Experimental Research of an Airfoil Cascades in Varying Air Humidity Conditions

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PRESENTATION AGENDA

1. Motivation & introduction
2. Cascade models
3. Cascade windtunnel and measurement apparatus
4. Pressure measurements & flow visualisation analysis
5. Conclusions & plans for future cascade research
6. Summary
7. Questions?

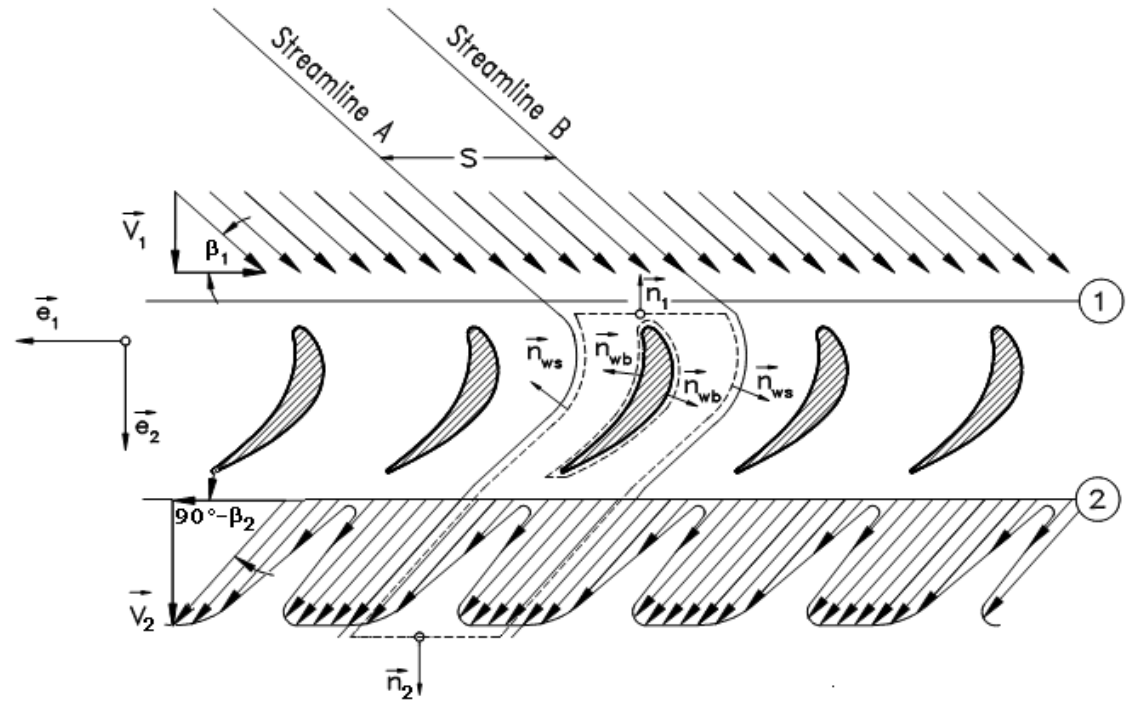
RESEARCH MOTIVATION

- **The deepening of knowledge of the turbomachinery flow phenomena such as boundary layer – shock wave interaction and separation shock wave pattern**

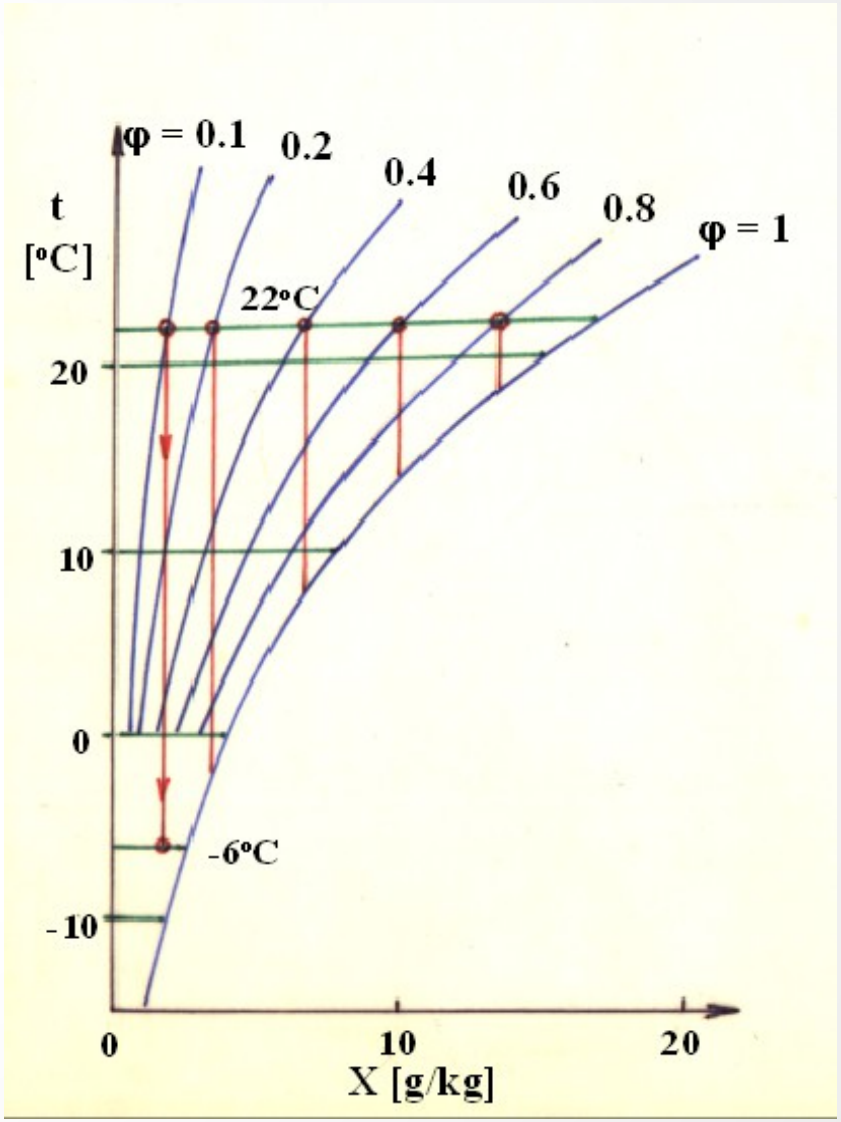
- **Experimental research of humidity influence on Mach number distribution over a turbine cascade blade, thus the impact of humidity on its global performance (o.e. defined as a pressure jump, loss coefficient, Mach distribution itself)**

- **Sensitivity study for condensation shock position and determination of favourable conditions for its occurence (minimum relative humidity value)**

CASCADE FLOW INTRODUCTION



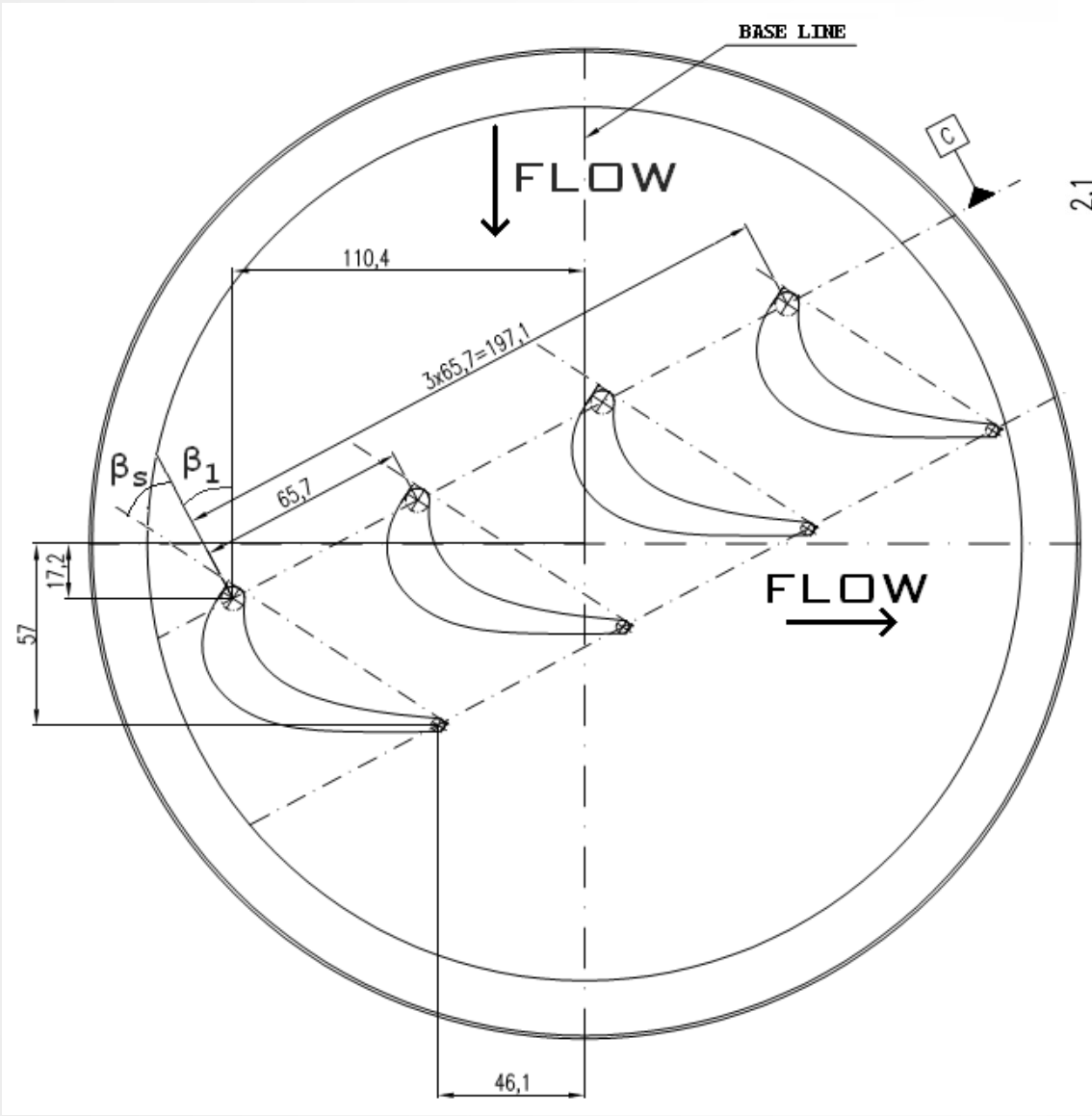
- **Viscous flow through a turbine cascade [1]**

