KTH ROYAL INSTITUTE
OF TECHNOLOGY

Particle Grouping in Vehicle Exhausts with Slow Sound

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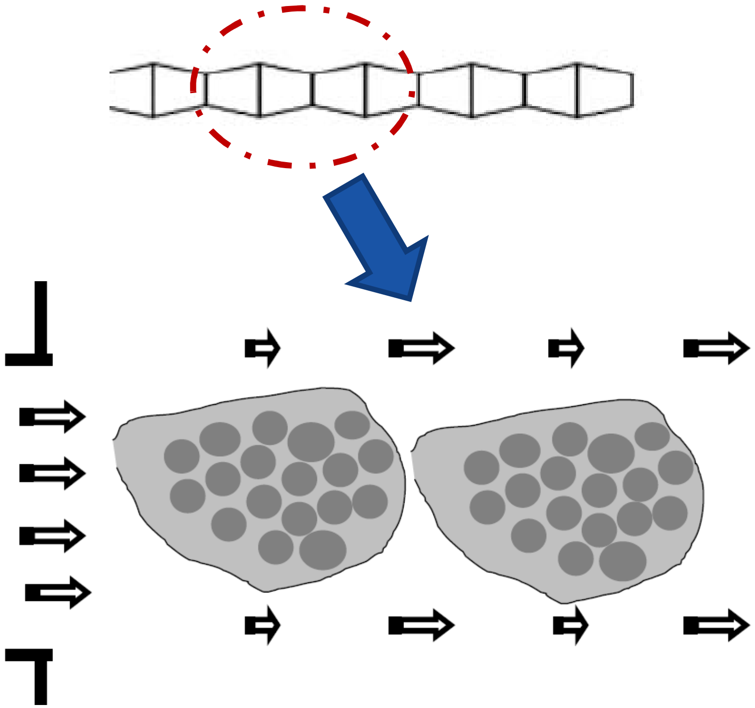
Energimyndigheten SCANIA VOLVO VOLVO BorgWarner

Outline

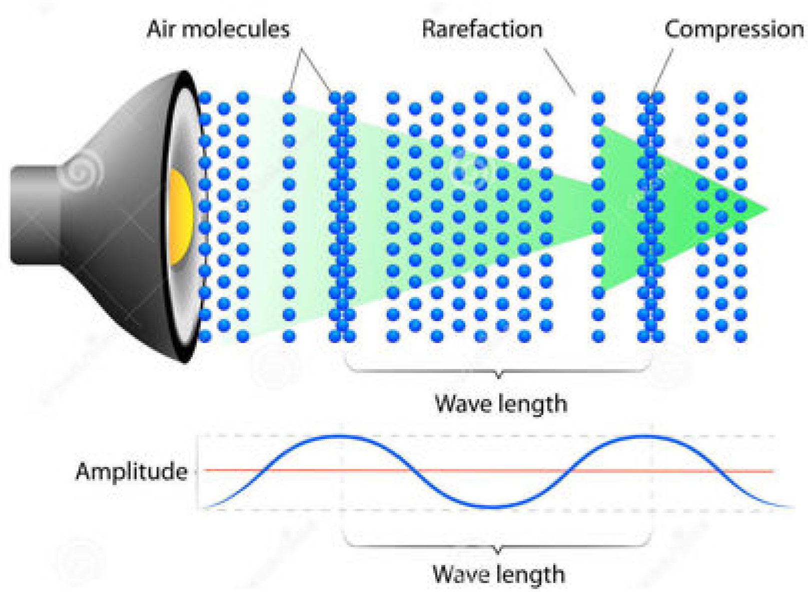
- **Introduction**
- **Model development**
- **Acoustic metamaterial ---- slow sound**
- **Agglomeration in metamaterial**

