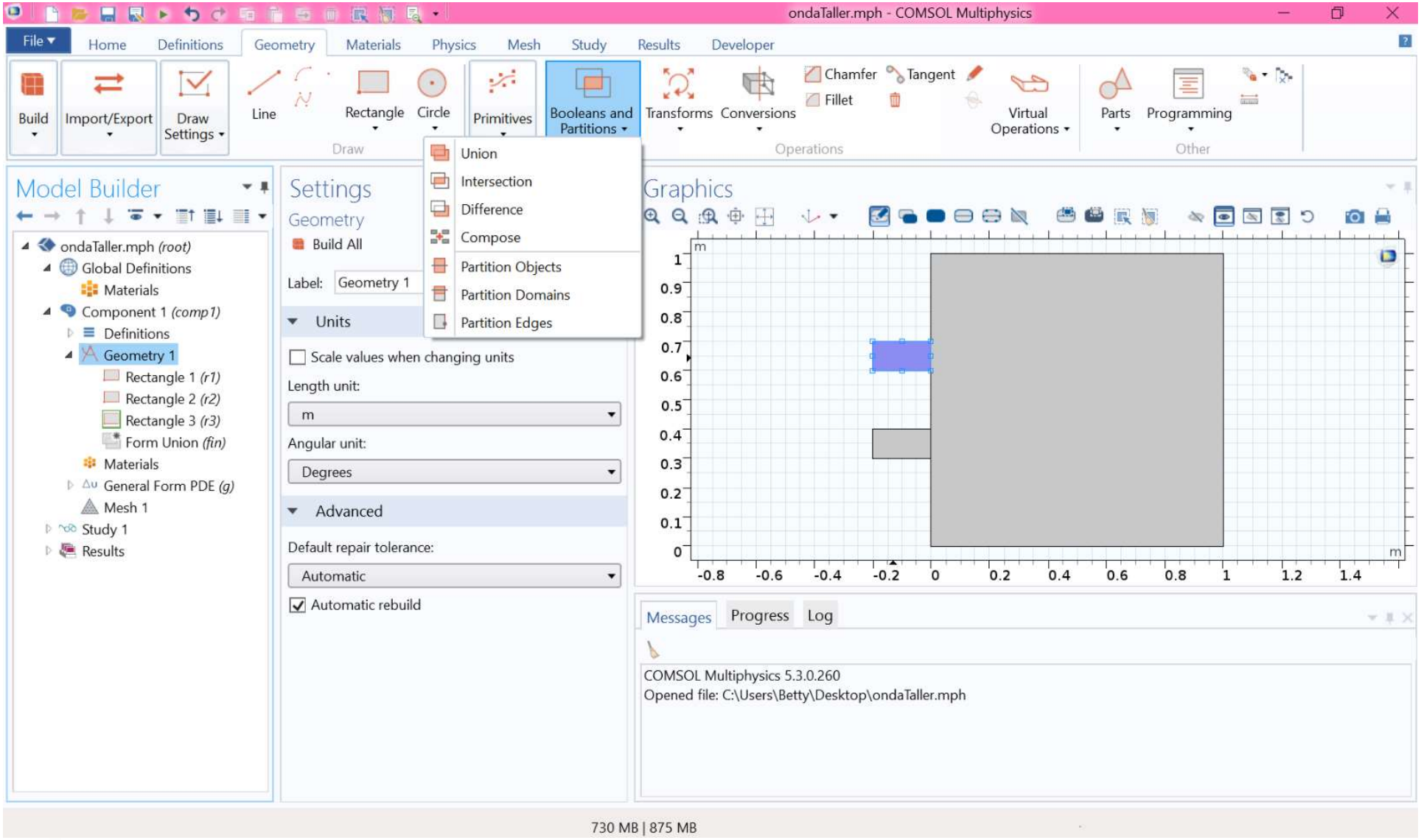
745 MB | 882 MB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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Difference
Compose
Partition Objects
Partition Domains
Partition Edges
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Rectangle 2 (r2)
Rectangle 3 (r3)
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Geometry
Build All
Label: Geometry 1
Units
Scale values when changing units
Length unit:
m
Angular unit:
Degrees
Advanced
Default repair tolerance:
Automatic
Automatic rebuild
Graphics
Messages
Progress
Log
COMSOL Multiphysics 5.3.0.260
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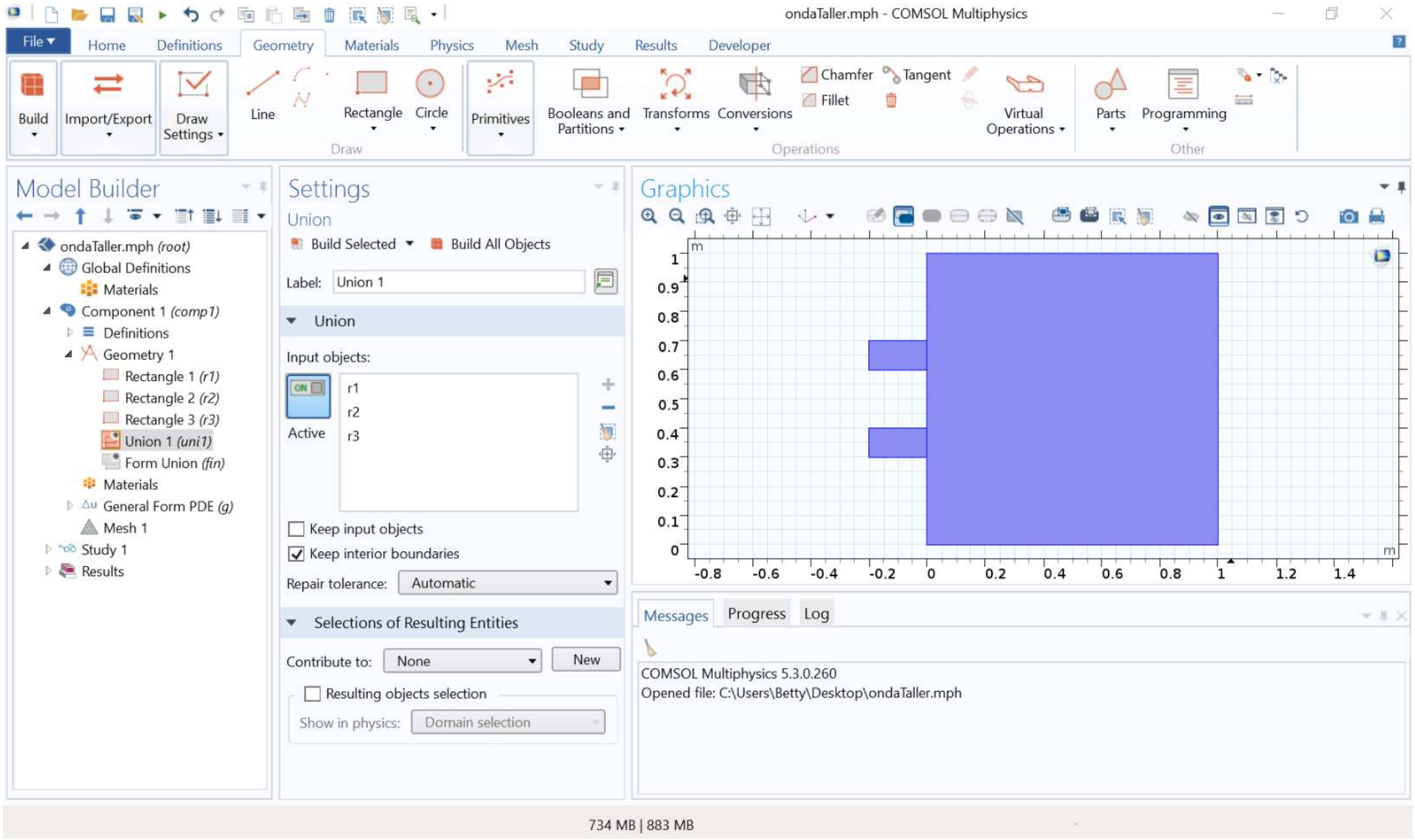
730 MB | 875 MB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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Draw Settings
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Rectangle 2 (r2)
Rectangle 3 (r3)
Union 1 (uni1)
Form Union (fin)
Materials
General Form PDE (g)
Mesh 1
Study 1
Results
Settings
Union
Build Selected
Build All Objects
Label: Union 1
Union
Input objects:
ON
Active
r1
r2
r3
Keep input objects
Keep interior boundaries
Repair tolerance: Automatic
Selections of Resulting Entities
Contribute to: None
New
Resulting objects selection
Show in physics: Domain selection
Graphics
m
1
0.9
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-0.6
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COMSOL Multiphysics 5.3.0.260
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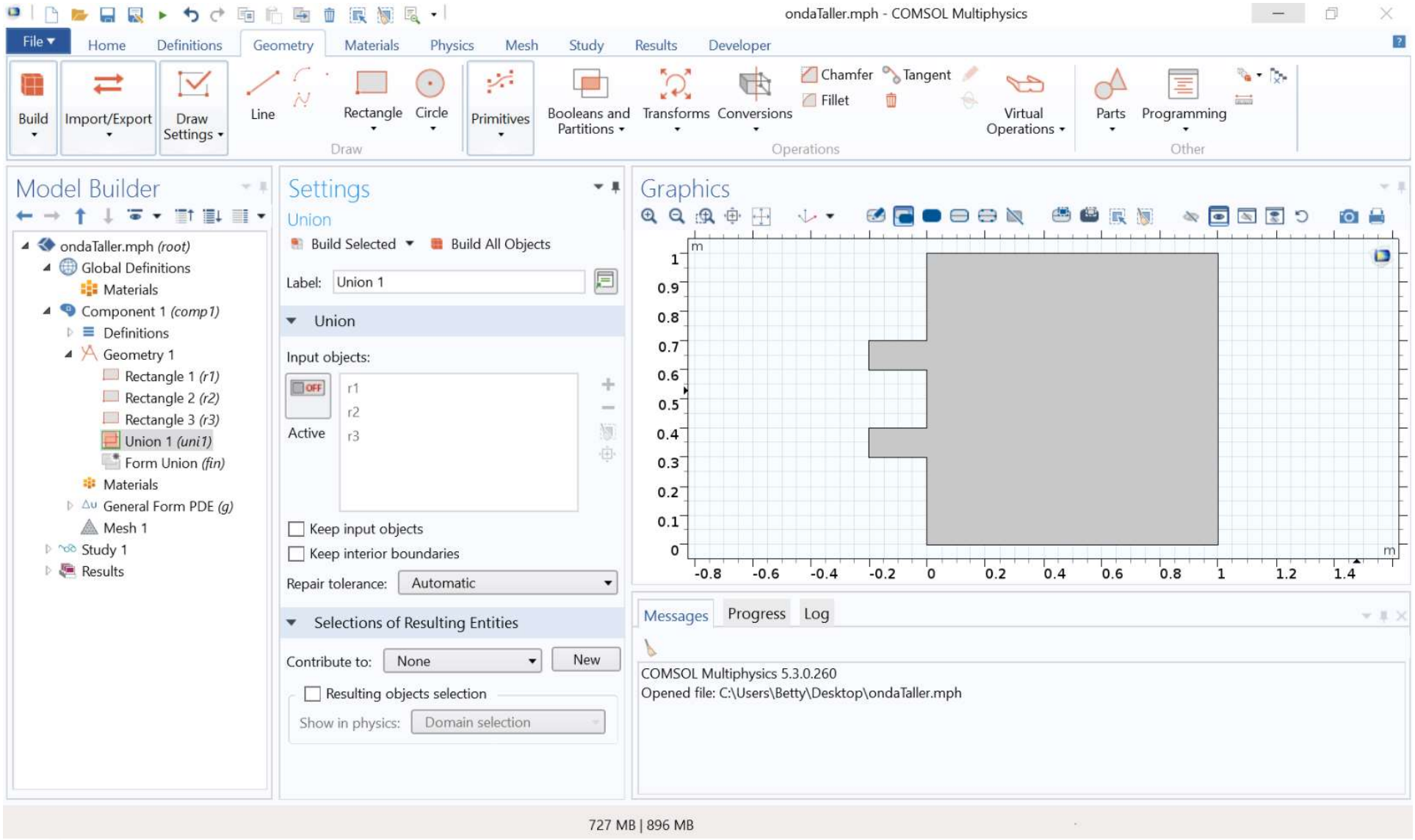
734 MB | 883 MB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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Rectangle 1 (r1)
Rectangle 2 (r2)
Rectangle 3 (r3)
Union 1 (uni1)
Form Union (fin)
Materials
General Form PDE (g)
Mesh 1
Study 1
Results
Settings
Union
Build Selected
Build All Objects
Label: Union 1
Union
Input objects:
OFF
Active
r1
r2
r3
Keep input objects
Keep interior boundaries
Repair tolerance: Automatic
Selections of Resulting Entities
Contribute to: None
New
Resulting objects selection
Show in physics: Domain selection
Graphics
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-0.4
-0.2
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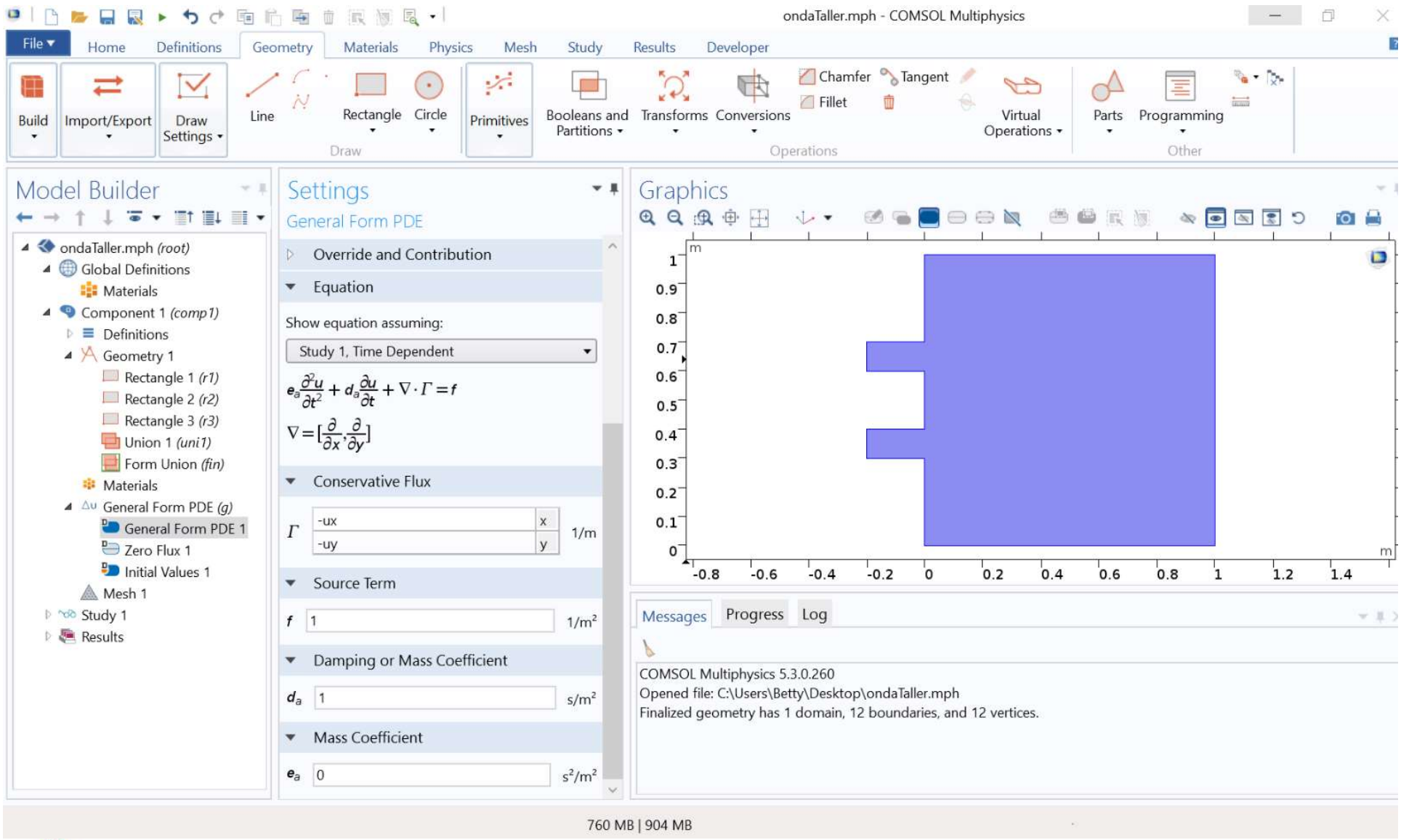
0.2
0.4
0.6
0.8
1
1.2
1.4
m
Messages
Progress
Log
COMSOL Multiphysics 5.3.0.260
Opened file: C:\Users\Betty\Desktop\ondaTaller.mph
727 MB | 896 MB

