

Untersuchung von schallabsorbierenden Wänden in Strömungskanälen

Anita Schulz

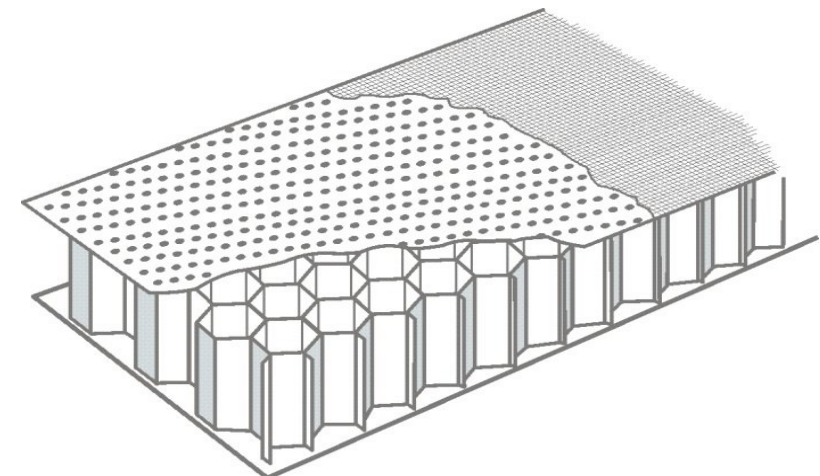
HTW FB1 Research School Kolloquium, Berlin, 02.05.2024

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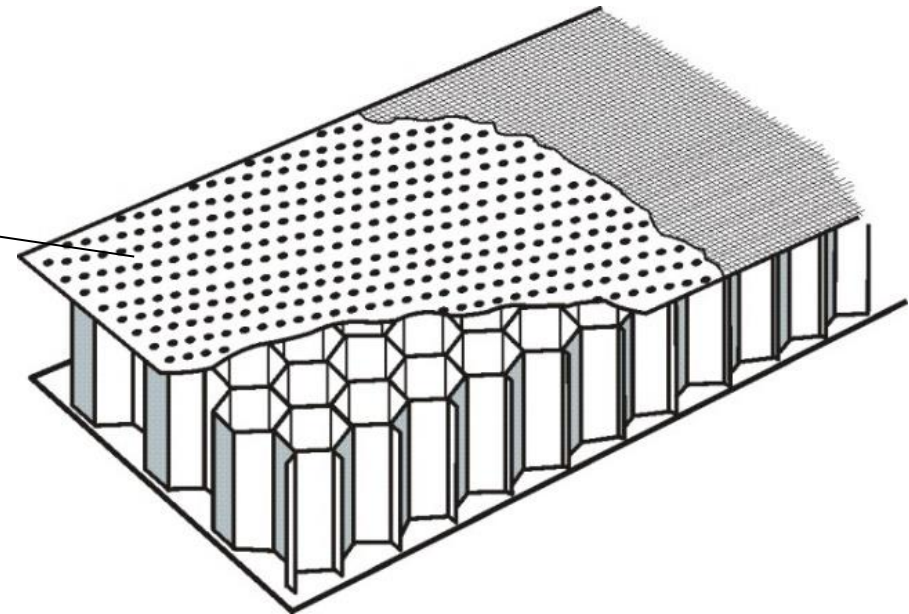
University of Applied Sciences

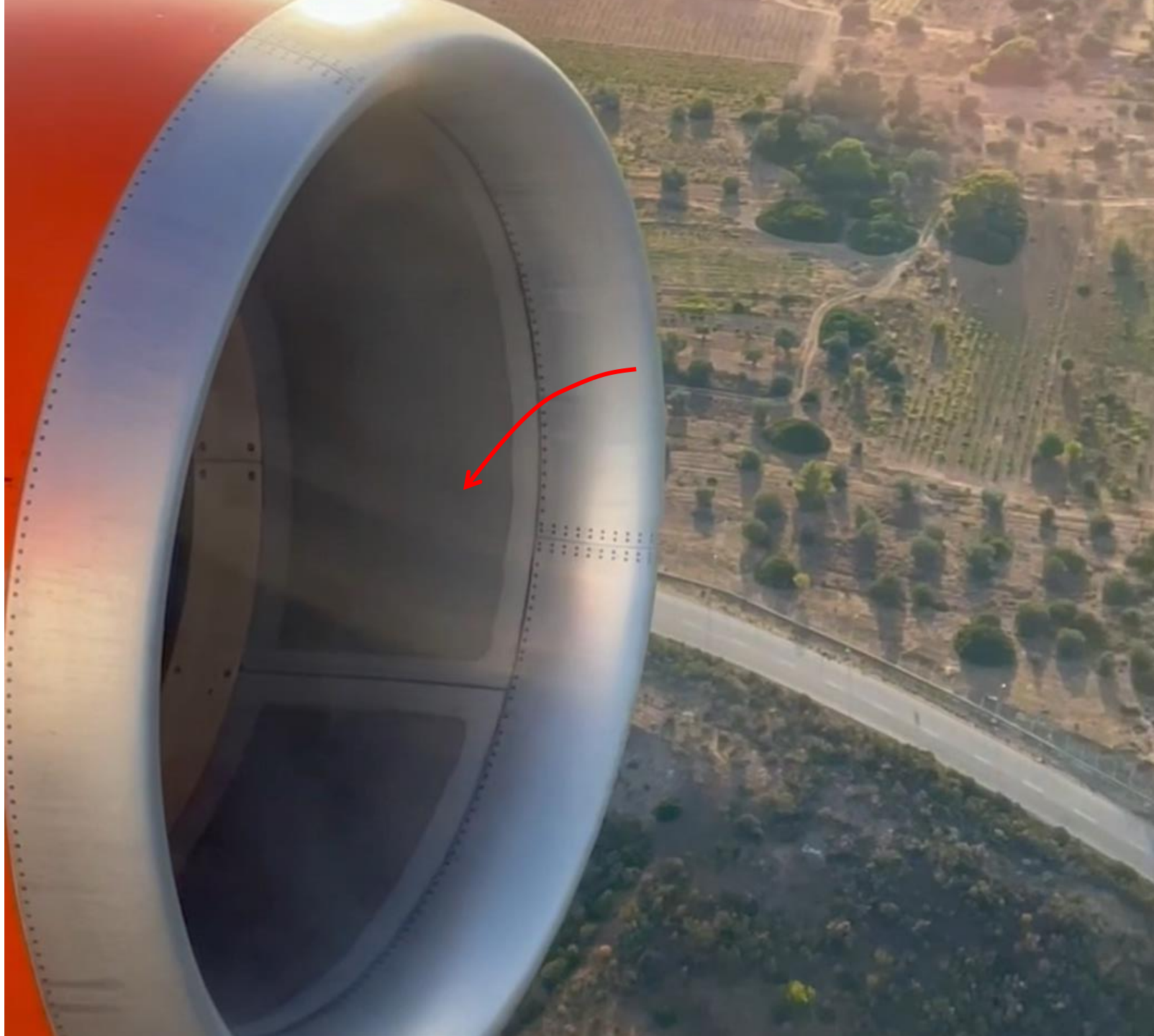


Liner im Triebwerk

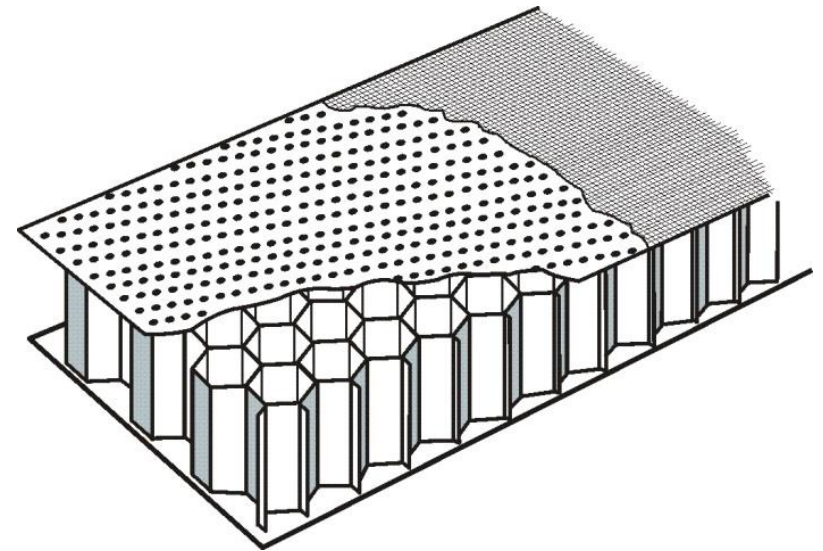


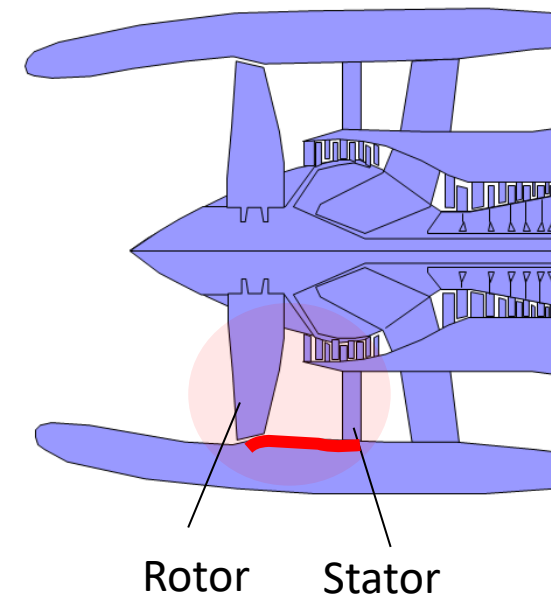
Akustisch dämpfende Wandauskleidung





Perforierte, akustische
Wände (acoustic liner)