Introduction

Hydrodynamic



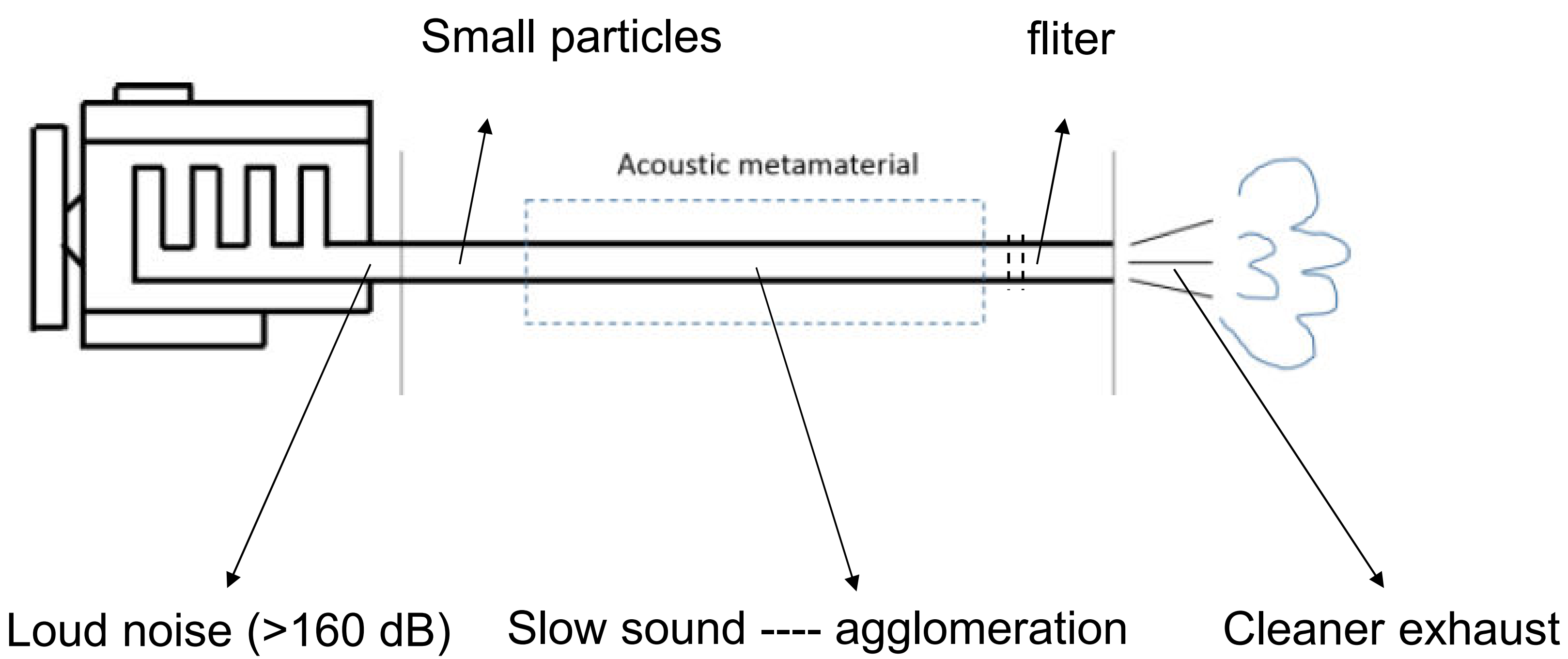
Acoustic



- **Acoustic metamaterials**

D. Katoshevski, "Particle grouping, a new method for reducing emission of submicron particles from diesel engines," Fuel 89: 2411-2416, 2010.

Introduction



Model Development

$$\rho_p V_p \frac{dv_p}{dt} = F_d = 6\pi r_p \mu_f (v_f' - v_p)$$

$$v_f' = V_a - V_{ac}\sin(kx - \omega t)$$

Acoustic particle velocity

$$\frac{du_p'}{d\tau} = \frac{1}{St}(u_f' - u_p')$$

$$\frac{dU_p'}{d\tau} = \frac{1}{St}(U_a - U_{ac}\sin X - U_p' - 1)$$

$$\beta = \frac{U_a - 1}{U_{ac}} = \frac{V_a - c}{V_{ac}} = \frac{c_0}{V_{ac}}$$

$$|\beta| \le 1$$

Z. Zhe, M. Åbom, H. Bodén, M. Karlsson D. Katoshevski, "Particle Number Reduction in Automotive Exhausts Using Acoustic Metamaterials ," SAE Engine, doi:10.4271/2017-01-0909.

