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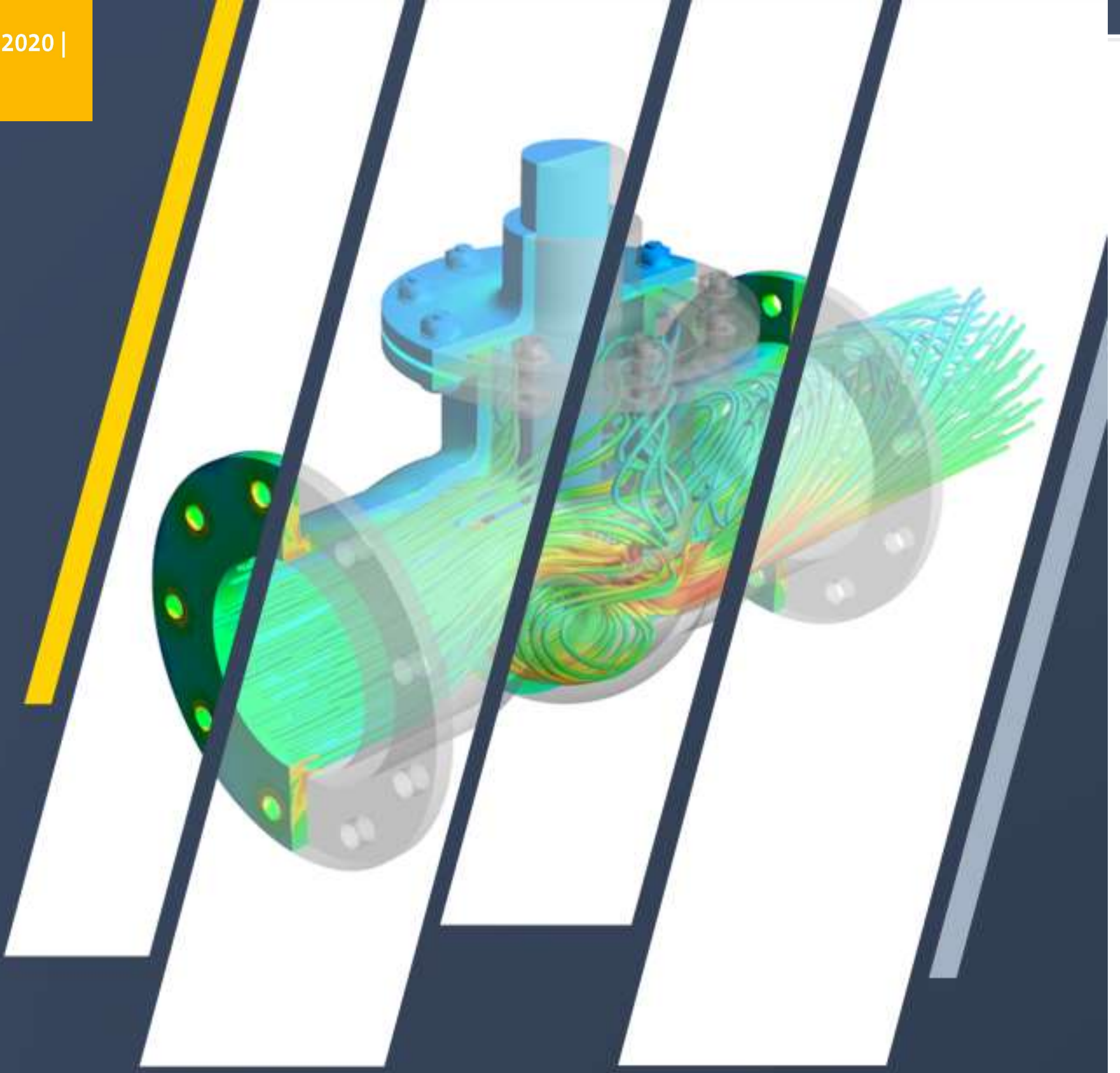
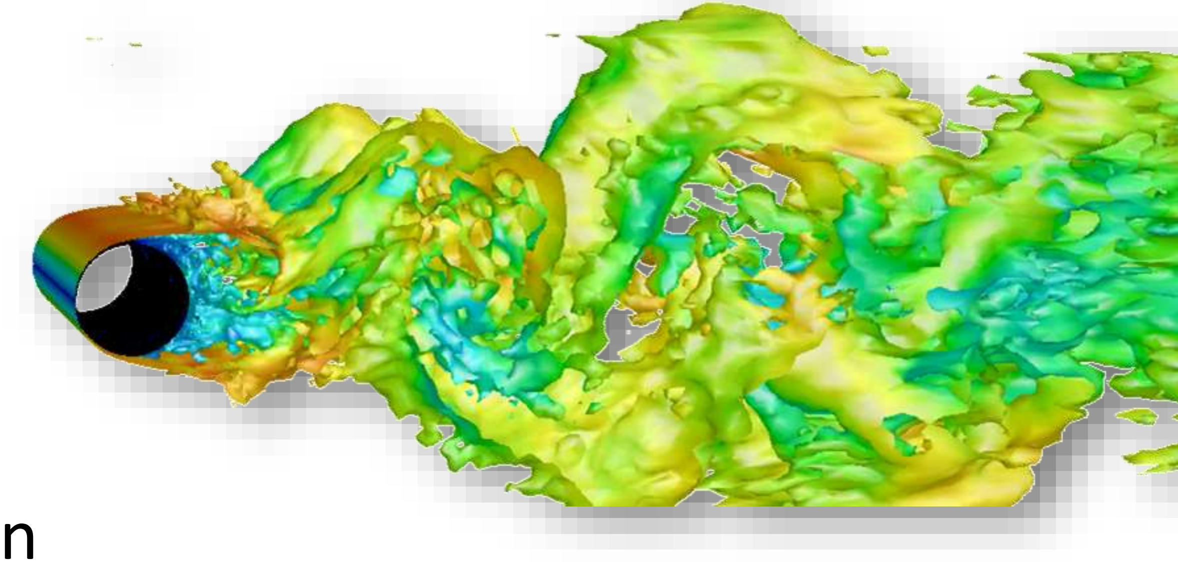
ANSYS

Calibration of the GEKO-Turbulence-Model Parameter with optiSLang

Johannes Einzinger



Agenda



Turbulence Modelling at a Glance

Generalized k-Omega Model (GEKO)

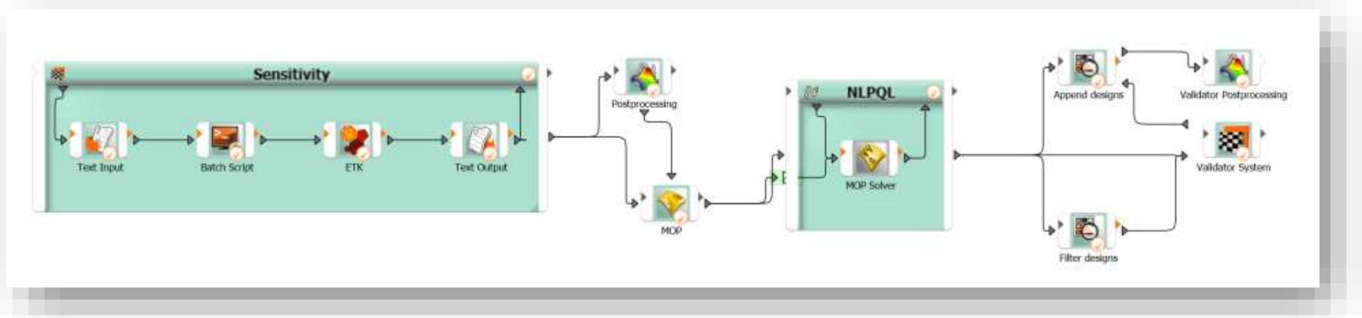
Parameter Calibration with optiSLang

- Workflow Template for CFX Simulation

Application Example

- Backward Facing Step
- …

Summary



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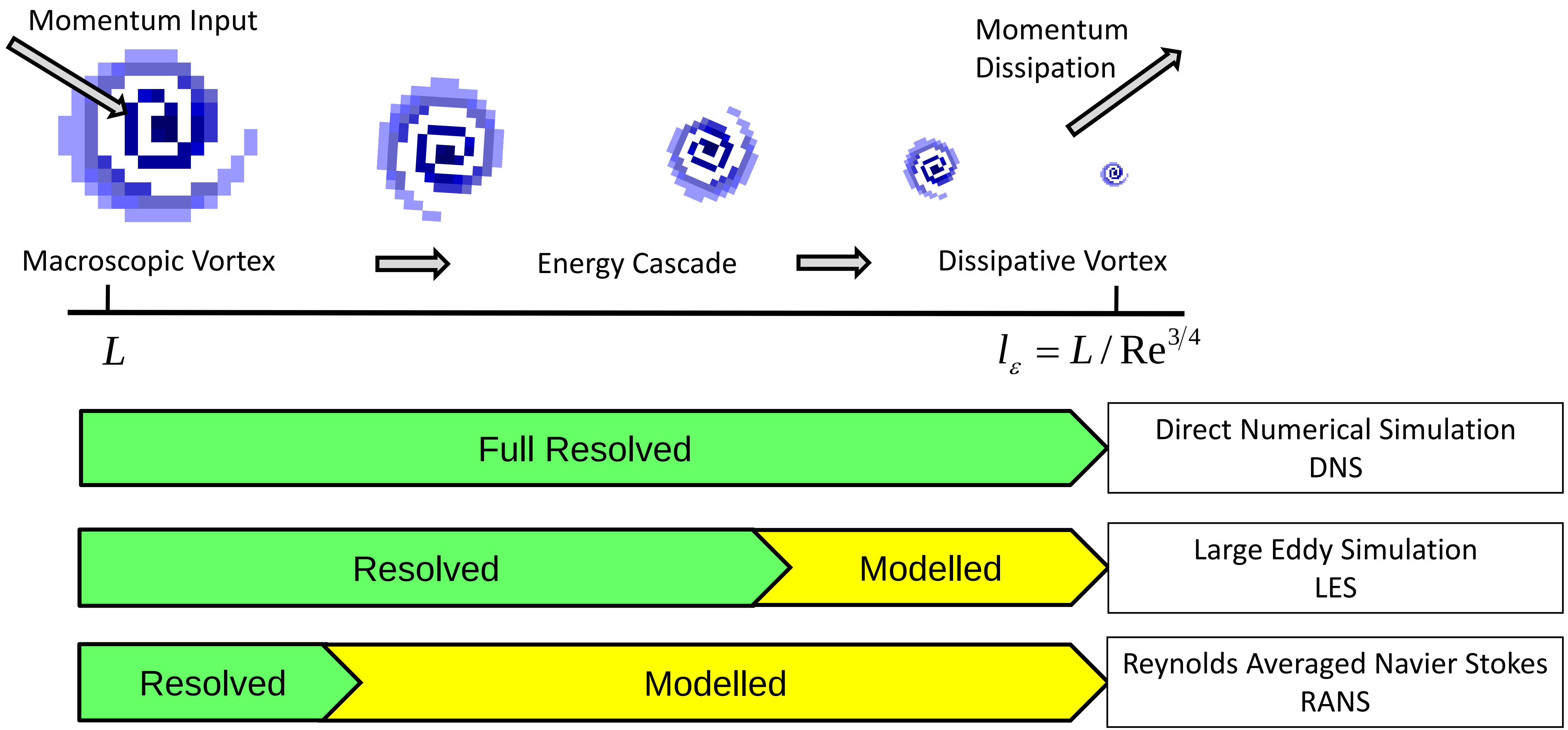
Turbulence Modelling at a Glance



