SmartAnswer
Nonlinear System Identification in Aeroacoustics

N. Sayyad Khodashenas[1], H. Bodén[2], S. Boij[3]

[1]PhD Candidate, [2]Professor , Department of Aeronautical and Vehicle Engineering, MWL, KTH . [3]Associate Professor, Department of Aeronautical and Vehicle Engineering, MWL, KTH. [4]Professor, Department of Aeronautical and Vehicle Engineering, MWL , KTH

Smart Mitigation of flow-induced Acoustic Radiation and Transmission for reduced Aircraft, surface traNSport, Workplaces and wind enERgy noise

Host institution

Marcus Wellenberg aboratoriet

Motivation

Perforate plates are in some applications used to **absorb sound**. They consist of plates, with small **hole** diameters in the order of a millimeter and with a low porosity. This material appears in many technical applications, e.g. automotive mufflers, and aircraft engine liners.

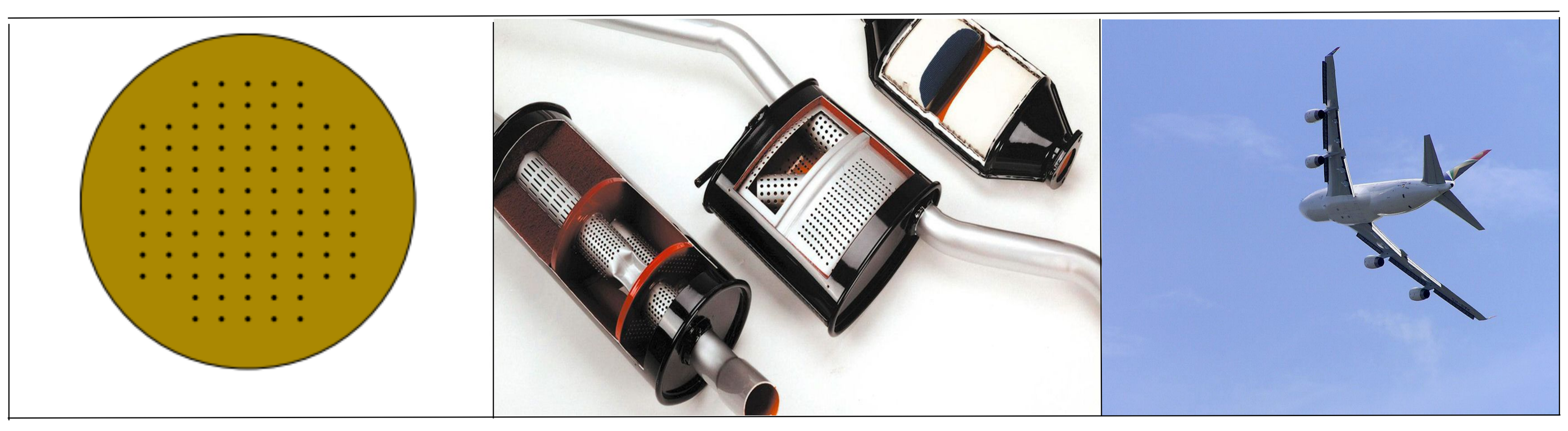

Fig.1 Schematic of samples and applications.

The noise reduction of the perforated plate can be influenced by the **mean flow and temperature field** as well as **high acoustic excitation levels.** If the **acoustic excitation is random** or **periodic** with multiple harmonics the acoustic properties at a certain frequency will depend also on the excitation level at other frequencies. Studying this harmonic interaction with the purpose to increase the physical understanding and to develop a model including these effects is the idea of this project.

Main objective of the present study

- To study the **non-linearity phenomenon** at the perforated plate which is associated with **large particle velocities.**
- To directly be able to extract the **non-linear acoustic properties including harmonic interaction** from a **limited set of experiments** using either **random** or **periodic** excitations.

