Experimental Analysis of Wet Compression in Axial Compressor Stage

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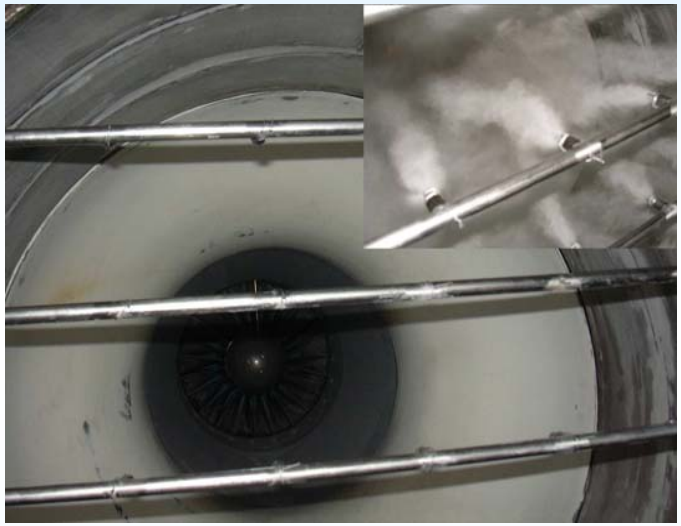
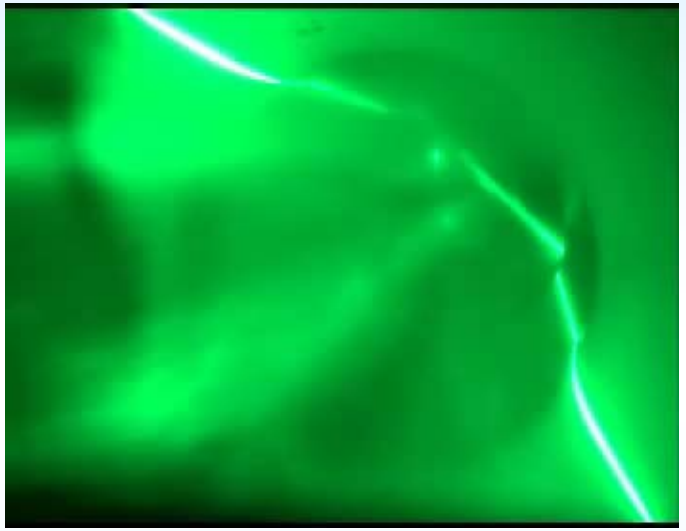
Experimental Analysis of Wet Compression in Axial Compressor Stage

- Experimental Set-Up
- Effect of Water Injection on Compressor Stage Aerodynamic Performance
- Effect on Stage Power Consumption
- Conclusions

Experimental Set - Up

First Stage of an Axial Compressor

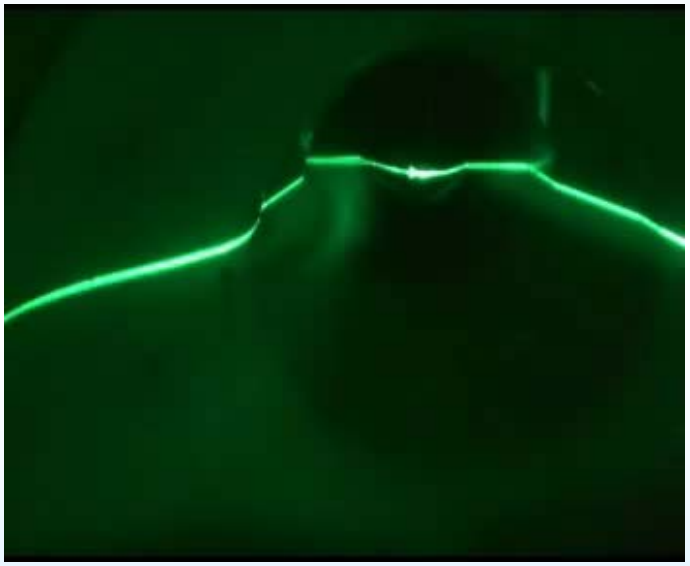


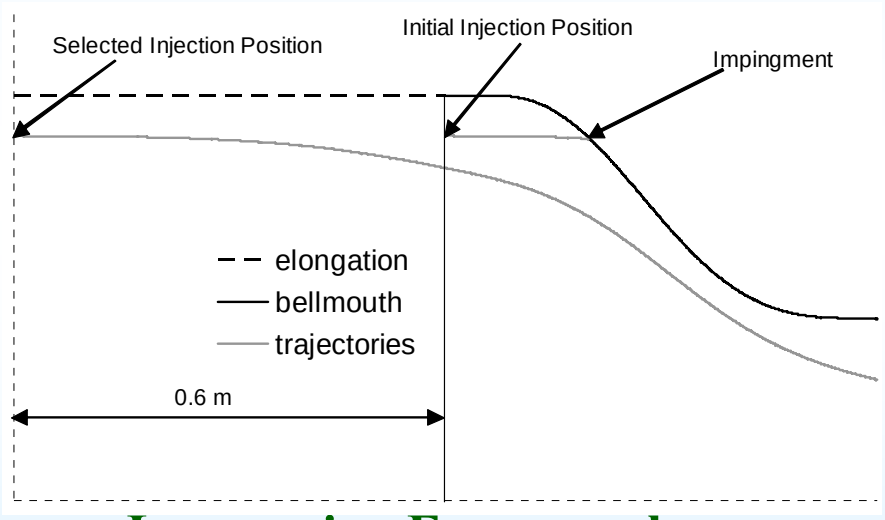


Impaction Pin Nozzles (Mee Industries)