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Turbulence

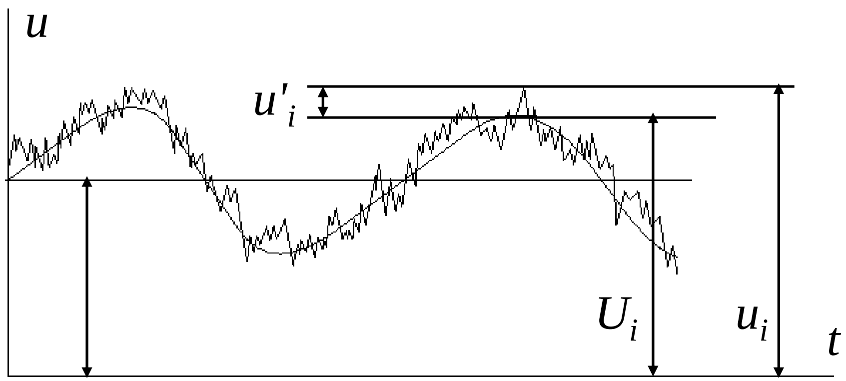
Properties:
- three dimensional
- transient
- multi scale

Macroscopic Effect:
- increased Friction
- increased Heat Transfer
- increased Mixing
- …

Objective:

Model Macroscopic Effects by RANS

fast! robust! accurate?



$$u_i(\vec{x},t) = \underbrace{U_i(\vec{x},t)}_{Average} + \underbrace{u_i'(\vec{x},t)}_{Fluctuation}$$

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Turbulence - Eddy Viscosity Models

Reynolds Averaged Navier-Stokes (RANS) Equations:

$$\frac{\partial(\overline{U}_i)}{\partial t} + \frac{\partial(\overline{U}_j\overline{U}_i)}{\partial x_j} = -\frac{1}{\rho}\frac{\partial\overline{P}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\tau_{ij}^{mol} + \tau_{ij}^{turb}\right]$$

Stokes Stress Tensor:

$$\tau_{ij}^{mol} = \nu\left(\frac{\partial\overline{U}_i}{\partial x_j} + \frac{\partial\overline{U}_j}{\partial x_i}\right)$$

Reynolds Stress Tensor:

$$\tau_{ij}^{turb} \approx \nu_t\left(\frac{\partial\overline{U}_i}{\partial x_j} + \frac{\partial\overline{U}_j}{\partial x_i}\right)$$

Eddy Viscosity:

$$\nu_t = const \cdot \frac{k}{\omega}$$

Model Equations are required for k and ω

a huge number of Models has been developed… *which one is the best?*

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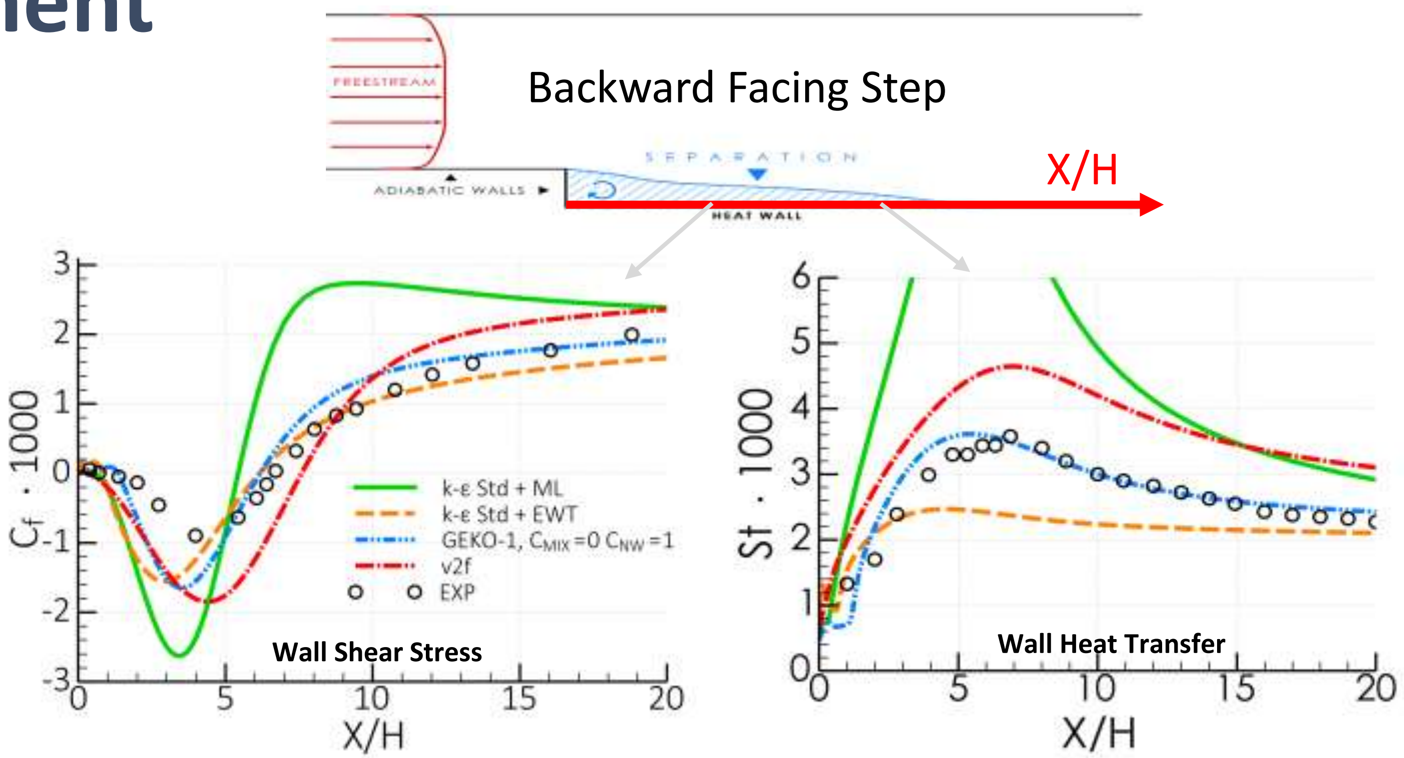
Turbulence - Wall Treatment

The Formulation of a Turbulence Model

when integrated through the viscous sublayer is a key aspect of turbulence modelling

- defines robustness
- defines accuracy
- can cause undesired pseudo-transition

makes or breaks a Turbulence Model



- 4x the same k-ε model with different near wall treatment
  - **ML – Menter-Lechner low-Re model**
  - **EWT – Enhanced wall treatment built on 2-Layer formulation**
  - **GEKO-1 exact transformation of k-ε to k-ω with k-ω wall treatment**
  - **V2F - k-ε model with V2F 'elliptic blending' wall treatment**
- Results are vastly different

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Motivation GEKO Model

Two-Equation Models are the Work-Horse in industrial CFD

They have typically 5 Coefficients which can be calibrated to match Physics

They are calibrated for

- Flat Plate Boundary Layers (log-Layer)
- Selected free Shear Flows (plane Mixing Layer, Plane Jet)
- Decaying Turbulence in Freestream

Central Question: Can we do such a simulation with one set of global constants?

Probably not …

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GEKO Model: Introducing Free Coefficients

Model Equations for Turbulent Kinetic Energy *k* and Dissipation ω:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho U_j k)}{\partial x_j}=P_k-\rho C_\mu k\omega+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] \qquad \nu_t=\frac{k}{\max(\omega, S/C_{Real})}$$

$$\frac{\partial(\rho\omega)}{\partial t}+\frac{\partial(\rho U_j \omega)}{\partial x_j}=C_{\omega 1}F_1\frac{\omega}{k}P_k-C_{\omega 2}F_2\rho\omega^2+F_3\frac{2}{\sigma_\omega}\frac{\rho}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\omega}\right)\frac{\partial \omega}{\partial x_j}\right]$$

The functions F_1, F_2, and F_3 *are not constant for GEKO Model, they* contain free Coefficients:

C_{SEP} – changes separation behavior

C_{MIX} – changes spreading rates of free shear flows

C_{NW} – changes near-wall behavior

C_{JET} – optimizes free jet flows

C_{CORNER} – affects corner flows

GEKO Coefficients can be varied without loosing the fundamental Correlations!

