Competence Center for Gas Exchange

CCGEx

"Charging for the future"

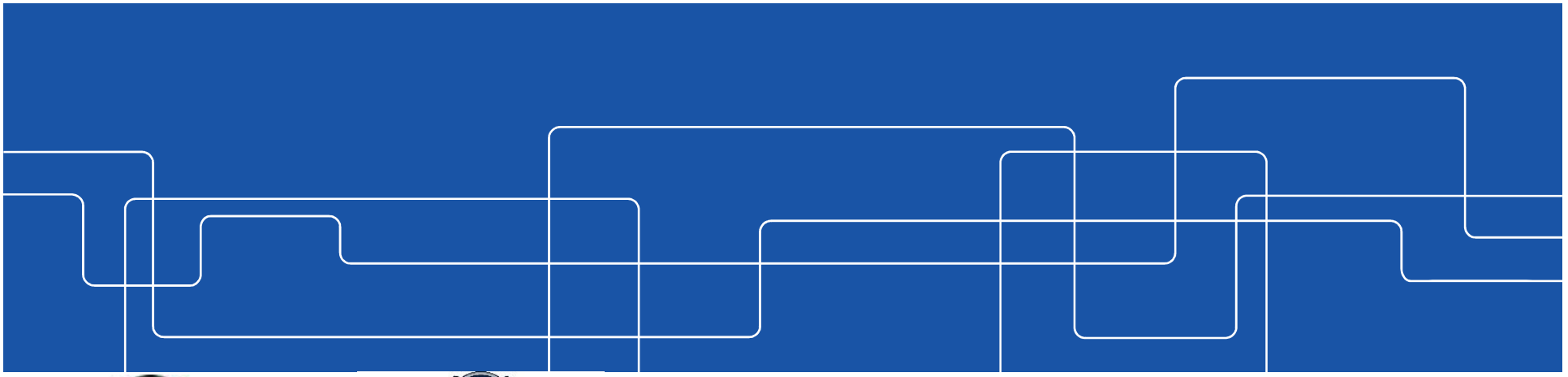
Energimyndigheten SCANIA VOLVO VOLVO BorgWarner

KTH ROYAL INSTITUTE
OF TECHNOLOGY

Analysis of flow features in centrifugal compressors

Elias Sundström

Supervisors: Mihai Mihaescu, Laszlo Fuchs



Overall Aims

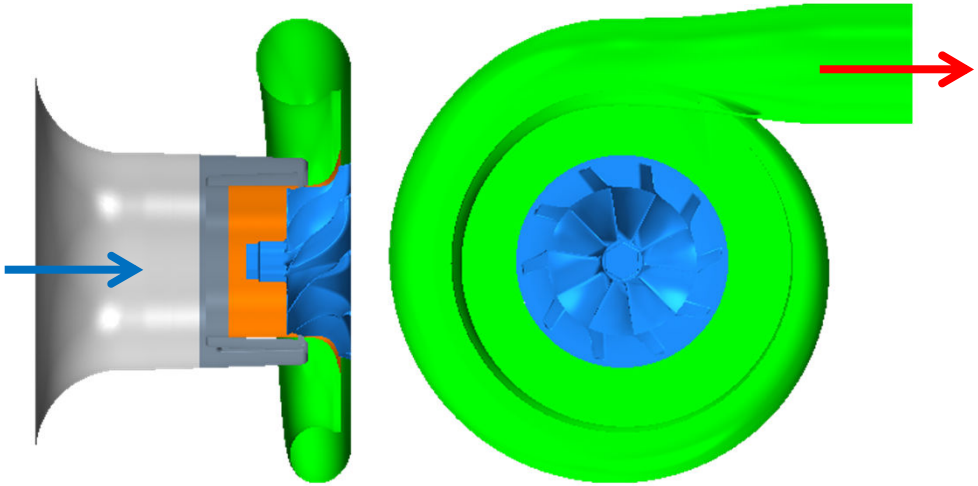
High-fidelity calculations

- Understand compressor behaviour at low mass flow rates
- Characterize flow instabilities near the stall point

