KTH ROYAL INSTITUTE
OF TECHNOLOGY

Experimental Analysis of Whistle Noise in a Particle Agglomeration Pipe

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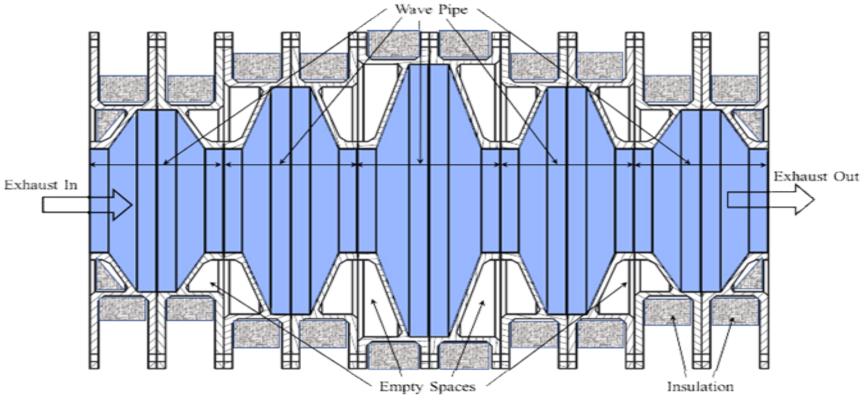
Outline

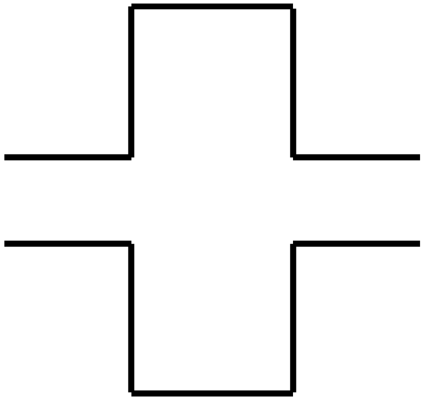
- ☐ Motivation of acoustic test
- ☐ Measurement
  - ✓ Test set-up
  - ✓ Results
  - ✓ Power balance
  - ✓ Stability analysis
- ☐ Conclusion

