Vývoj digitálního dvojčete

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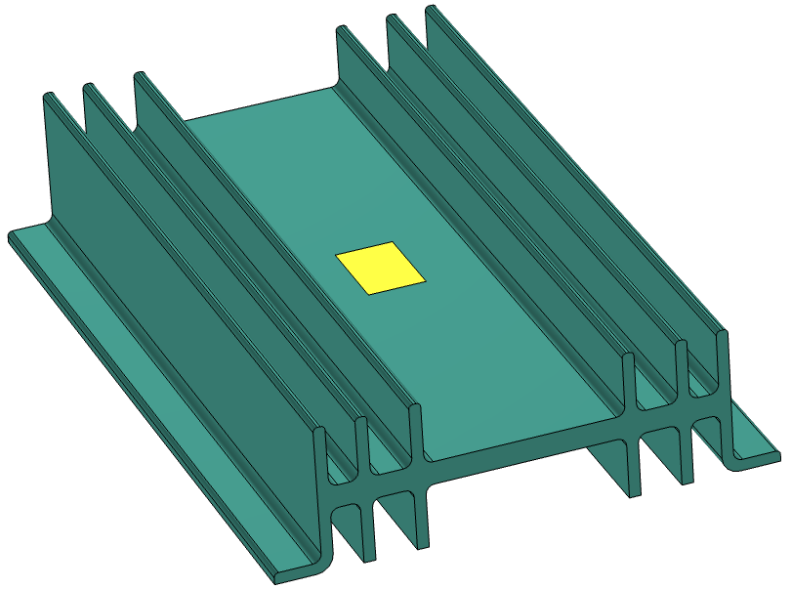
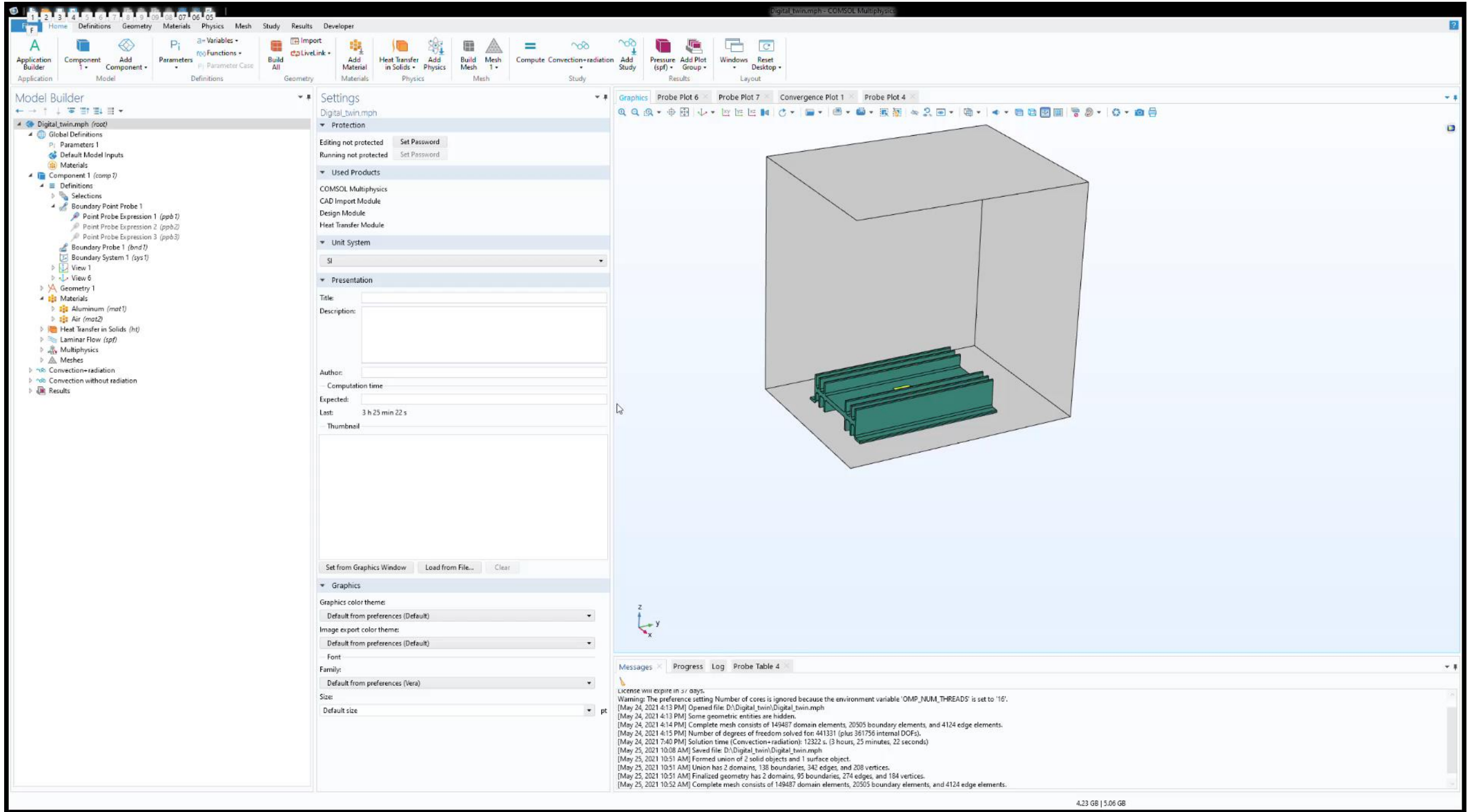
27.- 28. 5. 2021

Přehled

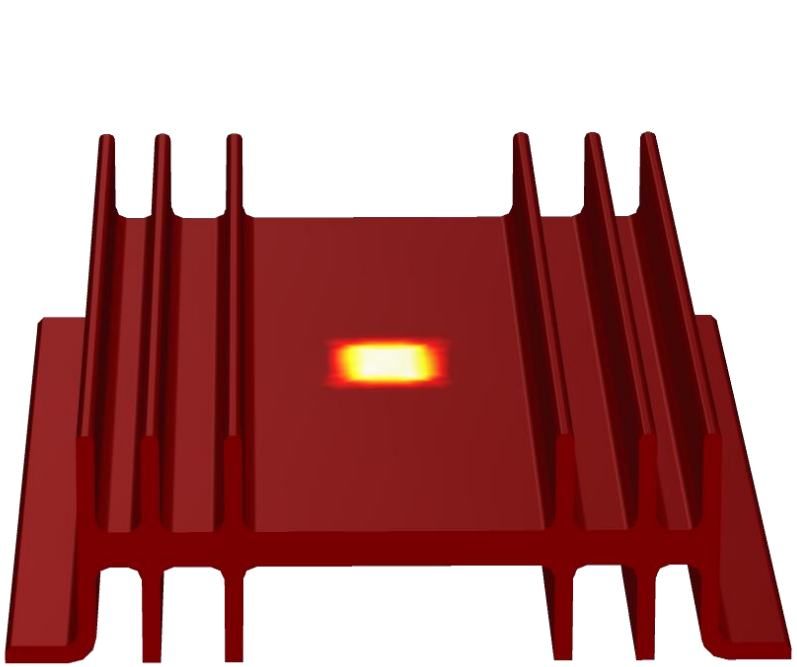
1. Vývoj výpočtového modelu
2. Přenesení MKP modelu do prostředí Simulink
3. Identifikace systému
4. Řízení výpočtového modelu