CEMAC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Zero Flux 1
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General Form PDE
Override and Contribution
Equation
Show equation assuming:
Study 1, Time Dependent
$e_a\frac{\partial^2 u}{\partial t^2}+d_a\frac{\partial u}{\partial t}+\nabla\cdot\Gamma=f$
$\nabla=[\frac{\partial}{\partial x},\frac{\partial}{\partial y}]$
Conservative Flux
Γ
-ux
-uy
x
y
1/m
Source Term
f
1
1/m²
Damping or Mass Coefficient
d_a
1
s/m²
Mass Coefficient
e_a
0
s²/m²
Graphics
m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Messages
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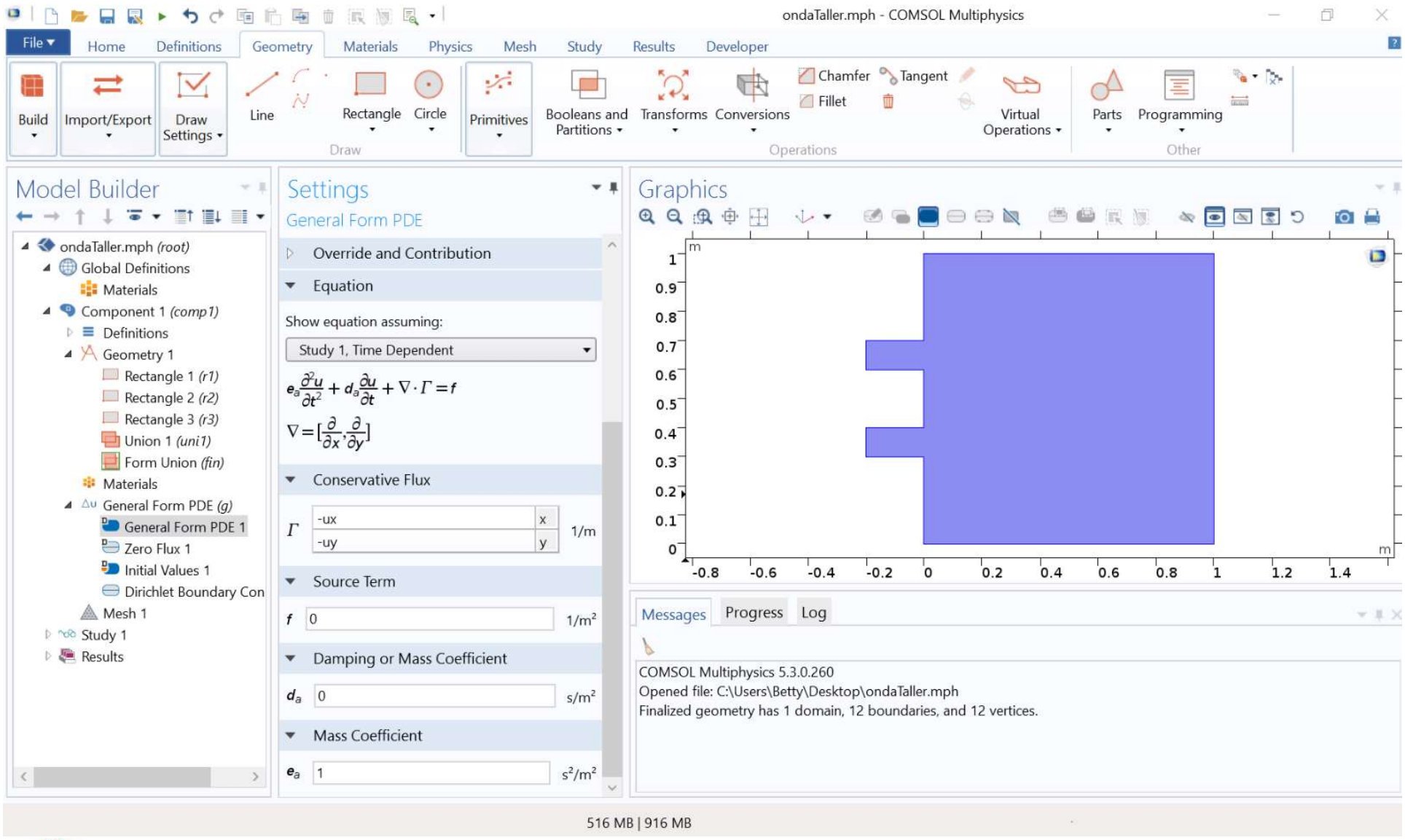
COMSOL Multiphysics 5.3.0.260
Opened file: C:\Users\Betty\Desktop\ondaTaller.mph
Finalized geometry has 1 domain, 12 boundaries, and 12 vertices.
760 MB | 904 MB