Motivation

Agglomeration pipe

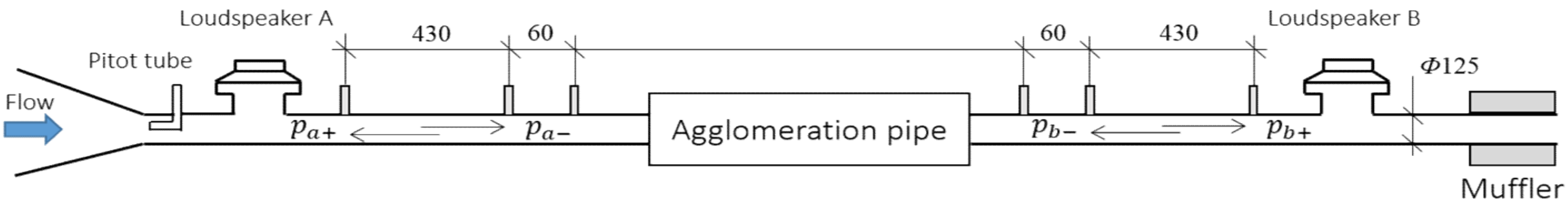


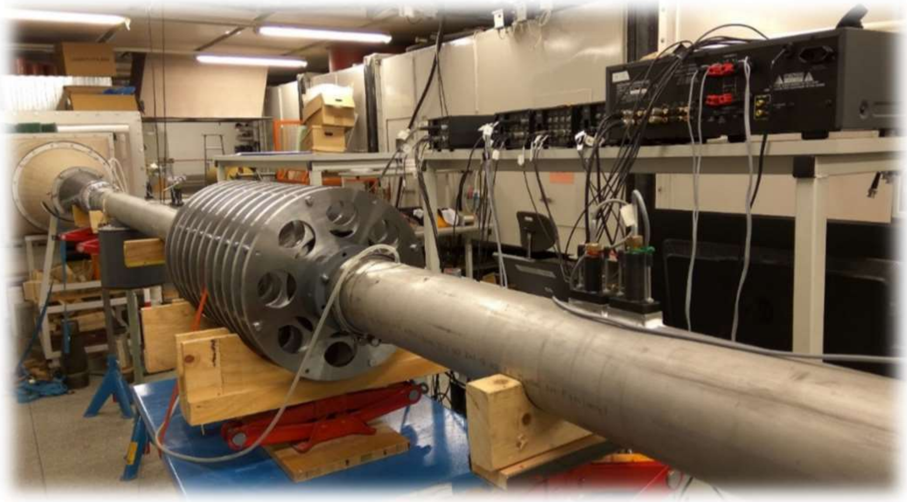
Expansion chamber



used as a muffler?

Test Set-up





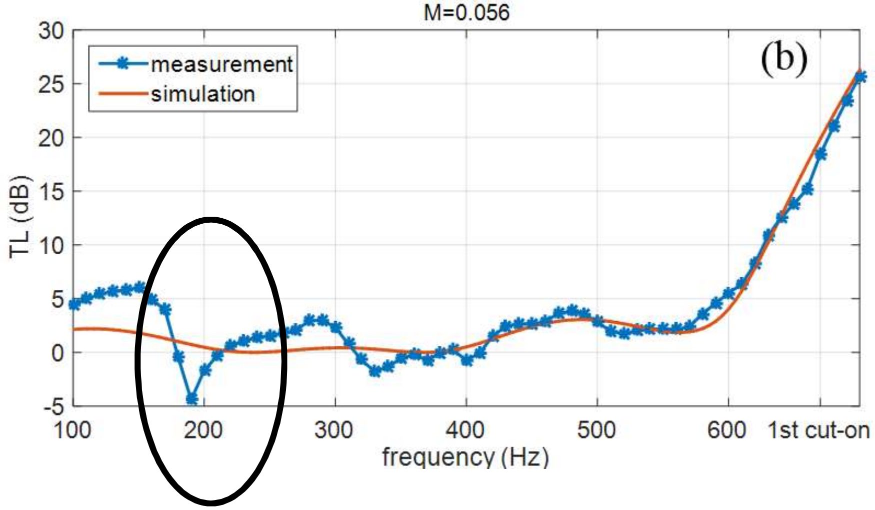
- A standard two-port measurement
- One no-flow case & two flow cases (M=0.056 & 0.1)

