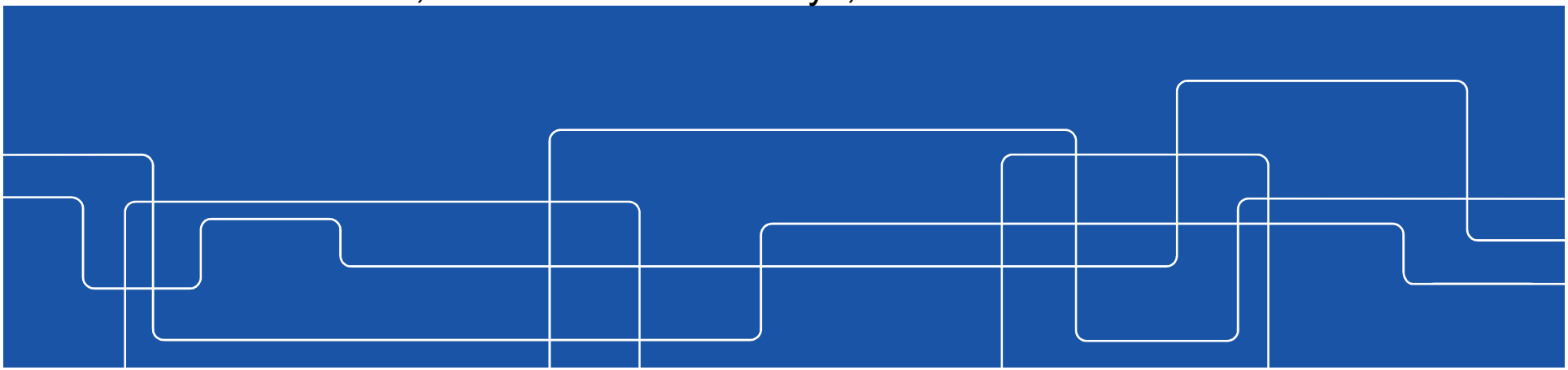
KTH ROYAL INSTITUTE
OF TECHNOLOGY

# CCGEx: Ongoing Projects

## Research Area: Compressor Off-Design Operation (CoD)

Mihai Mihaescu
Associate Professor, KTH-Mechanics

11-12 October 2018, CCGEx Research Days, Stockholm



Energimyndigheten SCANIA VOLVO VOLVO BorgWarner

# Research Area: Compressor Off-Design Operation (CoD)

**GOAL**

Increase compressor stable operation range and efficiency, enable silent operation and optimize unit integration with upstream/downstream components

**STRATEGY**

From physics-based understanding, build knowledge on critical operation conditions and enable viable control to mitigate flow instabilities, surge and noise

**TOOLS**

- High-fidelity simulations & detailed experiments
- Methods for stall/surge identification

⇨

- Flow & Acoustic characterization
- System diagnostics incl. ICE & Turbocharger

| Research Area | 2015 | | | | 2016 | | | | 2017 | | | | 2018 | | | | 2019 | | | | 2020 | | | | 2021 | | | | 2022 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| **i-COLD: Mihai Mihaescu** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bertrand Kerres, PhD student, ICE, EXP/1D | | | | | | | | | | PhD | | | | | | | | | | | | | | | | | | | | | | |
| Elias Sundström, PhD student, Mek, CFD | | | | | Lic | | | | | | | PhD | | | | | | | | | | | | | | | | | | | | |
| Raimo Kabral, PhD student, MWL, EXP | | | | | | | | | | PhD | | | | | | | | | | | | | | | | | | | | | | |
| Asuka Pietroniro, **Ind. PhD stud Volvo Cars**, MWL/Mek, CFD/CAA | | | | | | | | | | | | | | | | | Lic | | | | | | | | | | PhD | | | | | |
| Valeriu Dragan, **Post-doc BW**, Mek, CFD on non-axisymmetric diffusers | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Emelie Trigell, PhD student, Mek, CFD. Compressor Response to upstream/downstream installation effects | | | | | | | | | | | | | | | NEW | | | | | | | | | | | | | | | PhD | | |
| Aerodynamically generated noise of Centrifugal Compressors-Experiments, Post-doc, MWL, EXP | | | | | | | | | | | | | | | | | NEW | | | | + 1 year SCANIA/VCC' | | | | | | | | | | | |
| Niloofar Sayyad Khodashenas, Marie Curie **Assoc. PhD Project**, MWL., Exp/model/Non-linear system ID for TC | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# CoD: Overall aims