Numerical Example ---- Normal Sound

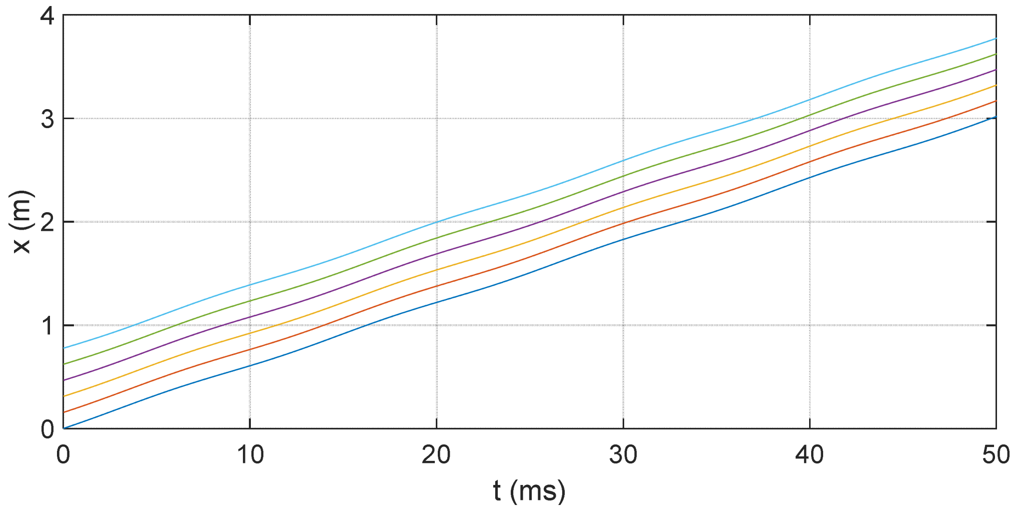
$$V_a = 60 m/s$$

$$V_{ac} = 6.8 m/s (160 dB)$$

$$c = c_0 + V_a = 400 (m/s)$$

$$\beta = \frac{U_a - 1}{U_{ac}} = \frac{V_a - c}{V_{ac}} = 50$$

Particle trajectory



Numerical Example ---- Slow Sound

$$V_a = 60 m/s$$

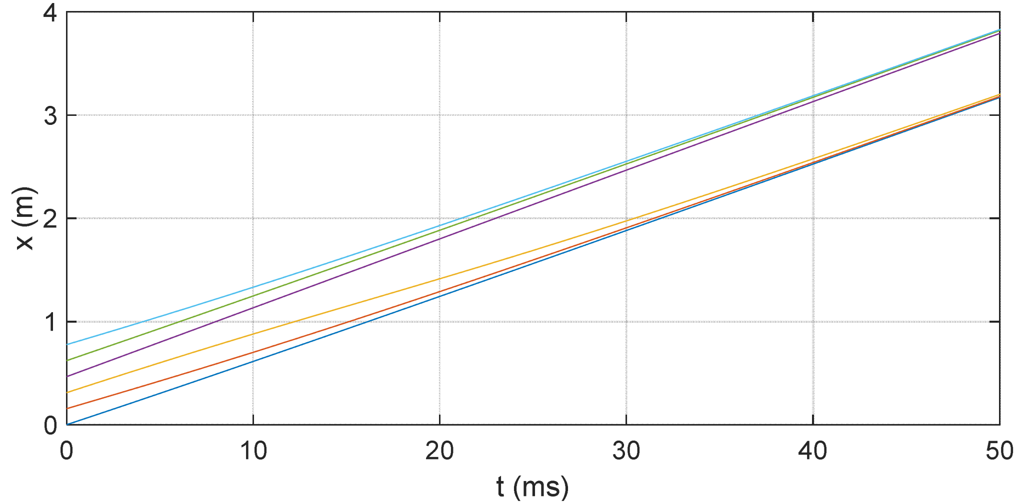