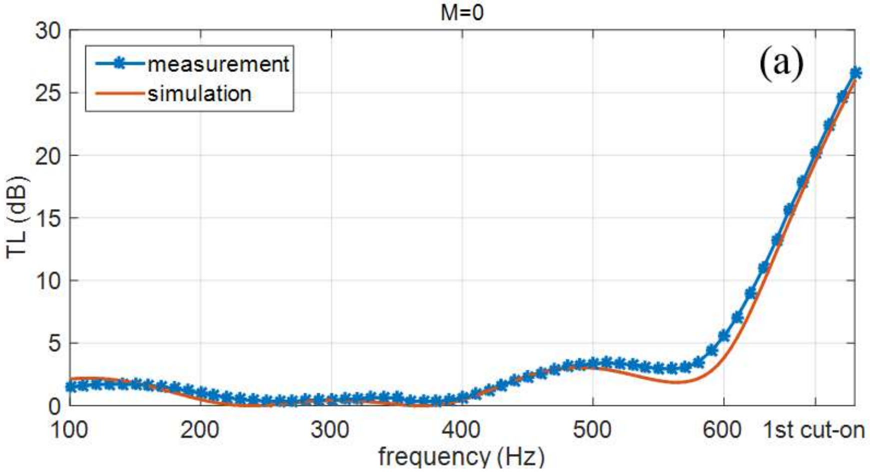
Transmission loss

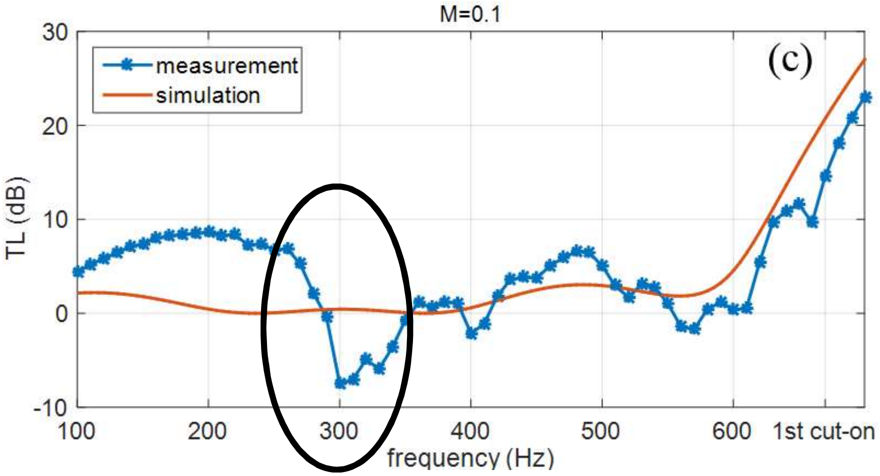
$$\begin{bmatrix} p_{a+}^1 & p_{a+}^2 \\ p_{b+}^1 & p_{b+}^2 \end{bmatrix} = \underbrace{\begin{bmatrix} R_{aa} & T_{ba} \\ T_{ab} & R_{bb} \end{bmatrix}}_{S} \begin{bmatrix} p_{a-}^1 & p_{a-}^2 \\ p_{b-}^1 & p_{b-}^2 \end{bmatrix}$$