Experimental Set - Up

Bellmouth Configuration



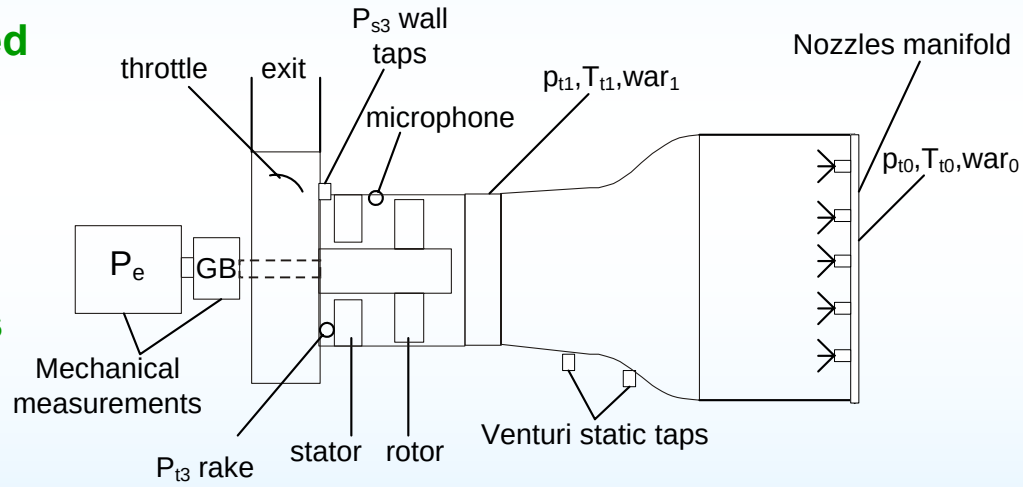


- Lagrangian Framework
- Droplet Evaporation Model
- Meridional Flow Solver (2D)

Experimental Set-Up

Test-Rig Measurements

1. The flow rate of water
2. The pressure at nozzle manifold
3. Compressor Rotational Speed
4. Power of the Shaft
5. Ambient Conditions (p_{t0},T_{t0},war_0)
6. Compressor Inlet Conditions (p_{t1}, p_{s1}, T_{t1}, war_1)
7. Inlet Flow Rate (Venturi)
8. Compressor Exit Conditions (p_{t3}, p_{s3})
9. Oil Thermal Losses



Experimental Set-Up

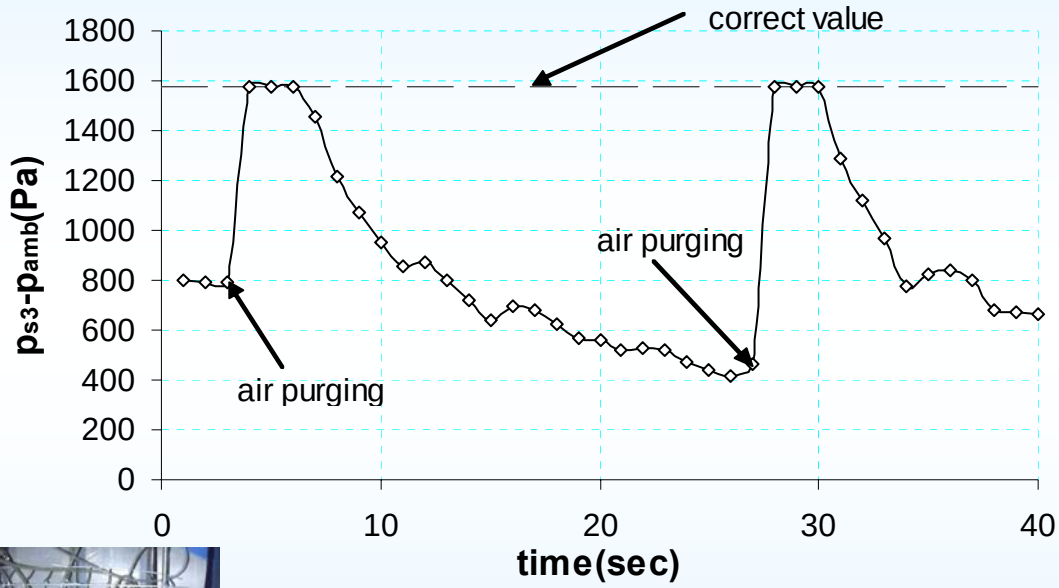
Measurements Considerations

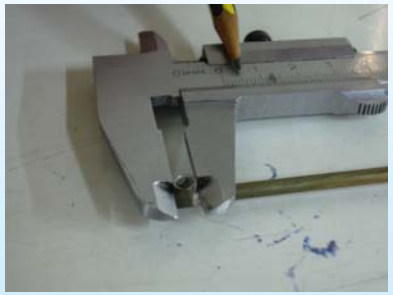
- **Pressure Measurement**: Potential Plugging of Pressure Holes and Connections due to Droplets
- **Temperature Measurement**: Droplets impingement at Temperature Sensors tend to Mask the Flow Temperature
- **Humidity Measurement**: Influencing the Magnitudes used for calculating the Stage Performance Characteristics
- **Unstable Operation Determination**: Hot Wire use in Droplet Laden Flow is not Plausible

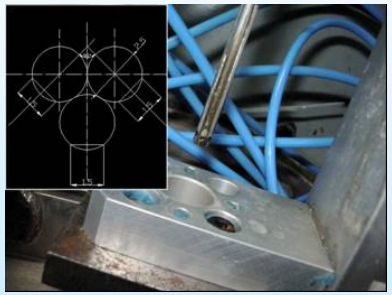
Experimental Set-Up

Pressure Measurements

- Increased Pressure Holes Diameter
- Purging System using Pressurized Air and Electronic Vanes
- Defining of Acquisition Time to 1 sec