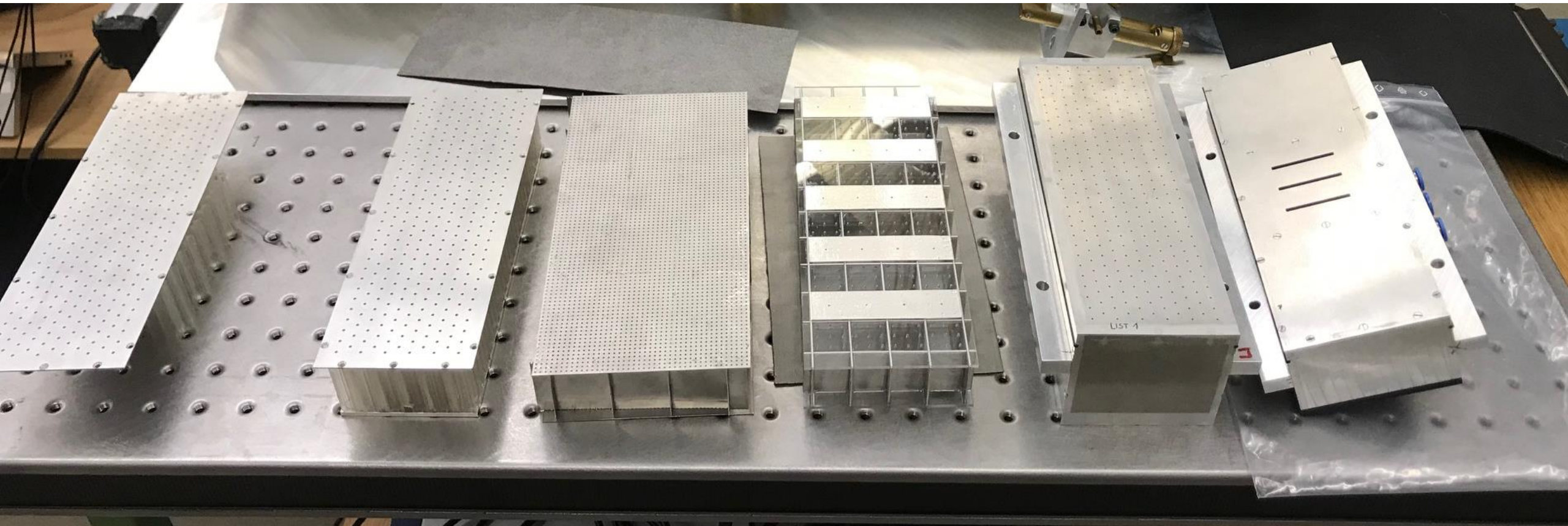




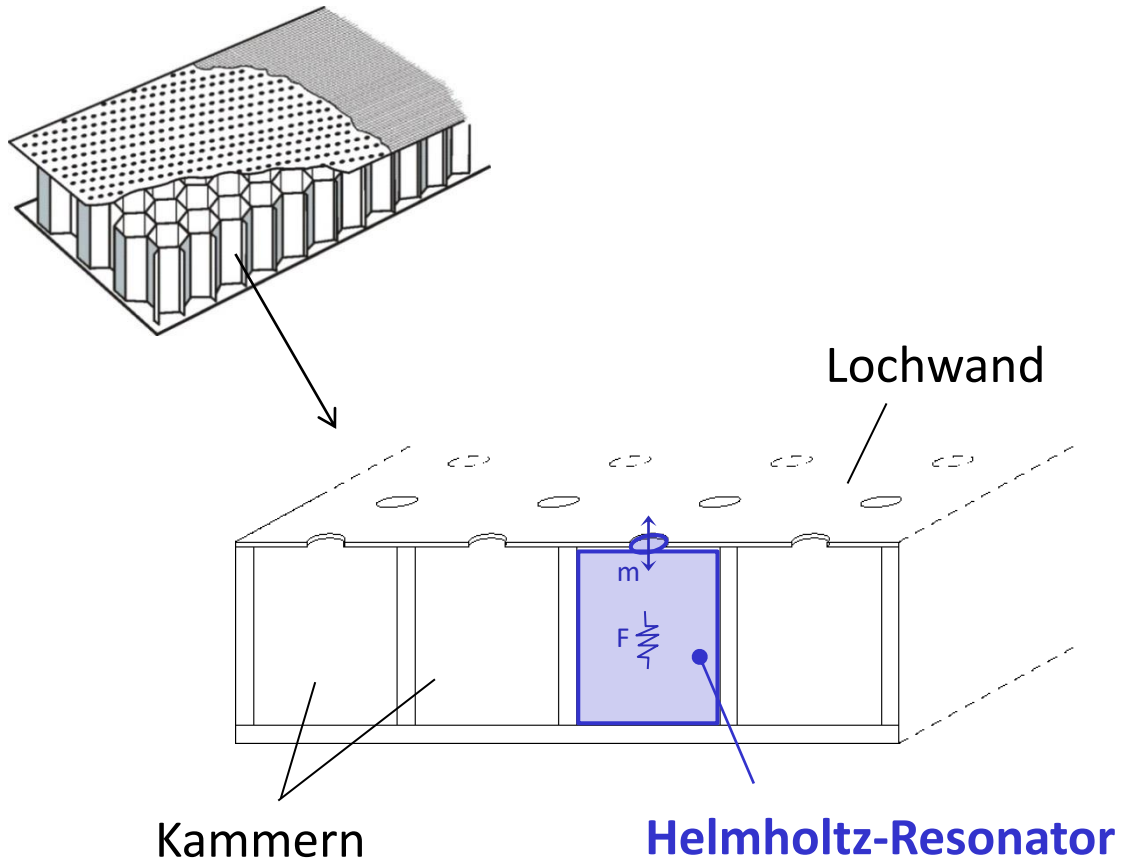
Perforierte Liner

Experimentelle Untersuchung von Linern

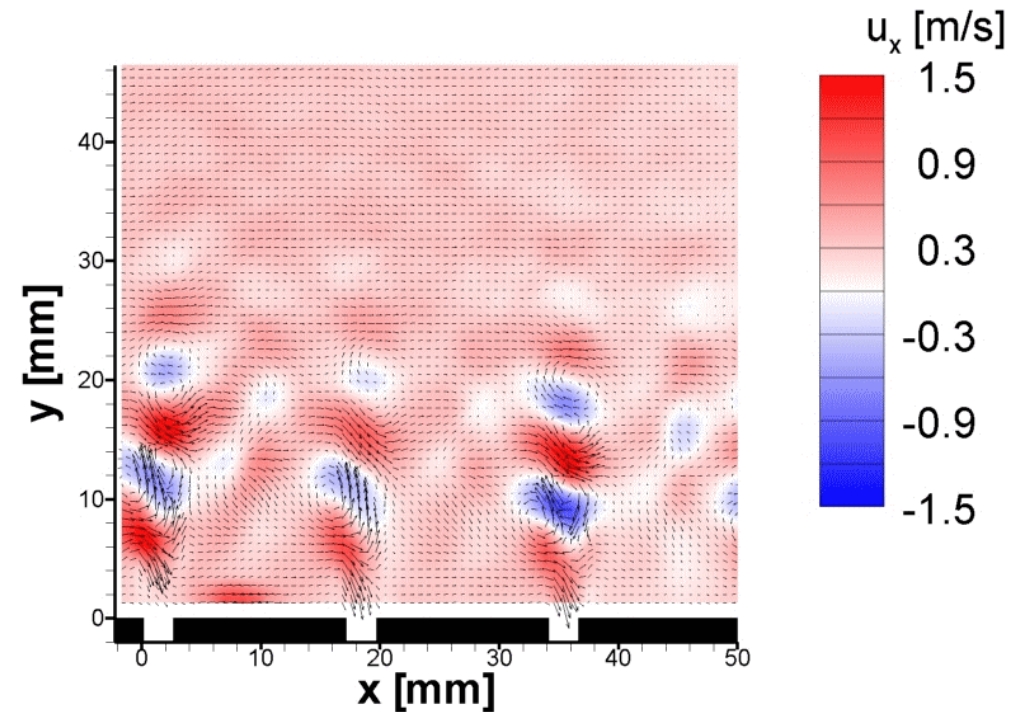
Verschiedene Geometrien, Dämpfungsprinzipien, Betriebsparameter ...



Verschiedene Schalldämpfungs-Mechanismen

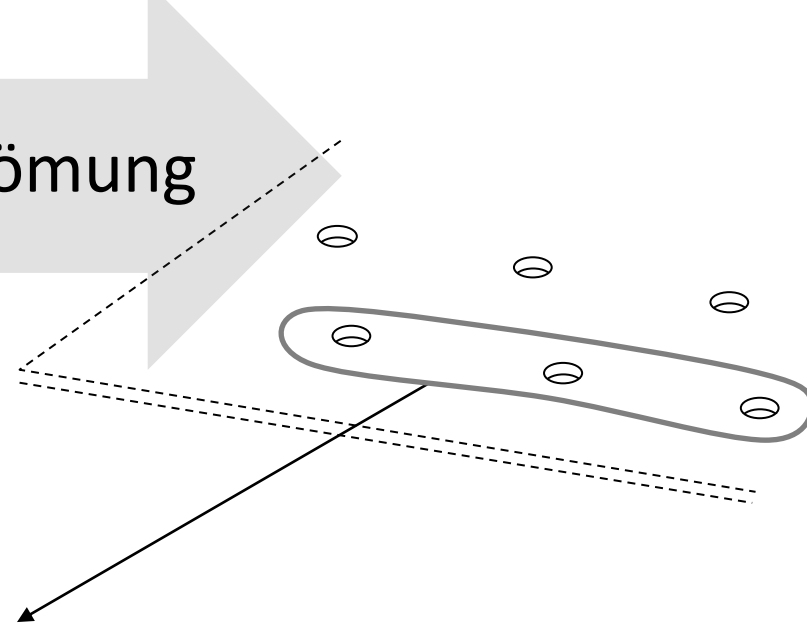


Dissipation durch viskose Reibung

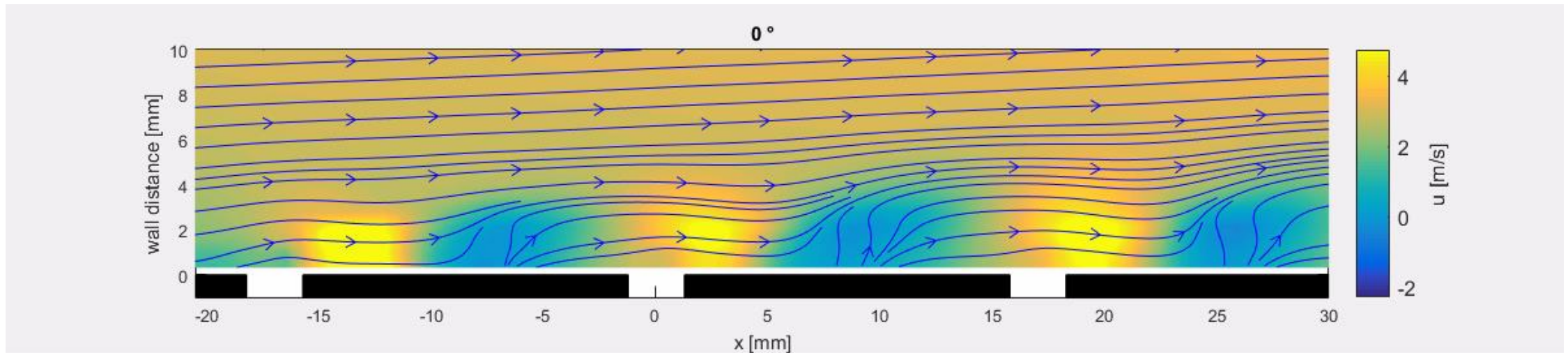


Dämpfung durch Wirbelablösungen

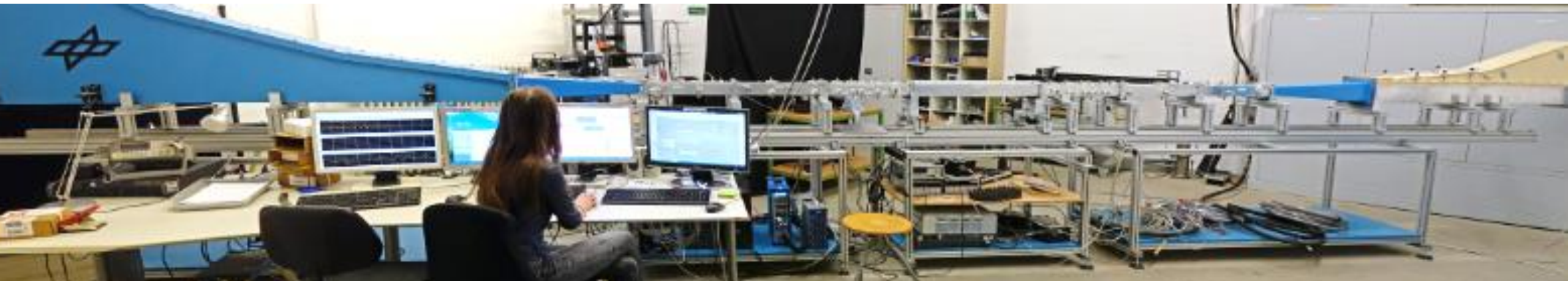
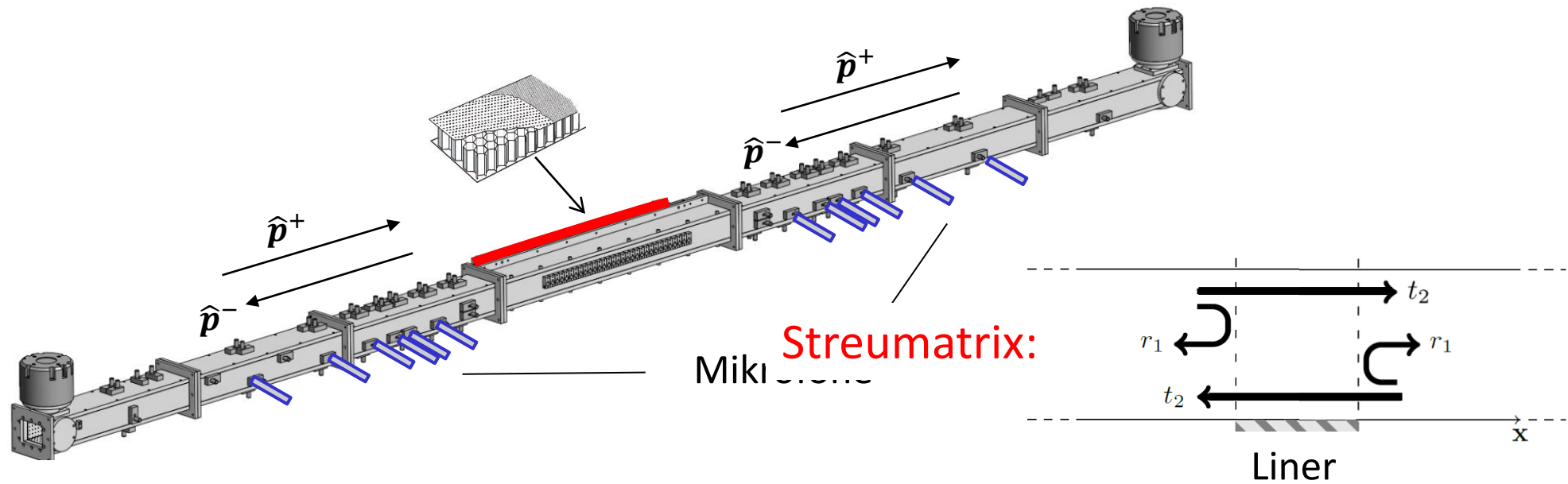
Strömung