$$\Downarrow$$

$$\mathrm{TL}_{ab} = 10\log_{10}(\,1/|\,T_{ab}\,|^2\,)$$

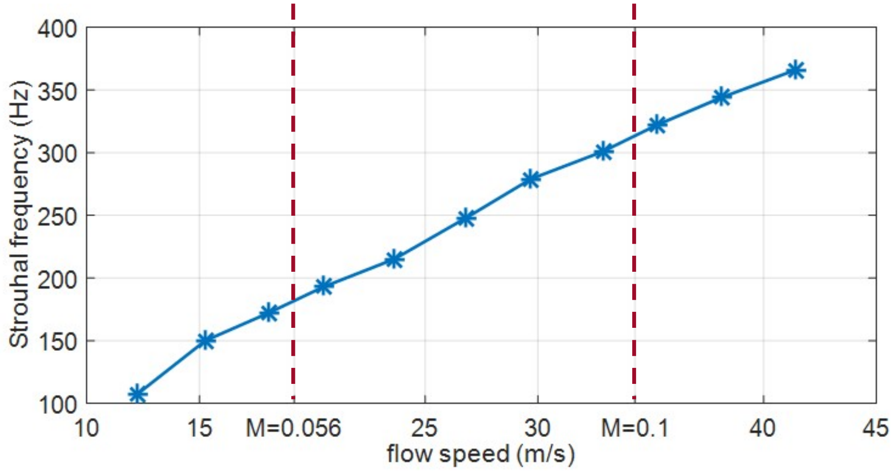


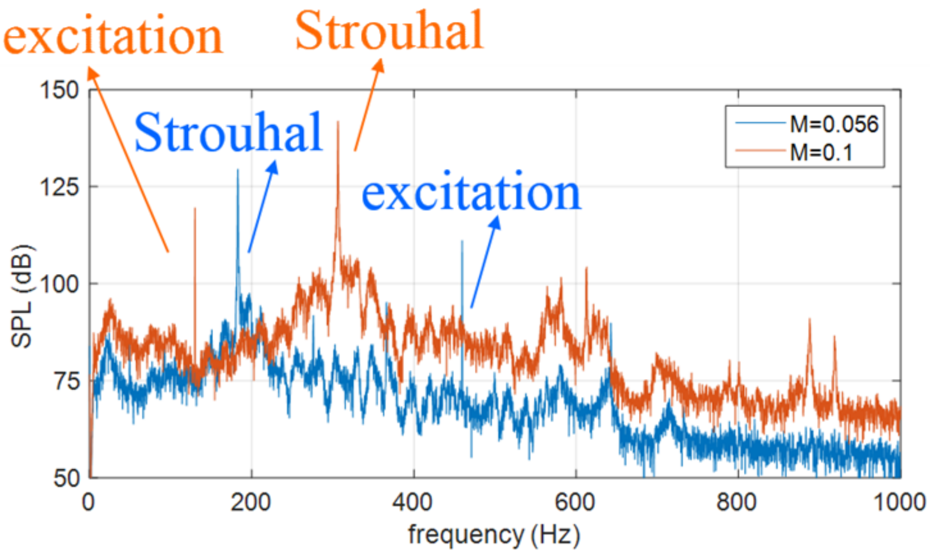




The simulation is conducted assuming ‘potential flow’ so …

Strouhal tones

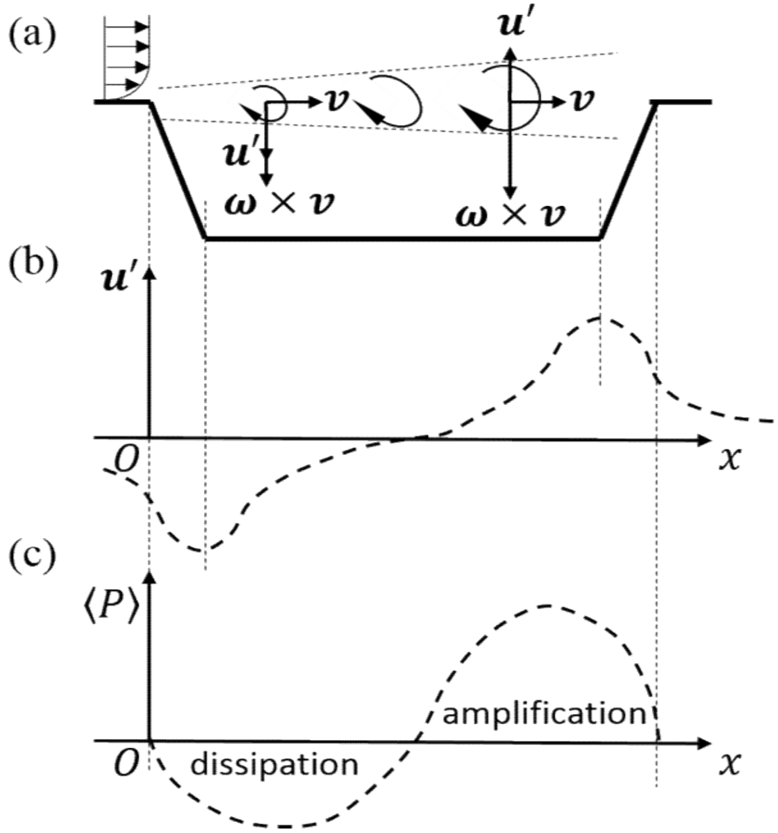




