Design Automation for ANSYS Workbench using VisualDOC

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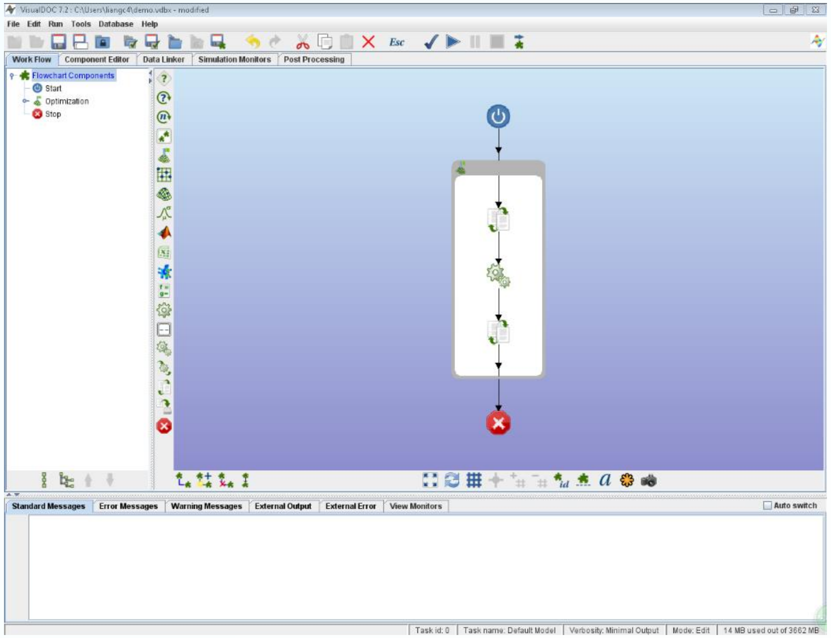
Overview

- VisualDOC Optimization
- Parametrization in ANSYS Workbench
- Coupling method
- Numerical Examples

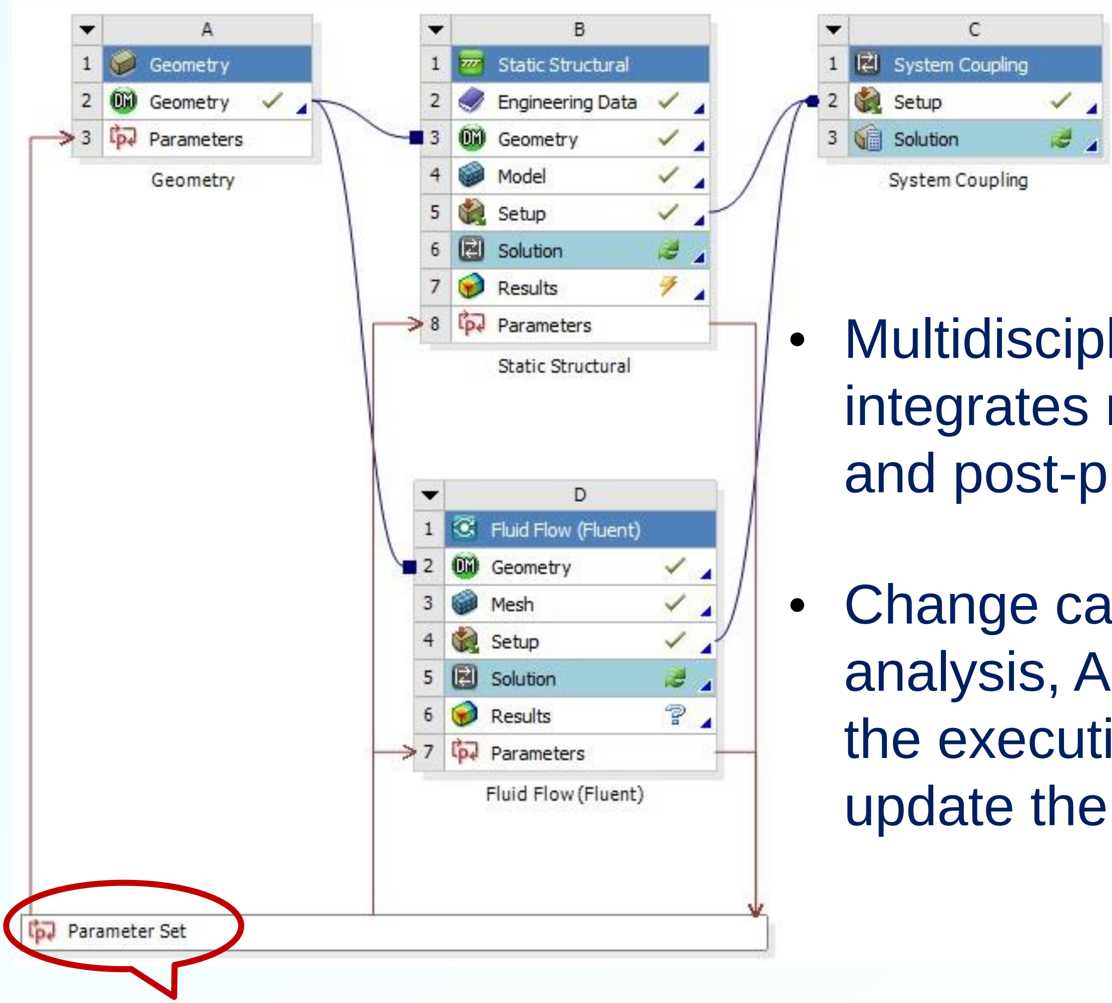


User interface of VisualDOC

VisualDOC Optimization

- Integrated tool for design process integration, execution and automation
- Single objective, multi-objective, DOE, Response surface, etc.
- Visualized configuration and optimization flow
- Execution of external software to via batch mode

ANSYS Workbench



- Multidisciplinary engineering platform that integrates modeling, meshing, analysis and post-processing.
- Change can be made to any part of the analysis, ANSYS Workbench will manage the execution of the required application to update the project automatically.

Parametric analysis facilitates management of parameters across different ANSYS products and make design automation easier

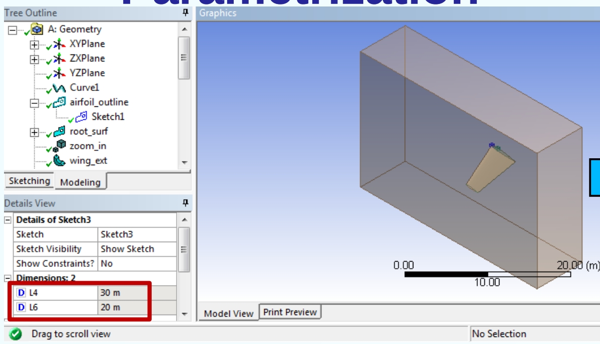
Coupling Tactic

Two approaches for software coupling:

- **Optimization outside ANSYS (Scripting: Python):**
  - Regard the ANSYS analysis as blackbox
  - Specify the parameters within ANSYS Workbench
  - Call ANSYS from VisualDOC, extract variables from the parameter-set and classify the parameters into input and output files
  - Run optimization, ANSYS Workbench will be executed in the batch mode
- **Optimizer as ANSYS plug-in (SDK: C#)**
  - Optimization within ANSYS (DesignXplorer)
  - In progress