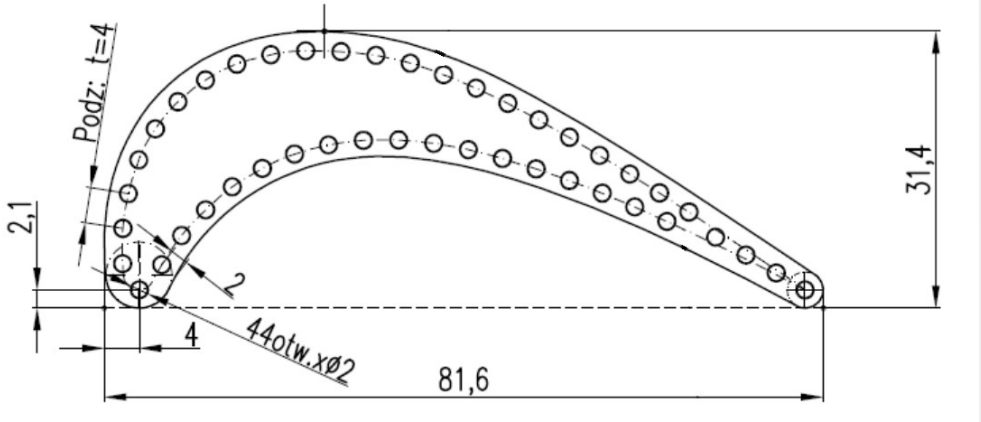


- **Mollier diagram for air**

- [1] Schobeiri, M. (2005) Turbomachinery Flow Physics and Dynamic Performance

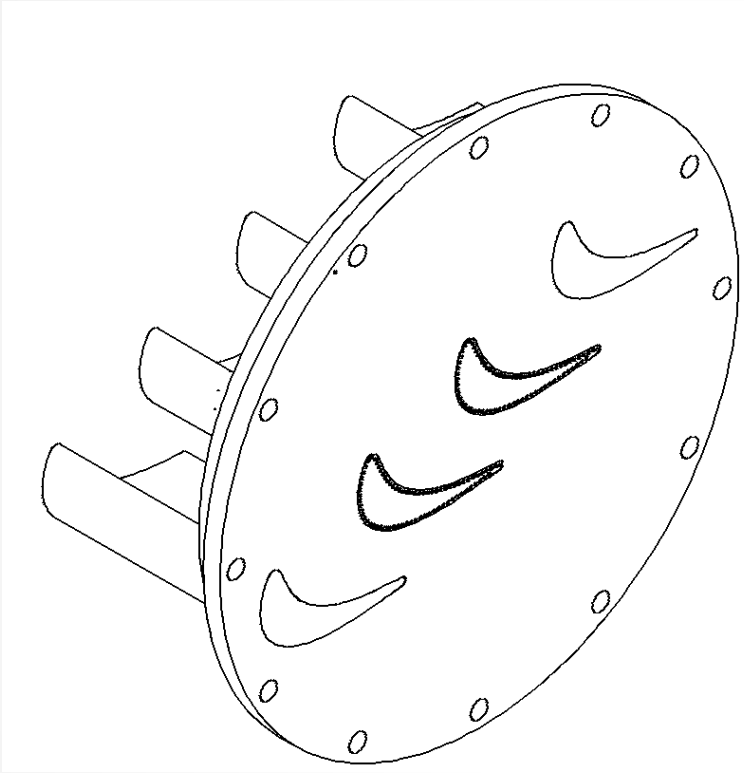
„ANSYS” CASCADE ARRANGEMENT

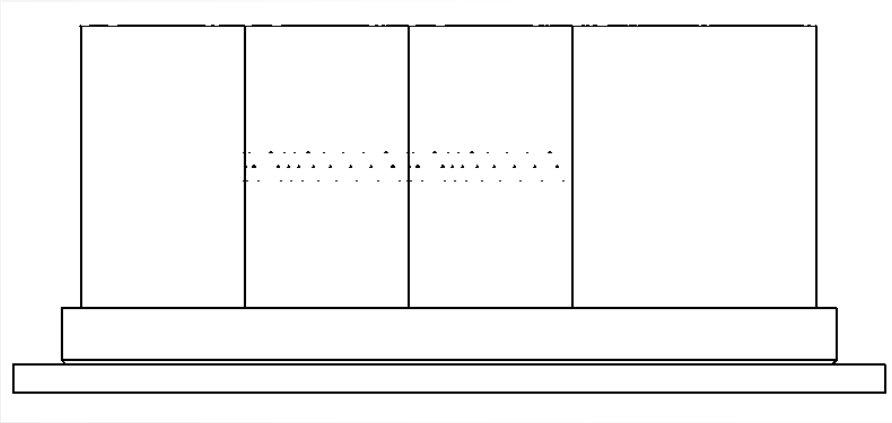


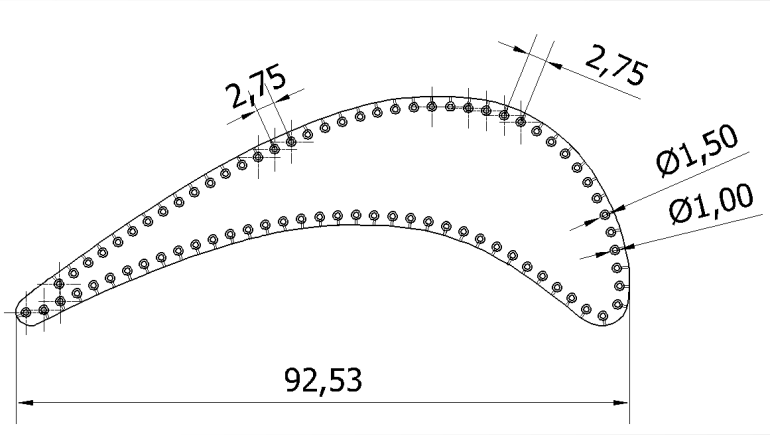


- **Chord (c): 81,6 mm**
- **Spacing (s): 65,7 mm**
- **Throat (o): 36,6 mm**
- **Flow angle (β1): 28°**
- **Blade angle relative to cascade axis (βs): 30,5°**
- **s/c: 0,805**
- **arccos(o/s): 56,1°**

VKI LS-59 CASCADE ARRANGEMENT

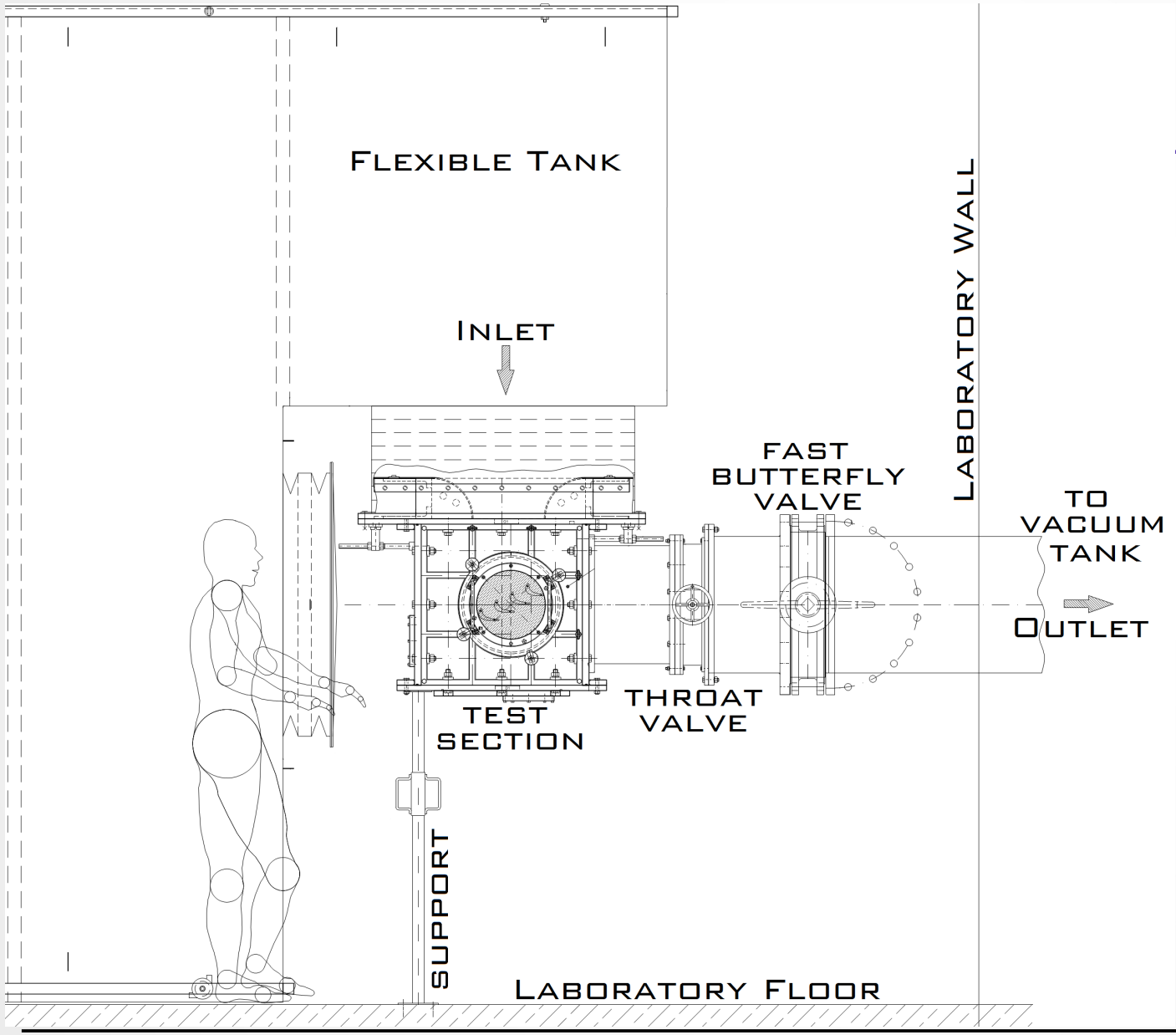






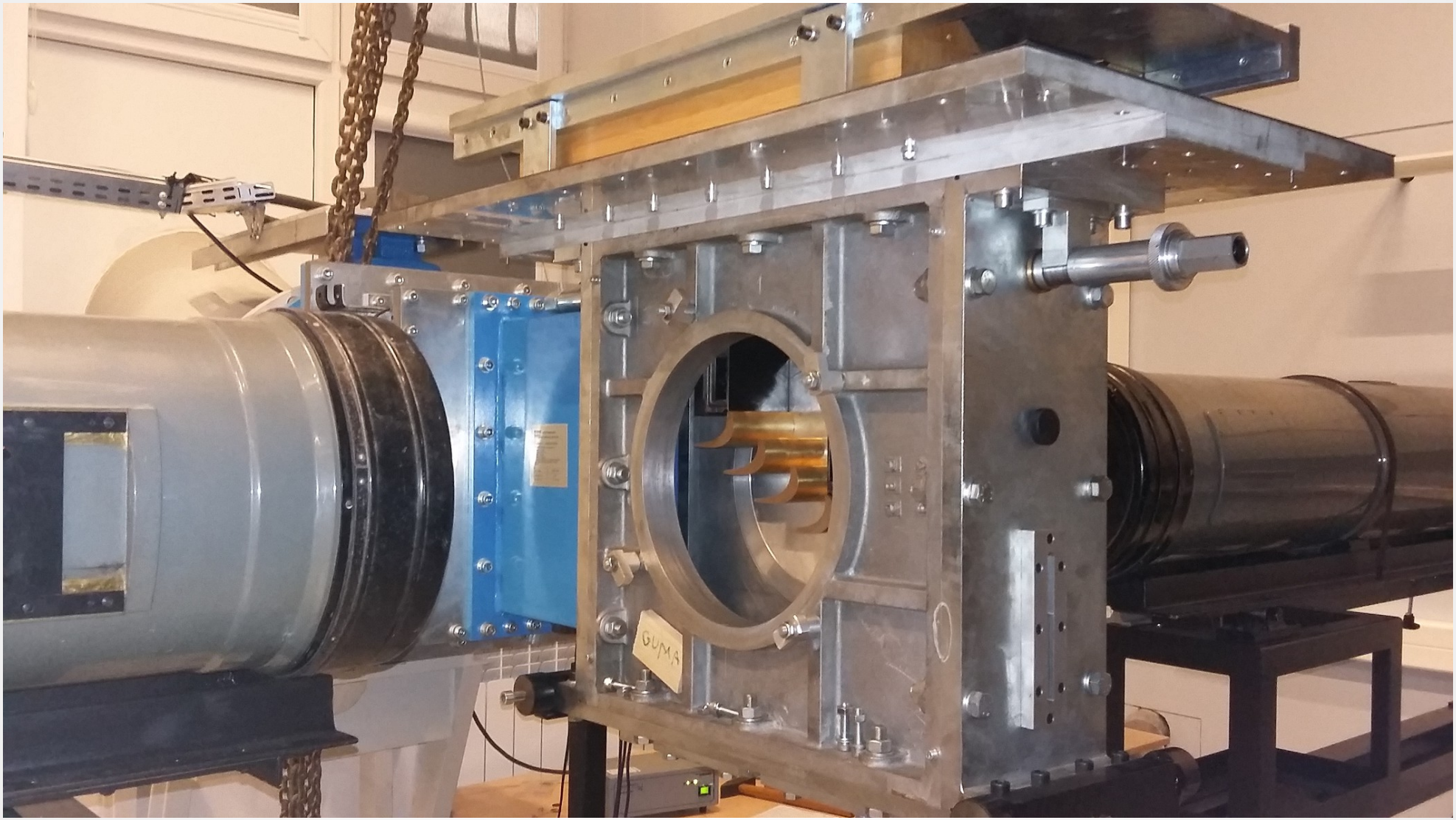
- **Chord (c):** 92,53 mm
- **Spacing (s):** 65,7 mm
- **Throat (o):** 24,8 mm
- **Flow angle (β1):** 28,5°
- **Blade angle relative to cascade axis (βs):** 33,3°
- **s/c:** 0,71
- **arccos(o/s):** 67,8°

CASCADE WIND TUNNEL



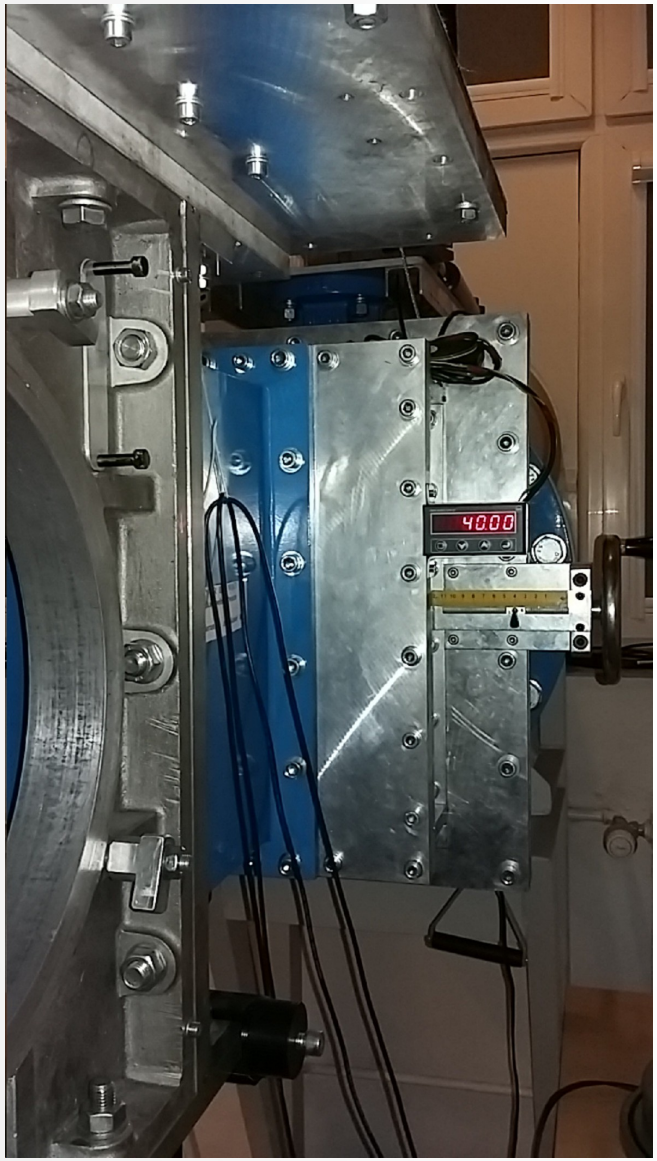
- Open circuit intermittent, in-draft (suction) type wind tunnel
- Convergent intake nozzle (intake channel width depends on angle of attack)
- Depth: 100 mm
- Angle of incidence range: +/- 15°
- Inlet turbulence intensity: ~2,5%
- Inlet Mach: ~0,27 (AoA 0°)
- Vacuum tank capacity: 150m³
- Flexible tank capacity: 60m³