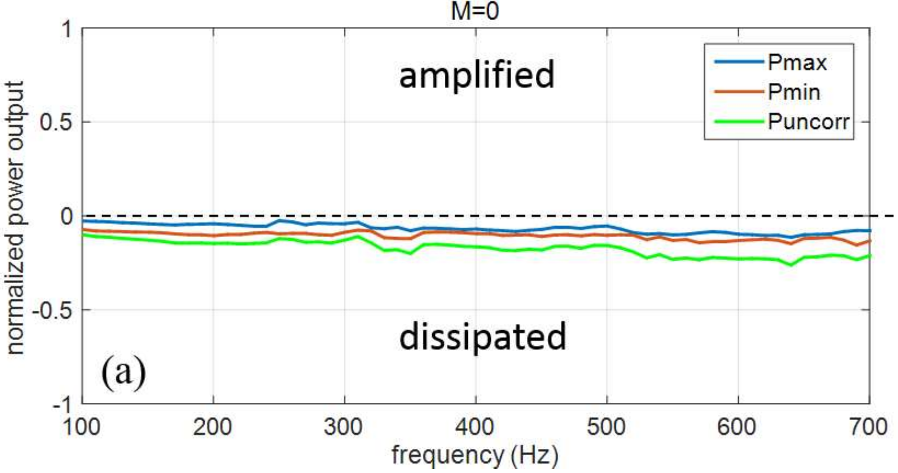
Whistling ???

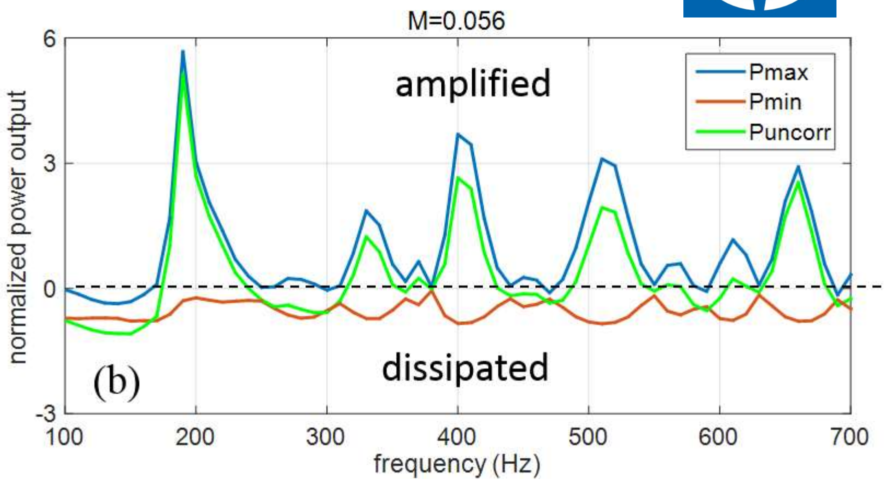
Whistle noise

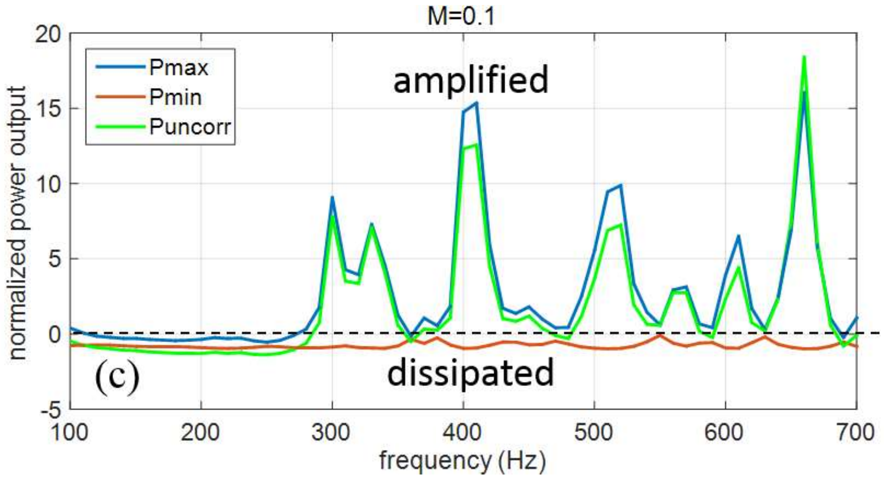
$$\langle P \rangle = -\rho_0 \int_V \langle (\boldsymbol{\omega} \times \boldsymbol{v}) \cdot \boldsymbol{u}' \rangle \, dV$$