Dämpfung durch Wirbelablösung bei überströmten Öffnungen

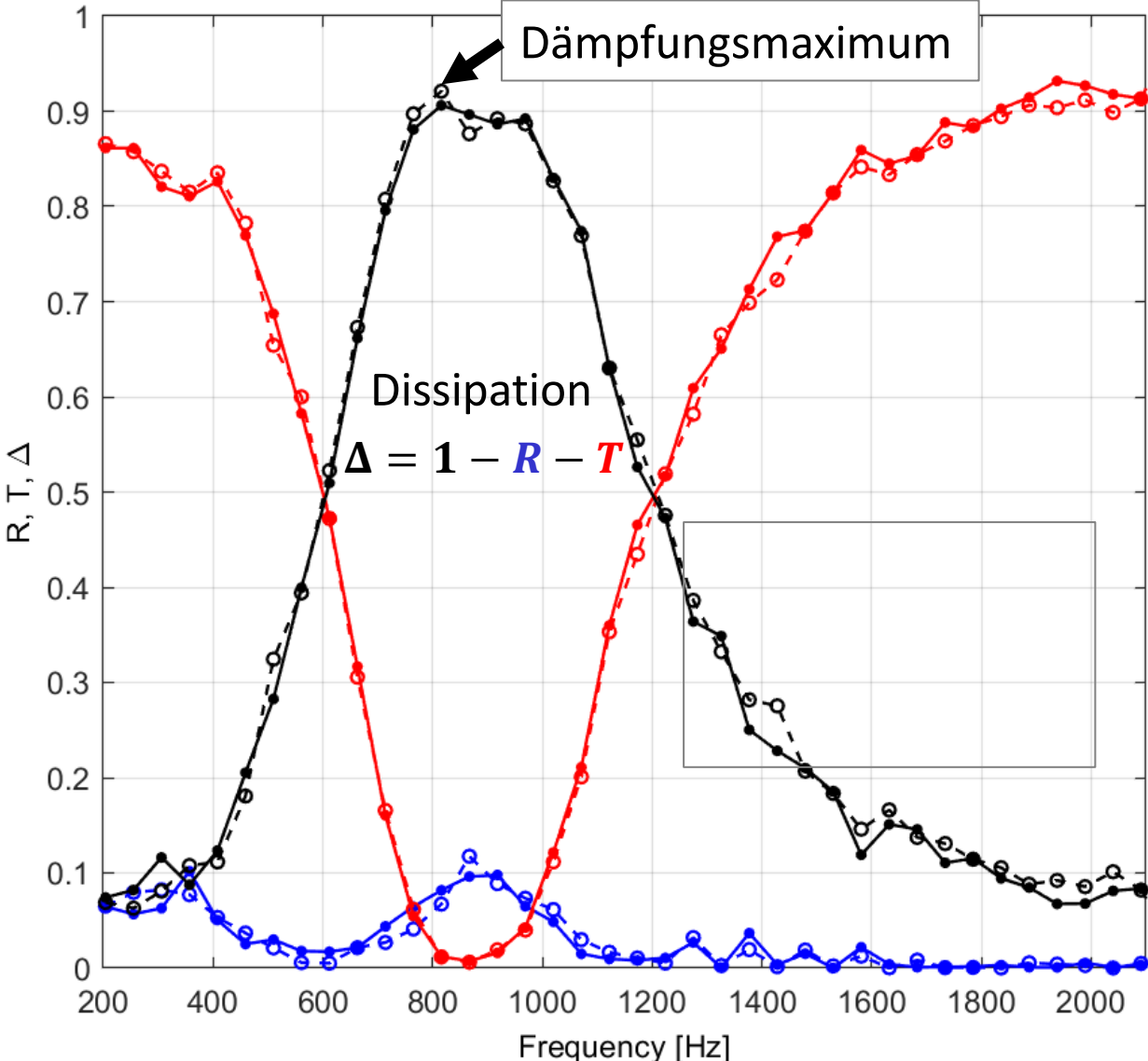
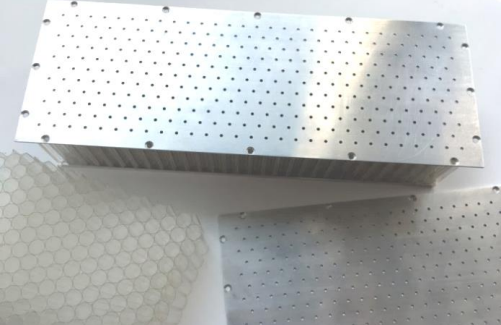