Flow Chart

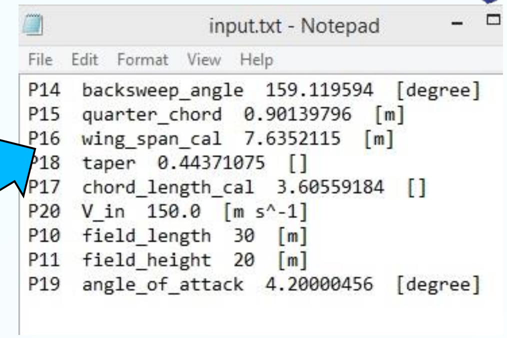
Problem Setup & Parametrization



Parameter classification

Outline of All Parameters

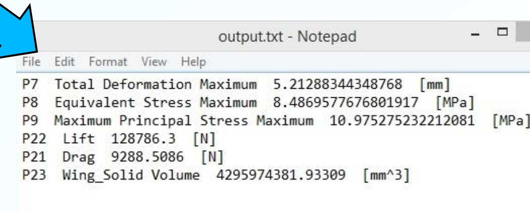
	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Geometry (A1)			
4	P10	field_length	30	m
5	P11	field_height	20	m
6	P14	backsweep_angle	153.75	degree
7	P15	quarter_chord	0.975	m
8	P16	wing_span_cal	7.6683	m
9	P17	chord_length_cal	3.9	
10	P18	taper	0.6	
[illegible]	P19	angle_of_attack	7	degre
[illegible]	Fluid Flow (Fluent) (D1)			
[illegible]	P20	V_in	150	m s^-1
*	New input parameter	New name	New expression	
15	Output Parameters			
16	Static Structural (B1)			
17	P7	Total Deformation Maximum	0	mm
18	P8	Equivalent Stress Maximum	0	MPa
19	P9	Maximum Principal Stress Maximum	0	MPa
20	P23	Wing_Solid Volume	5.623E+09	mm^3
21	Fluid Flow (Fluent) (D1)			
22	P21	Drag	13950	N
23	P22	Lift	1.7777E+05	N
*	New output parameter		New expression	
25	Charts			



input.txt - Notepad

File Edit Format View Help

```
P14  backsweep_angle  159.119594  [degree]
P15  quarter_chord  0.90139796  [m]
P16  wing_span_cal  7.6352115  [m]
P18  taper  0.44371075  []
P17  chord_length_cal  3.60559184  []
P20  V_in  150.0  [m s^-1]
P10  field_length  30  [m]
P11  field_height  20  [m]
P19  angle_of_attack  4.20000456  [degree]
```

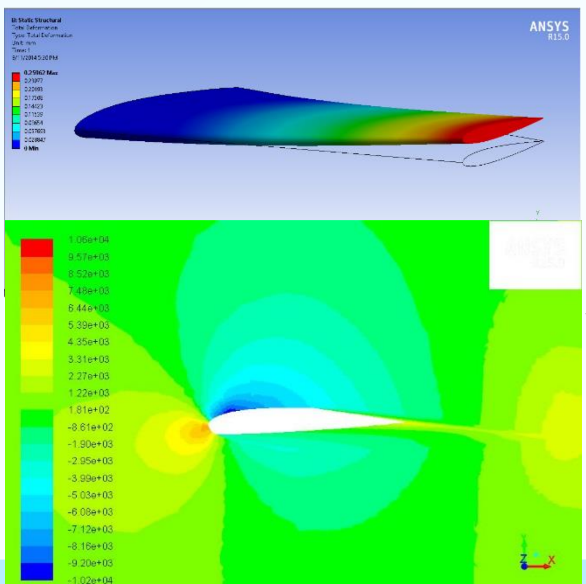


output.txt - Notepad

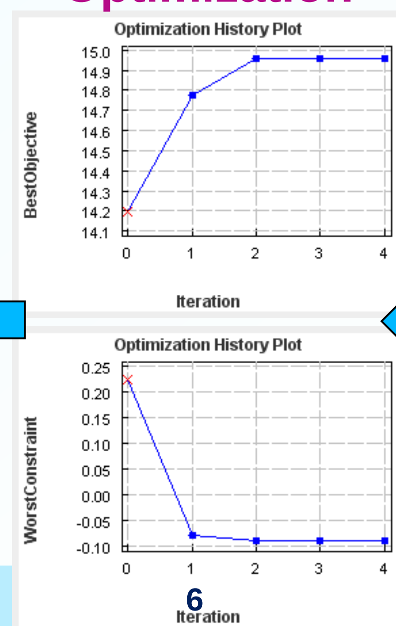
File Edit Format View Help

```
P7   Total Deformation Maximum  5.21288344348768  [mm]
P8   Equivalent Stress Maximum  8.48695776768O1917  [MPa]
P9   Maximum Principal Stress Maximum  10.975275232212081  [MPa]
P22  Lift  128786.3  [N]
P21  Drag  9288.5086  [N]
P23  Wing_Solid Volume  4295974381.93309  [mm^3]
```

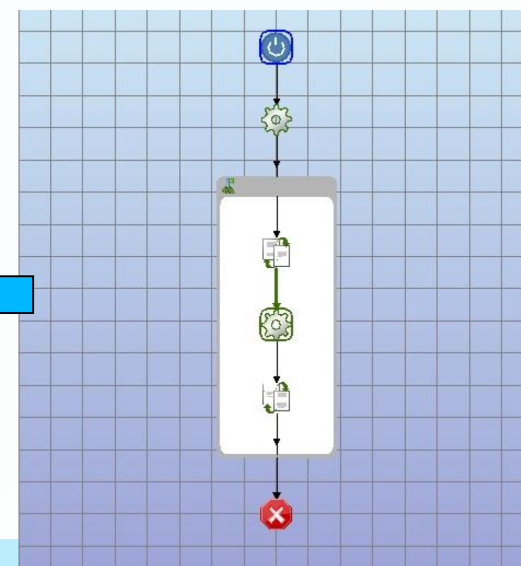
Solution Check



Optimization



VisualDOC Setup

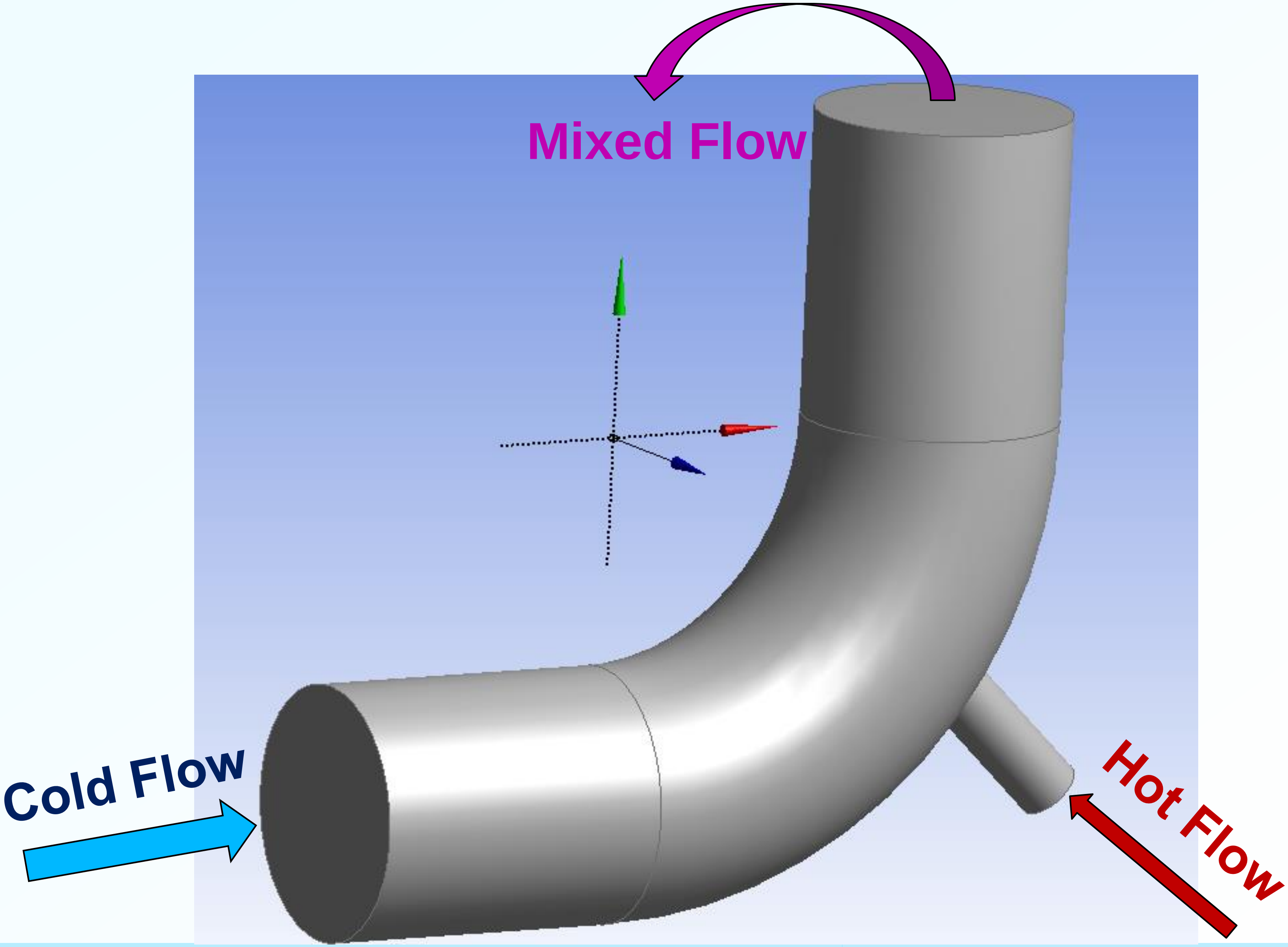


Numerical Examples

Three examples are created to demonstrate VisualDOC design automation for ANSYS Workbench:

- Single disciplinary single objective optimization for a heat transfer problem using Fluent
- Multi-disciplinary multi-objective optimization for an aero-elastic wing analysis (FSI)
- Response surface based multi-disciplinary optimization for an aero-elastic flapping problem (FSI transient)

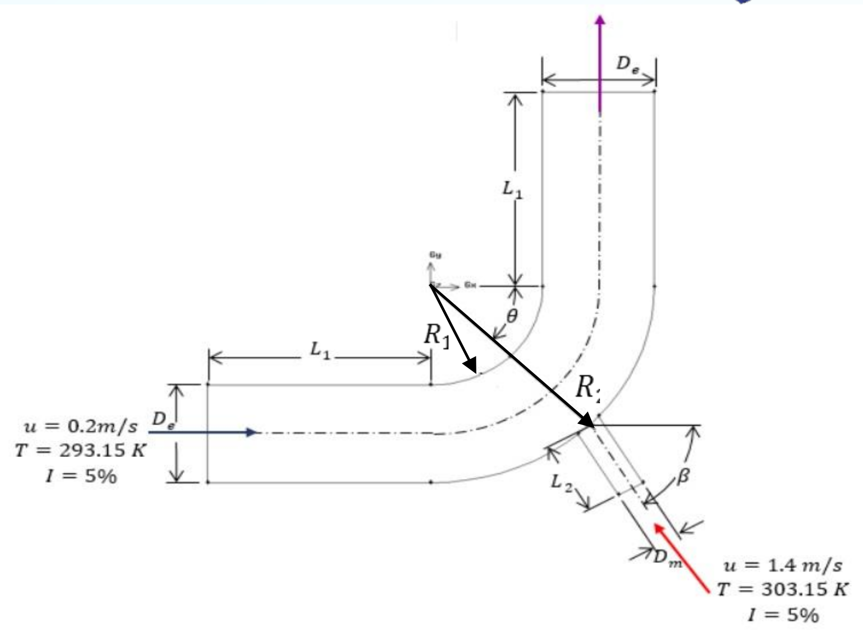
Heat transfer in a mixing elbow



Optimization Formulation

Boundary conditions:

Flows	Speed (m/s)	Temperature (K)
Cold inflow	0.2	293.15
Hot inflow	1.4	313.15
Mixed outflow	N\A	Output



Target:

Maximize the average outlet temperature: $\bar{T}$

The Design variables include:

- Inner radius of the torus: R_1
- Degree of the cylinder position angle: θ
- Degree of the cylinder angle: β

Optimization setup:

$$max\ (\ \bar{T}\ )$$

$s.t.$

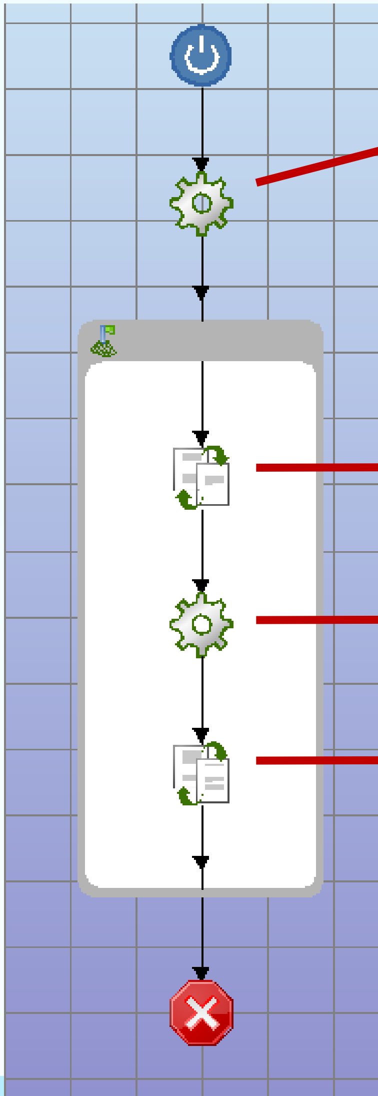
$$140mm \le R \le 170mm$$

$$21° \le \theta \le 73°$$

$$0° \le \beta \le 90°$$

Software Coupling

VisualDOC flow chart



Extract defined parameter from ANSYS, and classify the input and output variables into two files (initially generated using *Test* function)

Input file

Execute ANSYS Workbench analysis

Output file

Define Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	⊟ Input Parameters			
3	⊟ Mixing Elbow (A1)			
4	P6	R1	90	mm
5	P7	R2	190	mm
6	P8	x0	129.76	mm
7	P9	y0	-188.79	mm
8	P10	Lx	0	mm
9	P11	Ly	136.23	mm
*	New input parameter	New name	New expression	
11	⊟ Output Parameters			
12	⊟ Mixing Elbow (A1)			
13	P12	T_out	298.96	K
*	New output parameter		New expression	
15	Charts			

Outline of All Parameters

All parameters in ANSYS Workbench

Design variables: R_1, θ, β

Synthetic variables:

$$R_2 = R_1 + 100$$

$$x_0 = L_x + \cos(\theta) * (R_1 + 50)$$

$$y_0 = -L_y - \sin(\theta) * (R_1 + 50)$$

$$L_x = f_{L_x}(R_1, \beta, \theta)$$

$$L_y = f_{L_y}(R_1, \beta, \theta)$$

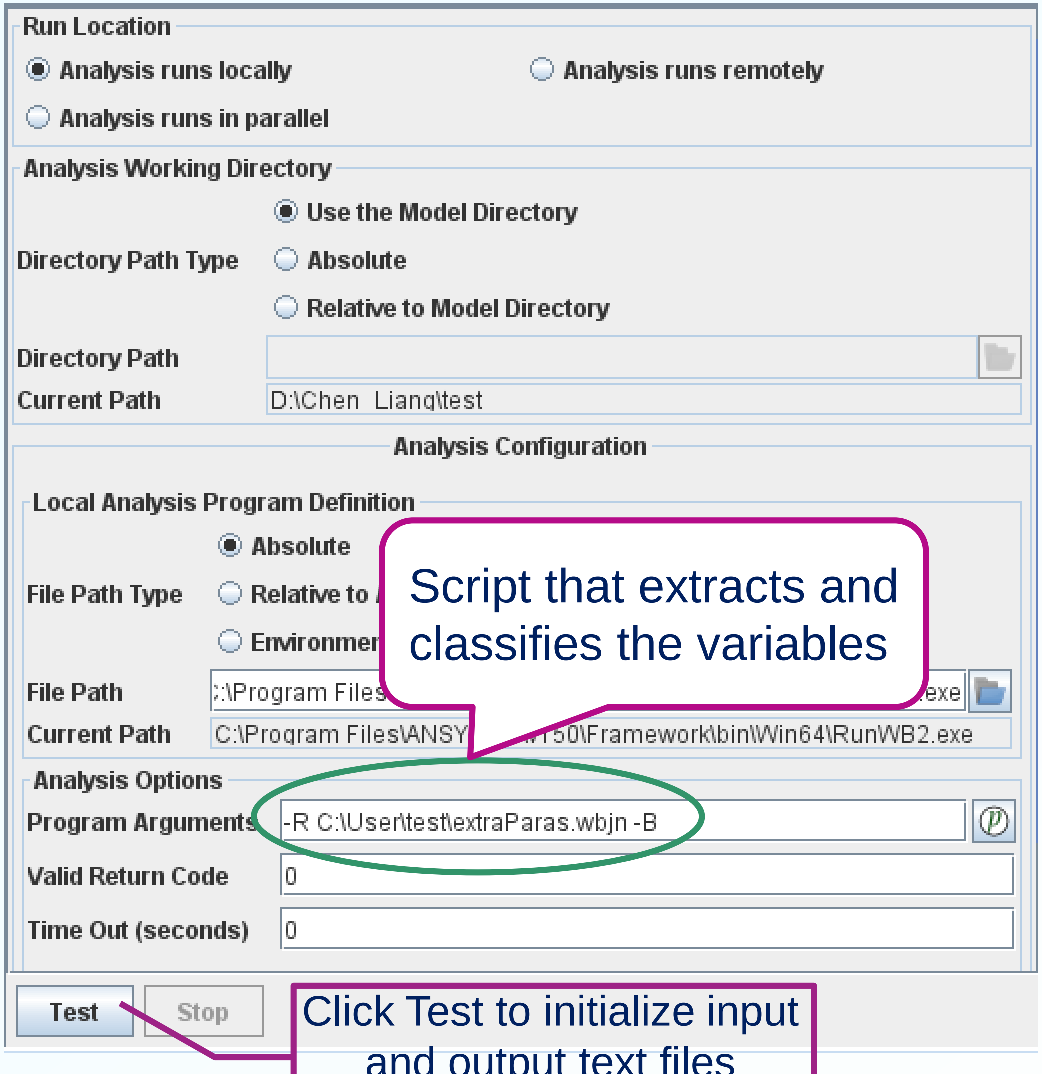
Basic | Attributes | Scaling | Objective

Name	Input/Output	Data Type	Value Type	Adv. Attribute
R1	Input	Scalar	Real	None
Theta	Input	Scalar	Real	None
Beta	Input	Scalar	Real	None
R2	Input	Scalar	Real	Synthetic
x0	Input	Scalar	Real	Synthetic
y0	Input	Scalar	Real	Synthetic
Lx	Input	Scalar	Real	Synthetic
Ly	Input	Scalar	Real	Synthetic
T_out	Output	Scalar	Real	None

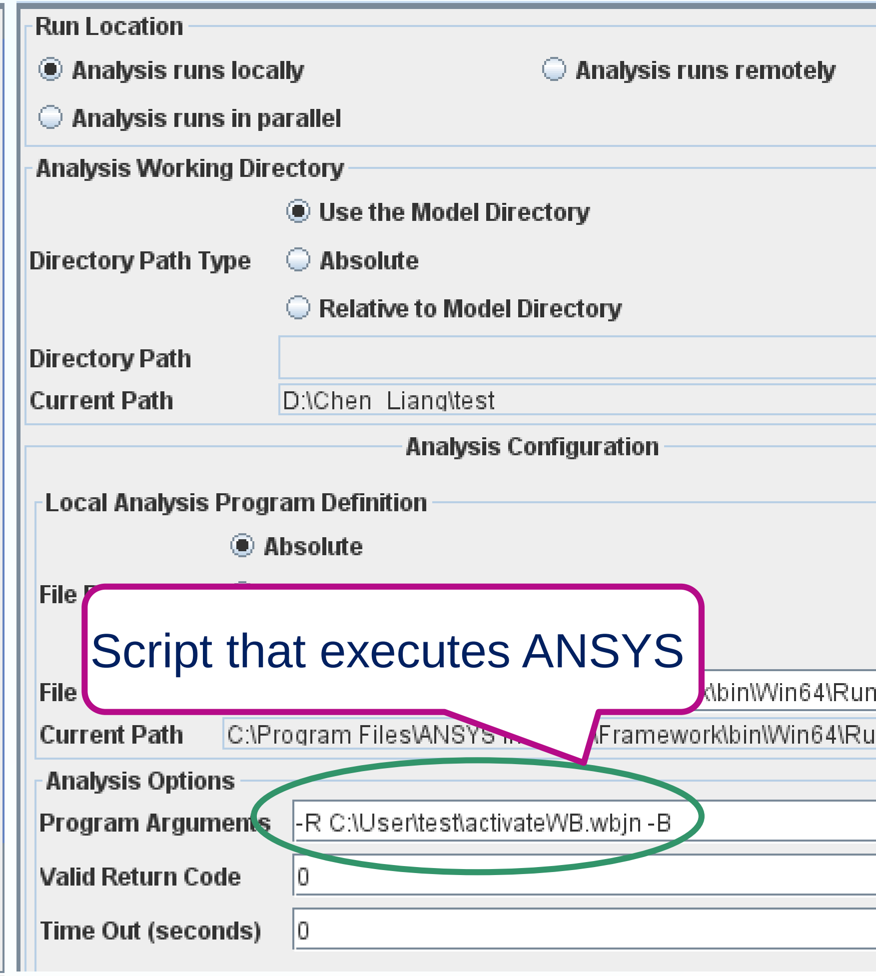
- The geometric parameters in ANSYS are the synthetic functions of the design variables.
- Define synthetic variables in VisualDOC using the given equations.