CEMAC

The problem under consideration is $\ddot{u} - \Delta u = 0$ in a domain Ω composed of a square with two smaller rectangular strips added on one side. This domain is shown in Fig. 5.3. The boundary conditions are $u = 0.1 \sin(8\pi t)$ on the line segments $\Gamma_D = \{x : x_1 = -0.25\}$, and $n \cdot \nabla u = 0$ on the rest of the boundary Γ_N. Thus, we have both Dirichlet and Neumann boundary conditions. The initial condition u_0 is zero.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Mesh 1
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General Form PDE
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Equation
Show equation assuming:
Study 1, Time Dependent
$e_a\frac{\partial^2 u}{\partial t^2}+d_a\frac{\partial u}{\partial t}+\nabla\cdot\Gamma=f$
$\nabla=[\frac{\partial}{\partial x},\frac{\partial}{\partial y}]$
Conservative Flux
Γ
-ux
-uy
x
y
1/m
Source Term
f
0
1/m²
Damping or Mass Coefficient
d_a
0
s/m²
Mass Coefficient
e_a
1
s²/m²
Graphics
m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
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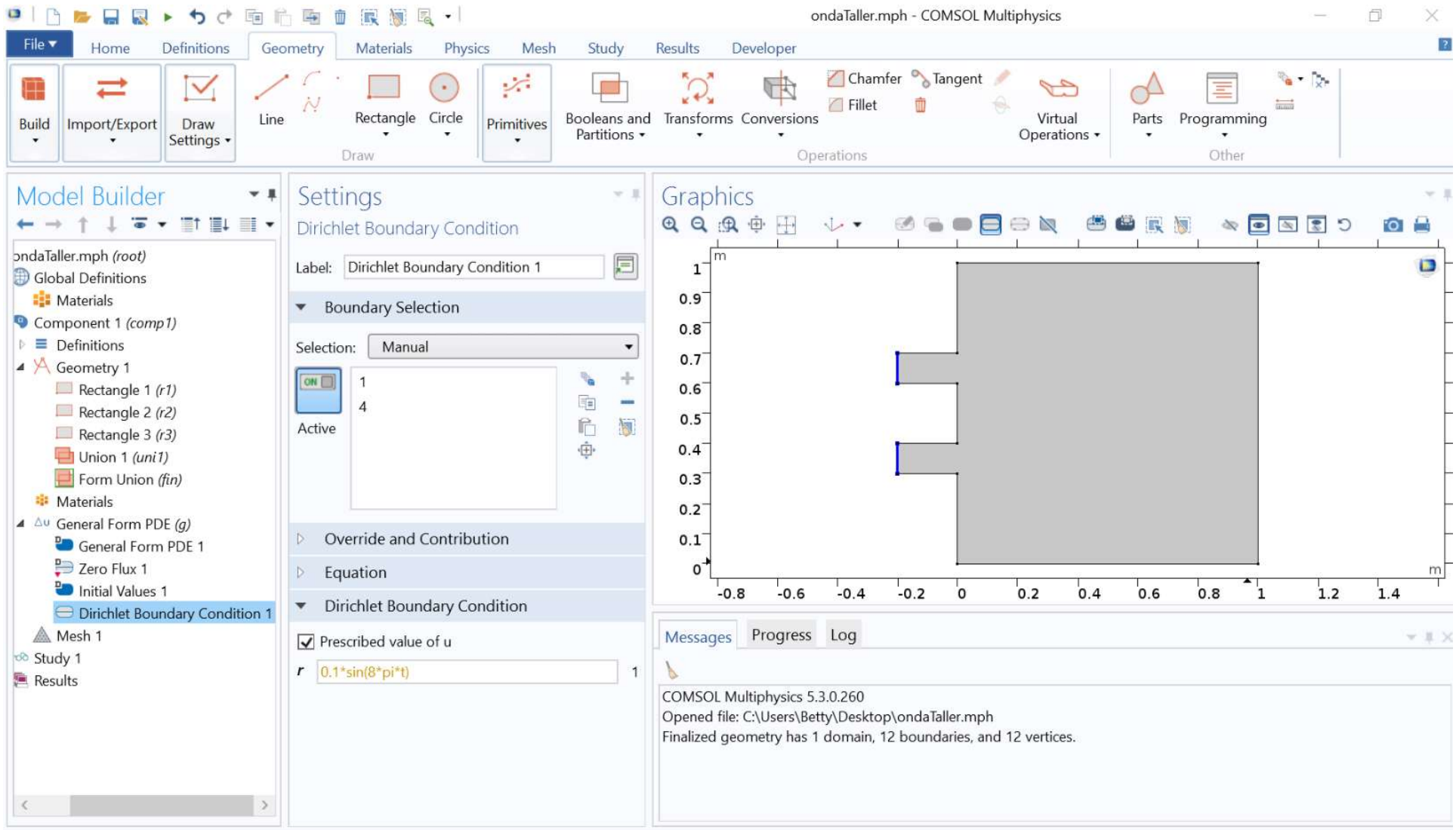
COMSOL Multiphysics 5.3.0.260
Opened file: C:\Users\Betty\Desktop\ondaTaller.mph
Finalized geometry has 1 domain, 12 boundaries, and 12 vertices.
516 MB | 916 MB

CEMAC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Label: Dirichlet Boundary Condition 1
Boundary Selection
Selection: Manual
Active
1
4
Override and Contribution
Equation
Dirichlet Boundary Condition
Prescribed value of u
r
0.1*sin(8*pi*t)
1
Graphics
m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
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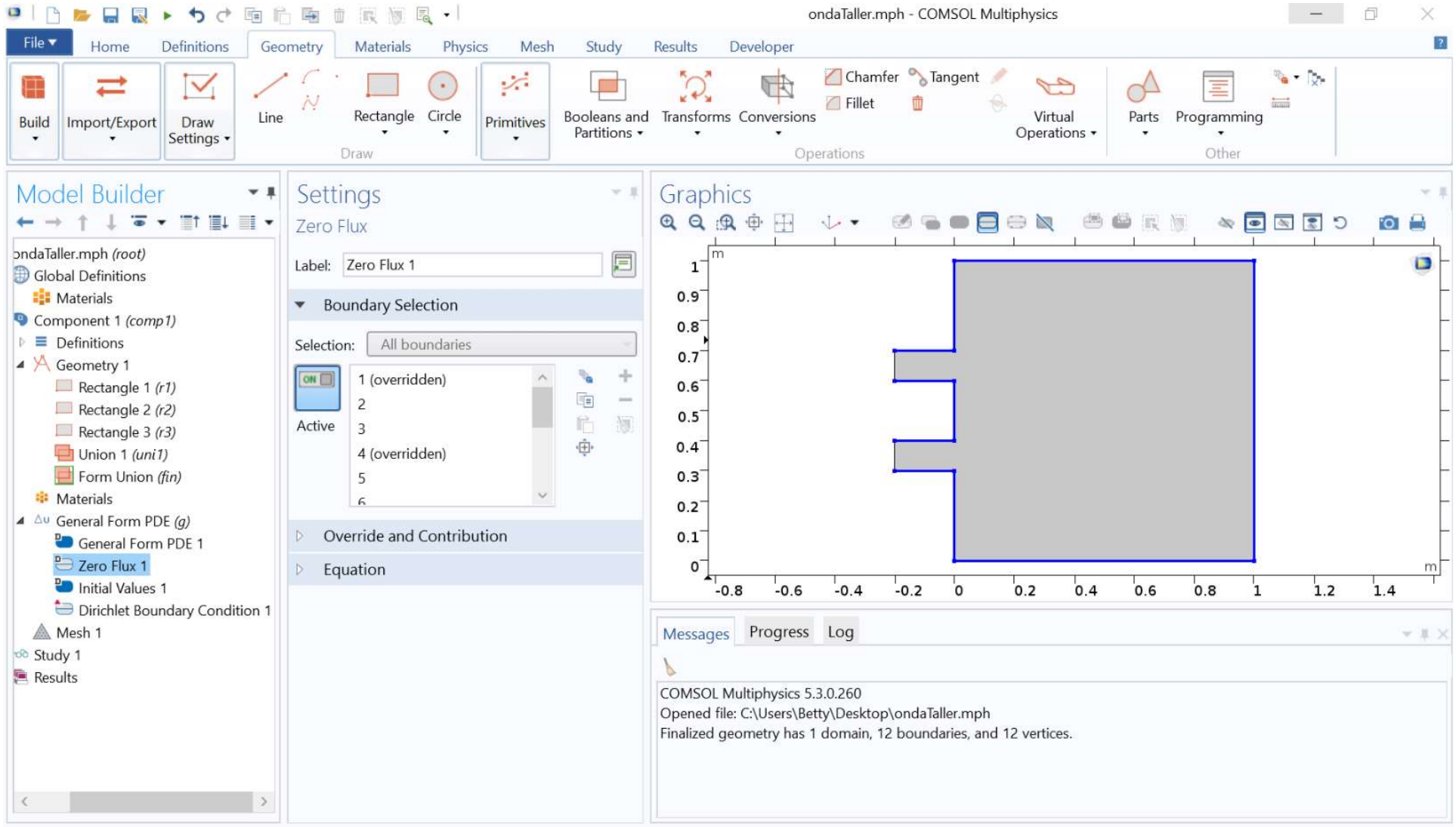
COMSOL Multiphysics 5.3.0.260
Opened file: C:\Users\Betty\Desktop\ondaTaller.mph
Finalized geometry has 1 domain, 12 boundaries, and 12 vertices.
536 MB | 925 MB

