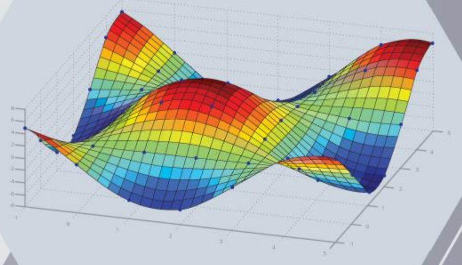
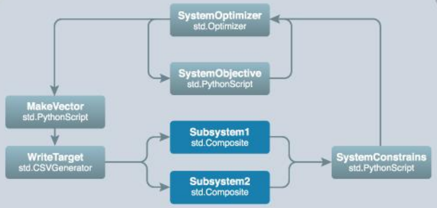
FloEFD User Conference 2017

Bi-level airfoil optimization with FloEFD and pSeven





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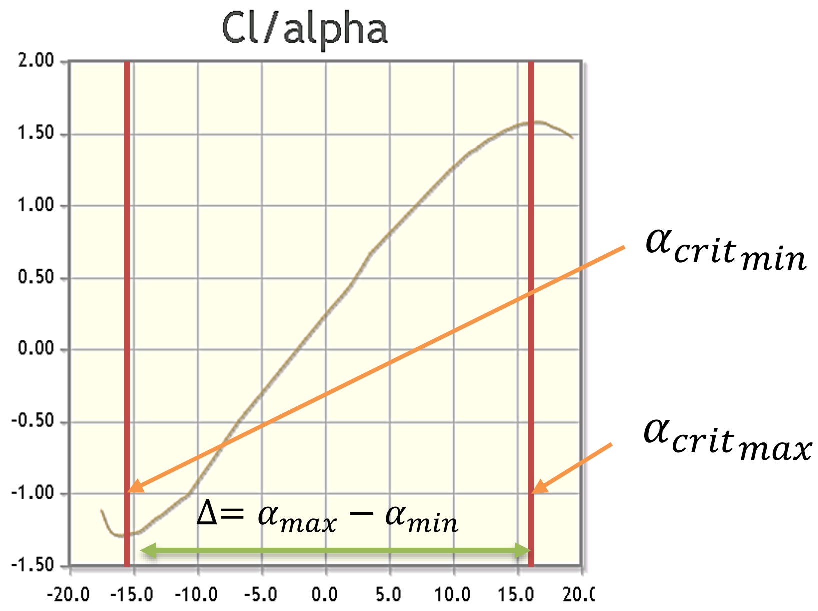
Use case: maximizing the stabilizer angle-of-attack range

Helicopter horizontal tail stabilizer provides a back-reaction in pitch.

In normal mode its lifting force Cy increases with the angle of attack.

However at critical angles the airfoil can stall and lifting force will decrease.
This effect limits the working range of fixed stabilizer.



<u>The goal of the study:</u>

Find the airfoil shape to provide **maximum** angle of attack **range with positive derivative** of Cy over α

Outline

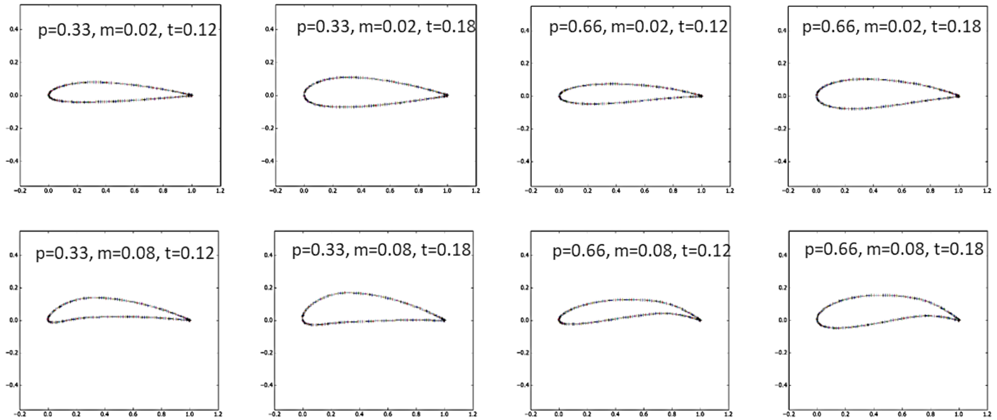
- **Airfoil parametrization and CFD model**
- **Bi-level optimization in general and in particular**
- **Definition of the angle-of-attack range (lower level)**
- **Airfoil geometry optimization (upper level)**

Airfoil parametrization and simulation setup

Airfoil is described by NACA 4digit parametrization:

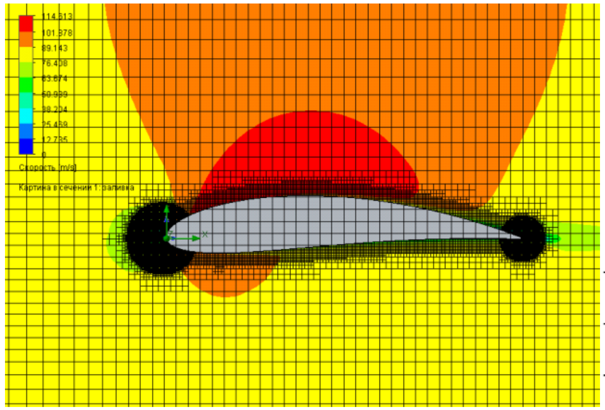
3 parameters:

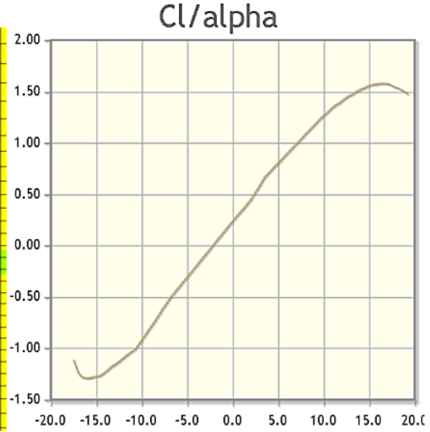
- maximum camber **m**
- maximum camber position **p**
- maximum thickness **t**



Simulation settings:

- 2D simulation
- M=0.25, Re=~10e06 (chord 0.2 m)
- Steady flow, stopping criteria – travels
- Local meshing domains
- Approx 4.5 minutes simulation time