$$V_{ac} = 6.8 m/s (160 dB)$$

$$c \in [53.2, \quad 66.8] (m/s)$$

$$\beta = \frac{U_a - 1}{U_{ac}} = \frac{V_a - c}{V_{ac}} \in [-1, 1]$$

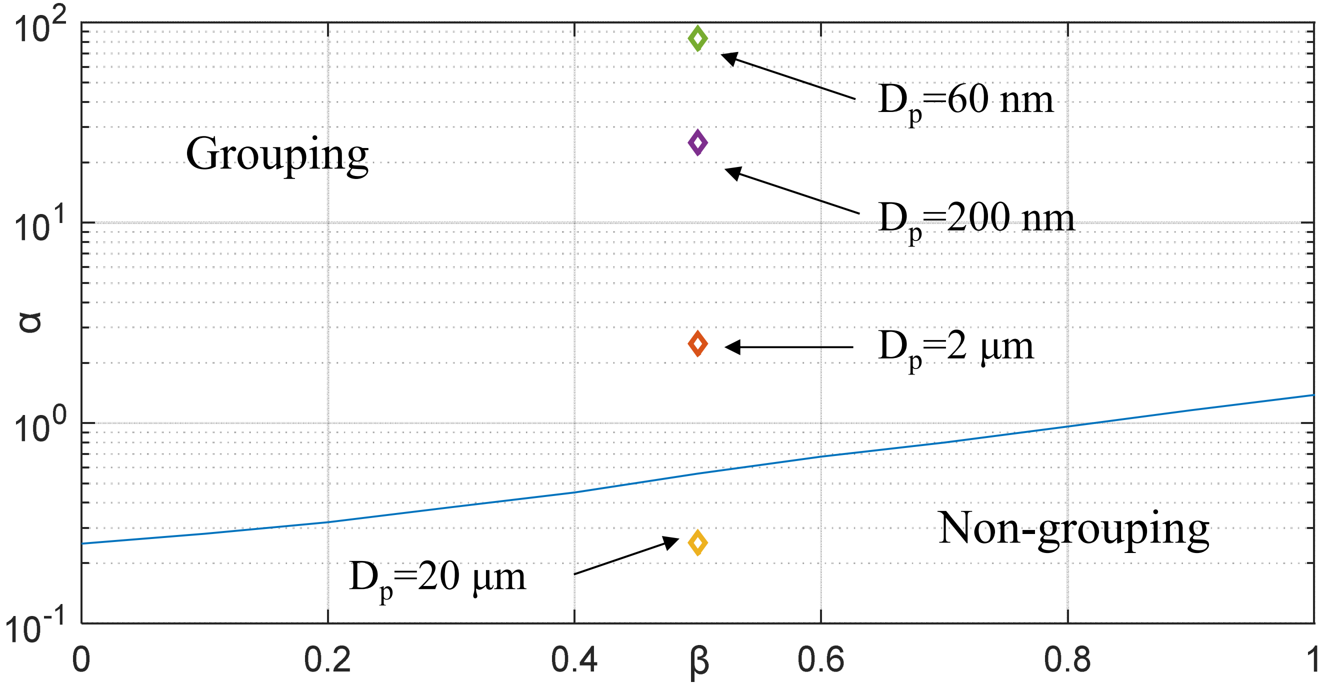
$$c_0 \in [-6.8, \quad 6.8] (m/s)$$

Particle trajectory



Numerical Example ---- Slow Sound

$$\alpha = 1/\sqrt{StU_{ac}} \propto 1/D_p$$



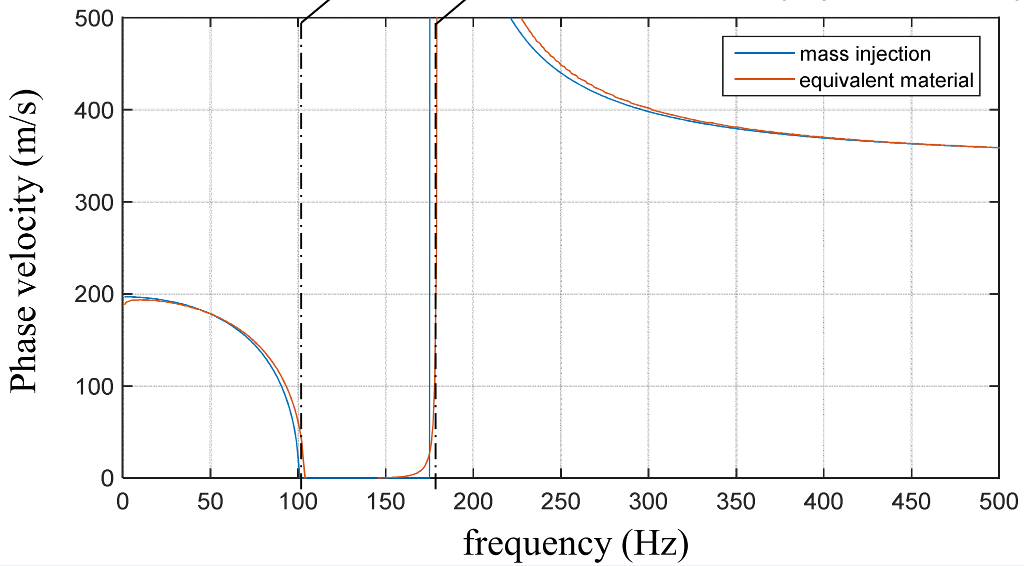