CEMAC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General Form PDE 1
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Zero Flux
Label: Zero Flux 1
Boundary Selection
Selection: All boundaries
Active
1 (overridden)
2
3
4 (overridden)
5
Override and Contribution
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m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
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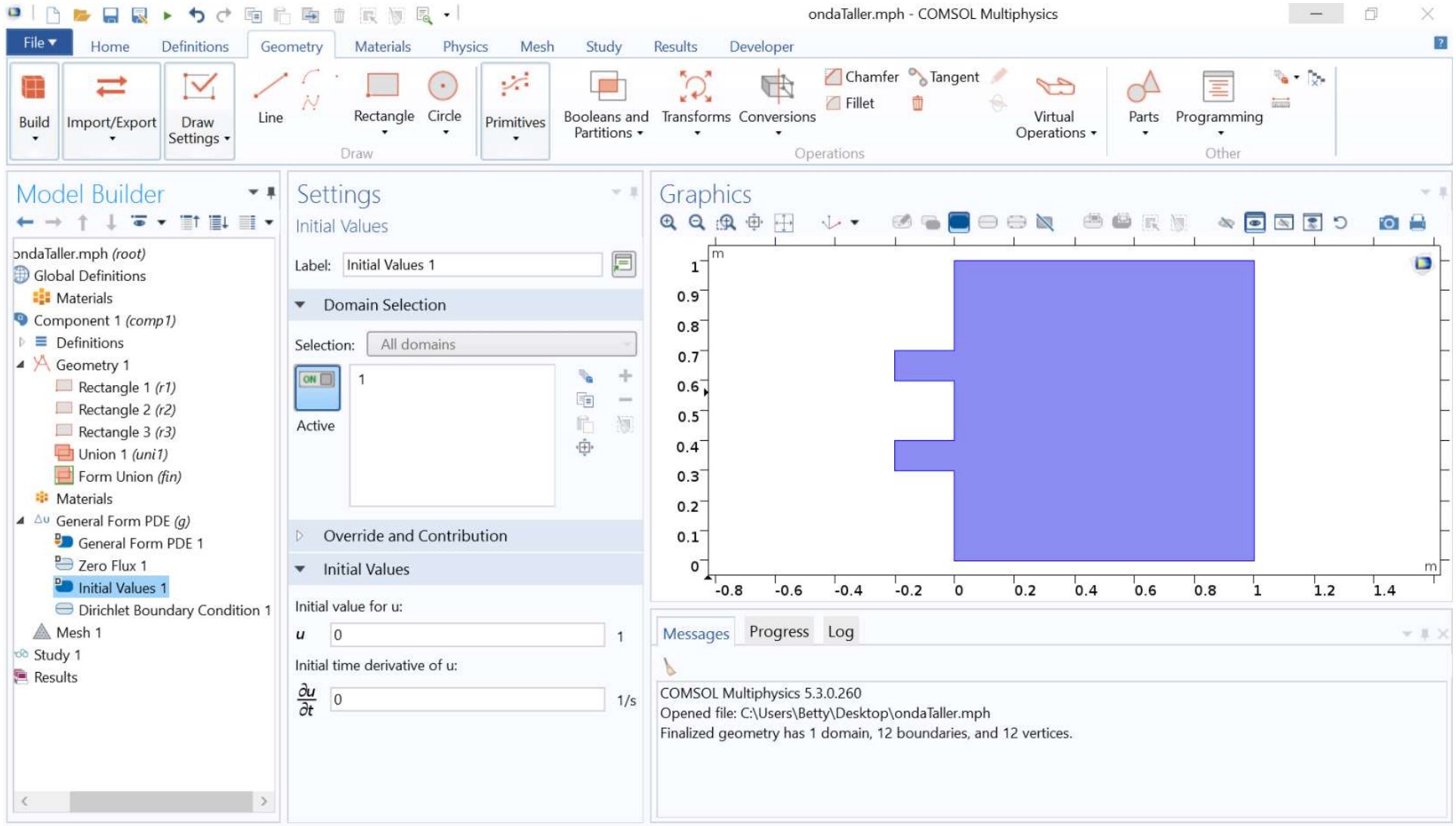
COMSOL Multiphysics 5.3.0.260
Opened file: C:\Users\Betty\Desktop\ondaTaller.mph
Finalized geometry has 1 domain, 12 boundaries, and 12 vertices.
535 MB | 919 MB

CEMAC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General Form PDE 1
Zero Flux 1
Initial Values 1
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Settings
Initial Values
Label: Initial Values 1
Domain Selection
Selection: All domains
Active
1
Override and Contribution
Initial Values
Initial value for u:
u 0 1
Initial time derivative of u:
∂u/∂t 0 1/s
Graphics
m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
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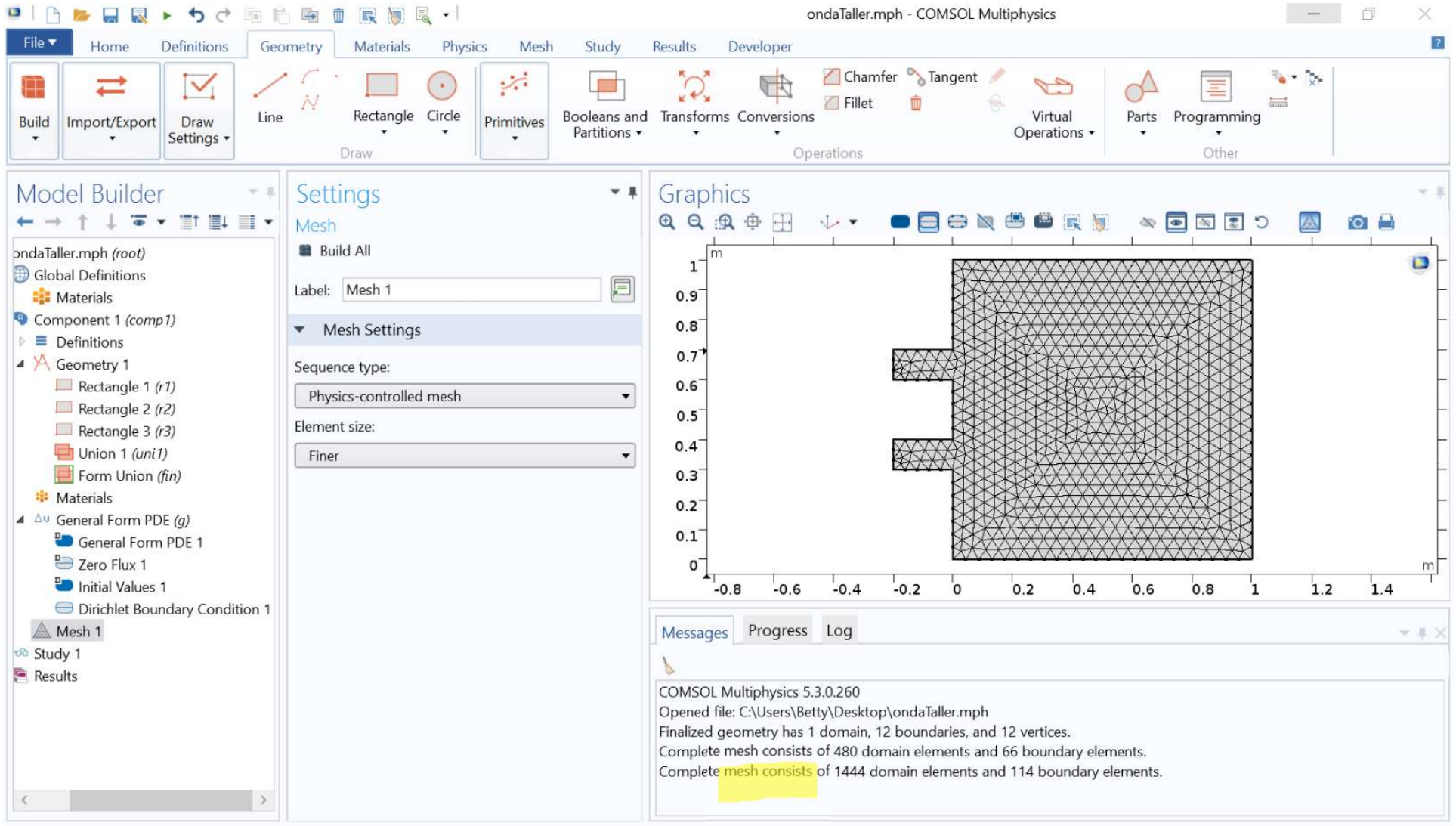
COMSOL Multiphysics 5.3.0.260
Opened file: C:\Users\Betty\Desktop\ondaTaller.mph
Finalized geometry has 1 domain, 12 boundaries, and 12 vertices.
529 MB | 921 MB

CEMAC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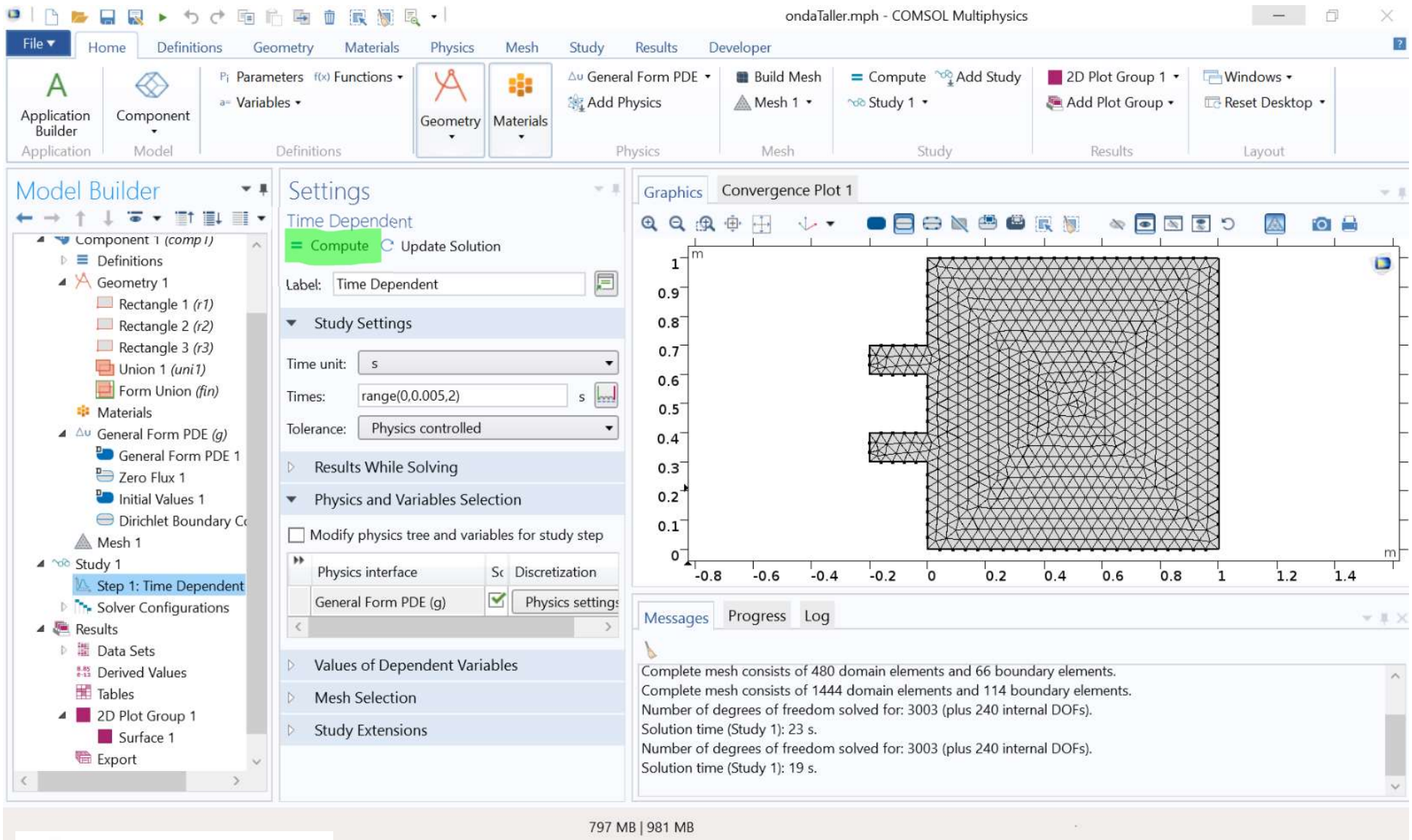
Settings
Mesh
Build All
Label: Mesh 1
Mesh Settings
Sequence type:
Physics-controlled mesh
Element size:
Finer
Graphics
m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
m
Messages
Progress
Log
COMSOL Multiphysics 5.3.0.260
Opened file: C:\Users\Betty\Desktop\ondaTaller.mph
Finalized geometry has 1 domain, 12 boundaries, and 12 vertices.
Complete mesh consists of 480 domain elements and 66 boundary elements.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
516 MB | 876 MB

