The work is also supported by the “*FlowAirS*” initial training network
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Accurate determination and control of compressor noise

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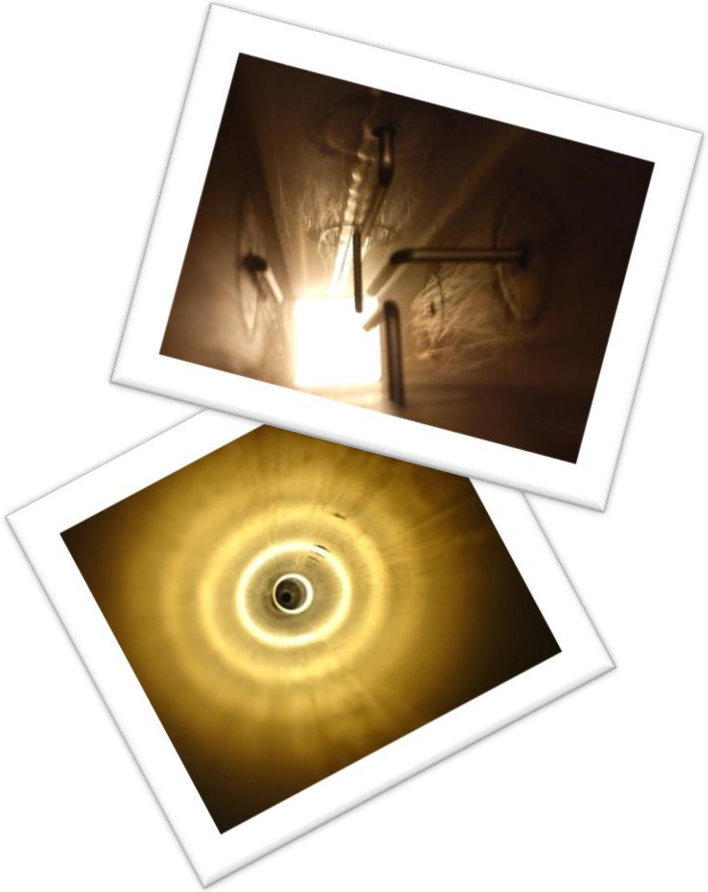
supervised by **Prof. Mats Åbom** and
Prof. **Hans Bodén**

Competence Center Gas Exchange
CCGEx
”Charging for the future”

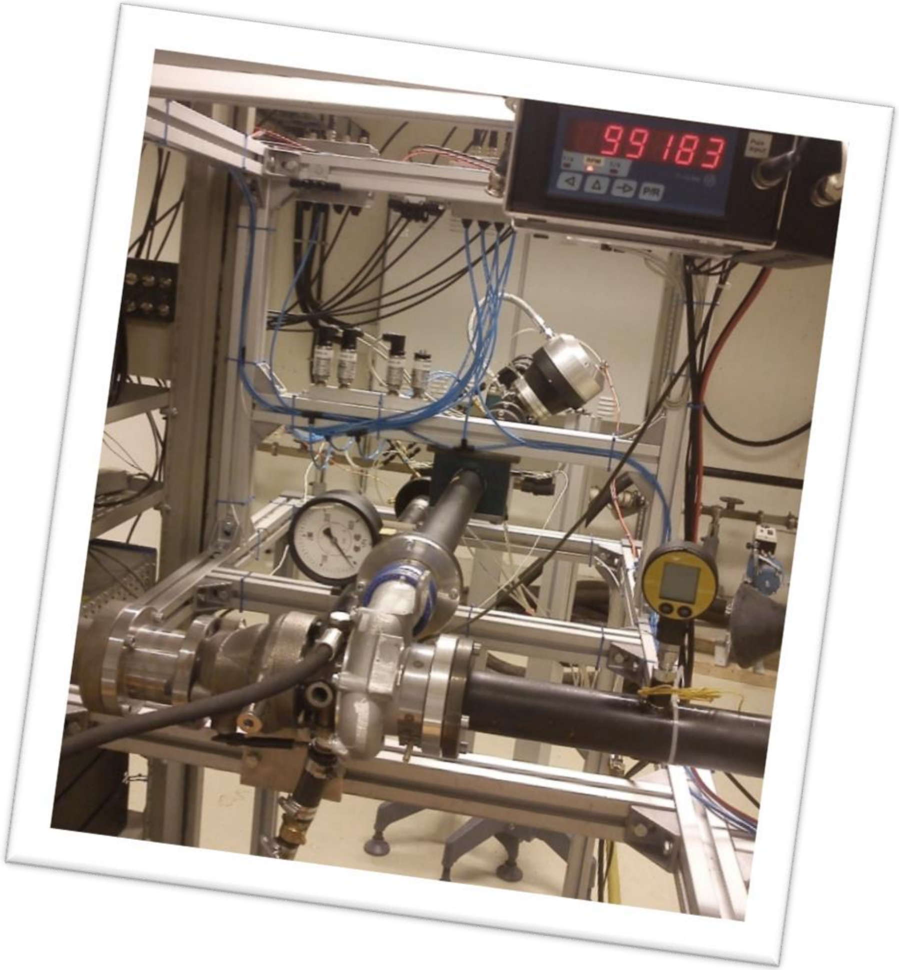
Layout of the presentation

1. Compressor studied
2. Accurate determination of sound generation
3. Dissipative noise control of the compressor
   - ✓ Concept of compact silencer
   - ✓ Improved FEM model
   - ✓ Modified optimal impedance model

