Fan System Design and Performances Prediction Through Optimization Process

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Vedat Adat – Metacomptech
1 – Industrial background
Industrial background

- Fan system product lines and thermal components
  - Components intended for mass production
  - High pressure for reducing the cost of these products
Technical constraints for fan system

- More and more constraint of packaging in the underhood
  - The downstream flow of the fan is affected by the aerodynamic blockage created by mechanical components (motor, gear-box, …)
  - The fan is no longer working as a standard axial turbomachinery

- Need to improve development methods
  - Standard theory for axial machine not fully valid for such flow
  - For energy efficiency, the fan must provide optimum performances
2 – Objectives
New type of specifications for fan system

- Fluid simulation intended to improve fan systems
  - Simulation can take into account complex environments
  - Realistic configuration compared to real usage of the fan in the under hood

Black-plate configuration: 120 mm Hx to plate

Specifications

Domaine of simulation

INLET (flow rate)

N=2400 Rpm

Back-plate

OUTLET (pressure)

Only one blade passage meshed (1/7)
Build a methodology to conduct complex development

- Combine optimization method with aerodynamic fan simulation
  - Build the methodology on the base of the know-how of experts
  - Link the CFD tool CFD++ (Metacomptech) with Hyperworks platform (Altair)
  - Provide solutions for best performances with a high level of confidence

- Experiment and test the method to be implemented with high power computing
  - Demonstrate the benefit of big computing capacities (Expamtion Project)
  - Save time and resources to go further in our research (acoustic for instance with CAA++...)

![Cartoon of a person working at a computer]
3 – Methods
The different steps

- **Sensitivity analysis**
  - Several parameters are chosen on the base of the know-how of experts
  - A first DOE is conducted with coarse meshes
  - Results analysis help ranking parameters and determine cross-correlation between them

- **Optimization conducted with a reduce set of parameters**
  - Most influential parameters are selected to drive the optimization with fine meshes
  - The objective is to minimise the torque
  - Two constraints are established:
    - Pressure rise > 210 Pa at nominal point (QN)
    - Pressure rise > 0 at high flow rate (QH)

- **Optimization conducted with a full set of parameters (to be continued)**
  - Demonstrate the ability of using highly parallelised computing to reduce development time
  - Evaluate the cost and benefit of running the full set of parameter compared to the reduce one
Parameters

- **Chosen Parameters to describe a complex blade surface**
  - 4 selected radius to obtain the effect of the twist: bottom, mid span, 80% of the span, top
  - For each radius, chord can be move from 80% to 120%
  - For each radius, camber can be modified from 100% to 20%
  - For each radius, stagger can be changed by +/- 4°

  - A total of 12 independent parameters
  - 2 different flow rates (the nominal one and a high flow rate)
  - Initial geometry based on a existing one

  - Blade thickness distribution kept constant
  - Sweep variation not studied

**Variations can be considered as small**

→ **Local optimization in the field of solutions**
Process

HyperStudy
Optimization Algorithm

Templex
Update Shape values

HyperMesh (batch mode)
Generate the morphed mesh

HyperMesh (batch mode)
Export the CFD++ model

CFD++
Run the 2 simulations

CFD++ / HyperStudy
Extract the 3 responses
Mesh morphing

- **Process to deform the mesh (full hexa meshing)**
  - The blade surface mesh is deformed by the help of handles
  - The mesh around the blade aimed to catch the boundary flow is morphed according to the new shape (O-grid topology)
  - The external domain is reconstructed to kept constant dimensions although the package of the fan has changed
  - Automated re-meshing between the O-grid and the external limits of the domain
Mesh morphing

- Handles control the morphing
  - Handles placed according to the description of a aerodynamic profile: leading edge, trailing edge, mid chord
  - Handles are located at for different radius (bottom, mid-span, ¾ span and top)

General view of the blade with 4 chosen radius

Locations of handles:
Red = master (can be move independently)
Yellow = slave
Mesh morphing

- Chord variation
Mesh morphing

- Stagger angle variation
Mesh morphing

- Camber variation
Mesh morphing

- Maximum envelope
Mesh morphing

- Some variations

Objective: give a maximum of freedom to the shape
Fan simulation (CFD++)

Mesh size: 616 500 nodes / 585 000 cells
(Inlet: 92 500 cells / Fan: 398 000 cells / Outlet: 94 000 cells)
4 – DOE and sensitivities
First set of simulations

