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

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

Mixed Flow

Cold Flow

Hot Flow
Optimization Formulation

Boundary conditions:

<table>
<thead>
<tr>
<th>Flows</th>
<th>Speed (m/s)</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold inflow</td>
<td>0.2</td>
<td>293.15</td>
</tr>
<tr>
<td>Hot inflow</td>
<td>1.4</td>
<td>313.15</td>
</tr>
<tr>
<td>Mixed outflow</td>
<td>N/A</td>
<td>Output</td>
</tr>
</tbody>
</table>

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: $\theta$
- Degree of the cylinder angle: $\beta$

Optimization setup:

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

$$s.t.$$

$140mm \leq R \leq 170mm$

$21^\circ \leq \theta \leq 73^\circ$

$0^\circ \leq \beta \leq 90^\circ$
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

<table>
<thead>
<tr>
<th>Outline of All Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>
* | New input parameter | New name | New expression | |

Output Parameters

| 12 | Mixing Elbow (A1) | | | |
| 13 | P12 | T_out | 298.96 | K |
* | New output parameter | New expression | |

All parameters in ANSYS Workbench

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

Design variables: $R_1$, $\theta$, $\beta$

Synthetic variables:

$$R_2 = R_1 + 100$$
$$x_0 = L_x + \cos(\theta) \ast (R_1 + 50)$$
$$y_0 = -L_y - \sin(\theta) \ast (R_1 + 50)$$
$$L_x = f_{L_x}(R_1, \beta, \theta)$$
$$L_y = f_{L_y}(R_1, \beta, \theta)$$
Software Coupling

Parameter Extraction

- Run Location:
  - Analysis runs locally
  - Analysis runs remotely
  - Analysis runs in parallel

- Analysis Working Directory:
  - Use the Model Directory
  - Absolute
  - Relative to Model Directory

- Directory Path Type:
  - Absolute
  - Relative to Model Directory

- Directory Path:
  - D:\Chen_LiangTest

- Current Path:
  - D:\Chen_LiangTest

- Analysis Configuration:
  - Local Analysis Program Definition
    - Absolute
    - Relative to Model Directory

- File Path Type:
  - Relative to Model Directory

- File Path:
  - C:\Program Files\ANSYS Inc\150\Framework\bin\Win64\RunWB2.exe

- Analysis Options:
  - Program Arguments: -R C:\User\test\extraParas.wbjn -B
  - Valid Return Code: 0
  - Time Out (seconds): 0

Click Test to initialize input and output text files

Run ANSYS

- Run Location:
  - Analysis runs locally
  - Analysis runs remotely
  - Analysis runs in parallel

- Analysis Working Directory:
  - Use the Model Directory
  - Absolute
  - Relative to Model Directory

- Directory Path Type:
  - Absolute
  - Relative to Model Directory

- Directory Path:
  - D:\Chen_LiangTest

- Current Path:
  - D:\Chen_LiangTest

- Analysis Configuration:
  - Local Analysis Program Definition
    - Absolute

- File Path Type:
  - Absolute

- File Path:
  - C:\Program Files\ANSYS Inc\150\Framework\bin\Win64\RunWB2.exe

- Analysis Options:
  - Program Arguments: -R C:\User\test\activateWB.wbjn -B
  - Valid Return Code: 0
  - Time Out (seconds): 0

Script that extracts and classifies the variables

Script that executes ANSYS
Identify I/O Variable

- 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

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

Displacement

Pressure

Stress, deflection, etc.

CFD

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: $k - \varepsilon$
- Inlet speed: 100m/s

Optimization setup:
$$\begin{align*}
\text{Max}(L/D), \\
\text{Min}(\text{Maximum deformation})
\end{align*}$$

$$s.t.
\begin{align*}
\text{Vol}_{\text{wing}} & \leq 5m^3 \\
\text{Area} & \leq 24 \text{ m}^2 \\
\text{Drag force} & \leq 9000 \text{ N}
\end{align*}$$

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

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

Calculated in ANSYS or VisualDOC
VisualDOC Setup

Design variable, but not direct input to the model

Synthetic functions

<table>
<thead>
<tr>
<th>Name</th>
<th>input/output</th>
<th>Augmentor</th>
<th>Variable</th>
<th>Objective</th>
<th>Constraint</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>BsA</td>
<td>Input</td>
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<td></td>
<td></td>
<td>150.0</td>
<td>160.0</td>
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<tr>
<td>Taper_Ratio</td>
<td>Input</td>
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<td></td>
<td></td>
<td>0.4</td>
<td>0.5</td>
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<tr>
<td>Lrootchord</td>
<td>Input</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
<td>3.0</td>
<td>4.0</td>
</tr>
<tr>
<td>angle_of_attack</td>
<td>Input</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
<td>4.0</td>
<td>6.0</td>
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<tr>
<td>Wing_Span</td>
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<td>15.0</td>
<td>16.0</td>
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<tr>
<td>inflow_speed</td>
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<td></td>
<td></td>
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<tr>
<td>Lquarterchord</td>
<td>Input</td>
<td>Synthetic</td>
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<td></td>
<td></td>
<td>1.0</td>
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<tr>
<td>Lswoth</td>
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<td>Synthetic</td>
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<td></td>
<td></td>
<td>6.49519052838</td>
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<td>Lift</td>
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<tr>
<td>Smax</td>
<td>Output</td>
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<td></td>
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<tr>
<td>Wing_Volume</td>
<td>Output</td>
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<tr>
<td>Drag</td>
<td>Output</td>
<td>None</td>
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<td></td>
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<tr>
<td>Dmax</td>
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<td>None</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Result

Pareto frontier:

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

- 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 (Maximum deformation) s.t.

\[ \sigma_v \leq 60,000 \ Pa \]

\[ 0.15 \ m \leq \text{Height} \leq 0.25 \ m \]

\[ 0.004 \ m \leq \text{Thickness} \leq 0.012 \ m \]
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, $\sigma_v = 60,300$Pa

ANSYS Validation

- At the optimum: MaxDef = 5.13mm, $\sigma_v = 93,261$Pa
Response Surface Approximated Optimization

Approach

- Using the previous 20 design points
- Optimization $\rightarrow$ validate result $\rightarrow$ update RMS $\rightarrow$ re-optimization
- 6 design points are added and the computational time is $\sim$48 min

Result

- Optimum: $\text{MaxDef} = 12.058 \text{ mm, } \sigma_v = 61,470 \text{ Pa}$
- $\text{MaxDef} = 12.15 \text{ mm, } \sigma_v = 61,460 \text{ Pa}$ (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!