Acoustic Metamaterial ---- Slow Sound

- Artificially fabricated composite structures
- Slow sound in certain frequency ranges

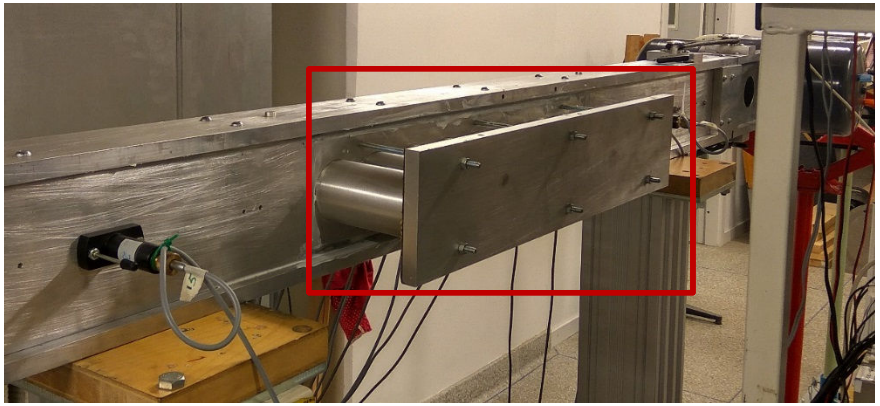
$$c = \mathrm{Re}\left(\frac{c_0}{1+\sqrt{\rho_0 c_0^2 / i\omega d_h Z_w}}\right)$$

Resonance frequency

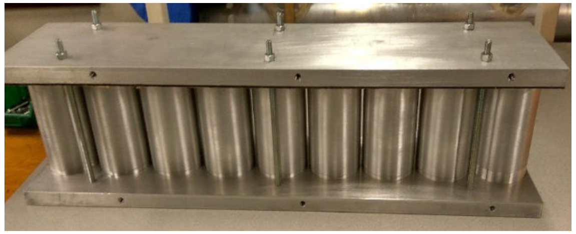
Threshold frequency (decided by d_h)