Vývoj výpočtového modelu

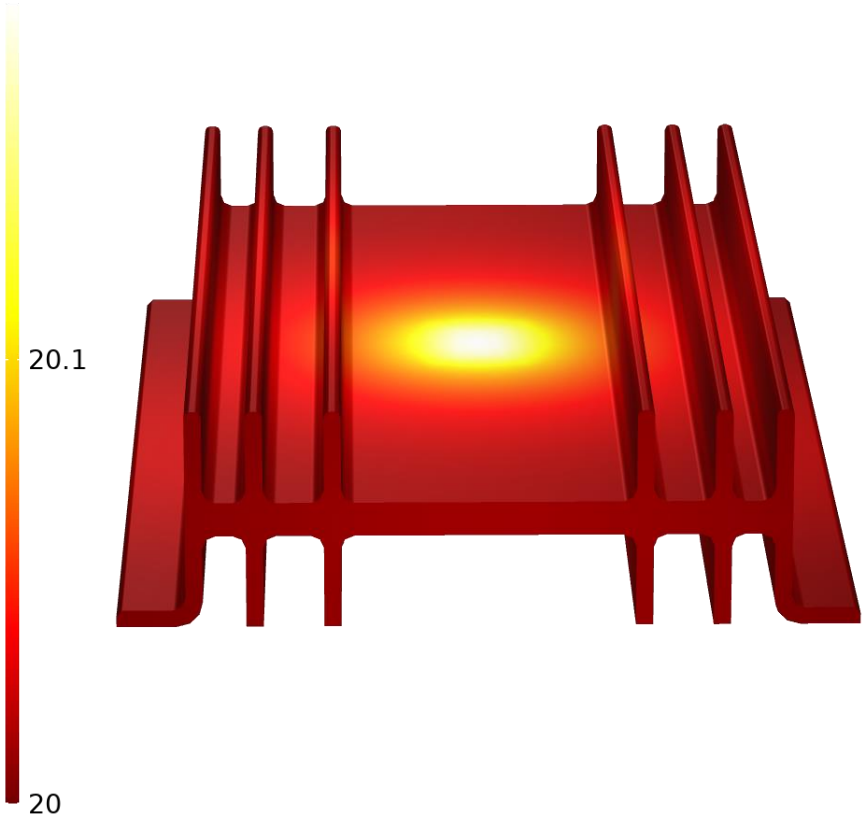



Digital_twin.mph - COMSOL Multiphysics
File Home Definitions Geometry Materials Physics Mesh Study Results Developer
Application Builder
Component 1
Add Component
Parameters
Variables
Functions
Parameter Case
Build All
Import
LiveLink
Add Material
Heat Transfer in Solids
Add Physics
Build Mesh
Mesh 1
Compute
Convection+radiation
Add Study
Pressure (spf)
Add Plot Group
Windows
Reset Desktop
Application
Model
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Layout
Model Builder
Digital_twin.mph (root)
Global Definitions
Parameters 1
Default Model Inputs
Materials
Component 1 (comp 1)
Definitions
Selections
Boundary Point Probe 1
Point Probe Expression 1 (ppb1)
Point Probe Expression 2 (ppb2)
Point Probe Expression 3 (ppb3)
Boundary Probe 1 (bnd1)
Boundary System 1 (sys1)
View 1
View 6
Geometry 1
Materials
Aluminum (mat1)
Air (mat2)
Heat Transfer in Solids (ht)
Laminar Flow (spf)
Multiphysics
Meshes
Convection+radiation
Convection without radiation
Results
Settings
Digital_twin.mph
Protection
Editing not protected
Set Password
Running not protected
Set Password
Used Products
COMSOL Multiphysics
CAD Import Module
Design Module
Heat Transfer Module
Unit System
SI
Presentation
Title:
Description:
Author:
Computation time
Expected:
Last: 3 h 25 min 22 s
Thumbnail
Set from Graphics Window
Load from File...
Clear
Graphics
Graphics color theme:
Default from preferences (Default)
Image export color theme:
Default from preferences (Default)
Font
Family:
Default from preferences (Vera)
Size:
Default size
pt
Graphics
Probe Plot 6
Probe Plot 7
Convergence Plot 1
Probe Plot 4
z
y
x
Messages
Progress
Log
Probe Table 4
License will expire in 37 days.
Warning: The preference setting Number of cores is ignored because the environment variable 'OMP_NUM_THREADS' is set to '16'.
[May 24, 2021 4:13 PM] Opened file: D:\Digital_twin\Digital_twin.mph
[May 24, 2021 4:13 PM] Some geometric entities are hidden.
[May 24, 2021 4:14 PM] Complete mesh consists of 149487 domain elements, 20505 boundary elements, and 4124 edge elements.
[May 24, 2021 4:15 PM] Number of degrees of freedom solved for: 441331 (plus 361756 internal DOFs).
[May 24, 2021 7:40 PM] Solution time (Convection+radiation): 12322 s. (3 hours, 25 minutes, 22 seconds)
[May 25, 2021 10:08 AM] Saved file: D:\Digital_twin\Digital_twin.mph
[May 25, 2021 10:51 AM] Formed union of 2 solid objects and 1 surface object.
[May 25, 2021 10:51 AM] Union has 2 domains, 138 boundaries, 342 edges, and 208 vertices.
[May 25, 2021 10:51 AM] Finalized geometry has 2 domains, 95 boundaries, 274 edges, and 184 vertices.
[May 25, 2021 10:52 AM] Complete mesh consists of 149487 domain elements, 20505 boundary elements, and 4124 edge elements.
4.23 GB | 5.06 GB

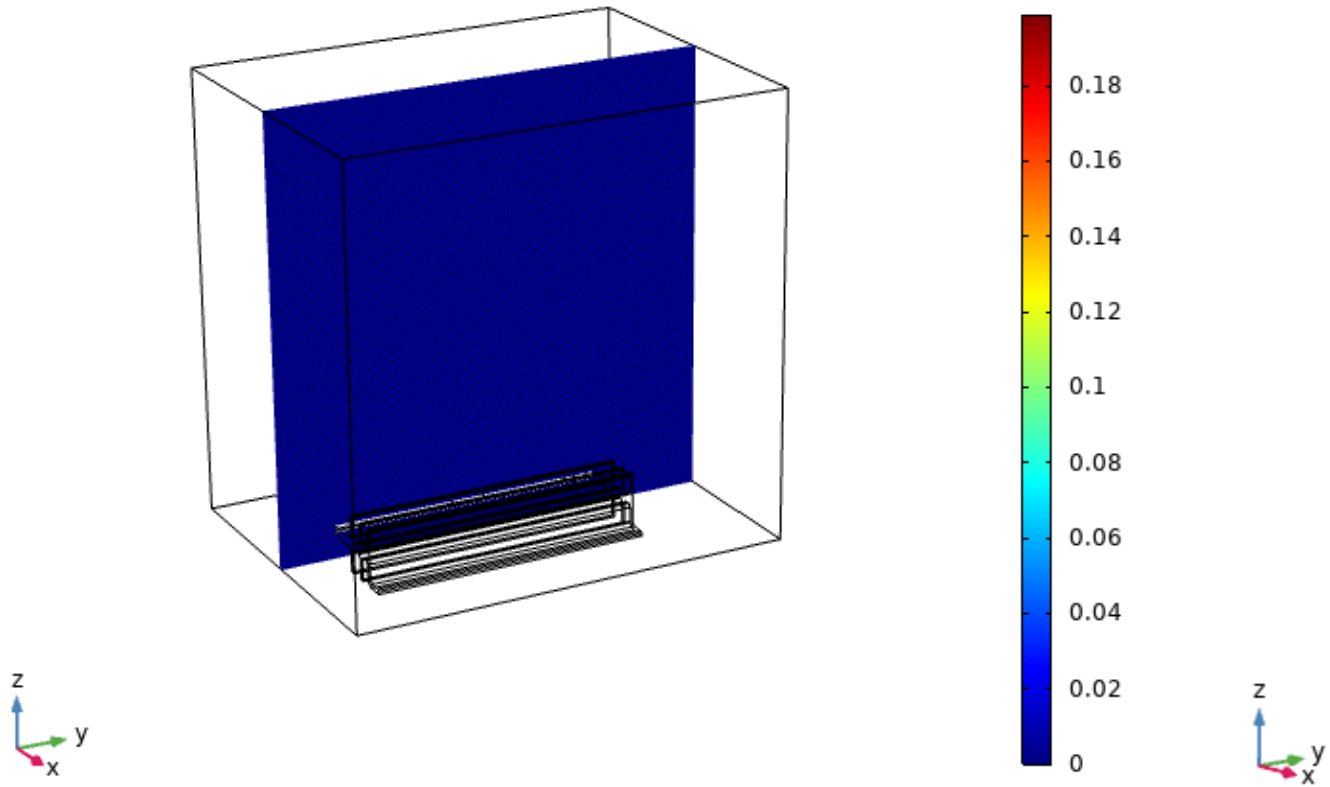
Výsledek rozložení teploty



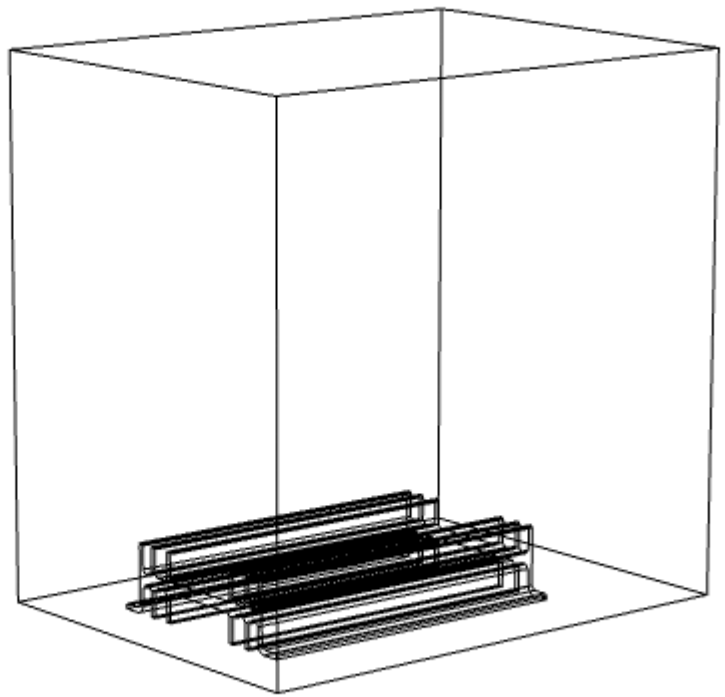
t=0 s



t = 900 s



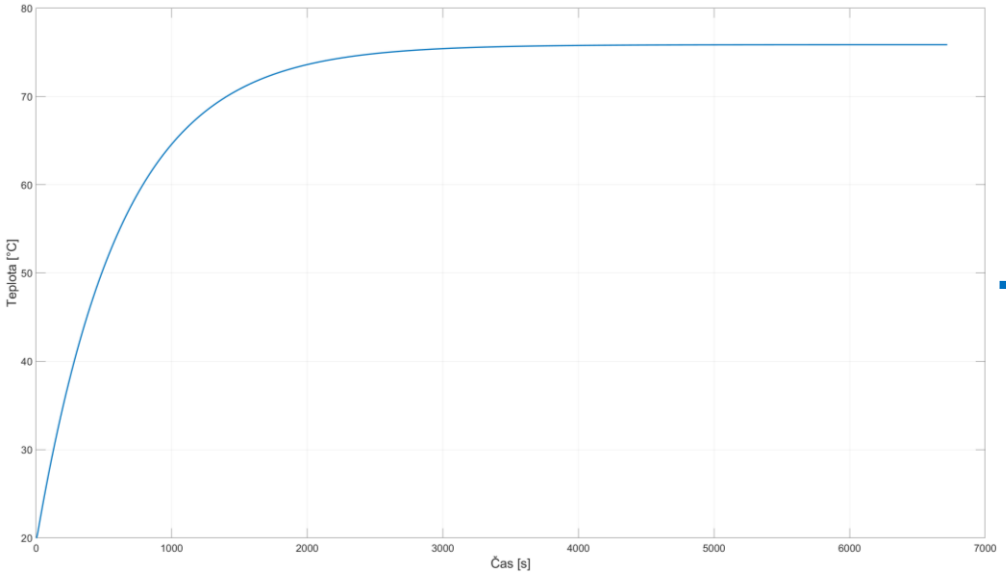
Rychlost [m/s]