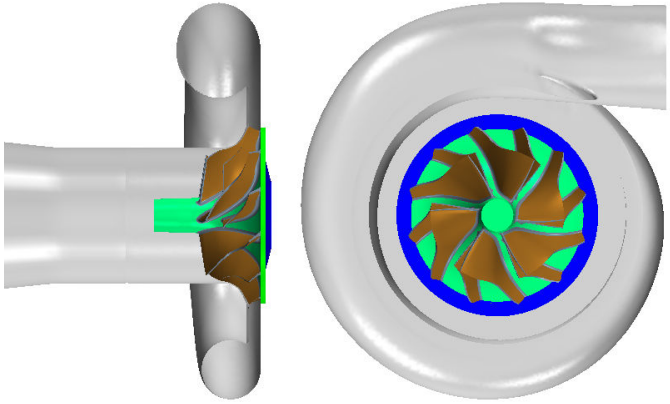
Steady-state 3D RANS & 0D/1D modelling

- Investigate validity ranges for RANS & 0D/1D models

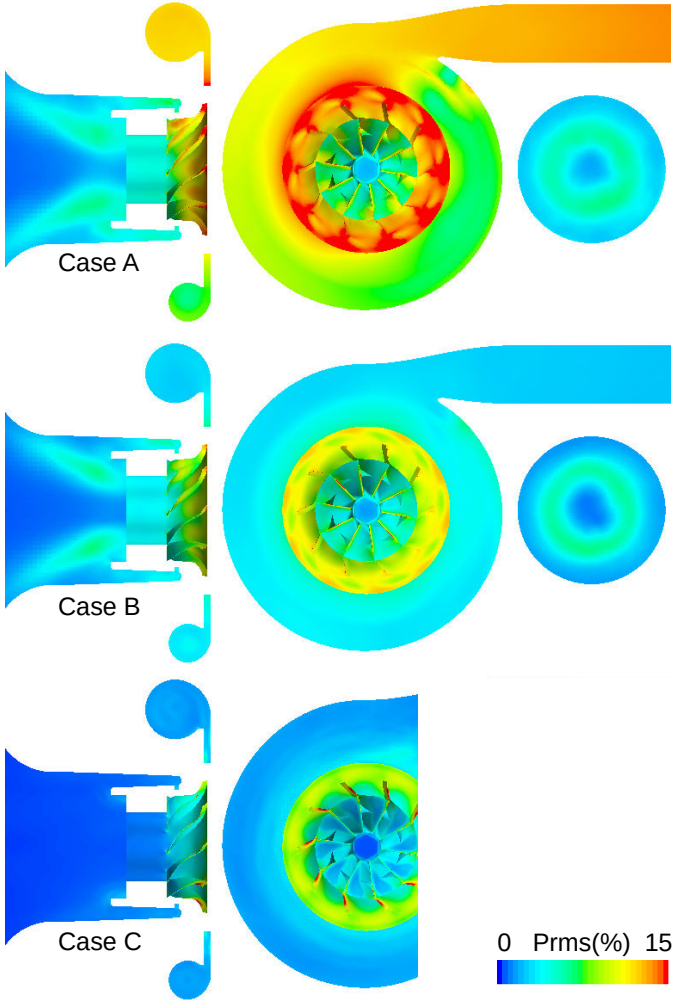
Medium size HDV (Honeywell)