Experimentelle Charakterisierung



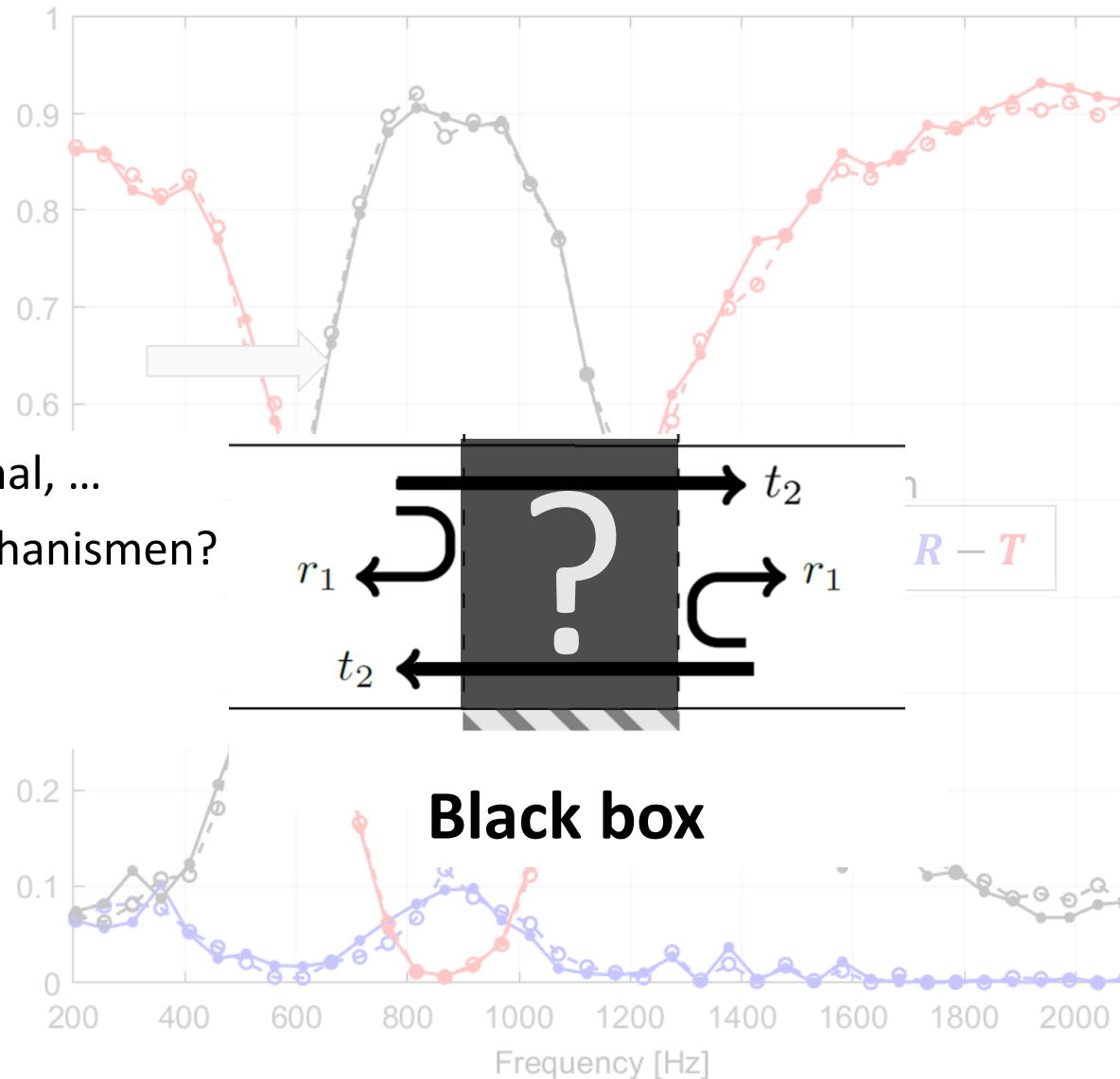
Messung der Streukoeffizienten

Resonator-Liner

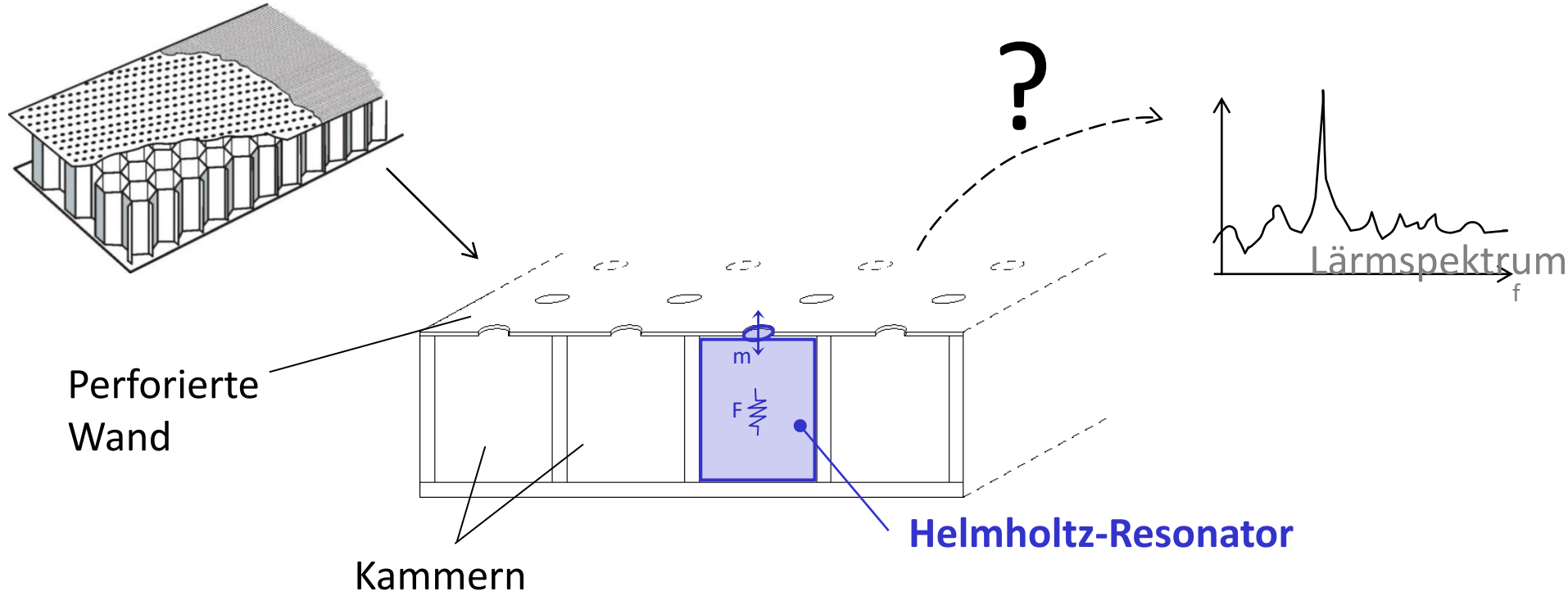


Messung der Streukoeffizienten

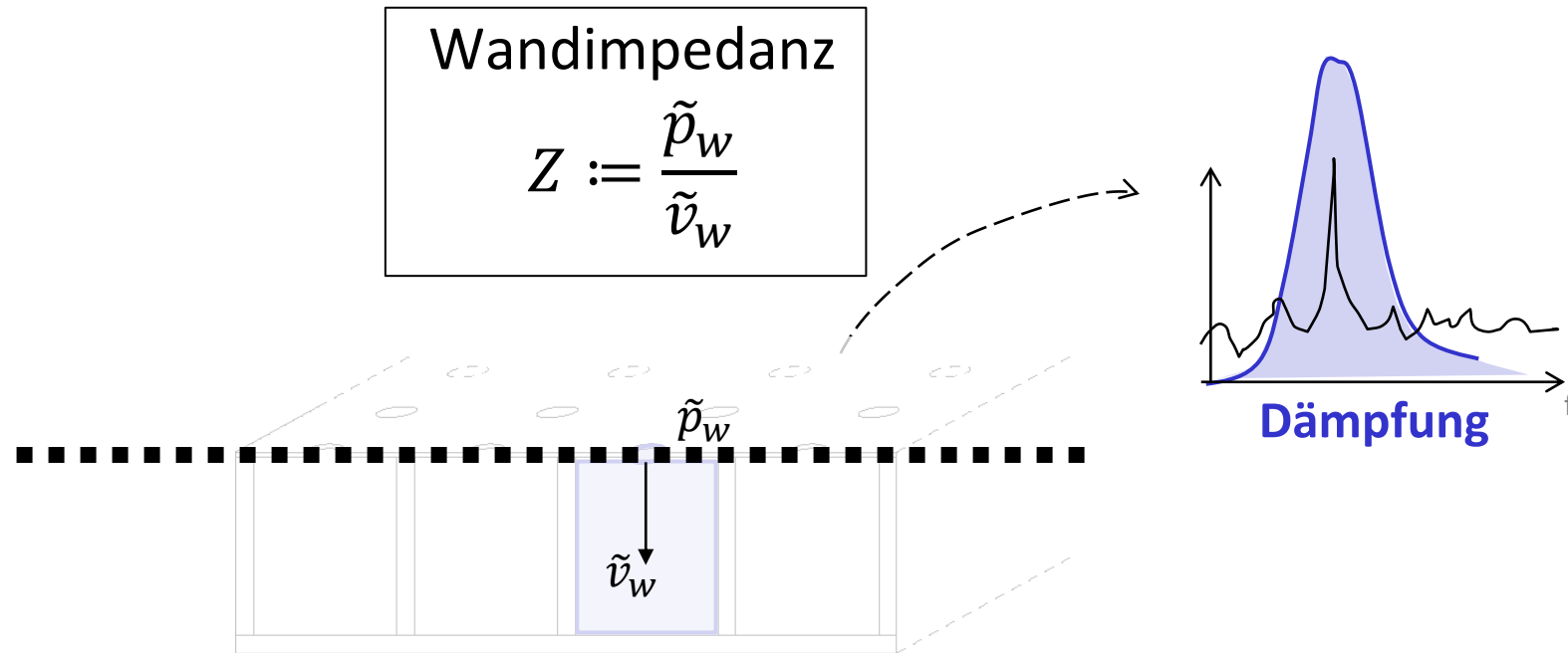
- Abhängig von Einbausituation, Kanal, ...
- Rückschlüsse auf Dämpfungs-Mechanismen?
- Vorhersagen? Modellbildung?



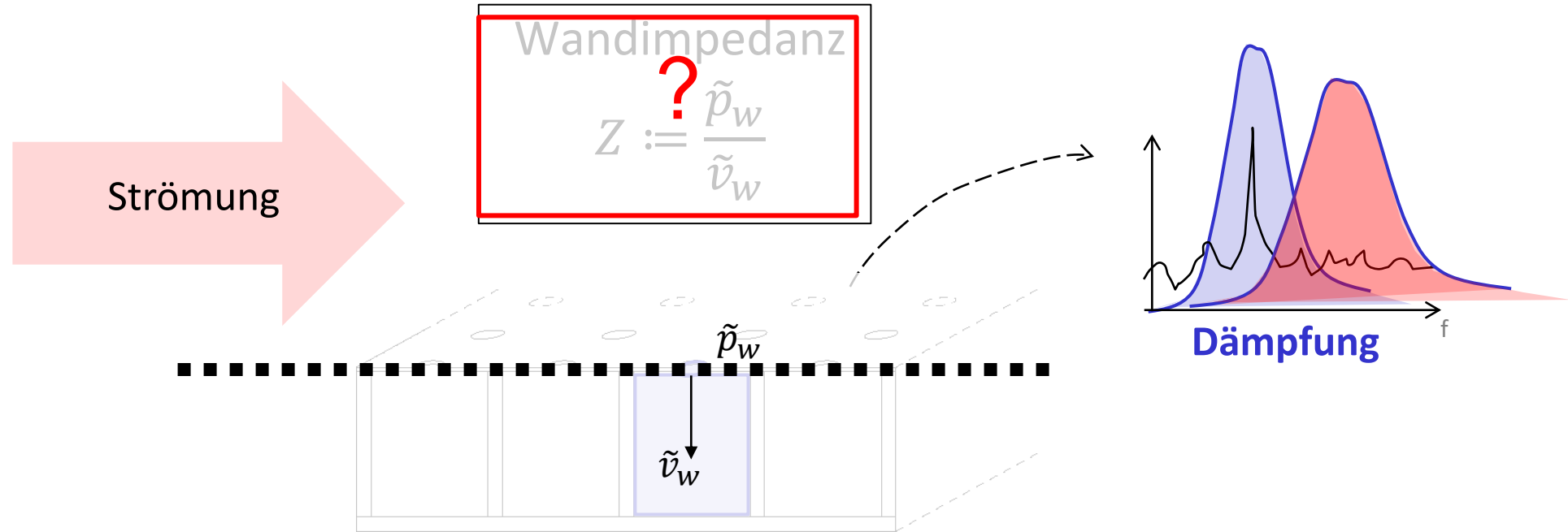
Gezielte Auslegung von Linern



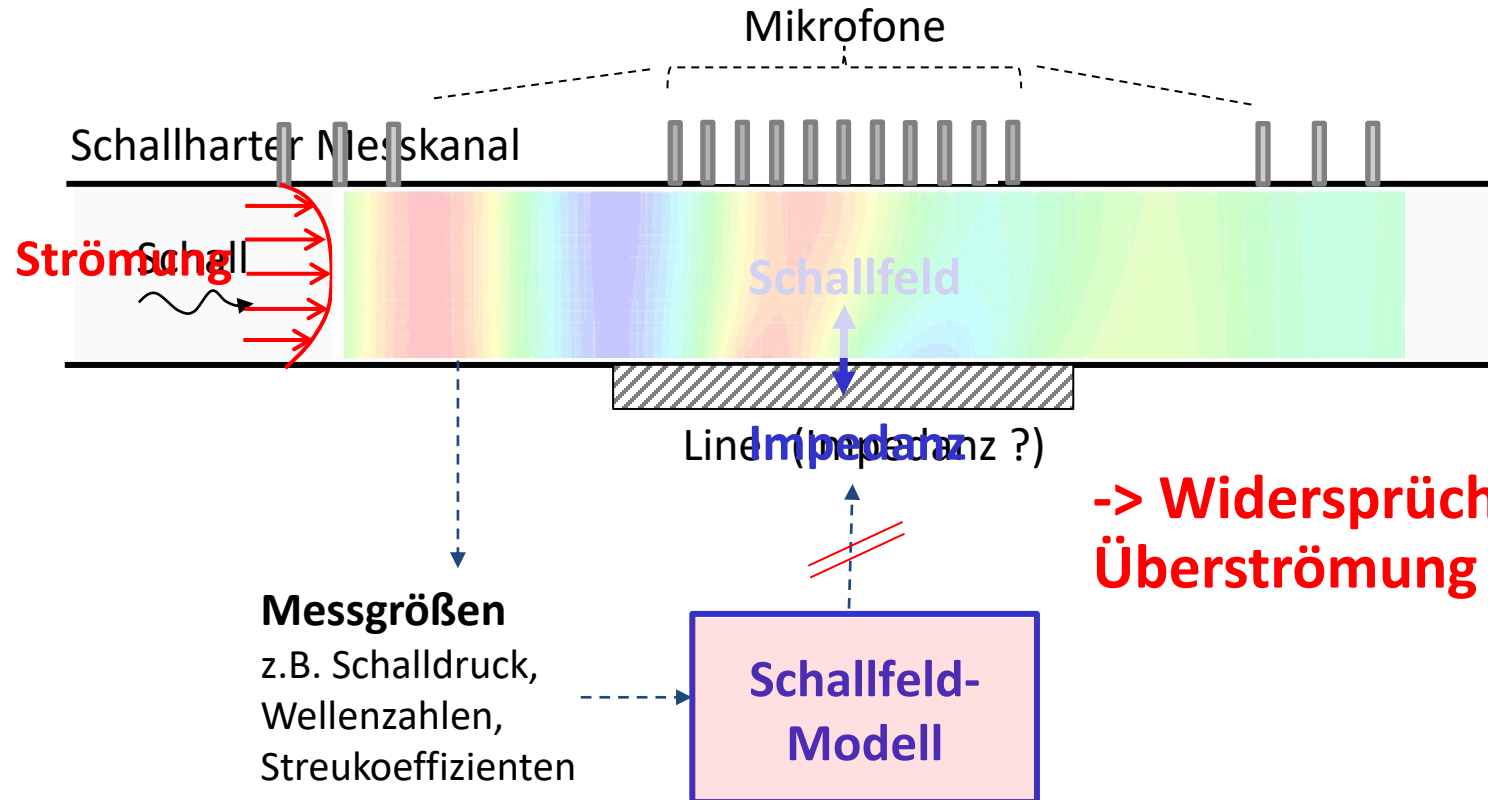
Akustische Randbedingung muss bekannt sein



