NICFD 2020
for Propulsion & Power

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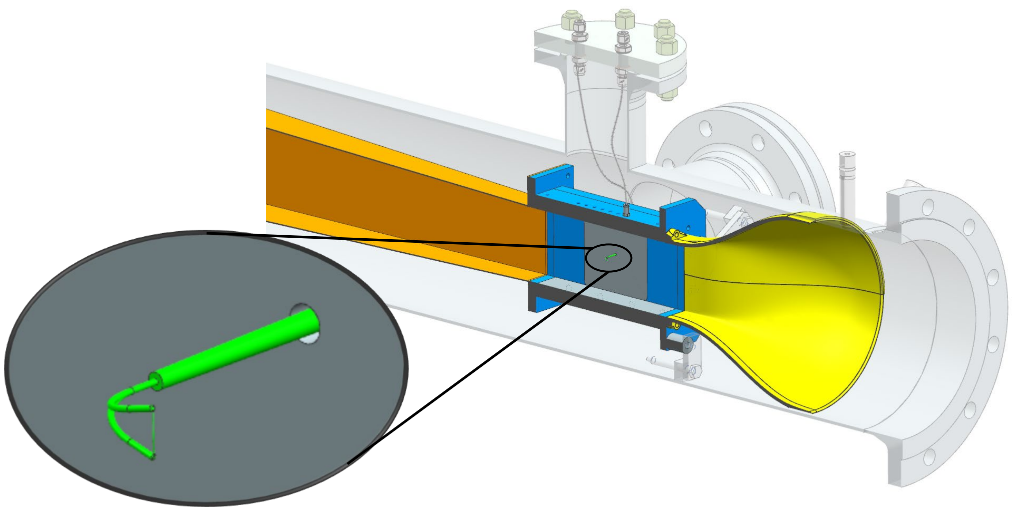
Application of Hot-Wire Anemometry in the High Subsonic Organic Vapor Flow Regime



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Paper ID: 7

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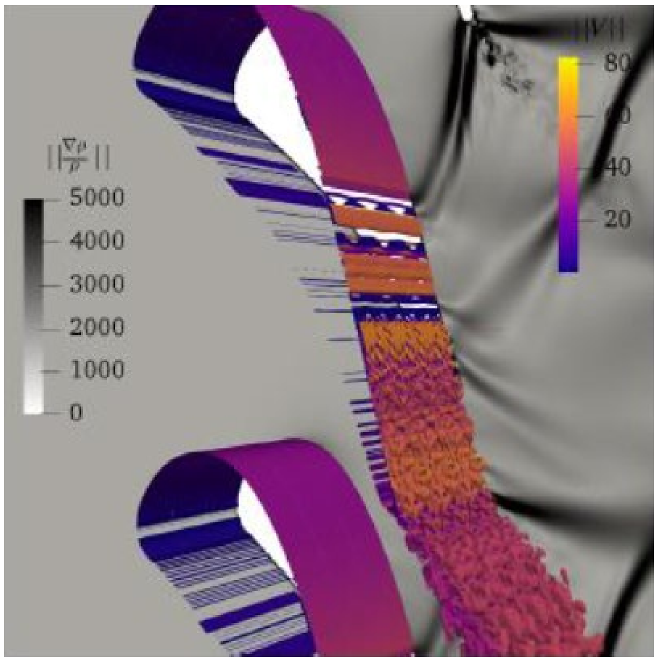
Introduction & Motivation

CFD

Wall-resolved LES of transitional supercritical flow of PP11 across the VKI LS89 turbine cascade.



ARTS ET MÉTIERS ParisTech

DynFluid Fluid Dynamics Laboratory

Experiment

<u>Hot Wire Anemometrie (HWA):</u>

The classical tool for experimental studies in turbulent flows

- ✓ Incompressible flows (deep knowledge)
- ➢ Compressible flows (still in focus)

<u>What about dense gases?</u>

- ❑ High dynamic loads (High Re-number)
- ❑ Lifetime (calibration – application)
- ❑ Effect of thermodynamic fluctuations (velocity vs. density)

Comparison to air experiences

Hot Wire: Basics

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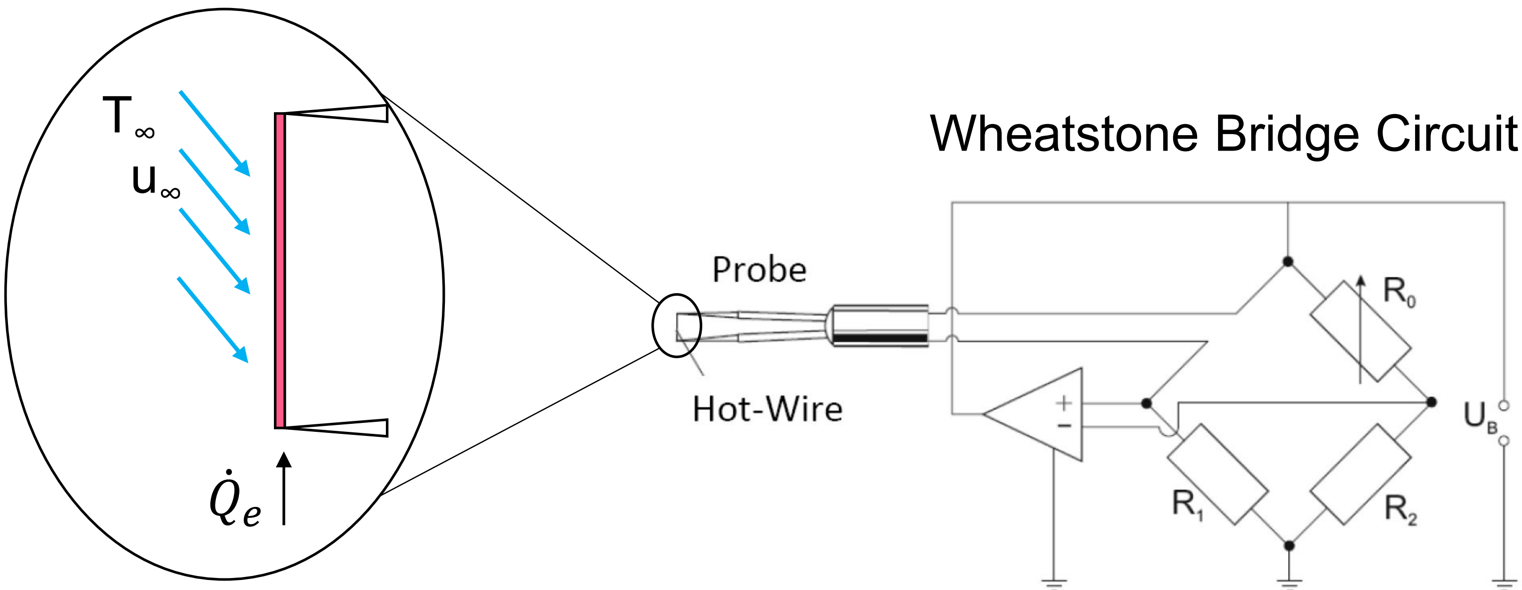
Working Principle: Metallic element is heated by electric current (Joule Effect), convective heat transfer to fluid is detected by external circuit.
Modes: Constant Current (CCA) & **Constant Temperature (CTA)**
Purpose: measuring mean and fluctuating velocity components (?)
→ Turbo machinery flow in general: unsteady & turbulent!



