Numerical Investigations on the Performance Characteristic of Radial Fans with Forward Curved Blades by means of CFD

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STAR European Conference 2011

March 22-23
Agenda

- Sirocco fan Introduction
  - Applications
  - Advantages/Disadvantages
  - Characteristic curves
- Model parameters / Modeling physics
- CFD Simulations outline
- Rotation modeling
- Overview of the generated mesh configurations
- Results
  - Characteristic curves: CFD vs. Experiment
  - Simulation time
  - Steady vs. Unsteady simulations
- Conclusions
Commonly used blade shapes in Radial fans
(with their maximum attainable efficiencies)

Key factors for fan type selection:
- Pressure
- Flow rate
- Efficiency
- Noise generation
- Space constraints
- Drive configuration
- Cost
- ...

Forward curved blades (65%)
Radial-Tip blades (70%)
Radial blades (60%)
Backward inclined Airfoil blades (92%)
Backward inclined blades (78%)
Backward curved blades (85%)
Sirocco fan specifications

◊ Large blade angles
◊ Small size relative to other fan types
◊ Operation at low speeds → low level of noise
  ➢ Flow separation between the blades
  ➢ Low efficiency
  ➢ Scroll housing is required

Applications:
  – Automotive industry
  – HVAC applications
Sirocco Fan Performance Curve

- Best Efficiency Point (BEP)
- Region of Instability
- Throttle Range
- Overload Range

Increasing Pressure vs. Increasing Flow Rate
**Model Parameters**

- Fan wheel outer diameter (D2) : 200 mm
- Inner/Outer diameter (D1/D2) : 0.8
- Number of blades : 38
- Rotor width : 82 mm
- Scroll housing width: 87 mm
- Volute opening angle (α) : 7°

**Modeling Physics**

- Ideal gas
- Segregated flow
- Mass Inlet / Pressure outlet
- Rotational speed: 1000 rpm
- Steady-State Moving Reference Frame (MRF)
- Rotor Positions: 0°, 3°, 6°
CFD Simulations outline

- Turbulence models
  - Realizable k-ε
  - SST k-ω
  - Spalart-Allmaras

- Mesh Configuration
  - Polyhedral
  - Trimmer
  - Polyhedral-Trimmer
  - Structured grid

- Steady-state
  - (Moving Reference Frame)

- Unsteady
  - (Rigid Body Motion)
Rotation of computational domains

- **Rigid Body Motion (RBM):**
  - Implicit unsteady
  - Position of the cell vertices: Moving
  - Instantaneous local flow behavior → Time accurate solution
  - Time consuming
  - Powerful computer is needed
Rotation of computational domains

- **Moving Reference Frame (MRF):**
  - Frozen Rotor (in some literatures)
  - Steady-state
  - Position of the cell vertices: Fixed
  - Constant grid flux generation → conservation equations
  - Approximate analysis of Motion (Time-averaged solution)
  - Time efficient
## Mesh configurations

<table>
<thead>
<tr>
<th></th>
<th>Polyhedral</th>
<th>Trimmer</th>
<th>Polyhedral-Trimmer</th>
<th>Structured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mesh generator</strong></td>
<td></td>
<td>Star-CCM+</td>
<td></td>
<td>ANSYS ICEM</td>
</tr>
<tr>
<td><strong>Number of Cells</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(in millions)</td>
<td>Total</td>
<td>4.2</td>
<td>6.1</td>
<td>4.0</td>
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<tr>
<td></td>
<td>Rotor</td>
<td>2.6</td>
<td>4.8</td>
<td>2.7</td>
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<tr>
<td></td>
<td>Stator</td>
<td>1.6</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Interface Mesh</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conformal</td>
<td></td>
<td>Non-conformal</td>
<td>Non-conformal</td>
</tr>
<tr>
<td><strong>Mesh generation time</strong></td>
<td></td>
<td></td>
<td><strong>2-4 hours</strong></td>
<td><strong>5-7 days</strong></td>
</tr>
</tbody>
</table>

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Conformal Interface

Non-Conformal Interface
Mesh configurations comparison
Mesh configurations comparison

\[ \eta_{st} = \frac{\Delta p \times \dot{V}}{T \times \omega} \]

Workstation:
CPU: Intel Core i7 (2.8 GHz)
RAM: 8 GB
Turbulence models comparison
Turbulence models comparison

\[ \eta_{st} = \frac{\Delta p \times \dot{V}}{T \times \omega} \]

**Workstation:**
- CPU: Intel Core i7 (2.8 GHz)
- RAM: 8 GB
Flow separation in the Nozzle at lower flow rates

Non-uniform inlet flow:
» Dominant flow field generated by Rotor
» Flow attachment to one side & separation from the other side
Steady vs. unsteady simulation at 675 m³/h (Overload range)

<table>
<thead>
<tr>
<th></th>
<th>Static Pressure in Pa</th>
<th>Torque in Nm</th>
<th>Efficiency in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp.</td>
<td>115.8</td>
<td>0.500</td>
<td>41.5</td>
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<tr>
<td>MRF</td>
<td>112.6</td>
<td>0.460</td>
<td>43.9</td>
</tr>
<tr>
<td>RBM</td>
<td>114.5</td>
<td>0.470</td>
<td>43.7</td>
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</tbody>
</table>
Steady vs. unsteady simulation at 145 m³/h (Throttle range)

<table>
<thead>
<tr>
<th></th>
<th>Static Pressure in Pa</th>
<th>Torque in Nm</th>
<th>Efficiency in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp.</td>
<td>115</td>
<td>0.100</td>
<td>44</td>
</tr>
<tr>
<td>MRF</td>
<td>126</td>
<td>0.101</td>
<td>48</td>
</tr>
<tr>
<td>RBM</td>
<td>118</td>
<td>0.099</td>
<td>46</td>
</tr>
</tbody>
</table>
Conclusions

- Unstructured mesh configurations can be used effectively for simulating sirocco fans.
- The best results are achieved by using polyhedral cells.
- The best balance between the simulation time and accuracy is achieved by using Polyhedral cells as well.
- Trimmer (as a single mesher) is not suitable for sirocco fan simulation.
- \( SST \ k-\omega \) turbulence model is the most suitable model for simulating sirocco fans.
- At intermediate and higher flow rates, steady-state \( MRF \) approach provides the same level of accuracy as unsteady \( RBM \) approach.
- At lower flow rates, flow becomes highly unsteady, and the flow condition is not suited to steady-state \( MRF \) approach.
Thank you for your attention!