Transient Radial Blower Simulation as Part of the Development Process

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Outline

- Behr GmbH & Co. KG
  - The company
  - Simulation @ Behr

- Motivation for transient blower simulation

- Method development and Validation

- Integration in development process -> transient blower simulation as part of the automated HVAC workflow

- Summary + Outlook
Behr – Systems Partner for Thermal Management

Founded in 1905 by Julius Friedrich Behr
Behr – a global company
We are where cars are built

Mexico
USA
Brazil

Russia

China
Korea
Japan

Germany
Czech Republic

Spain
France

Slovakia

South Africa

USA: Dayton, Troy/Detroit, Charleston, Fort Worth
Mexico: Saltillo
Brazil

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3D Simulation @ Behr
More than 20 years of product development supported by simulation (CFD + FEA)

Central department for Simulation Method development:
- New simulation methods + standardization
- Guidelines, documentation, training, user support
- Standardization of software + hardware
- Engineering service

USA
Brazil
Germany
France
Rouffach
Stuttgart
China
India
Shanghai
Pune
Troy/Detroit
Jundiai

TDR4 Dr. Kühnel March 2013, Behr_Blower.pptx
Air-Conditioning
Structure of a HVAC unit
Motivation 1/2

- Standard HVAC analysis -> concept improvements with regard to:
  - Pressure drop
  - Flow distribution
  - Temperature control curve

\[ \text{Automated workflow in steady state} \]
\[ \text{(presented at STAR European Conference 2011)} \]
Motivation 2/2

- Steady-state simulation is insufficient for:
  - Radial blower development => development traditionally by experimental means:
    - Measurement of integral values (flow rate, pressure, air velocities…)
    - Flow visualization
    - High sophisticated flow measurements: PIV, LDA, hot-wire
  - Air flow analysis in suction ducts
  - Air flow analysis in blower diffuser or in the vicinity of the blower
  - Aero-acoustics

- Increasing time pressure for the improvement of products i.e. radial blower
  - Experimental investigations are time-consuming and do not allow a comprehensive flow analysis
  - Optical measurement techniques require transparent housings => not possible everywhere on real HVAC units (as they are “black boxes”).
Objectives for development of blower simulation method

- Capture and show all physical phenomena like:
  - time dependency
  - flow fluctuations
  - vorticity

- Quantitative prediction of integral values like pressure increase, mass flow rate
  => good quantitative prediction of blower characteristics

- Applicable within an industrial development process
  - easy set-up of the model and running the simulation
  - acceptable computational times
  - Automation of post-processing

- Mainly used by blower development in advanced engineering
Pre-studies
Mesh, turbulence …

- **Mesh study**
  - 3 levels of refinement
  - Level 2 (6,4 mio cells) shows good compromise of mesh size and accuracy
    -> selected for analysis of turbulence models

- **Turbulence study**
  - CFD results were compared with PIV measurements
Pre-studies

Turbulence studies

120° section

PIV: 1.558 e-1 kg/s

Mesh level 2, k-ε realizable, all y+ 1.264e-1kg/s @ 3290 rpm

Mesh level 2, DES k-ω SST 1.55e-1kg/s @ 3290 rpm

- k-ε realizable model underestimates mass flow => 0,126 kg/s vs. 0,1558 kg/s in test
- Good correlation of mass flow with DES k-ω SST => 0,155 kg/s vs. 0,1558 kg/s in test
- Instantaneous flow field distribution in CFD does not match to PIV flow field => PIV integrates over a certain time frame
Pre-studies
Turbulence studies

300° section

Mesh level 2, DES k-ω SST

PIV

Mesh level 2, DES k-ω SST

For comparison of CFD with PIV mean velocity over at least one rotation has to be considered
=> good correlation with PIV
Pre-studies
Turbulence studies

- Further improvement in correlation to PIV showed simulation with mesh level 3 (11,4 mio cells) and DES k-ω SST