Hot Wire: Flow Regimes

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Incompressible flow

✓

Kings equation:

$$Nu = 0.42\,Pr^{1/5} + 0.57\,Pr^{1/3}\,Re^{1/2}$$

$$\frac{I^2 R_w}{T_w - T_f} = A + B\,w^{1/2}$$

$$w = \left(a + b\frac{U_B^2}{T_w - T_f}\right)^2$$

$$w = \left(a + b\frac{U_B^2}{T_w - T_f}\right)^e$$

$$Nu = f(Re, Pr)$$

High subsonic & transonic flow

Sensitivity Coefficients

$$S_u = \left.\frac{\partial \ln E}{\partial \ln U}\right|_{\rho, T_0},$$

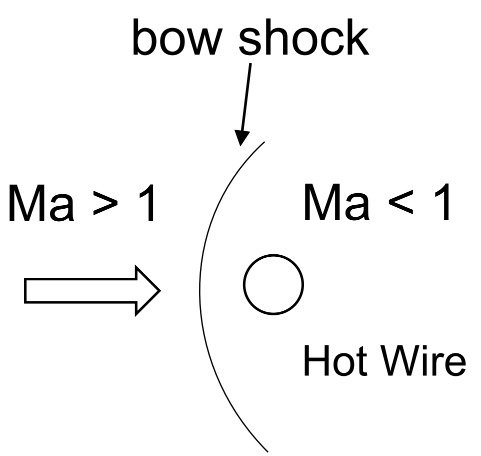
$$S_\rho = \left.\frac{\partial \ln E}{\partial \ln \rho}\right|_{U, T_0},$$

$$S_t = \left.\frac{\partial \ln E}{\partial \ln T_0}\right|_{U, \rho}$$

$$Nu = f(Re, M, Pr, (Kn), \tau)$$

Supersonic flow

(✓)