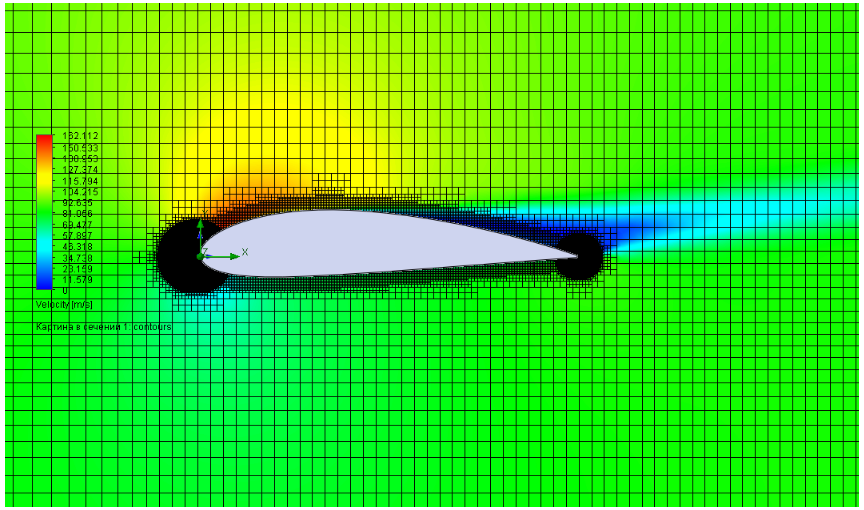




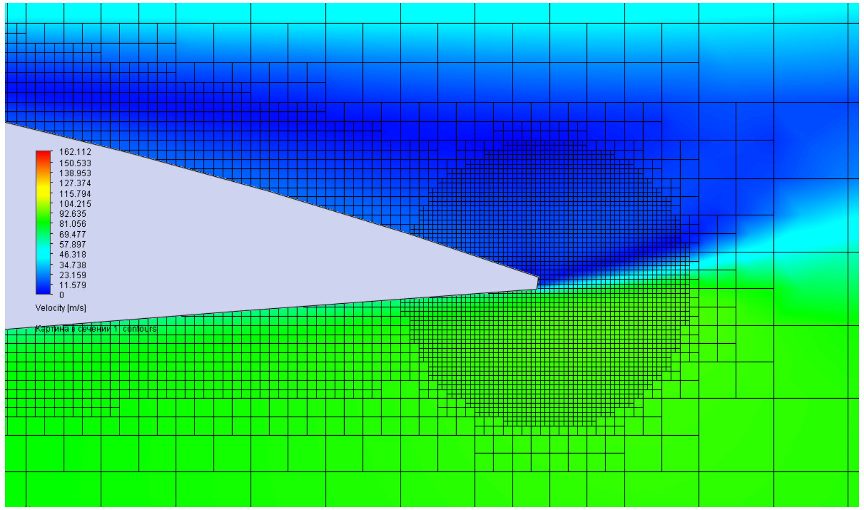
Airfoil parametrization and simulation model

NACA 4418 airfoil at AoA=13° (near stall)

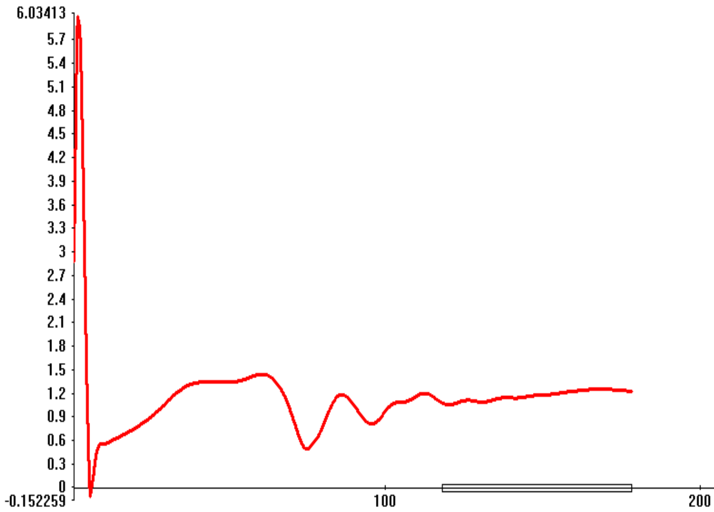
Mesh structure in general:
~ 170 000 cells
~ Not adaptive to flow



Mesh structure in details:
Local refinement areas
“Coarse” mesh for time-saving



Iteration convergence:
Stopping at 1.5 travels
Set based on convergence study



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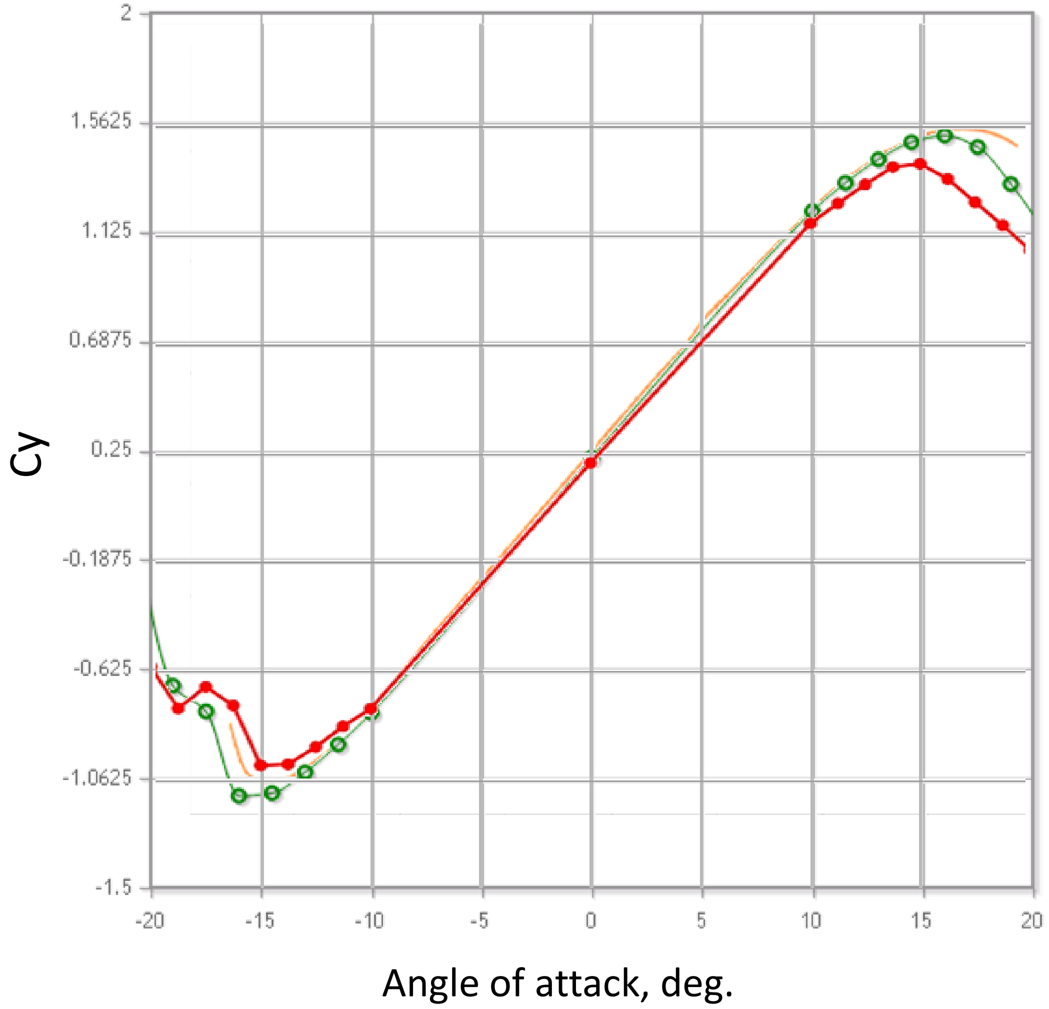
Airfoil parametrization and simulation model



Comparison for NACA 2412

- Ansys Fluent
- FloEFD
- Xfoil reference

FloEFD: Δ=30,7°

Ansys: Δ=31,8°

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FloEFD benefits for Design Space Exploration

Design Space Exploration is a way to *systematically and automatically* explore large numbers of design alternatives to find *optimal* performance parameters.