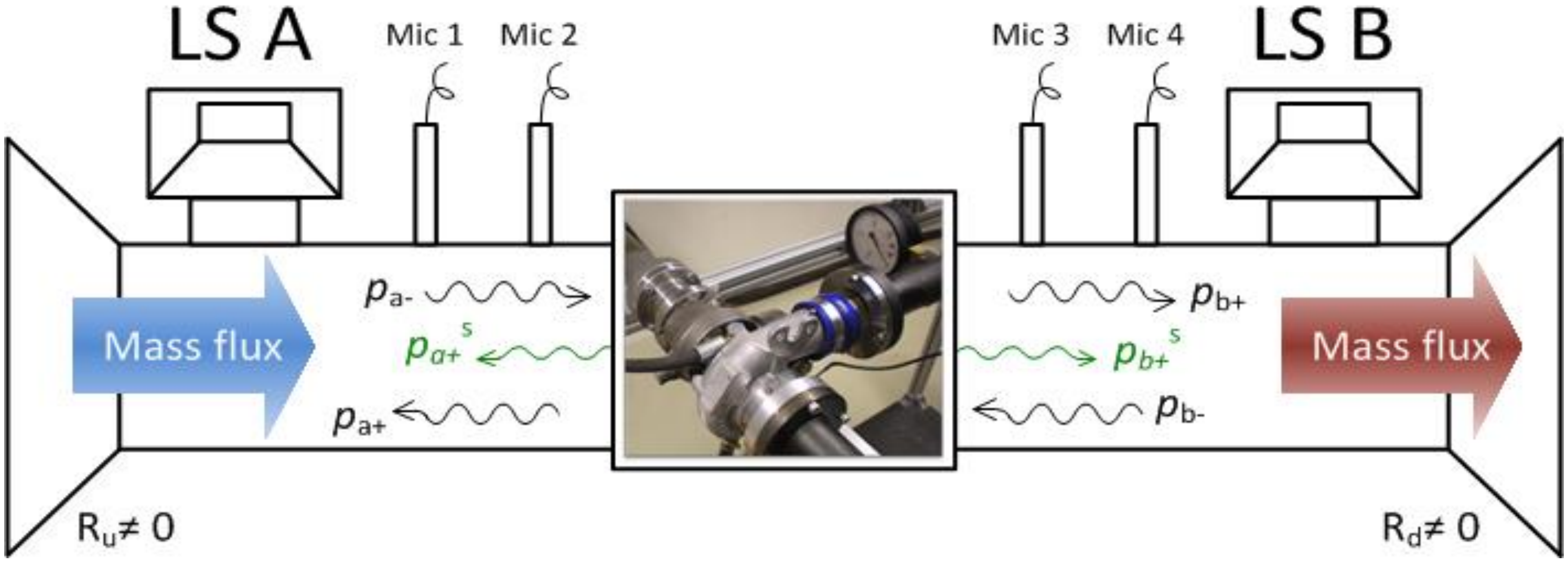


Compressor studied

- Passenger car turbocharger Garrett GT1752 driven by the "warm" compressed air feed to the turbine.
- Inlet diam. is 44mm.
- Outlet diam. is 42mm.
- The rotor has 6 (+6 splitter) blades.
- Shaft frequency ~80…180kRPM – blade pass frequency 8…18kHz.



Reflection-free sound generation

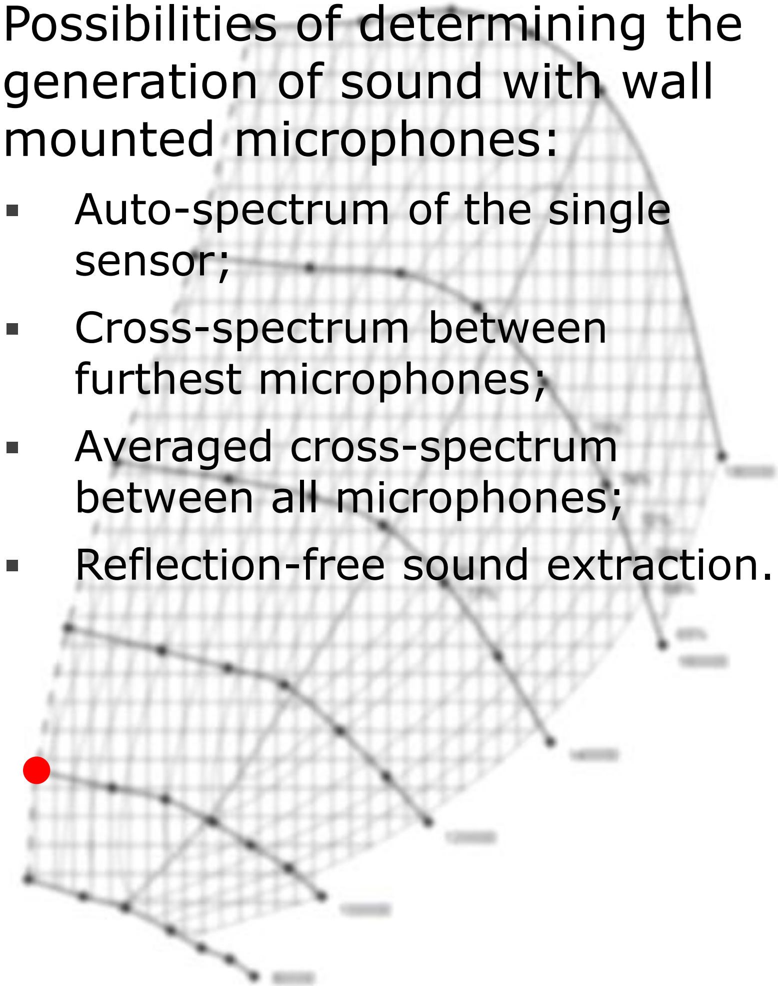


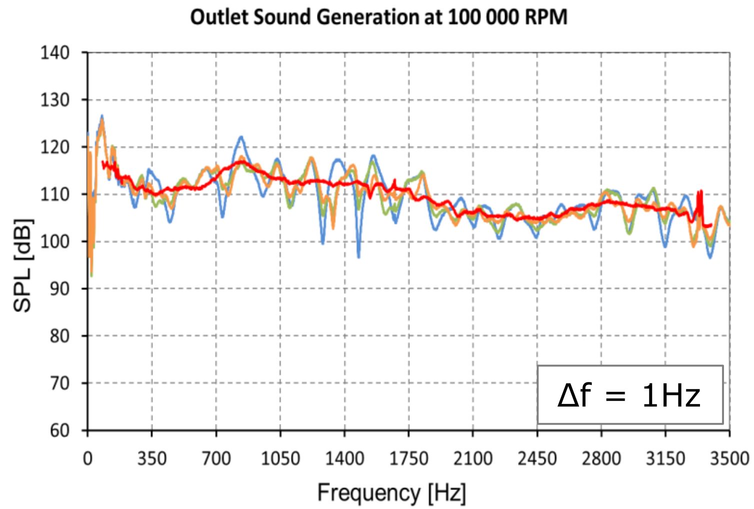
$$\boldsymbol{p}_{+}^{s} = (\boldsymbol{E} - \boldsymbol{SR})(\boldsymbol{E} + \boldsymbol{R})^{-1}\boldsymbol{p}$$

$$\boldsymbol{G}^{s} = \boldsymbol{p_s}(\boldsymbol{p}_s')^{\dagger} = \begin{bmatrix} G_{p_a^s p_a^s} & G_{p_b^s p_a^s} \\ G_{p_a^s p_b^s} & G_{p_b^s p_b^s} \end{bmatrix}$$

