Computational Fluid Dynamics
Comsol Lab 2
Lecture 9

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1. INTRODUCTION

This lab concerns the analysis of a turbulent 2D-channel flow.

We use the CFD-software Comsol and start from RANS-equations and use the Boussinesq hypothesis approach where we apply a k-ε model for the turbulent kinetic energy and dissipation.

We compare our simulation results with high accuracy Direct Numerical Simulation (DNS) data to learn how to perform the process of benchmarking a simulation model.

The general aims of this lab are:

- to learn how to analyze turbulent flow data and draw conclusions from it
- to understand the setting structure in the Comsol setup
- to understand how to import data and create an interpolation functions from it
- to investigate how simulation results may depend on flow domain and mesh settings

2. Theory

The k-ε model describes the turbulent kinetic energy k and the dissipation ε and is used in addition to the incompressible RANS-momentum equations. The model equations we use are

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\frac{\mu+\mu_t}{\rho}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right],$$

$$\frac{\partial U_i}{\partial x_i} = 0,$$

$$\boxed{\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = \overbrace{2\frac{\mu_t}{\rho} S_{ij}S_{ij}}^{\text{Production of k}} \overbrace{-\,\varepsilon}^{\text{Dissipation of k}} + \overbrace{\frac{\partial}{\partial x_j}\left[\frac{1}{\rho}\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]}^{\text{Diffusion of k}},}$$

$$\boxed{\frac{\partial \varepsilon}{\partial t} + U_j \frac{\partial \varepsilon}{\partial x_j} = 2\frac{\mu_t}{\rho} S_{ij}S_{ij}\left(C_{\varepsilon 1}\frac{\varepsilon}{k}\right) - \varepsilon\left(C_{\varepsilon 1}\frac{\varepsilon}{k}\right) + \frac{\partial}{\partial x_j}\left[\frac{1}{\rho}\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right],}$$

$$\boxed{\mu_t = C_\mu \rho \frac{k^2}{\varepsilon}}$$

$$\sigma_k = 1.4$$
$$\sigma_\varepsilon = 1.5$$
$$\left.\begin{aligned} C_{\varepsilon 1} &= 1.5 \\ C_{\varepsilon 2} &= 1.9 \\ C_\mu &= 0.09 \end{aligned}\right\}$$

In our simulation assumed to be functions that adjust near walls.
(Damping functions)

Q1: The k-ε simulation data for the velocity, U+, fits very good with the DNS-data. What can we say about the fit for P_k, ε and k data? To answer this you should import the DNS-data files for P_k, ε and k (can be found at the course Canvas) and plot them in the figure. What is your conclusion after you made the plot?

Q2: Decrease the length of the channel from 4m to 2m, and run the simulation. What can you conclude by comparing the 2m and 4m channel results?

Q3: The P_k and ε results data from the simulation seems to be almost identical (at least on average), what does this mean?

Q4: The P_k-curve is very staggered. Why is it so, and how do we smooth the curve?