$$Nu = f(Re, Pr, (M), (\tau))$$

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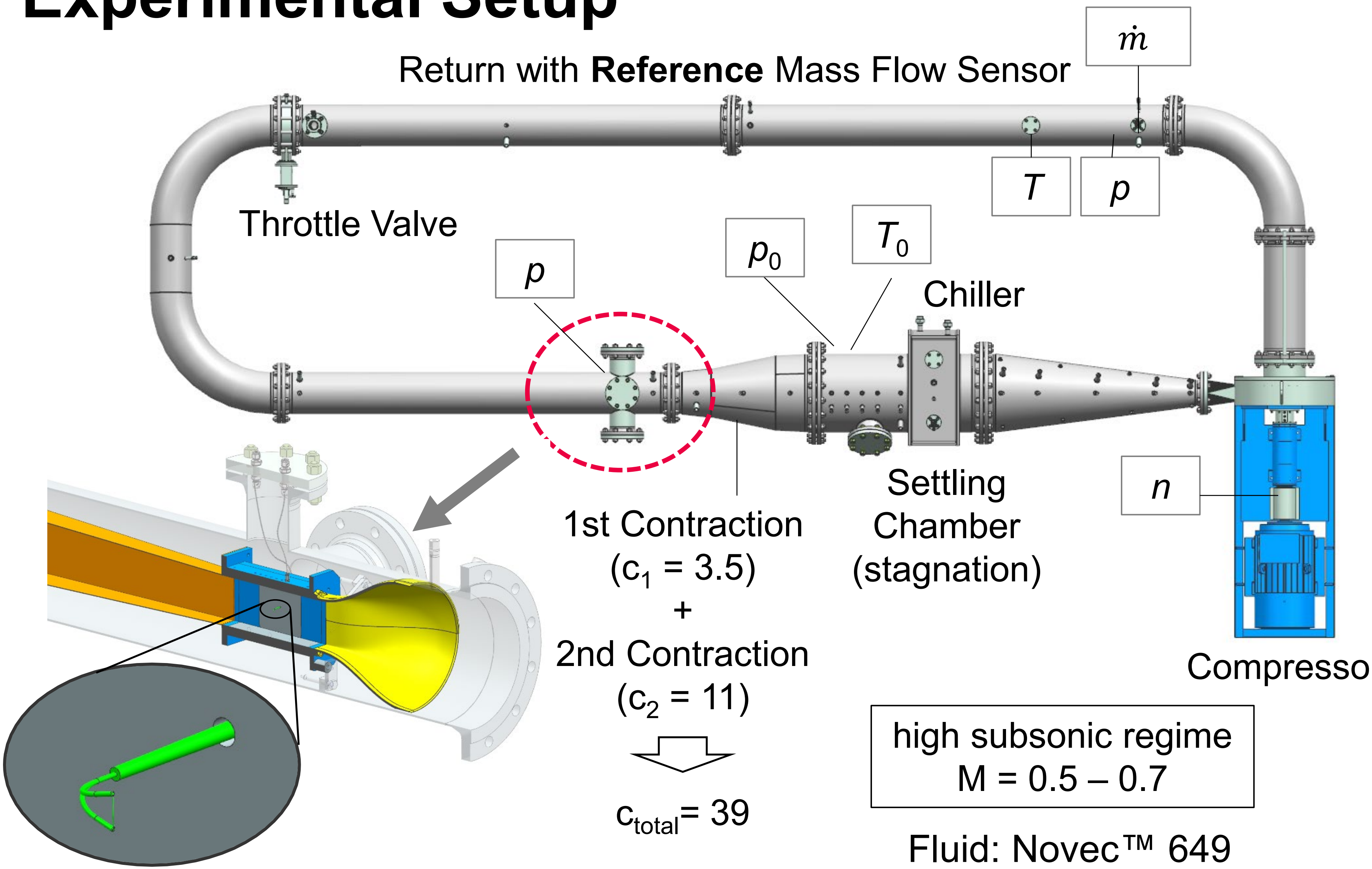
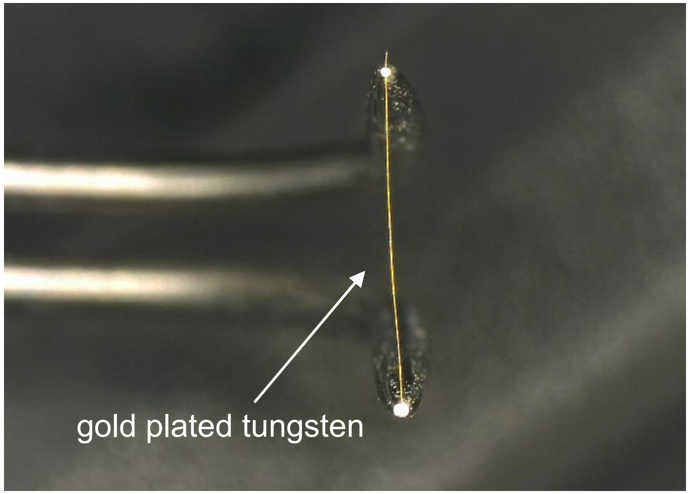
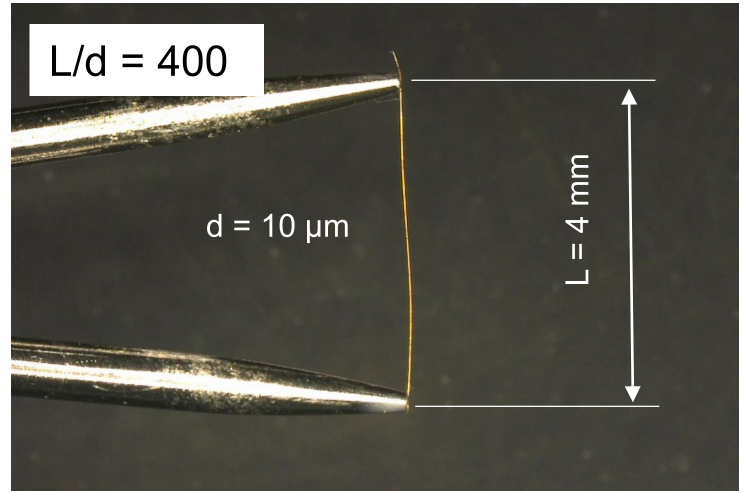
Experimental Setup



Experimental Setup





Partner: SVM-Tec, Stuttgart

<u>Signal processing:</u> Highspeed analog input module NI9229 of National Instruments (Delta-Sigma digitizer and analog prefiltering)

<u>Sampling rate:</u> 10 kHz

<u>Sampling duration:</u> t = 4s.

<u>Uncertainty level electrical bridge voltage $\Delta U_B/U_B$</u>: 1.5 - 2.0%

<u>Increased Wire Temperature:</u> T_{w1}= 170°C → T_{w2} = 318°C

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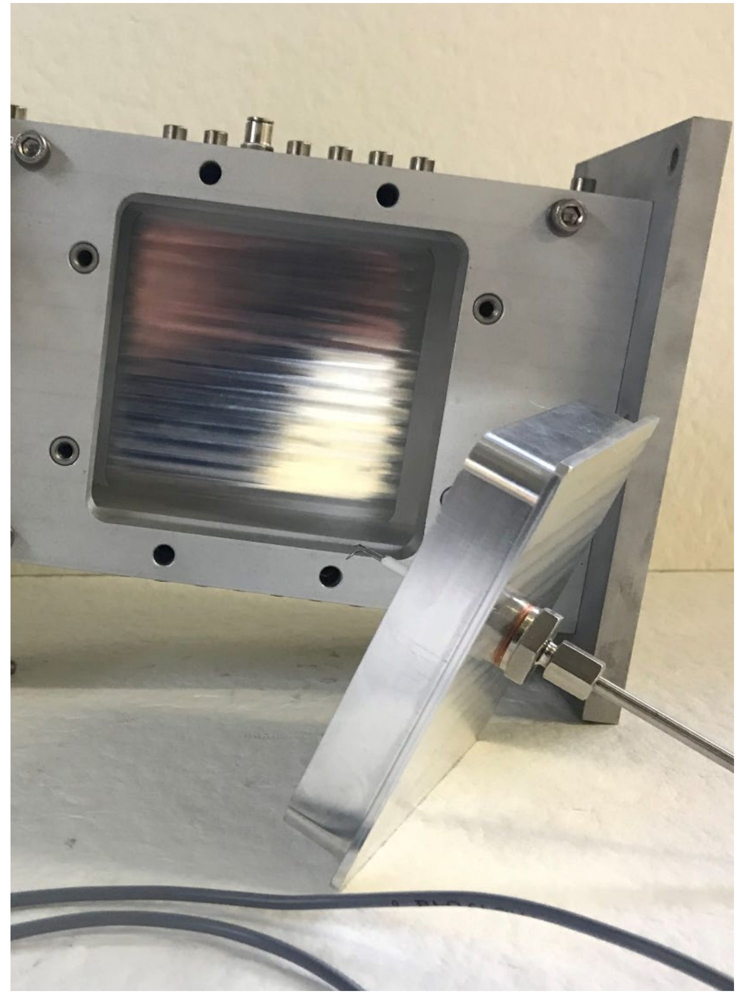
Experimental Setup

