Numerical simulation of the flow field in the vicinity of an axial flow fan

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Can the flow field in the vicinity of an axial fan be modeled, using a RANS/U-RANS approach?

If we can, how does it look?

(especially at low flow rates)
Question

Why?

- Impress people with colorful CFD pictures…
- RANS is computationally cheap
- If successful: Advantages for development of simplified fan models
- Implementation: Modeling of large scale fan systems (ACHEs)
Introduction: ACHEs
Introduction: Present study

- Numerical modelling of flow for a range of flow rates
- Test subject: 8 bladed, ACHE fan (B2a-fan)
Numerical: Computational technique

- 1/8th sector modeled (assume rotational symmetry)
- Solving: ANSYS Fluent 14
- Realizable $k-\varepsilon$ model with Standard wall function
- Steady simulations for $\varphi > 0.137$ (13 m$^3$/s)
  
  \[ \varphi_D = 0.168 \text{ (16 m}^3\text{/s)} \]
- Unsteady simulations for $\varphi < 0.137$
Numerical: Computational domain
Numerical: Results verification

\[ \varphi_{D} = 0.168 \]

\[ \varphi = 0.042 \]

\[ R_{\Psi_{FS}} = 0.996 \]

\[ R_{\eta_{FS}} = 0.966 \]

**British Standard 848, Type A**

B2a fan, 8 bladed

- \( d_f = 1542 \text{ mm} \)
- \( t_{cf} = 31 \text{ mm} \)
- \( \rho_a = 1.2 \text{ kg/m}^3 \)
- \( N_F = 750 \text{ rpm} \)
Results: $\varphi_D = 0.168$ (16 m$^3$/s)
Results: $\varphi_D = 0.168$ (16 m$^3$/s)
Results: $\varphi = 0.042 \ (4 \text{ m}^3/\text{s})$
Results: \( \varphi = 0.042 \ (4 \text{ m}^3/\text{s}) \)
Results: Lift/Drag coefficients

![Graph showing Lift coefficient, $C_l$, vs Flow coefficient, $\Phi$, for different $S_{dim}$ values.](image)

Blade section

$S_{dim}$
Results: Lift/Drag coefficients

NASA LS 413, Re = 2.2(10)^6

Lift coefficient, Cₗ

Drag coefficient, C₀

Angle of attack, α, °
Conclusions

Can the flow field in the vicinity of an axial fan be modeled, using a RANS/U-RANS approach?

Depends…

“Everything should be made as simple as possible, but not simpler” - Albert Einstein
Conclusions

Yes

- Comparison between experimental and numerical results are fair with $R_{\psi_{FS}}^2 = 0.996$ and $R_{\eta_{FS}}^2 = 0.966$.
- Practical engineering estimation
- Further development of simplified fan model
  But also, no…
- No solution for $\varphi < 0.042$ (maybe due to symmetry assumption)
- Scientific view: Some flow phenomena are ‘missed’ due to RA approach
Thank you

- Supervisors/Other personnel
- Late Prof. D.G. Kröger

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- Department of M&M Engineering, Dr. vd Spuy (Eskom, GEA)
- National Research Foundation (NRF)
- Solar thermal energy research group (STERG)
ACHEs
Low flow problem
### Numerical: Computational technique

#### Solver settings:

<table>
<thead>
<tr>
<th>Setting</th>
<th>Steady state simulations</th>
<th>Transient simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discretization scheme (Gradient)</td>
<td>Least squares cell based</td>
<td>Least squares cell based</td>
</tr>
<tr>
<td>Discretization scheme (Pressure)</td>
<td>PRESTO!</td>
<td>PRESTO!</td>
</tr>
<tr>
<td>Discretization scheme (Other)</td>
<td>QUICK</td>
<td>QUICK</td>
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<tr>
<td>Pressure-velocity coupling</td>
<td>SIMPLE</td>
<td>PISO</td>
</tr>
<tr>
<td>Convergence</td>
<td>$10^{-5}$</td>
<td>$10^{-3}$</td>
</tr>
</tbody>
</table>
Numerical: Computational domain

- Combination of three domains: *Inlet, Rotor and Outlet*
- Grid size: $2.5(10)^6$ cells ($y^+ > 30$)
Numerical: Boundary proximity analyses
Numerical: Time step independence analyses

<table>
<thead>
<tr>
<th>φ</th>
<th>$\Delta t, (10)^{-3}s$</th>
<th>$\psi_{Fs}$</th>
<th>$\eta_{Fs}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.168</td>
<td>0.5</td>
<td>No result</td>
<td>No result</td>
</tr>
<tr>
<td>0.2</td>
<td>0.084</td>
<td>0.617</td>
<td></td>
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<tr>
<td>0.1</td>
<td>0.084</td>
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<tr>
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<td>0.618</td>
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<tr>
<td>0.025</td>
<td>0.084</td>
<td>0.618</td>
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<tr>
<td>0.042</td>
<td>0.2</td>
<td>No result</td>
<td>No result</td>
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<tr>
<td>0.1</td>
<td>0.174</td>
<td>0.313</td>
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<tr>
<td>0.05</td>
<td>0.173</td>
<td>0.313</td>
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<tr>
<td>0.025</td>
<td>0.174</td>
<td>0.314</td>
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</tbody>
</table>
Numerical: Grid independence

- Conducted at $\varphi_D = 0.168$
- Rotor domain axial length: $z_r = 0.1d_c$
- Convergence obtained between $1(10)^6$ and $2(10)^6$ cells

<table>
<thead>
<tr>
<th>Cell count</th>
<th>Fan static pressure coefficient, $\psi_{Fs}$</th>
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<tbody>
<tr>
<td>240$(10)^3$</td>
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<tr>
<td>500$(10)^3$</td>
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<td>990$(10)^3$</td>
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<tr>
<td>2000$(10)^3$</td>
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<table>
<thead>
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<th>$\varphi$</th>
<th>Cell count</th>
<th>$\psi_{Fs}$</th>
<th>$\eta_{Fs}$</th>
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<tbody>
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<td>0.168</td>
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<td>0.627</td>
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<td>5.5$(10)^6$</td>
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<td>0.617</td>
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<tr>
<td>0.042</td>
<td>2.5$(10)^6$</td>
<td>0.174</td>
<td>0.313</td>
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<tr>
<td></td>
<td>5.5$(10)^6$</td>
<td>0.175</td>
<td>0.307</td>
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</table>
Numerical: Convergence

\[ \varphi_D = 0.168 \]

\[ \varphi = 0.042 \]
Results: $\varphi_D = 0.168 (16 \text{ m}^3/\text{s})$
Results: $\varphi = 0.042$ (4 m$^3$/s)