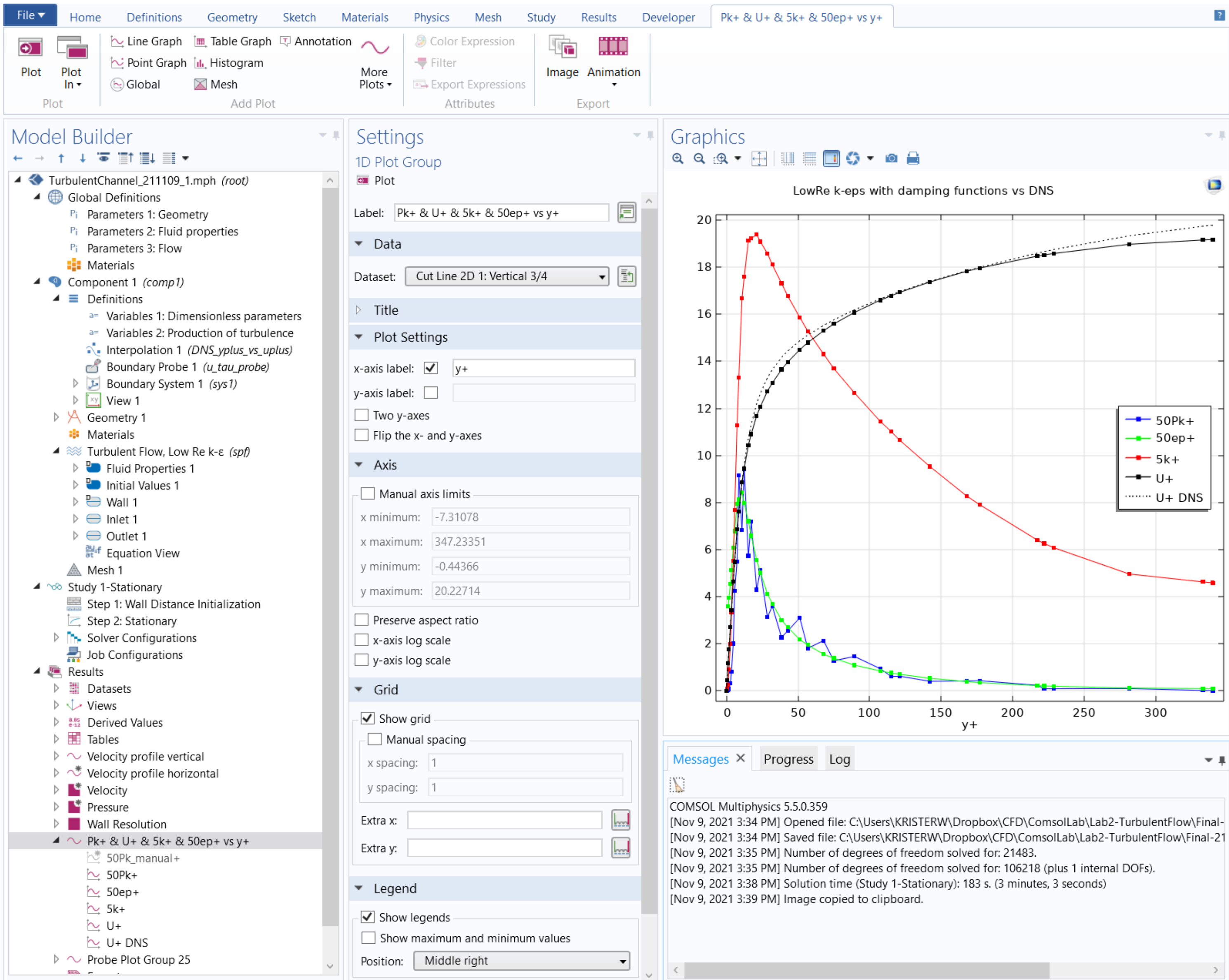
Three approaches to test:

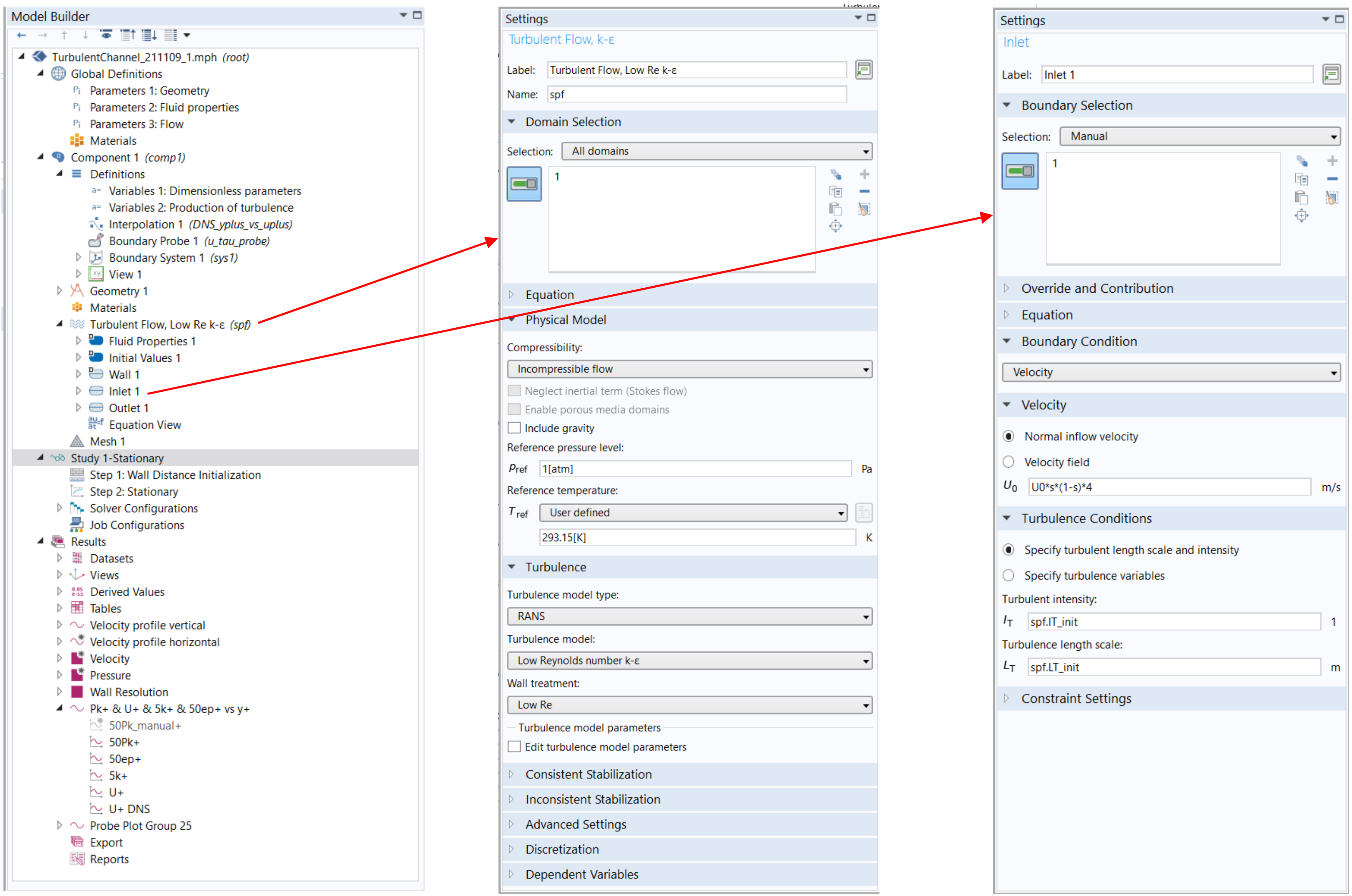
a) Run a simulation with a finer mesh by under Mesh applying Element size =Coarser. What do you conclude from the result?

b) Run a second simulation. Change settings under Mesh/Sequence type to "User-controlled mesh". Use Size=Extra coarse, Size1=Coarse, but under the Boundary Layer setting use Number of BL=20 and Stretching factor =1.1. What do you conclude from the result?

c) Run a third simulation. For the mesh use "Physics-controlled mesh" with "Extremely coarse" element size. Under the main node "Turbulent Flow, Low Re k-ε" change Discretization from *P1+P1* to *P2+P1*. What do you conclude from the result?

Note: It is expected that the simulation time becomes 3-4 times longer for P2+P1 compared to P1+P1.