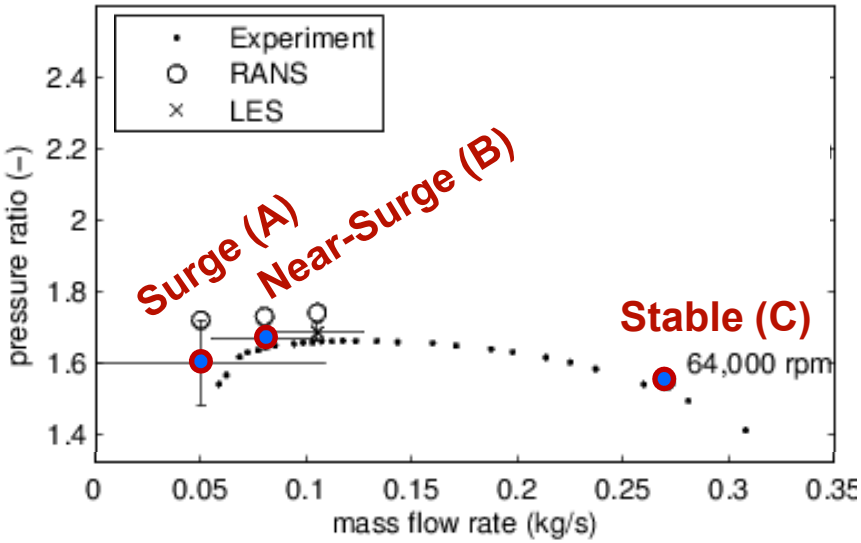


Smaller size LDV (MP, BorgWarner)



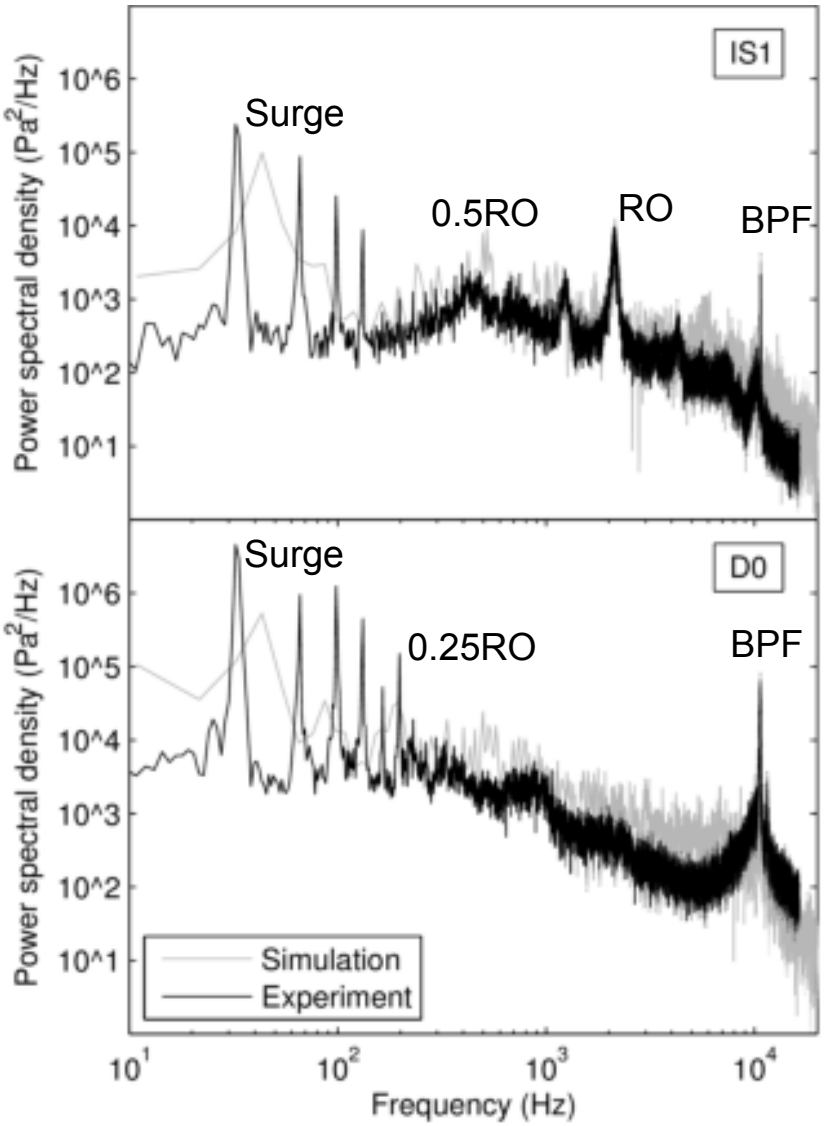
Pressure fluctuation intensity (LES data)