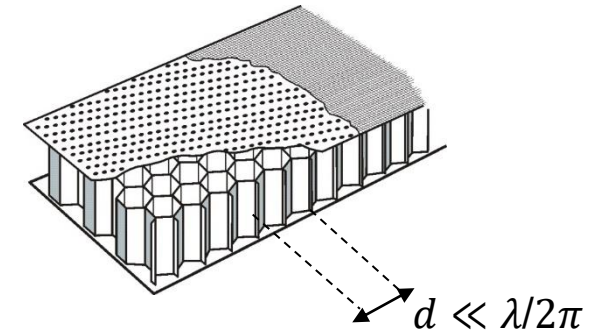
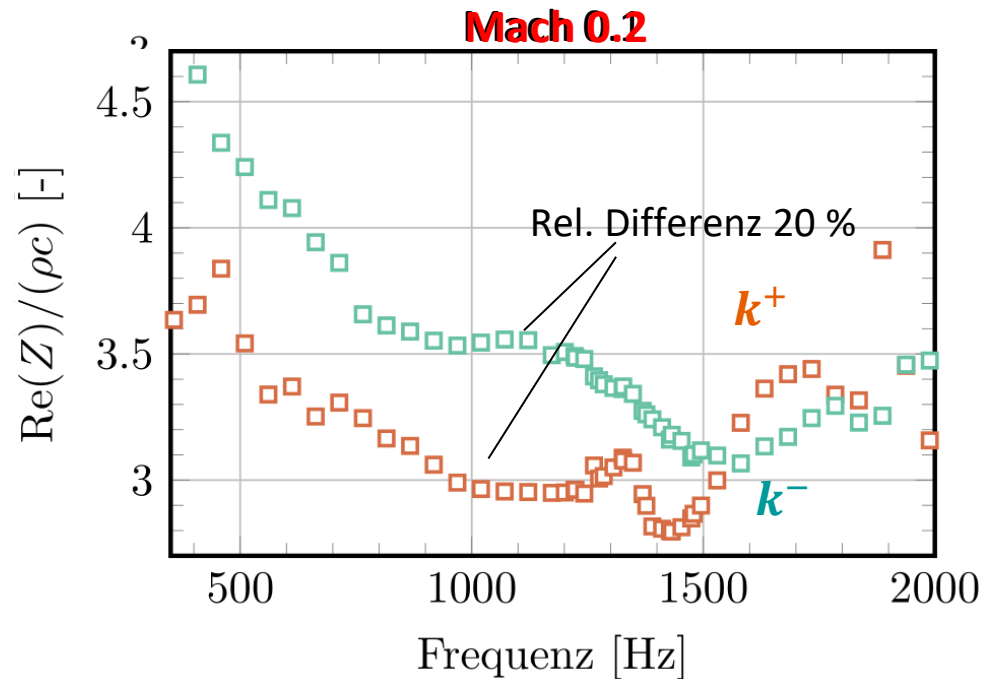
Falsche Vorhersagen



Indirekte Impedanzmessung



Problem mit Strömung



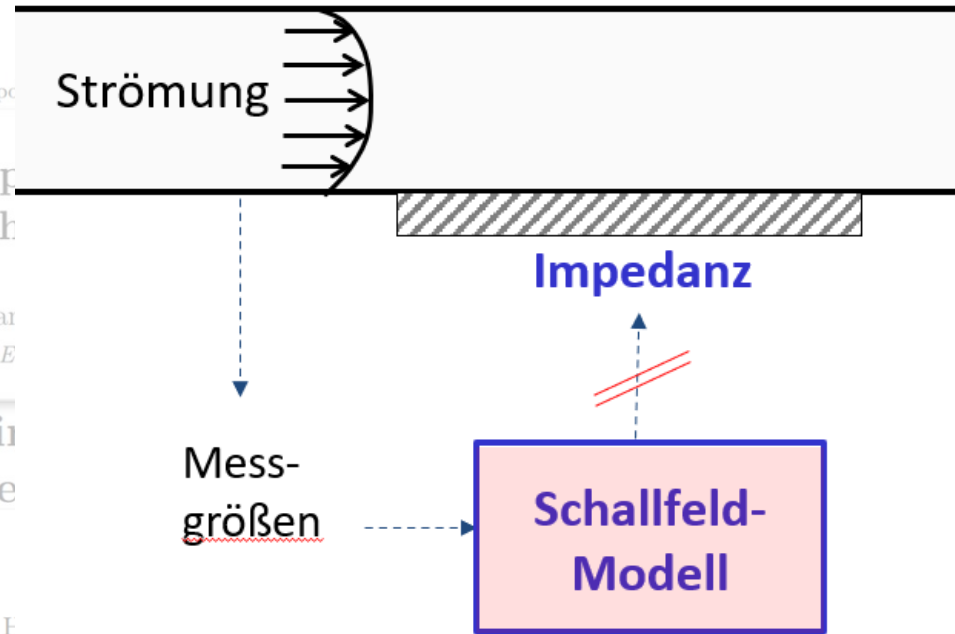
Lokal reagierender Liner, also

$$\frac{\partial Z}{\partial k} \equiv 0$$

Widerspruch: Impedanz ist von der räumlichen Schallfeldstruktur abhängig.

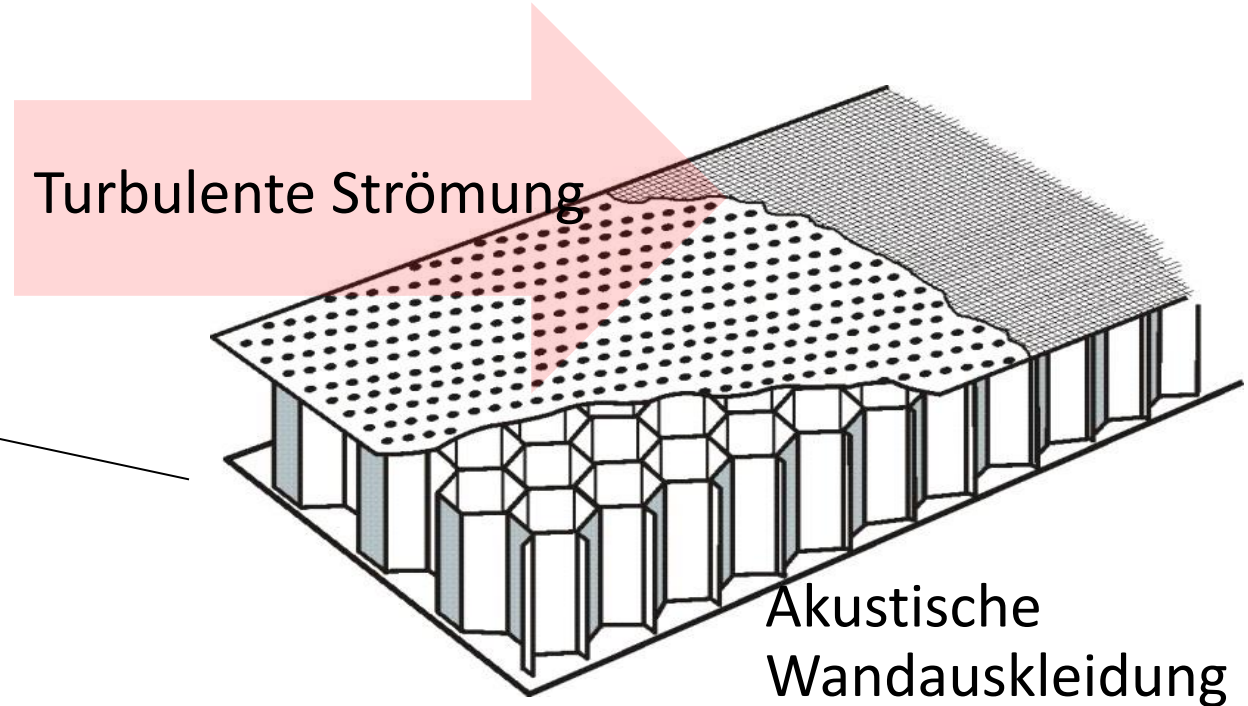
Dafür gibt es keine Erklärung

Problem bei der Modellierung



Verbesserung der Genauigkeit des Schallfeldmodells hat nicht geholfen.

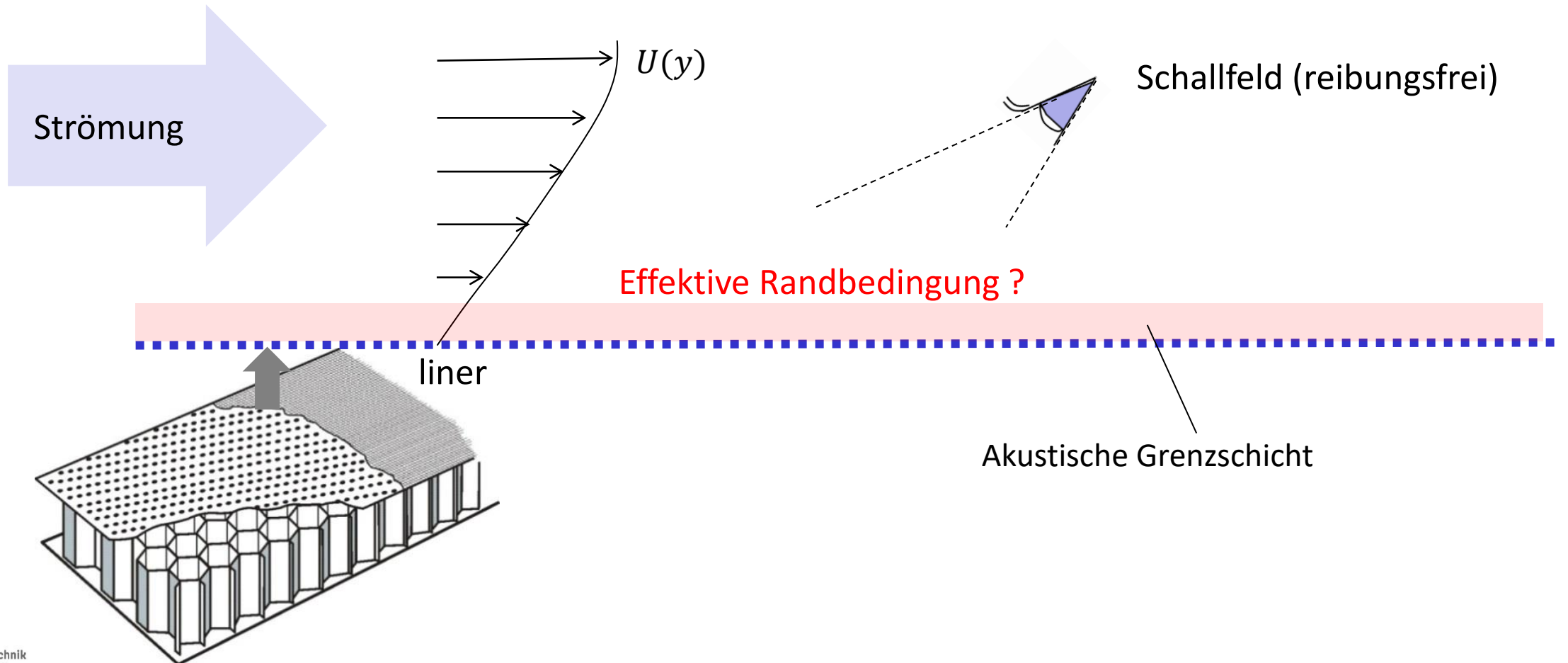
→ Die Formulierung der Randbedingung selber ist ungenügend.