File
Home
Definitions
Geometry
Sketch
Materials
Physics
Mesh
Study
Results
Developer
Pk+ & U+ & 5k+ & 50ep+ vs y+
Plot
Plot In
Line Graph
Table Graph
Annotation
Point Graph
Histogram
Global
Mesh
More Plots
Color Expression
Filter
Export Expressions
Image
Animation
Plot
Add Plot
Attributes
Export
Model Builder
TurbulentChannel_211109_1.mph (root)
Global Definitions
Parameters 1: Geometry
Parameters 2: Fluid properties
Parameters 3: Flow
Materials
Component 1 (comp1)
Definitions
Variables 1: Dimensionless parameters
Variables 2: Production of turbulence
Interpolation 1 (DNS_yplus_vs_uplus)
Boundary Probe 1 (u_tau_probe)
Boundary System 1 (sys1)
View 1
Geometry 1
Materials
Turbulent Flow, Low Re k-ε (spf)
Fluid Properties 1
Initial Values 1
Wall 1
Inlet 1
Outlet 1
Equation View
Mesh 1
Study 1-Stationary
Step 1: Wall Distance Initialization
Step 2: Stationary
Solver Configurations
Job Configurations
Results
Datasets
Views
Derived Values
Tables
Velocity profile vertical
Velocity profile horizontal
Velocity
Pressure
Wall Resolution
Pk+ & U+ & 5k+ & 50ep+ vs y+
50Pk_manual+
50Pk+
50ep+
5k+
U+
U+ DNS
Probe Plot Group 25
Settings
1D Plot Group
Plot
Label: Pk+ & U+ & 5k+ & 50ep+ vs y+
Data
Dataset: Cut Line 2D 1: Vertical 3/4
Title
Plot Settings
x-axis label: y+
y-axis label:
Two y-axes
Flip the x- and y-axes
Axis
Manual axis limits
x minimum: -7.31078
x maximum: 347.23351
y minimum: -0.44366
y maximum: 20.22714
Preserve aspect ratio
x-axis log scale
y-axis log scale
Grid
Show grid
Manual spacing
x spacing: 1
y spacing: 1
Extra x:
Extra y:
Legend
Show legends
Show maximum and minimum values
Position: Middle right
Graphics
LowRe k-eps with damping functions vs DNS
20
18
16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
y+
50Pk+
50ep+
5k+
U+
U+ DNS
Messages
Progress
Log
COMSOL Multiphysics 5.5.0.359
[Nov 9, 2021 3:34 PM] Opened file: C:\Users\KRISTERW\Dropbox\CFD\ComsolLab\Lab2-TurbulentFlow\Final-