CASCADE WIND TUNNEL

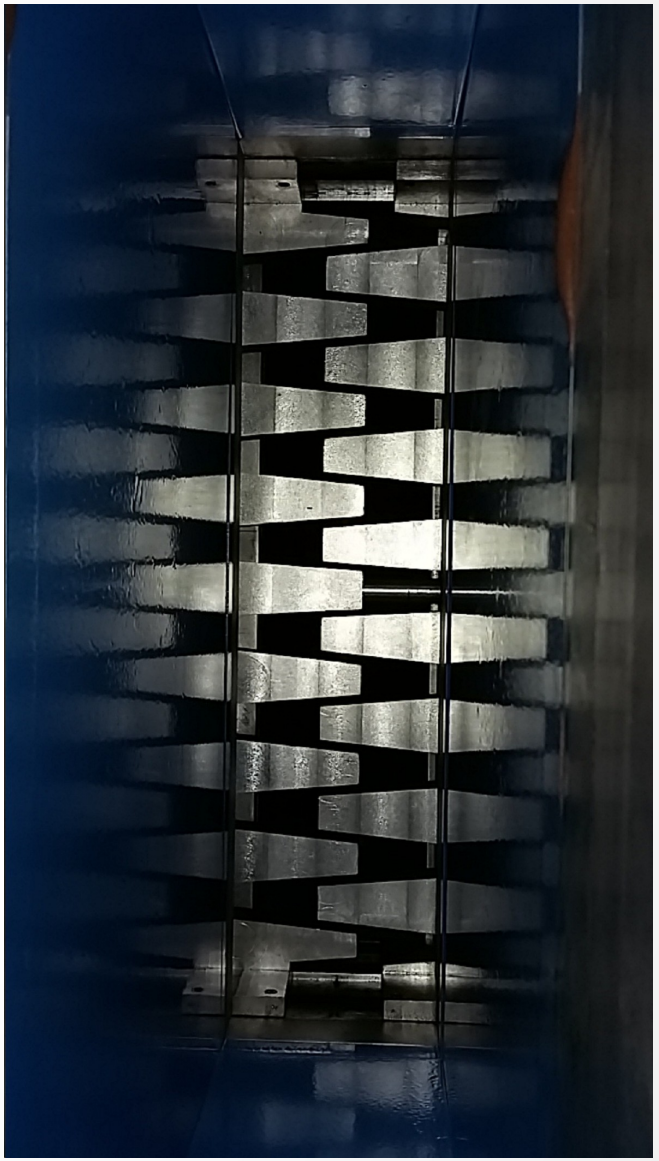


- **Cascade wind tunnel with side plate removed**

CASCADE WIND TUNNEL



- Throat valve (outside)



- Throat valve (inside)

APPARATUS – PRESSURE MEASUREMENTS

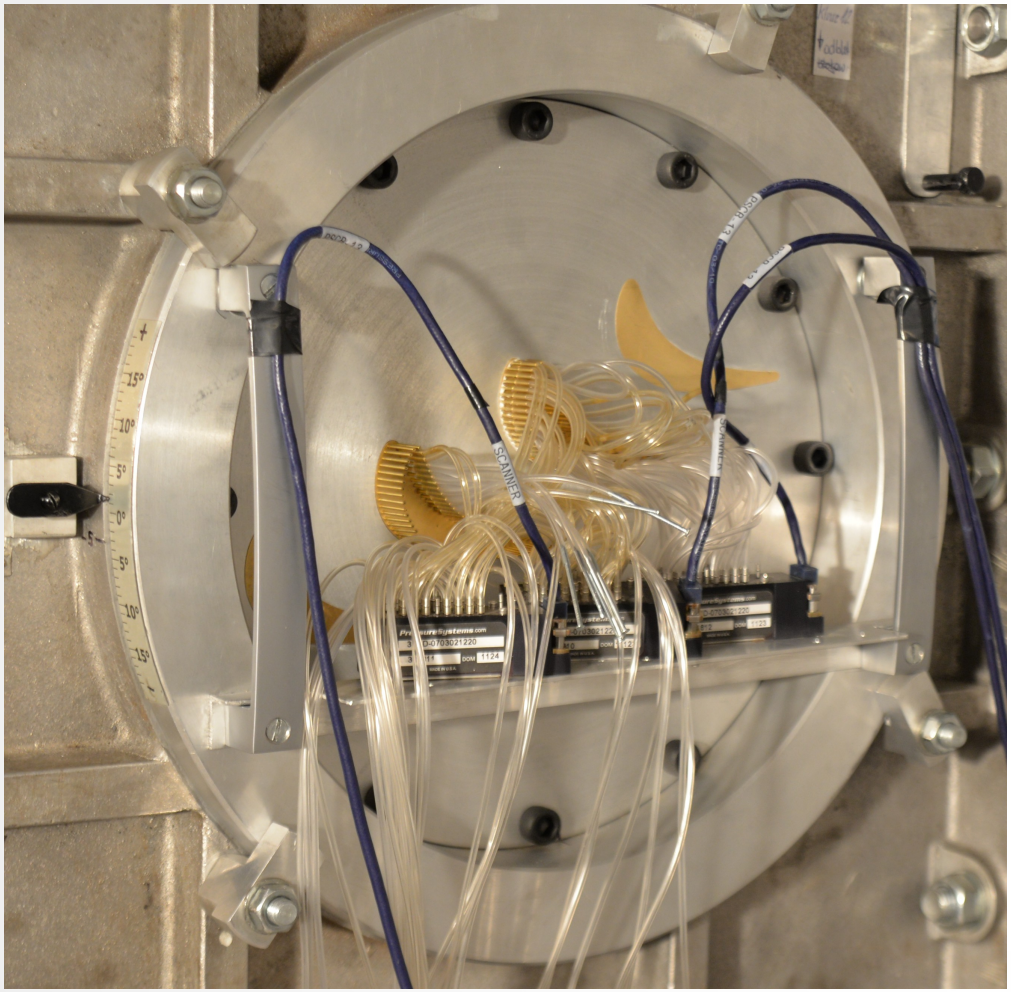
- **1,5 mm internal diameter elastic tubes connecting the sensor and pressure ports of model**

- **ESP-32HD DTC fast, piezoresistive miniature electronic differential pressure sensor consisting of an array of 32 individual channels each. Pressure range ±103 kPa (15 psid). Data acquisition frequency – 100 Hz (Maximum – 1200 Hz)**

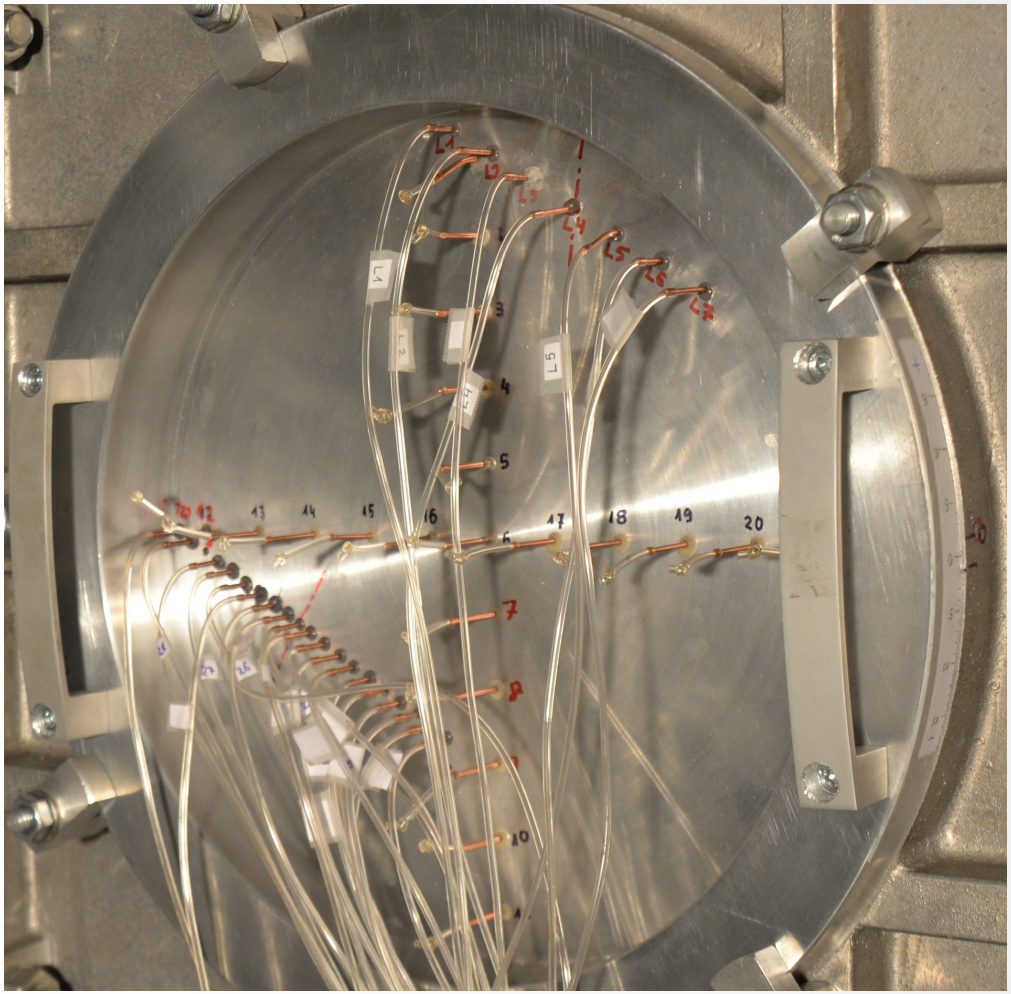
- **Single DTC (Digital Temperature Compensation) Initium Data Acquisition System (10/100 Base-T Ethernet Interface)**

- **In-house developed LabView software package for the fast butterfly valve control, data acquisition, post-processing and data reduction of obtained results**

APPARATUS – PRESSURE MEASUREMENTS

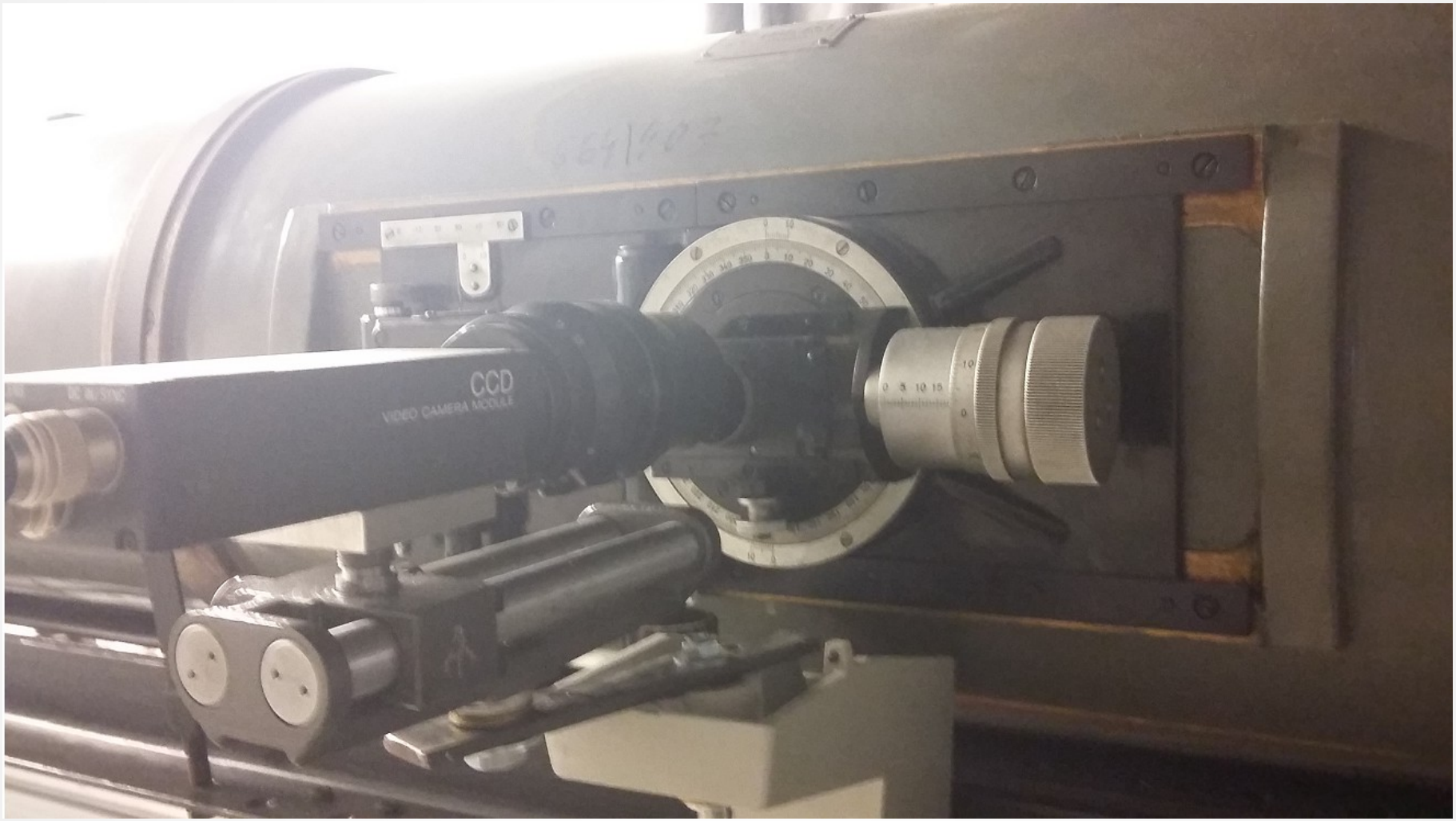


- **Pressure scanners connected to the VKI instrumented blades**



- **Inlet & wake pressure taps arrangement on vis-a-vis side plate**

APPARATUS – FLOW VISUALISATION (CONTINUOUS LIGHT)