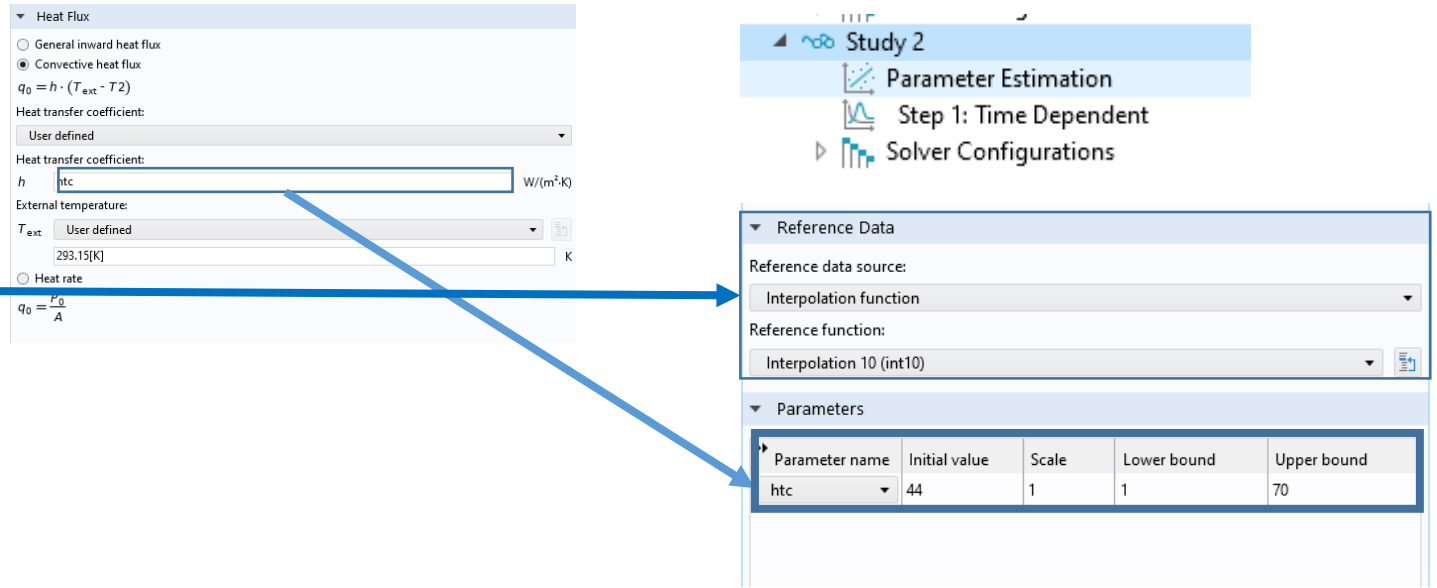
Teplota [°C]

Pouze teplotní úloha

- Parameter estimation



Input – výsledek z úlohy s laminárním prouděním



Algoritmy:

- **BOBYQA**

Použití na estimaci geometrie/sítě

- **Levenberg- Marquardt**

Nepodporuje podmínky

- **SNOPT**

Podporuje okrajové podmínky

New.mph - COMSOL Multiphysics

File Home Definitions Geometry Materials Physics Mesh Study Results Developer

Application Builder | Component 1 | Add Component | Parameters | Variables | Functions | Parameter Case | Import | LiveLink | Build All | Add Material | Heat Transfer in Solids 2 | Add Physics | Build Mesh | Mesh 2 | Compute | Study 3 | Add Study | 1D Plot Group 9 | Add Plot Group | Windows | Reset Desktop

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

Model Builder

- New.mph *(root)*
  - Global Definitions
    - Parameters 1
    - Default Model Inputs
    - Materials
    - Reduced-Order Modeling
    - Cosimulation for Simulink 1
  - Component 1 *(comp 1)*
    - Definitions
    - Geometry 1
    - Materials
    - Heat Transfer in Solids 2 *(ht2)*
    - Mesh 2
  - Study 1
  - Study 4
  - Study 3
    - Model Reduction
    - Step 1: Time Dependent
    - Solver Configurations
    - Job Configurations
  - Study 5
  - Results

Settings

Cosimulation for Simulink

Export

Label: Cosimulation for Simulink 1

Filename

Filename: D:\Digital_twin\Reduced_order3.fmu Browse...

Inputs

Parameter name	Initial value	Unit
P0	16[W]	W

Block Parameters

Outputs

Expression	Unit	Name
comp1.ppb2	K	Boundary Point Probe 2, T2

Expression:

Name:

Study

Study: Study 5

Store solution

At communication points: End of communication step

According to study step settings

Dependencies

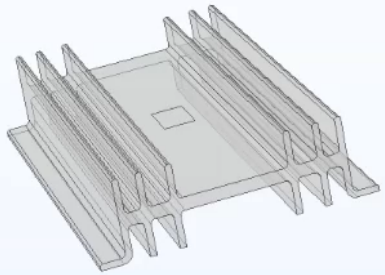
	comp1.ppb2
P0	

Image

Image: Browse... Import Set from Graphics Window

Image preview

Graphics

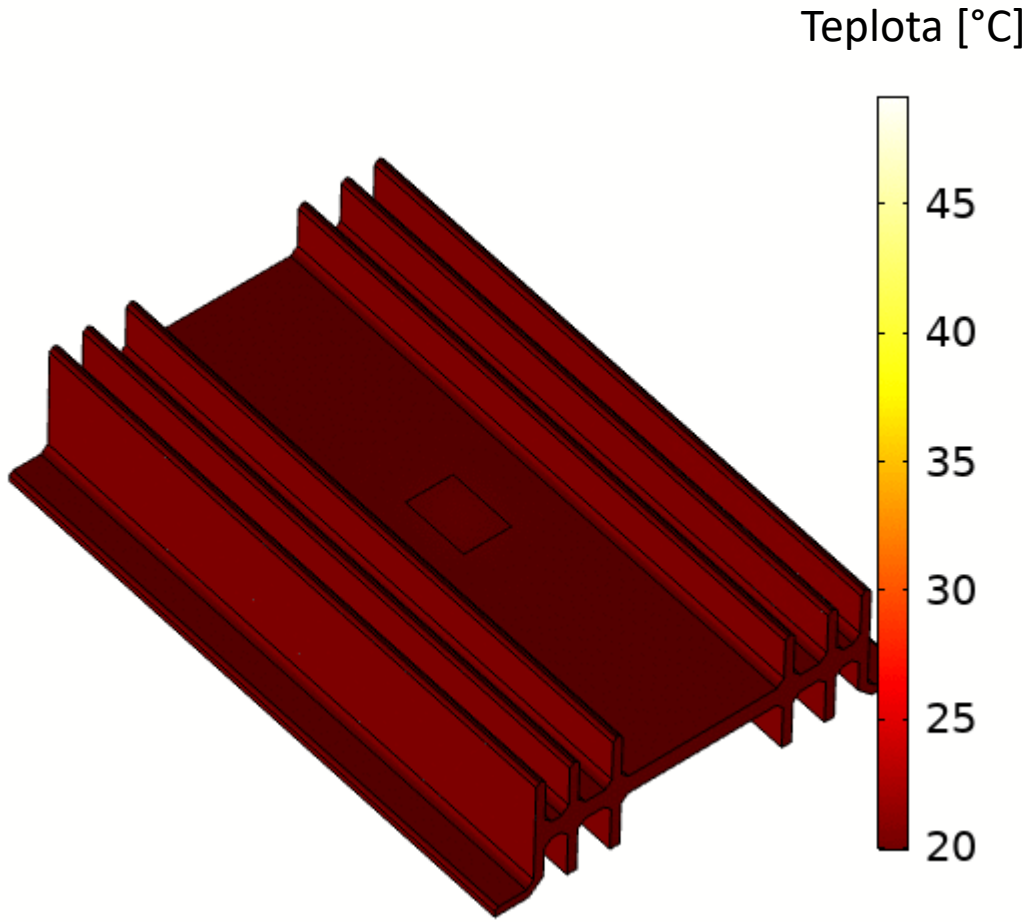


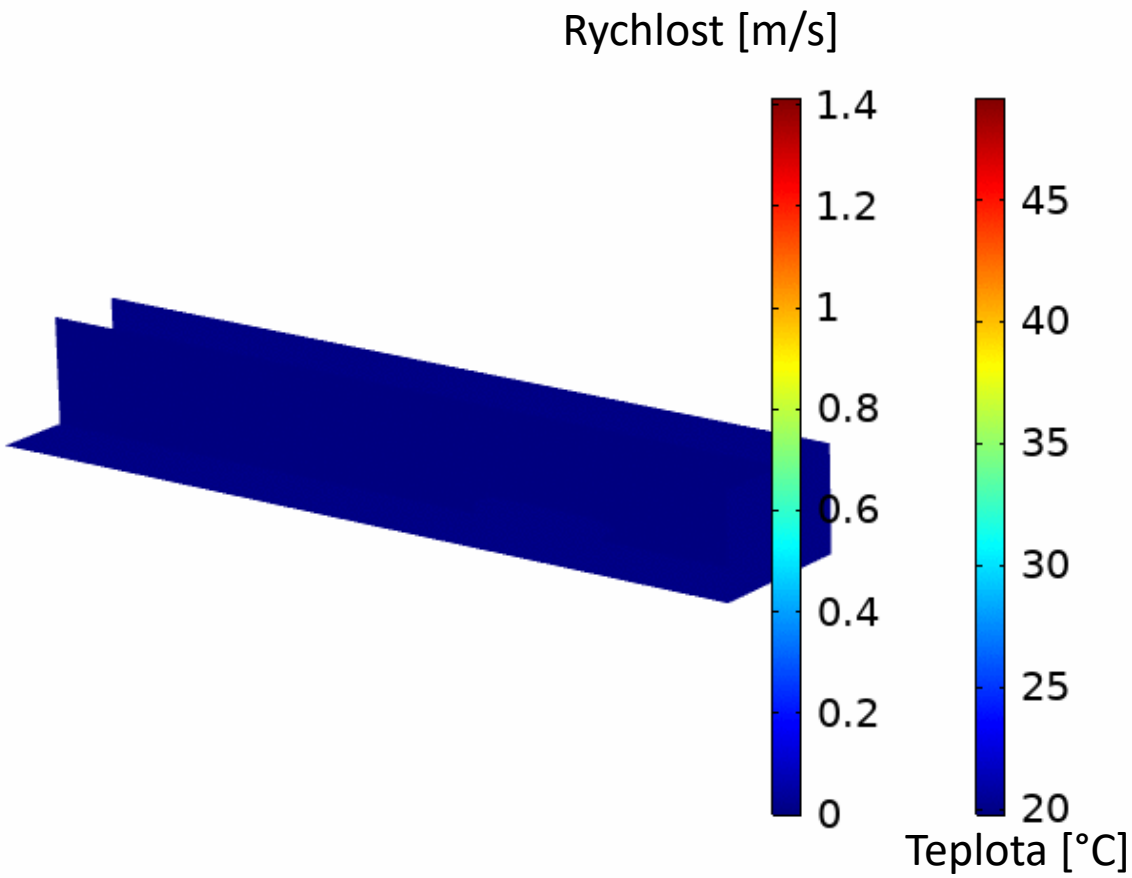
Messages | Progress | Log | Probe Table 1

```
COMSOL Multiphysics 5.6.0.280
License will expire in 36 days.
Warning: The preference setting Number of cores is ignored because the environment variable 'OMP_NUM_THREADS' is set to '16'.
[May 25, 2021 9:56 AM] Opened file: D:\Digital_twin\New.mph
[May 25, 2021 9:56 AM] Saved file for cosimulation for Simulink: D:\Digital_twin\Reduced_order3.fmu
[May 25, 2021 10:21 AM] Saved file for cosimulation for Simulink: D:\Digital_twin\Reduced_order3.fmu
[May 25, 2021 10:23 AM] Saved file for cosimulation for Simulink: D:\Digital_twin\Reduced_order3.fmu
[May 25, 2021 11:12 AM] Saved file for cosimulation for Simulink: D:\Digital_twin\Reduced_order3.fmu
```