Direct association with CAD → **Robust** automated **meshing** for wide range of geometry changes

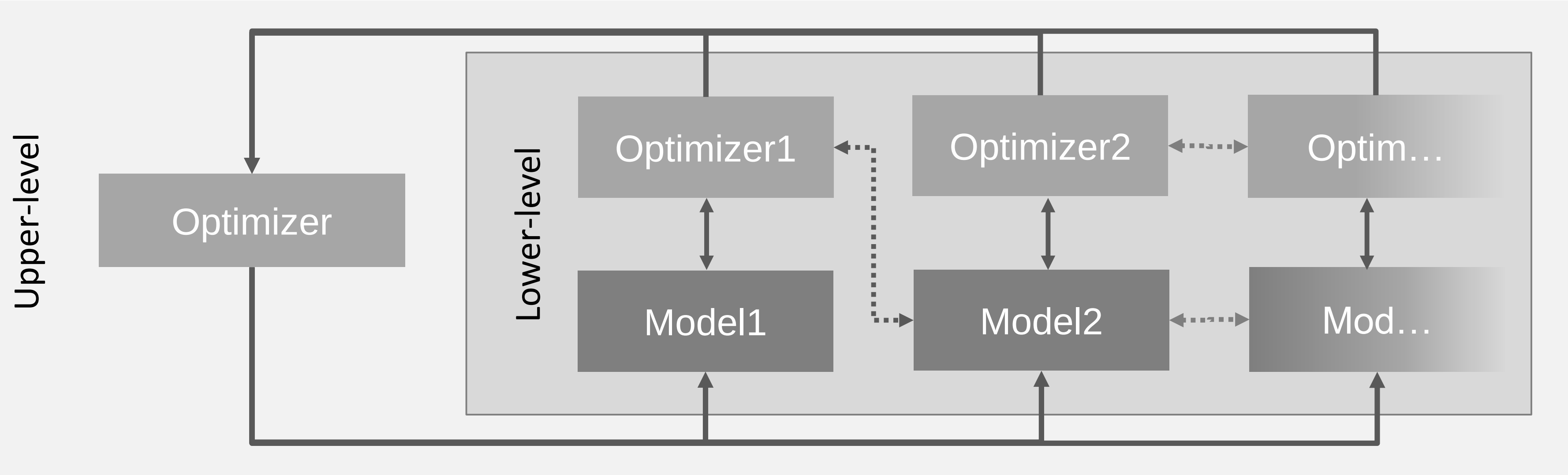
SmartCells meshing → **Robust** automated **meshing** for wide range of geometry changes; Fast convergence. Typically able to **catch physics** with extremely coarse meshes

Semi-empirical models (channels etc.) → Fast convergence. Typically able to **catch physics** with extremely coarse meshes

External optimizer option & API → **Full control** from external optimizers and routines.

What is bi-level optimization?

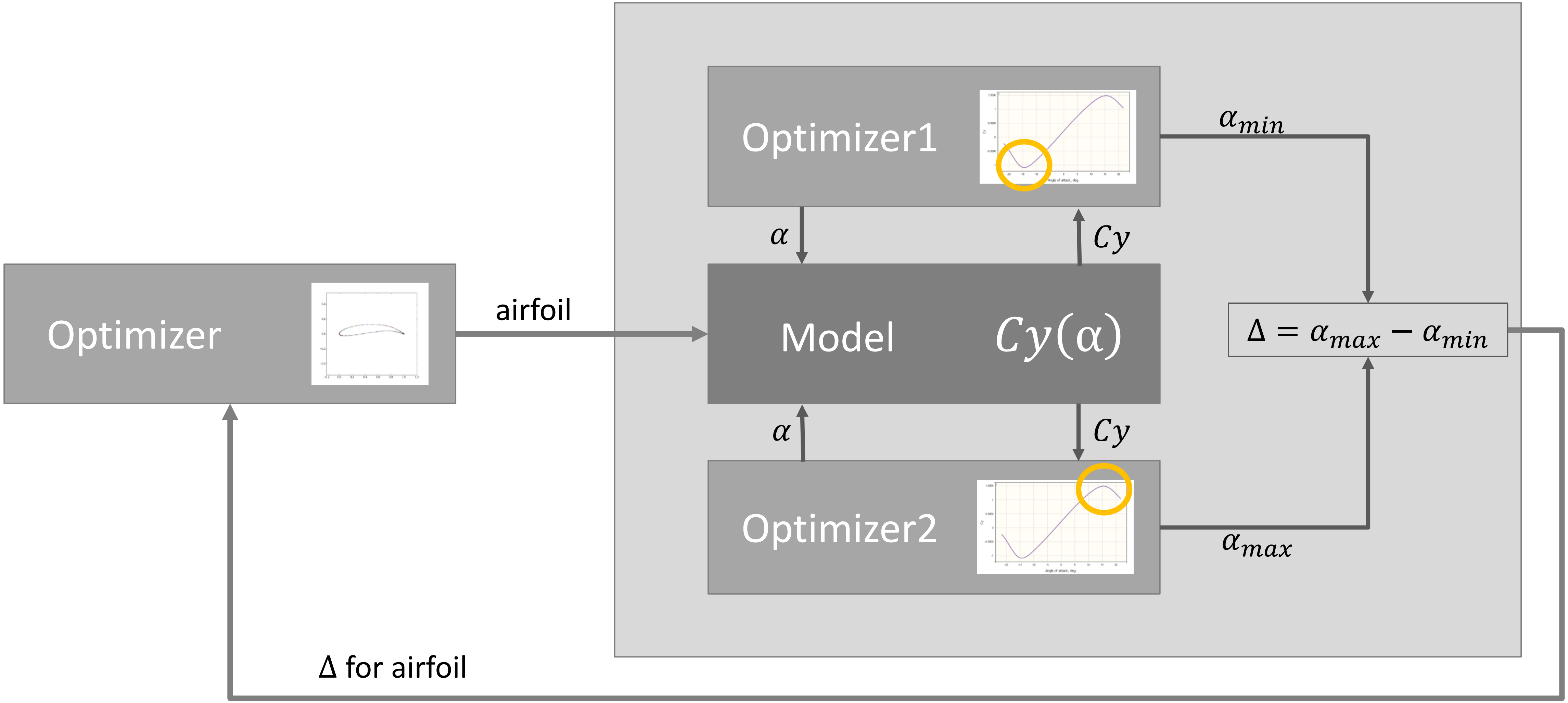
Bi-level optimization is a hierarchical problem where one optimization loop in embedded within another.