Free static wall pressure

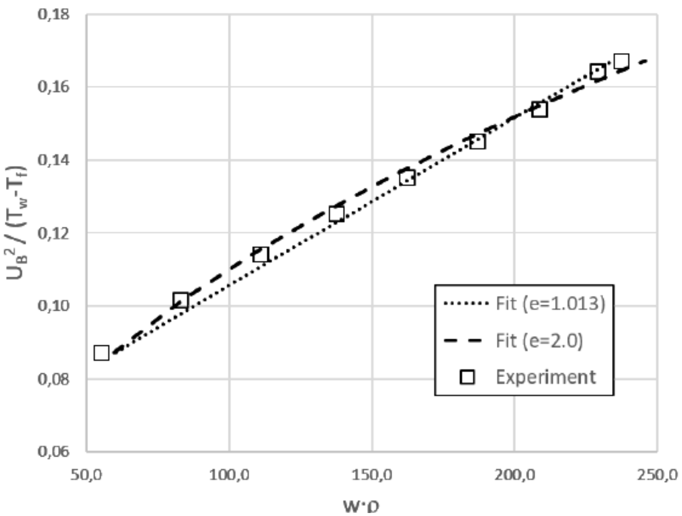
Inlet with probe-mounting

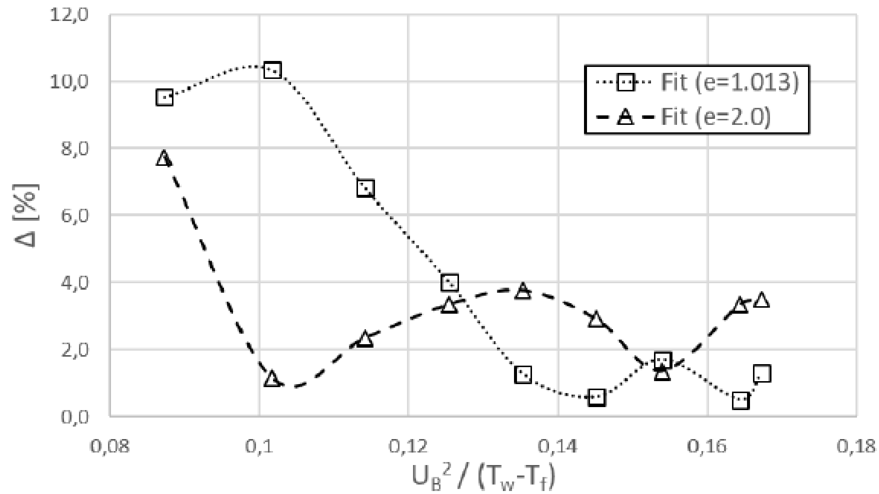


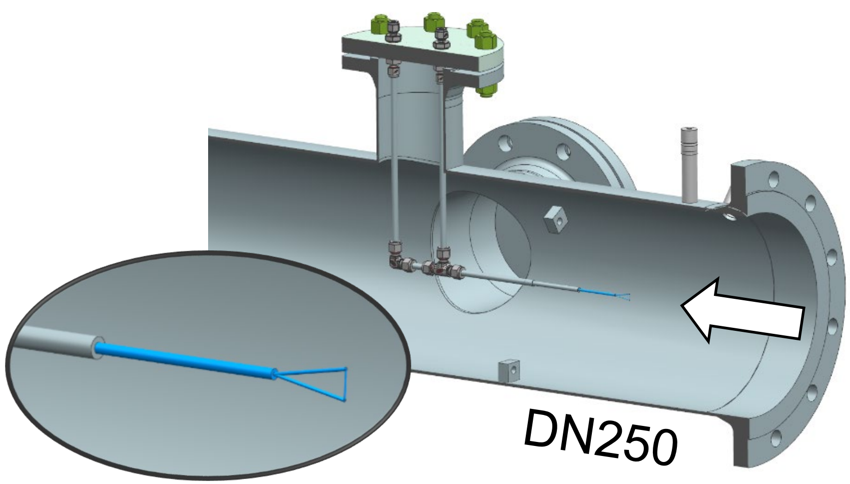
Experimental Results

Incompressible Flow – static calibration

$$\mathrm{Nu} = A(M,\tau) + B(M,\tau)\,\mathrm{Re}^{1/2}$$
$$\mathrm{Nu} \sim U_B^2/(T_w - T_f)$$