- **CCD camera mounted to the Schlieren system**

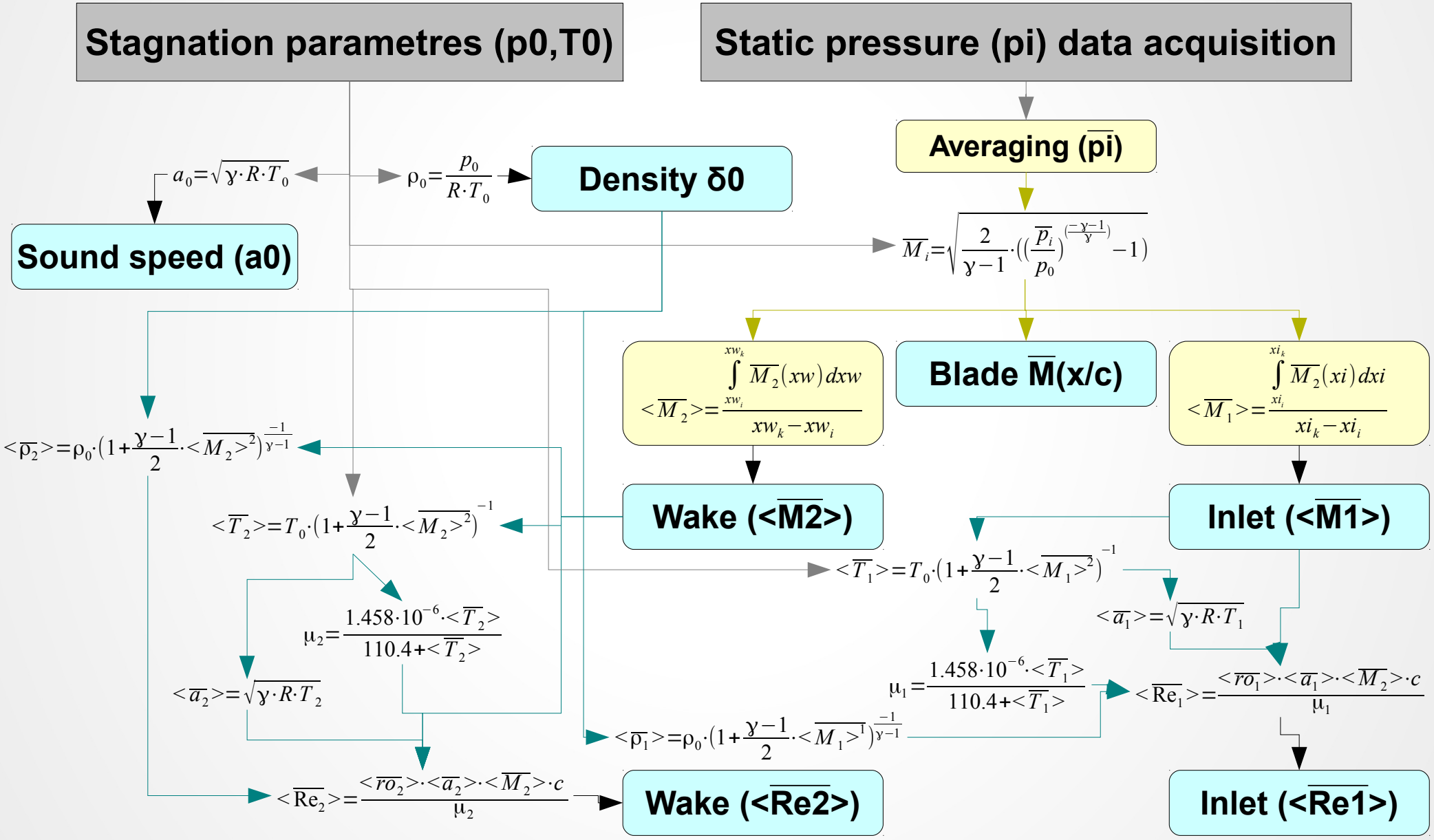
APPARATUS – FLOW VISUALISATION (FLASH LIGHT)

- **Photron SA-5 fast camera mounted in place of CCD camera 1 kHz repetition rate, TTL synchronization with Ministrobokin**

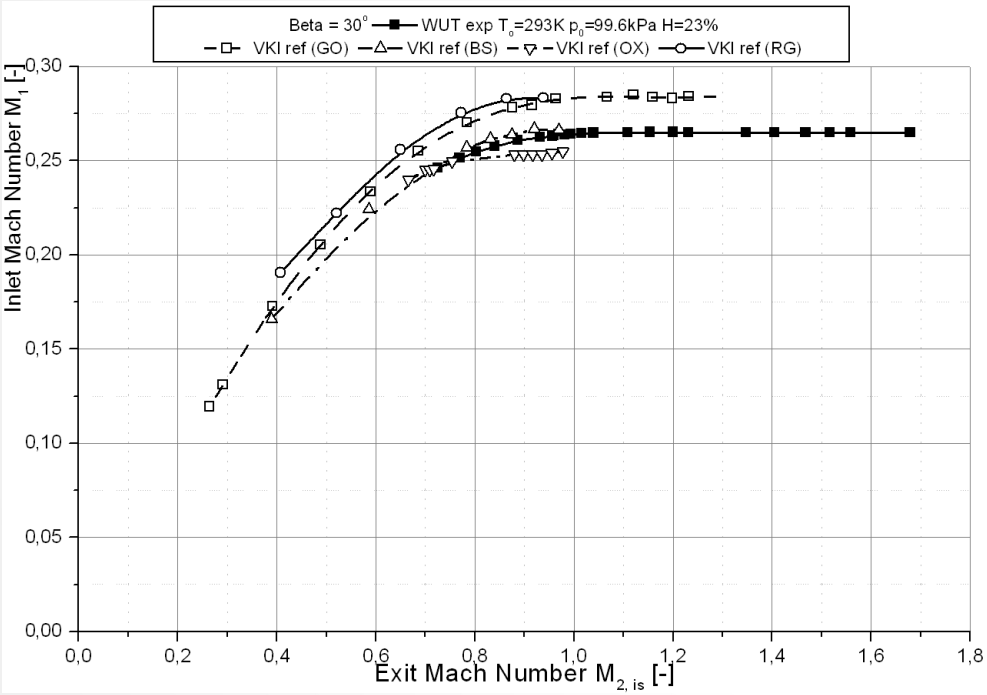
- **Ministrobokin 20 flash generator (external triggering up to 20 kHz)**

- **Fisher-Nanolite KL-L Flashlamp 18 ns single flash duration (25mJ)**

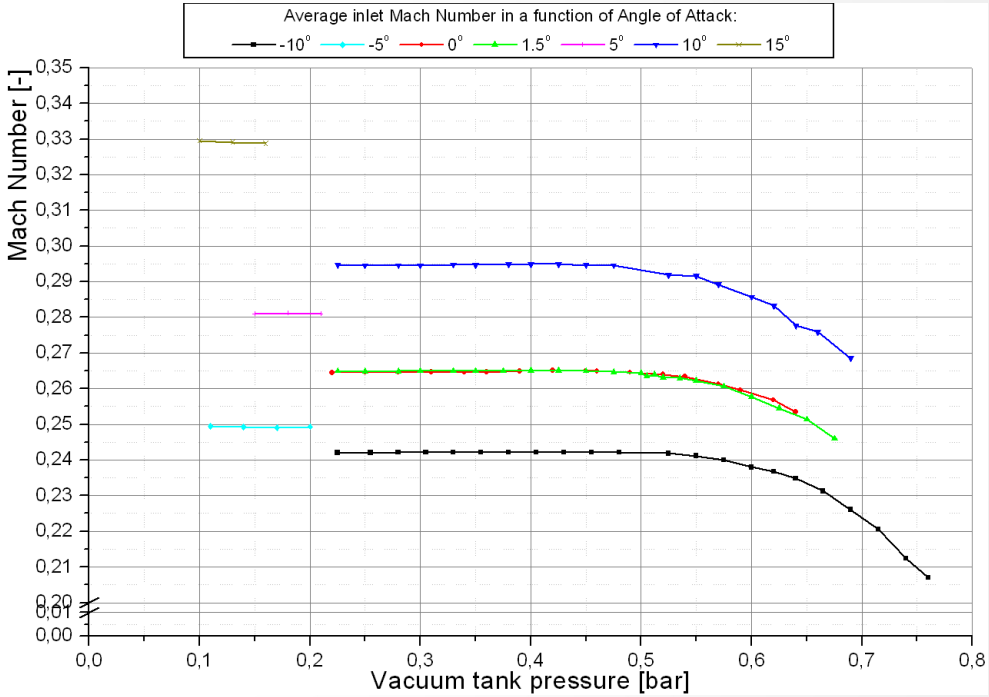
PRESSURE MEASUREMENTS – METHODOLOGY



PRESSURE MEASUREMENTS – LOW HUMIDITY VKI LS-59 CASCADE

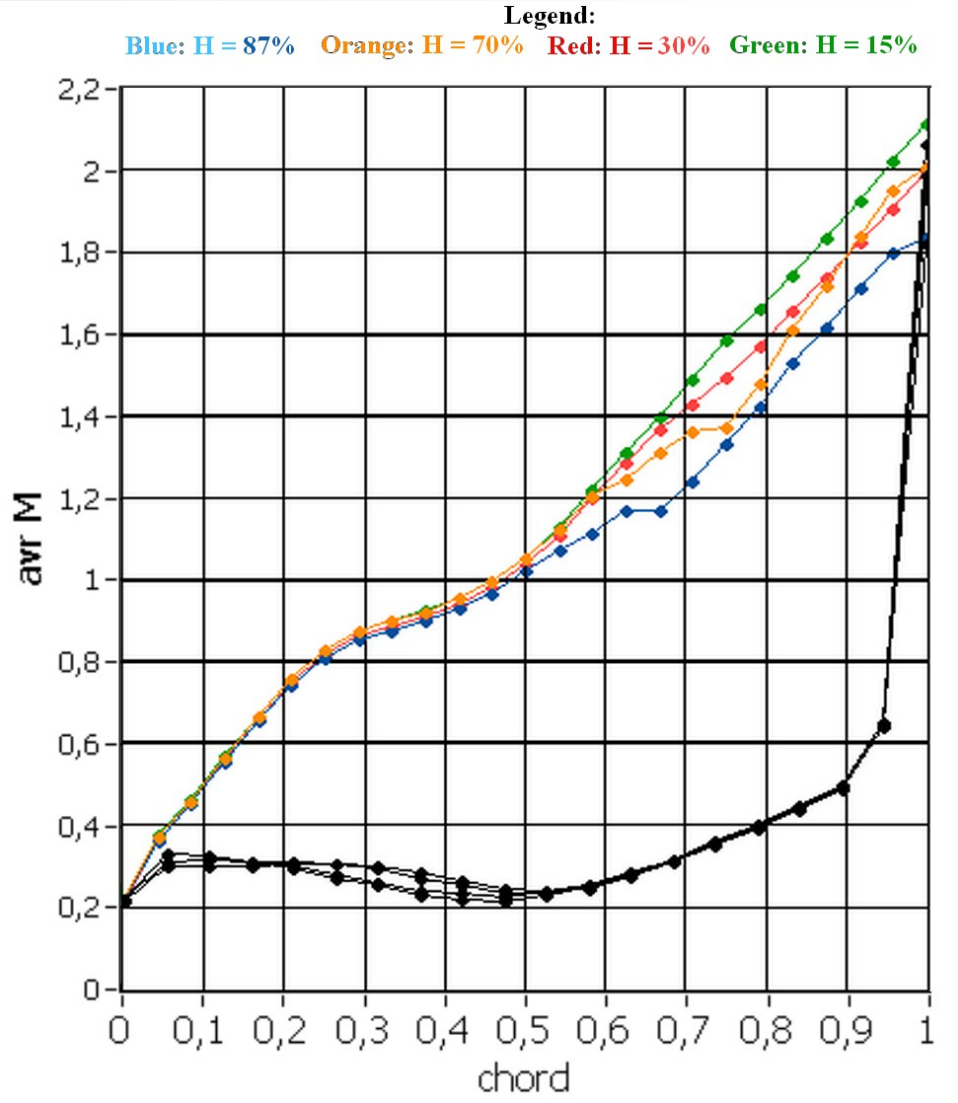


- **Inlet Mach Number M1 in function of Exit Mach Number M2**

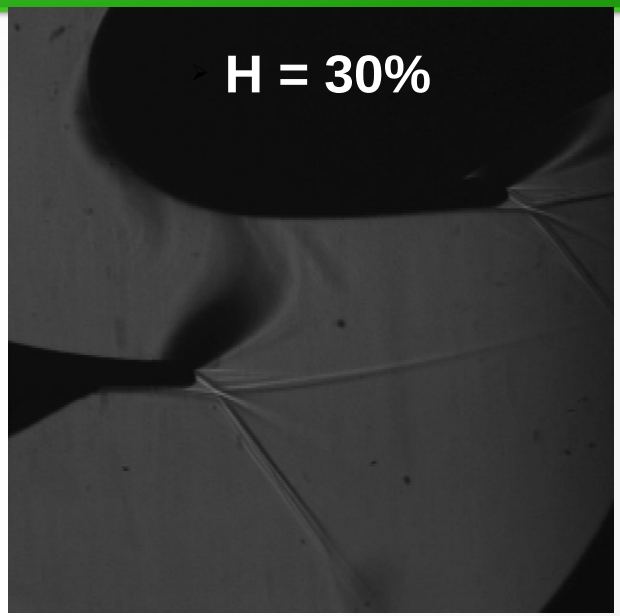


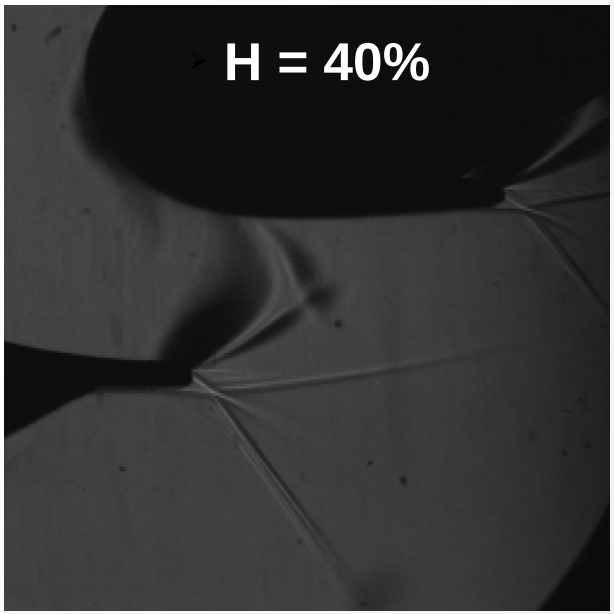
- **Inlet Mach Number M1 in function of Vacuum tank pressure p3**