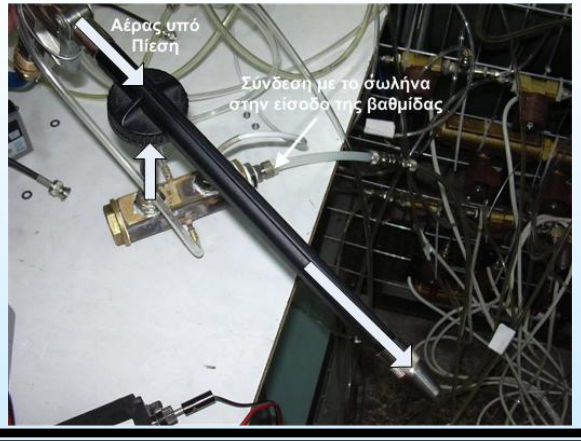




Experimental Set-Up

Compressor Measurements

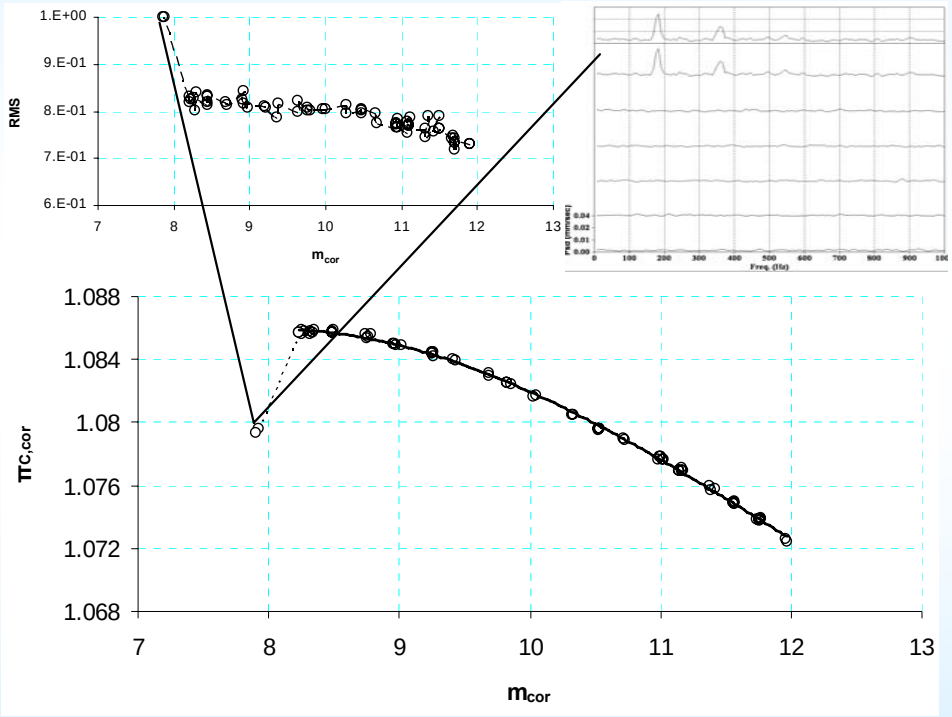
- Bleeding Air from the Stage Inlet introducing a bent tube facing downstream
- Using Power of the Shaft for the measurement of consumed power



Experimental Set-Up

Unstable Operation Determination

- Unstable operation can be detected by acoustic measurements
- Use of a Hot-Wire for dry Measurements
- Microphones used for Droplet Laden Flows



Experimental Analysis of Wet Compression in Axial Compressor Stage

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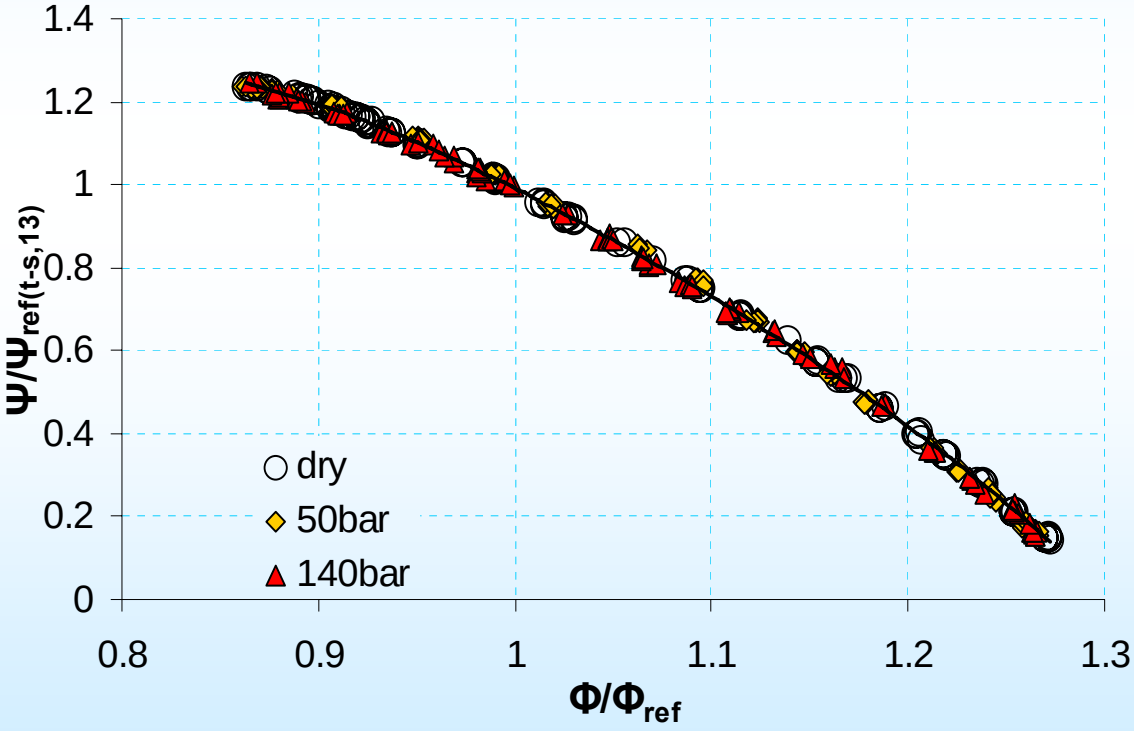
Effect of Water Injection on Compressor Stage Aerodynamic Performance