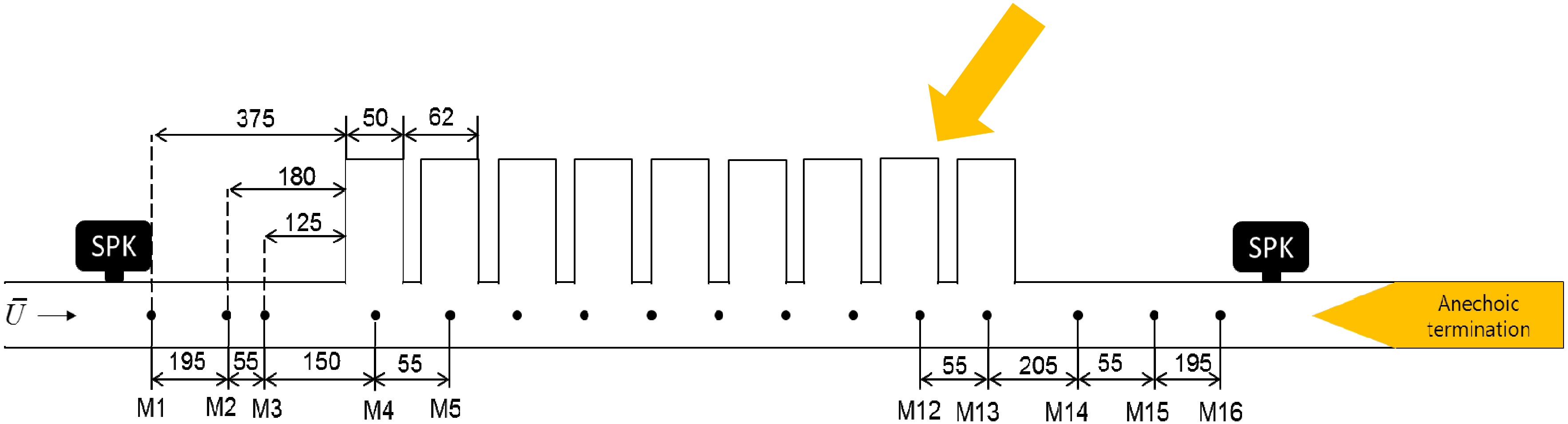


Acoustic Metamaterial ---- Measurement



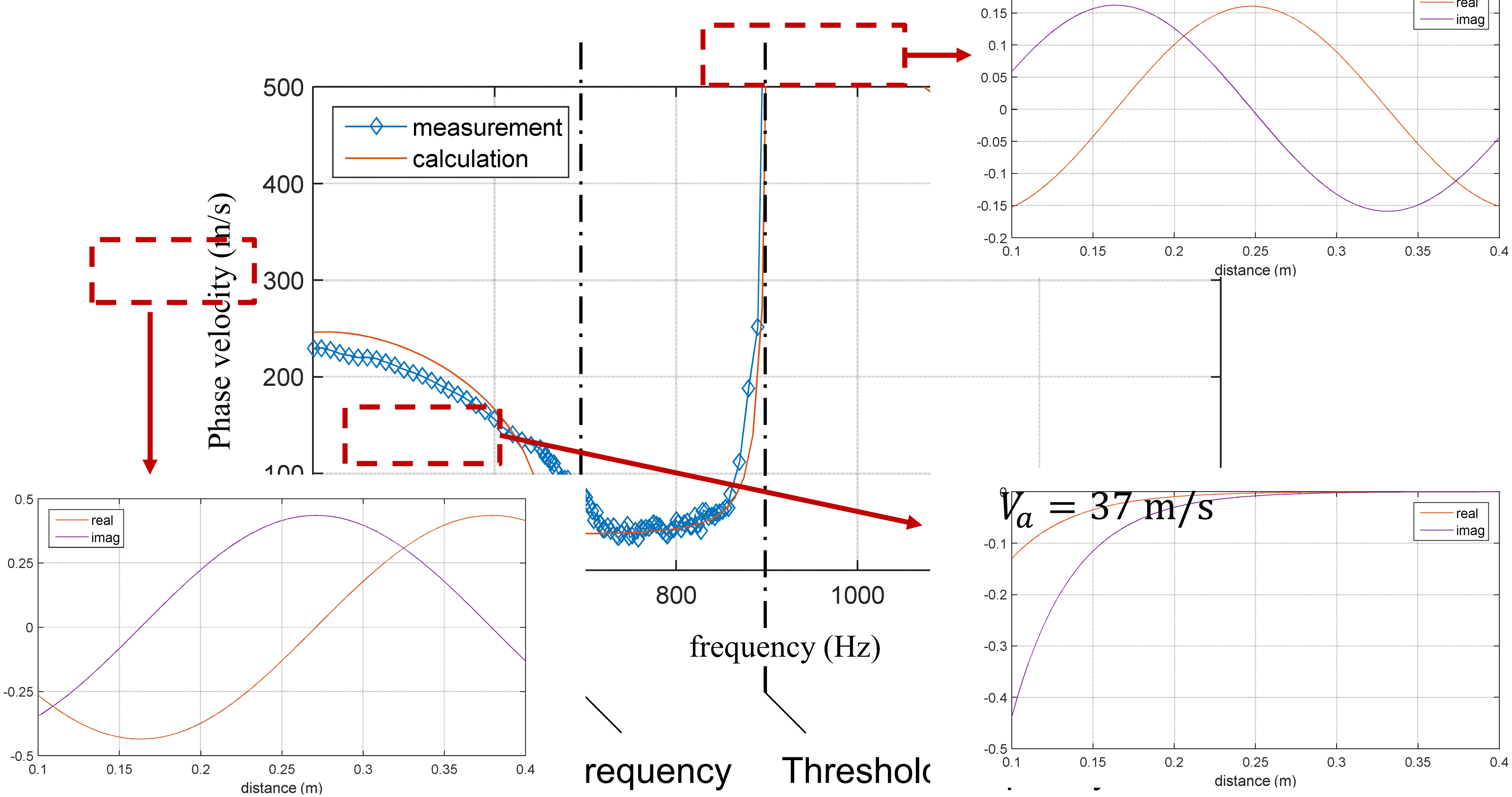
Metamaterial prototype





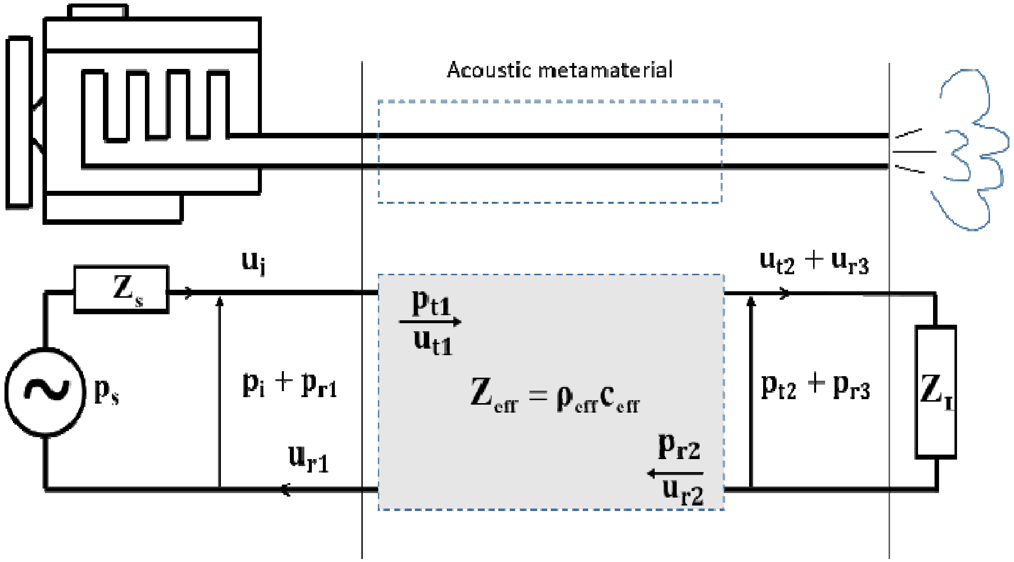
Acoustic Metamaterial ---- Measurement

$$\beta = \frac{V_a - c}{V_{ac}} < 1$$



Agglomeration in Metamaterial

$$|\beta| = \left|\frac{V_a - c}{V_{ac}}\right|$$



Upstream