Sound generation of the compressor

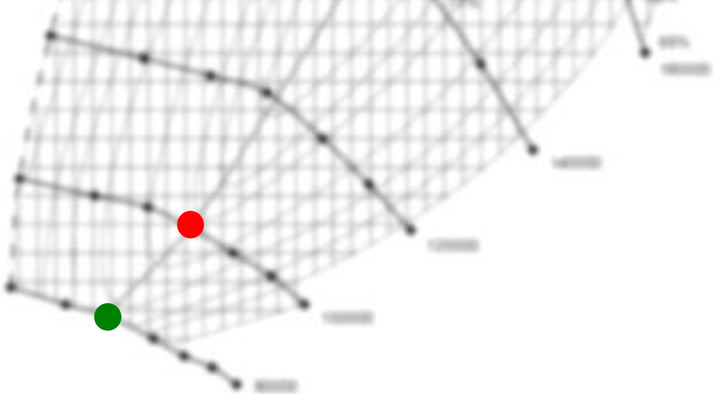
- Possibilities of determining the generation of sound with wall mounted microphones:
  - Auto-spectrum of the single sensor;
  - Cross-spectrum between furthest microphones;
  - Averaged cross-spectrum between all microphones;
  - Reflection-free sound extraction.

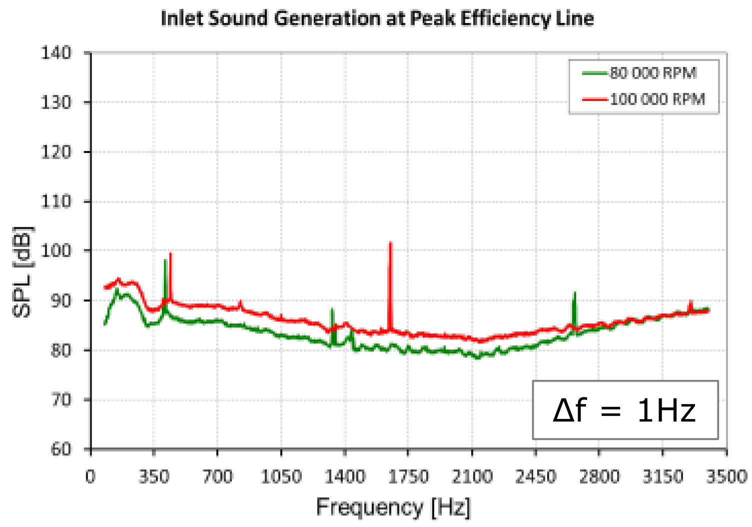


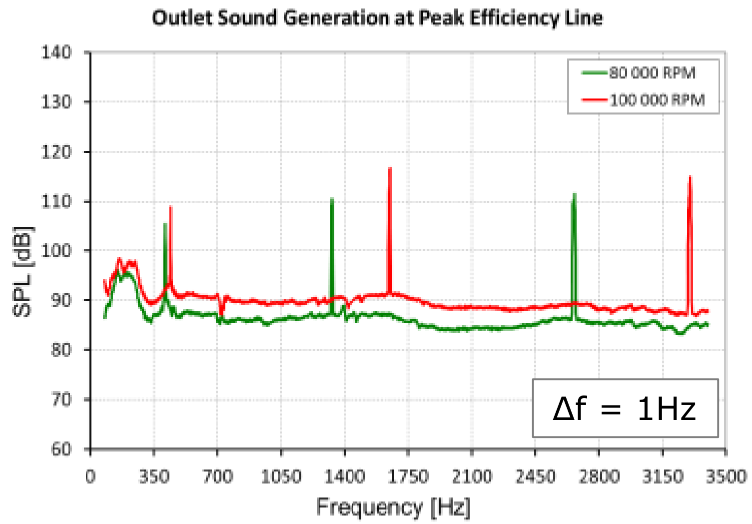


Results: Sound generation

- The auto-spectrum density functions of generated sound consist of broad-band flow noise and shaft frequency harmonics.
- The level of broad-band flow noise and also rotor harmonics is higher at the outlet.