- NOLH designs (*Nearly Orthogonal Latin Hypercube*)
- 65 designs
- Each parameter has only one time the same value
- Theoretically, the distances between each design are maximized

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**Second set of simulations**

- Extreme values + Hammersley run
- 116 designs
- Fitted for design of experiment

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Result Analysis

- **Correlation**
  - 65 designs (NOLH) + 116 designs (Hammersley)
  - Low correlations between parameters: all are useful (green area)
  - High correlation between objectives: non independent (blue area)
Result Analysis

- Global sensitivities
  - All parameters count, with different loads
  - Stagger is the main parameter
  - Chord 14 (80% span) is the most important location

- Reduce set of parameters (8)
  - Parameters at bottom can be rejected at first (chord, stagger, camber)
  - Camber at mid span is also rejected
4 – Optimization
Optimisation with Adaptative Surface Response Method (ARSM)

- Parameters at bottom and camber at mid span are disabled

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- Minimize the torque (in absolute value)

Define objective

Goal: Maximize

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- 2 constraints on the pressure rise

Define constraints

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<tr>
<td>✓</td>
<td>c_1</td>
<td>Deterministic</td>
<td>delta_p_rpm2300</td>
<td>&gt;=</td>
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<td>SOLVER</td>
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<td>SOLVER</td>
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<td></td>
</tr>
</tbody>
</table>
Optimisation with Adaptative Surface Response Method (ARSM)

- Objectives and constraints are approximated with a second order polynomial
- The polynomial coefficient are determined using a square fit on previous design points
- Stop when converged below a certain level of error from one iteration to the other
Convergence of the process

- Great improvement on the objective (+6.5%)
- Constraint are still met
- not so much iterations

<table>
<thead>
<tr>
<th>Pressure rise</th>
<th>Torque</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Run</td>
<td>221.45 Pa</td>
<td>1.0416 N.m</td>
</tr>
<tr>
<td>Optimized shape</td>
<td>218.65 Pa</td>
<td>0.9184 N.m</td>
</tr>
</tbody>
</table>
Result: pressure distribution on the optimized blade

- The fan blade is not highly loaded at the top, probably a consequence of the objective of reducing the torque (pressure momentum increases with radius)
- Low load at tip may improve the acoustic
Result: radial distribution on the optimized blade

- The optimization went naturally to a radially equilibrated fan (concentrically flow pattern on the blade), which is in theory the optimum.
- Less good at bottom, where parameters were disabled for the reduced set.
5 – Aeroacoustic
Aeroacoustic: module simulation (CFD++ / CAA++)

Aeroacoustic capabilities provided by the simulation:

- A complete mesh of the module (rotor-stator interaction) is built to predict pressure fluctuation on surfaces.

- Regular mesh required for propagation.
Aeroacoustic: sound propagation and directivities

- Tonal noise is predicted from pressure post-processing
- Domain of propagation allows studies on directivities
- Provide data to understand noise mechanism and related geometrical effects
6 – Conclusions
Conclusions: results

- **Fan systems optimisation**
  - Main parameters were chosen by expert in charge of fan system development
  - Analysis of sensitivity was conducted to check the relevancy of these parameters
  - A reduce set of parameters was used to perform a optimisation

- **Optimization results**
  - A complete loop of optimization has been established on Hyperworks platform linked to CFD++ to evaluate the fan performance
  - Despite the initial run started from a blade considered as good, a great improvement (+6.5%) on efficiency was obtained in few iterations

- **Gain on the methodology**
  - The development time can be reduced from one month with the “standard human process” to less than one week with a reduced set of parameters
  - High power computing can even improve the process to 2 days of simulation with the complete set of 12 parameters (estimated time, work on progress)
Conclusions: the role of an optimization process

- Standard design process is more complicated regarding new specifications
  - Some risks exist with classical methods: no solution found in the timeframe or below the optimum

- Optimization process should secure the situation
  - Establish the methodology helps capture the current know-how and the expertise
  - Several preferred solutions can be evaluated by accurate numerical simulations

- Need to concentrate our human resources on system analysis
  - Less human time on fan development
  - Going further in our research (acoustic, module, under hood...)

Product design must be automated by the help of optimization process
R&D efforts must be focused on innovation