$$p_i + p_{r1} = p_{t1} + p_{r2}$$
$$u_i + u_{r1} = u_{t1} + u_{r2}$$

Downstream

$$p_{t1} + p_{r2} = p_{t2} + p_{r3}$$
$$u_{t1} + u_{r2} = u_{t2} + u_{r3}$$

Inlet

$$p_i + p_{r1} = p_s + Z_s' u_i$$

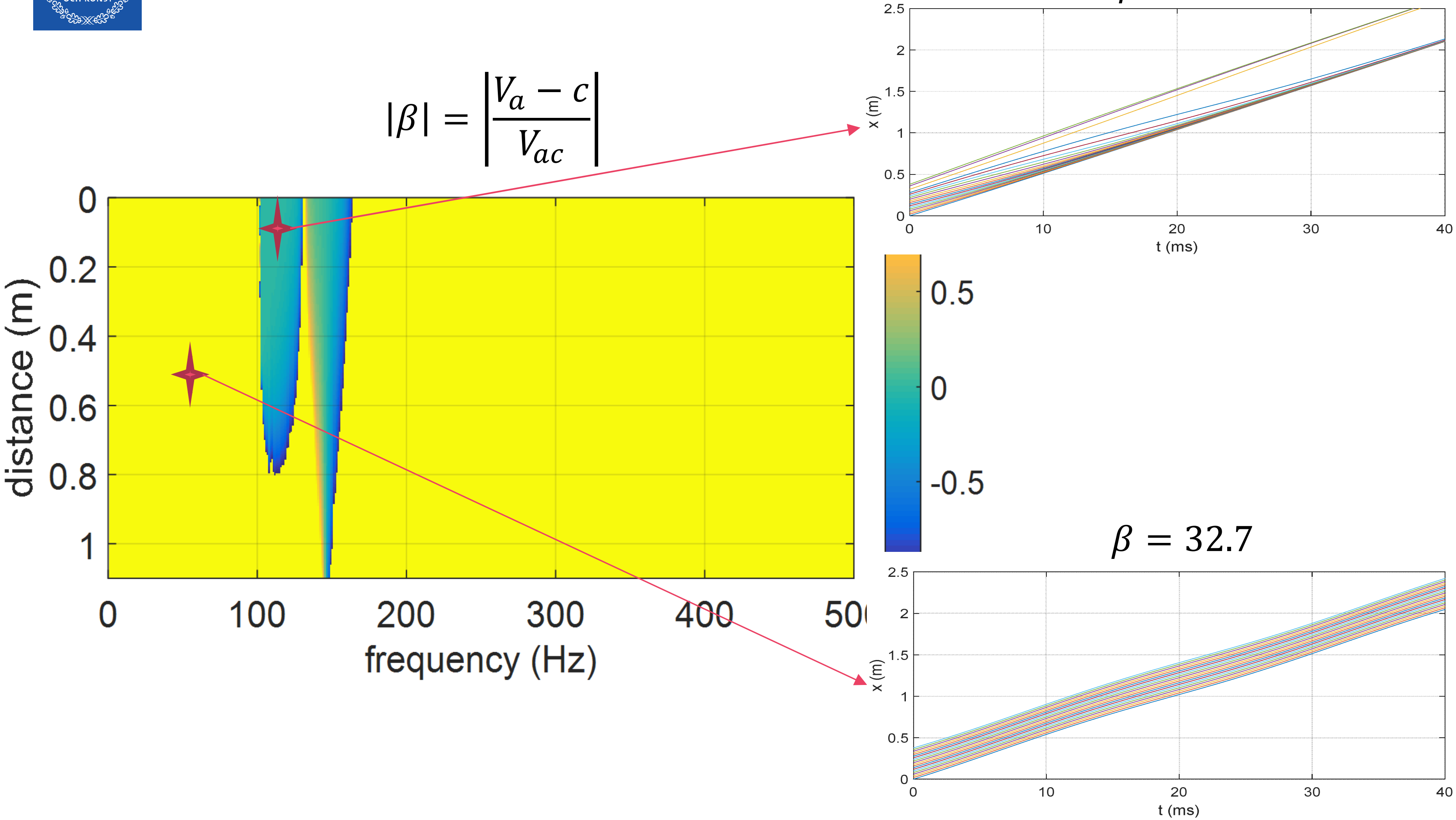
Outlet

$$p_{t2} + p_{r3} = Z_L'(u_{t2} + u_{r3})$$

$$V_{ac}(f, x) = \frac{p_{t1} + p_{r2}}{Z_{eff} S}$$

Agglomeration in Metamaterial

$$|\beta| = \left|\frac{V_a - c}{V_{ac}}\right|$$



Conclusion

- An acoustic approach to increase particle size and reduce particle number
- Acoustic metamaterial ---- slow sound

  ---- decaying wave

- Agglomeration in metamaterial (need experimental validation)

Thank you for your attention!

Competence Center for Gas Exchange

CCGEx

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