Background

The quantities that characterize **the sample impedance** are **pressure difference over the sample** and **particle velocity through the sample.** In the **linear** case the impedance is independent of the excitation level but when the sound **pressure level is high** the perforate impedance is dependent on **the acoustic particle velocity in the holes**. Semi-empirical models indicate that the sample impedance is proportional to the **peak particle velocity** through the sample in the **non-linear** regime.

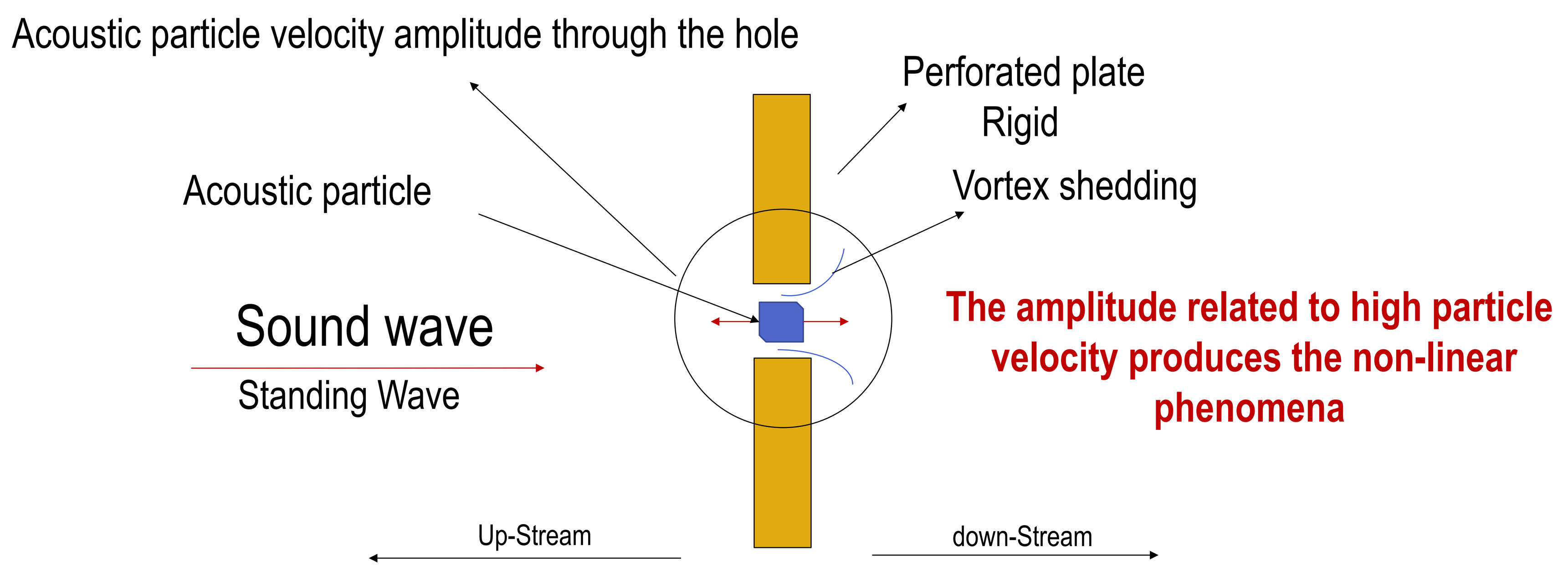

Fig. 2 Schematic of perforated plates.

Previous studies for tonal excitations has been made [1-3]. A preliminary study using **band-limited** broadband random excitation for different levels of excitations showed that it is **potentially promising to find a method** for determination of non-linear scattering matrix data [4].

Methodology

- **Experimental Approach**

Determination of the **non-linear acoustic properties in terms of the non-linear scattering matrix** of perforates in an impedance tube where the sample is placed in a holder in the middle of the duct.