Software Coupling

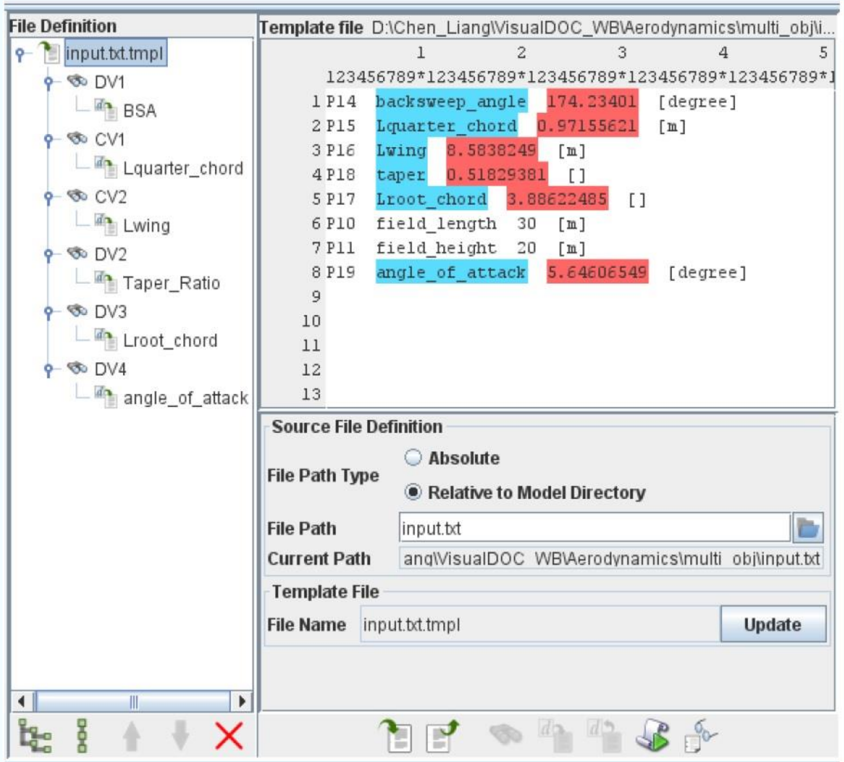
Parameter Extraction



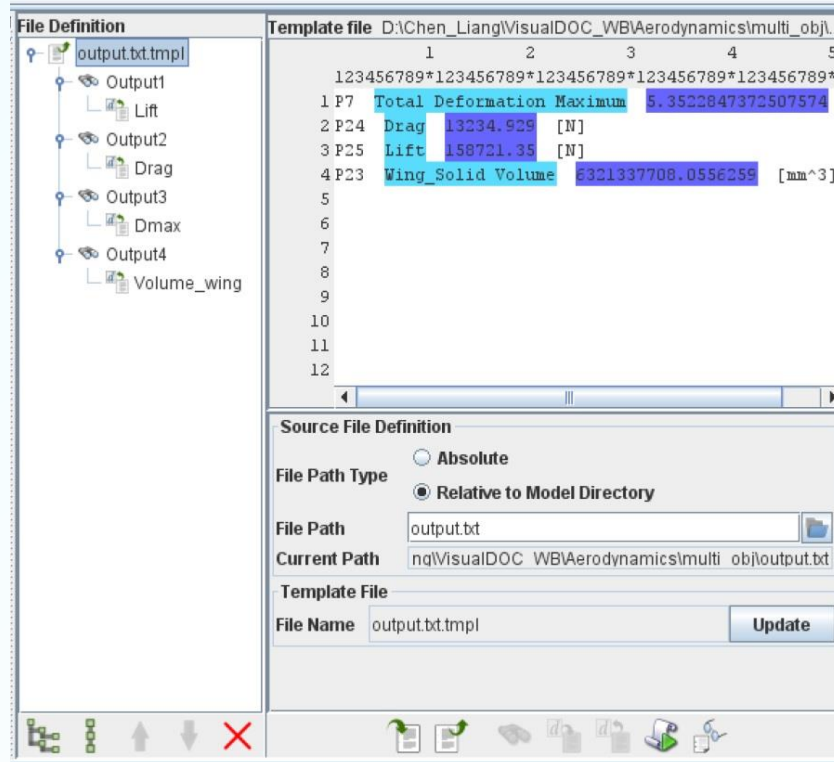
Run ANSYS



Identify I/O Variable



Input file

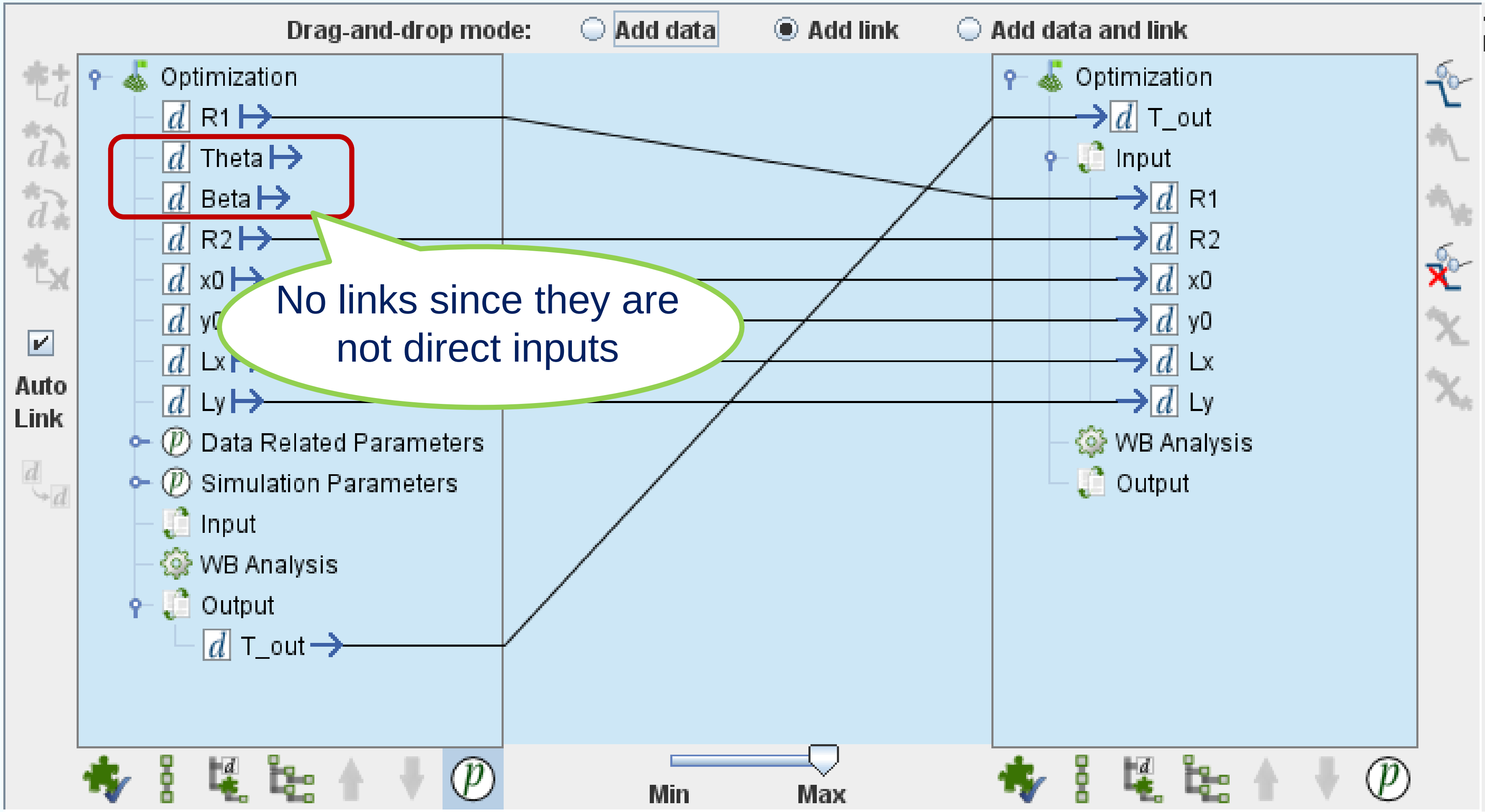


Output file

- Highlight and name the target string
- Highlight and name the corresponding values to write (read)
- VisualDOC identifies the values by relative positioning

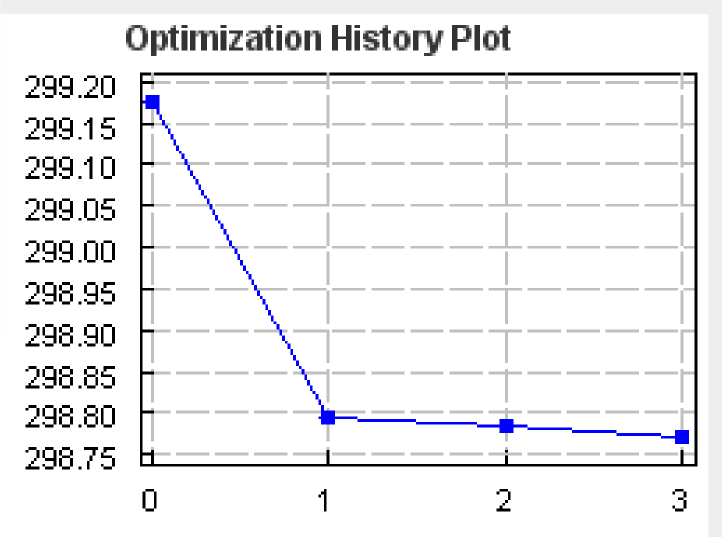
Note that the design variables are not necessarily the direct input to the model

Data Linker

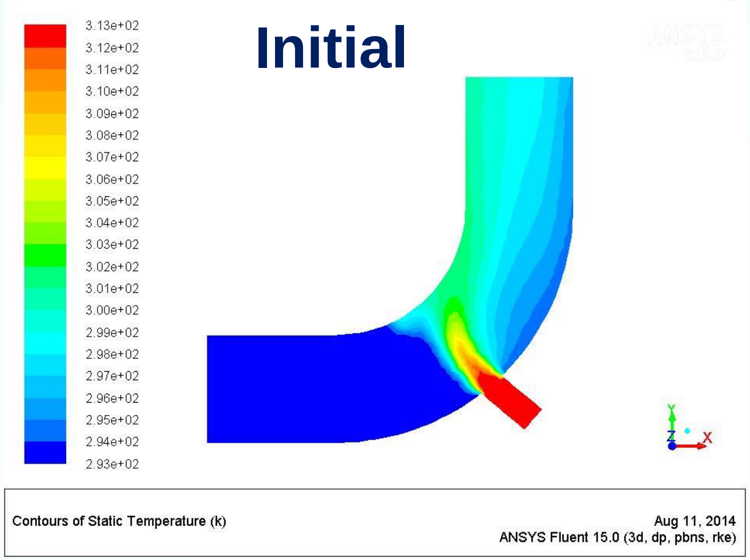

Drag-and-drop mode:
Add data
Add link
Add data and link
Optimization
R1
Theta
Beta
R2
x0
y0
Lx
Ly
Data Related Parameters
Simulation Parameters
Input
WB Analysis
Output
T_out
Optimization
T_out
Input
R1
R2
x0
y0
Lx
Ly
WB Analysis
Output
Auto Link
Min
Max
No links since they are not direct inputs