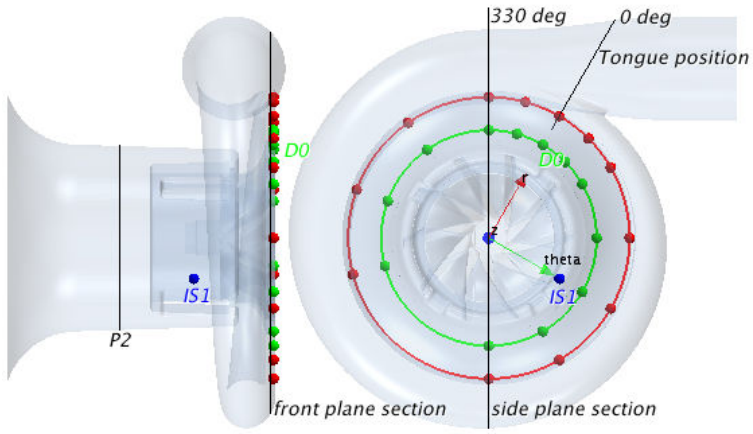




$$\frac{<p'^2>^{1/2}}{\frac{1}{2}\rho_{ref}u_{redC}^2} \cdot 100$$

Single point Fourier Spectra @ surge



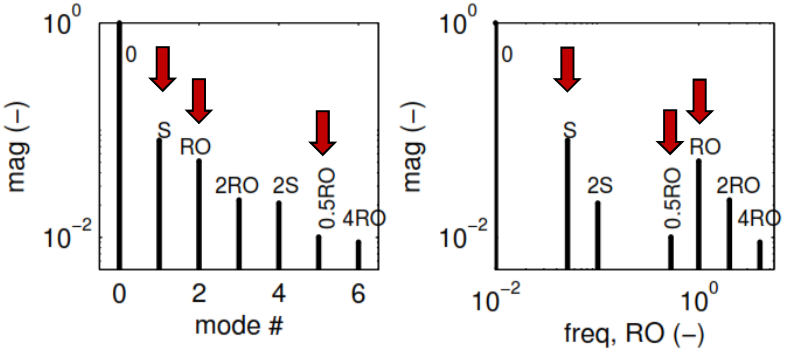


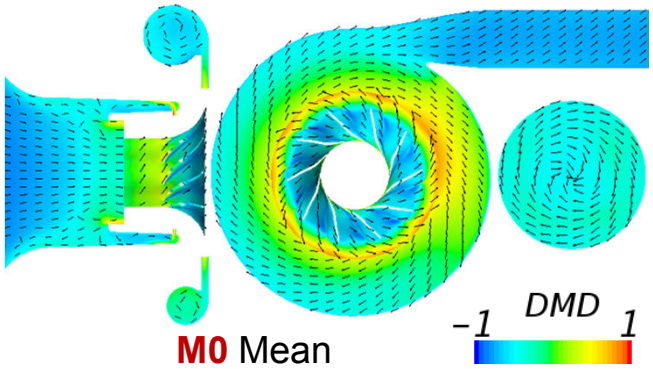
- Tonality at 43 Hz, 1st surge cycle harmonic, blade passing frequency and rotating order
- Broadband: mid-frequency range
- Narrowband: 250~600 Hz (peak at 0.5 RO)
- RO - rotating order of the shaft
- BPF - blade passing frequency

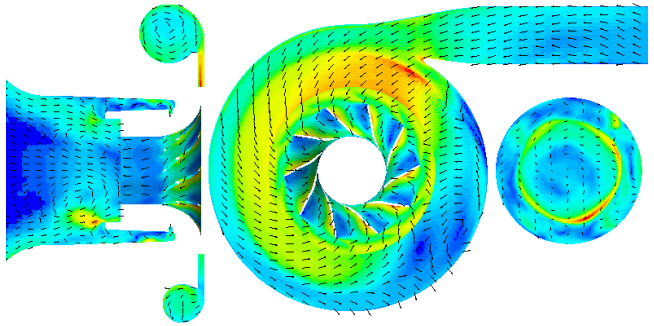
Sundström E., Semlitsch B., & Mihaescu M.
SAE2014-01-2856