Bi-level optimization and other MDO methods lay a specific requrements for workflow engine:

1) Triggering of the optimization process by outer signal
2) Changing the lower-level optimization setup during the runtime
3) Updating the lower-level model if needed
4) Combining several lower-level models
5) Caching the previously obtained data

General optimization scheme

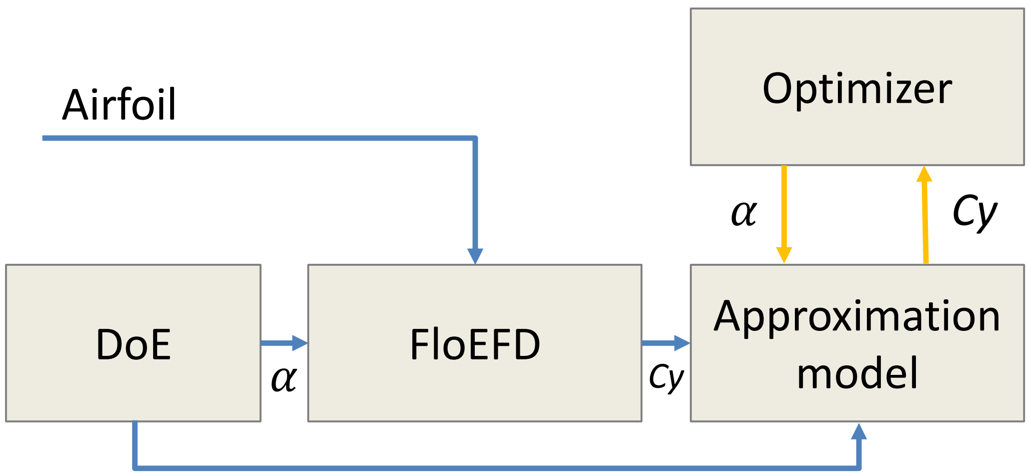


Definition of AoA range: two approaches

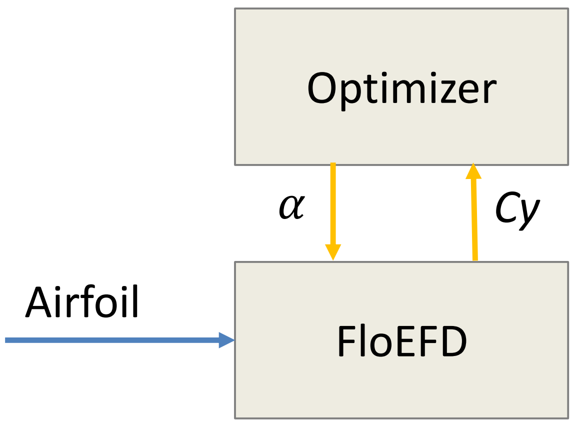
In order to find the range we need to **locate maximum and minimum of $Cy(\alpha)$ function**: 2 optimization problems!

CFD simulation model provides the Cy for a particular airfoil and angle of attack.
It can be directly coupled to optimizer or used to create the approximation model.

<u>Optimization based on approximation model</u>



<u>Optimization based directly on CFD simulation</u>



The same approximation model can be used both for maimum and minimum localization to save the evaluations of CFD model

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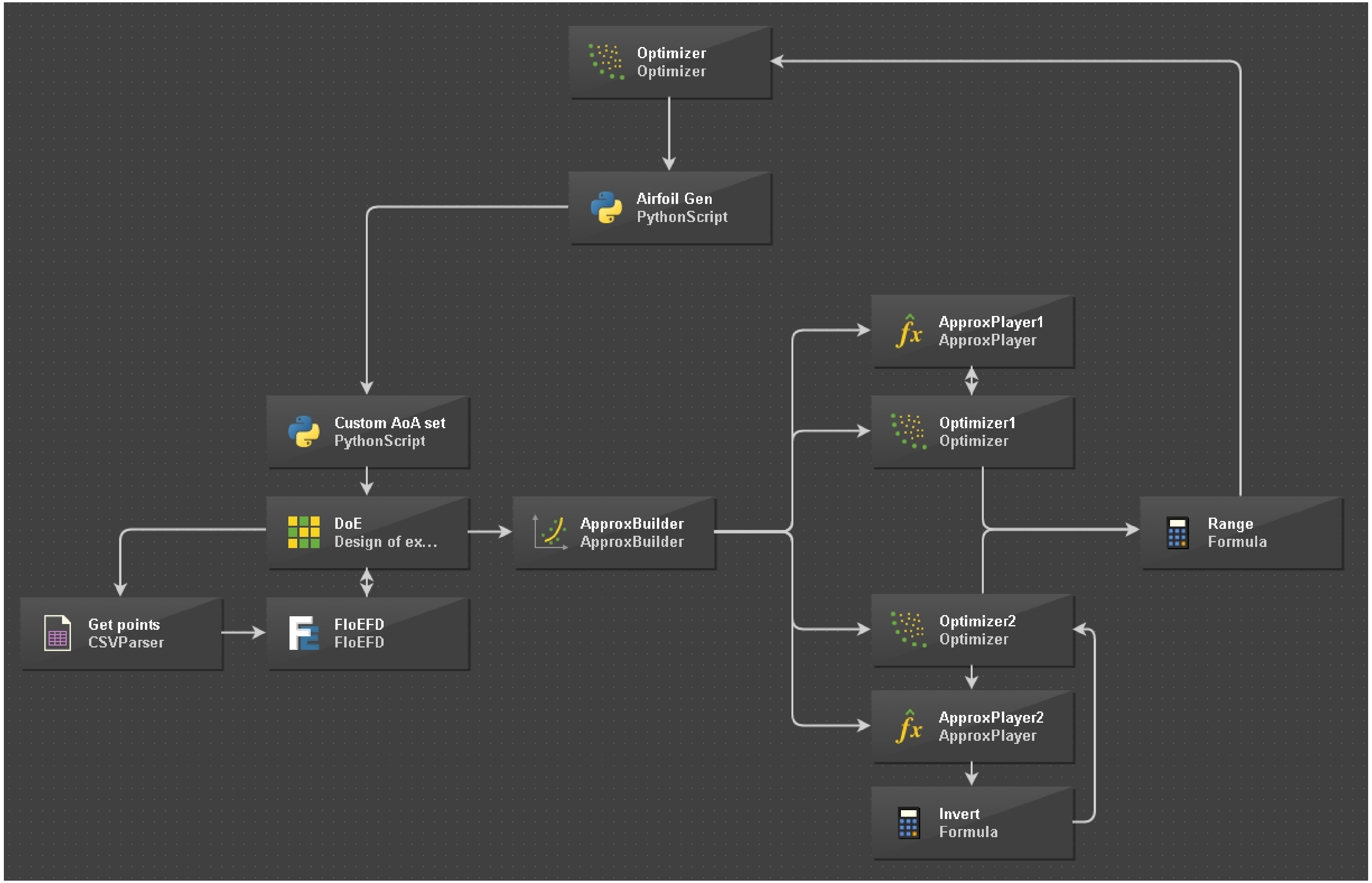
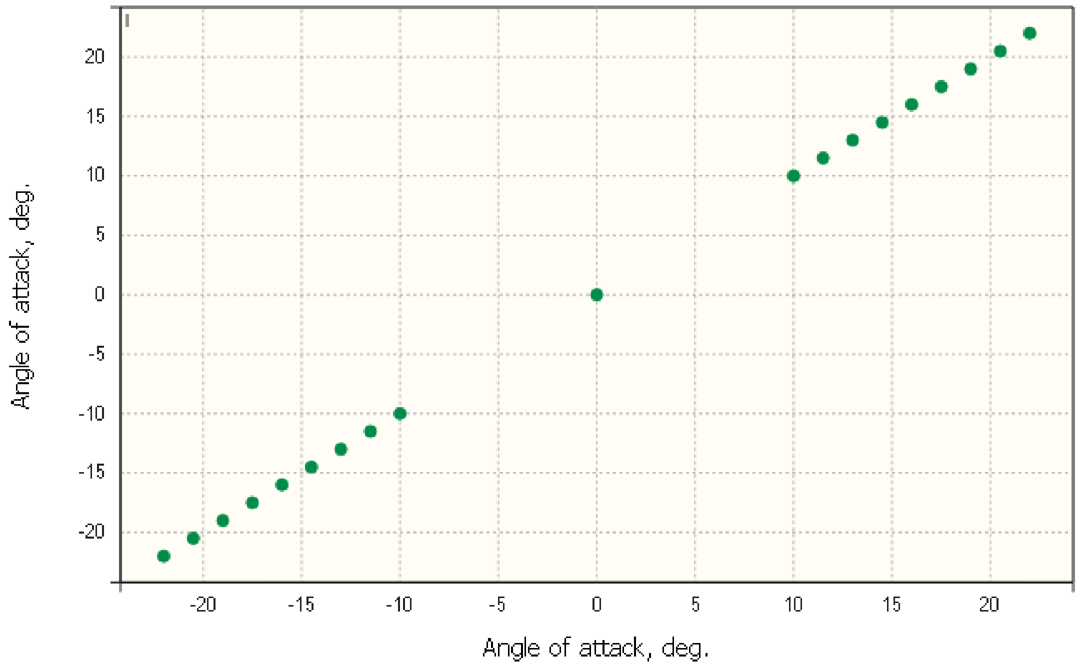
Workflow in pSeven (DSX platform by DATADVANCE)