HUMIDITY INFLUENCE „ANSYS” CASCADE, CONTINUOUS LIGHT

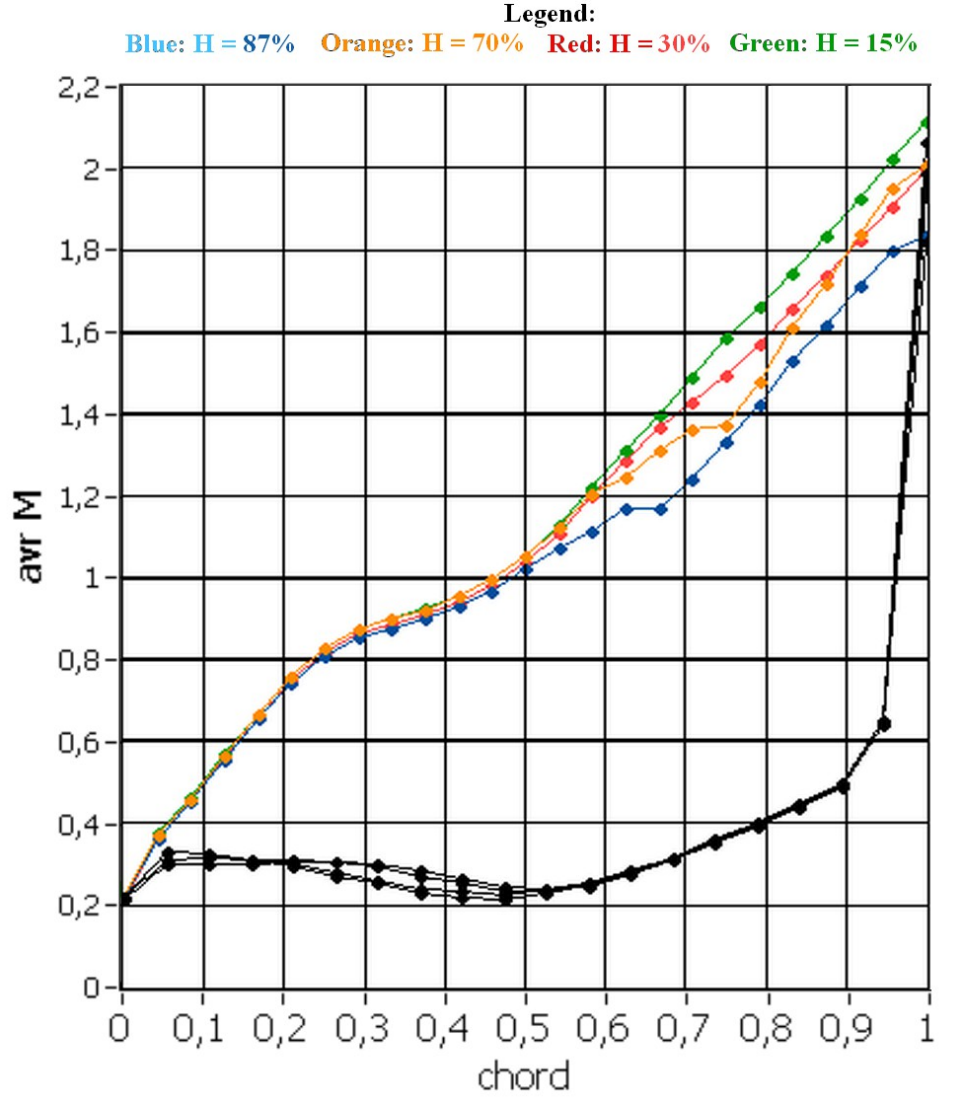


- β1 = 28°, Vacuum tank p = 0.23 bar

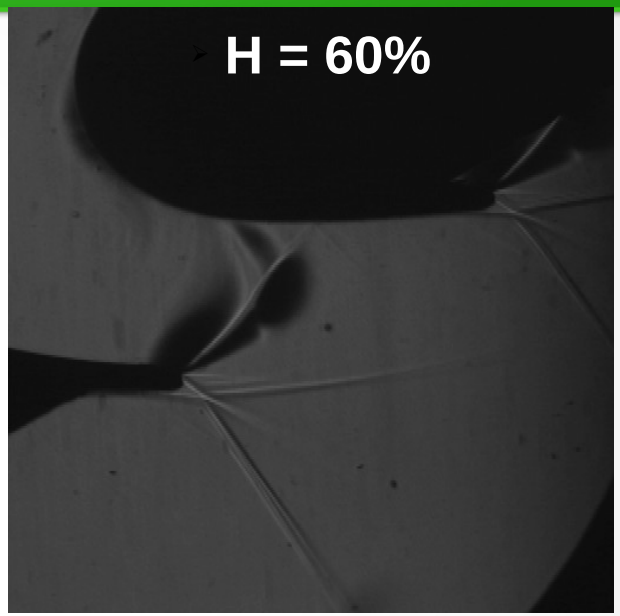


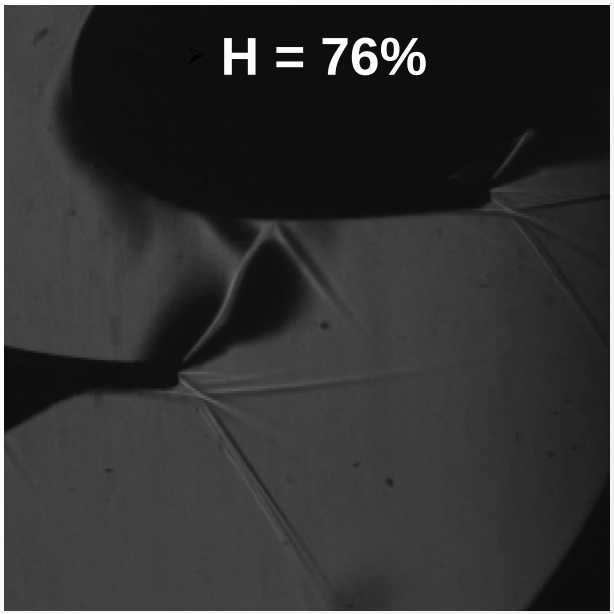


HUMIDITY INFLUENCE „ANSYS” CASCADE, CONTINUOUS LIGHT

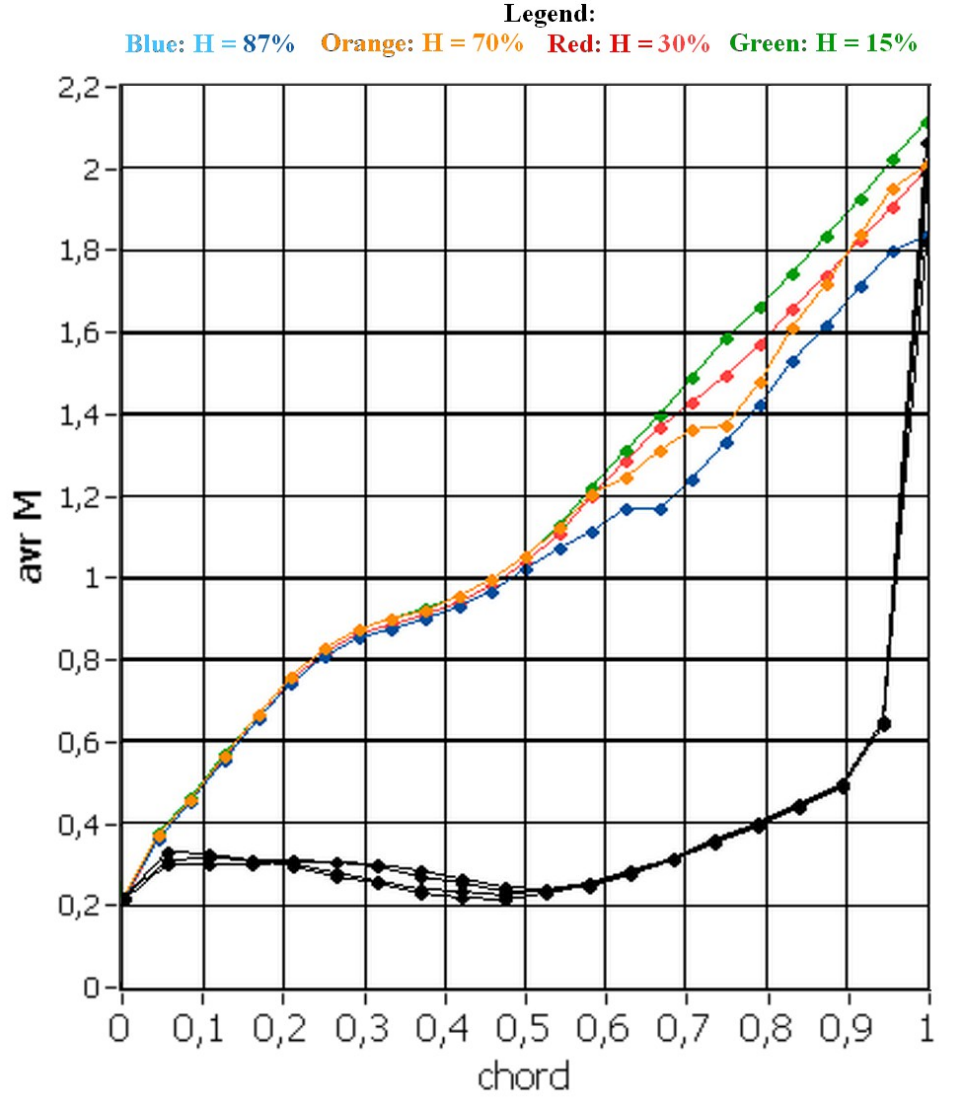


- β1 = 28°, Vacuum tank p = 0.23 bar

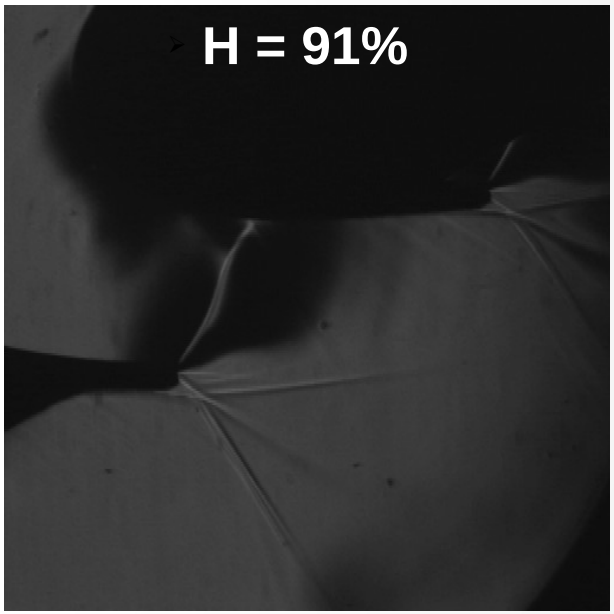




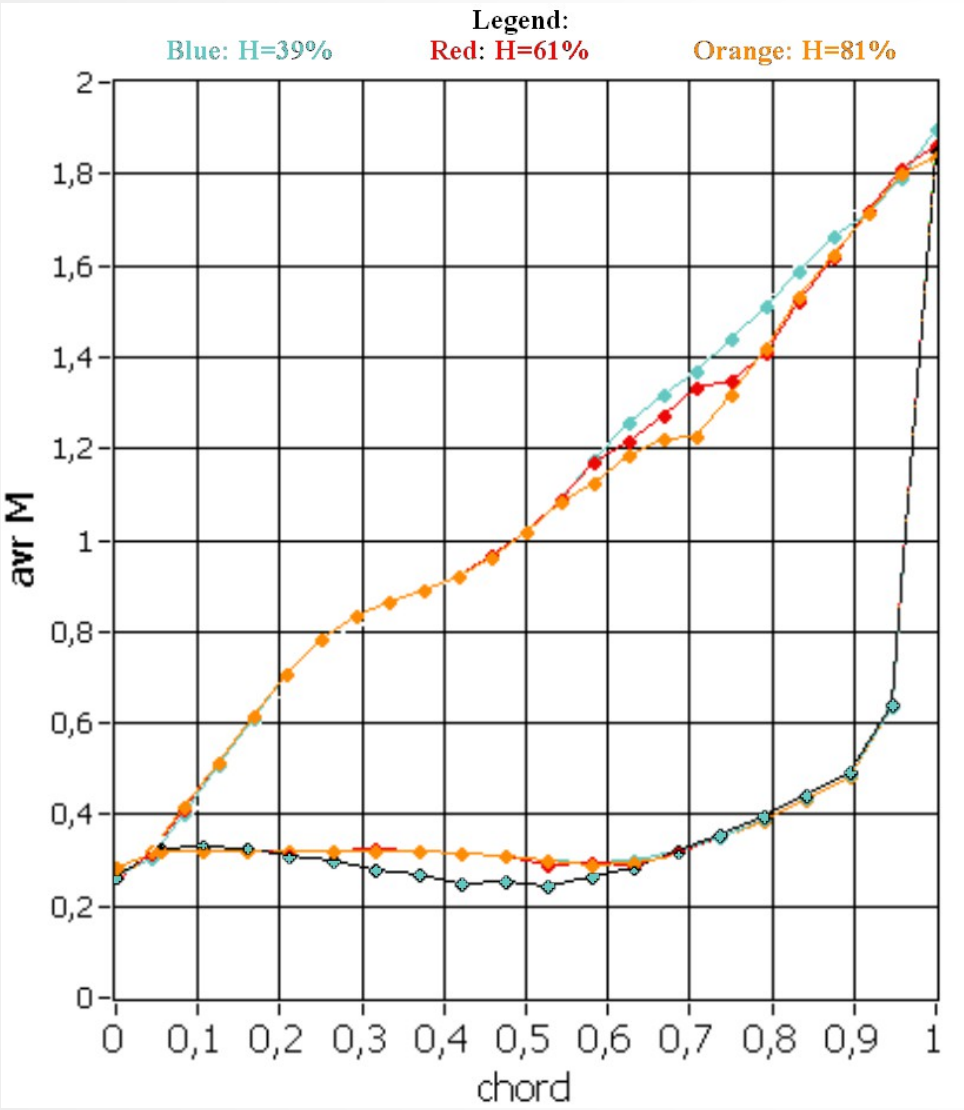
HUMIDITY INFLUENCE „ANSYS” CASCADE, CONTINUOUS LIGHT



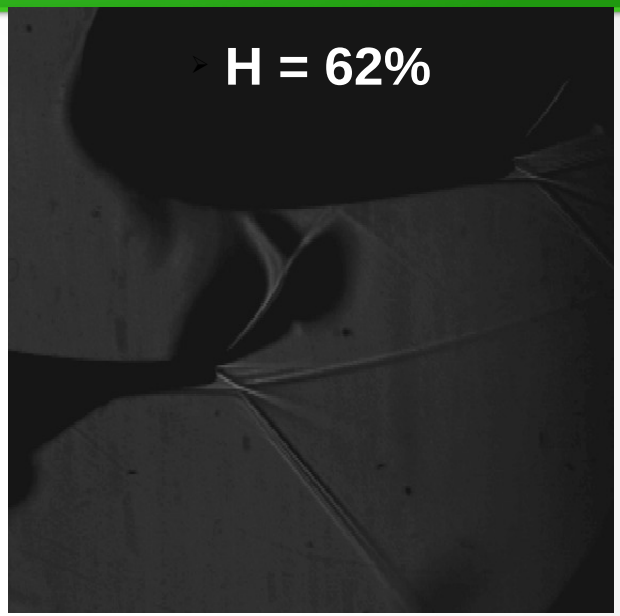