Flow modes @ off-design / surge condition

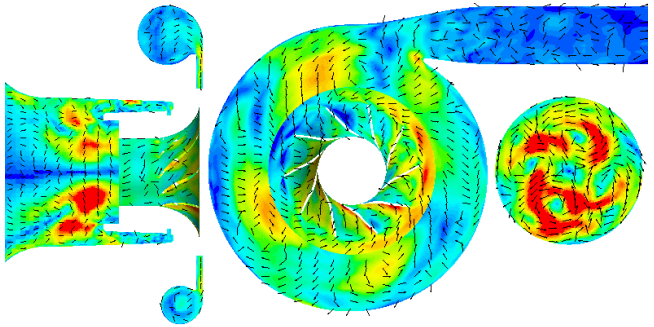
- Quantification of flow instabilities observed
- Dynamic Mode Decomposition at surge (velocity) based on LES data



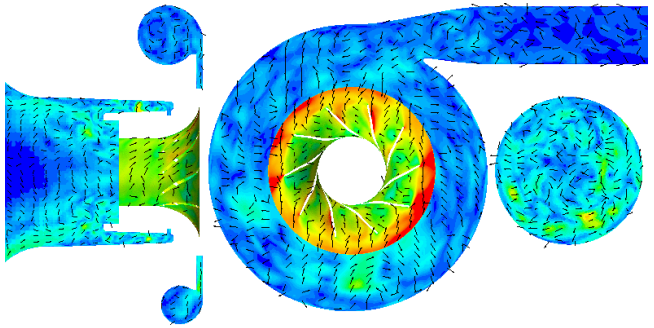




Surge (43 Hz, pulsating)



0.5RO (rotating stall in the diffuser)



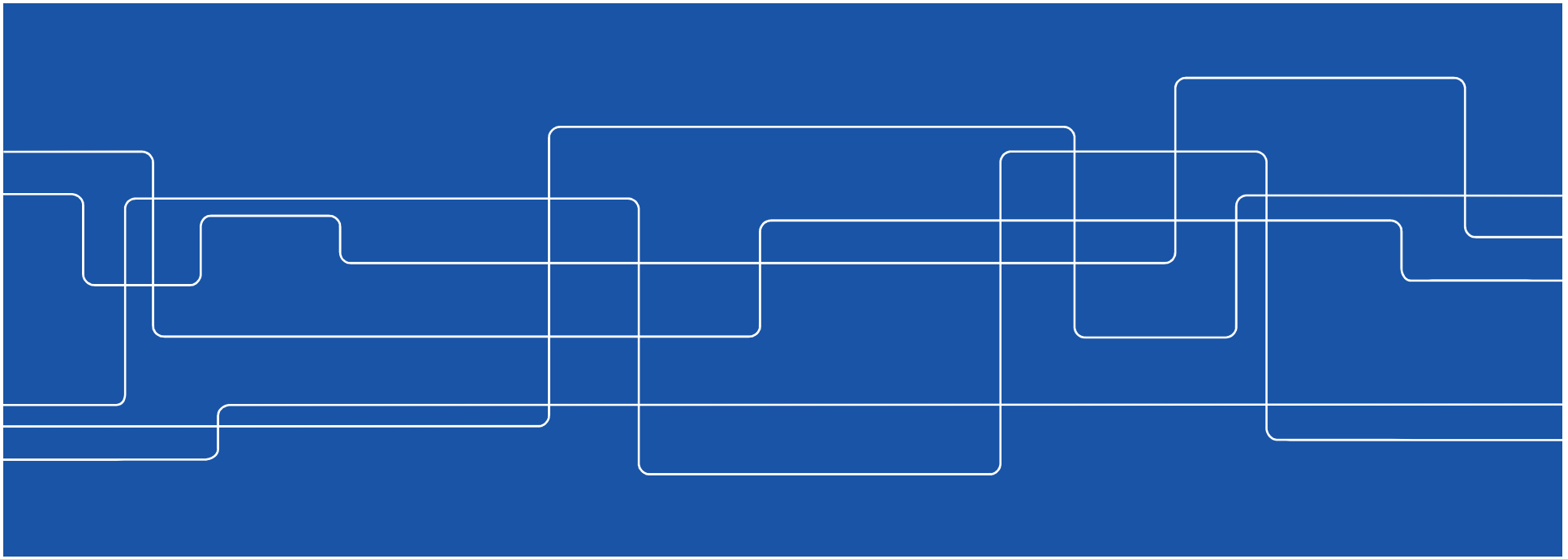
RO (spinning mode)