CEMAC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Surface 1
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Time Dependent
Compute
Update Solution
Label: Time Dependent
Study Settings
Time unit: s
Times: range(0,0.005,2) s
Tolerance: Physics controlled
Results While Solving
Physics and Variables Selection
Modify physics tree and variables for study step
Physics interface
Sc
Discretization
General Form PDE (g)
Physics settings
Values of Dependent Variables
Mesh Selection
Study Extensions
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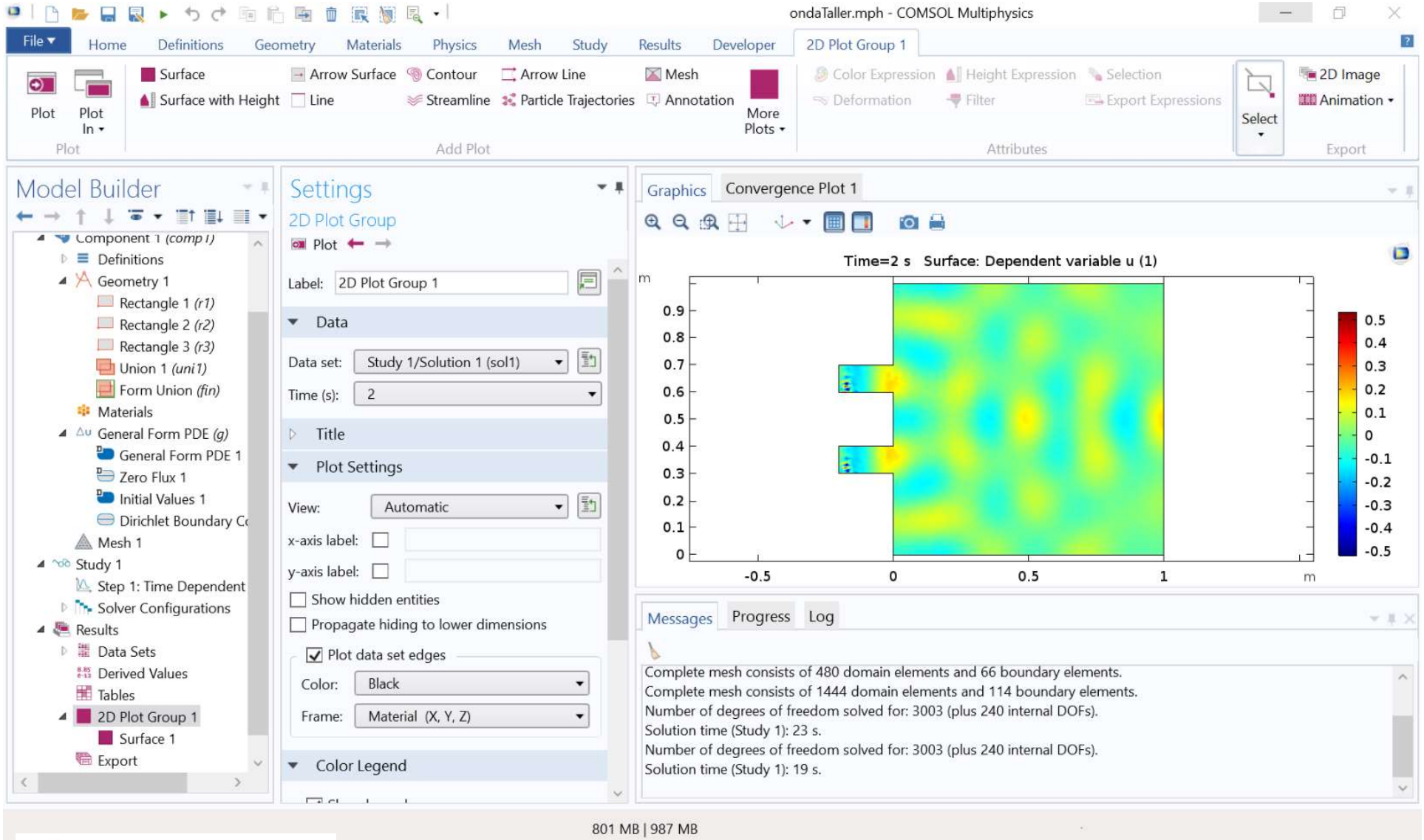
Convergence Plot 1
m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
m
Messages
Progress
Log
Complete mesh consists of 480 domain elements and 66 boundary elements.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 23 s.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 19 s.
797 MB | 981 MB

CEMAC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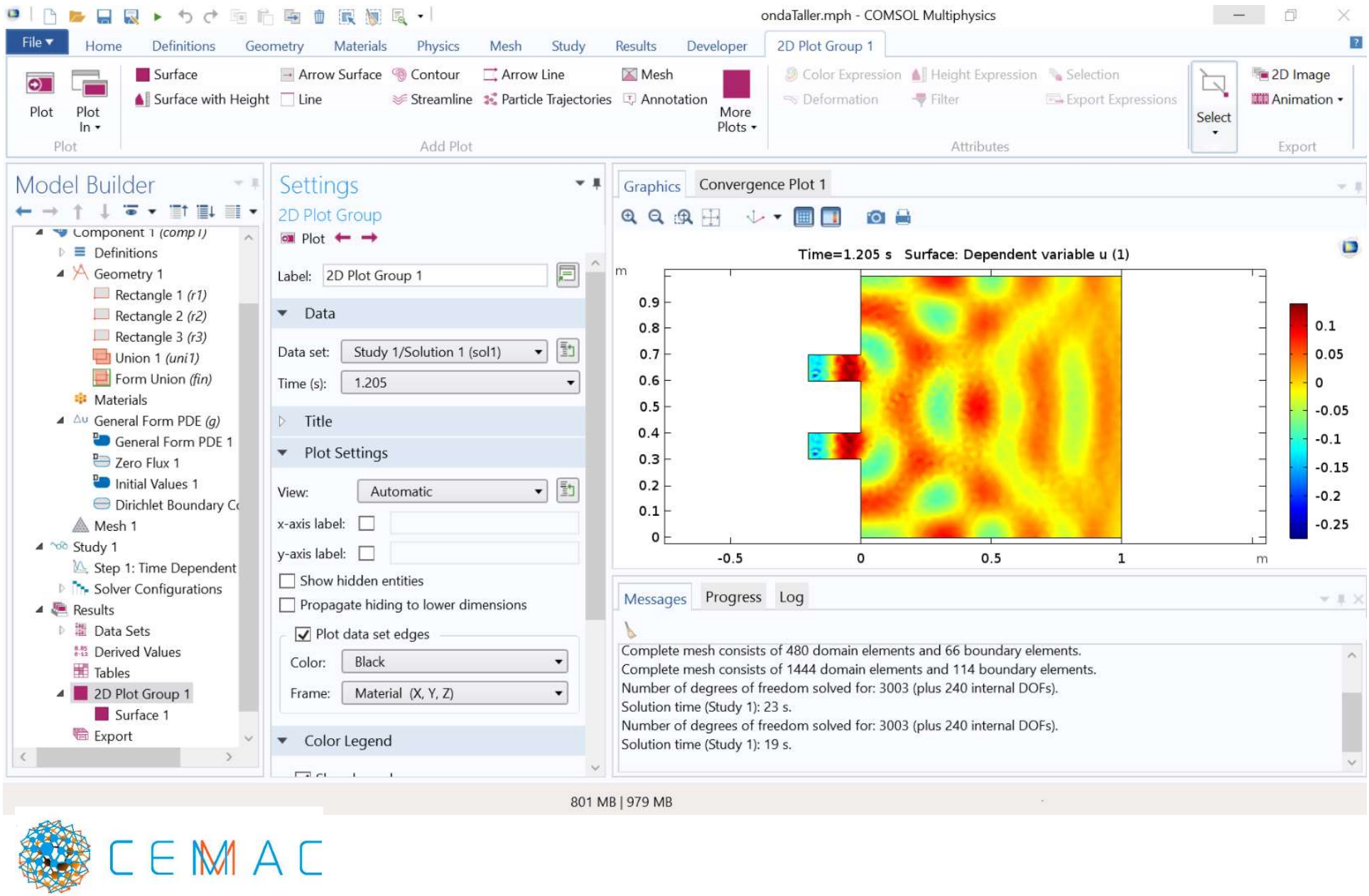
Label: 2D Plot Group 1
Data
Data set: Study 1/Solution 1 (sol1)
Time (s): 2
Title
Plot Settings
View: Automatic
x-axis label:
y-axis label:
Show hidden entities
Propagate hiding to lower dimensions
Plot data set edges
Color: Black
Frame: Material (X, Y, Z)
Color Legend
Graphics
Convergence Plot 1
Time=2 s Surface: Dependent variable u (1)
m
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.5
0
0.5
1
m
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Messages
Progress
Log
Complete mesh consists of 480 domain elements and 66 boundary elements.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 23 s.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 19 s.
801 MB | 987 MB