- β1 = 28°, Vacuum tank p = 0.23 bar

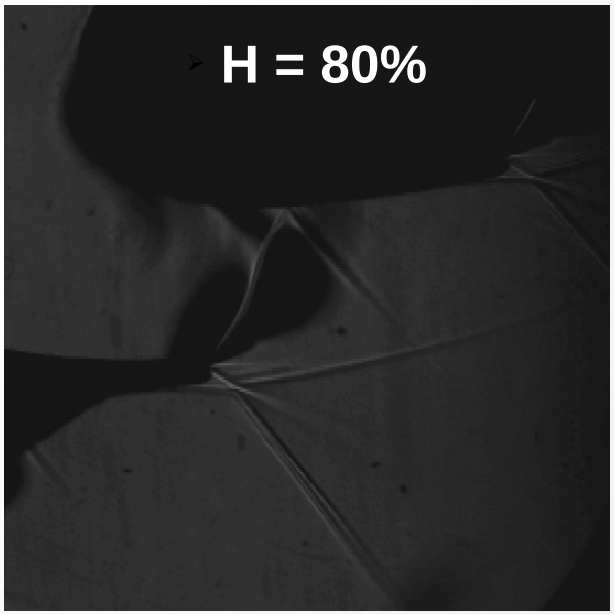


HUMIDITY INFLUENCE
„ANSYS” CASCADE, CONTINUOUS LIGHT

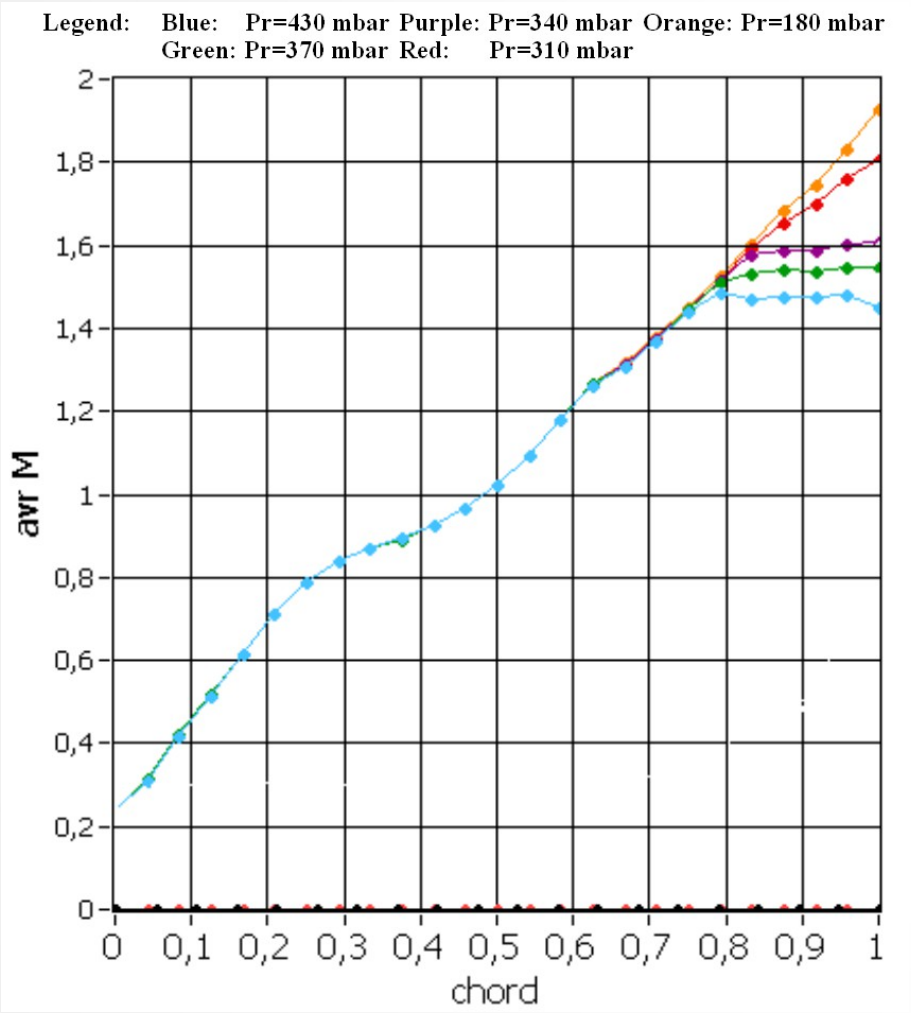


β1 = 33°, Vacuum tank p = 0.23 bar

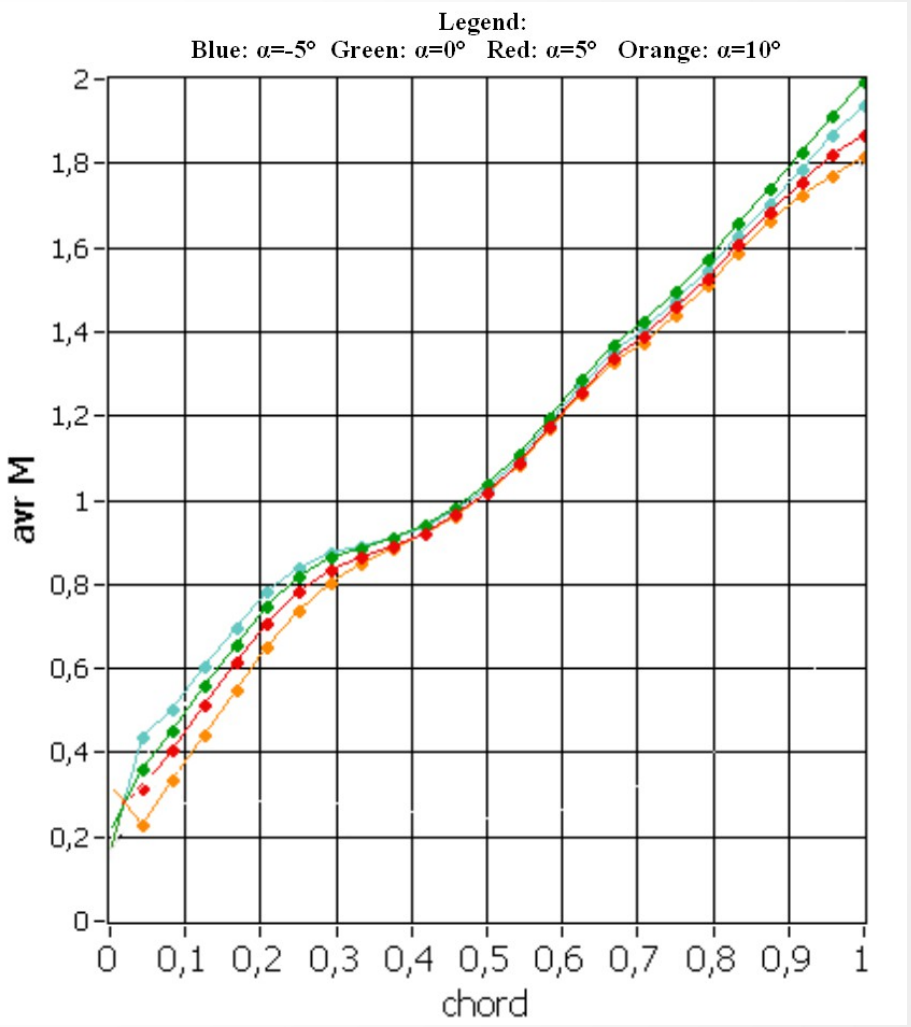




PRESSURE MEASUREMENTS – LOW HUMIDITY

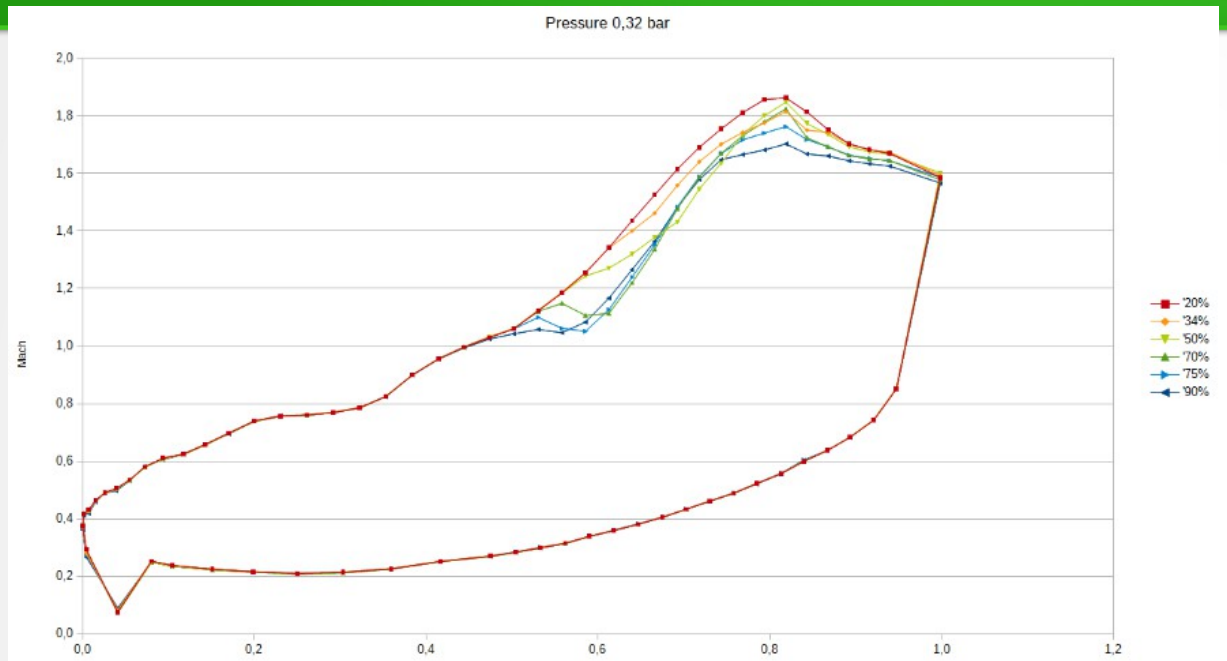


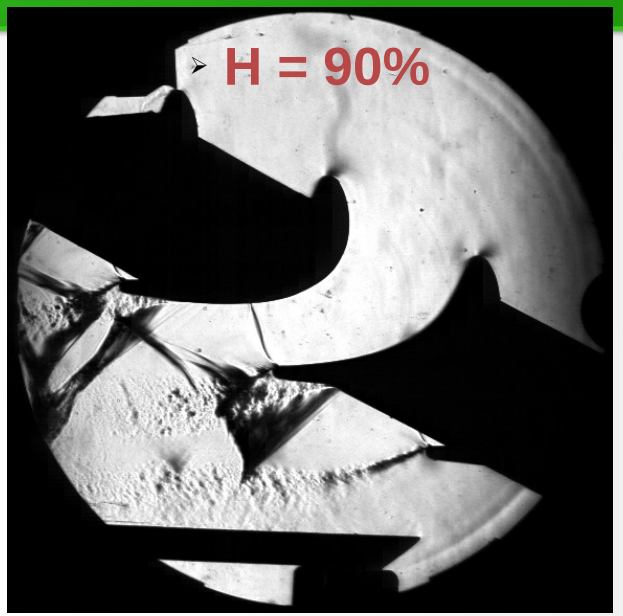
- β1 = 28°, Vacuum tank p influence

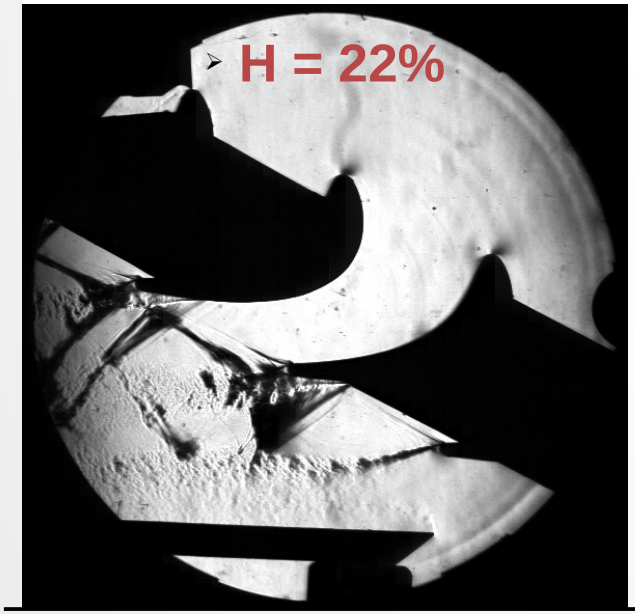


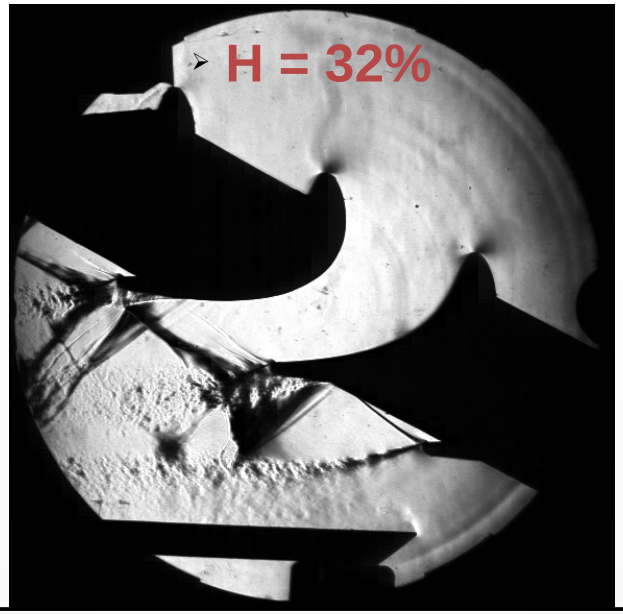
- Alfa influence, Vacuum tank p=0.23 bar