- Improve understanding of the compressor flow at off-design conditions
  - high-fidelity simulations and experiments
  - quantify the flow instabilities with advanced mode decomposition techniques
- Quantify the geometry installation effects on the on-set of flow instabilities and surge
  - effect on compressor performance
- Aeroacoustics characterization of compressor surge
- Develop and /or adopt methods for stall/surge identification
- Surge inception scenario definition

**PhD Students / Postdoc:**
Asuka Pietroniro, (Aeroacoustics), MWL/Mek
Emelie Trigell, New PhD Student (CFD), Mek
New Post-doc, (Exp) (NN, VT2019)
Elias Sundström, (CFD), **PhD: 2017/12**
Valeriu Dragan (CFD), **Postdoc: 2017/12**
Bertrand Kerres (Exp), **PhD: 2017/06**
Raimo Kabral, (Acoustics), **PhD: 2017/06**

**CCGEx Coordinator:** Mihai Mihaescu

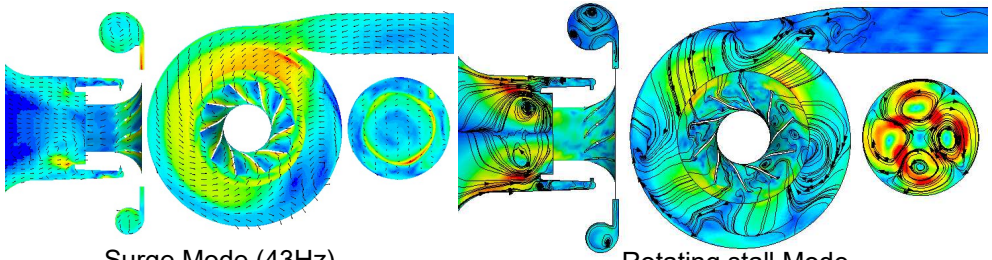
**Reference group:**
Habib Aghaali, Volvo Cars
Magnus Knutsson, Volvo Cars
Magnus Ising, Volvo GTT
Per-Inge Larsson, Scania
Jonas Holmborn, Scania
Tom Heuer, Borg Warner
Thomas Lischer, Borg Warner

# i-COLD: Individual projects

*Flow instabilities in Centrifugal Compressors at Low Mass Flow Rate*

**Doctoral student:**
Elias Sundström (CFD), Mek

**Supervisors:**
Mihai Mihaescu, Laszlo Fuchs



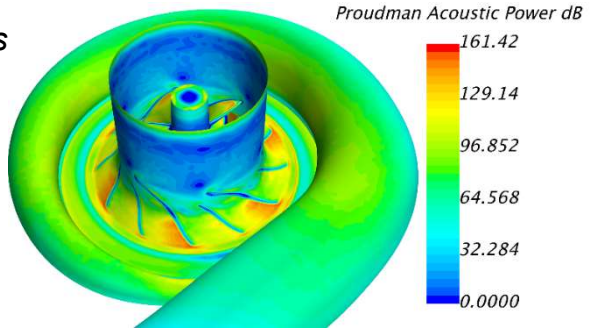
Surge Mode (43Hz)

Rotating stall Mode

*On the aerodynamically generated sound of centrifugal compressors*

**Ind. Doctoral student (Volvo Cars); started 05/12/2016:**
Asuka Gabriele Pietroniro (CFD/CAA)

**Supervisors:**
Mihai Mihaescu, Mats Åbom, Magnus Knutsson (VCC)




*Compressor response to upstream/downstream installation effects and perturbations*

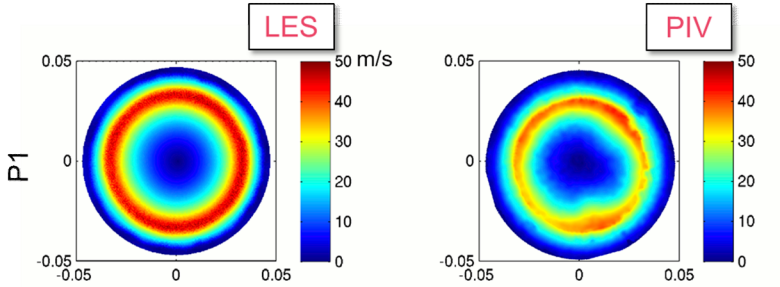
**Proposed PhD student (HT2018):**
Emelie Trigell (CFD), Mek