1.67 GB | 2.12 GB

Simulace s prouděním

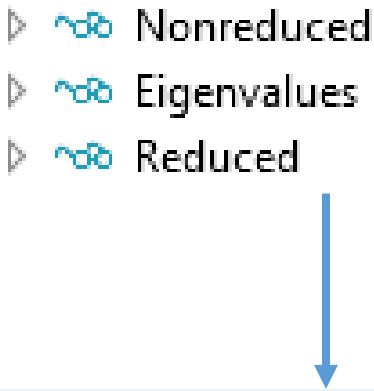


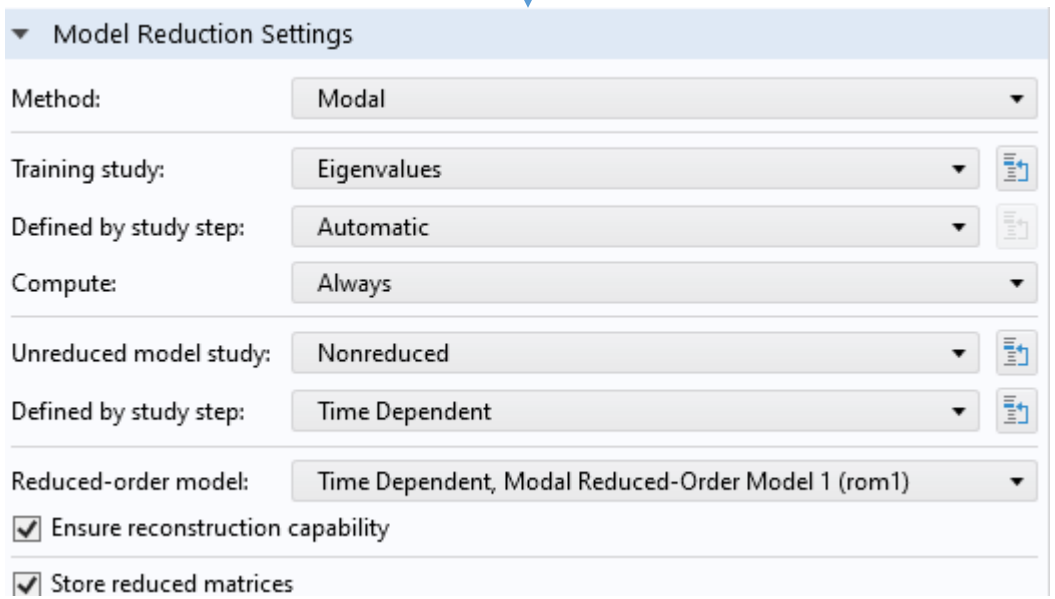


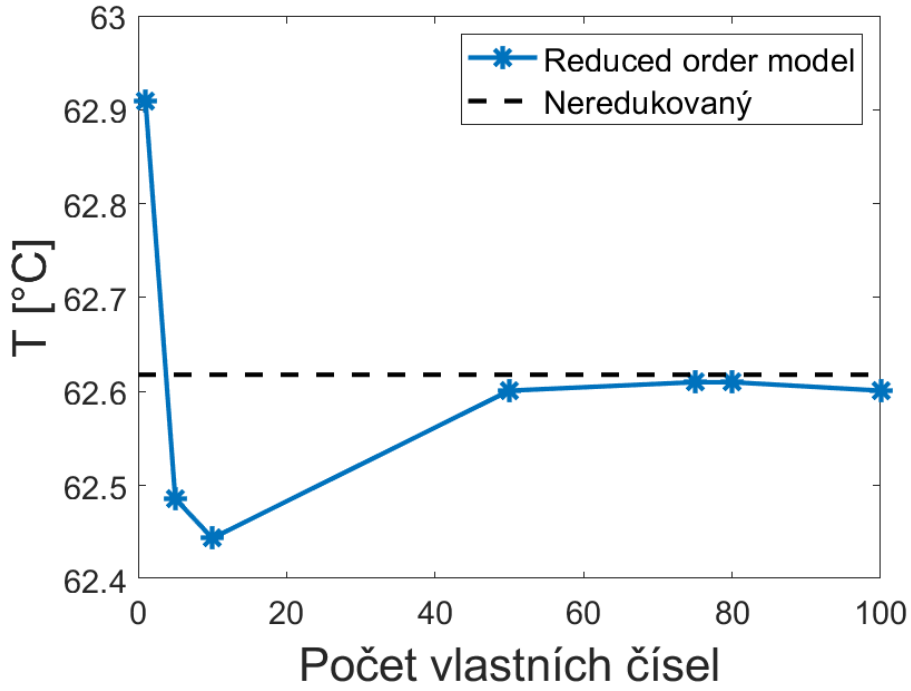
Redukce systému

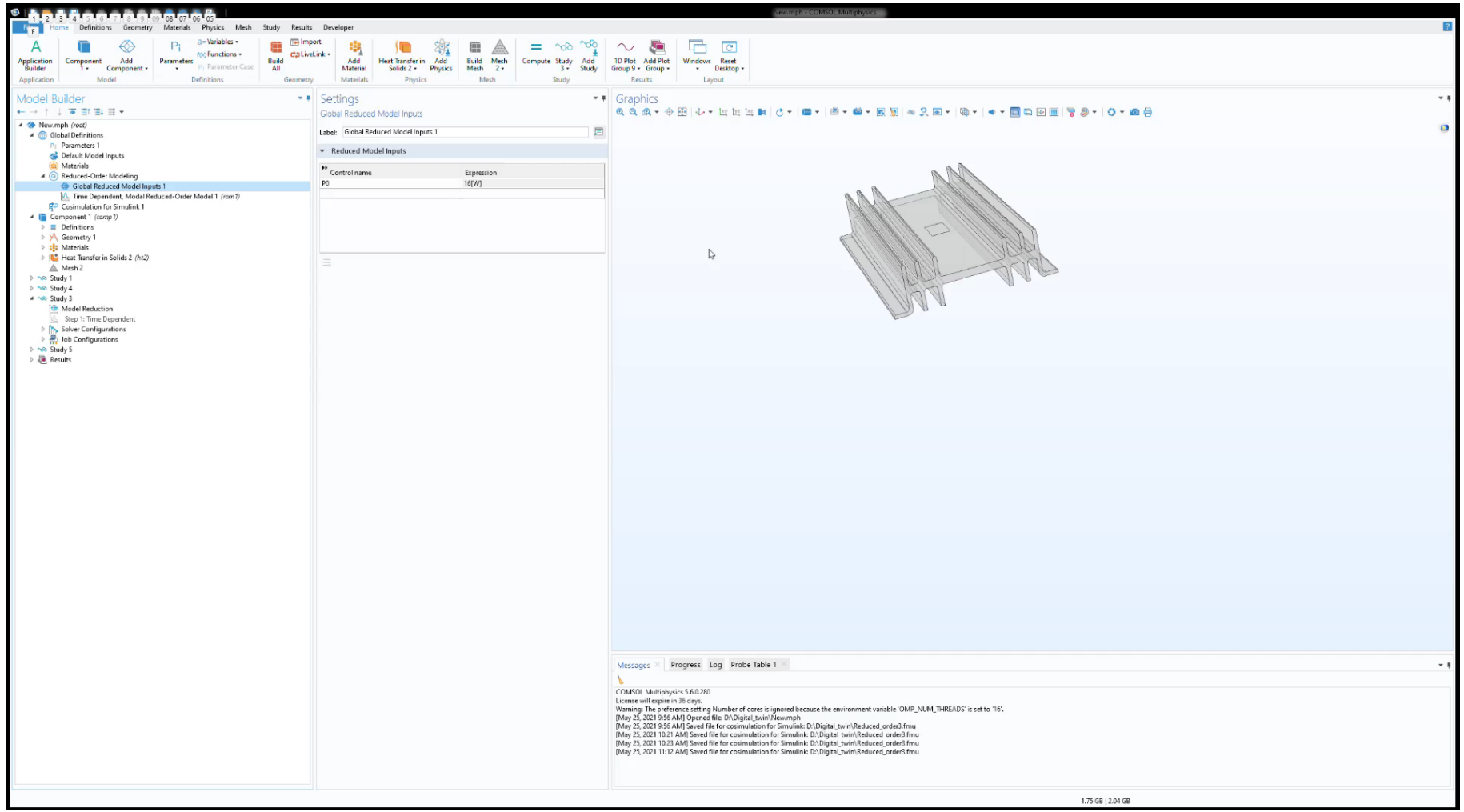
Redukovaný model

Redukce systému na základě vlastních čísel








New.mph - COMSOL Multiphysics
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
Application Builder
Component 1
Add Component
Parameters
Variables
Functions
Parameter Case
Build All
Import
LiveLink
Add Material
Heat Transfer in Solids 2
Add Physics
Build Mesh
Mesh 2
Compute
Study 3
Add Study
1D Plot Group 9
Add Plot Group
Windows
Reset Desktop
Model Builder
New.mph (root)
Global Definitions
Parameters 1
Default Model Inputs
Materials
Reduced-Order Modeling
Global Reduced Model Inputs 1
Time Dependent, Modal Reduced-Order Model 1 (rom1)
Cosimulation for Simulink 1
Component 1 (comp1)
Definitions
Geometry 1
Materials
Heat Transfer in Solids 2 (ht2)
Mesh 2
Study 1
Study 4
Study 3
Model Reduction
Step 1: Time Dependent
Solver Configurations
Job Configurations
Study 5
Results
Settings
Global Reduced Model Inputs
Label: Global Reduced Model Inputs 1
Reduced Model Inputs
Control name
Expression
P0
16[W]
Graphics
Messages
Progress
Log
Probe Table 1
COMSOL Multiphysics 5.6.0.280
License will expire in 36 days.
Warning: The preference setting Number of cores is ignored because the environment variable 'OMP_NUM_THREADS' is set to '16'.
[May 25, 2021 9:56 AM] Opened file: D:\Digital_twin\New.mph
[May 25, 2021 9:56 AM] Saved file for cosimulation for Simulink: D:\Digital_twin\Reduced_order3.fmu
[May 25, 2021 10:21 AM] Saved file for cosimulation for Simulink: D:\Digital_twin\Reduced_order3.fmu
[May 25, 2021 10:23 AM] Saved file for cosimulation for Simulink: D:\Digital_twin\Reduced_order3.fmu
[May 25, 2021 11:12 AM] Saved file for cosimulation for Simulink: D:\Digital_twin\Reduced_order3.fmu
1.75 GB | 2.04 GB