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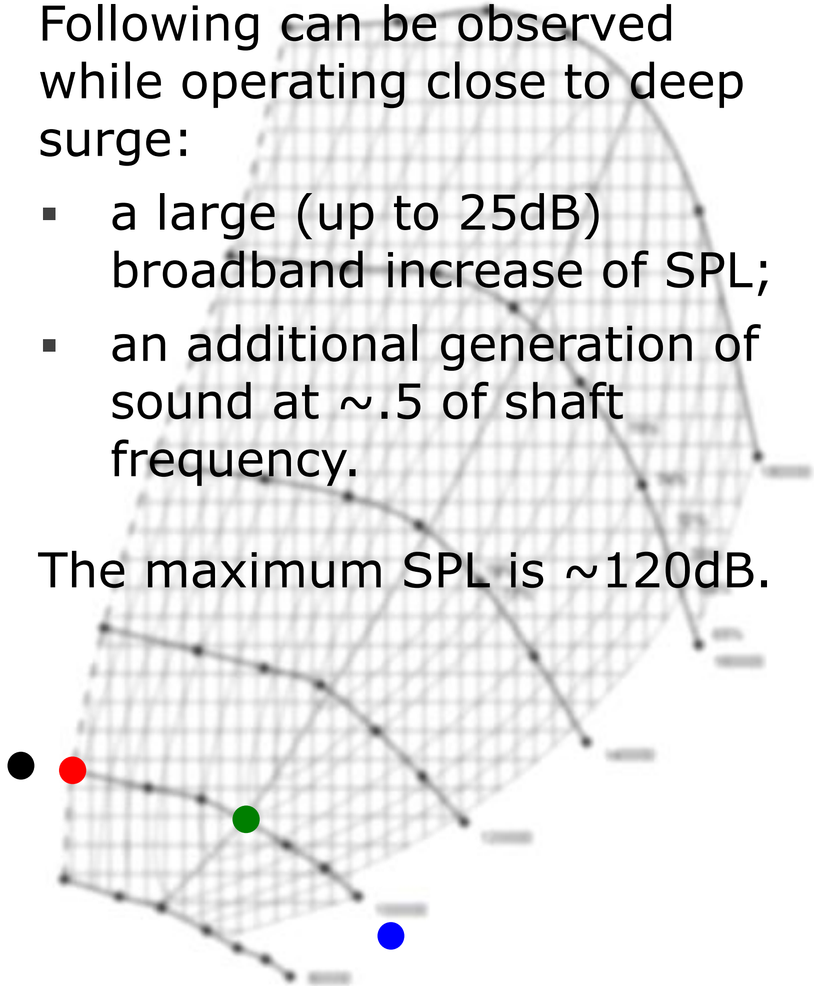
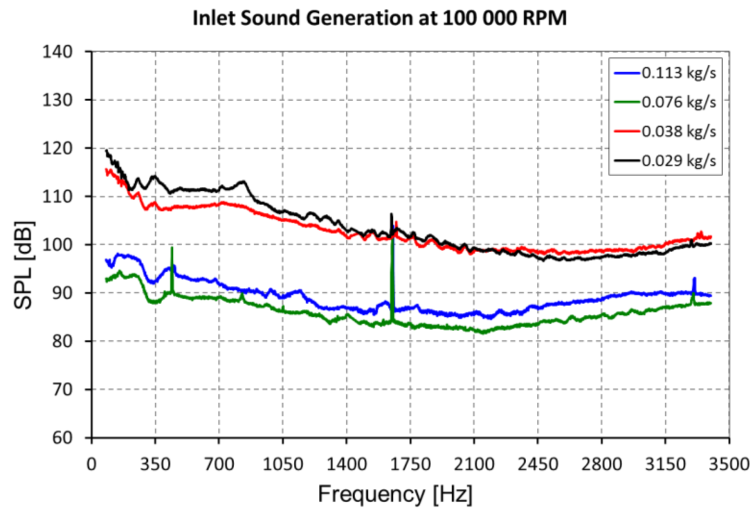
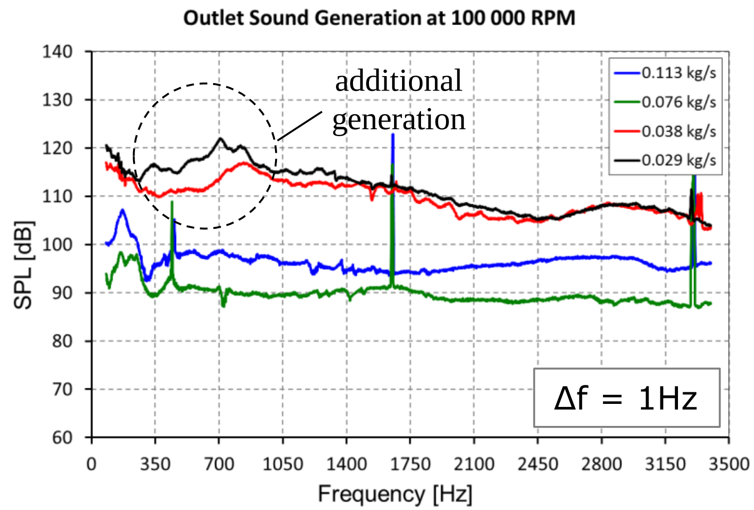
Sound generation of the compressor

- Following can be observed while operating close to deep surge:
  - a large (up to 25dB) broadband increase of SPL;
  - an additional generation of sound at ~.5 of shaft frequency.

- The maximum SPL is ~120dB.

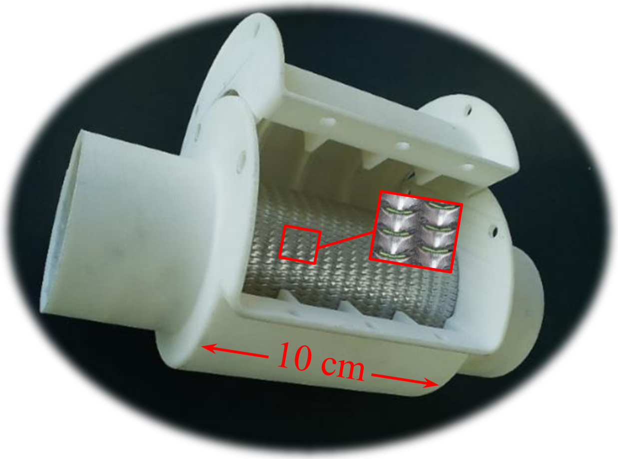


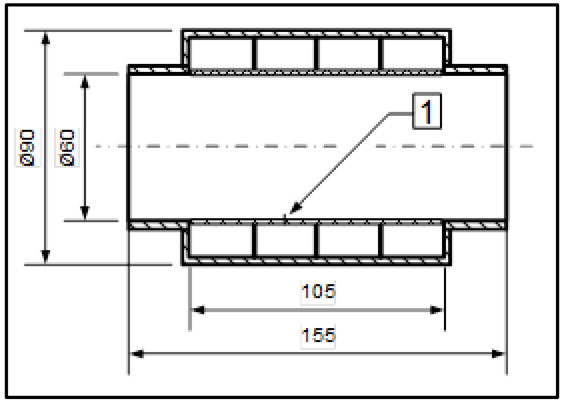




Concept of compact silencer

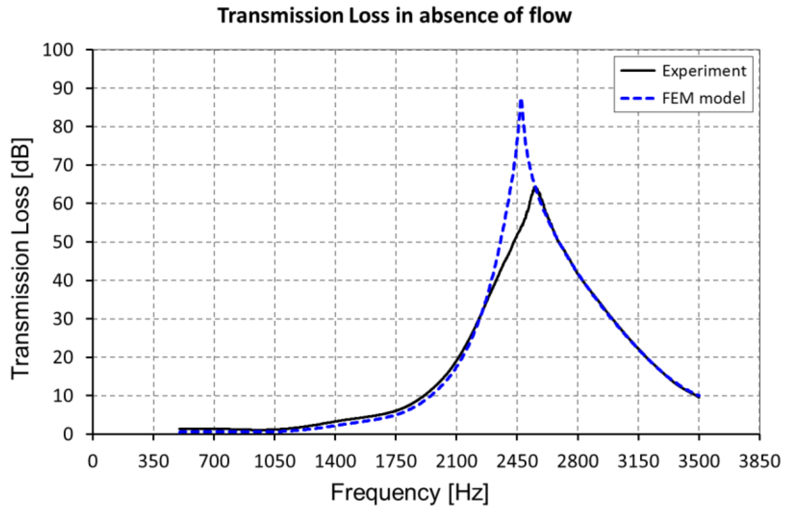
- Lightweight and compact noise control solution for flow duct applications (e.g. compressors).
- Consist of straight-flow channel with included acoustic **resistance** and **locally reacting cavity**.
- The prototype silencer employs the custom Acustimet™ MPP.
- The acoustic performance is controlled by the acoustic impedance of the locally reacting surface.