**Supervisors:**
Mihai Mihaescu, Mats Åbom, Lisa Prahl-Wittberg

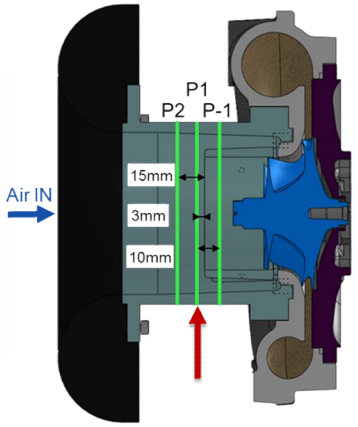
# Verified and Validated tool

## Compressor assessment @ design / off-design

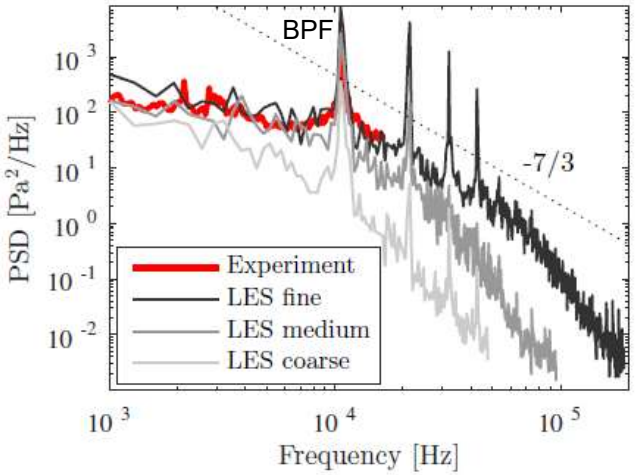
Closed ported Shroud: Stable operating condition (0.28kg/s); LES vs. experiments



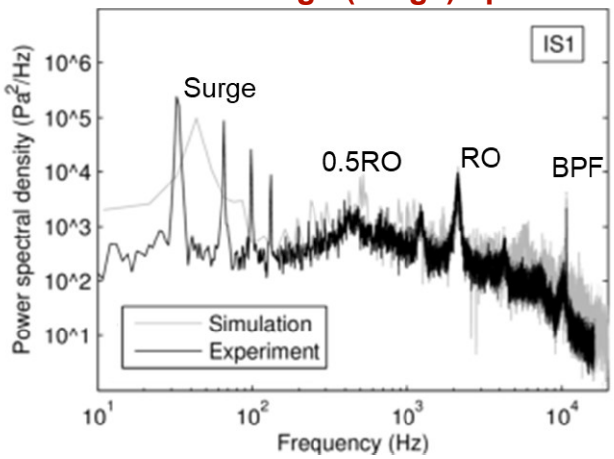

Design Condition, 64k rpm; In-plane velocity magnitudes (m/s)

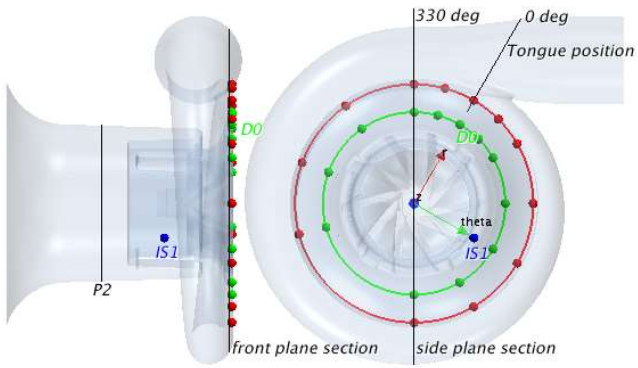



**Stable operation**




**Off-Design (Surge) operation**




Experimental data from University of Cincinnati (Dr. Gutmark)