Effect on Pressure Rise Coefficient

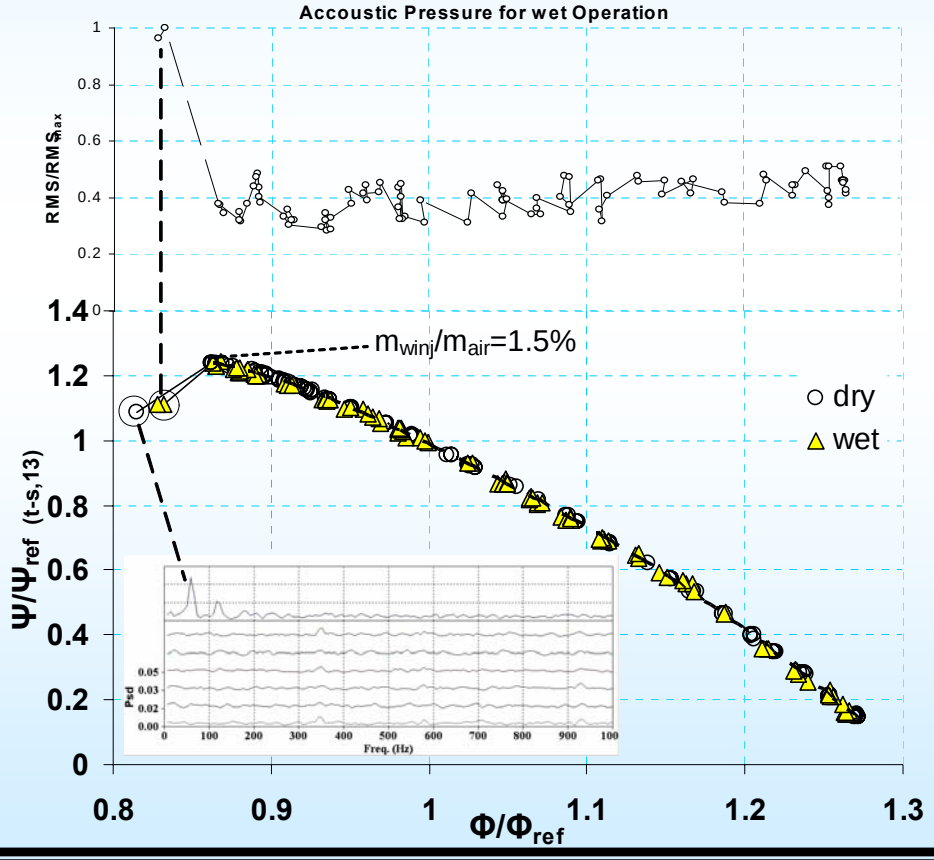
- **Manifold Pressure: 50bar**
  - m_{winj}/m_{air}=0.6÷0.85%
  - MMD=20μm
- **Manifold Pressure: 140bar**
  - m_{winj}/m_{air}=1.1÷1.5%
  - MMD=12μm
- **Assuming Incompressible Flow**

$$\Psi_{s\text{-}s,is} = \frac{p_{s3} - p_{s1}}{\rho_1 \times U_{tip}^2}$$



Effect of Water Injection on Compressor Stage Aerodynamic Performance

Effect on Pressure Rise Coefficient



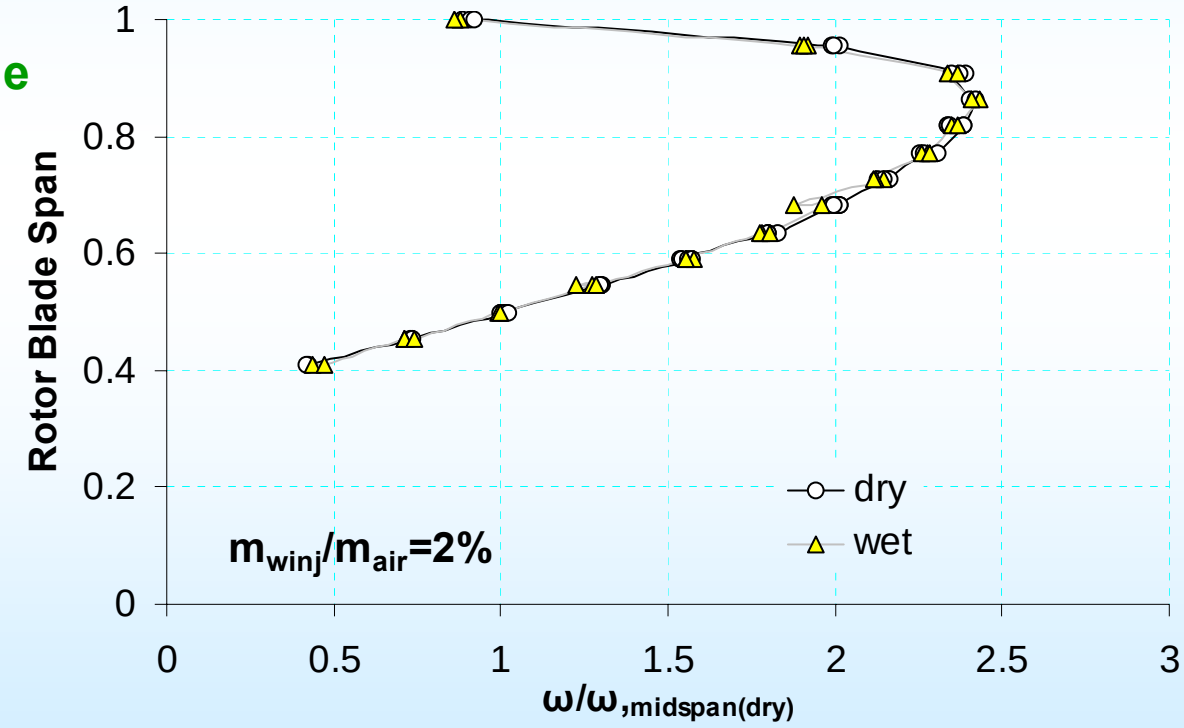
Effect of Water Injection on Compressor Stage Aerodynamic Performance