CEMAC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Export
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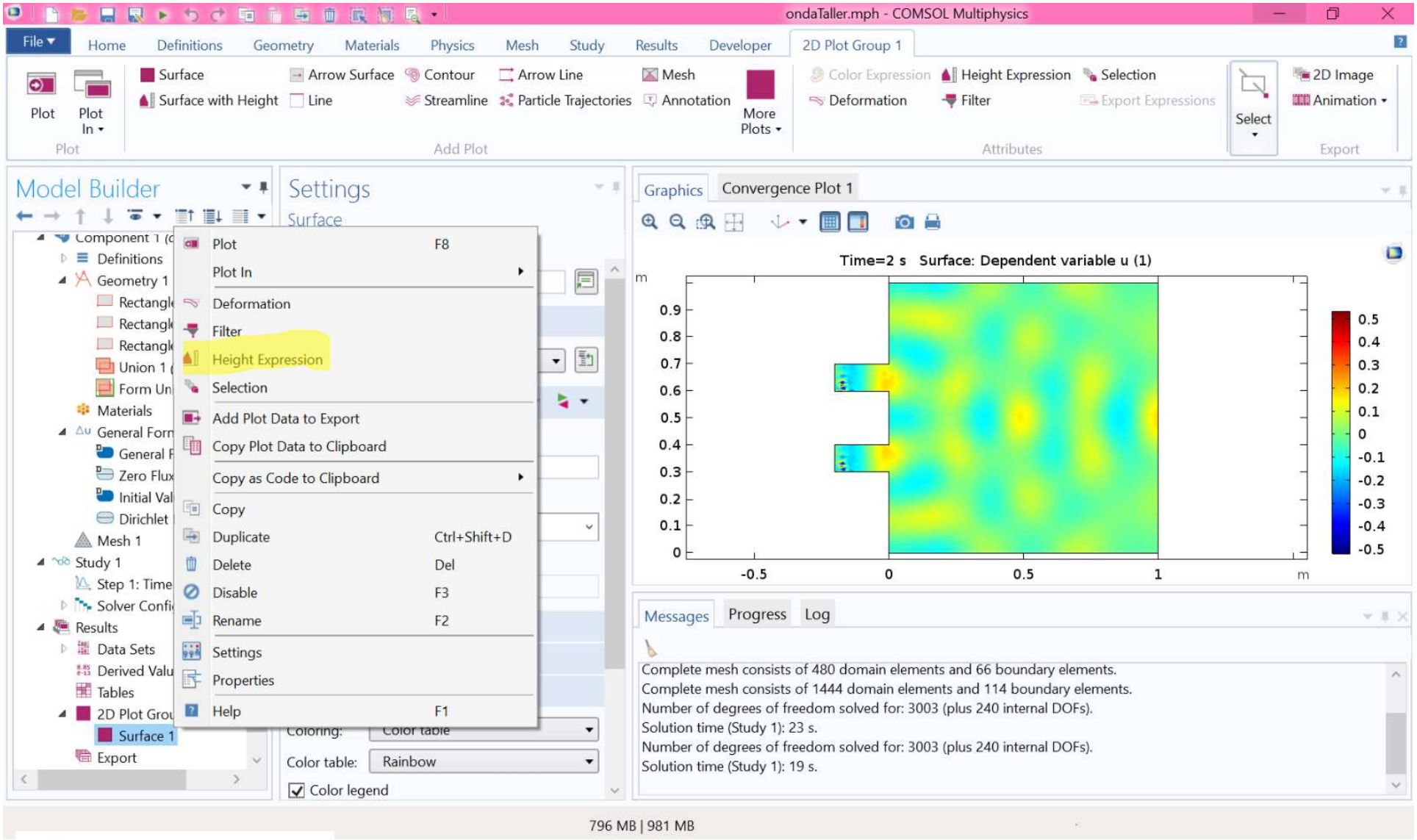
2D Plot Group
Plot
Label: 2D Plot Group 1
Data
Data set: Study 1/Solution 1 (sol1)
Time (s): 1.205
Title
Plot Settings
View: Automatic
x-axis label:
y-axis label:
Show hidden entities
Propagate hiding to lower dimensions
Plot data set edges
Color: Black
Frame: Material (X, Y, Z)
Color Legend
Graphics
Convergence Plot 1
Time=1.205 s Surface: Dependent variable u (1)
m
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.5
0
0.5
1
m
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
Messages
Progress
Log
Complete mesh consists of 480 domain elements and 66 boundary elements.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 23 s.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 19 s.
801 MB | 979 MB

CEMAC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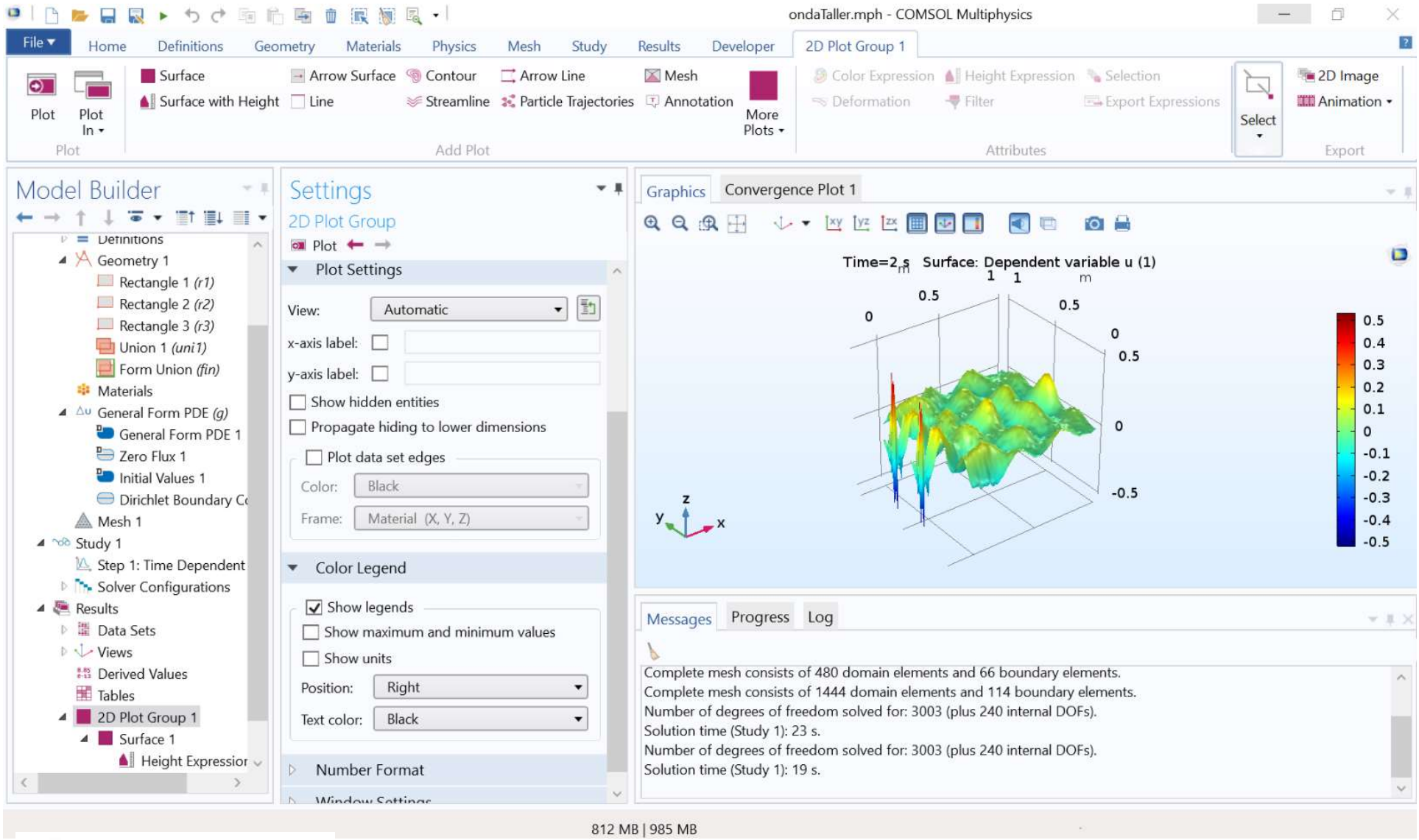
Copy as Code to Clipboard
Copy
Duplicate Ctrl+Shift+D
Delete Del
Disable F3
Rename F2
Settings
Properties
Help F1
Coloring:
Color table
Color table: Rainbow
Color legend
Graphics
Convergence Plot 1
Time=2 s Surface: Dependent variable u (1)
m
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.5
0
0.5
1
m
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Messages
Progress
Log
Complete mesh consists of 480 domain elements and 66 boundary elements.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 23 s.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 19 s.
796 MB | 981 MB