$$Tu = \frac{w'}{\bar{w}}$$

$$Tu = 1.3 - 1.8\ \%$$

Experimental Results

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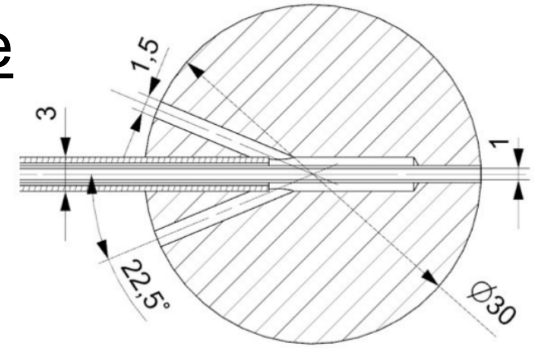
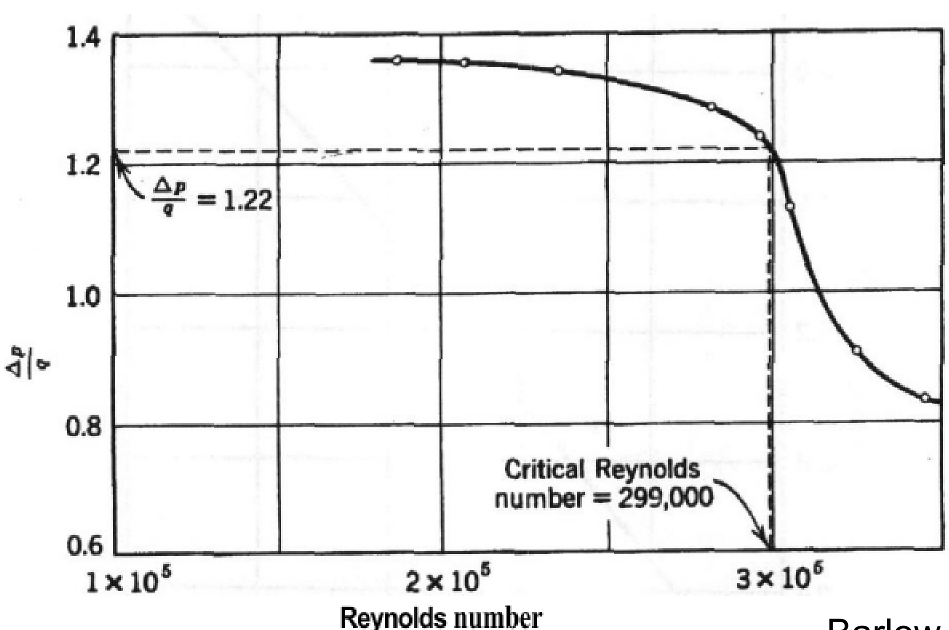
Incompressible Flow – Turbulence Sphere

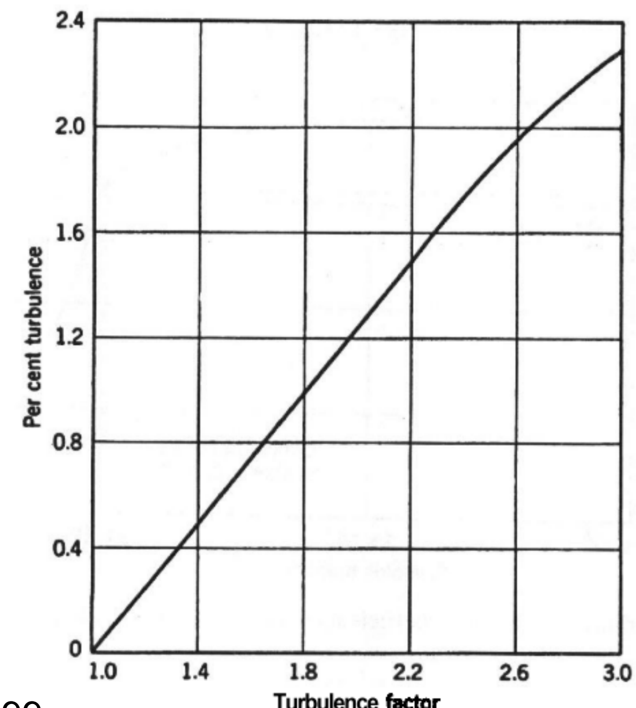


Turbulence Sphere Experiment

- Basis: Turbulent transition at critical Reynolds number
- ❑ Drag-measurement (C_D=0.3) → sensible calibration!
- ✓ Pressure Coefficient (Cp=1.22) → robust