→ Model Calibration wrt to Experiment possible

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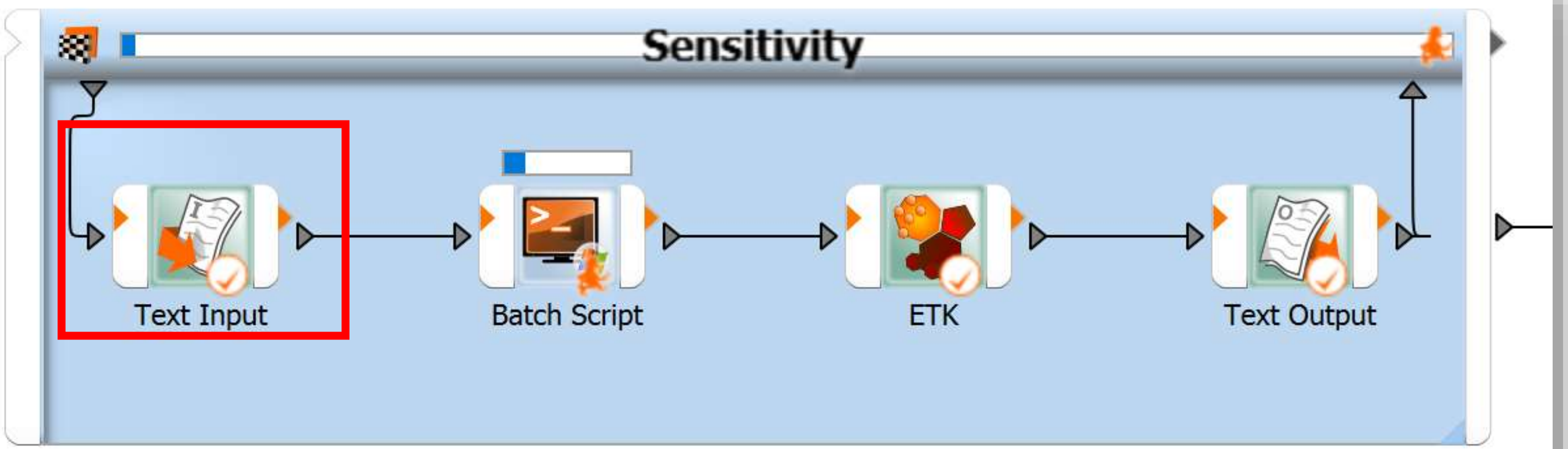
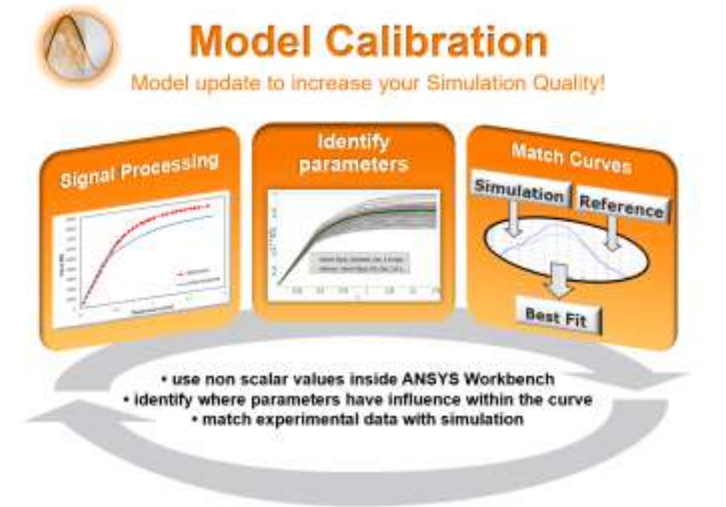
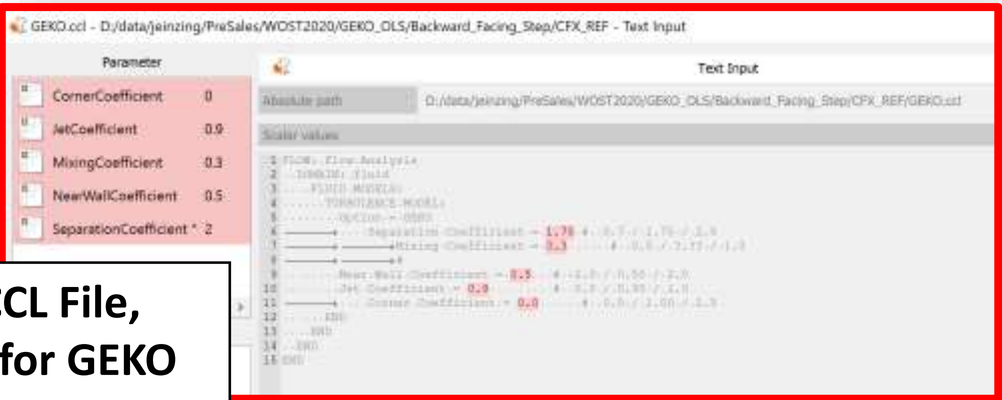
Workflow optiSLang CFX – Template – Input







CFX-CCL File, parsed for GEKO Parameter

GEKO.ccl

```
FLOW: Flow Analysis
  DOMAIN: fluid
    FLUID MODELS:
      TURBULENCE MODEL:
        Option = GEKO
        Separation Coefficient = 1.75
        Mixing Coefficient = 0.3
        #
        Near Wall Coefficient = 0.5
        Jet Coefficient = 0.9
        Corner Coefficient = 0.0
      END
    END
  END
END
```

CFX-CCL-Snippet Linked to Solver at Start

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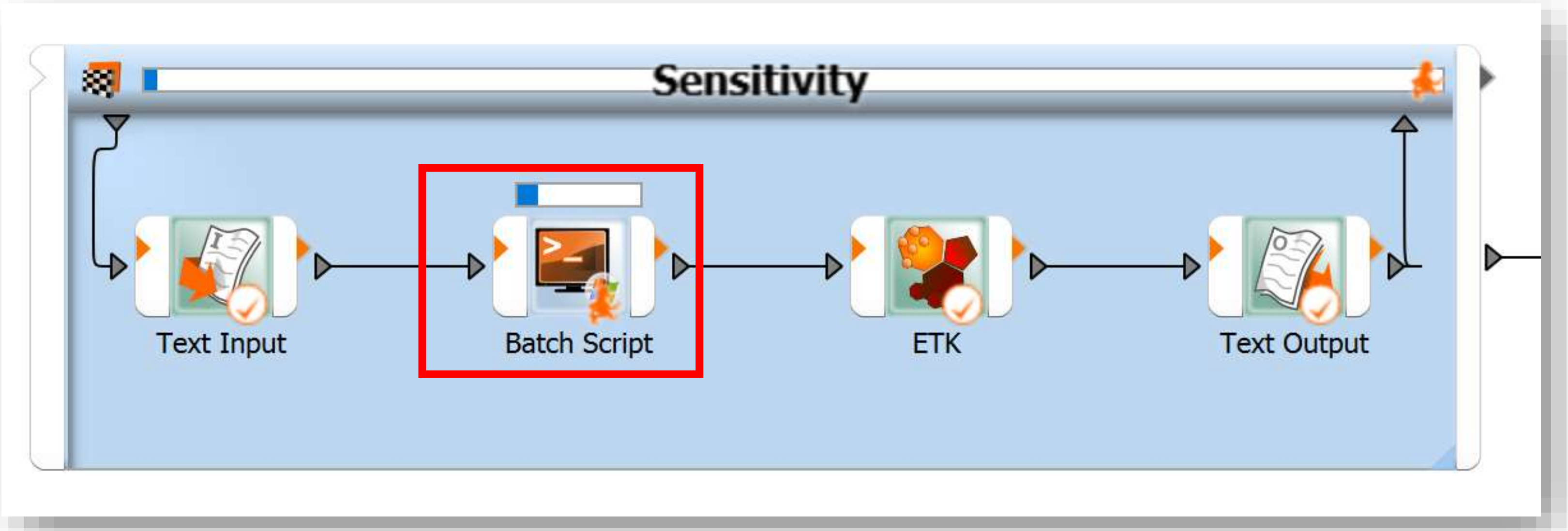
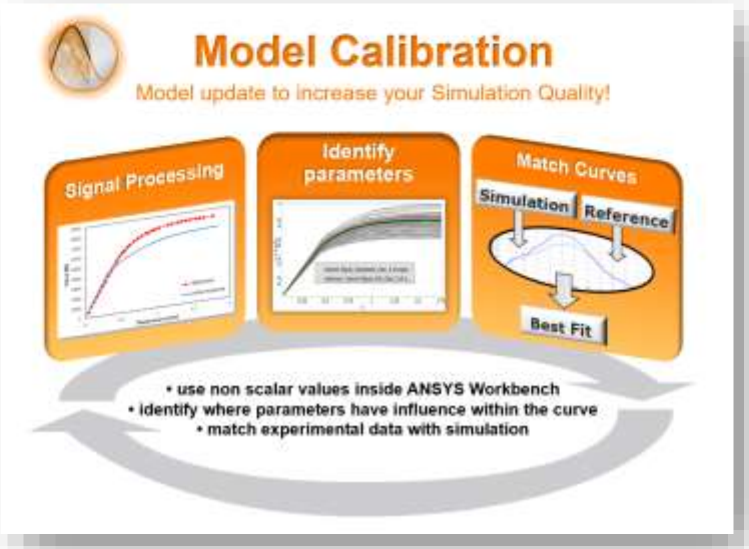
Workflow optiSLang CFX – Template – Solver





cfx_batch.bat - Notepad

File Edit Format View Help

```
copy D:\data\jeinzing\PreSales\WOST2020\GEKO_OLS\Backward_Facing_Step\CFX_REF\BFS.def .
copy D:\data\jeinzing\PreSales\WOST2020\GEKO_OLS\Backward_Facing_Step\CFX_REF\BFS.cst .
copy D:\data\jeinzing\PreSales\WOST2020\GEKO_OLS\Backward_Facing_Step\CFX_REF\cfxpost_varvector.cse .
"C:\Program Files\ANSYS Inc\v201\CFX\bin\cfx5solve.exe" -def BFS.def -ccl GEKO.ccl
"C:\Program Files\ANSYS Inc\v201\CFX\bin\cfx5post.exe" -batch cfxpost_varvector.cse
del BFS_001.res
```

Copy Reference Files,
CFX-Solver&Post Script
Start CFX-Solver
Start CFX-Post
Delete Result File