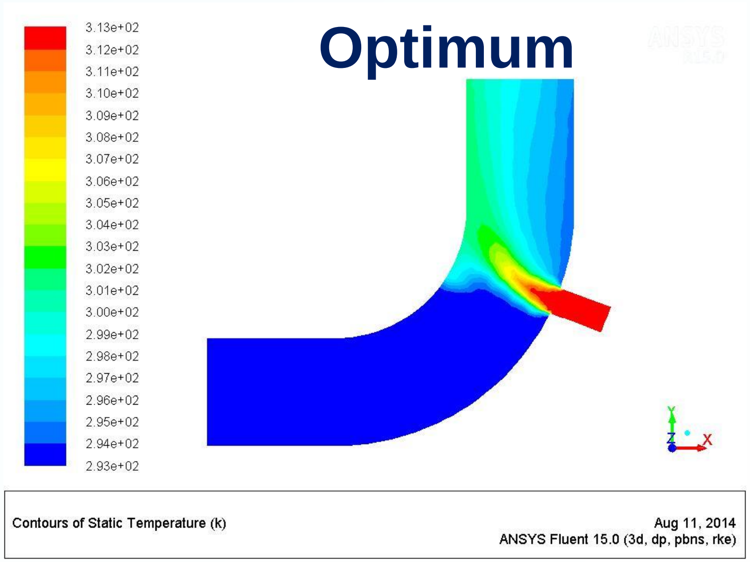
Results

Best objective history



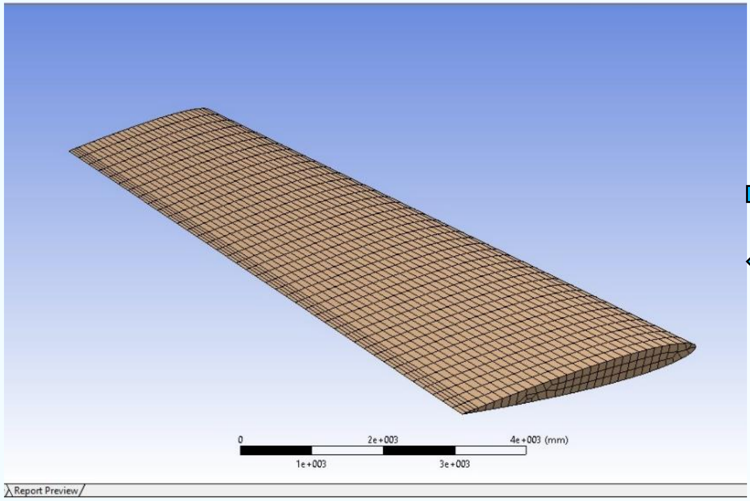
- Unconstraint optimizer: BFGS
- 4 optimization iterations
- 31 function evaluations
- 3,300 seconds on i-5 desktop
- Temperature drop from initial 299.18 → minimum 298.77



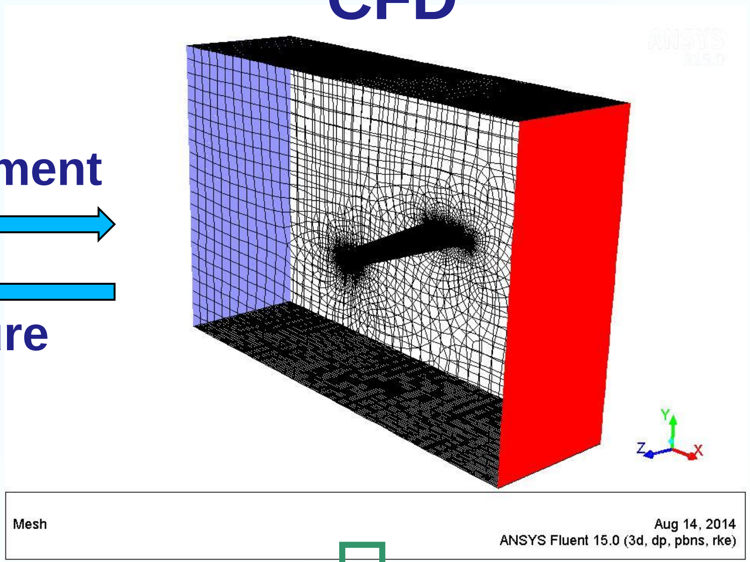


Multi-Objective Wing Design

FEA



CFD



Displacement

Pressure

Stress, deflection, etc.

Lift, drag, moment, etc

Targets:

High lift-to-drag ratio

Small wing deflection(stress)

Multi-objective optimization (Pareto Frontier)

Optimization Formulation

Model description:

- NACA 0012 airfoil
- Cantilevered wing
- Turbulent model: $k-\epsilon$
- Inlet speed: 100m/s

Design variables:

- Backsweep angle (BSA)
- Taper ratio (TR)
- Root chord length (L)
- Angle of attack (AoA)
- Wing span (S)

Optimization setup:

$$Max(L/D),$$
$$Min(Maximum\ deformation)$$

$s.t.$

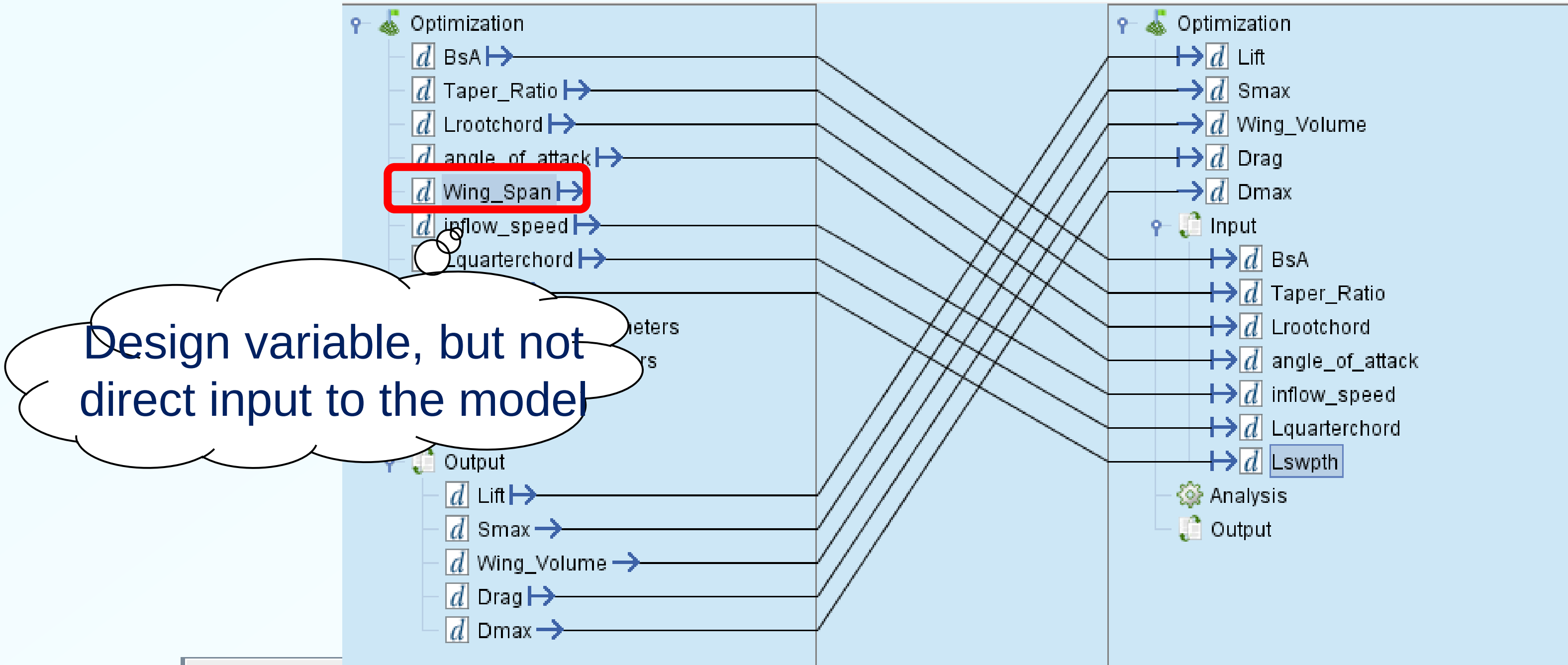
$$Vol_{wing} \leq 5m^3$$
$$Area \leq 24\ m^2$$
$$Drag\ force \leq 9000\ N$$
$$15° \leq BSA \leq 30°$$
$$0.4 \leq TR \leq 0.6$$
$$3m \leq L \leq 5m$$
$$4° \leq AoA \leq 8°$$
$$15m \leq S \leq 18m$$