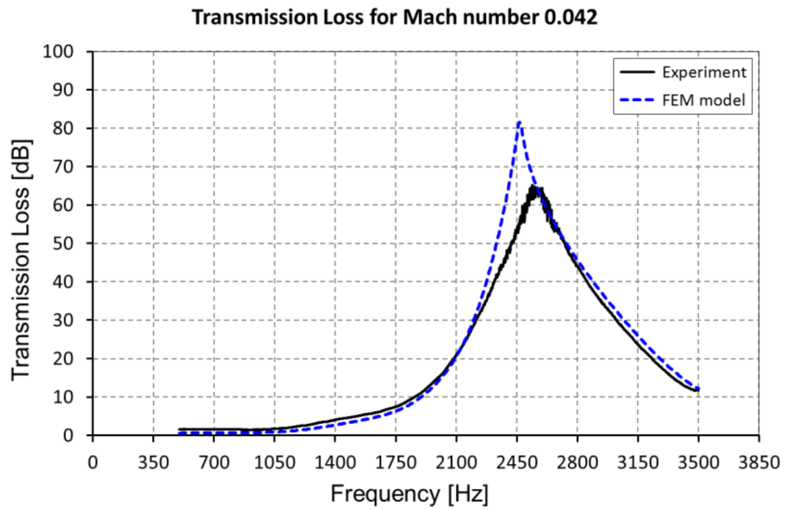




Improved FEM model

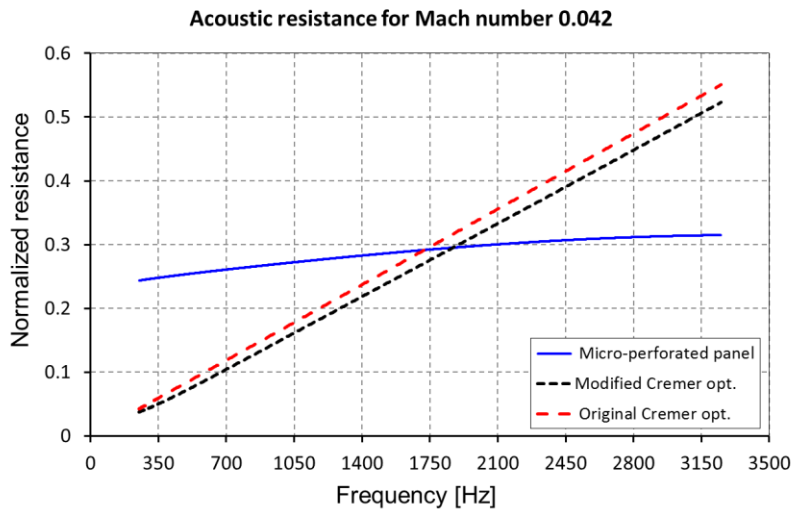
- Improvements are:
  - ✓ Full 3D → 2D with axisymmetric boundary condition.
  - ✓ Inhomogeneous Helmholtz equation → convective wave equation ("plug flow").
  - ✓ Modified grazing flow models for the acoustic transfer impedance of the Acustimet™ micro-perforated panels.
  - ✓ Cavity baffles included in the geometry.
- The model can predict the acoustic performance reasonably well.

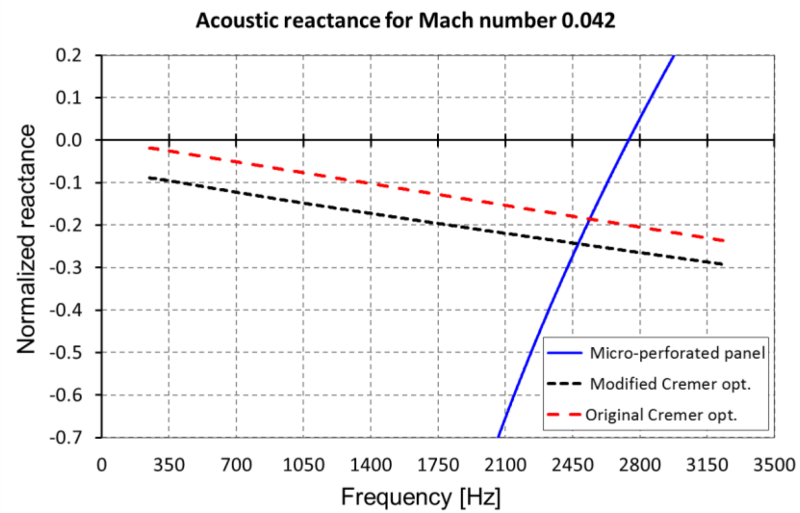




Modified optimal impedance model

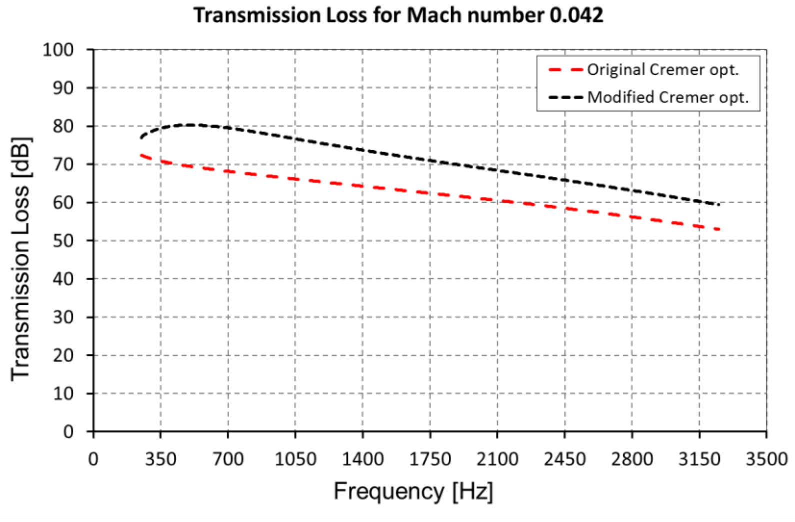
- The assumption of very high frequency (i.e. well cut-on acoustic modes) is eliminated.
- In order to obtain modified Cremer impedance, the boundary condition equation has to be solved numerically.
- Difference in the optimal impedance result will grow with **mean flow Mach number**.