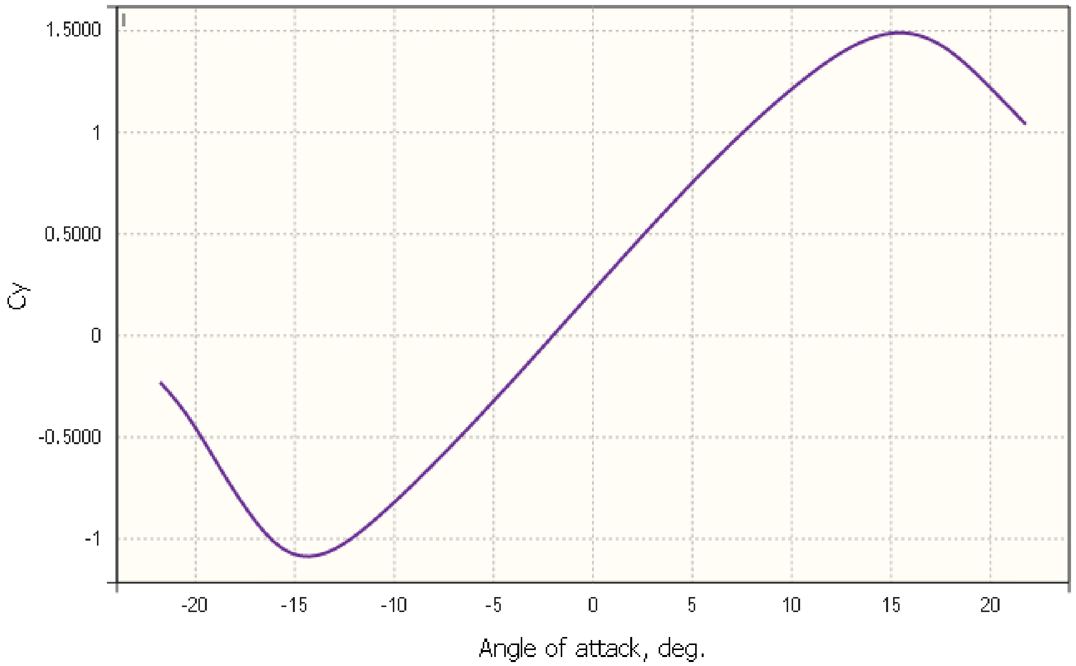
Approx based search: training set

Function areas of interest are known → special DoE set is the best option

DoE set: 19 points in total



Resulting Cy model



Approx based search: statement and optimizer settings

Problem features:

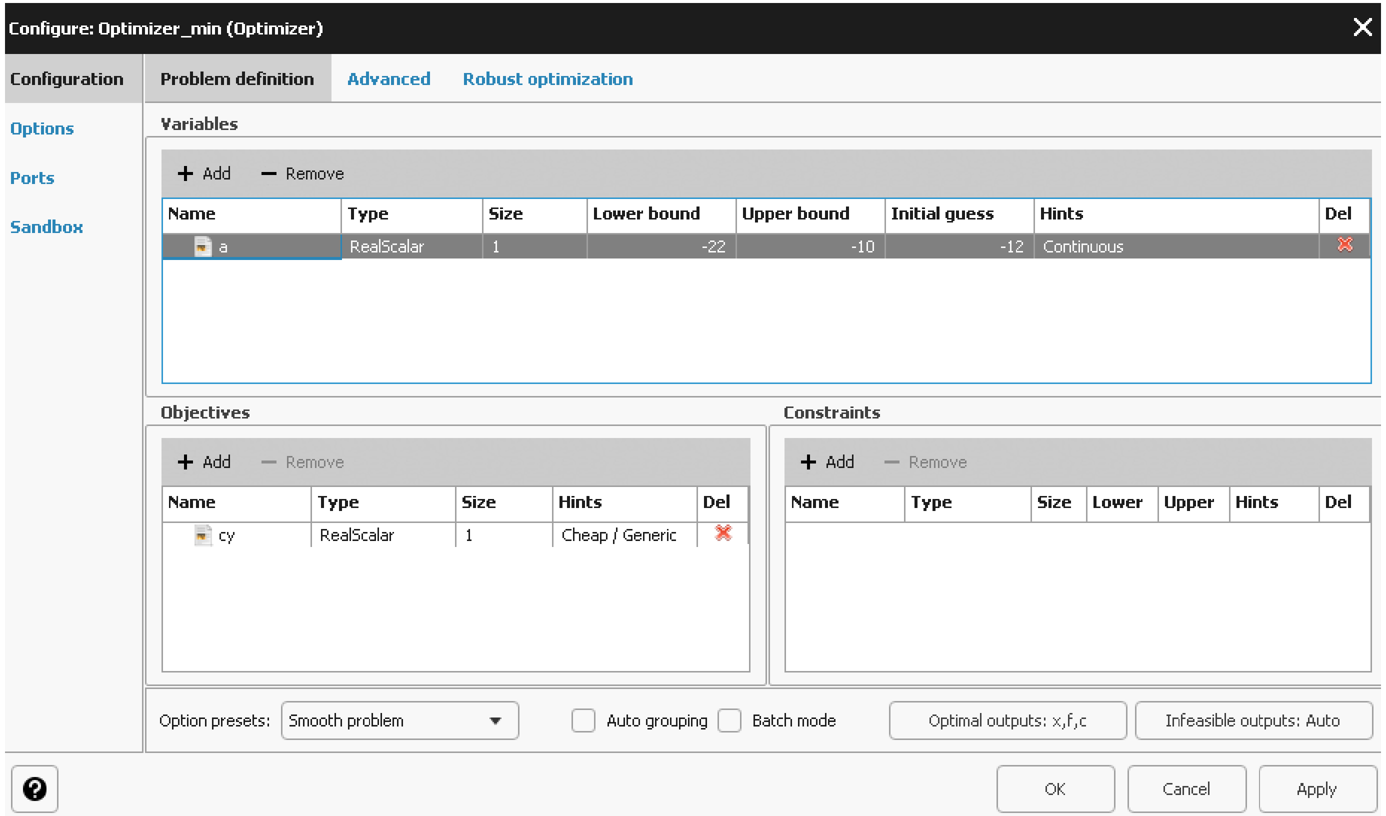
- Single-objective and one-dimensional
- Function behavior is expected
- **Single minimum**
- **Smooth approximation model**
- **Almost instant response**