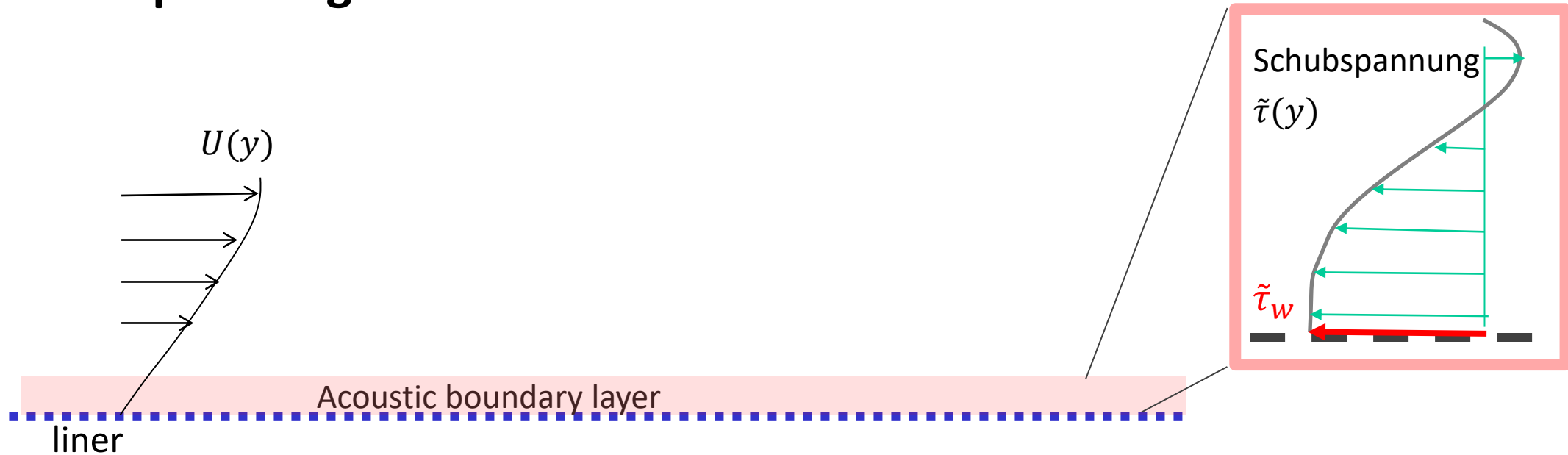
Was ist die korrekte akustische Randbedingung ?

Was ist die korrekte akustische Randbedingung ?

Strömungskanal

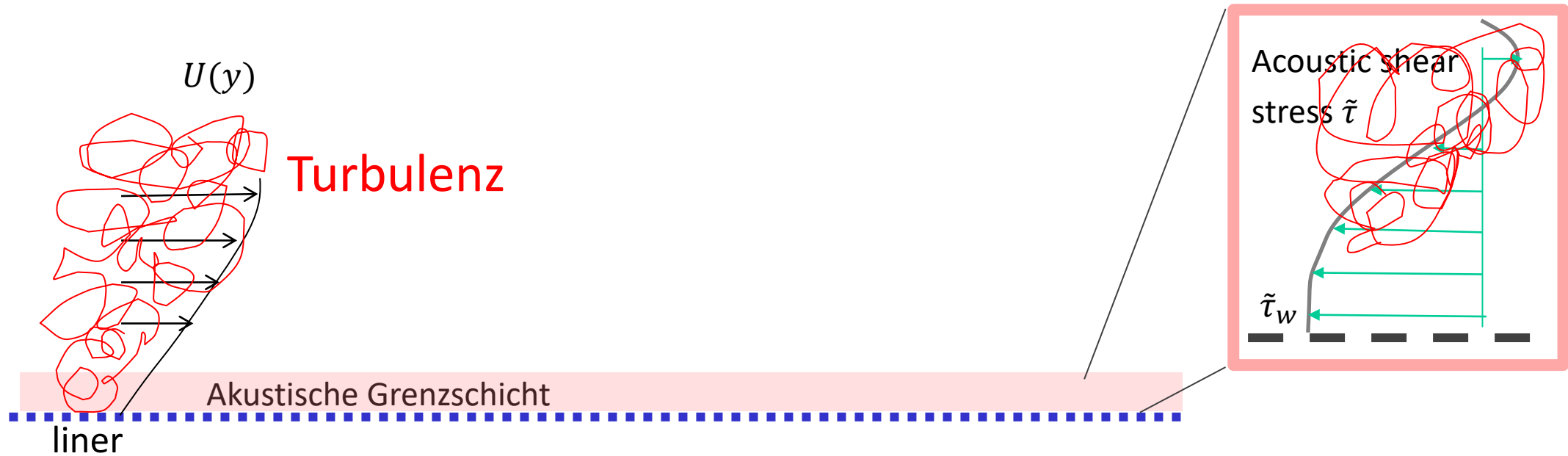


Schubspannungen in der akustischen Grenzschicht



- With flow $\tilde{\tau}(y)$ is increased by **several orders of magnitude** → **The viscous shear stress should not be neglected**
- For laminar flow $\tilde{\tau}(y)$ can be calculated straightforward (e.g. Brambley 2009 with Blasius boundary layer)

But with turbulent flow?



Wir reagieren die turbulenten Schubspannungen auf eine instationäre (akustische) Änderung der Strömungs-Randbedingung ?

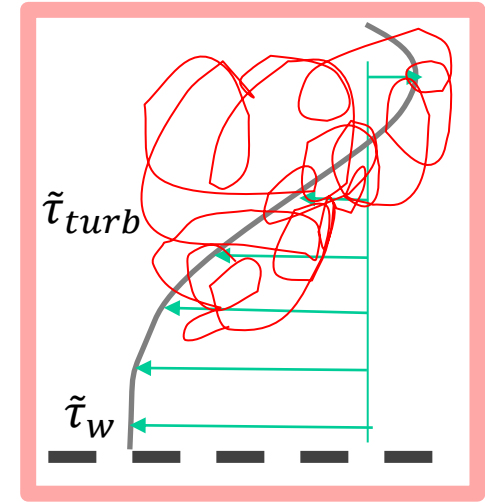
Dies berührt 2 quasi unerforschte Effekte ...

Turbulence effect 1

The turbulence is **sheared and deformed** by the acoustic shear wave -> The turbulent shear stresses $\tilde{\tau}_{turb}$ are acoustically modulated.

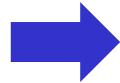
How to determine $\tilde{\tau}_{turb}$?

The **Boussinesq hypothesis (mean flow)** is applied for the acoustic case (due to the lack of better knowledge)



Mean flow

$$-\rho \overline{u'v'} = \mu_{trb,0}(y) \frac{d\bar{u}}{dy}$$



Acoustic flow

$$\tilde{\tau}(y, \omega) = \mu_{eff}(y, \omega) \frac{\partial \tilde{u}}{\partial y}$$

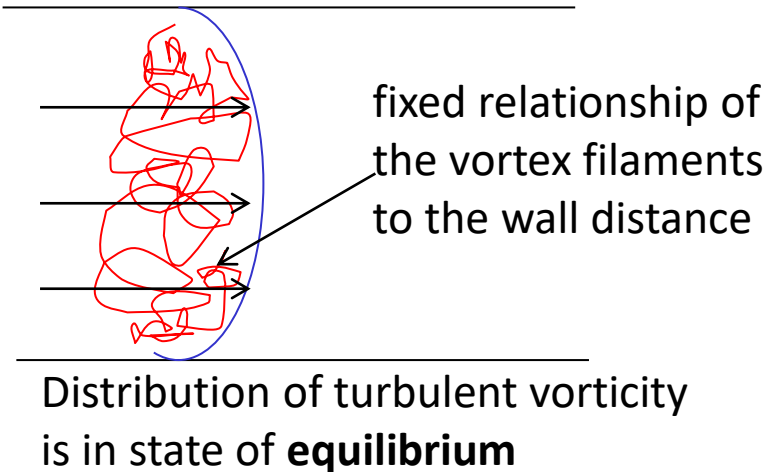
Questioned by DNS-Data results (Hartmann* 2002)

Turbulent “eddy viscosity”: links the shear rate and the shear stress by a local relationship

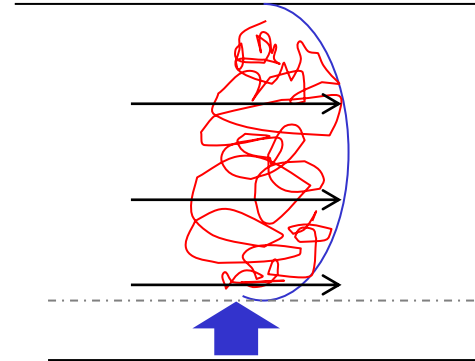
Turbulence effect 2: Relaxation process

The turbulent shear stresses will somehow react dynamically to the acoustic displacement of the fluid at the liner wall.

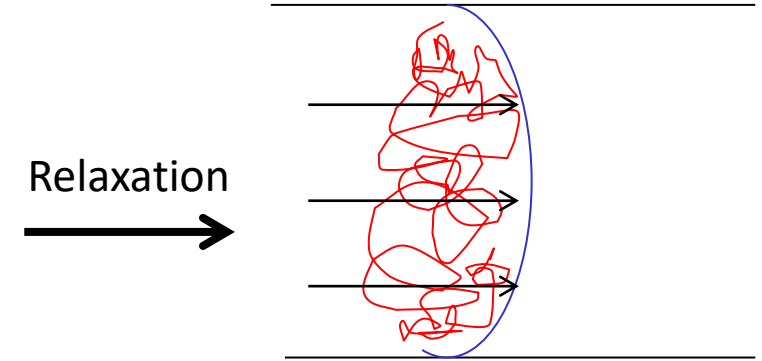
1. Steady turbulent duct flow



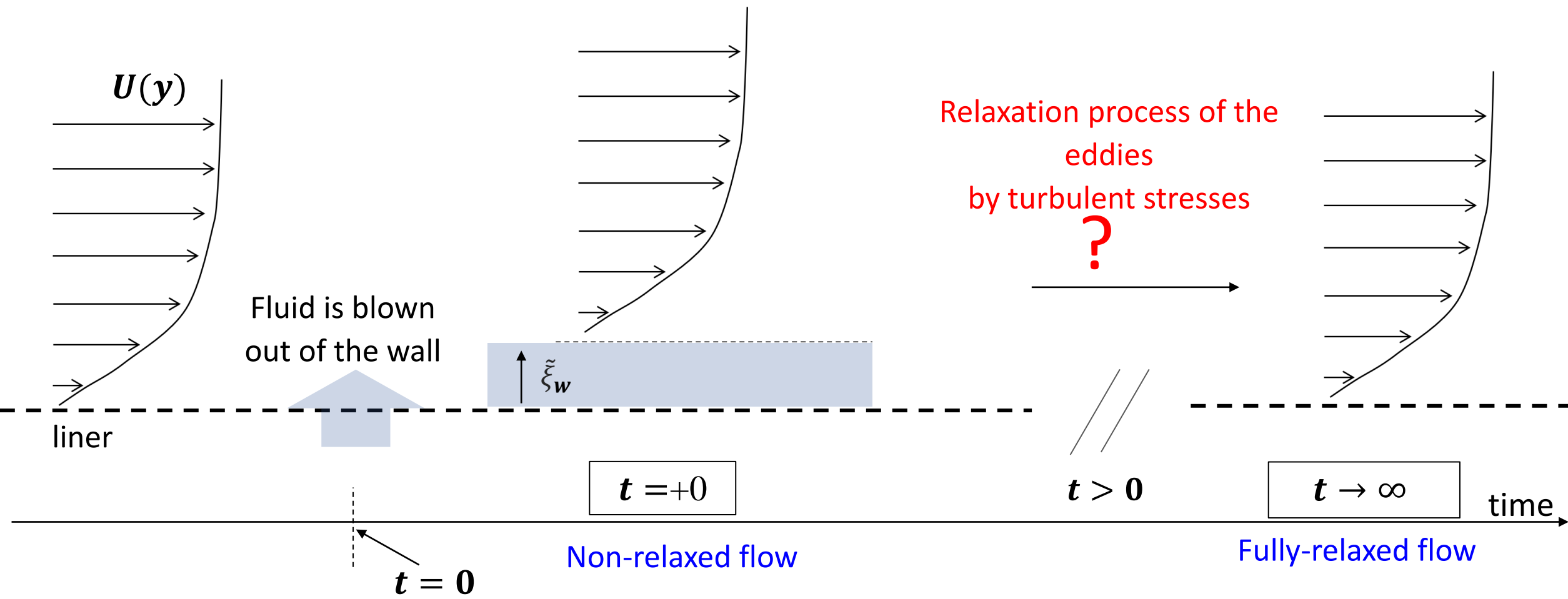
2. Sudden push and displacement of the flow



3. After relaxation: fluid elements are displaced, but the flow profile is restored

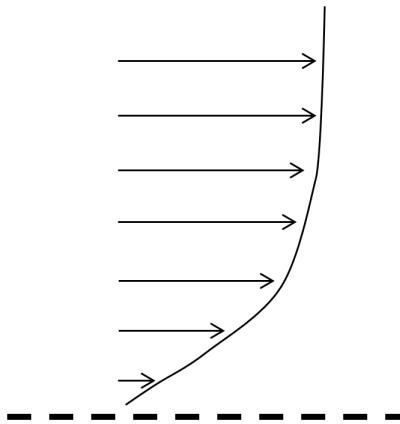


The dynamics of this relaxation are basically unexplored in the case of an acoustic boundary condition.