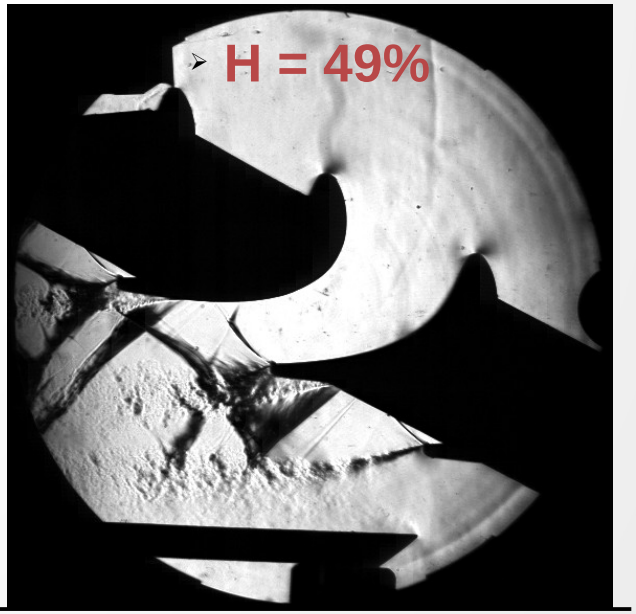
INFLUENCE OF HUMIDITY
VKI LS-59 CASCADE + ADDITIONAL PLATE



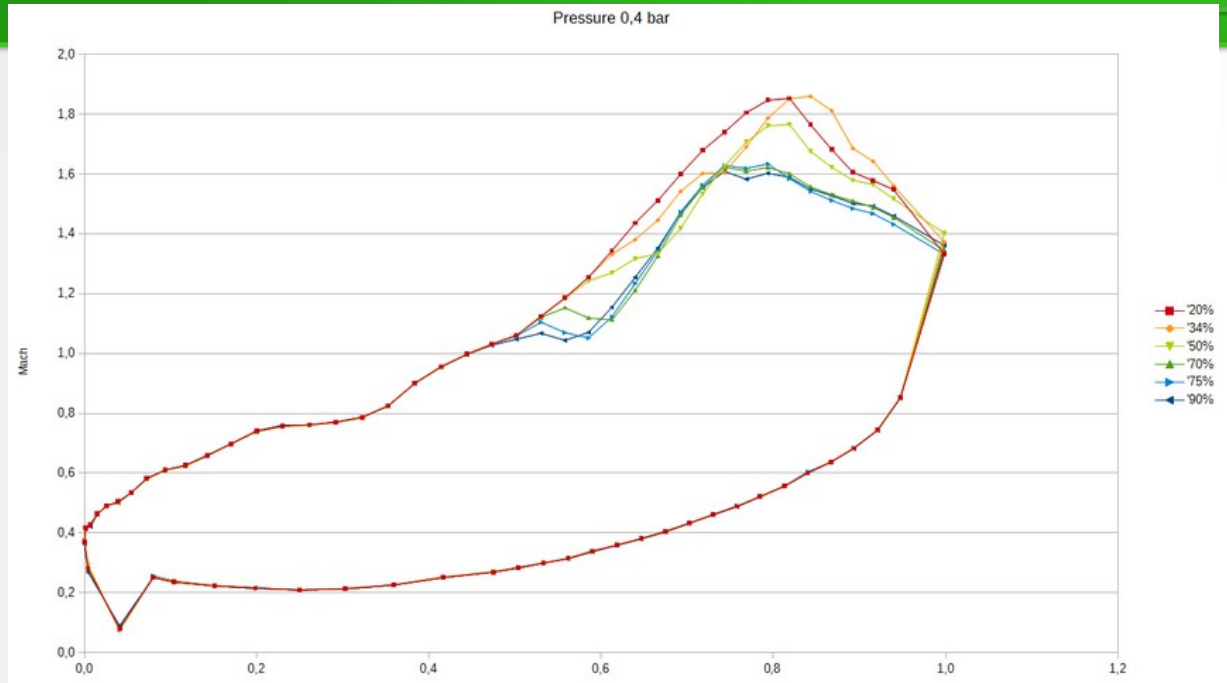


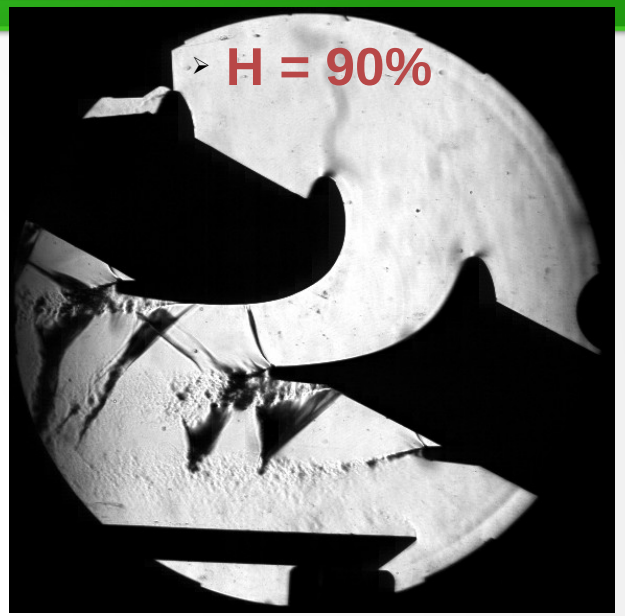


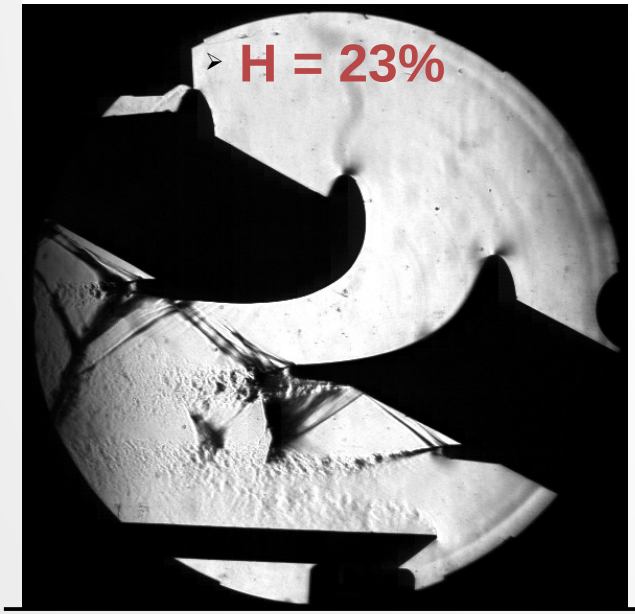


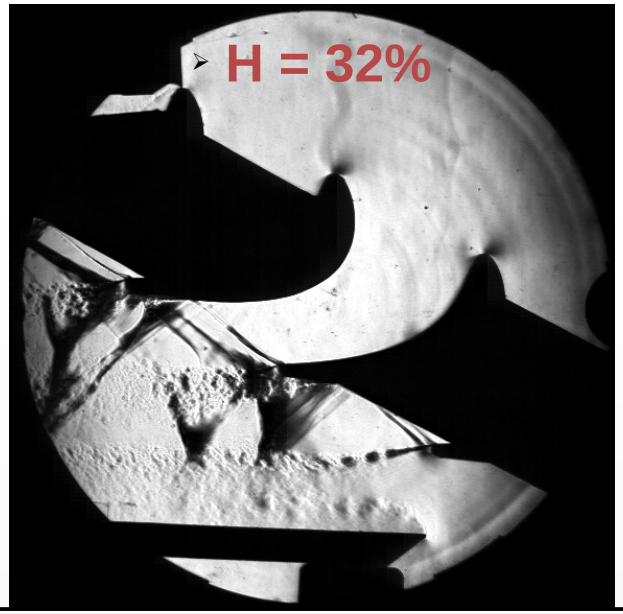


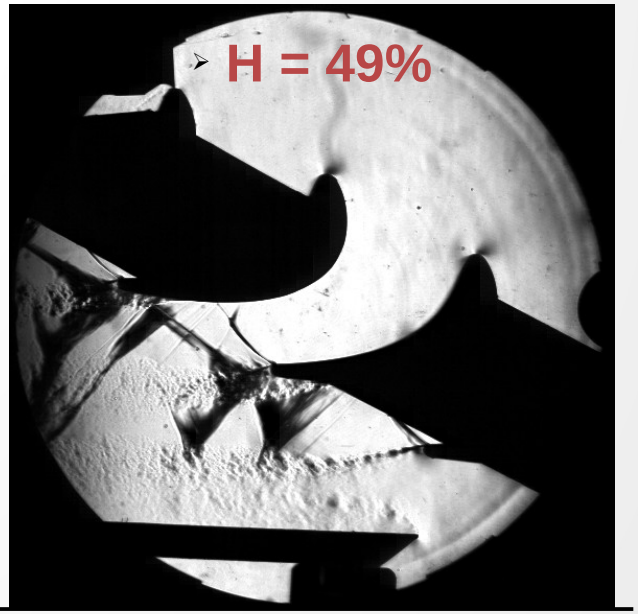
INFLUENCE OF HUMIDITY
VKI LS-59 CASCADE + ADDITIONAL PLATE



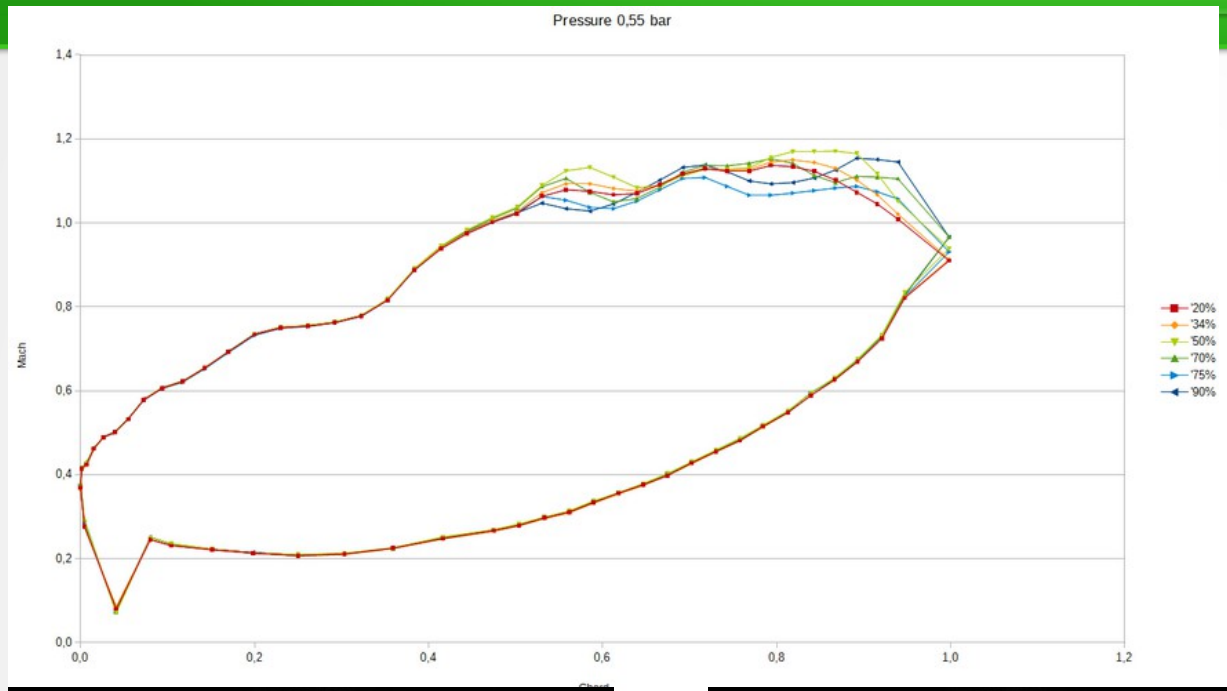


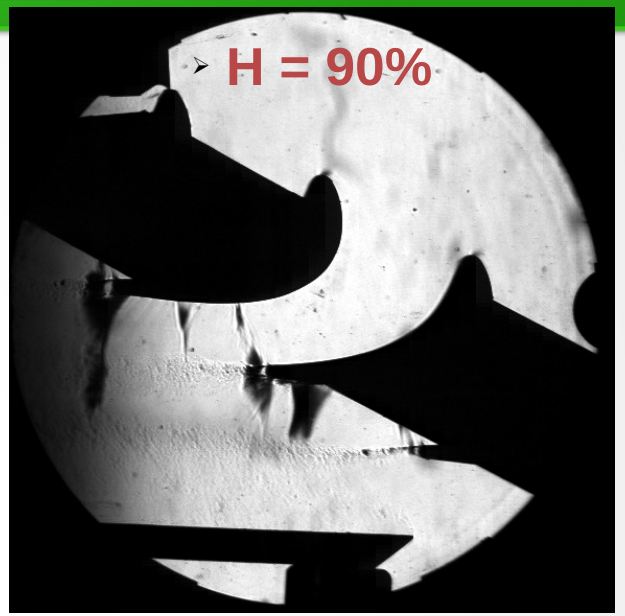


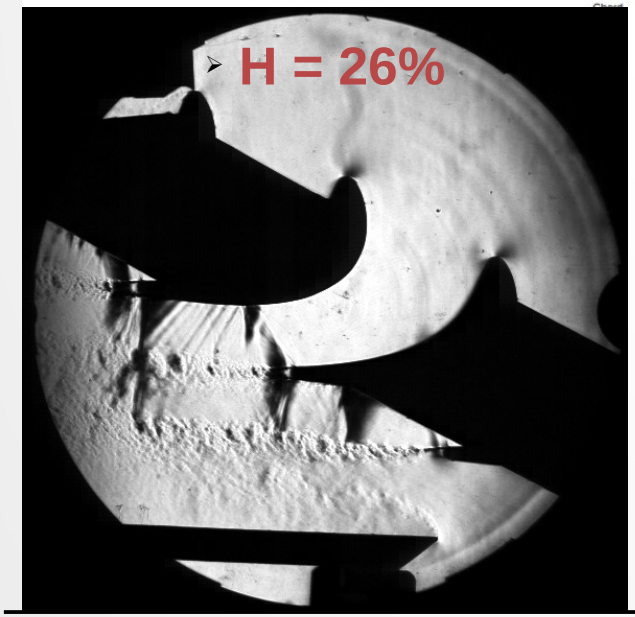


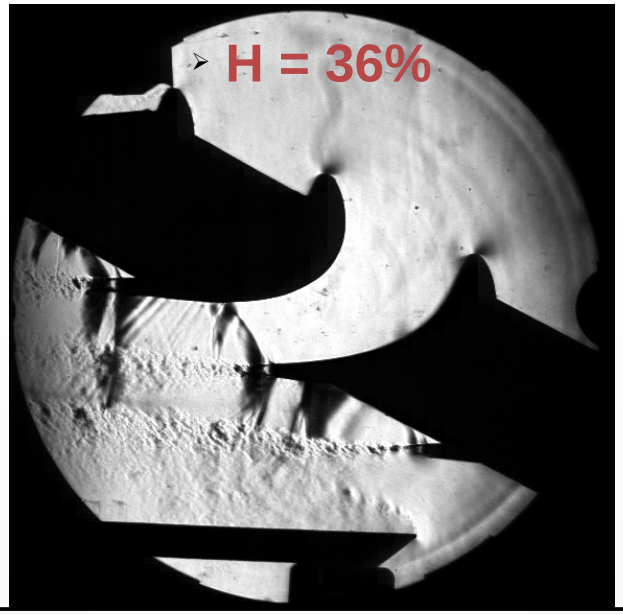


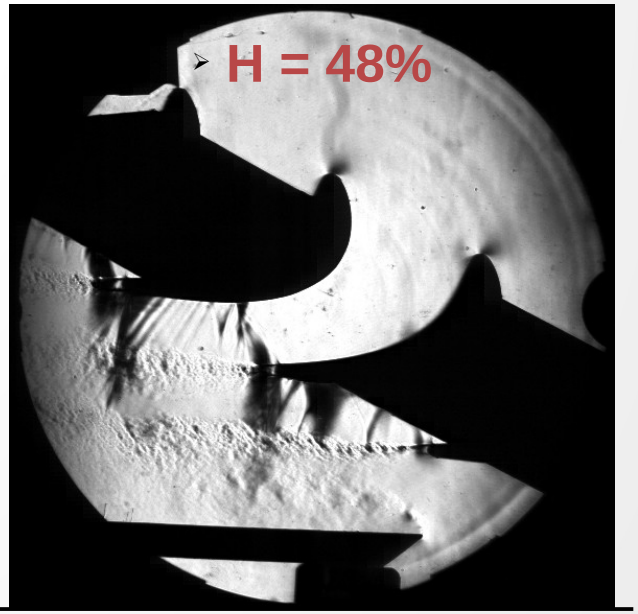
INFLUENCE OF HUMIDITY
VKI LS-59 CASCADE + ADDITIONAL PLATE



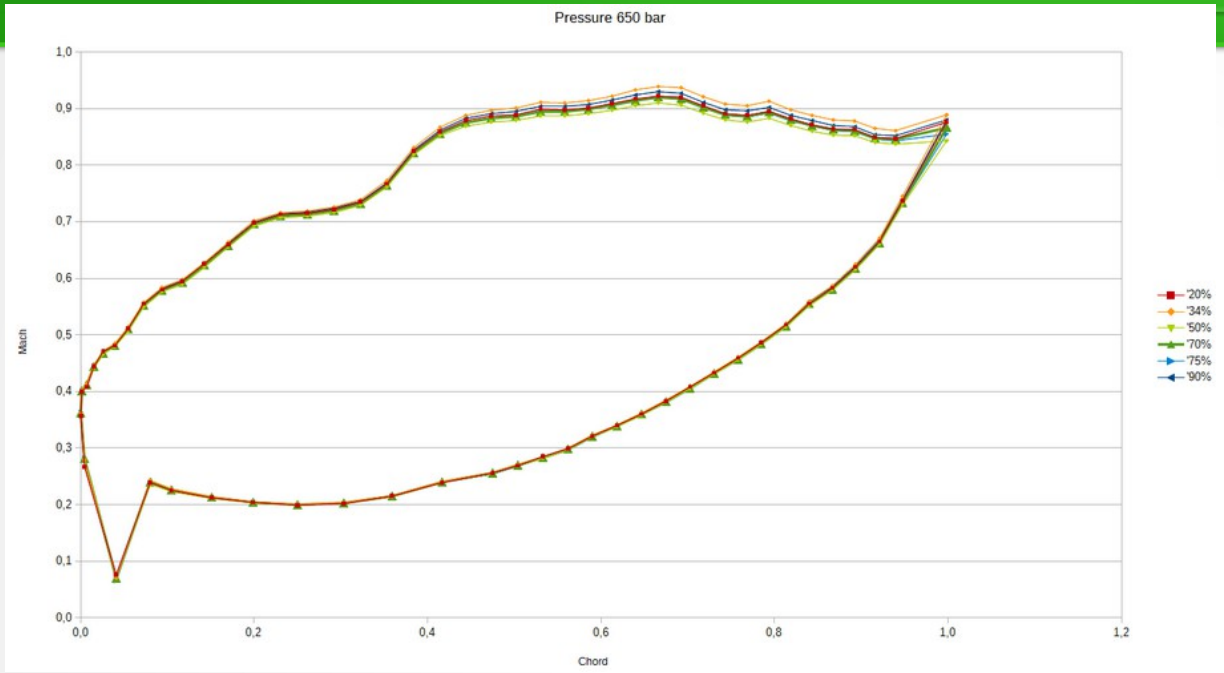


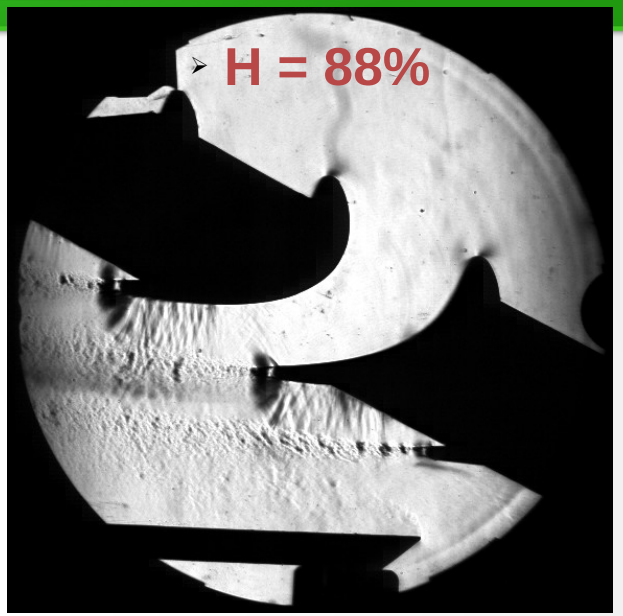


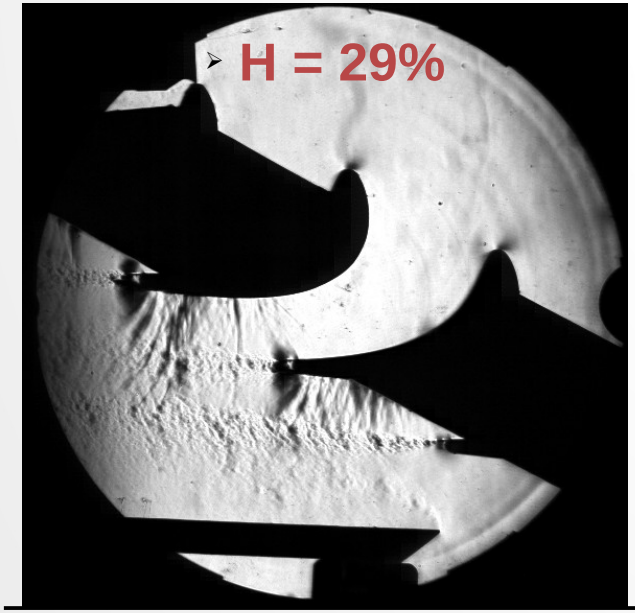


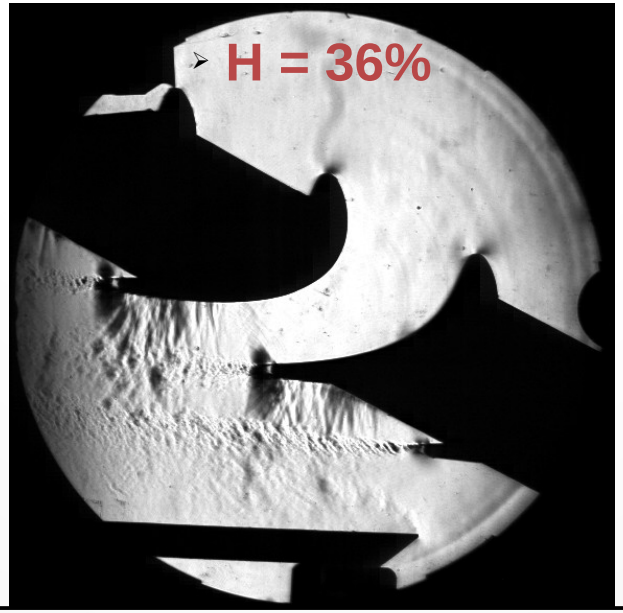


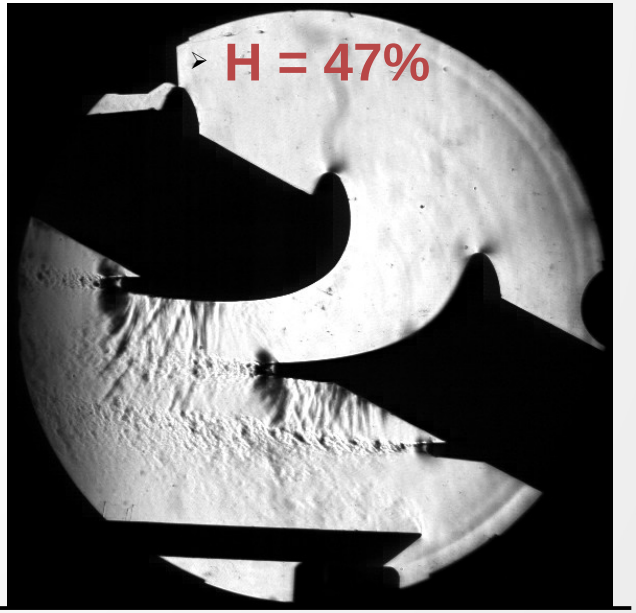
INFLUENCE OF HUMIDITY
VKI LS-59 CASCADE + ADDITIONAL PLATE











CONCLUSIONS

- **Design, theoretical inlet Mach number of a cascade wind tunnel was confirmed by experiment**
- **Humidity negatively affects the performance of the blade cascade, mostly in the rear part of its suction surface, then the pressure drop is lower**
- **Notable condensation waves and reconfiguration of flow field past the throat were observed, condensation slows down the flow before the trailing edge. There was no such a distinguishable effect for purely subsonic flow.**

LESSONS LEARNED & FURTHER RESEARCH POSSIBILITIES

- **Supplementary pressure measurements for high humidity conditions, VKI LS-59 cascade to close gaps in a set of collected data**

- **The measurement of stagnation pressure in wake – crucial for determination of loss coefficient and proper recalculation of M2. Kulite based wake rake may give such an opportunity**

- **Development of integrated system for monitoring of humidity distribution inside flexible tank as well as ensuring its homogeneousness by the set of fans.**

QUESTIONS?

Thank You for your attention!