Total Pressure Loss Coefficient Profile

- Assuming Incompressible Flow
- Total Pressure Loss Coefficient:

$$\bar{\omega}=\frac{p_{tR1}-p_{tR2}}{1/2\times\rho_1\times W_1^2}$$

$$p_{tR}=p_s+\rho\times\frac{W^2}{2}$$

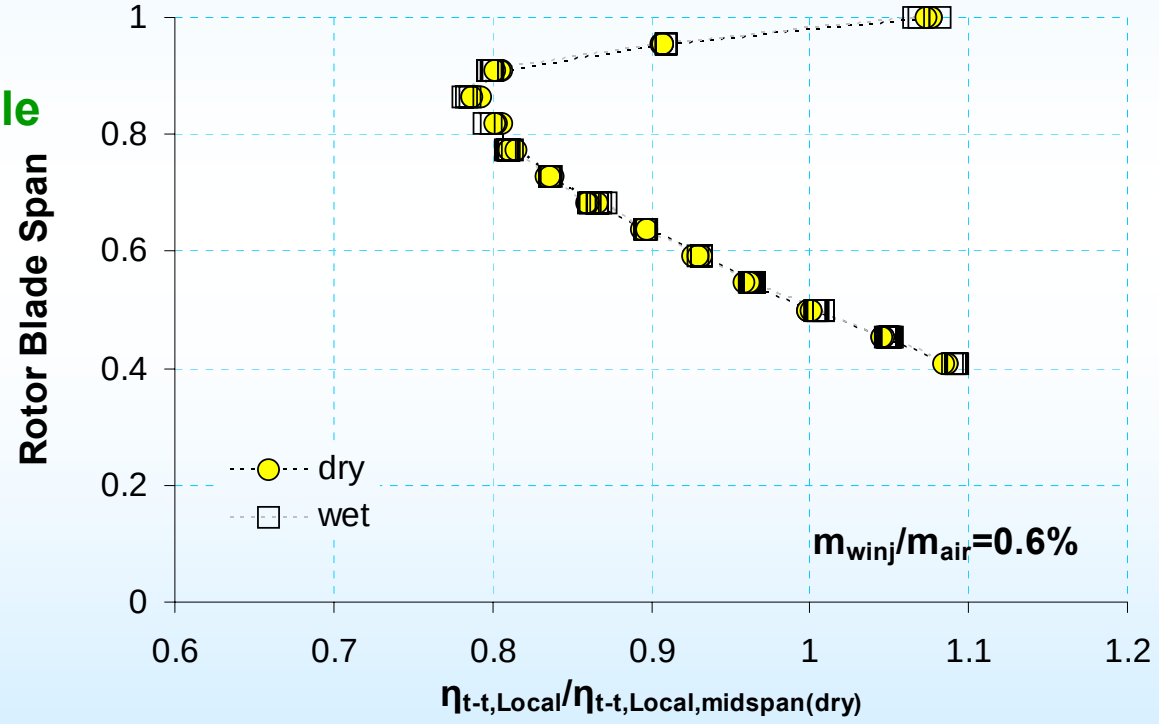


Effect of Water Injection on Compressor Stage Aerodynamic Performance

Total to Total Efficiency Profile

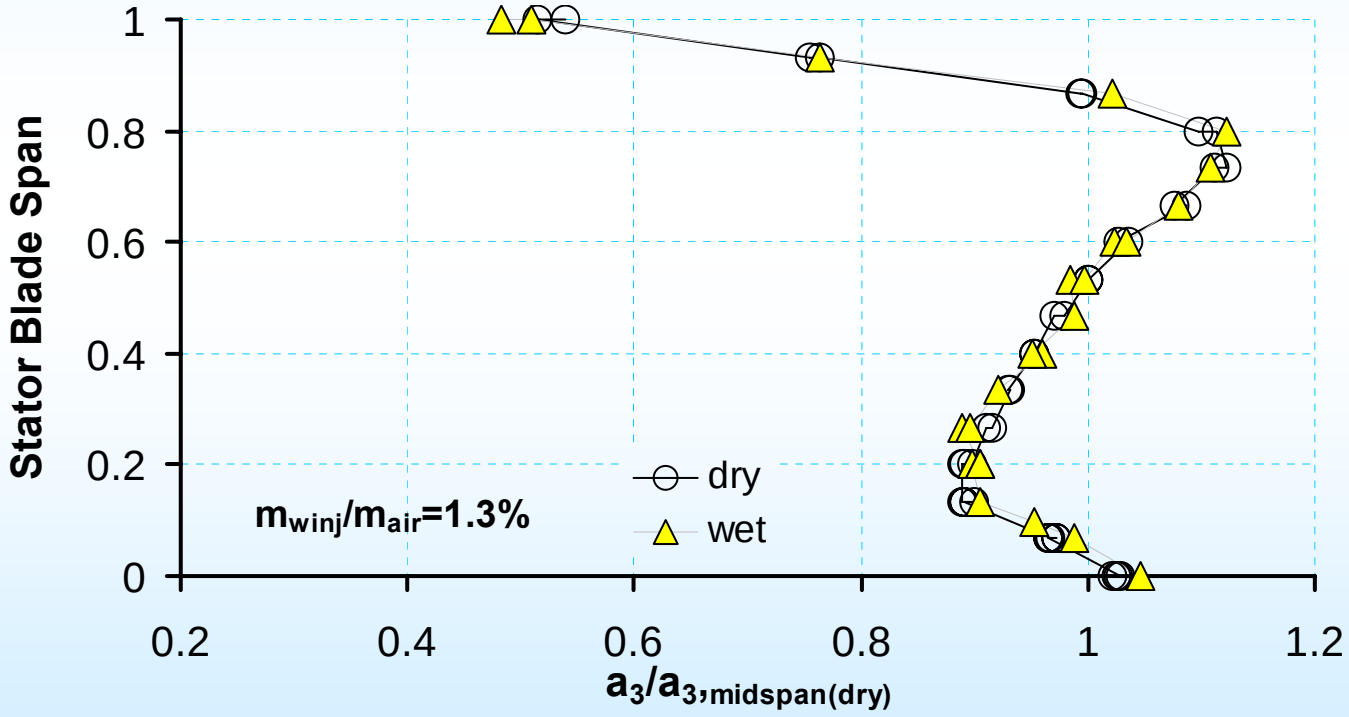
- Assuming Incompressible Flow
- Local Total to Total Efficiency:

$$\eta_{t\text{-}t,Local} = \frac{p_{t2} - p_{t1}}{\rho_1 \times U\left(V_{u2} - V_{u1}\right)}$$