Zwei Modelle und zwei Grenzfälle der Relaxation

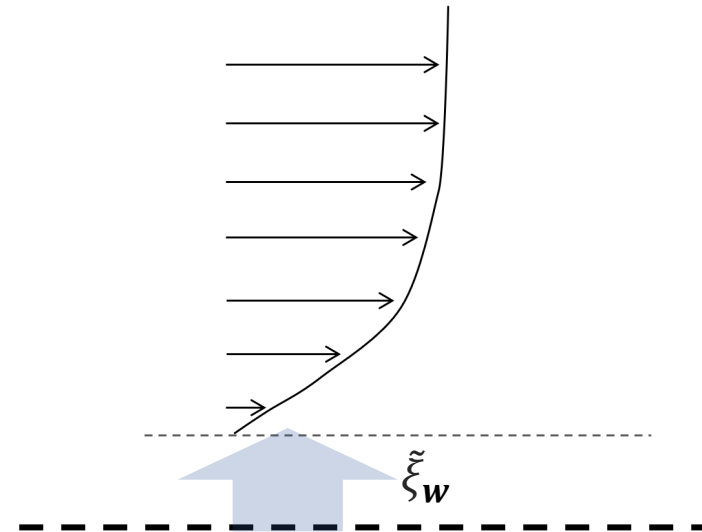
Fully-relaxed flow (t=∞)



- Low frequency limit (flow can adjust to slow changes)
- The acoustic shear stress is calculated in the **wall-fixed coordinate system**

$$\tilde{\tau}(y) = \mu_{\text{eff}}(\omega') \frac{\partial \tilde{u}}{\partial y}$$

Non-relaxed flow (t=0)



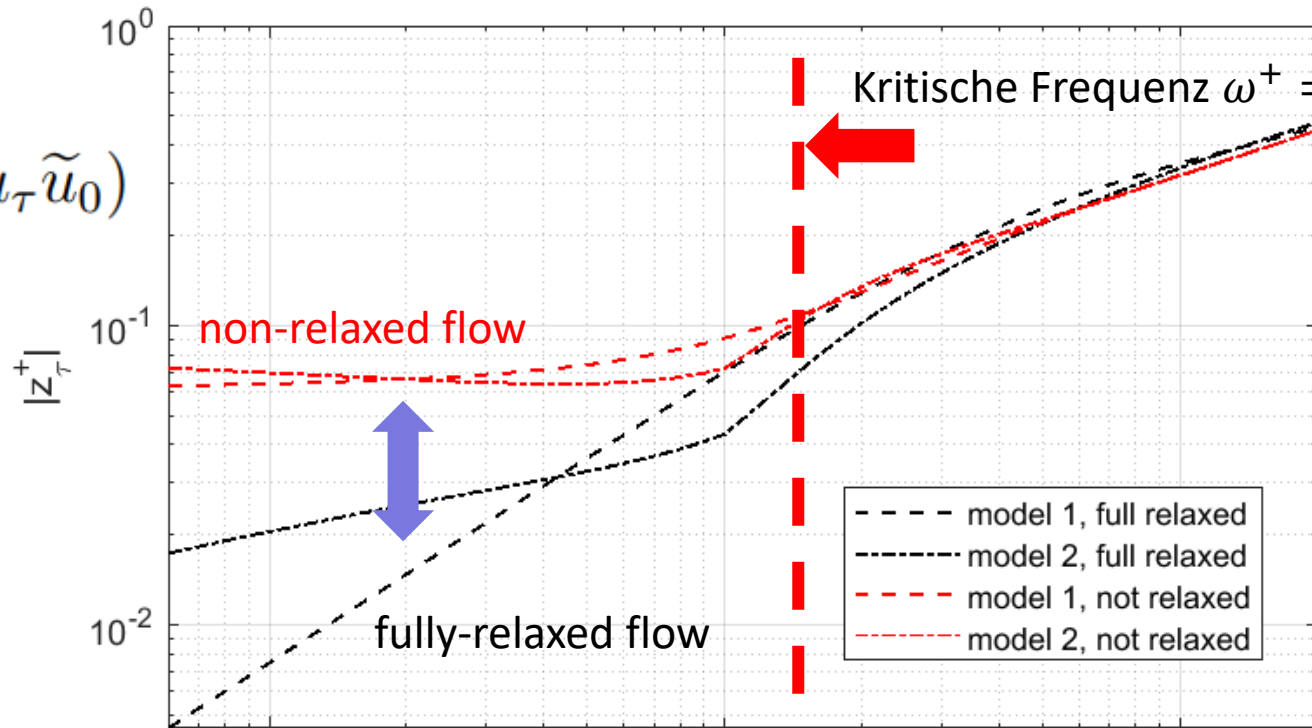
- High frequency limit
- **Moving coordinate system**

$$\tilde{\tau}_{\uparrow}(y_{\uparrow}) = \mu_{\text{eff}}(\omega') \left\{ \frac{\partial u_{\uparrow}}{\partial y_{\uparrow}} \right\}$$

Ergebnisse

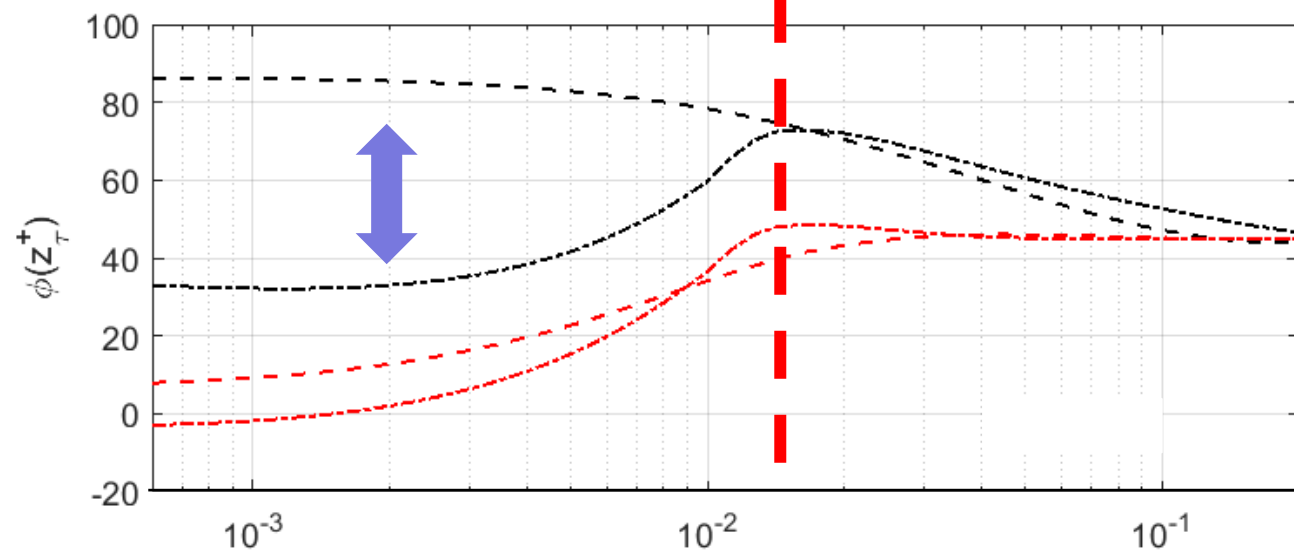
$$z_{\tau}^{+} = \frac{\tilde{\tau}_w}{(\rho u_{\tau} \tilde{u}_0)}$$