Variable	Lower bound	Upper bound	Initial guess
α	-22	-10	-12

Objective	Type	Cost
Cy	generic	cheap

“Smooth” preset

Number of evaluations is not limited

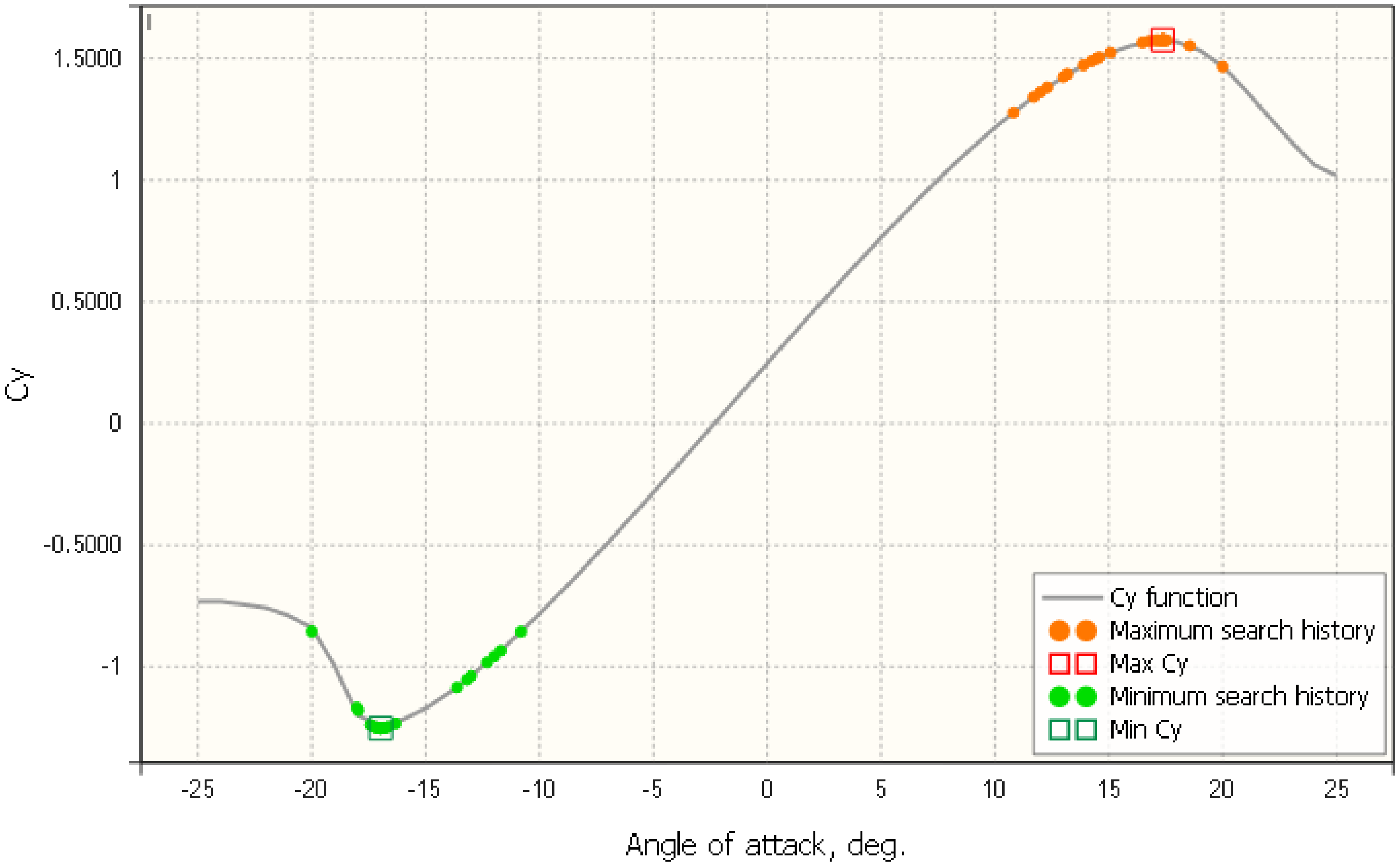


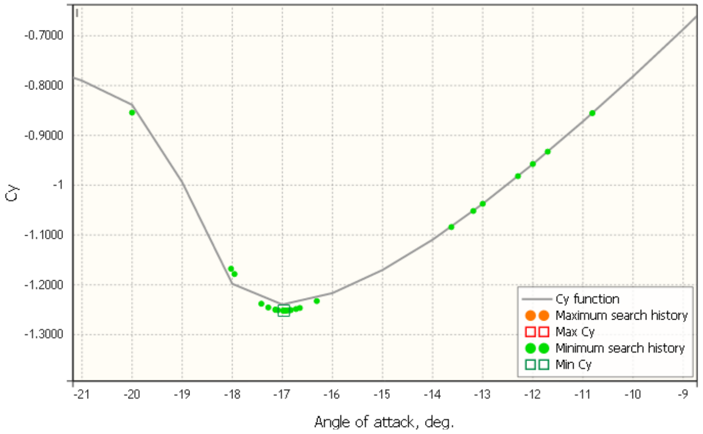
Local gradient-based algorithm with standard step limit is enabled by **SmartSelection**.