$$TF = 385{,}000/RN_{tunnel}$$

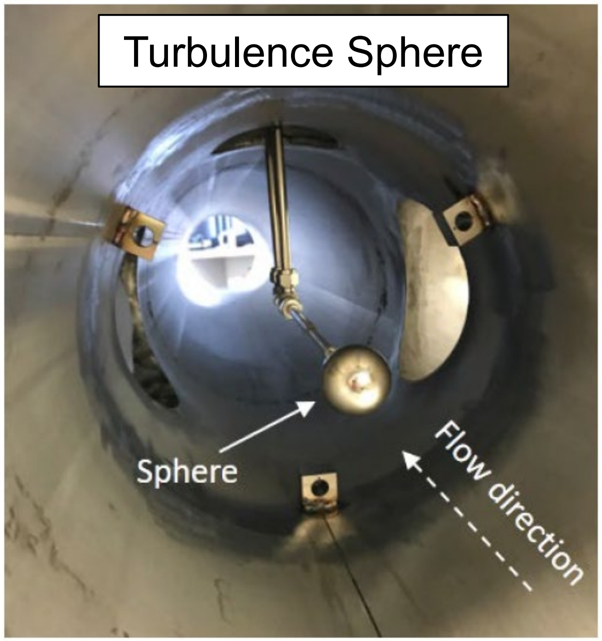


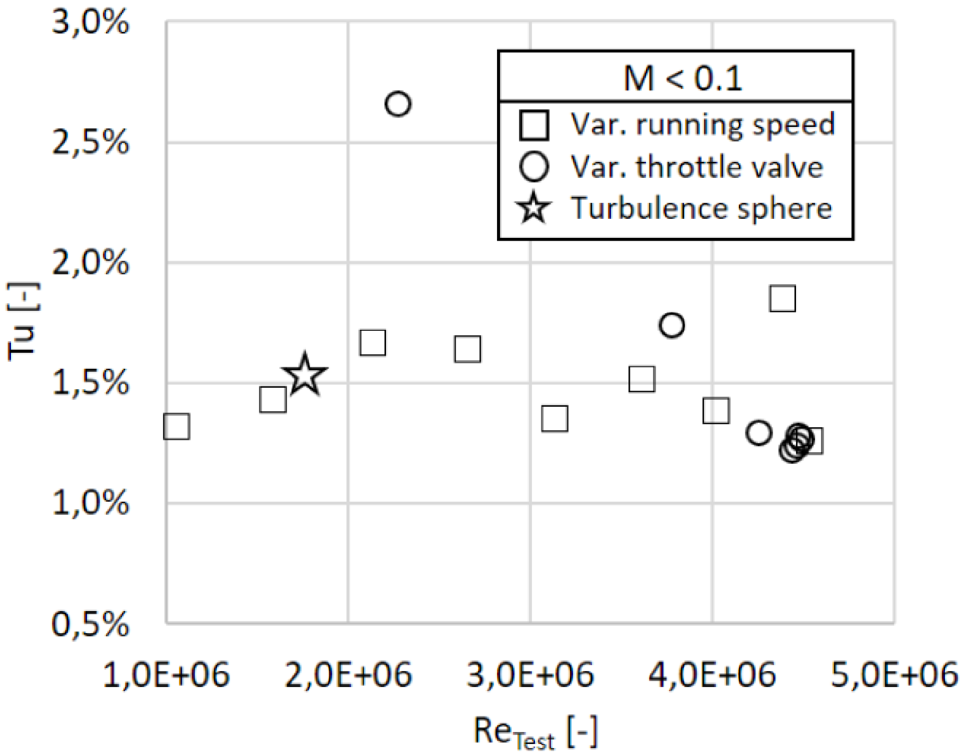


Barlow J.B. 1999

Experimental Results

Incompressible Flow



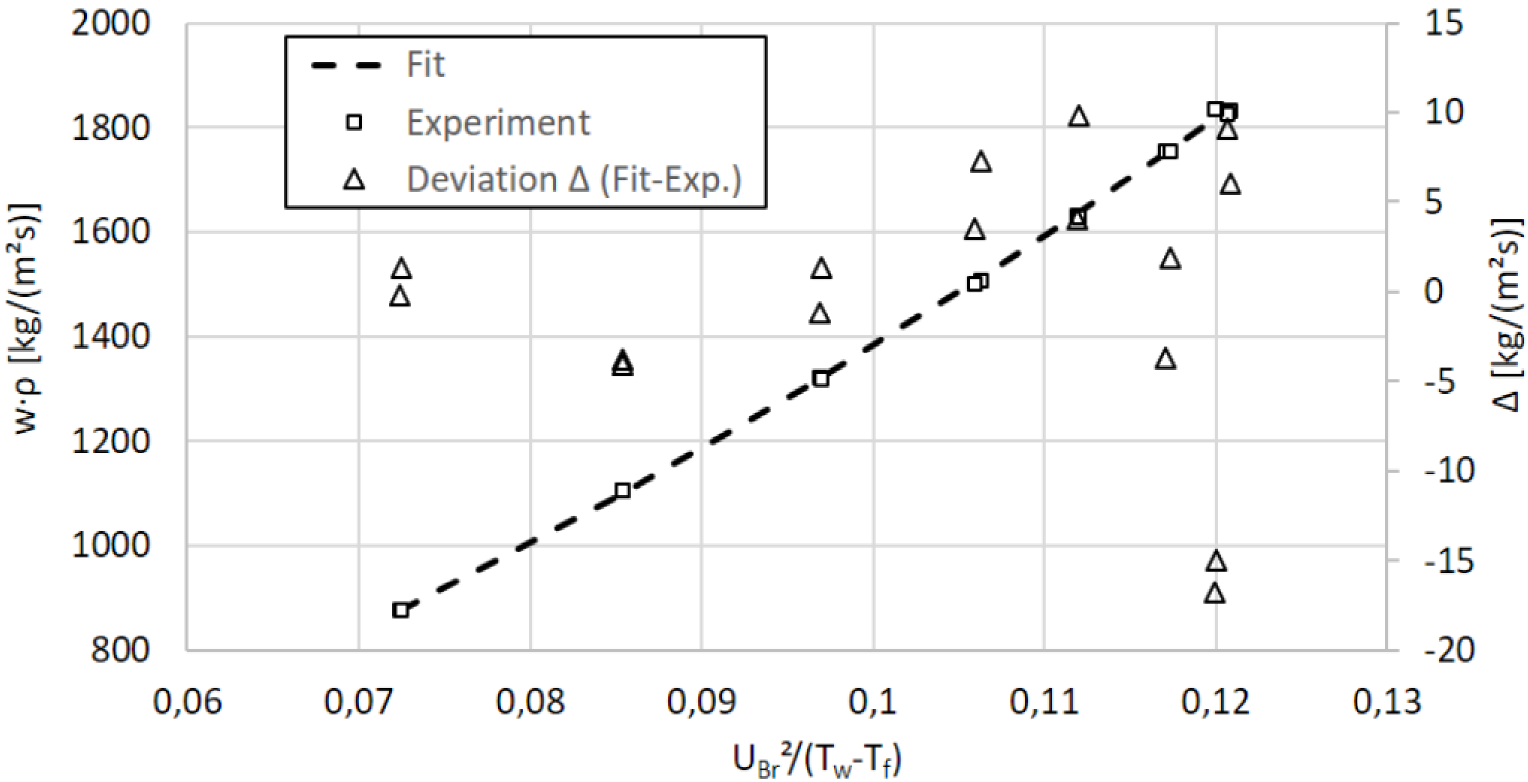


Experimental Results

High Subsonic static calibration (M=0.3 - 0.7)

$$\mathrm{Nu} = A(M,\tau) + B(M,\tau)\,\mathrm{Re}^{1/2}$$
$$\mathrm{Nu} \sim U_B^2/(T_w - T_f)$$