Modified optimal impedance model

- The modified Cremer impedance model will result in the higher dissipation and TL.



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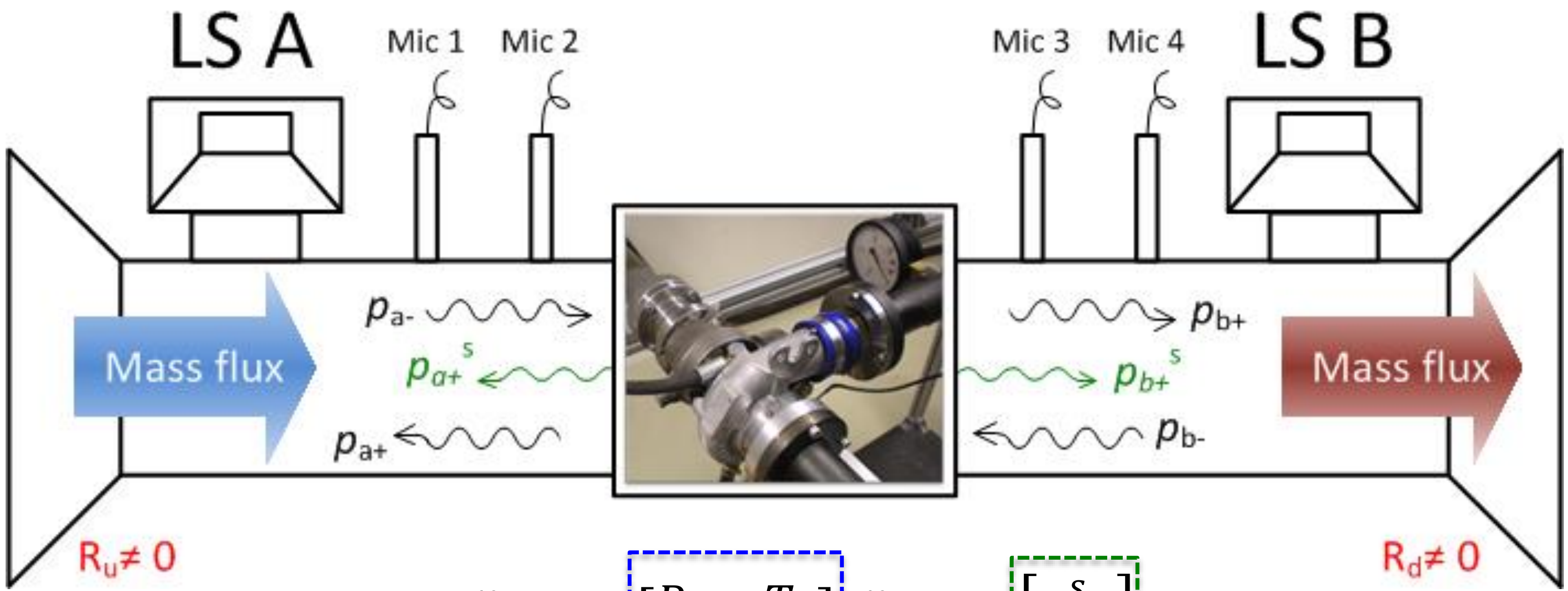
Acoustic 2-port formulation

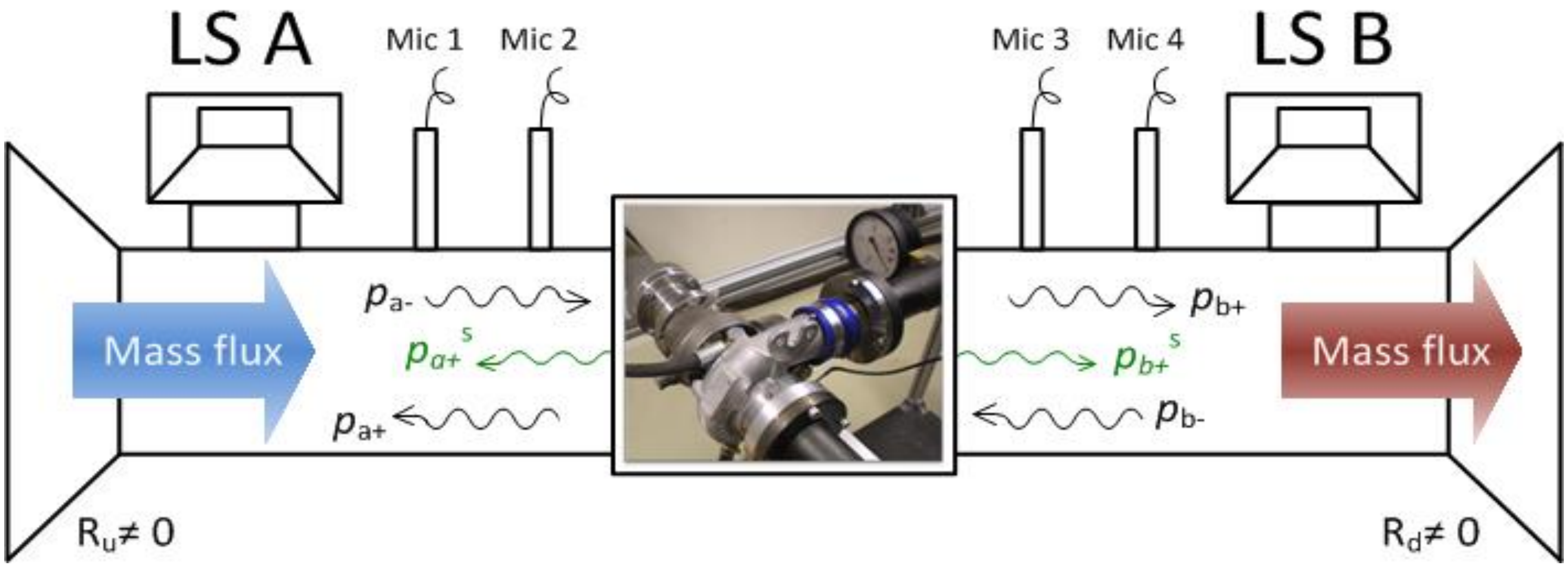


$$\begin{bmatrix} p_{a+} \\ p_{b+} \end{bmatrix} = \begin{bmatrix} R_a & T_b \\ T_a & R_b \end{bmatrix} \begin{bmatrix} p_{a-} \\ p_{b-} \end{bmatrix} + \begin{bmatrix} p_{a+}^{s} \\ p_{b+}^{s} \end{bmatrix}$$