![PIV Mesh level 2, DES k-ω SST](image1)

![Mesh level 3, DES k-ω SST](image2)

Mean velocity at 5th rotation (without rotating region)
The Simulation Methodology
3-Step Method

Run transient MRF
Purpose: Get an initial flow field in the entire domain since the simulation starts without any flow in the domain.
• The impeller is not moving at this stage
• Runs with large $\Delta t$
• The resulting flow field is quasi-steady due to large $\Delta t$

Initialize the Flow with RBM
Purpose: Allow real turbulence fluctuations to develop.
• Run for a fixed number of rotations with constant $\Delta t$

Average the Flow Field with RBM
Purpose: Record mean and rms flow quantities.
• Average over $x$ rotations with constant $\Delta t$
• The simulation is automatically stopped by an adaptive stopping criteria

► A fixed number of rotations in step 3 is not feasible for all cases!
► An adaptive stopping criteria was developed which delivers consistent results (independent of the user)
Validation of the Methodology

Flow Field

Blower Curve

PIV

Very good correlation in blower characteristic!
Automated workflow
Transient blower simulation as part of HVAC workflow

- The transient blower workflow is fully integrated and consistent with the HVAC Wizard which controls the automated workflow. (presented at *STAR European Conference 2011*)
- Several Java macros are provided to run the simulation
Automated post-processing
Standard MS PowerPoint Report Generation

- An automated PowerPoint report can be created with:
  - General information (geometry views, boundary conditions…)
  - Convergence information (and warnings, if popped-up)
  - Various visualization … as selected => (pressure along paths, surface plots, streamlines, FFT…)

Customize post-processing

- Basic Post-Processing (always required)
- One rotation averaging functions
- Velocity magnitude scenes of components
- Isometric velocity scenes
- Impeller planes, cylinders and scenes (incl. unwrap)
- Additional planes and scenes every 10°
- Streamlines
- Wall shear stress graphs (LUM)
- Point FFTs: Number of points: 10
- TKE reports
- Fieldview export
- Solution history
- Paths lines
- Mapping from Rotating --> Non-Rotating

Select all  Deselect all  Create
Post-processing within development process
Using CFD by non-CFD blower expert

- Transient blower simulation is used today in:
  - Advanced engineering – development of new blower
  - Product development – application of blower in HVAC systems

- Blower development is supported with CFD-simulations performed by CFD experts.

- Standard PowerPoint report is fine

  .... but sometimes not enough:

=> Advanced result analysis by export of results to

![ParaView](image)

- Blower developer go deeper into the CFD results by using ParaView to improve the design of blower and HVAC parts.
Examples
Blower development

- **Impeller design**
  - Blade shapes
  - Shroud design
  - Volute design
  - ....

- **Blower motor cooling**
  - Design of bypass duct for cooling air
  - Positioning of bypass duct
  - ....
Examples
Air flow distribution and diffuser flow field

Steady-state

Transient

Big Differences

=> In the vicinity of the blower only transient simulations show physical results!
Summary

- Simulation method for the transient analysis of radial blower was developed

- The method enables:
  - accurate and reliable prediction of the local and instantaneous flow field (vortices, flow separation, recirculation …)
  - accurate prediction of the mean flow field and pressure characteristic, such as, efficiency
  - evaluation of geometrical influences of the volute, impeller, air intake and diffuser
  - parameter and optimization studies
  - realistic boundary conditions for diffuser optimization

- The transient blower method is integrated into a highly automated simulation workflow for HVAC simulation which enables a very efficient analysis of HVAC systems.
Outlook

- Further speed-up is needed:
  => possible when parallelization in STAR-CCM+ for rotating parts in transient is improved. Actually as a maximum 64 cores is reasonable.

- Research project for aero-acoustic simulation of real HVAC geometries in cooperation with several industrial and academic partners started. The project is managed by:

  Virtual Vehicle Competence Center (ViF), Graz, Austria
Thank you for your attention!