CEMAC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Rectangle 3 (r3)
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2D Plot Group
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Automatic
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y-axis label:
Show hidden entities
Propagate hiding to lower dimensions
Plot data set edges
Color:
Black
Frame:
Material (X, Y, Z)
Color Legend
Show legends
Show maximum and minimum values
Show units
Position:
Right
Text color:
Black
Number Format
Graphics
Convergence Plot 1
Time=2 s Surface: Dependent variable u (1)
m
0.5
0
0.5
0
0.5
0
-0.5
z
y
x
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Messages
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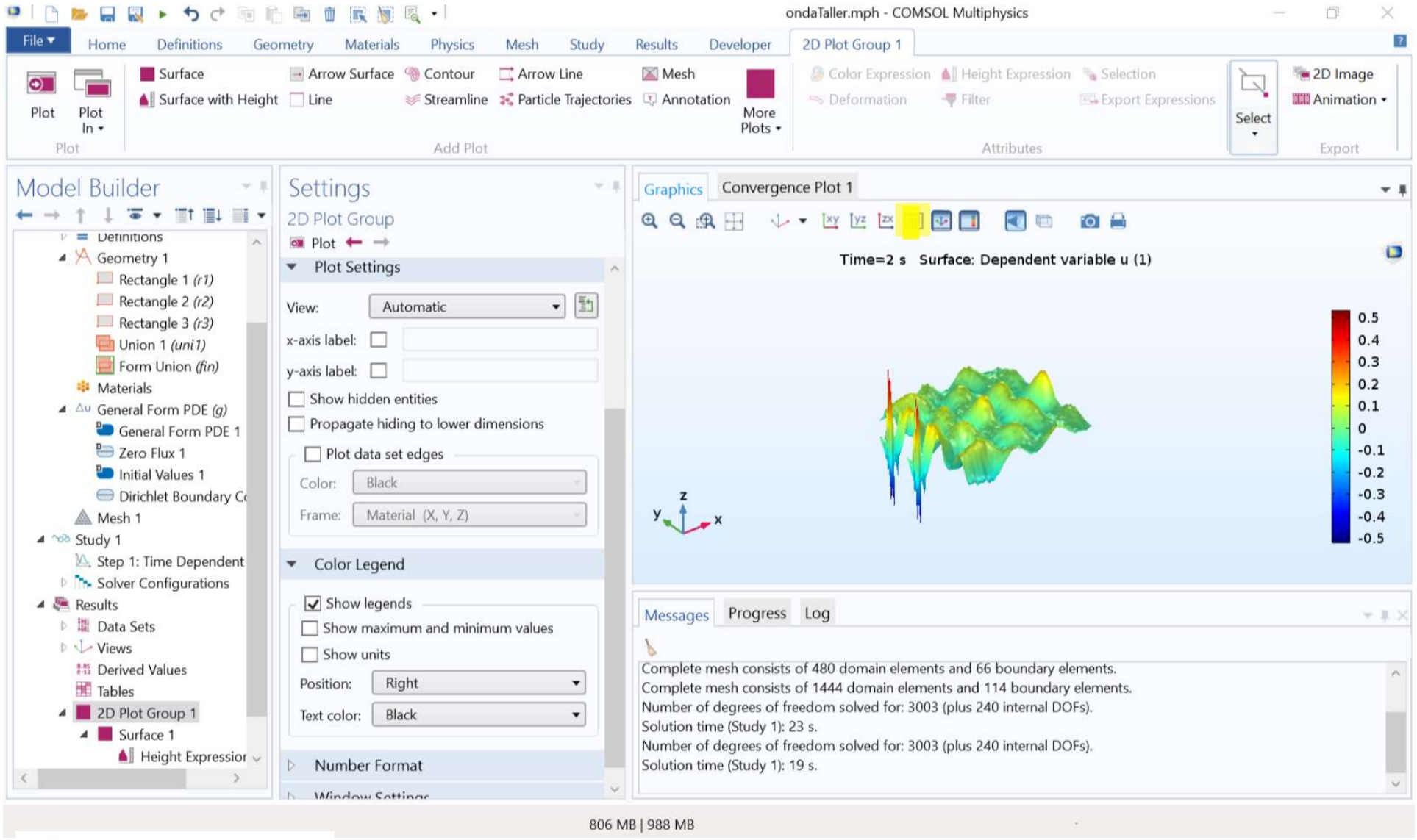
Log
Complete mesh consists of 480 domain elements and 66 boundary elements.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 23 s.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 19 s.
812 MB | 985 MB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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Arrow Surface
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Contour
Streamline
Arrow Line
Particle Trajectories
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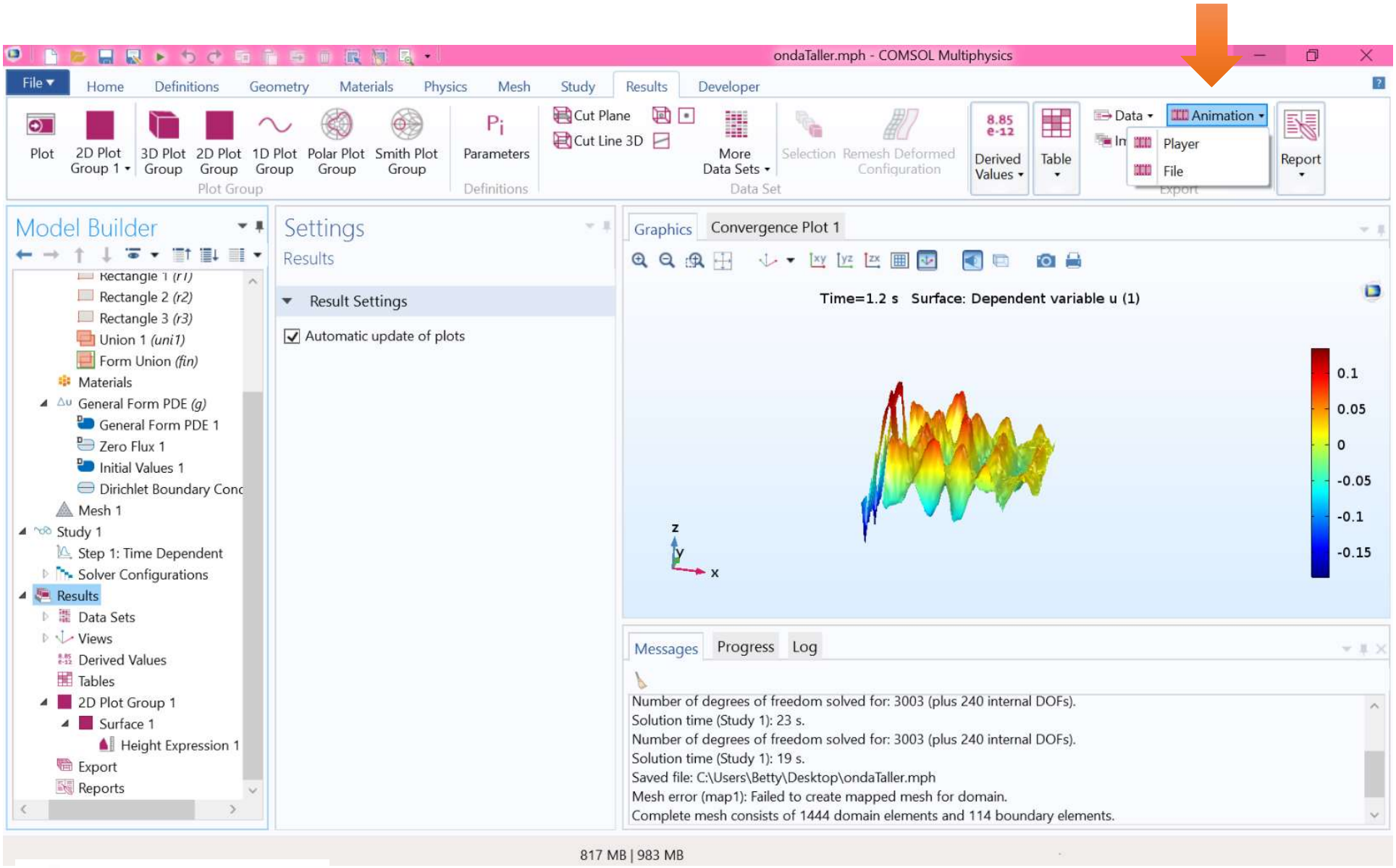
Plot
Plot Settings
View:
Automatic
x-axis label:
y-axis label:
Show hidden entities
Propagate hiding to lower dimensions
Plot data set edges
Color:
Black
Frame:
Material (X, Y, Z)
Color Legend
Show legends
Show maximum and minimum values
Show units
Position:
Right
Text color:
Black
Number Format
Graphics
Convergence Plot 1
Time=2 s Surface: Dependent variable u (1)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
z
y
x
Messages
Progress
Log
Complete mesh consists of 480 domain elements and 66 boundary elements.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 23 s.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 19 s.
806 MB | 988 MB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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3D Plot Group
2D Plot Group
1D Plot Group
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Smith Plot Group
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Data Set
8.85 e-12
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Rectangle 3 (r3)
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General Form PDE 1
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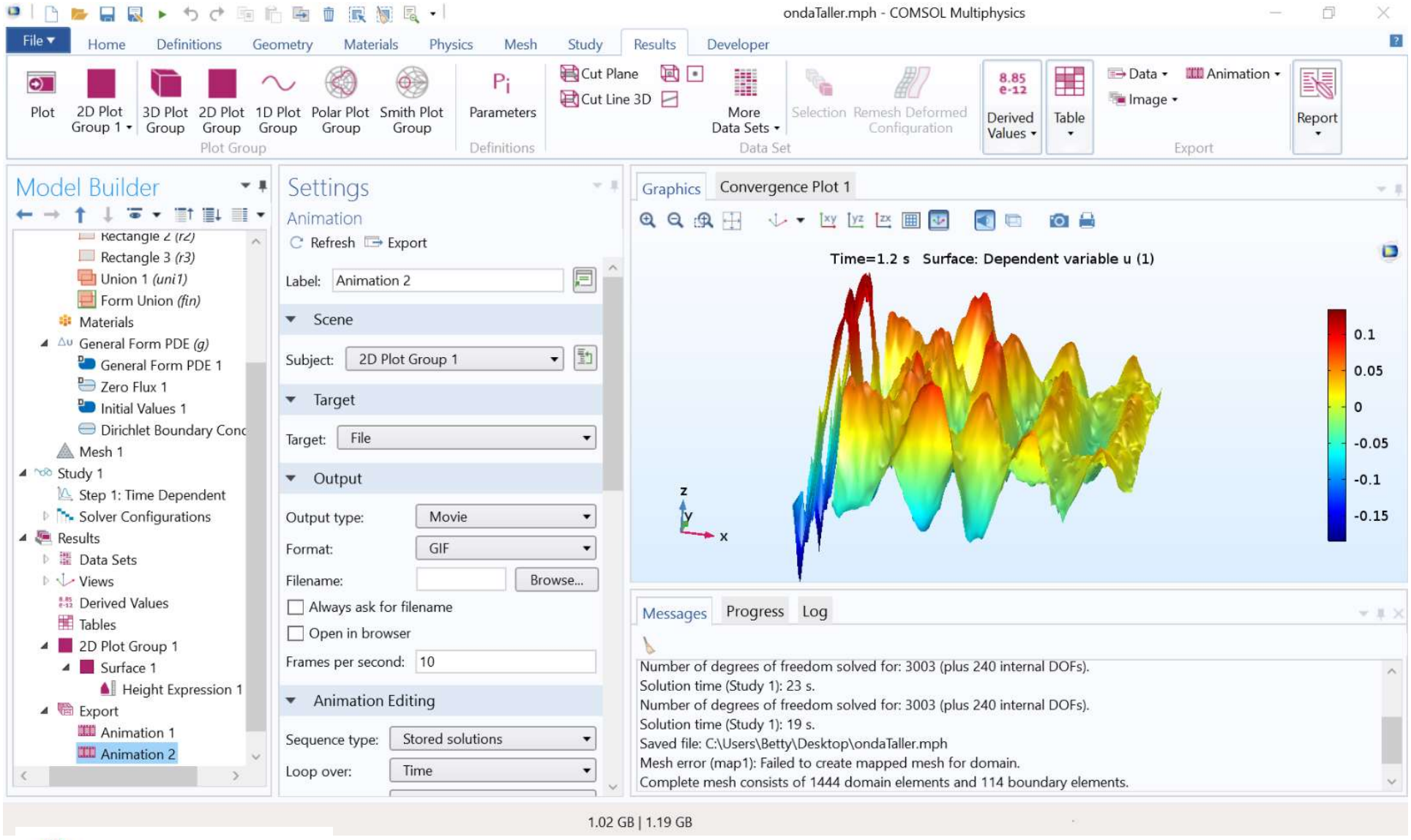
Surface 1
Height Expression 1
Export
Reports
Settings
Results
Result Settings
Automatic update of plots
Graphics
Convergence Plot 1
Time=1.2 s Surface: Dependent variable u (1)
0.1
0.05
0
-0.05
-0.1
-0.15
z
y
x
Messages
Progress
Log
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 23 s.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 19 s.
Saved file: C:\Users\Betty\Desktop\ondaTaller.mph
Mesh error (map1): Failed to create mapped mesh for domain.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
817 MB | 983 MB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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3D Plot Group
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Form Union (fin)
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Surface 1
Height Expression 1
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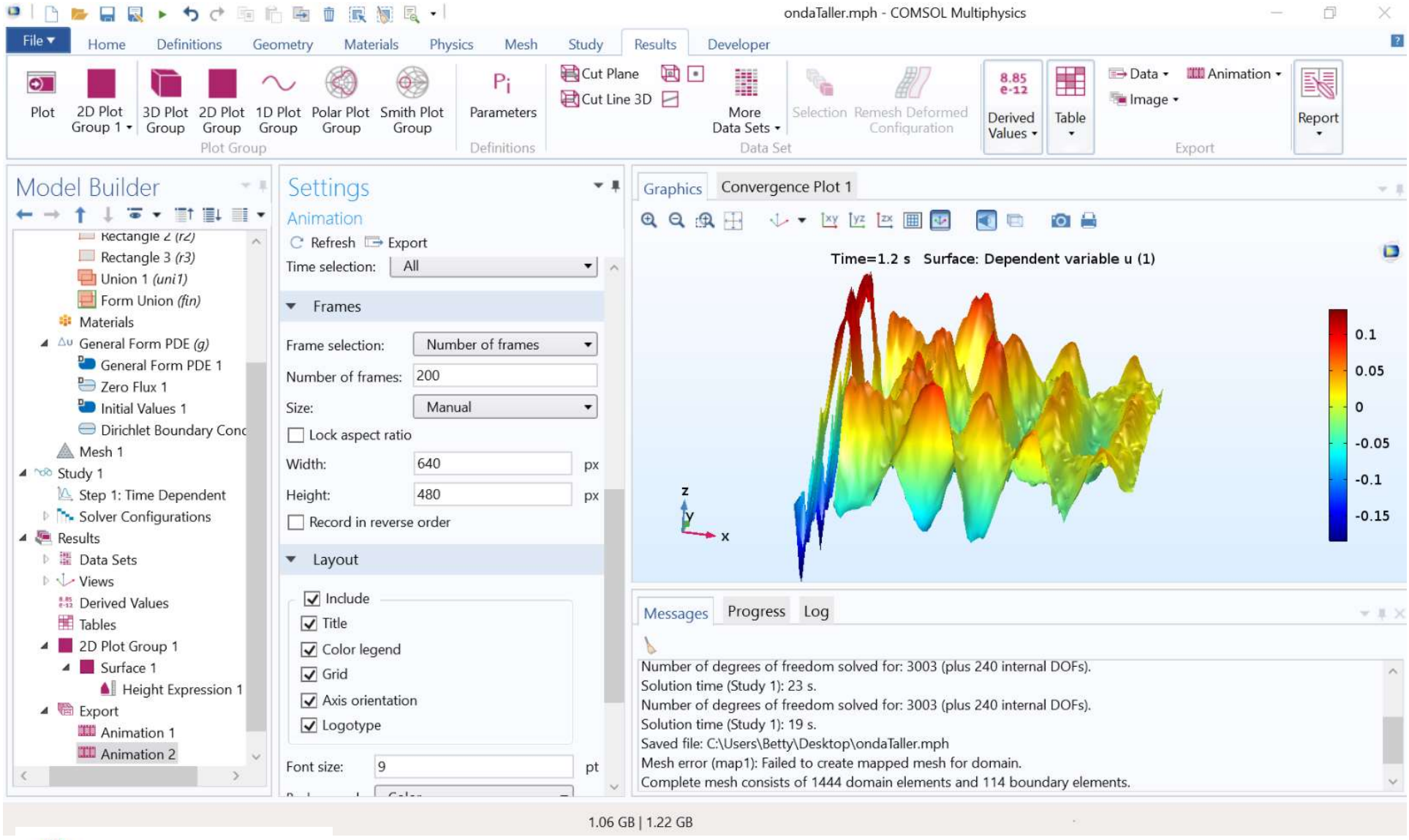
Animation 2
Settings
Animation
Refresh
Export
Label: Animation 2
Scene
Subject: 2D Plot Group 1
Target
Target: File
Output
Output type: Movie
Format: GIF
Filename:
Browse...
Always ask for filename
Open in browser
Frames per second: 10
Animation Editing
Sequence type: Stored solutions
Loop over: Time
Graphics
Convergence Plot 1
Time=1.2 s Surface: Dependent variable u (1)
0.1
0.05
0
-0.05
-0.1
-0.15
z
y
x
Messages
Progress
Log
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 23 s.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 19 s.
Saved file: C:\Users\Betty\Desktop\ondaTaller.mph
Mesh error (map1): Failed to create mapped mesh for domain.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
1.02 GB | 1.19 GB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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Animation 2
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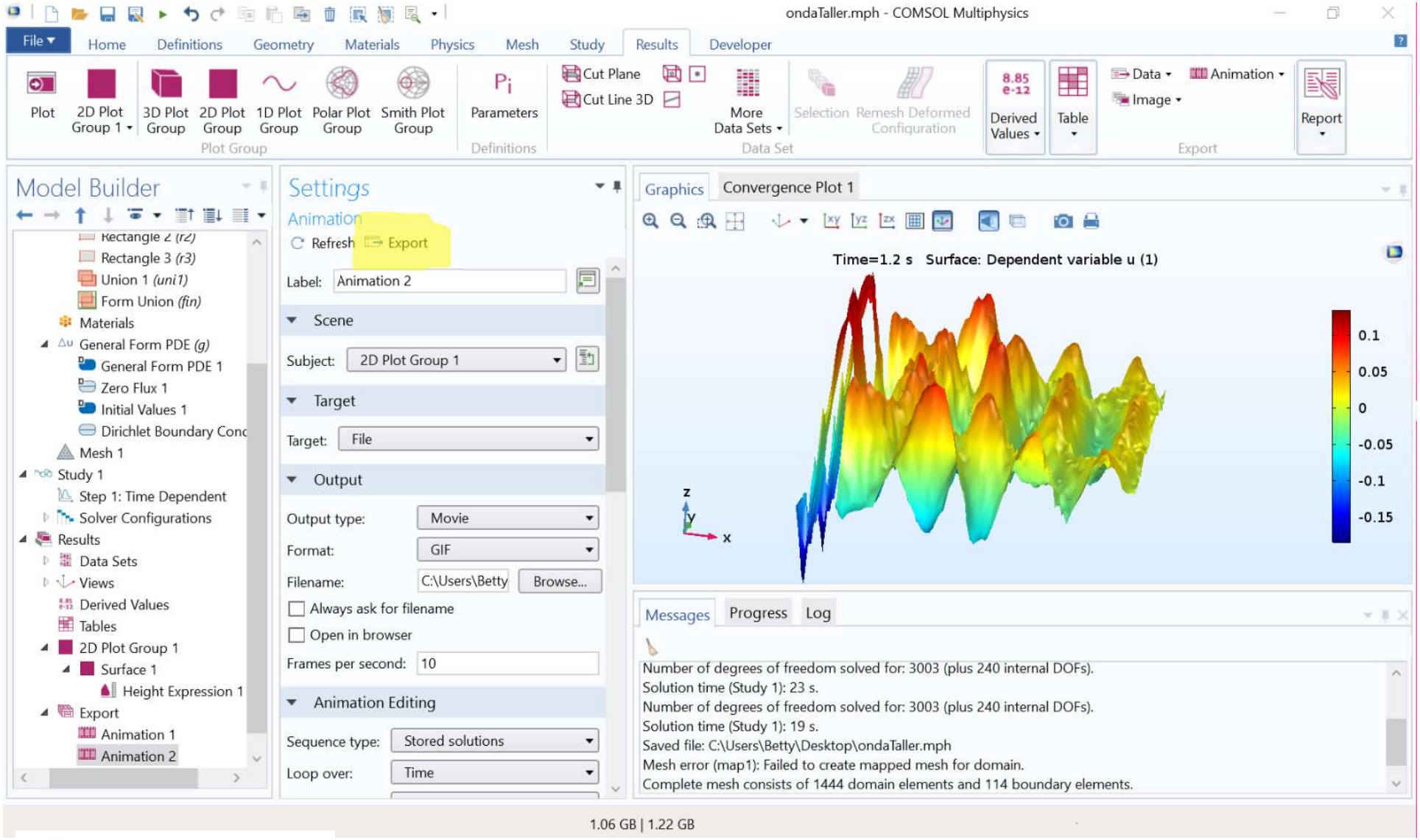
Animation
Refresh
Export
Time selection:
All
Frames
Frame selection:
Number of frames
Number of frames:
200
Size:
Manual
Lock aspect ratio
Width:
640
px
Height:
480
px
Record in reverse order
Layout
Include
Title
Color legend
Grid
Axis orientation
Logotype
Font size:
9
pt
Graphics
Convergence Plot 1
Time=1.2 s Surface: Dependent variable u (1)
0.1
0.05
0
-0.05
-0.1
-0.15
z
y
x
Messages
Progress
Log
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 23 s.
Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
Solution time (Study 1): 19 s.
Saved file: C:\Users\Betty\Desktop\ondaTaller.mph
Mesh error (map1): Failed to create mapped mesh for domain.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
1.06 GB | 1.22 GB