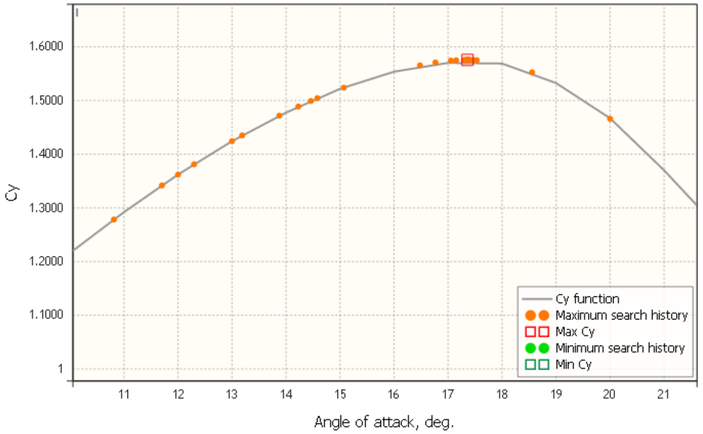
Stopping by convergence criteria.

Approx based search: results

Optimization history on $Cy(\alpha)$ plot:







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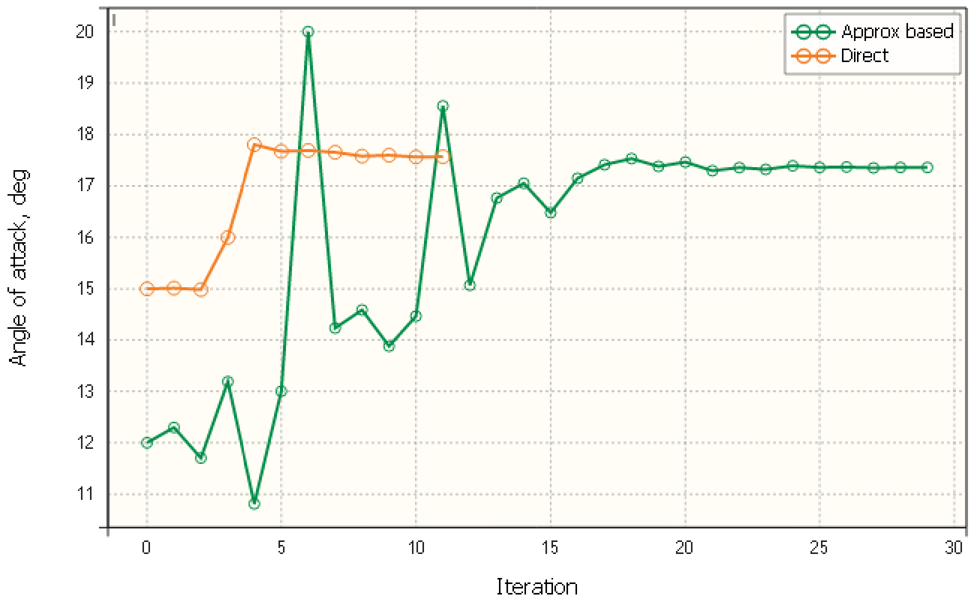
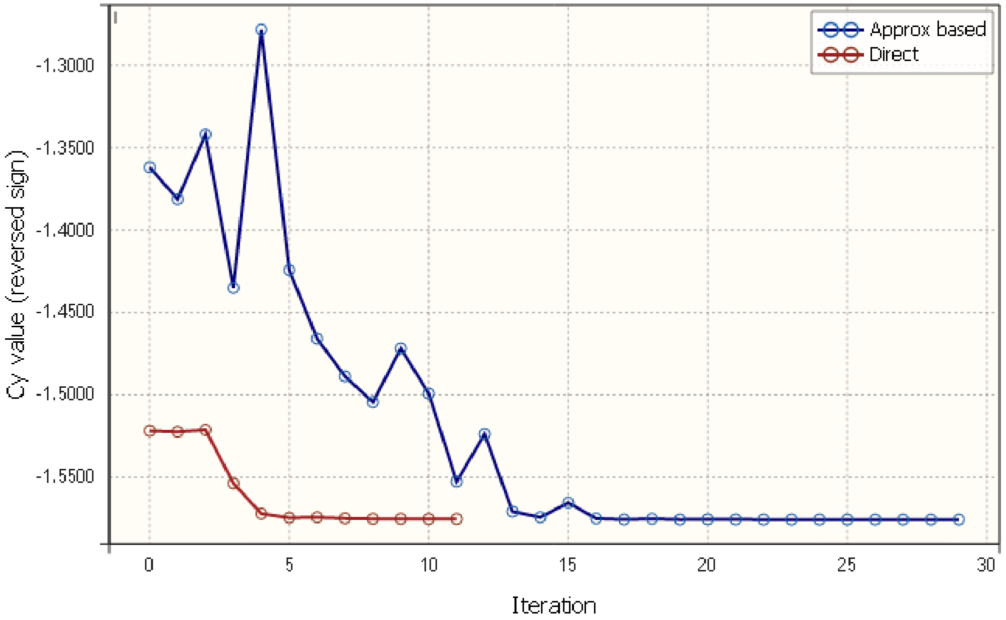
Comparison of methods (location of maximum)

Parameter	Direct search	Approx based search	Discrepancy
Angle of attack, deg.	17.59°	17.35°	~1.5%
Cy	1.575	1.576	<1%

Angle of attack history for both approaches:



Cy history for both approaches:



Number of simulation runs

- Direct: 12 for min + 12 for max = 24
- Approx based: 19 for model building

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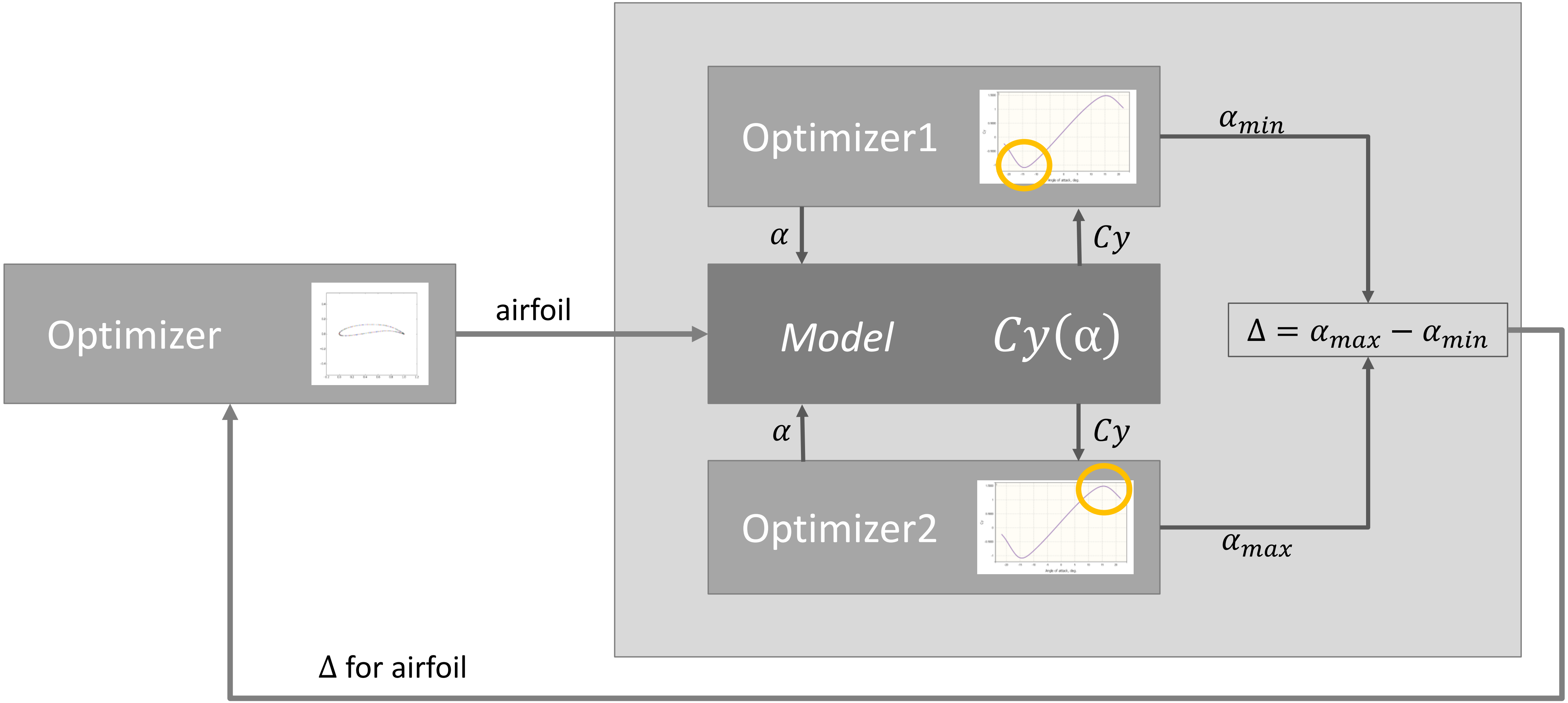
General optimization scheme