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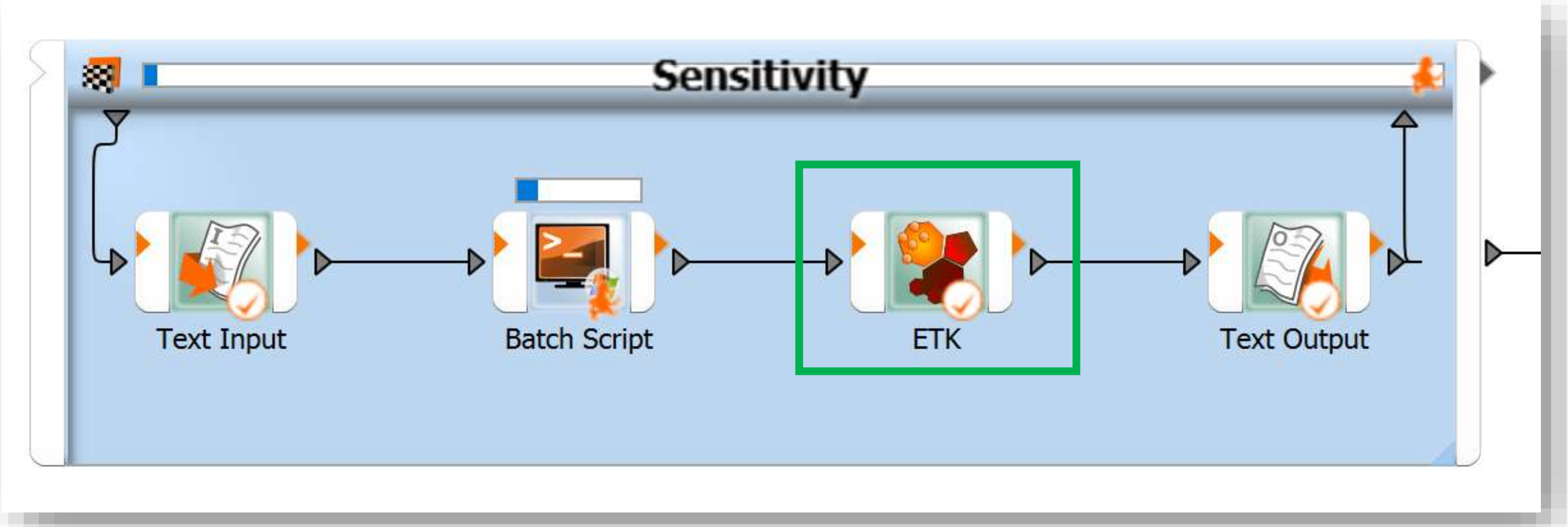
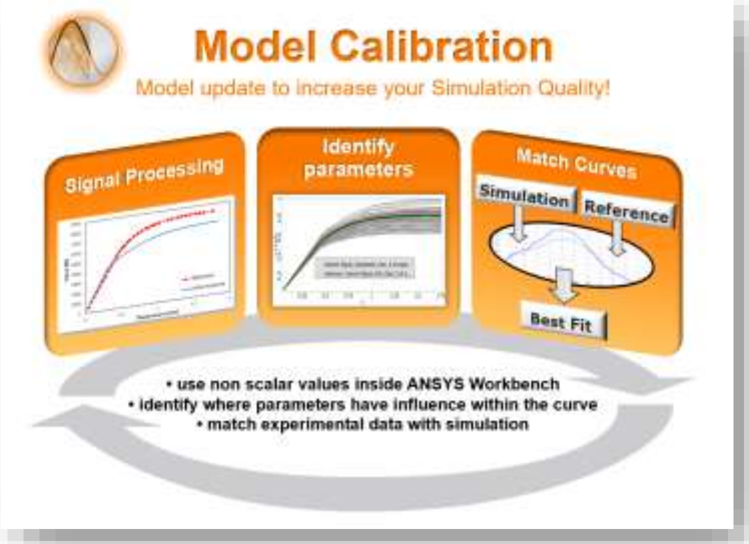
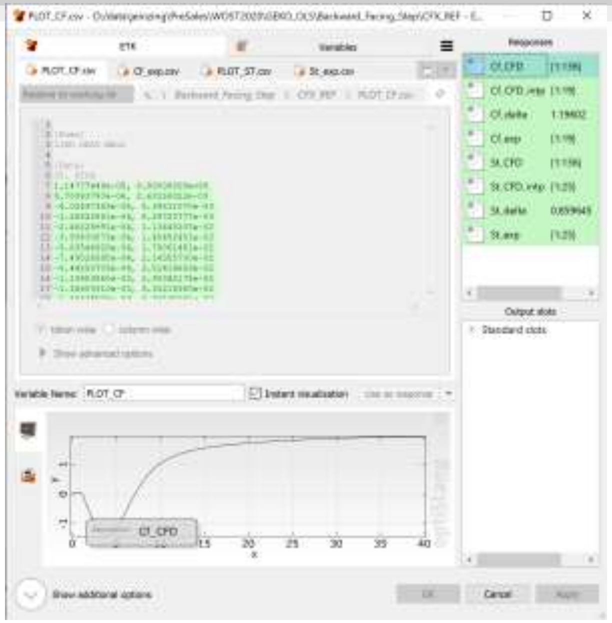
Workflow optiSLang CFX – Template – Signals







Read Signals:
Velocity Distributions
Friction Coefficient
Stanton Number
CFD Simulation and Experiment
Calculate Difference of Curves

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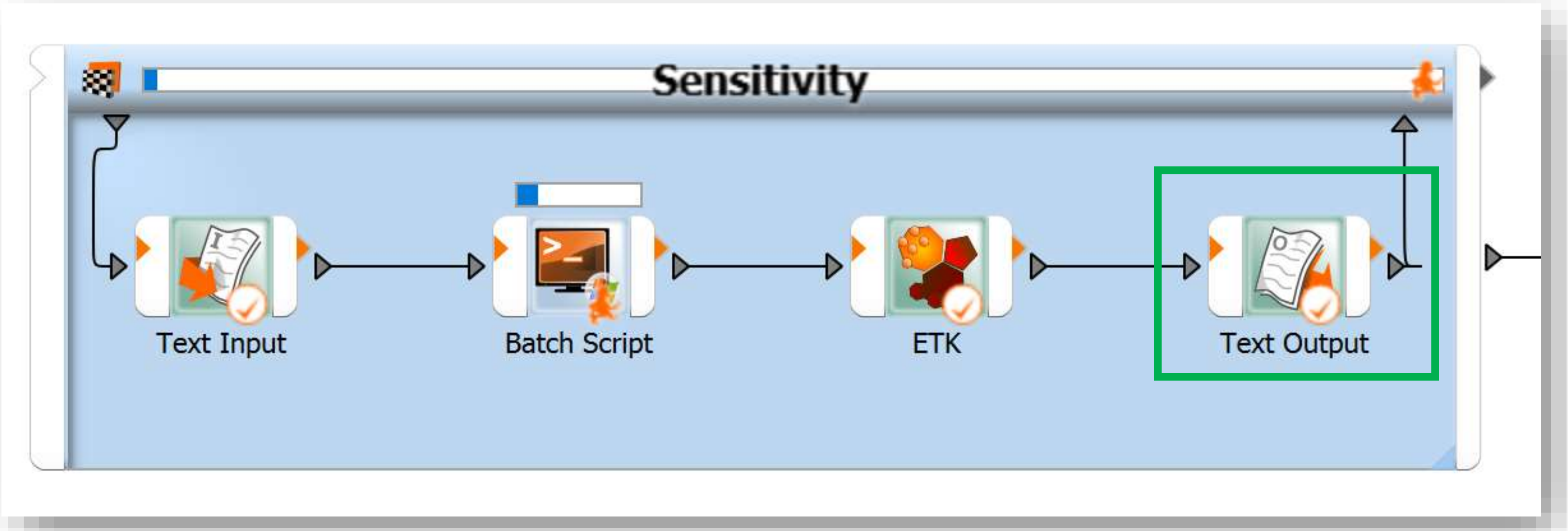
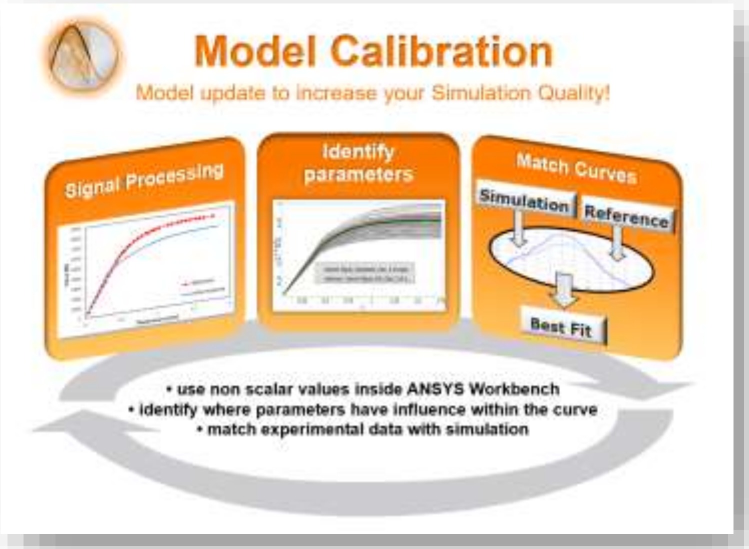
Workflow optiSLang CFX – Template – Output





Parse Scaler Output Parameter
Maximum Residual and Iteration Number, to check convergence for all Design Points

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Test Case: Backward Facing Step

2D Test Case with Recirculation

Inlet:

- Velocity Profile
- k-ω Profile
- constant Temperature

Outlet:

- constant Pressure

Fluid:

- incompressible

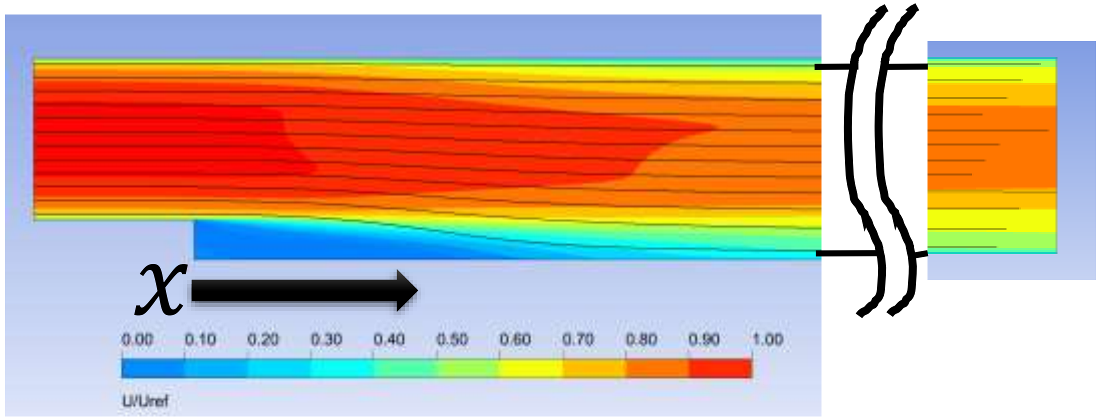
Reynolds Number = 10^5

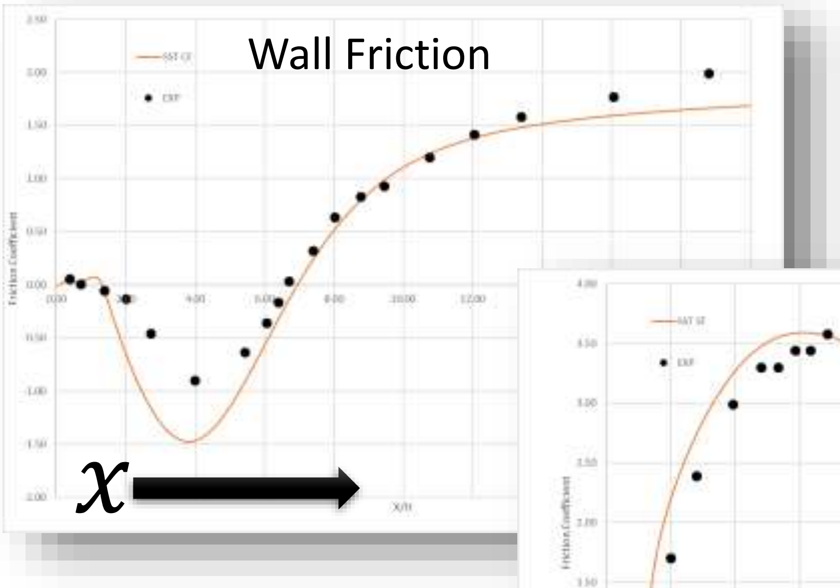
Reference Turbulence Modell

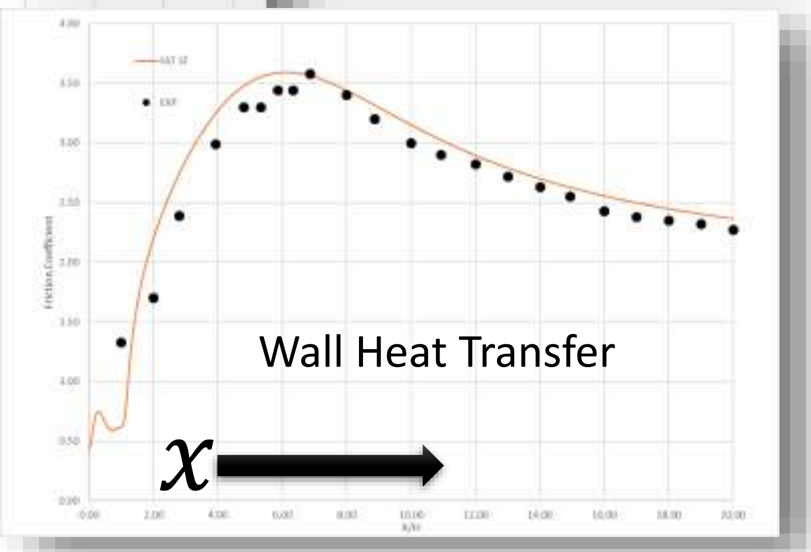
- SST

Output:

- Wall Friction Coefficient
- Wall Heat Transfer Coefficient







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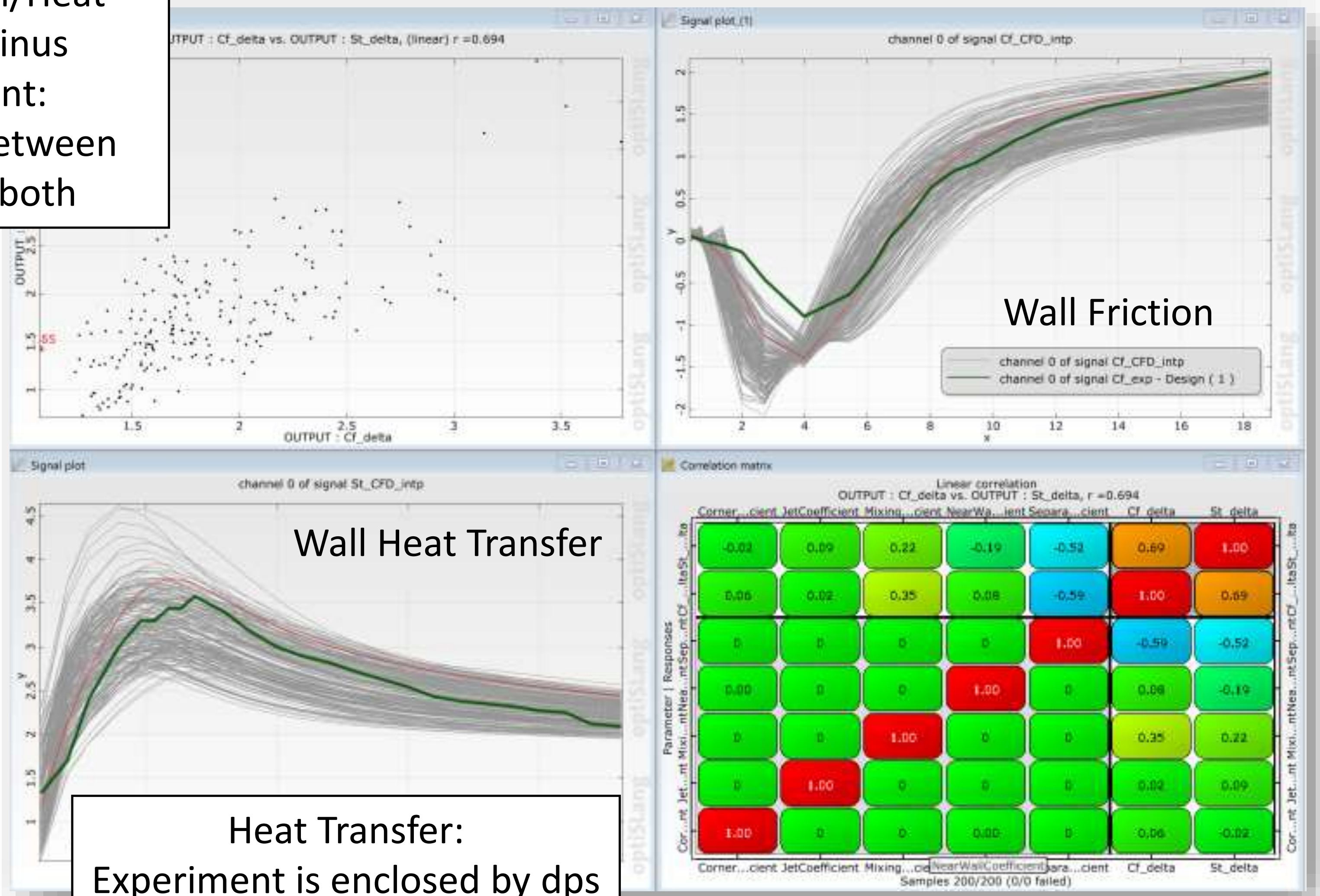
Sensitivity Study – 200 Samples

Delta Friction/Heat Transfer minus Experiment:
No Conflict between best fit for both



Heat Transfer:
Experiment is enclosed by dps

Wall Friction:
Experiment is not fully enclosed by dps

GEKO Parameter	min	max
Separation Coefficient	0.9	2.3
Mixing Coefficient	0.15	0.95
Near Wall Coefficient	-1.25	1.25
Jet Coefficient	0.0	1.0
Corner Coefficient	0.0	1.5

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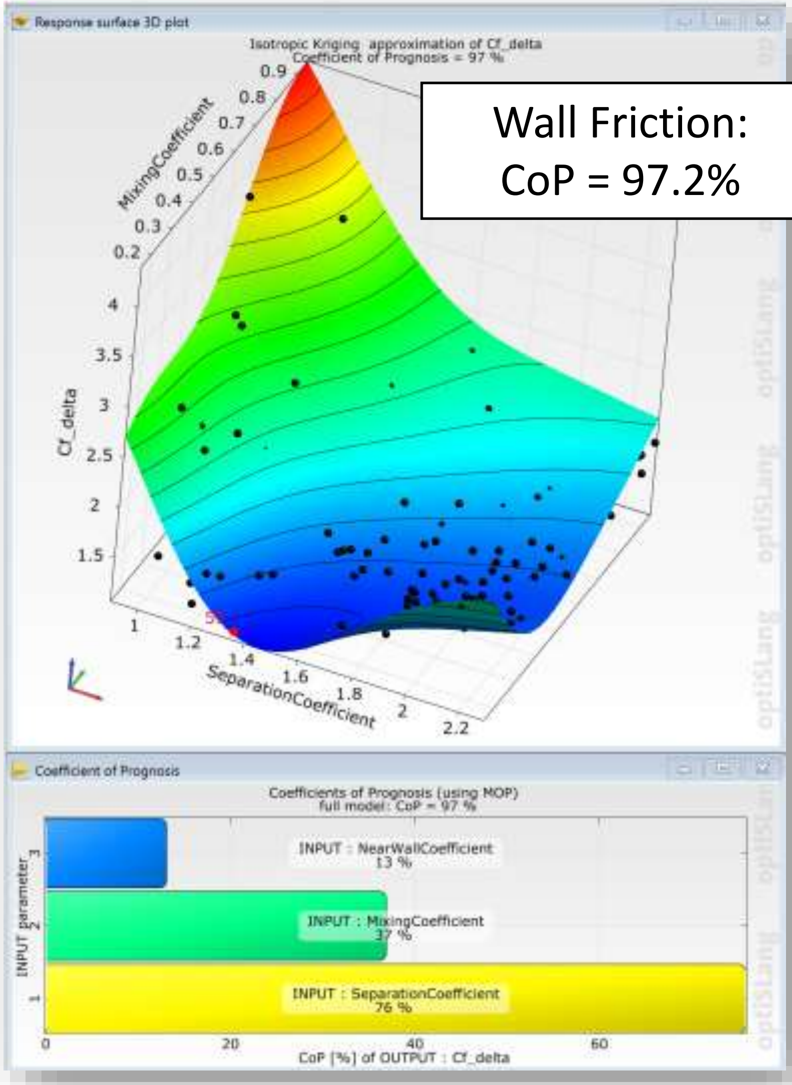
Meta Model of Optimal Prognosis

Good CoP for both Delta Sim vs Exp

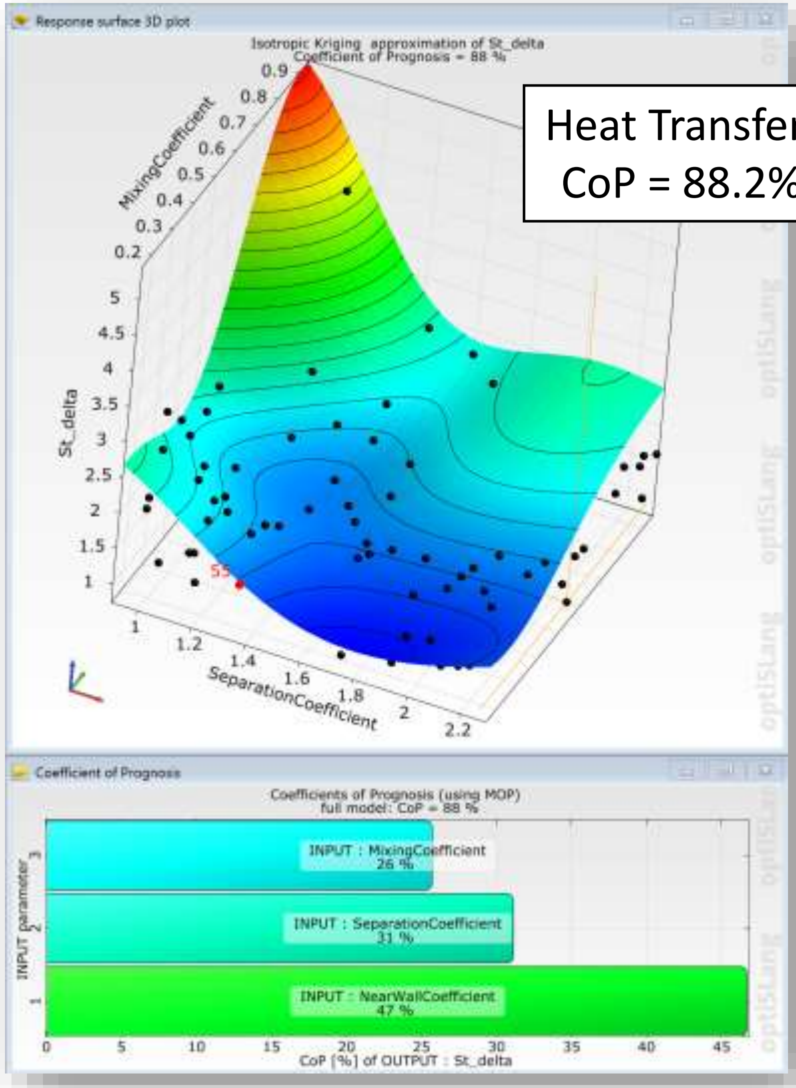
Input Parameter:
C-Separation: dominating Parameter
C-Mixing: important
C-Near-Wall: important
C-Jet: filtered out
C-Corner: filtered out