Effect of Water Injection on Compressor Stage Aerodynamic Performance

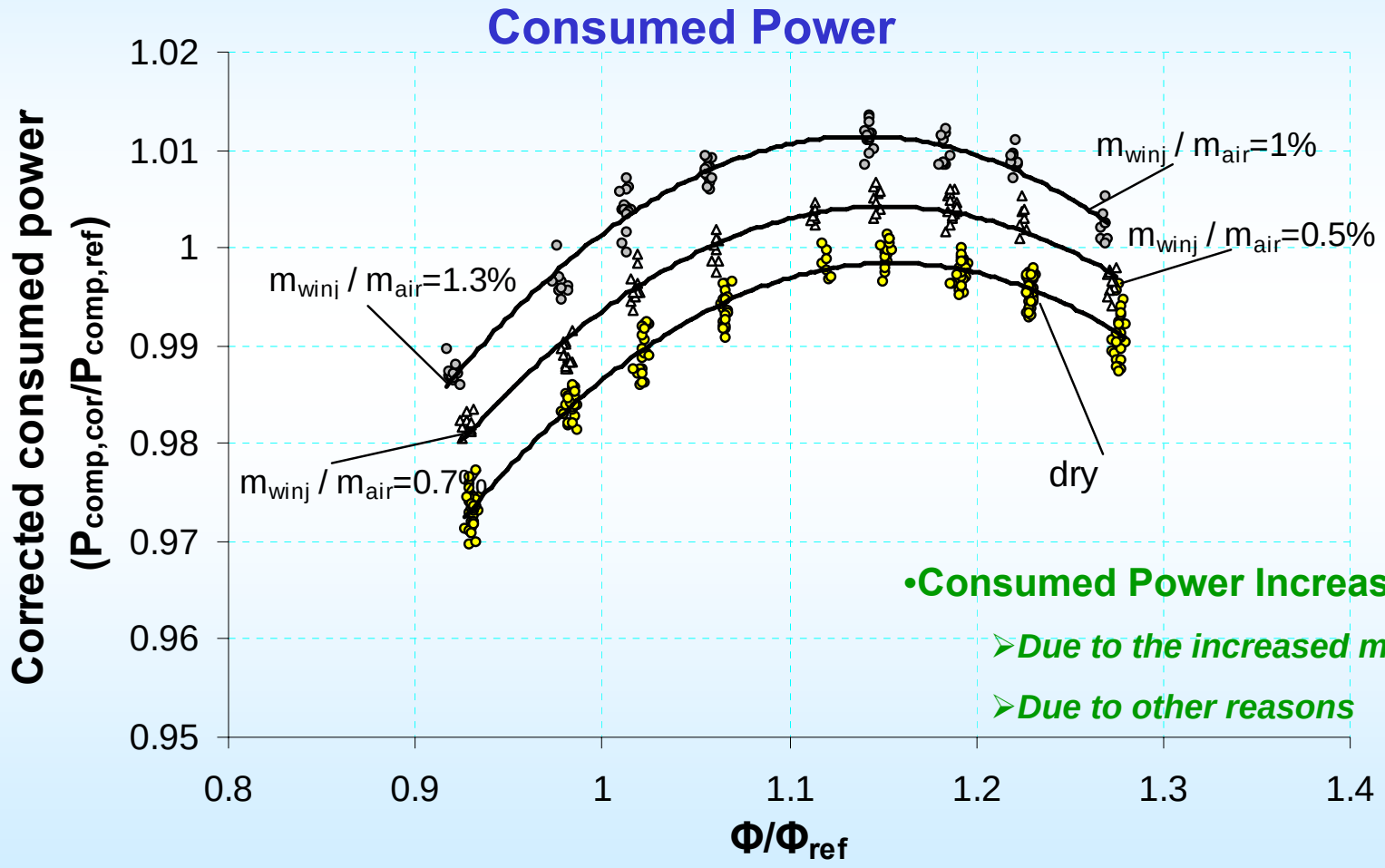
Stator Absolute Exit Angle Profile



Water Injection Effect on Compressor Stage Operation

- Experimental Set-Up
- Effect of Water Injection on Compressor Stage Aerodynamic Performance
- Effect on Compressor Power Consumption
- Conclusions