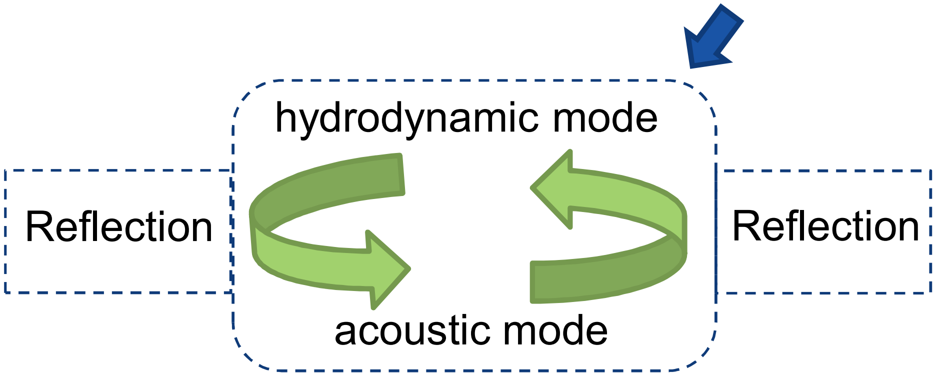
Power balance







Amplified incident power ≠ whistling!



hydrodynamic mode

Reflection

Reflection

acoustic mode

Analysis of Feedback Loop*

$$\begin{bmatrix} p_{a+} \\ p_{b+} \end{bmatrix} = \mathbf{SR}\begin{bmatrix} p_{a+} \\ p_{b+} \end{bmatrix} + \begin{bmatrix} p^s_{a+} \\ p^s_{b+} \end{bmatrix}$$

$$\Downarrow$$

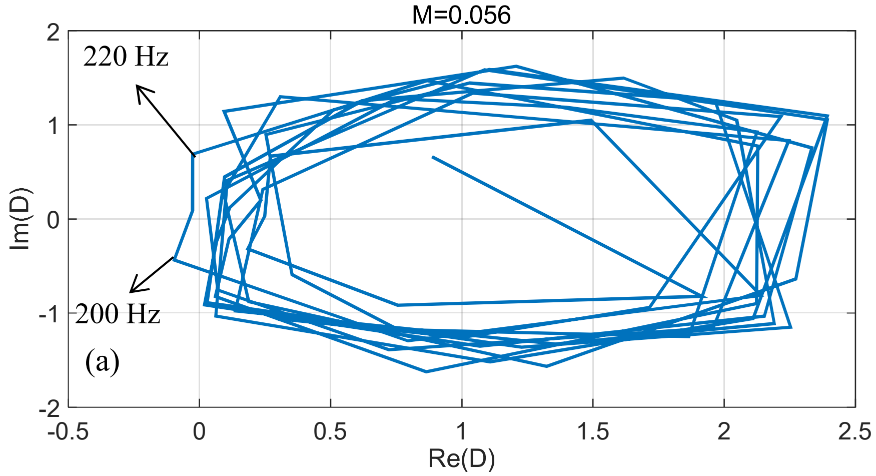
$$(\mathbf{I} - \mathbf{SR})\begin{bmatrix} P_{a+} \\ P_{b+} \end{bmatrix} = 0$$