Next Step:
Optimization on Meta-Model
CFX Calculation for Optimum
Objective Function:

$$\min(\Delta C_f + \Delta S_t)$$



Wall Friction:
CoP = 97.2%



Heat Transfer:
CoP = 88.2%

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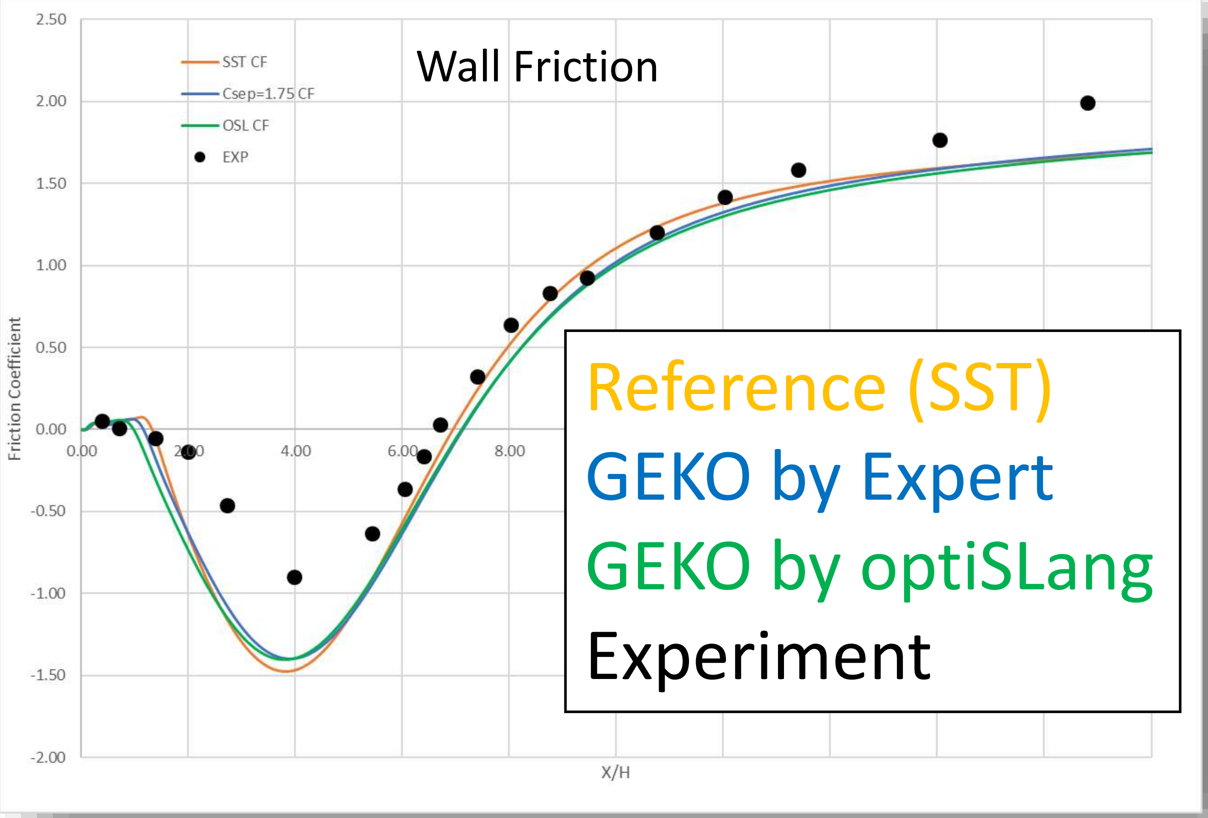
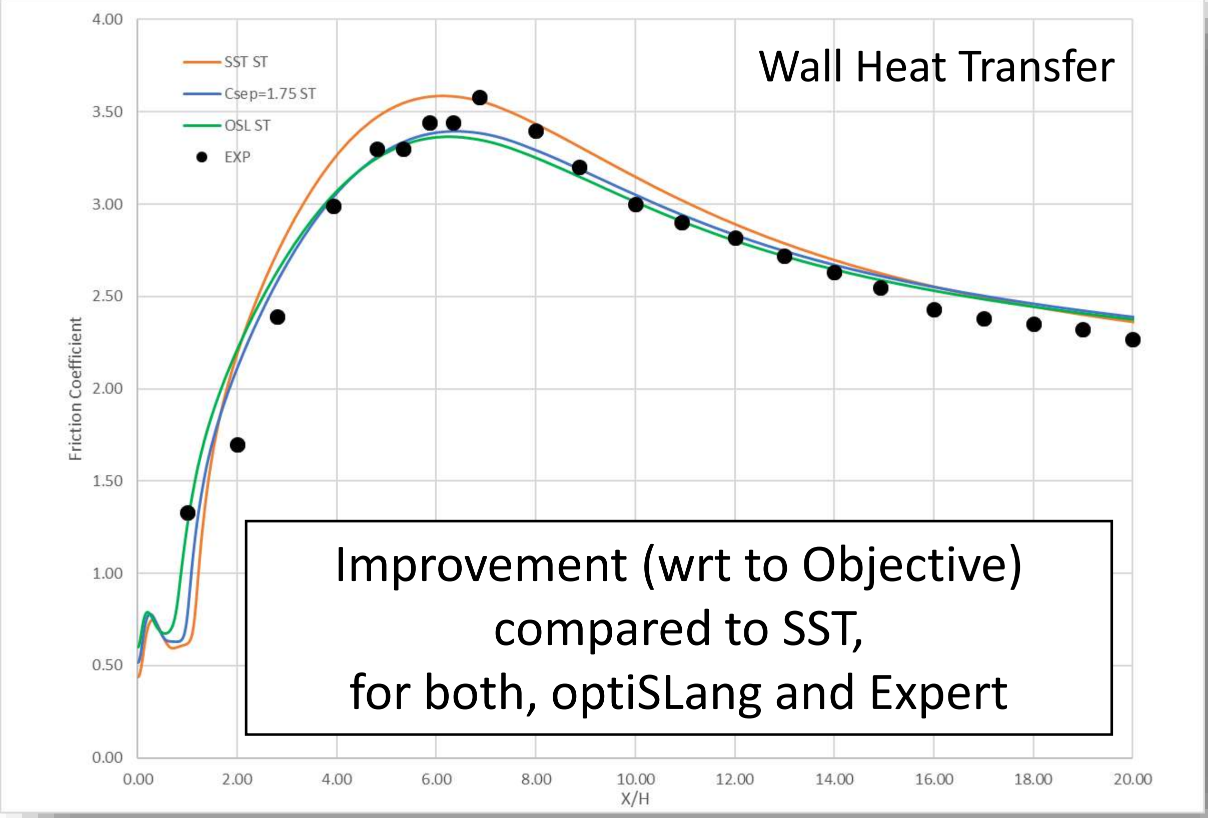
Optimization on Meta Model

	CoP [%]	Reference	Expert	MoP Prediction	CFX Simulation	Rel. Error [%]
Cf-Delta	97.2	1.228	1.221	1.303	1.293	0.54
St-Delta	88.2	0.969	0.713	0.782	0.754	3.71
OBJ: (Cf+St) = min	-	2.197	1.934	2.082	2.047	1.71





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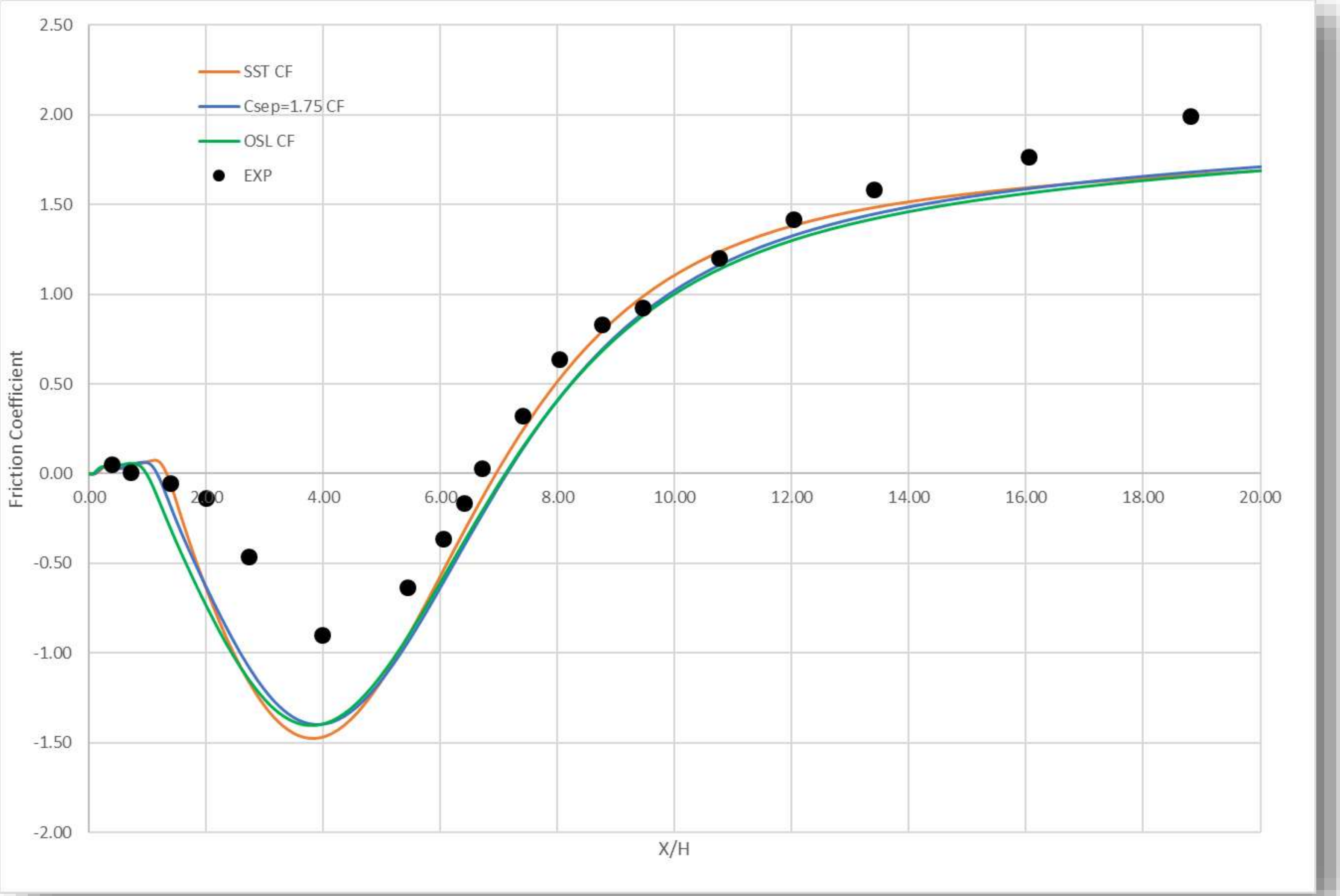
Result Comparison – Wall Friction