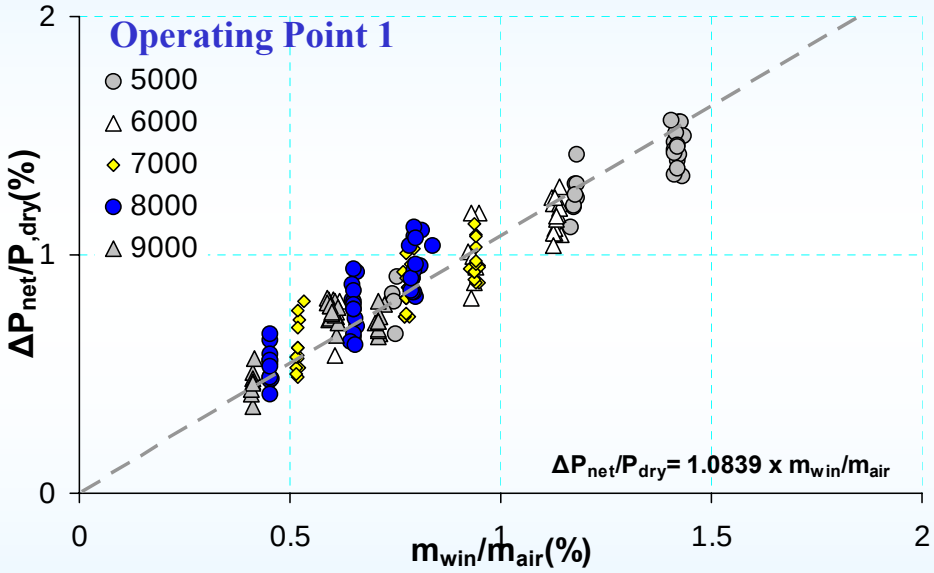
Effect on Compressor Power Consumption

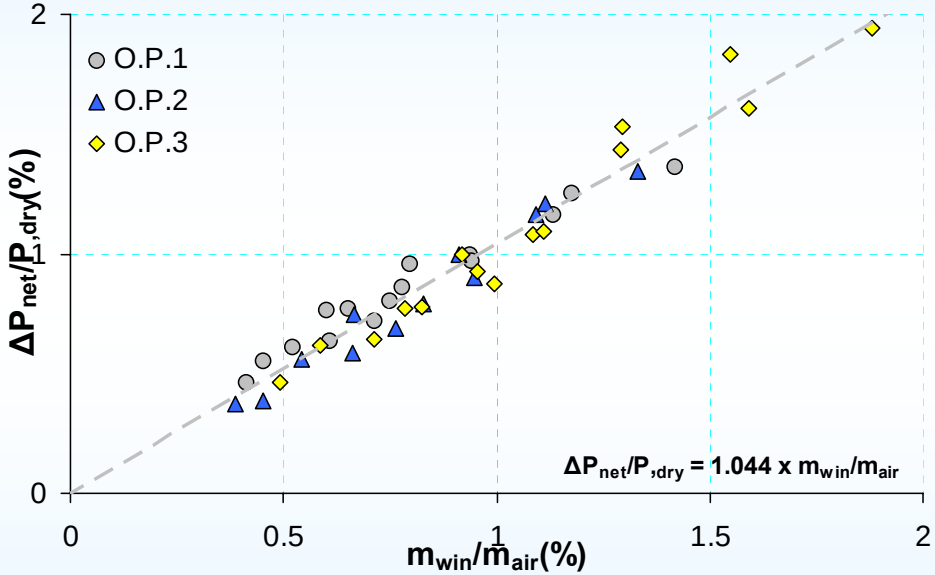


- **Consumed Power Increase**
  - ***Due to the increased mass flow***
  - ***Due to other reasons***

Effect on Compressor Power Consumption

Net Consumed Power Increase





- **Consumed Power Increase**
  - *Due to the increased mass flow*
  - *Due to other reasons*

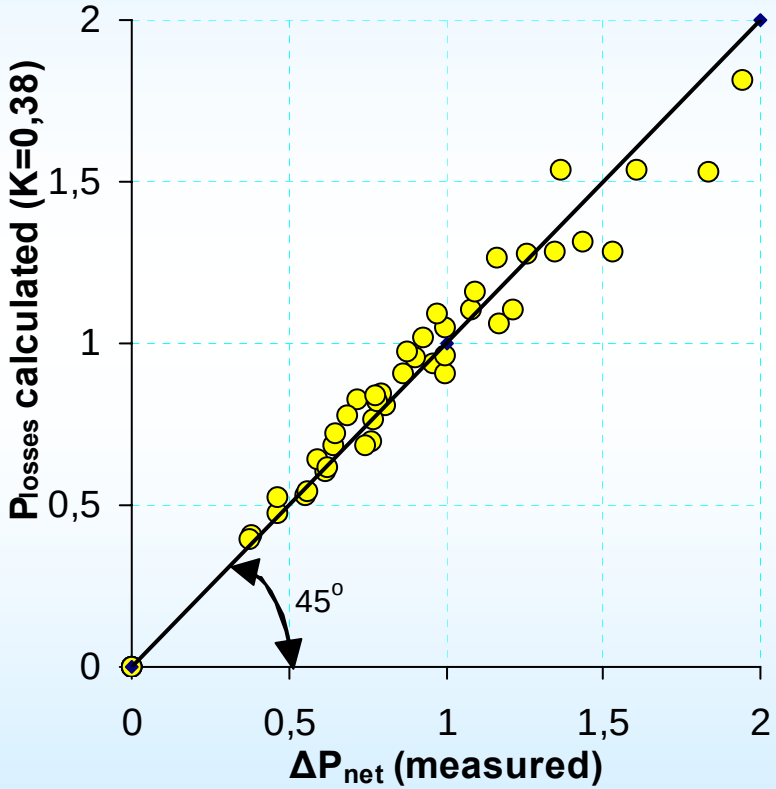
Effect on Compressor Power Consumption

Net Consumed Power Increase

Compressor stage aerodynamic efficiency is unchanged

Increase of net consumed power

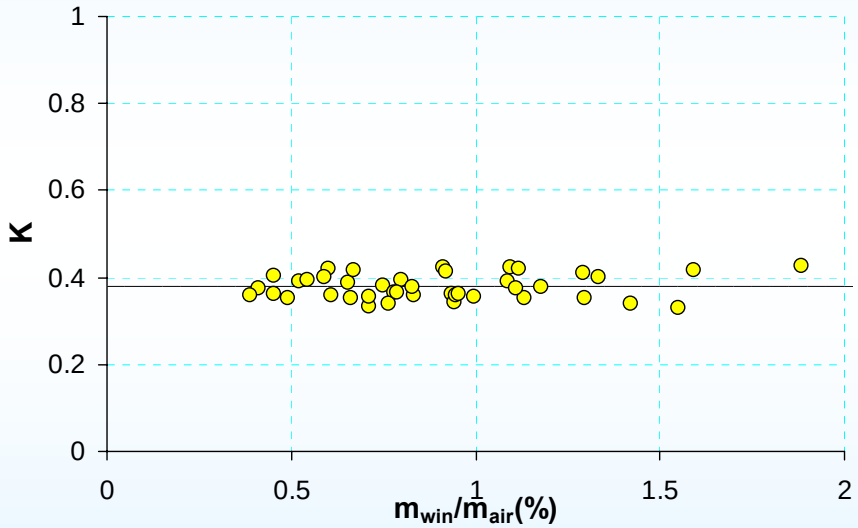
$$\Delta P_{net} = K \cdot m_{win} \cdot U_{TIP}^2$$