Upper-level optimization: statement and method

In upper-level optimization the airfoil geometry is varied and the working range is maximized

Variables and ranges

Variable	Lower bound	Upper bound
p (max camber position)	0.33	0.66
t (max thickness)	0.12	0.18
m (max camber value)	0.02	0.08

Objectives

Objective	Type	Cost
Δ (range)	generic	expensive

Surrogate-based optimization (SBO) algorithm is used:

- Global search
- **Noise stable**
- Natural NaN handling
- Evaluation saving
- Explicit budget option

Budget (number of points to evaluate) is set to **40**

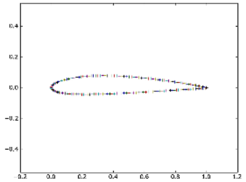
The SBO method selected automatically by **SmartSelection** basing on “expensive” hint.

Airfoil optimization: results

Angle of attack ranges for initial and optimal airfoils (obtained by two approaches)

Initial airfoil (2412)

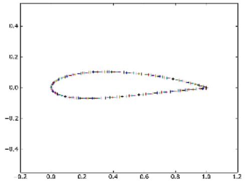
p	0.4
t	0.12
m	0.02



Δ=30,7°

Direct search optimization

p	0.54
t	0.17
m	0.023



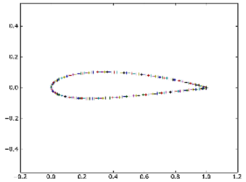
Δ=35,2°

Total simulation runs:

24*40=960

Approximation based optimization

p	0.51
t	0.17
m	0.021

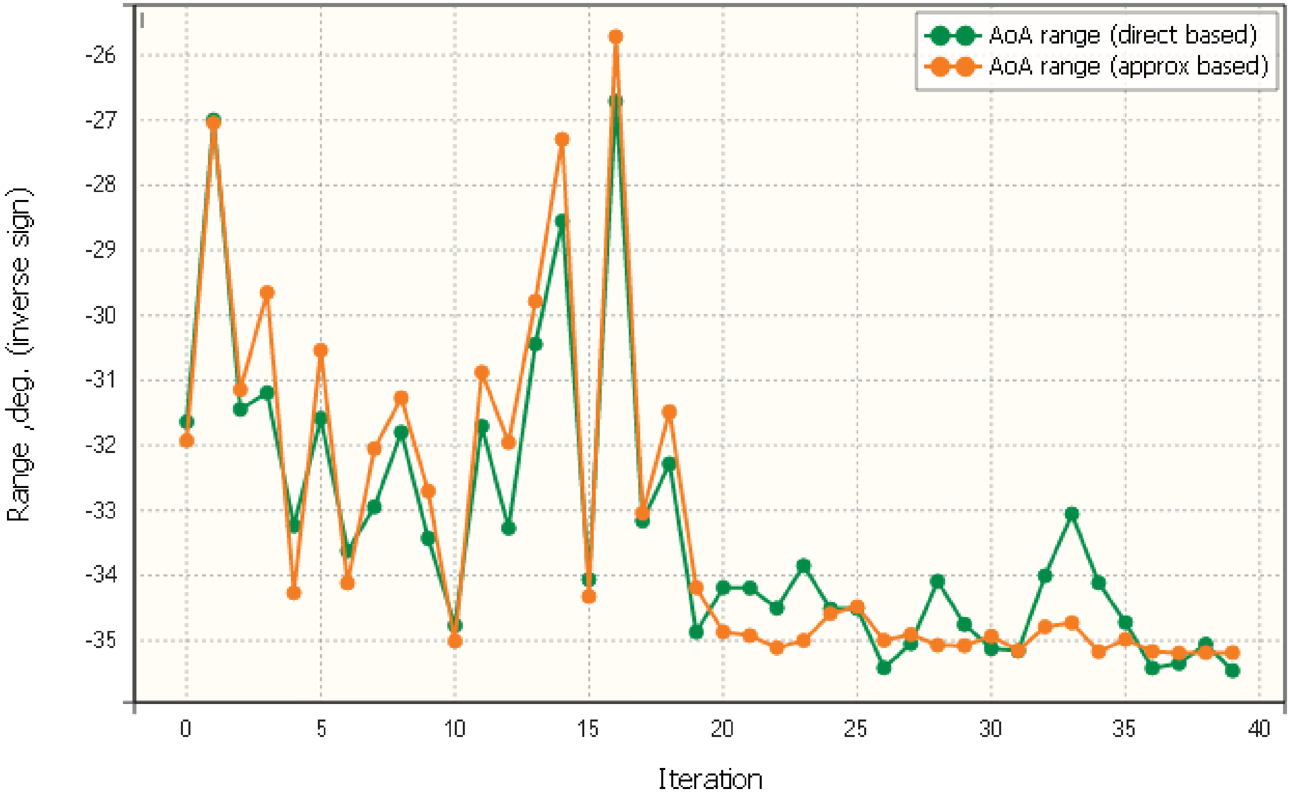


Δ=35,4°

Total simulation runs:

19*40=760

Optimization history for AoA range



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Conclusions

- FloEFD provides stable results for airfoil characteristics even near critical angles of attack
- Easy setup, meshing and convergence together with API (or external optimizer option) make it perfect for optimization
- Bi-level optimization workflow for horizontal stabilizer airfoil study was created in pSeven software
- Use of approximation models to reduce the number simulation runs was demonstrated
- Airfoil with the widest AoA range was discovered. Solution tends to symmetric (non-curved) shape.

Thank you for your attention!