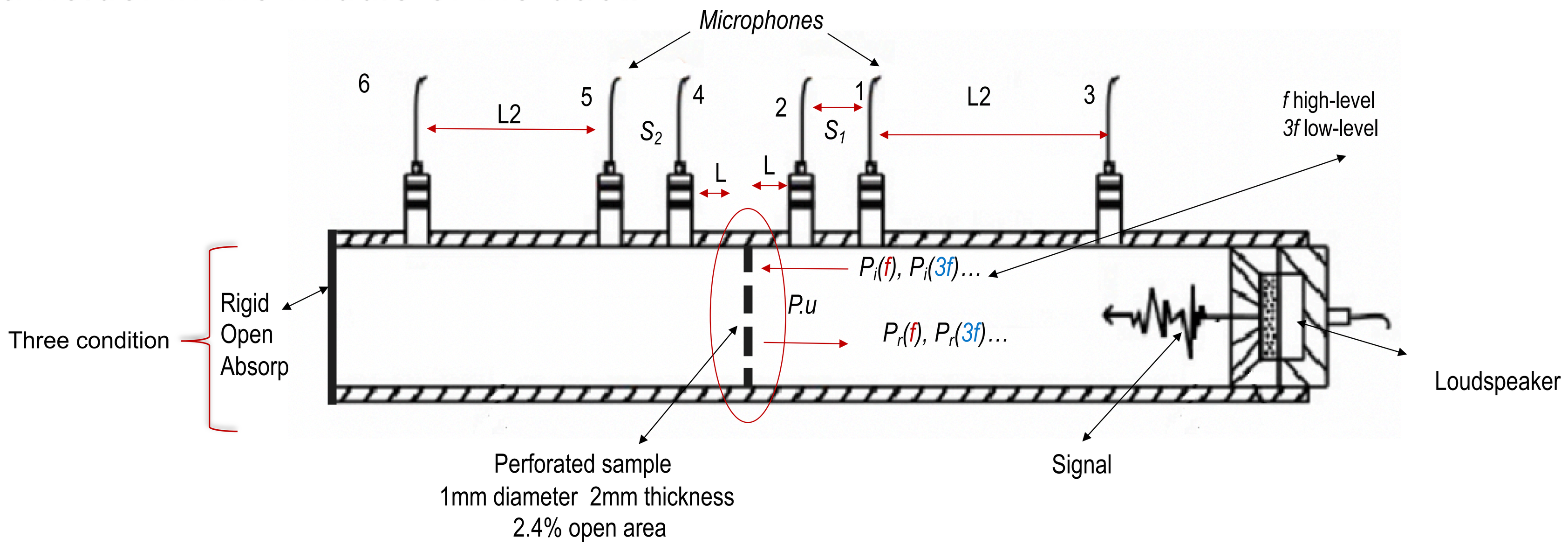

Fig. 3 Schematic of the setup.

Non-linear scattering matrix model

$$\begin{pmatrix} p_r(f) \\ p_r(3f) \end{pmatrix} = \begin{bmatrix} S_{f,f} & S_{f,3f} \\ S_{3f,f} & S_{3f,3f} \end{bmatrix} \begin{pmatrix} p_i(f) \\ p_i(3f) \end{pmatrix}$$

Indicator of the harmonic interaction

Assumptions for the model

$S_{f,f} = 0$ ⟷ **Negligible**

$S_{f,3f} = R(f)$ ⟷ **Reflection coefficient at *f* (non-linear)**

$S_{3f,3f} = R(3f)$ ⟷ **Low level (linear) result at *3f***

$S_{3f,f} = \frac{P_r(3f) - S_{3f,3f} P_i(3f)}{P_r(f)}$ ⟷ **Indication of harmonic interaction (non-linear)**

- **Analysis**

Comparison between the result of non-linear scattering matrix studies using **tonal, multi tone** and **broadband** excitation.