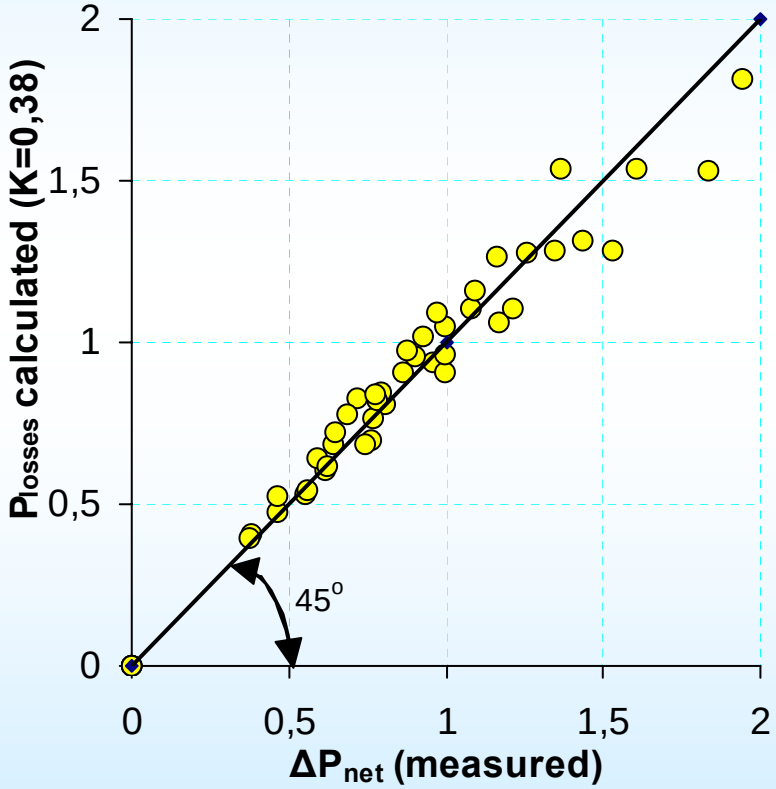
- The losses can be attributed to the centrifugation of the droplets by the Rotor

Effect on Compressor Power Consumption

Net Consumed Power Increase



$$\Delta P_{net} = K \cdot m_{win} \cdot U_{TIP}^2$$



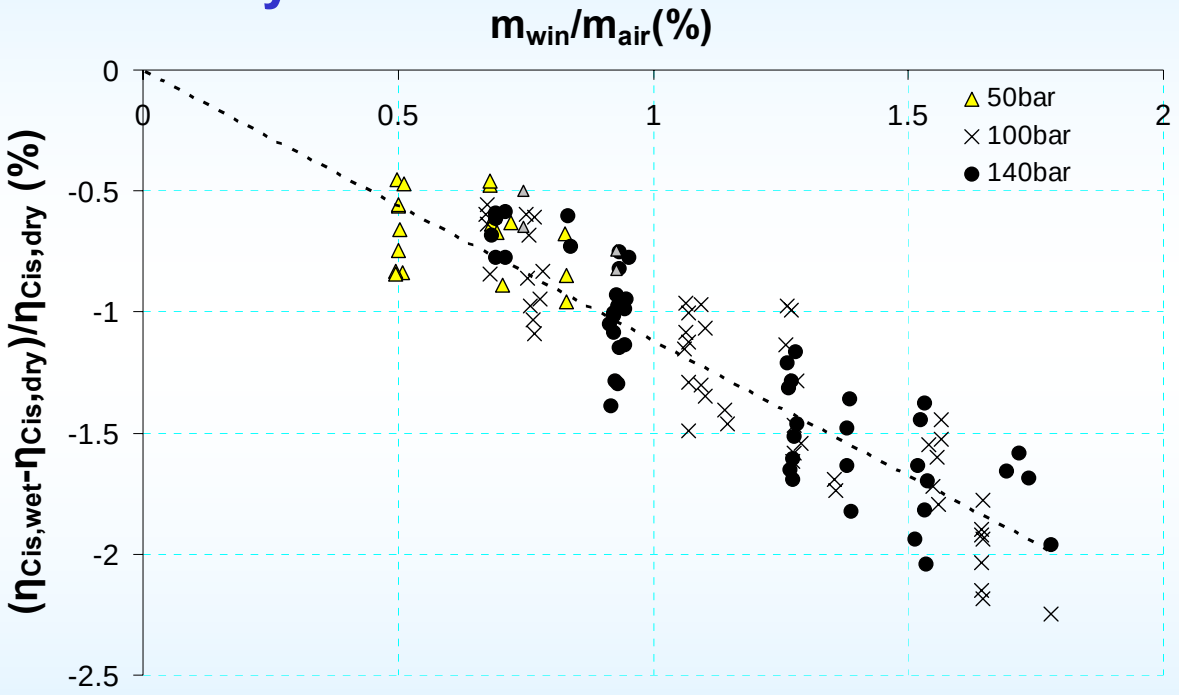
- The losses can be attributed to the centrifugation of the droplets by the Rotor

Effect on Compressor Efficiency

Efficiency Decrease

- Assuming Incompressible Flow
- Isentropic Efficiency via Mechanical Measurements :

$$\eta_{C,t\text{-}t,is} = \frac{\Delta p_{t\text{-}t,13}/\rho_1}{P_{COMP}/m_{in}}$$



Conclusions

- Special Techniques should be used in order to obtain data from a Wet Compressor
- The pressure rise coefficient presented no significant deviation with water injection up to 2%
- Aerodynamic measurements indicate that the stage aerodynamic behavior will not be affected by the presence of droplets for water quantities up to 2%
- Water injection result to an increase of power consumption
- The net increase of the consumed power can be attributed to the centrifugation of the droplets by the rotor
- The increase of power consumption can be described by a single coefficient and the droplet size (from 12μm to 20μm) seems to have no significant effect

Future Work

- Further examination of the mechanism resulting to the increase of consumed power at higher rotating speed is needed
- Visual examination of droplet behavior at rotor and stator
- Quantification of the losses in correlation to water collection rate on rotor blades
- Examination of the method of injection on the losses due to water injection (e.g. angle of injection)

Acknowledgments

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