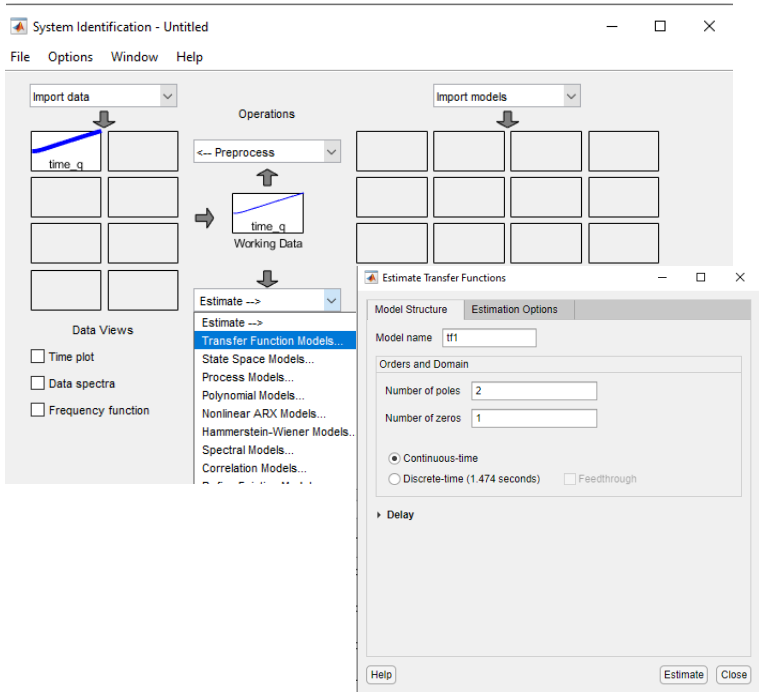
MATLAB® & SIMULINK®

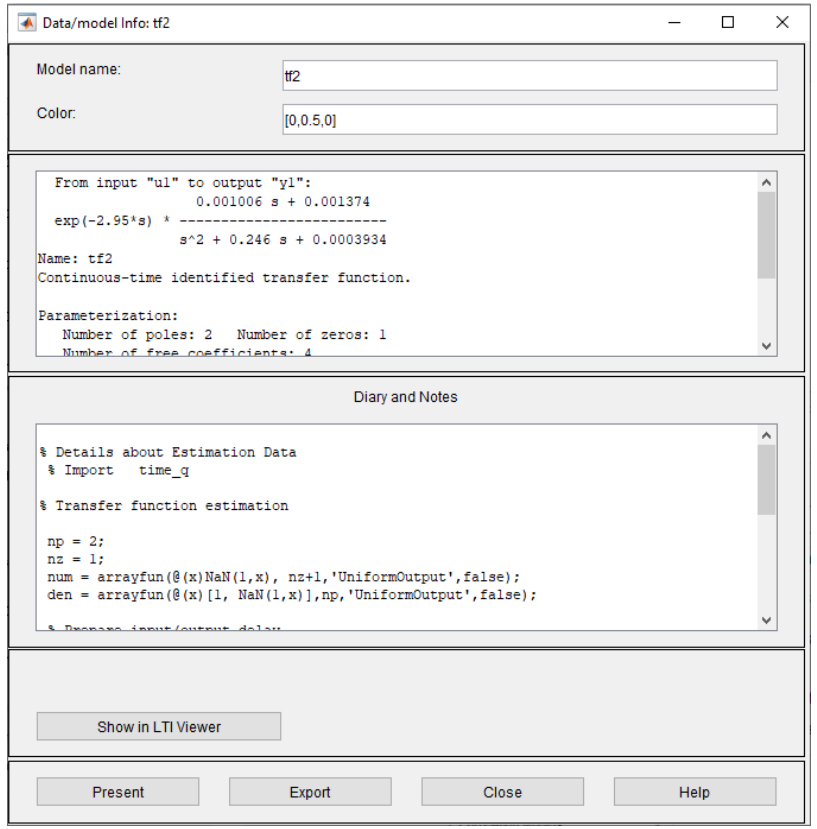
Řízení systému

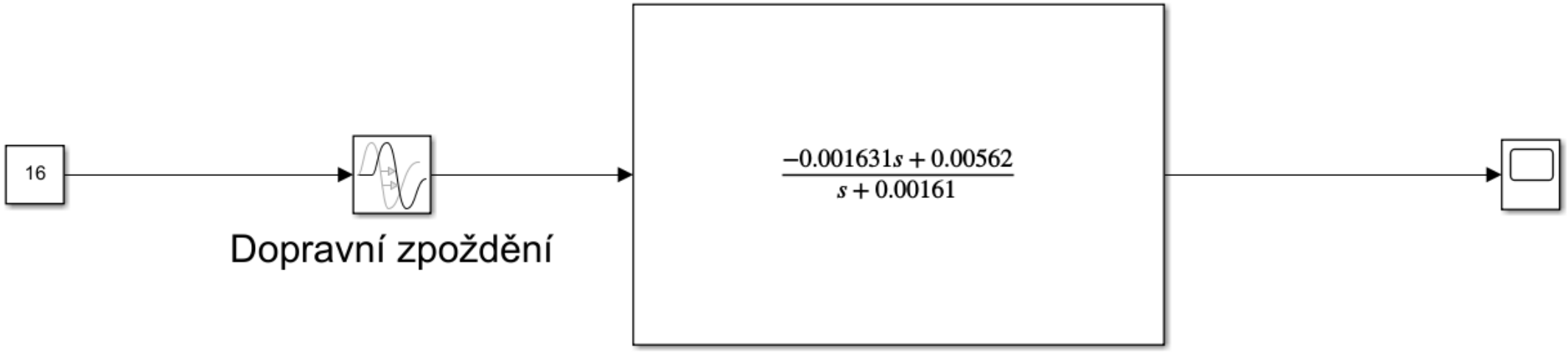
COMSOL

Identifikace systému

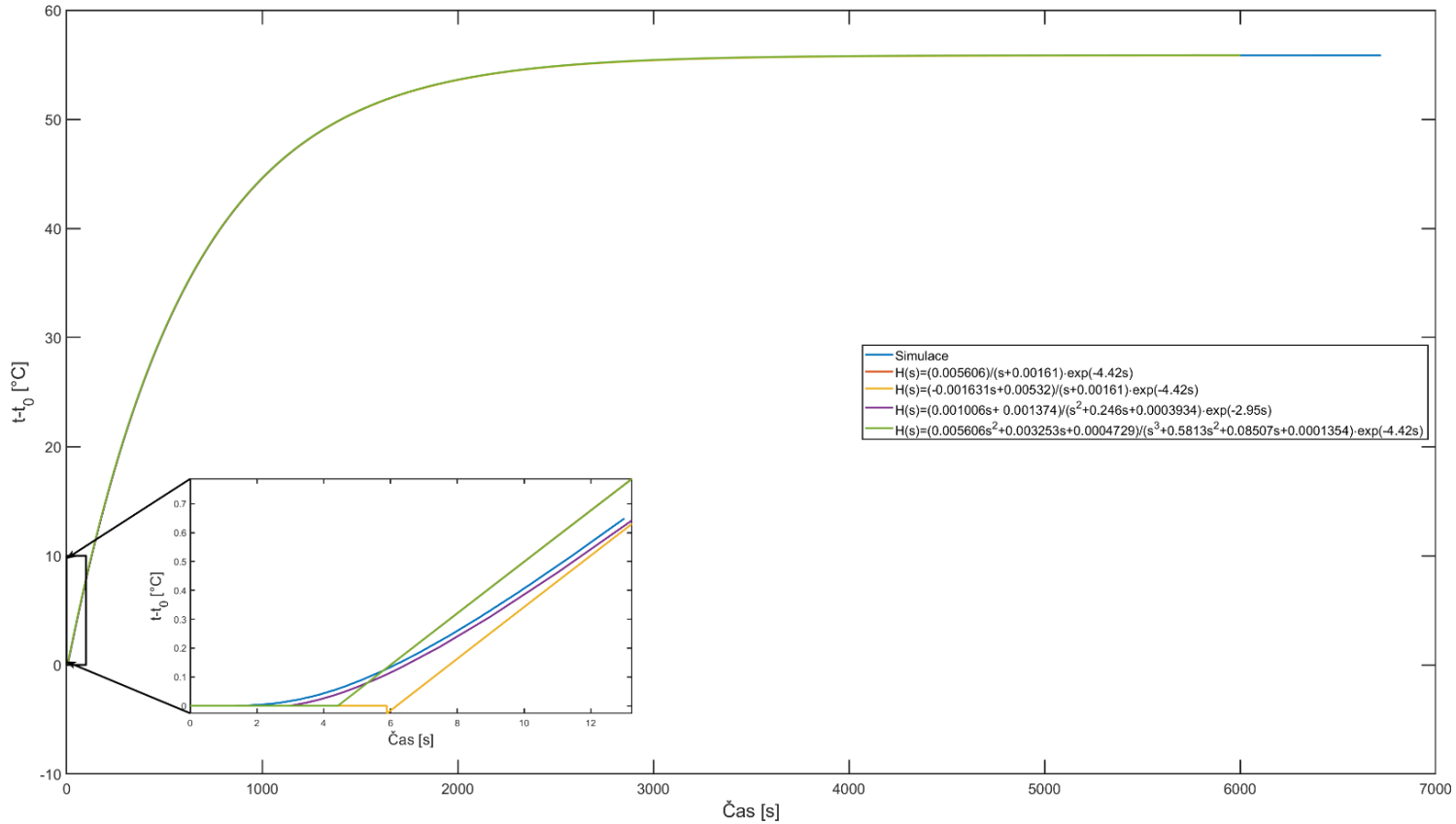
- Nalezení přenosové funkce
- Toolbox Systém Identification







Přenosová funkce



Import matic z Comsolu do Matlabu

- Při uložení matic ve workspace lze spoustit i Simulink

```
model=mphload("New.mph"); %Nacteni souboru
MR=mphreduction(model, 'roml','out',{'Mc' 'MA' 'MB' 'A' 'B' 'C' 'D' 'x0'});
% vytahnuti matic ze systemu
input=16;% vstup
func=@(t,x) MR.MA*x+MR.MB*input';% vypoctova rovnice
opt=odeset('mass',MR.Mc', 'Jacobian',MR.MA,'stats','on');
x0=zeros(size(MR.MA,1),1);
[t,x2]=ode23s(func,0:0.05:900,x0,opt);
y2t=MR.C*x2';
y20=MR.C*MR.x0;
y2=y2t+y20;
```

Matrices
Stiffness matrix (Kr)
Damping matrix (Dr)
Damping ratio matrix (Dra)
Mass matrix (Er)
Input matrix (Br)
Output matrix (Cr)
Input feedback matrix (F)
Initial value input matrix (B0r)
Initial value time derivative input matrix (B0rdot)
Time derivative input matrix (Brdot)
Second time derivative input matrix (Brdotdot)
Mass matrix (Mc)
Stiffness matrix (MA)
Input matrix (MB)
Input feedback matrix (D)
Output matrix (C)

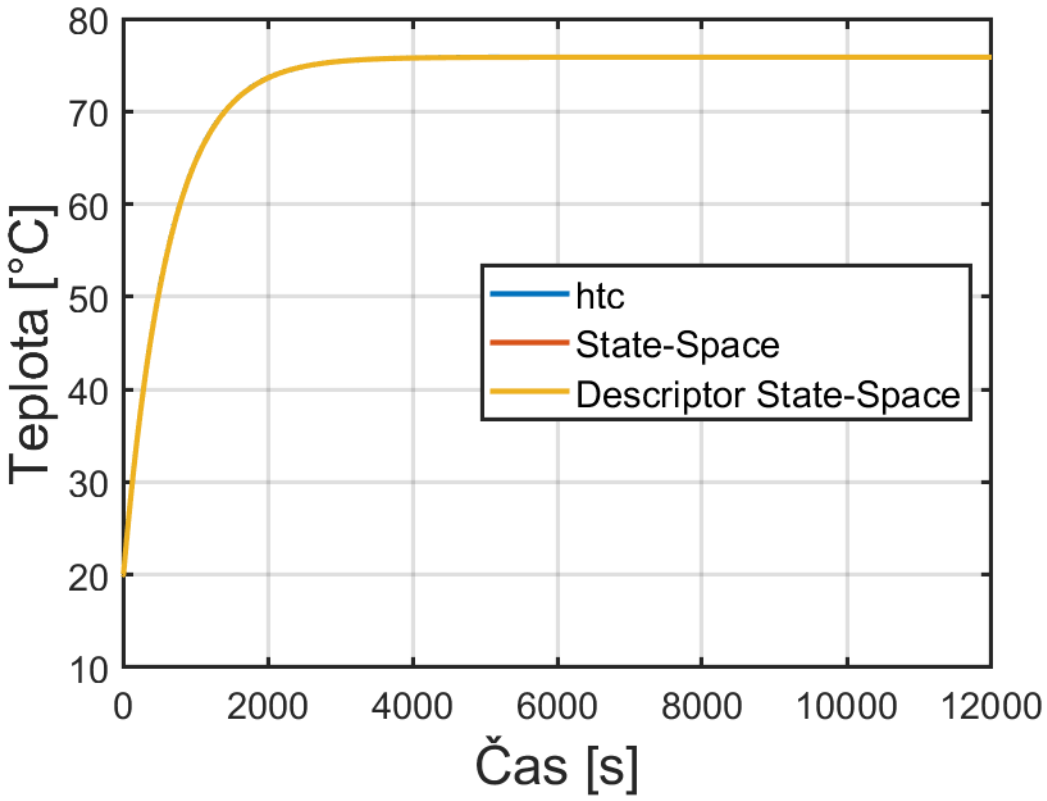
Vectors
Load vector (L)
Output bias (Y0)
Initial value vector (U0)
Initial derivative vector (Udot0)
Stiffness matrix times ud (Kud)
Initial value vector (x0)