Calculated in ANSYS or VisualDOC

Optimizer:

- Non-dominated sorting genetic algorithm – II (NSGA-II) multi-objective optimizer
- Population size: 20 (func eval / iter)
- Maximum number of iteration: 20

VisualDOC Setup



Name	Input/Output	Adv. Attribute	Variable	Objective	Constraint	Lower Bound	Initial Value	Upper Bound
BsA	Input	None	✔	☐	☐	150.0	160.0	175.0
Taper_Ratio	Input	None	✔	☐	☐	0.4	0.5	0.6
Lrootchord	Input	None	✔	☐	☐	3.0	4.0	5.0
angle_of_attack	Input	None	✔	☐	☐	4.0	6.0	8.0
Wing_Span	Input	None	✔	☐	☐	15.0	16.0	18.0
inflow_speed	Input	None	☐	☐	☐		150.0	
Lquarterchord	Input	Synthetic	☐	☐	☐		1.0	
Lswpth	Input	Synthetic	☐	☐	☐		6.49519052838	
Lift	Output	None	☐	☐	☐		65222.0	
Smax	Output	None	☐	☐	☐			
[illegible]olum[illegible]	Output	None	☐	☐	✔			5.0E9
[illegible]_area	Output	Synthetic	☐	☐	✔		21.0	24.0
[illegible]	Output	Synthetic	☐	☐	☐		0.19719425548	
[illegible]	Output	Synthetic	☐	☐	☐		0.020021164021	
[illegible]	Output	None	☐	☐	☐		6622.0	9000.0
Dmax	Output	None	☐	✔	☐			
LD_Ratio	Output	Synthetic	☐	✔	☐		9.84929024464	

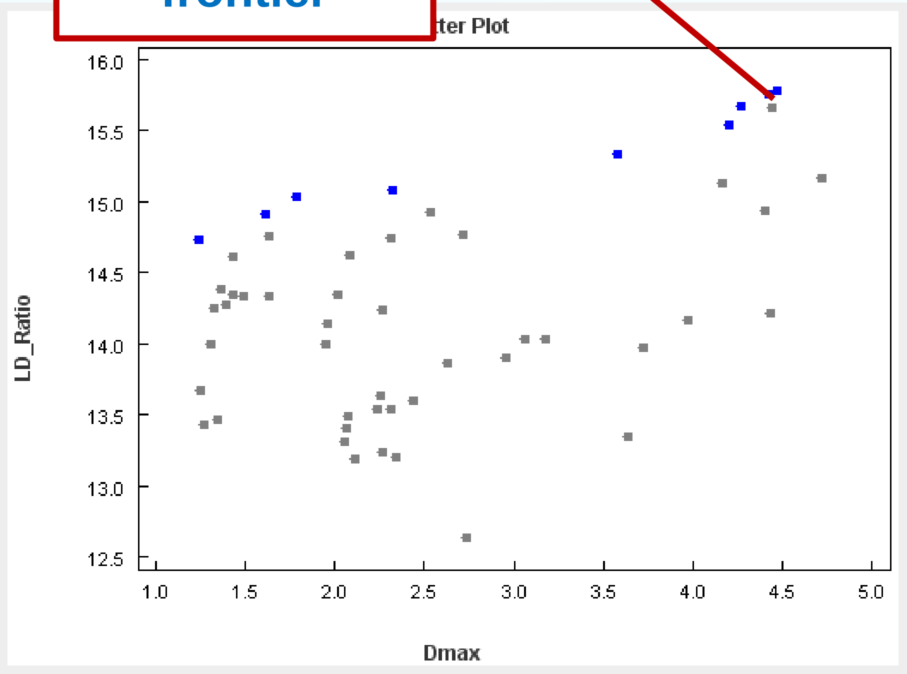
Synthetic functions

Result

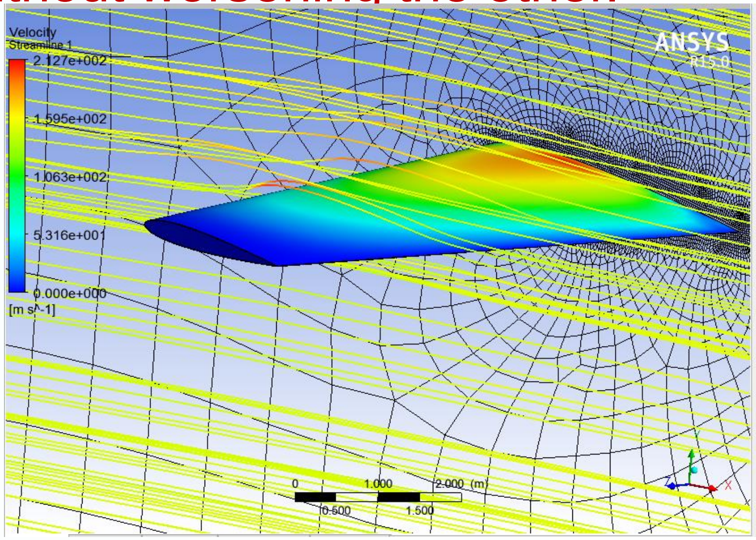
Pareto frontier:

- Number of function evaluations: 400
- Total computing time: ~ 80 hours

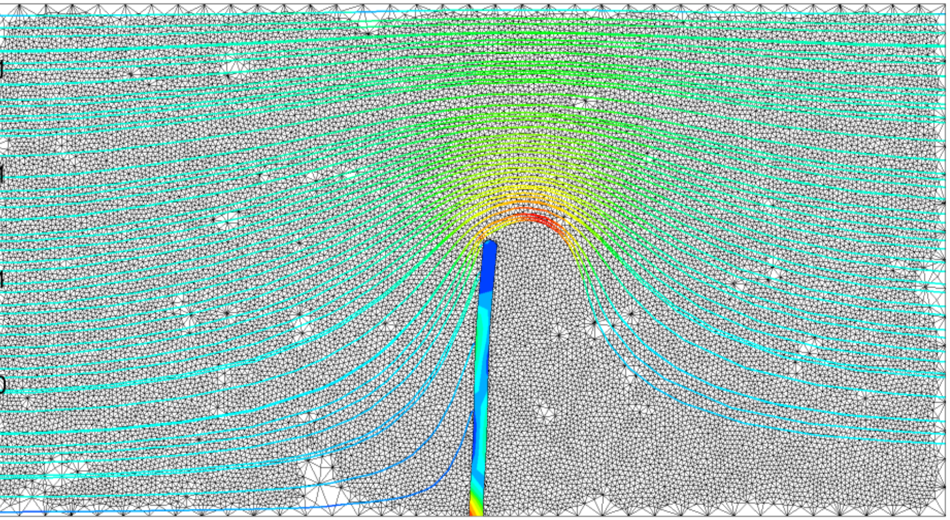
Optimal Pareto frontier



- Grey points are Paretos from other iterations.
- Best Pareto is given in blue dot → One objective cannot be improved without worsening the other.