- Max. Deviation < 1%
- Deviations not systematically



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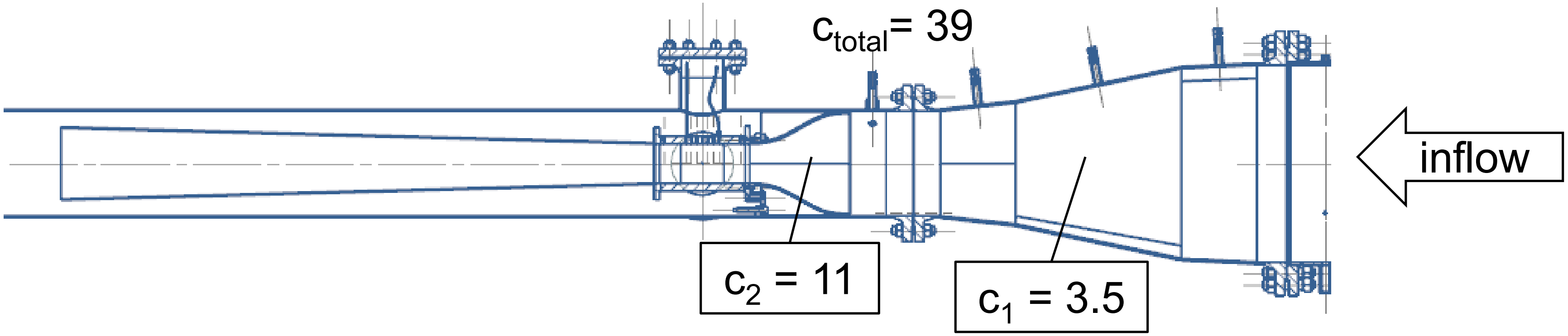
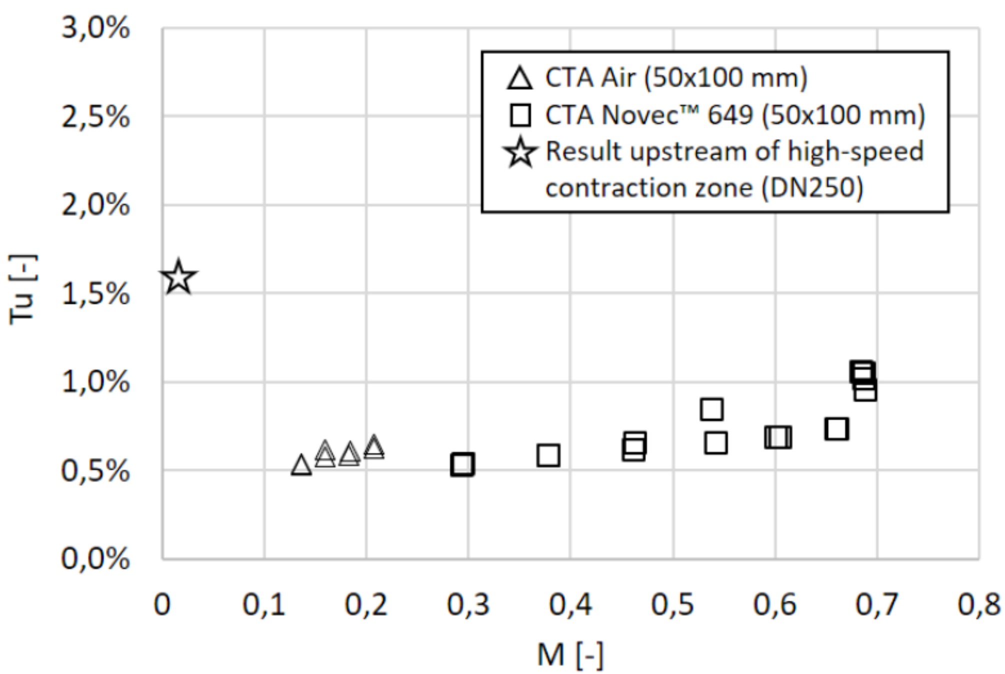
Experimental Results





$$Tu = \frac{w'}{\overline{w}}$$

$$Tu = 0.5 - 1.0\ \%$$

(without screens!)

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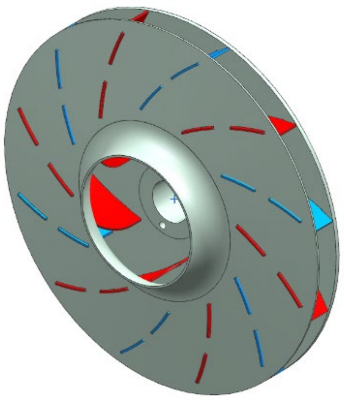
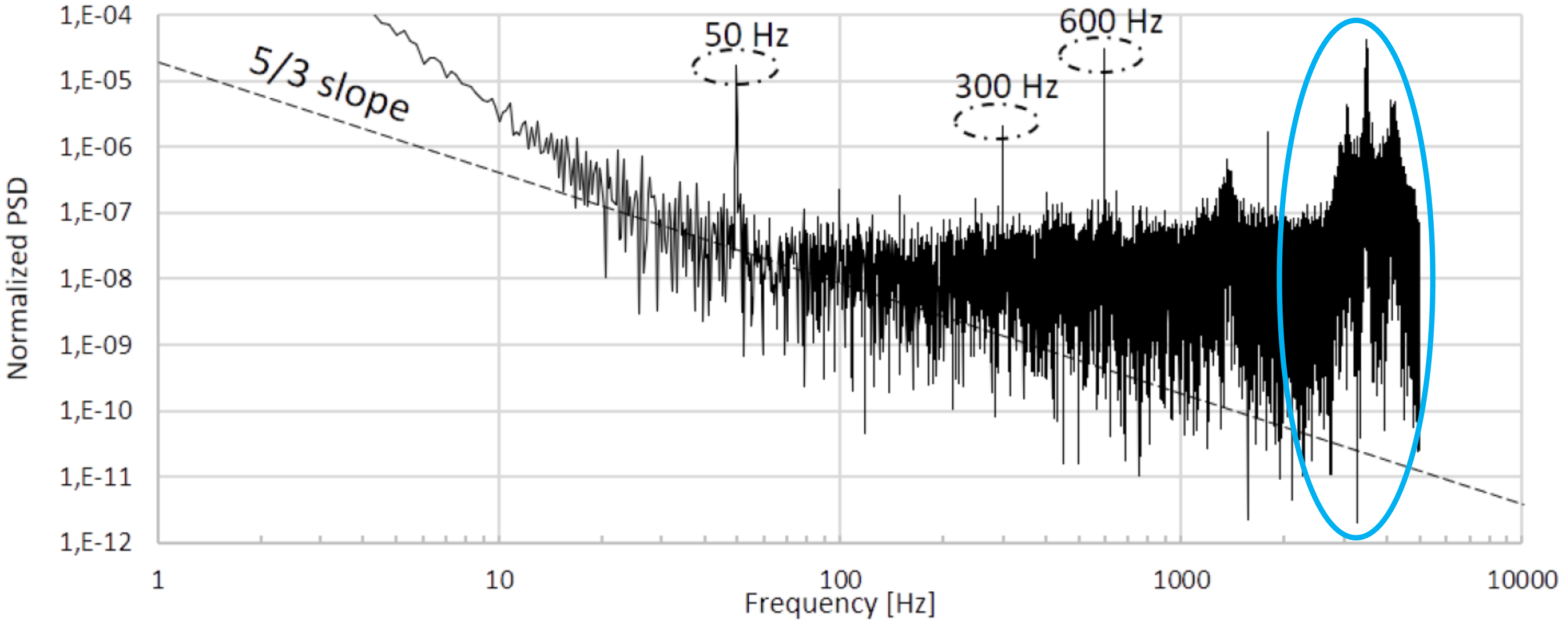
Experimental Results