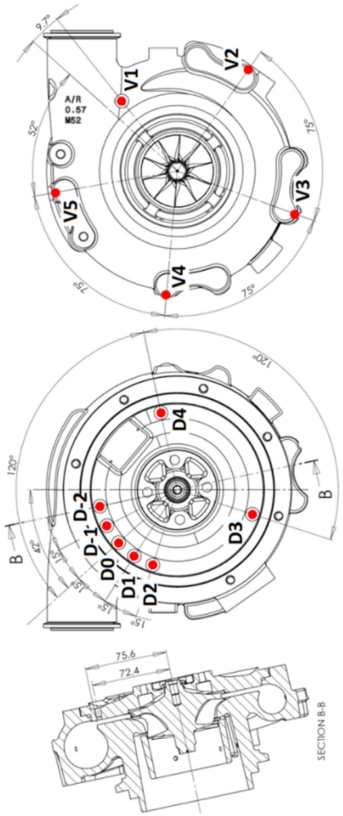

Sundström, Semlitsch, *and* Mihaescu (2018). *J. of Sound and Vibration* 434: 221-236.

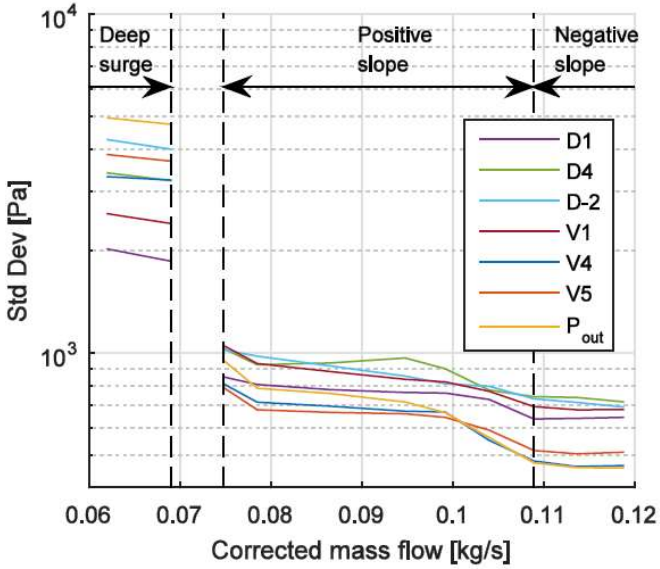
Sundström, Semlitsch, *and* Mihaescu (2018). *Flow, Turbulence and Combustion*. 100(3): 705-719.

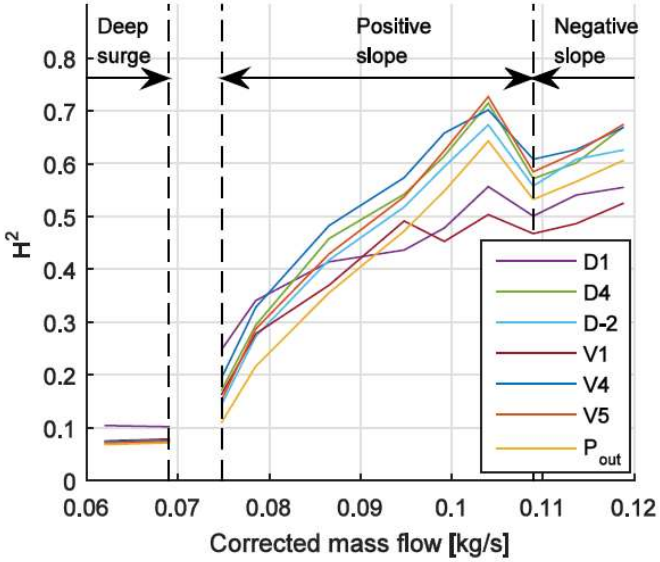
Semlitsch *and* Mihaescu (2016). *J. Energy*. 103: 572-587.

# Hurst exponent vs Std Deviation

E. Guillou (2011)




Honeywell GT40 (HD turbocharger, ported shroud), N=64 krpm:

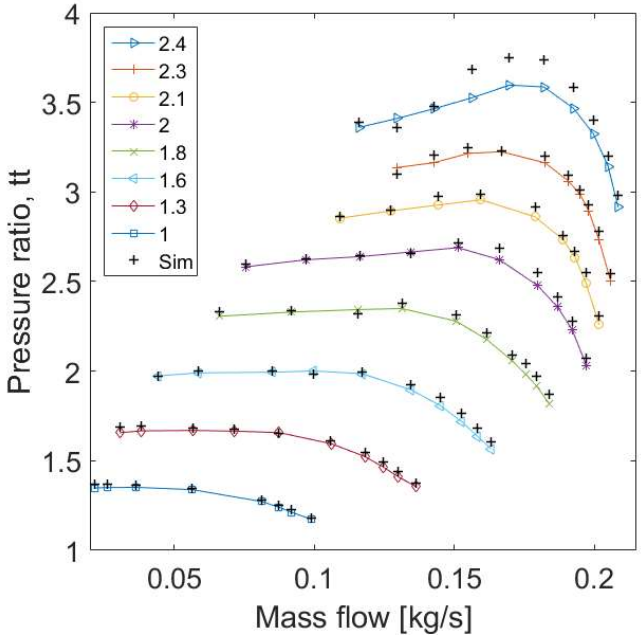
- Hurst exponent (H) gives information about long-term trends in a time-series
- Hurst exponent has better properties as warning indicator

**Kerres, B., Cronhjort, A., Mihaescu, M., and Stenlaas, O.** (2017) *A Comparison of On-Engine Surge Detection Algorithms using Knock Accelerometers.* SAE Technical Paper 2017-01-2420.doi:10.4271/2017-01-2420

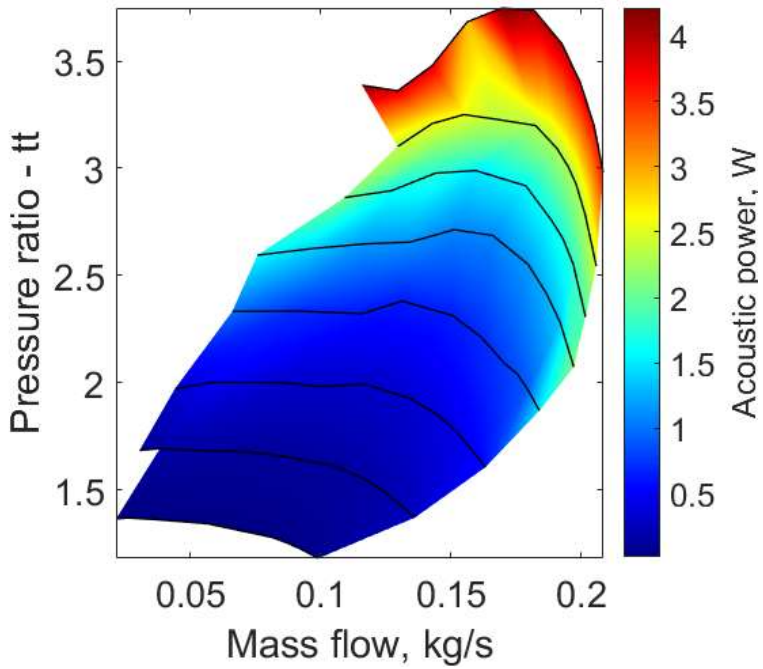
**Kerres, B., Mihaescu, M., Gancedo, M., and Gutmark, E.** (2017) *Optimal Pressure Based Detection of Compressor Instabilities Using the Hurst Exponent. SAE Int. J. Engines* 10(4).dx.doi.org/10.4271/2017-01-1040

# Aeroacoustic performance assessment

**Borg Warner Compressor**




*Acoustic power map*




- Compressor map: good match with experimental data;
- Noise map: produced noise proportional to rotational speed. Higher noise production towards choke line and surge line.

Pietroniro, Mihaescu, Åbom, and Knutsson (2018). *SAE Technical Paper*. 2018-01-1528

# i-COLD: Highlights

- Quantification of flow phenomena and instabilities precursor to surge in a large ported-shroud compressor by means of LES; demonstrated capability of extracting acoustics
- Validity range established for RANS & theoretical models for predicting compressor maps (Mek-MWL-ICE).
- Acoustic power map obtained based on steady-state CFD data
- Stability range extension at low mass flow rates explained for a non-axisymmetric hybrid volute-trimmed diffuser arrangement
- Determination of aeroacoustic coupling and system's characteristics (compressor-piping arrangement) @ design and off-design.
- An efficient and compact noise control solution, based on the optimal flow channel wall impedance was developed and proposed.
- Investigation of turbocharger compressor surge inception by means of an acoustic two-port model
- A surge criterion based on the fractal properties of time-resolved pressure signals was developed.

# Competence Center for Gas Exchange

CC GEx

## ”Charging for the future”

Energimyndigheten SCANIA VOLVO VOLVO BorgWarner