CEMAC


ondaTaller.mph - COMSOL Multiphysics
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Animation 1
Animation 2
Settings
Animation
Refresh
Export
Label: Animation 2
Scene
Subject: 2D Plot Group 1
Target
Target: File
Output
Output type: Movie
Format: GIF
Filename: C:\Users\Betty
Browse...
Always ask for filename
Open in browser
Frames per second: 10
Animation Editing
Sequence type: Stored solutions
Loop over: Time
Graphics
Convergence Plot 1
Time=1.2 s Surface: Dependent variable u (1)
0.1
0.05
0
-0.05
-0.1
-0.15
z
y
x
Messages
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Number of degrees of freedom solved for: 3003 (plus 240 internal DOFs).
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Mesh error (map1): Failed to create mapped mesh for domain.
Complete mesh consists of 1444 domain elements and 114 boundary elements.
1.06 GB | 1.22 GB

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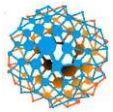
https://www.comsol.com/models

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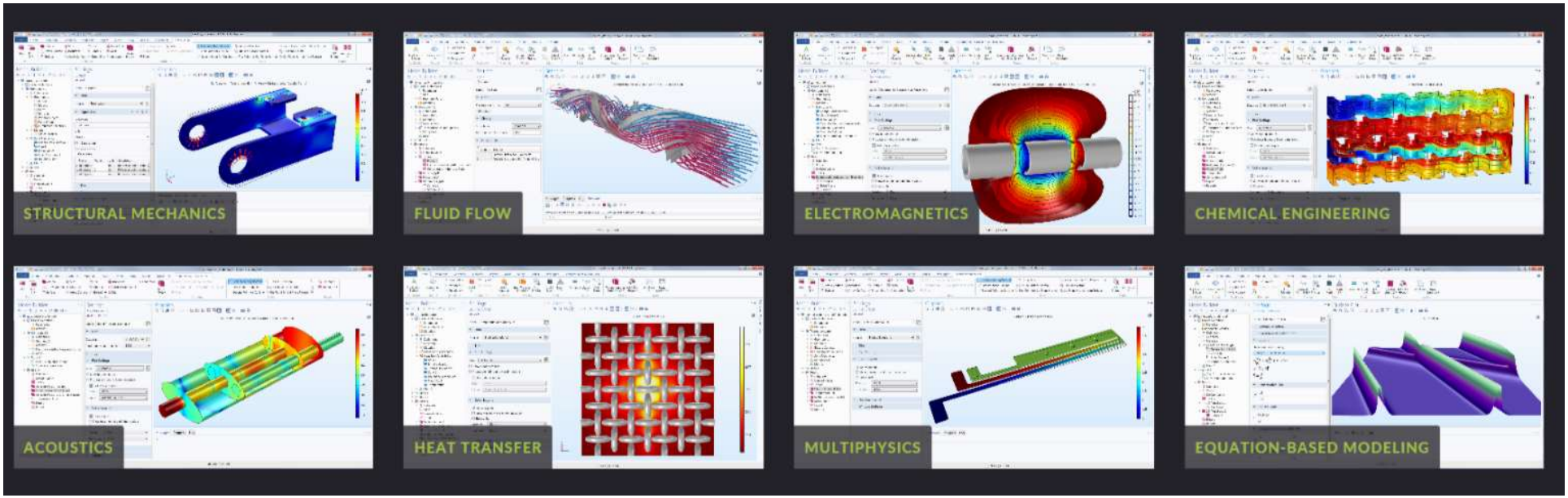

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Tutoriales en youtube.

- https://www.youtube.com/watch?v=qNc03bW18JE
- https://www.comsol.com/comsol-multiphysics