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

State-space

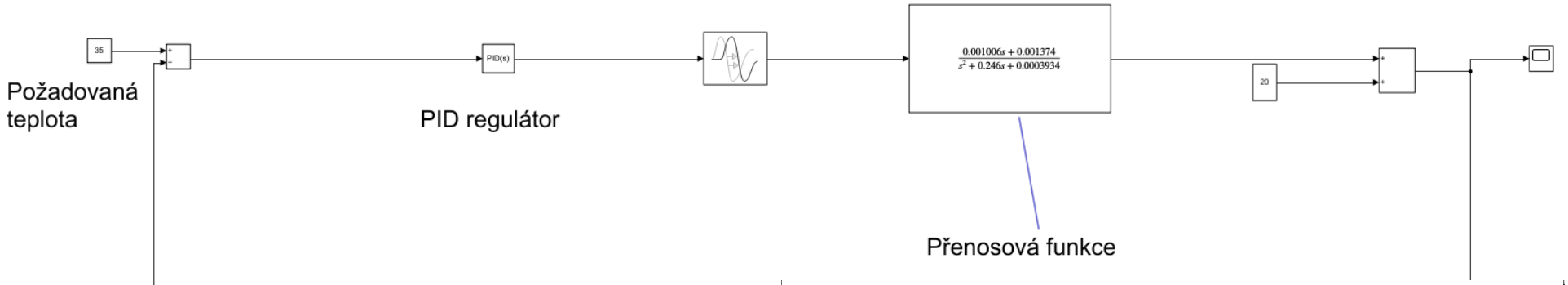
$$E\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