- The acoustical performance of a flow duct element is determined by the full 2-port model which consists both the passive and the active parts.

$$f_c = \frac{1.814 \cdot c}{\pi d}$$

Reflection-free sound generation



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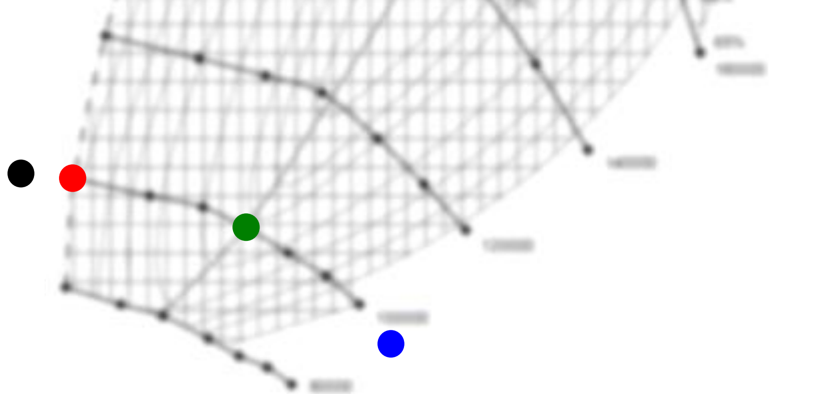