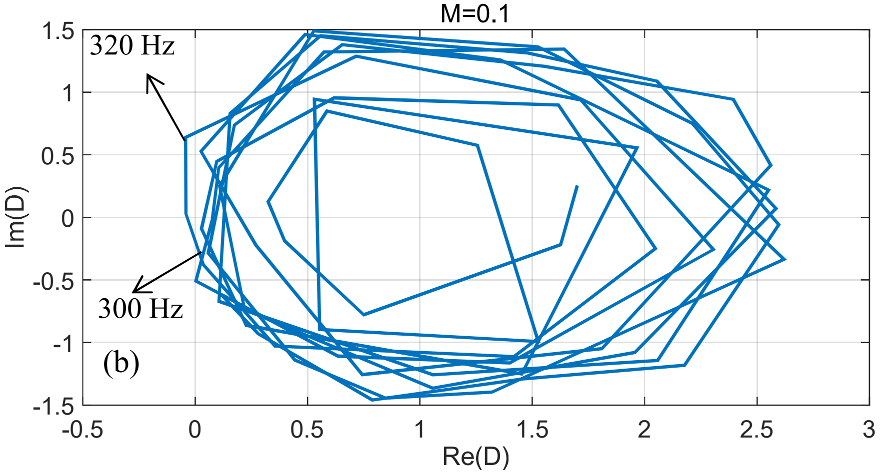
$$\Downarrow$$

$$D = \det(\mathbf{I} - \mathbf{SR})$$

$$\Downarrow$$

Nyquist stability criterion





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* Karlsson M., and Åbom M., (2011), "On the Use of Linear Acoustic Multiports to Predict Whistling in Confined Flows", Acta Acust united Ac, 97(1), 24-33.

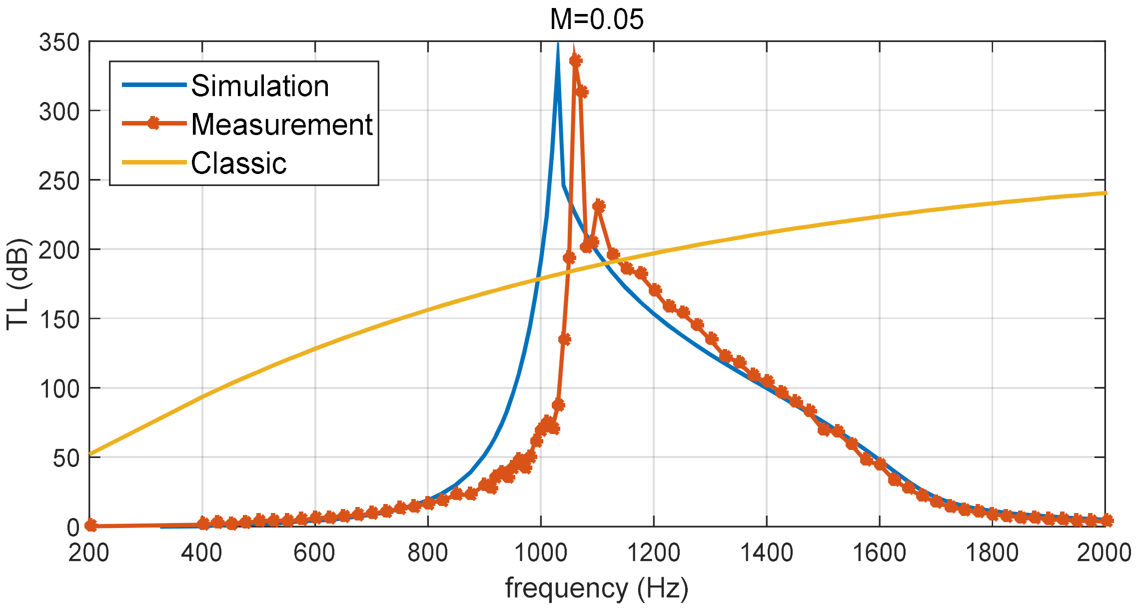
Conclusion

- Investigation of the acoustic dampíng properties of a particle agglomeration pipe
- The two-port data were measured including the rig reflections
- The results demonstrated negative transmission loss related to flow-sound interaction creating sound amplification and whistling
- The sound amplification was analysed using a power balance (two different formulations)
- The whistling was analysed by applying the Nyquist stability criterion
- The problem was also modelled numerically using a solver with a convected wave equation. This only worked for the no flow case since to capture the flow-sound interaction vorticity is required....