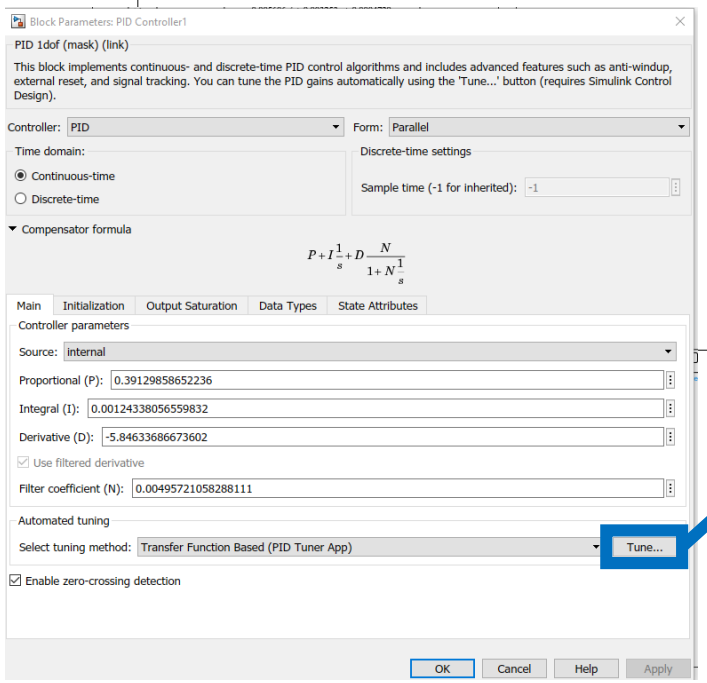
Descriptor State-Space

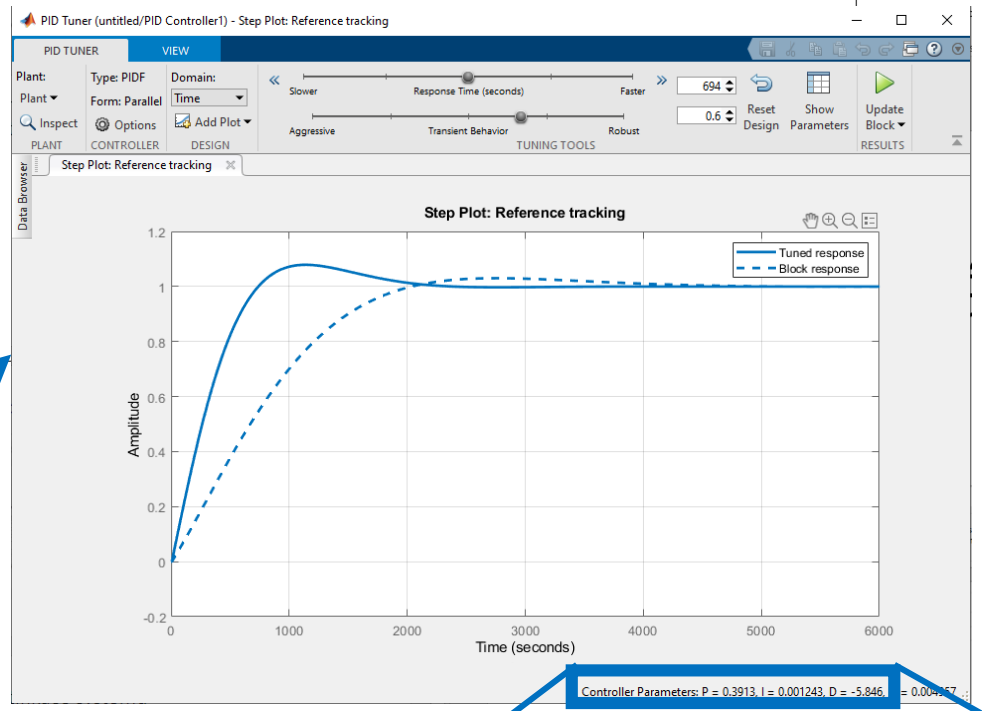


Kontrola řízení pomocí PID regulátoru

PID controller tunning

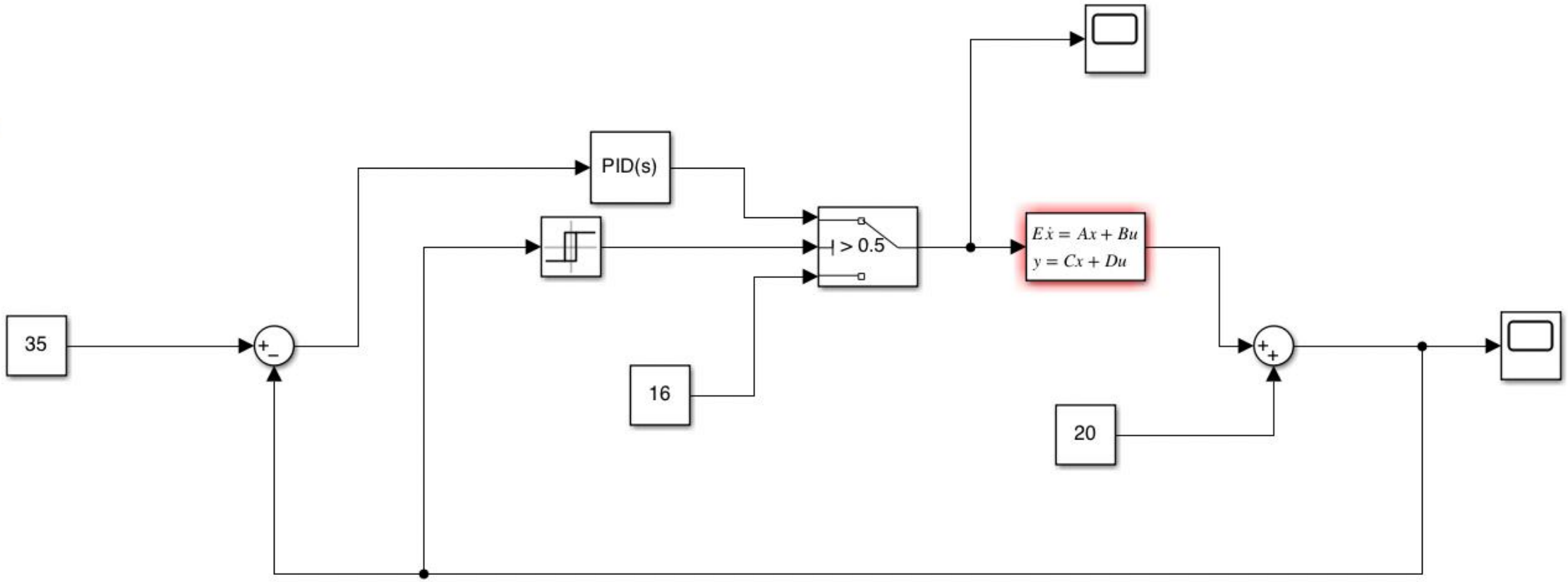




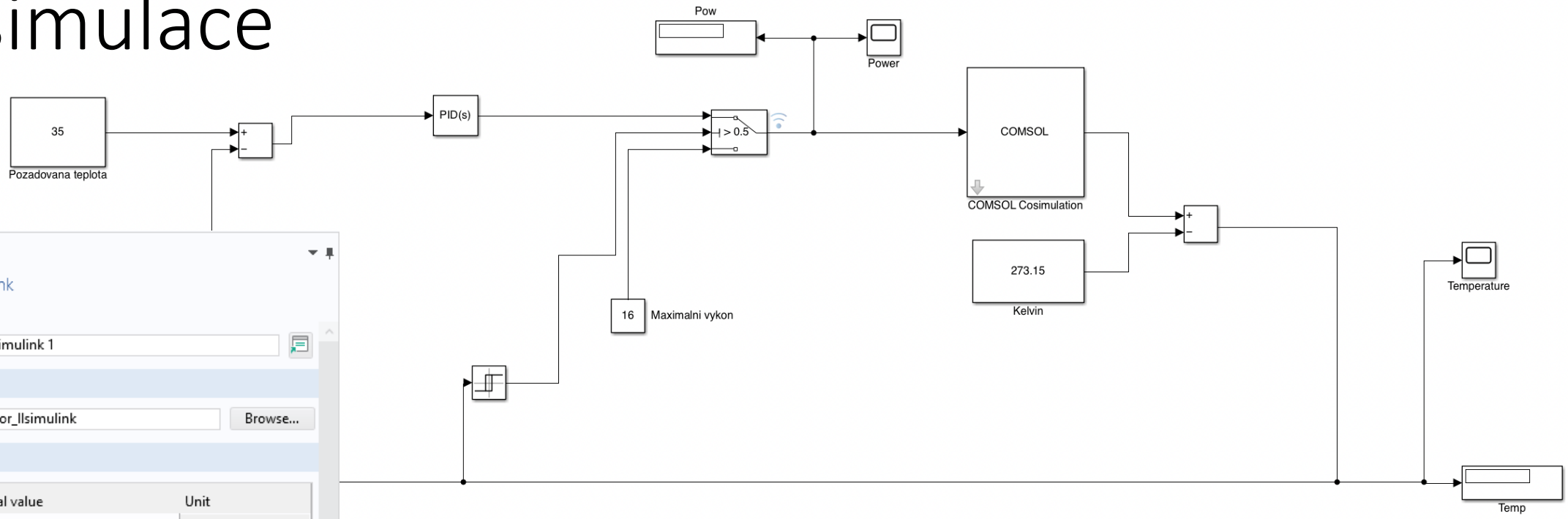


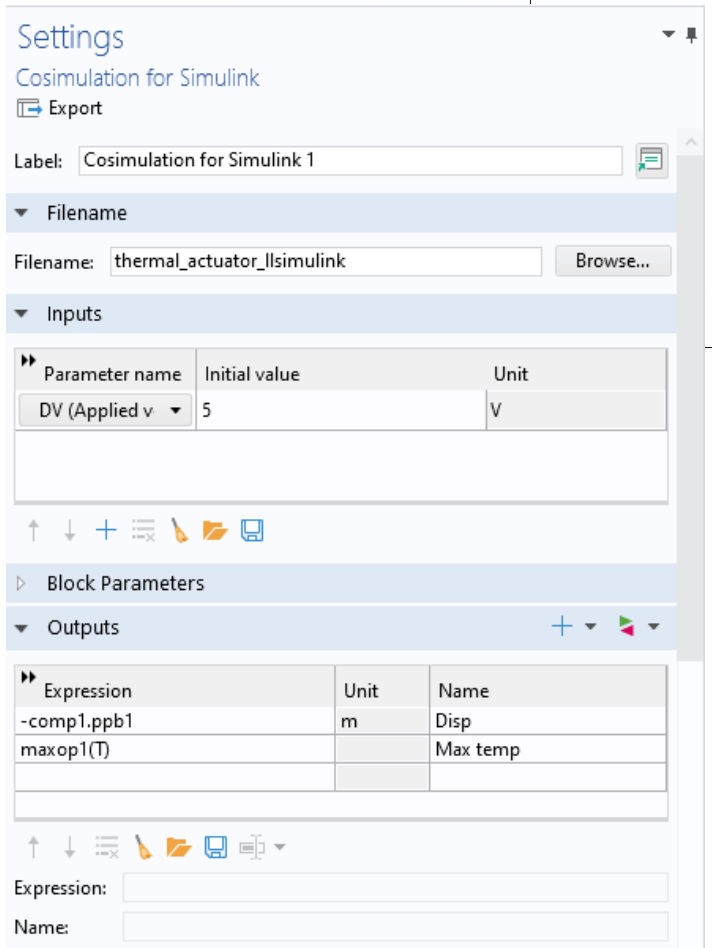
P=0.3913, I= 0.001243, D = -5.846

Vložení matic z redukovaného systému

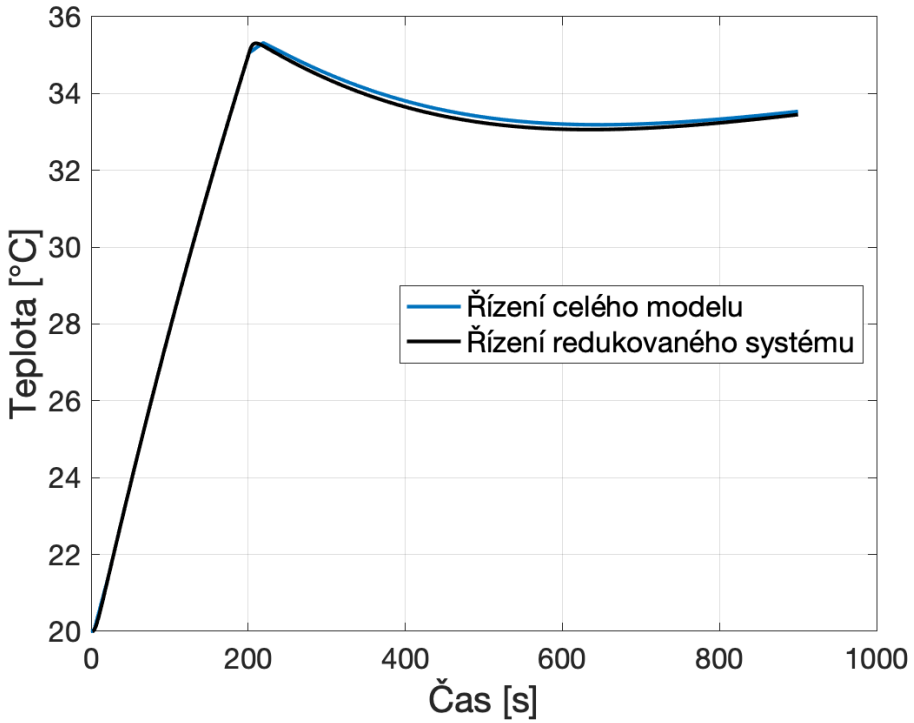


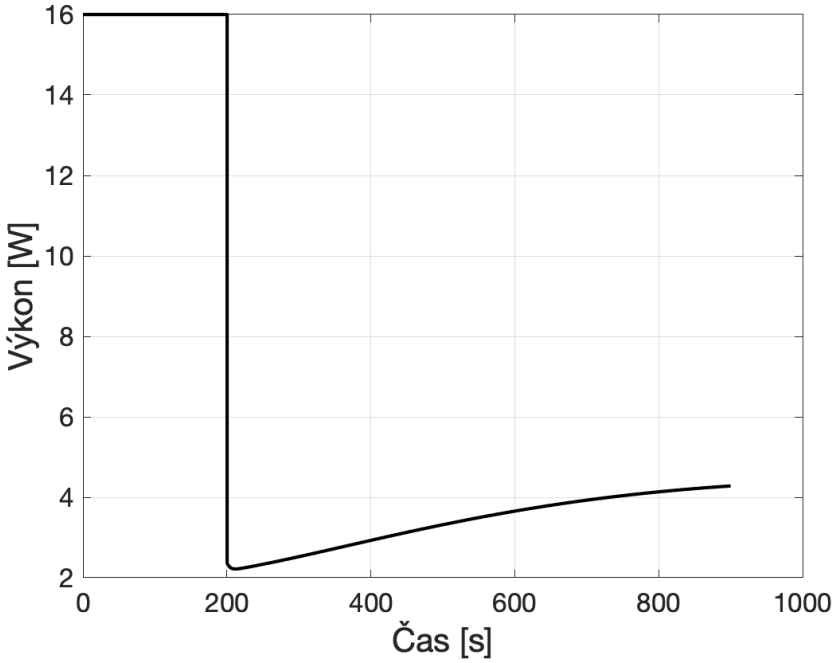
Cosimulace


Pow
Power
35
Pozadovana teplota
PID(s)
> 0.5
COMSOL
COMSOL Cosimulation
273.15
Kelvin
16
Maximalni vykon
Temperature
Temp


Settings
Cosimulation for Simulink
Export
Label: Cosimulation for Simulink 1
Filename
Filename: thermal_actuator_llsimulink
Browse...
Inputs
Parameter name
Initial value
Unit
DV (Applied v
5
V
Block Parameters
Outputs
Expression
Unit
Name
-comp1.ppb1
m
Disp
maxop1(T)
Max temp
Expression:
Name:

Co-simulace





Metoda	Čas
Co-simulace	15 min 19 sec
Import matic	2 sec

Poznámka v případě problému komunikace do Command Window: shareMATLABForFMUCoSim

Děkuji za pozornost