Betrag



Für "hohe" Frequenzen hat die Turbulenz keinen Einfluss

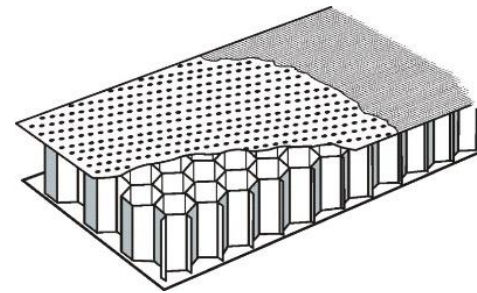
Phase



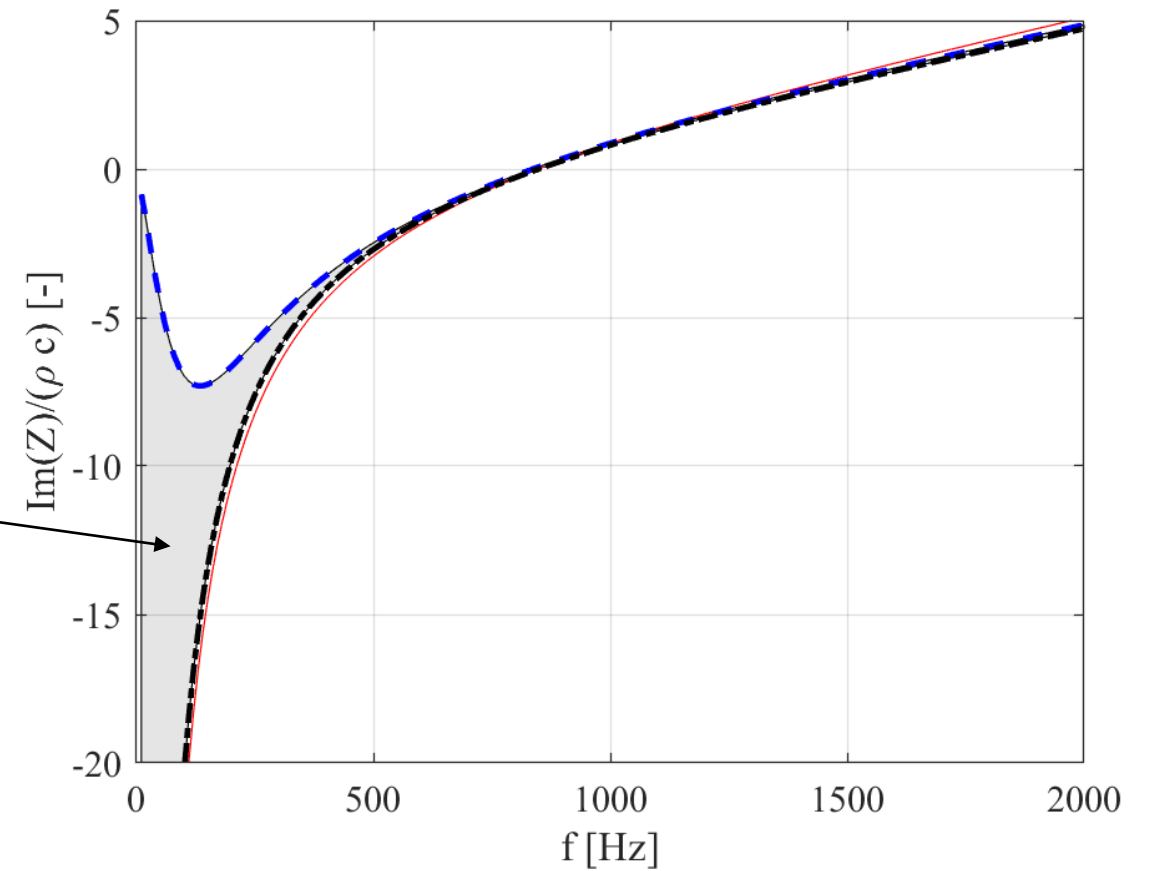
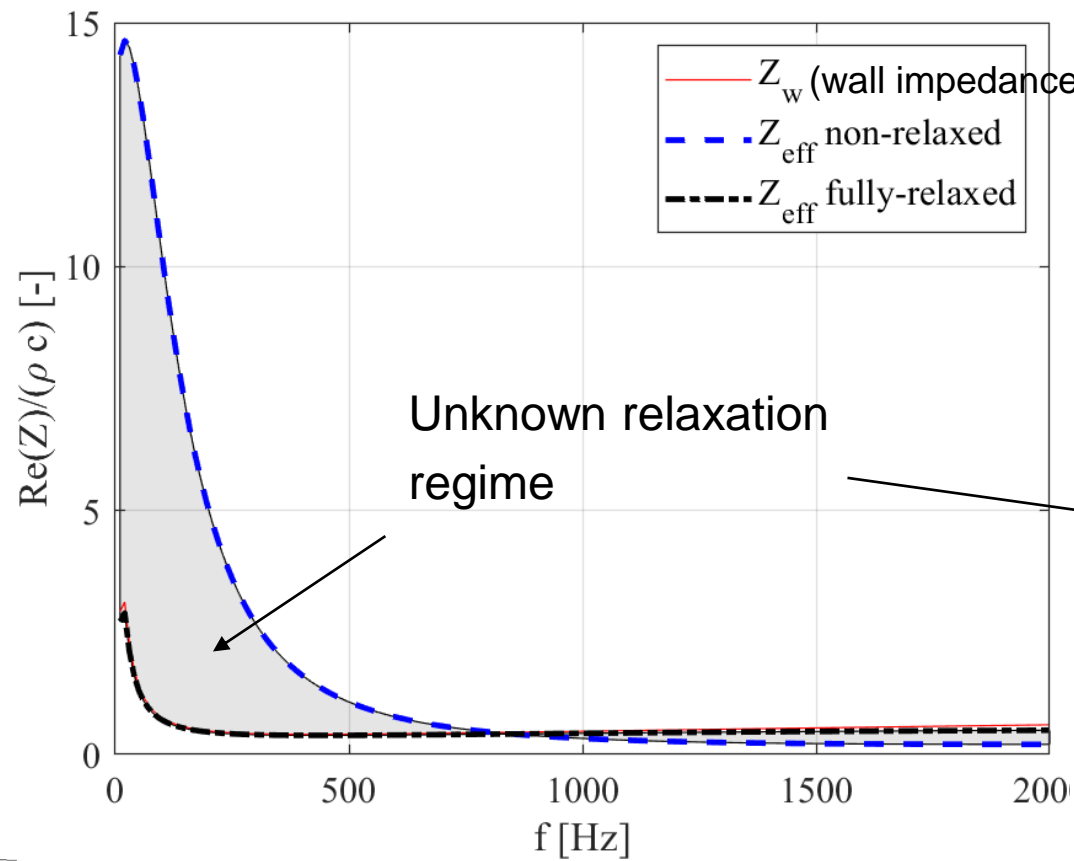
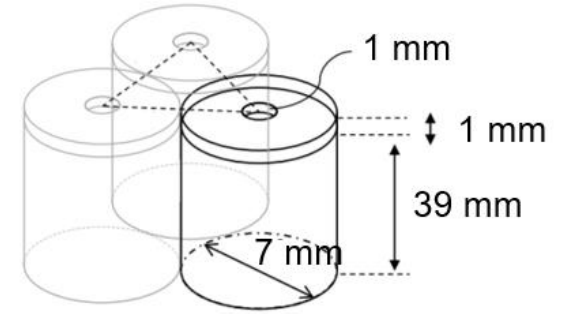
$$\omega^{+} = \omega \frac{\nu}{u_{\tau}^2}$$

Effective impedance

$$M_{avg} = 0.2$$

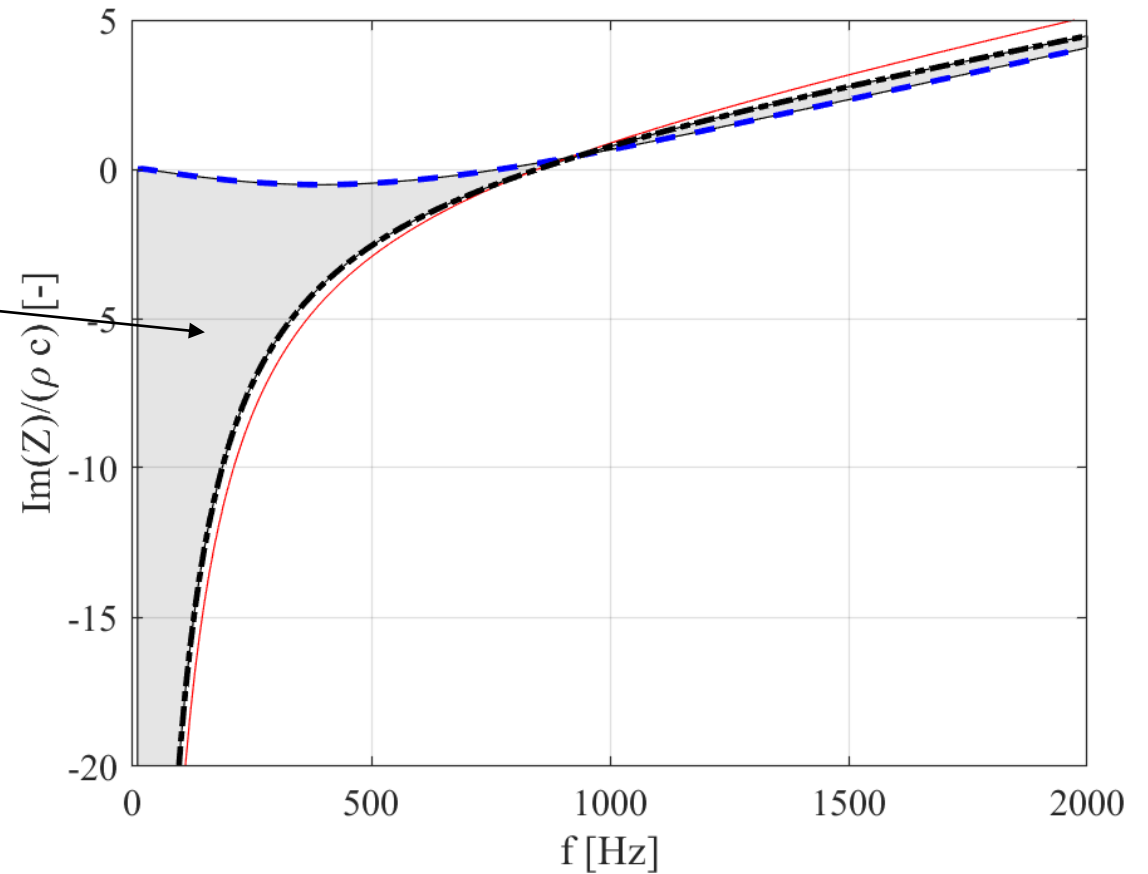
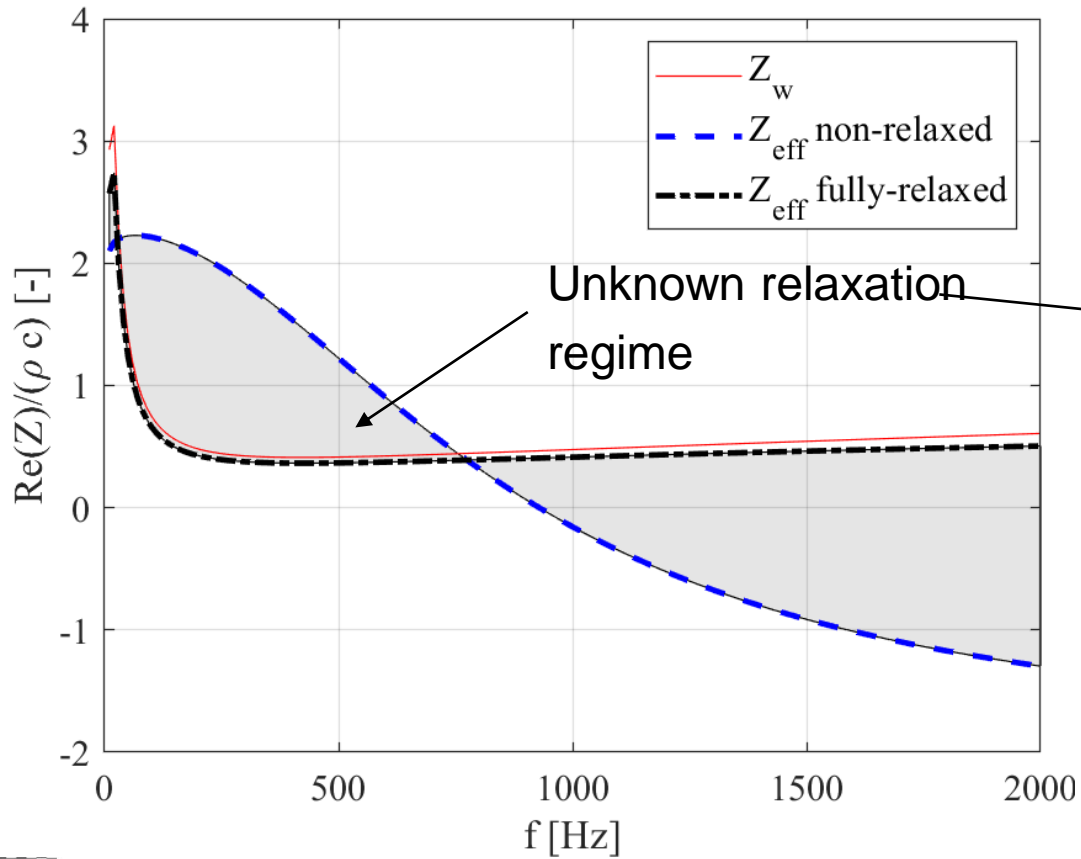
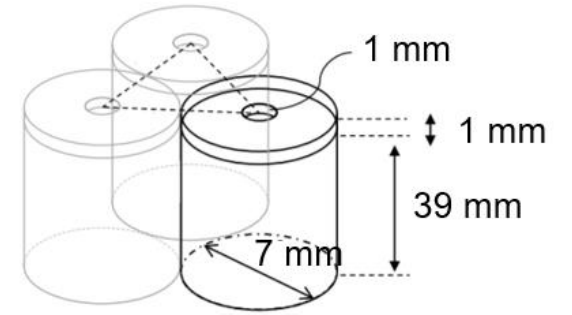
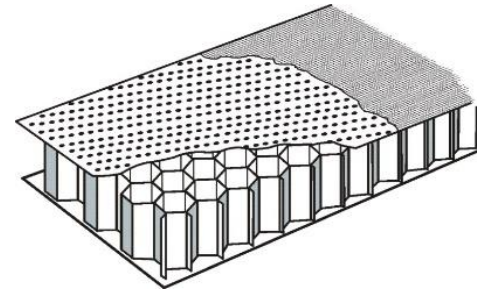


Resonator-Liner



Effective impedance

$$M_{avg} = 0.4$$



Zusammenfassung

- Aktuell: Berücksichtigung der turbulenten Relaxation in der akustischen Randbedingung
- 2 analytische Modelle, Parameter werden an numerische Turbulenzsimulation angepasst
- Gute Nachricht: für “hohe” Frequenzen $\omega^+ > 0.01$ interagiert die Schubspannungswelle nicht mit der Turbulenz → Die Turbulenz hat keinen Einfluss auf die akustische Randbedingung
- Schlechte Nachricht: Für tiefe Frequenzen große Unsicherheit zwischen den Modellen und den beiden Relaxations-Limits
- Zukunft: Direkte numerische Simulationen der turbulenten Strömung
 - Zur Validierung der Modelle
 - Besseres Verständnis der Physik einer schall-gestörten Turbulenz und des Effekts auf die akustische Randbedingung

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Prof. Dirk Ronneberger

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