Reference
GEKO by Expert
GEKO by optiSLang
Experiment

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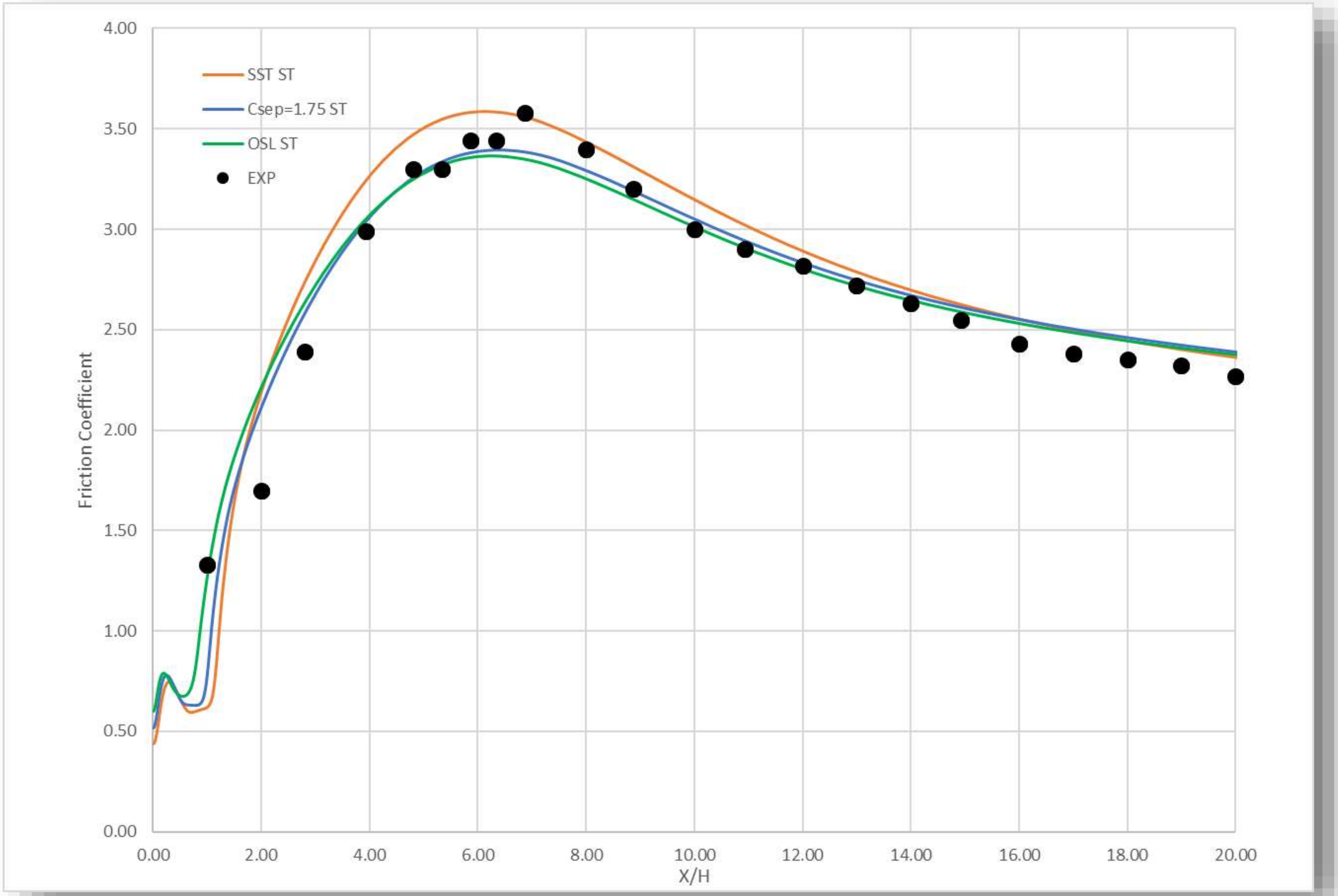
Result Comparison – Wall Heat Transfer



Reference
GEKO by Expert
GEKO by optiSLang
Experiment

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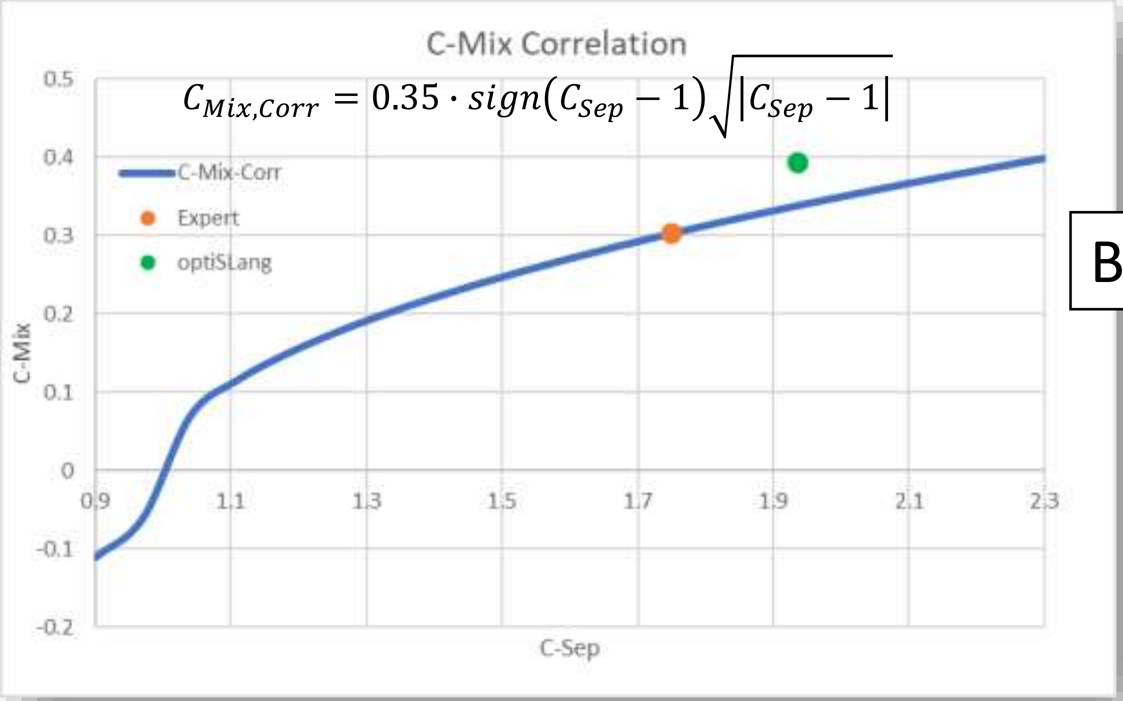
Result Comparison – GEKO Parameter

GEKO Parameter	Expert	optiSLang	min	max
Separation Coefficient	1.75	1.937	0.9	2.3
Mixing Coefficient	0.3	0.3925	0.15	0.95
Near Wall Coefficient	0.5	0.3603	-1.25	1.25
Jet Coefficient	0.9	0.9	0.0	1.0
Corner Coefficient	1.0	0.0	0.0	1.5

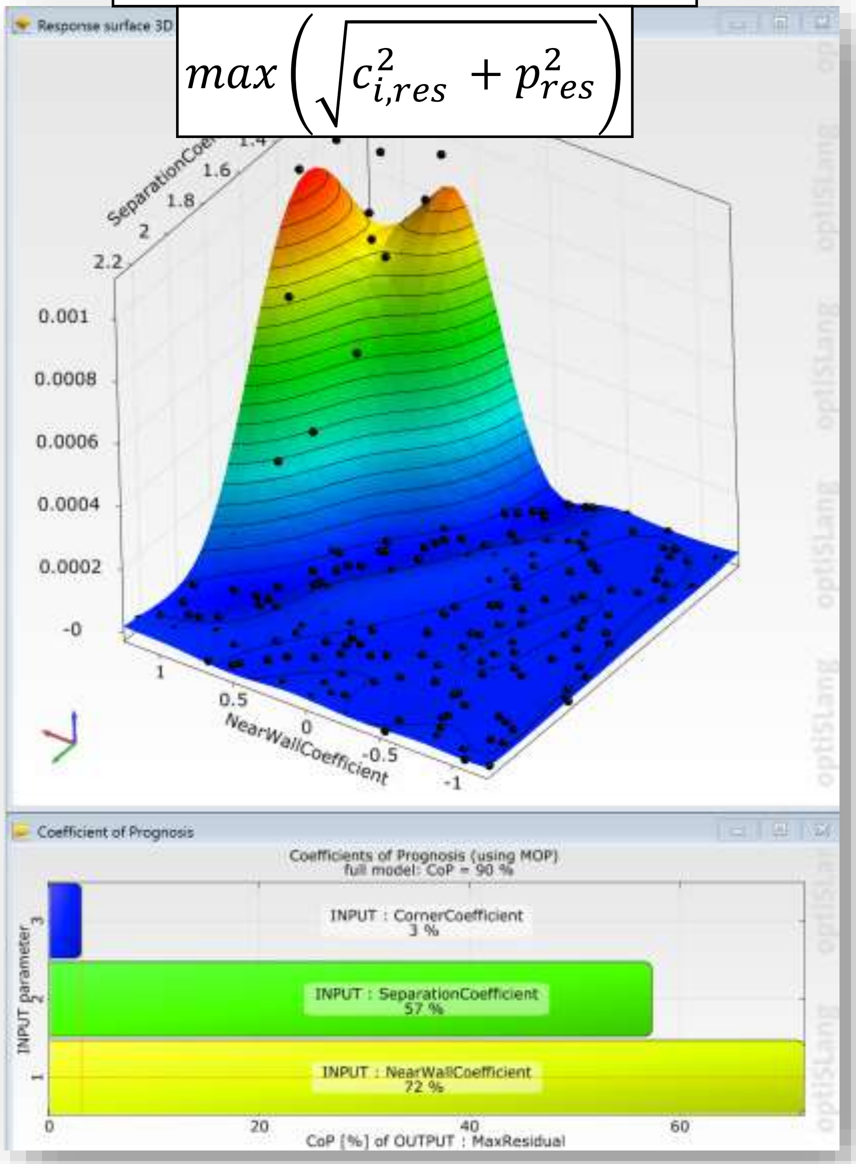


Bad Residuals for

$$C_{Sep} < 2C_{NW}$$

Max. Sum Residual:

$$max\left(\sqrt{c_{i,res}^2 + p_{res}^2}\right)$$



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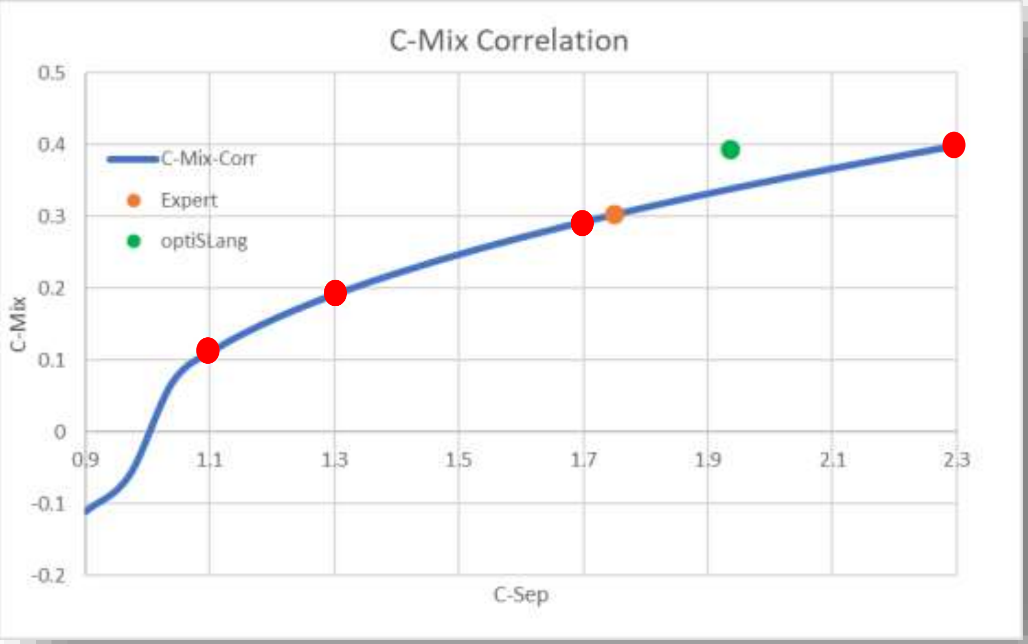
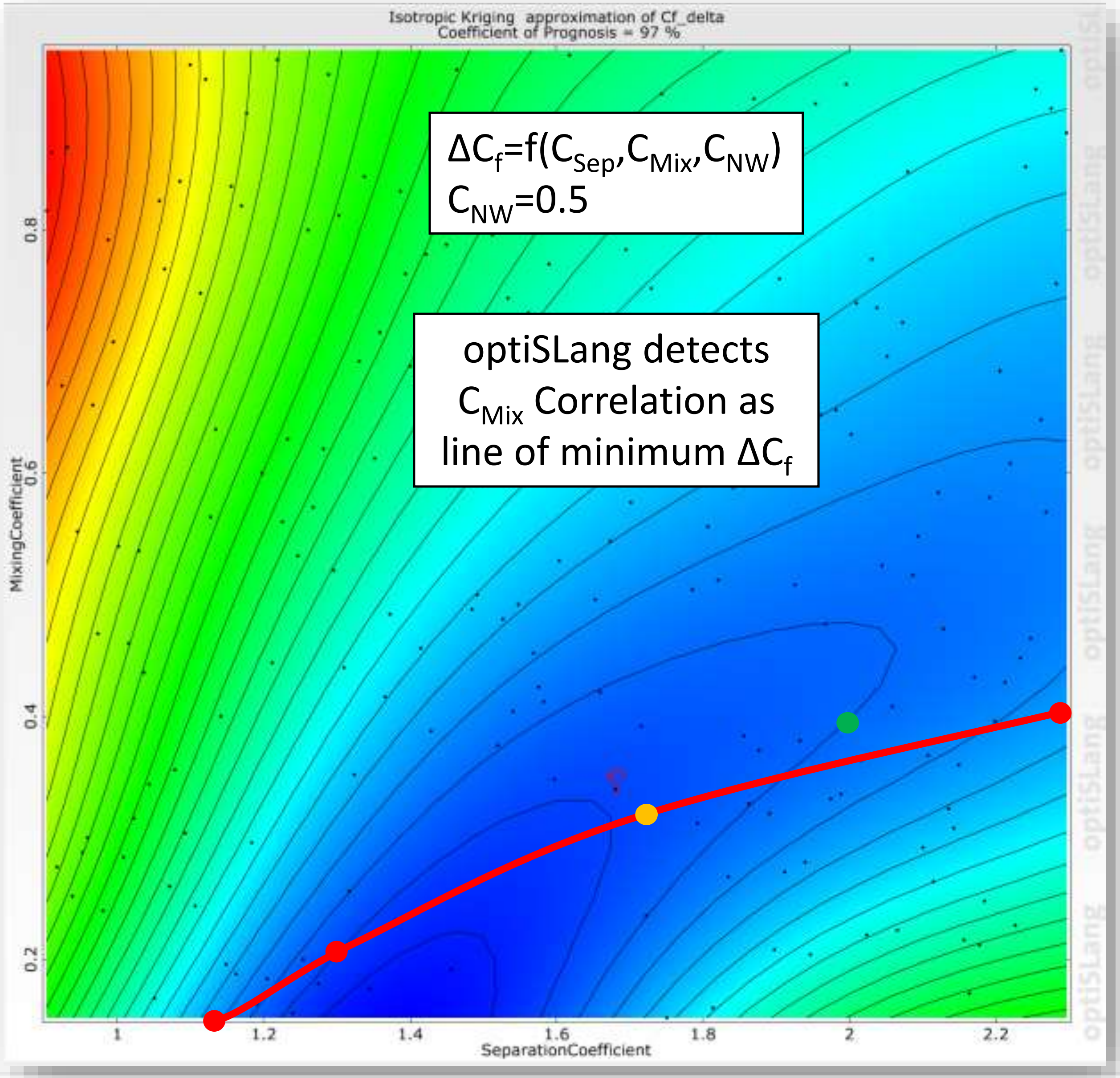
Result Comparison – C_{Mix} Correlation

GEKO_Model_Best_Practice_V1.0.pdf:
For each value of C_{SEP} an optimal value of C_{MIX} exists, which maintains optimal free shear flows. This value is given by the correlation:

$$C_{Mix,Corr} = 0.35 \cdot sign(C_{Sep} - 1)\sqrt{|C_{Sep} - 1|}$$





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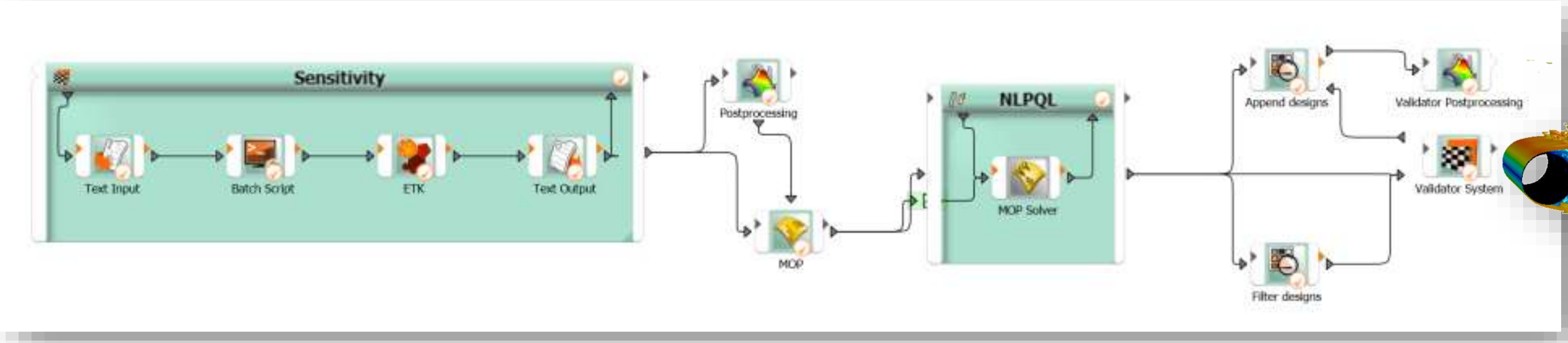
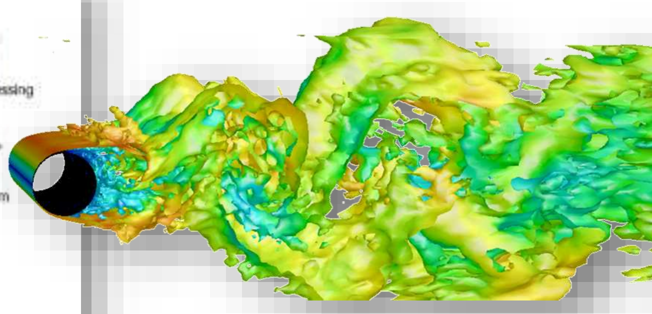
Summary

Generic GEKO Parameter Calibration Template for CFX is generated





Result for Backward Facing Step:

- Calibration by Expert
- Calibration by optiSLang

deliver comparable Results, both improved compared to SST, wrt to Objective Function

Benefit from optiSLang, if no Expert is available!

Note: other Objective Functions are possible!

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