Summary

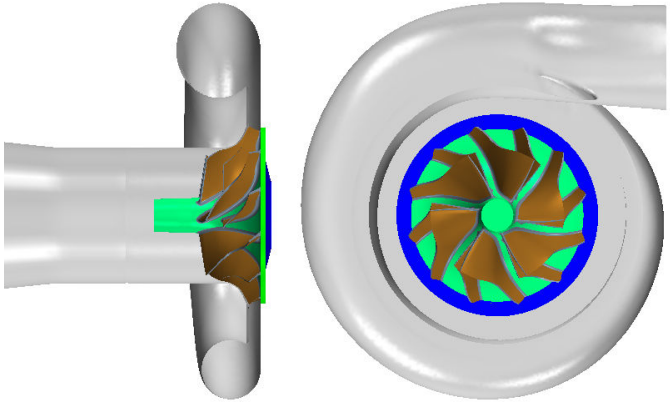
- V & V of the solver completed
- Demonstrated capability for extracting acoustics from the LES data
- Numerical prediction of flow instability mechanisms:
  - Shear-layers, BL separation
- Flow modes: Fourier point/surface spectra, POD/DMD
  - Surge (pulsating) and rotating stall (spinning)

Assessment of 0D/1D performance prediction models

B. Kerres, S. Sanz, E. Sundström, M. Mihaescu

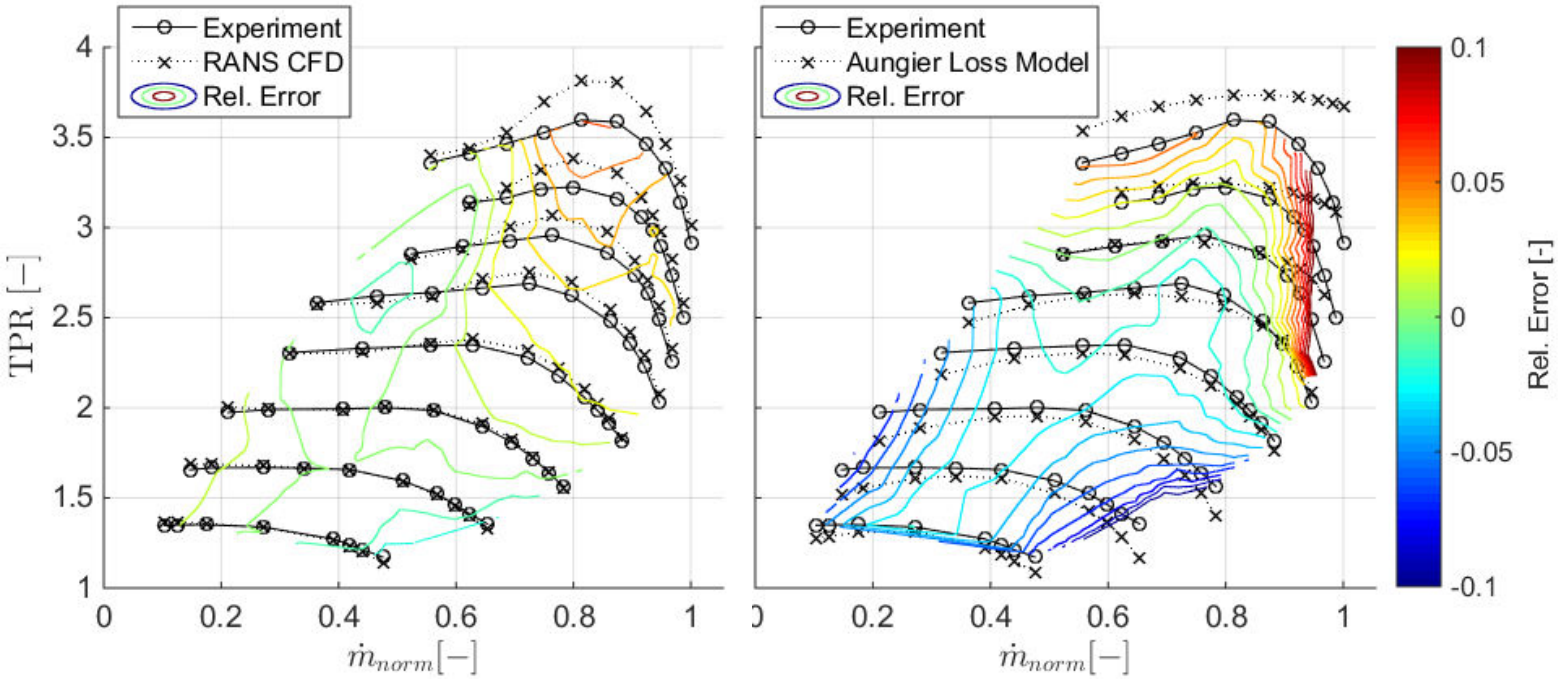


Performance map prediction with 0D/1D models compared to CFD

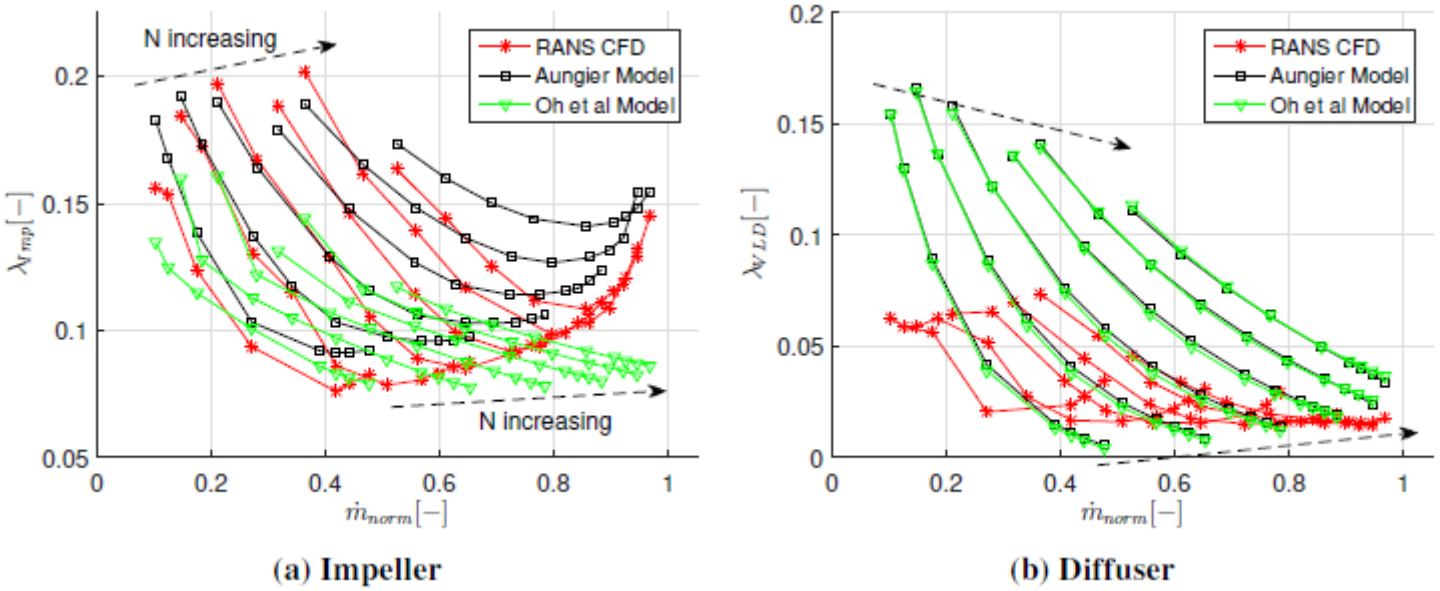


Main blades = 6

Splitter blades = 6