Response Surface Based Optimization



Objective

- Hyper-elastic flapping plate
- ANSYS Transient Structural ⇋ FLUENT
- Duration: 0.005 sec
- Time step: 5E-05 sec
- 7-9 minutes / run (Time consuming)

Optimization

- Maximize the largest deformation
- Stress constraint
- Design variables: plate height, thickness

$$Max\ \text{(Maximum deformation)}$$

s.t.

$$\sigma_v \le 60{,}000\ Pa$$

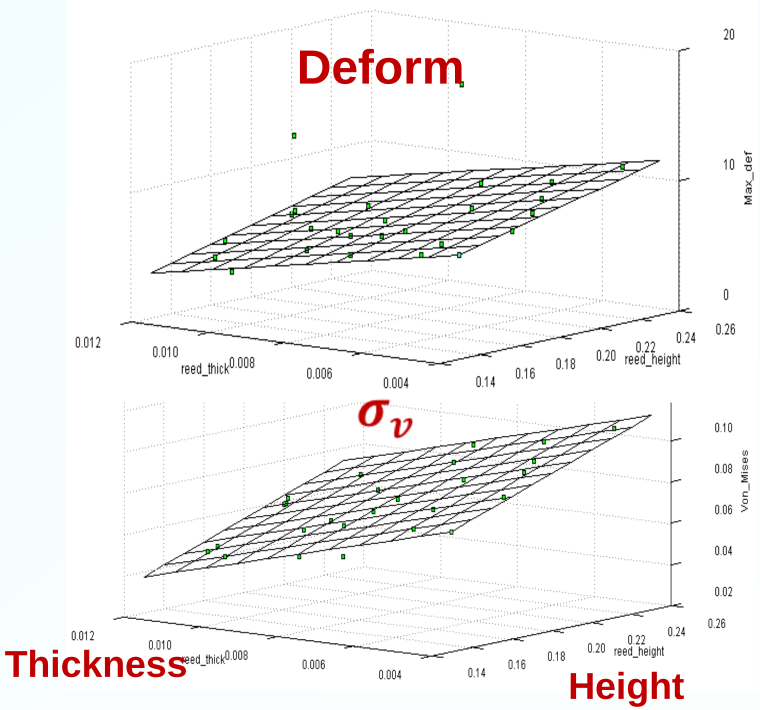
$$0.15\ m \ \le\ Height\ \le 0.25\ m$$

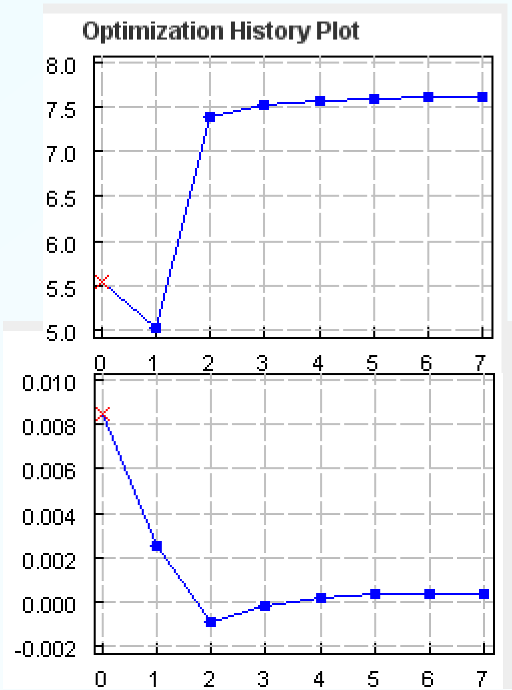
$$0.004\ m \le Thickness \le 0.012\ m$$

Design of Experiments

Approach

- Optimal Latin Hypercube sampling
- Number of design points: 20
- Total computational time: 168 min





Optimization using RSM

- Full-quadratic DOE model
- MMFD Optimizer: 7 iterations, 81 function evaluations
- Optimum: MaxDef = 7.61mm, σ_v = 60,300Pa

ANSYS Validation

- At the optimum: MaxDef = 5.13mm, σ_v = 93,261Pa

Large bias

Response Surface Approximated Optimization

Approach

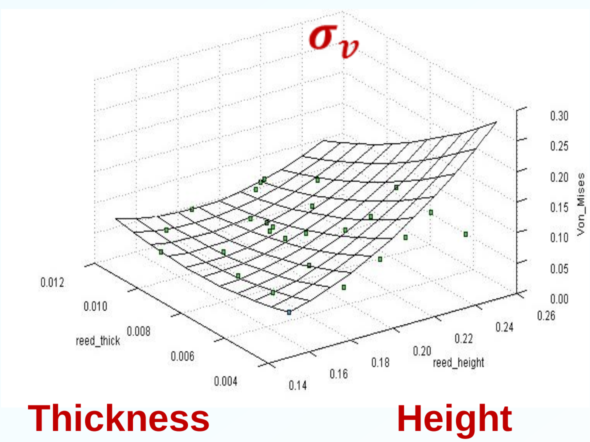
- Using the previous 20 design points
- Optimization → validate result →update RMS → re-optimization
- 6 design points are added and the computational time is ~48 min

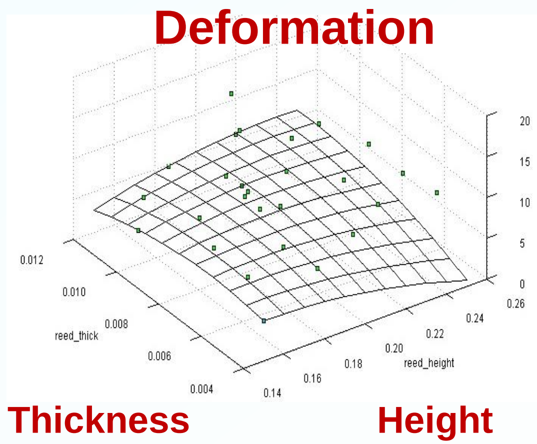
Result

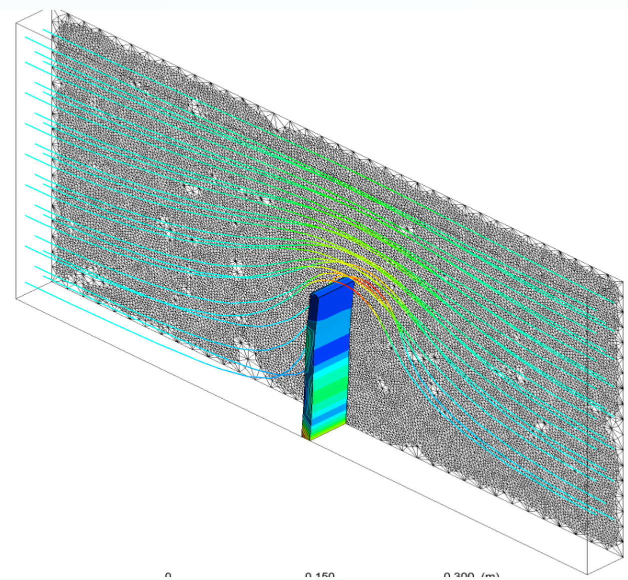
- Optimum: MaxDef = 12.058 mm, σ_v = 61,470 Pa

ANSYS Validation

- MaxDef = 12.15 mm, σ_v = 61,460 Pa (Close to the RMS result)







Note that the response surfaces are built based on the weighted value of the points

Summary

Coupled analysis for VisualDOC and ANSYS Workbench

- Design automation using VisualDOC optimizers
- Multi-disciplinary, multi-physics analysis and optimization based on ANSYS Workbench
- Parameter management (ANSYS) and parameter identification (VisualDOC python) guarantee the non-intrusive analysis to preserve the integrity of ANSYS models

Features of methodology

- Heat transfer in a mixing elbow
- Multi-objective MDO for an aero-elastic wing
- Pareto frontier
- Design of experiments
- Response surface based optimization

Thank you !