Cremer Impedance

✓ theoretically optimum impedance in an infinitely long duct

✓ ‘slow sound’ --- acoustic particle velocity



Zhang, Z., Tiikoja, H., Peerlings, L., and Abom, M., “Experimental Analysis on the ‘Exact’ Cremer Impedance in Rectangular Ducts,” SAE Technical Paper 2018-01-1523, 2018, doi:10.4271/2018-01-1523.

Competence Center for Gas Exchange

CCGEx

Thank you for your attention!

Energimyndigheten

SCANIA

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Power balance

Formulation 1:

$$\mathbf{P}_{p_\pm} = \begin{bmatrix} (1 \mp M_a)\sqrt{\dfrac{S_a}{\rho_{0a}c_{0a}}} \cdot p_{a\pm} \\ (1 \pm M_b)\sqrt{\dfrac{S_b}{\rho_{0b}c_{0b}}} \cdot p_{b\pm} \end{bmatrix}$$

$$\langle P_{out} \rangle = \mathbf{P}^*_{p_+}\mathbf{P}_{p_+} - \mathbf{P}^*_{p_-}\mathbf{P}_{p_-} = \mathbf{P}^*_{p_-}(\mathbf{S}^*_p\mathbf{S}_p)\mathbf{P}_{p_-} - \mathbf{P}^*_{p_-}\mathbf{P}_{p_-}$$

$$\mathbf{S}_p = \begin{bmatrix} \dfrac{1-M_a}{1+M_a}R_{aa} & \dfrac{1-M_a}{1-M_b}\sqrt{\dfrac{\rho_{0b}c_{0b}S_a}{\rho_{0a}c_{0a}S_b}} \cdot T_{ba} \\ \dfrac{1+M_b}{1+M_a}\sqrt{\dfrac{\rho_{0a}c_{0a}S_b}{\rho_{0b}c_{0b}S_a}} \cdot T_{ab} & \dfrac{1+M_b}{1-M_b}R_{bb} \end{bmatrix}$$

$$\langle \overline{P_{out,1\mathrm{W}}} \rangle = \sum_q \lambda_q \left|p'_q\right|^2 - 1$$

net power output assuming 1W incident power

$$\langle \overline{P^{max}_{out,1}} \rangle = \lambda_{max} - 1$$

$$\langle \overline{P^{min}_{out,1}} \rangle = \lambda_{min} - 1$$

maximum & minimum net power output

Aurégan Y., Starobinski R., (1999), “Determination of acoustical dissipation / production potentiality from the acoustical transfer function of a multiport”, Acta Acust united Ac, 85(6), 788-792

Power balance

Formulation 2 (New!):

$$\frac{P_{out}}{P_{in}^{a}} = \frac{|R_{aa}|^2(1-M_a)^2}{(1+M_a)^2} + \frac{|T_{ab}|^2(1+M_b)^2}{(1+M_a)^2}$$

$$\frac{P_{out}}{P_{in}^{b}} = \frac{|R_{bb}|^2(1+M_b)^2}{(1-M_b)^2} + \frac{|T_{ba}|^2(1-M_a)^2}{(1-M_b)^2}$$

power output with incident wave from the inlet and outlet, respectively, assuming uncorrelated but equal input

$$\langle \overline{P_{out,2}} \rangle = \frac{P_{out}}{P_{in}^{a}} + \frac{P_{out}}{P_{in}^{b}} - 2$$

total net power output

For both formulations, the incident sound power is $\left\{\begin{array}{l}\text{amplified} \\ \\ \text{dissipated}\end{array}\right.$ if $\langle \overline{P_{out}} \rangle$ is $\left\{\begin{array}{l}\text{larger} \\ \\ \text{smaller}\end{array}\right.$ than 0.