Component-wise comparison of loss parameter w.r.t. CFD



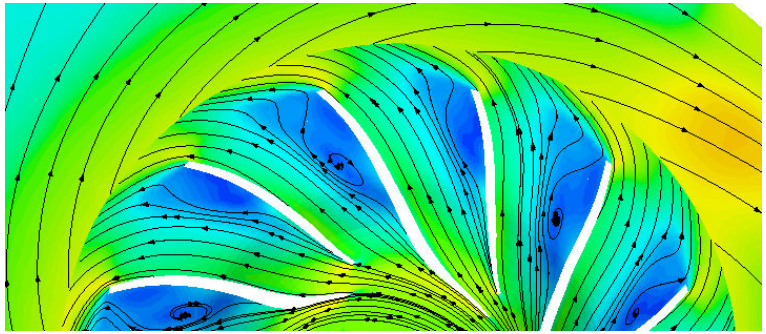
(a) Impeller (b) Diffuser

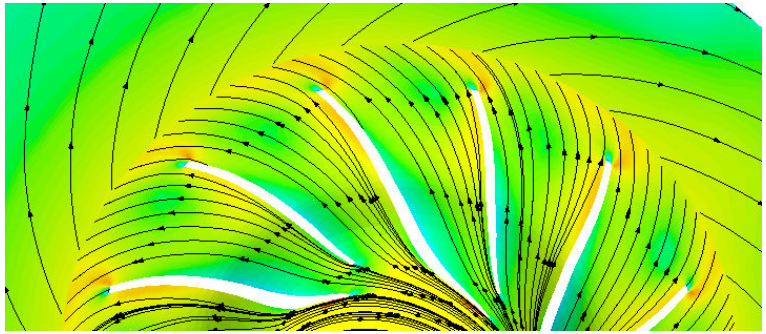
- Monotonic impeller loss increase towards surge and choke
  - Minimum at design *(Oh model have no choke relation)*
- Aungier/Oh: diffuser loss increase towards surge
  - 1D momentum conservation with empirical loss terms
  - Small diffuser inlet angle -> longer flow path -> higher loss
  - Higher than CFD. One reason why models predict low TPR

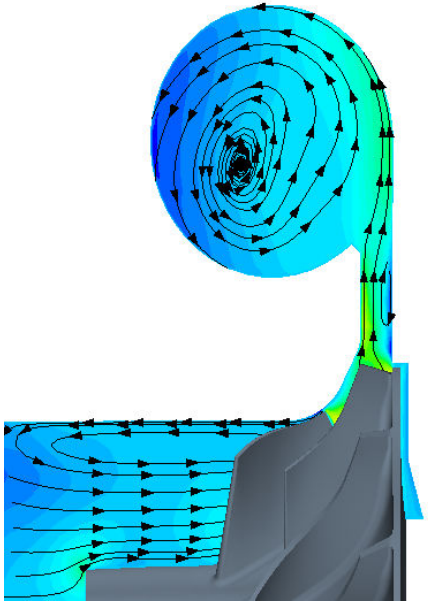
Off-Design vs. design condition

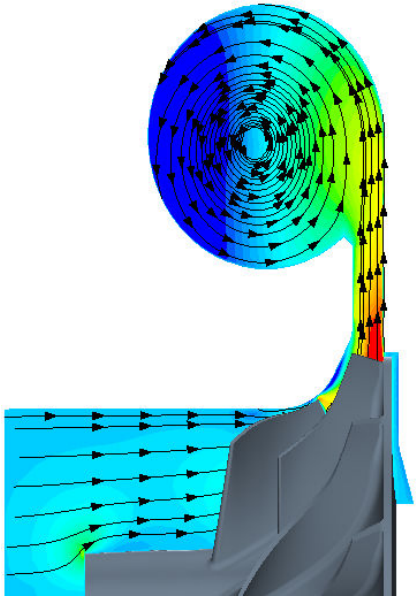
Last stable operation point

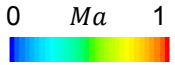
Near optimum efficiency











Summary and outlook

Assessment of RANS & 0D/1D performance prediction models

- RANS: good agreement with exp at low speeds
- Models: good agreement only at design conditions
- Validity bounds assessed
- Issues with 0D/1D models: Vaneless diffuser losses at low mass flows

Outlook

- Unsteady CFD (LES) on the BorgWarner **MP** & HP compressors at identified operating conditions of interest
- Similarities
- Expected PhD defense HT2017

Competence Center for Gas Exchange

CCGEx

"Charging for the future"

Energimyndigheten SCANIA VOLVO VOLVO BorgWarner