Result and Further Development

- **Result**

Scattering coefficient between incident wave excitation and three times of that for **tonal excitation** with different frequencies and varying levels of excitation

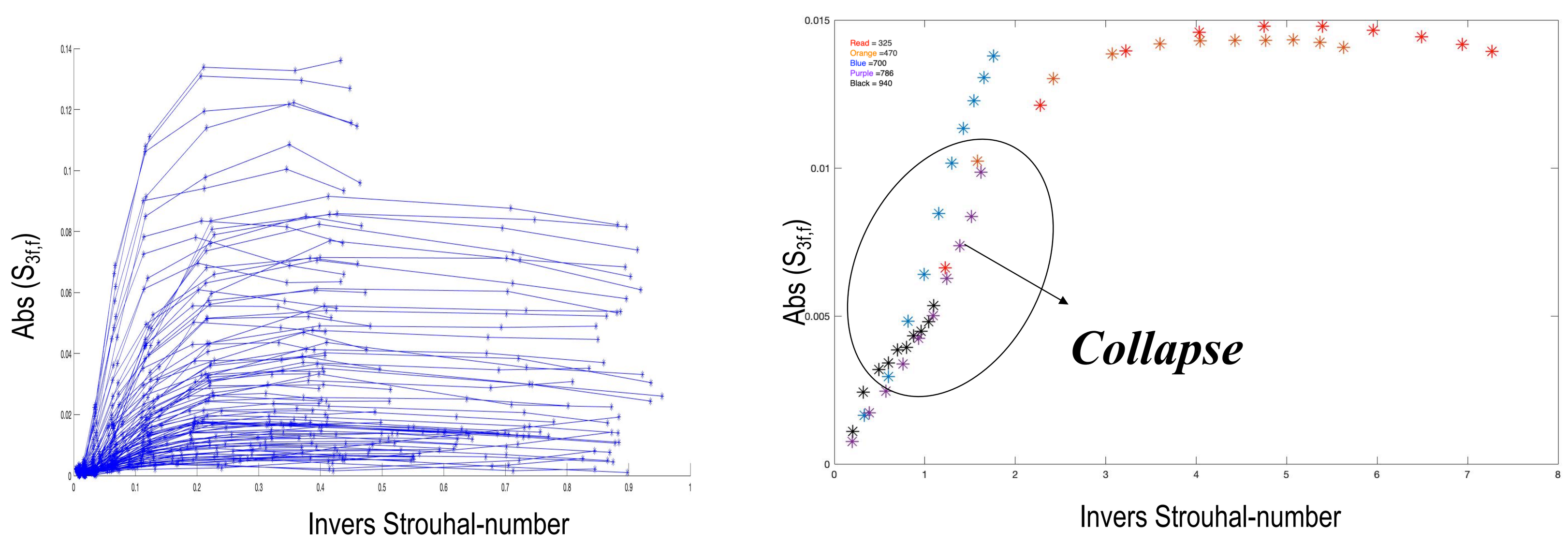

Fig. 4 Scattering matrix element $S_{3f,1f}$ for model.

- **Further development**
  - Perform experiments using tonal, multi ton and random excitation
  - Analyze phase relation between harmonics for different types of excitation
  - Analyze the Reflection factor, Transmission, and Absorption factor
  - Compare non-linear scattering matrix results obtained using tonal, multi tone and broadband excitation
  - Analyze data using other non-linear system identification techniques

References

[1] Bodén, Hans. "One-sided multi-port techniques for characterisation of in-duct samples with nonlinear acoustic properties." *Journal of Sound and Vibration* 331.13 (2012): 3050-3067.

[2] Bodén, Hans. "Two-sided multi-port techniques for characterisation of in-duct samples with non-linear acoustic properties." *Acta Acustica united with Acustica* 99.3 (2013): 359-378.

[3] Boden, Hans. "Non-linear System Identification Techniques for Determination of the Acoustic Properties of Perforates." *21st AIAA/CEAS Aeroacoustics Conference*. 2015.

[4] Khodashenas, Niloofar Sayyad, Hans Bodén, and Susann Boij. "Determination of nonlinear acoustic properties of perforates using band-limited random excitation." 11th European Congress and Exposition on Noise Control Engineering, Euronoise 2018 .

[5] Khodashenas, Niloofar Sayyad, Hans Bodén, and Susann Boij. "Determination of non-linear scattering matrices for perforated plates using tonal and random excitation." International Conference on Noise and Vibration Engineering, ISMA-USD 2020.

MARIE CURIE ACTIONS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 722401.