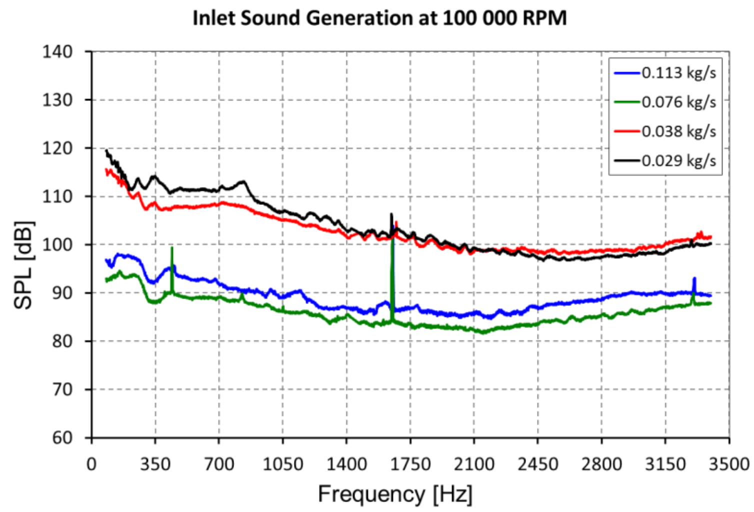

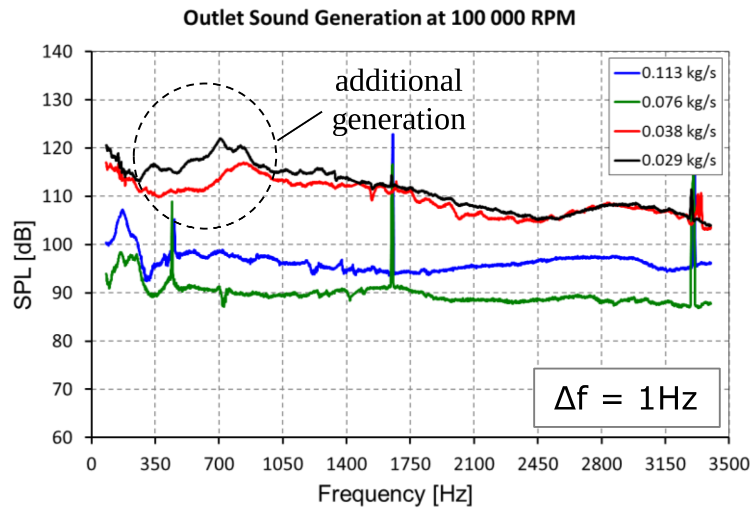

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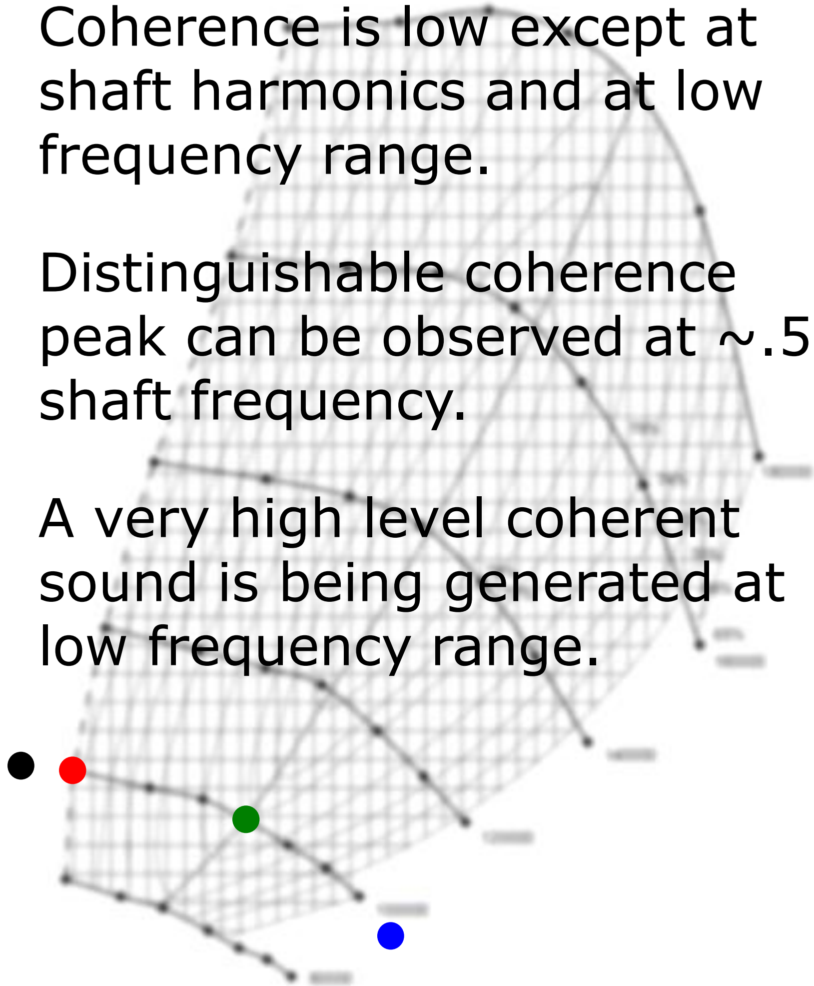
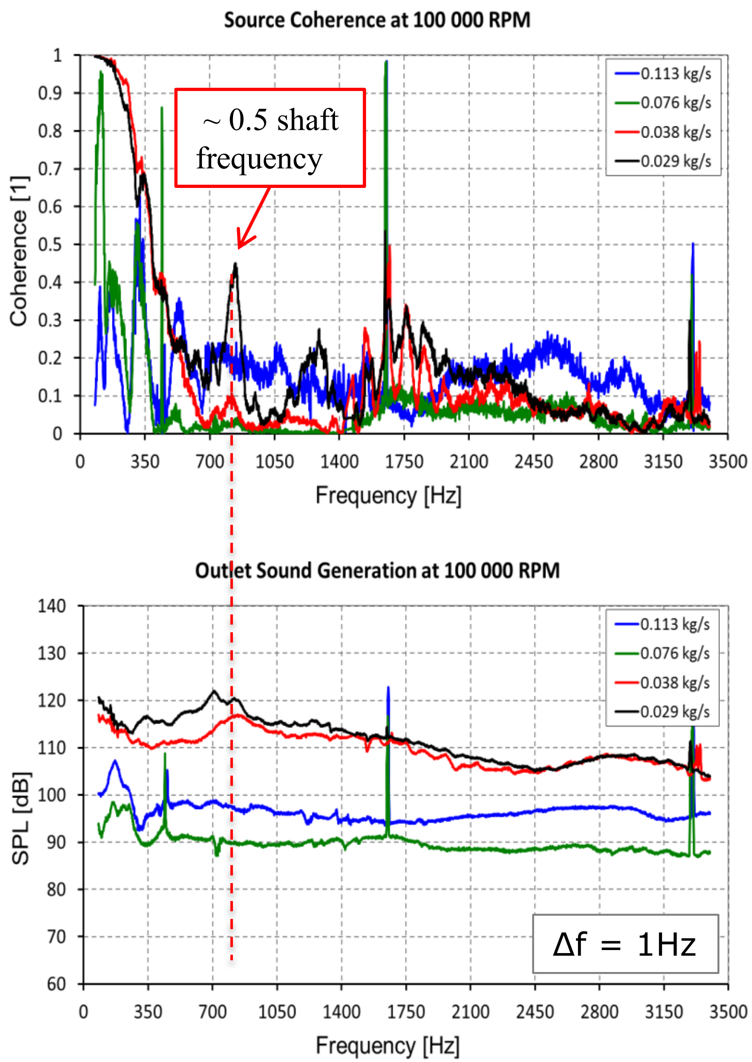
Compactness of a source

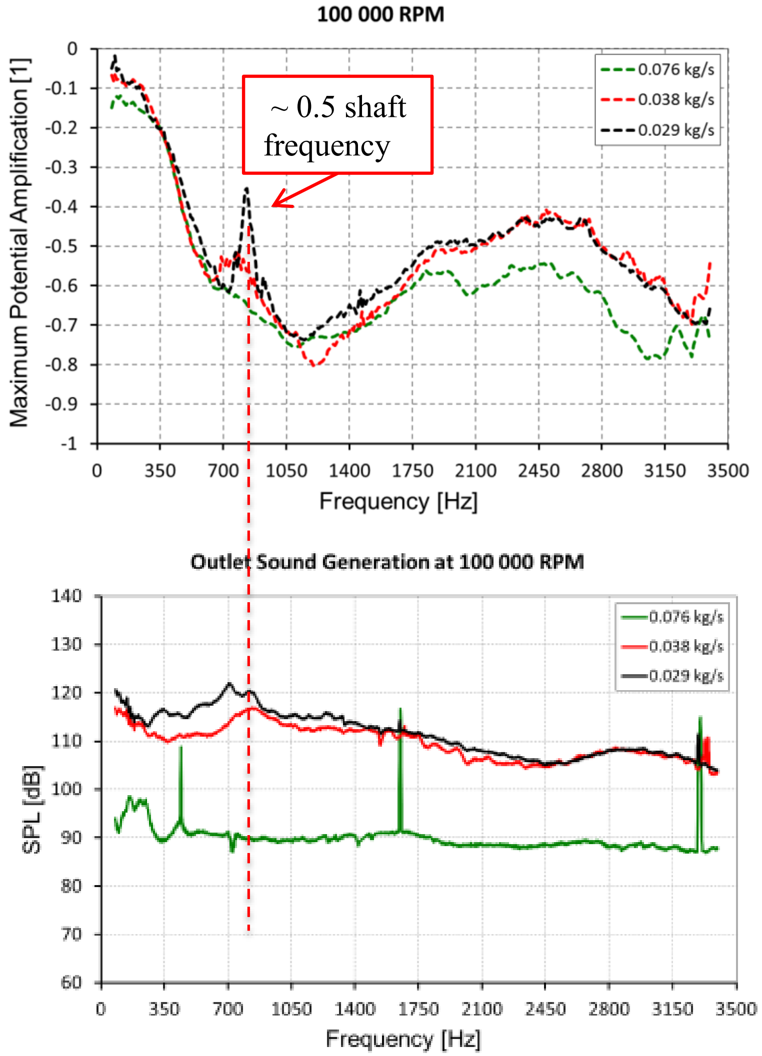
- Coherence is low except at shaft harmonics and at low frequency range.
- Distinguishable coherence peak can be observed at ~.5 shaft frequency.
- A very high level coherent sound is being generated at low frequency range.





Surge initiation by acoustic field?

- In case of reflective boundaries, the generated sound is sent back to the compressor.
- At ~.5 of shaft frequency the incident sound energy will be dissipated regardless the local amplification.
- At very low frequency the generated sound energy can accumulate in the system and potentially have a significant effect to flow conditions.



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Surge initiation by acoustic field?

- Negligible dissipation in low frequency range strongly depending on the incident sound field.
- The outlet excitation amplitude becomes dominant in cases of locally low dissipation.