Spectral Analysis (DIAdem)

- Without 2kHz Low Pass Filter
- Ma=0.69 ρ=35 kg/m³
- n=50Hz (3000rpm)
- Re_w: 400 – 1340
- Sr=0.21 → f_{vt}= 2570 Hz

Compressor rotor:
- 6 main blades
- 6 splitter blades

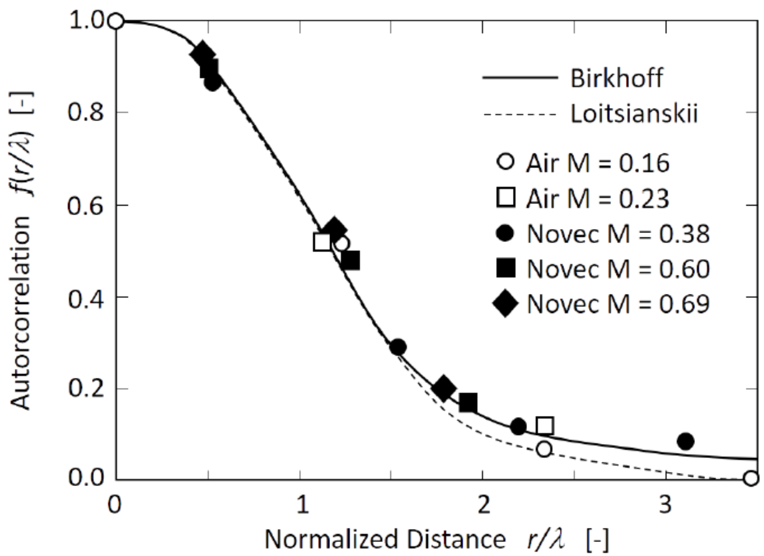




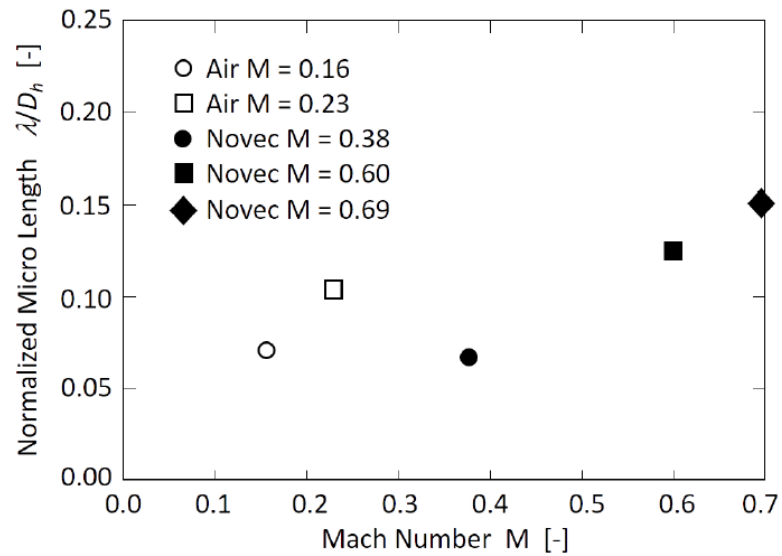
Experimental Setup

„Quick & dirty turbulence research“

Autocorrelation $f(r/\lambda)$ Based on Taylor Hypothesis



Normalized turbulent micro length scale λ



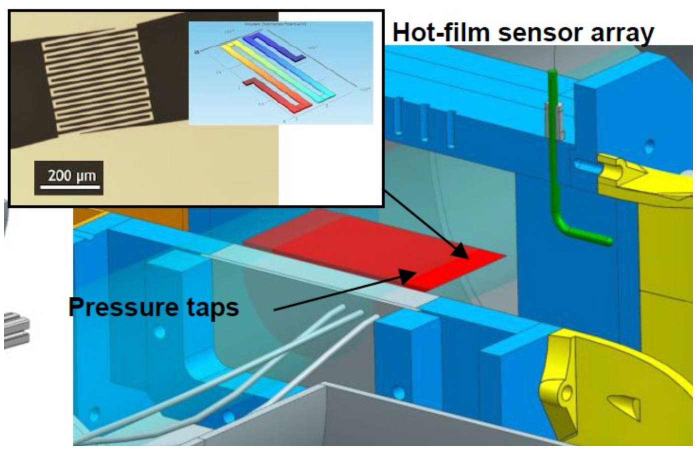
λ= 5-10 mm

No screens installed!

Conclusion & Outlook

- Hot wire did not break during experiments (robust design)
- Incompressible calibration was successfull (with laminar correlation)
- Compressible high subsonic calibration was also succesfull (lower deviations)
- Organic vapor turbomachinery fluctuations were detectable

- Future research: see REGAL-ORC (2021-2024)



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Thanks for your attention ☺