[Nov 9, 2021 3:34 PM] Saved file: C:\Users\KRISTERW\Dropbox\CFD\ComsolLab\Lab2-TurbulentFlow\Final-21
[Nov 9, 2021 3:35 PM] Number of degrees of freedom solved for: 21483.
[Nov 9, 2021 3:35 PM] Number of degrees of freedom solved for: 106218 (plus 1 internal DOFs).
[Nov 9, 2021 3:38 PM] Solution time (Study 1-Stationary): 183 s. (3 minutes, 3 seconds)
[Nov 9, 2021 3:39 PM] Image copied to clipboard.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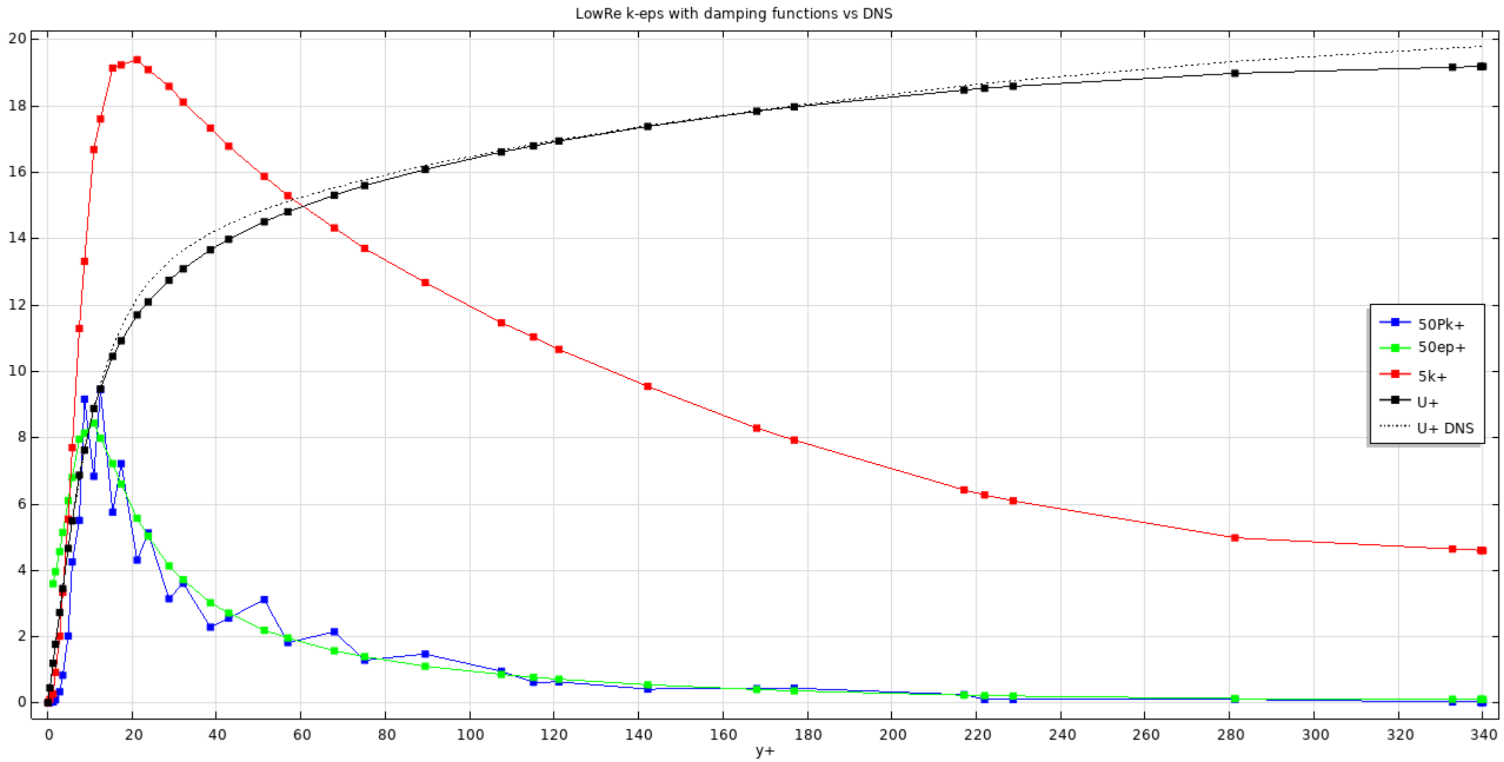
Velocity profile vertical
Velocity profile horizontal
Velocity
Pressure
Wall Resolution
Pk+ & U+ & 5k+ & 50ep+ vs y+
50Pk_manual+
50Pk+
50ep+
5k+
U+
U+ DNS
Probe Plot Group 25
Export
Reports
Settings
Turbulent Flow, k-ε
Label: Turbulent Flow, Low Re k-ε
Name: spf
Domain Selection
Selection: All domains
1
Equation
Physical Model
Compressibility:
Incompressible flow
Neglect inertial term (Stokes flow)
Enable porous media domains
Include gravity
Reference pressure level:
pref 1[atm] Pa
Reference temperature:
Tref User defined
293.15[K] K
Turbulence
Turbulence model type:
RANS
Turbulence model:
Low Reynolds number k-ε
Wall treatment:
Low Re
Turbulence model parameters
Edit turbulence model parameters
Consistent Stabilization
Inconsistent Stabilization
Advanced Settings
Discretization
Dependent Variables
Settings
Inlet
Label: Inlet 1
Boundary Selection
Selection: Manual
1
Override and Contribution
Equation
Boundary Condition
Velocity
Velocity
Normal inflow velocity
Velocity field
U0 U0*s*(1-s)*4 m/s
Turbulence Conditions
Specify turbulent length scale and intensity
Specify turbulence variables
Turbulent intensity:
IT spf.IT_init 1
Turbulence length scale:
LT spf.LT_init m


LowRe k-eps with damping functions vs DNS
50Pk+
50ep+
5k+
U+
U+ DNS
y+
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
2
4
6
8
10
12
14
16
18
20

Live Comsol demo

End of lecture