Water Injection Effects on Compressor Stage Operation

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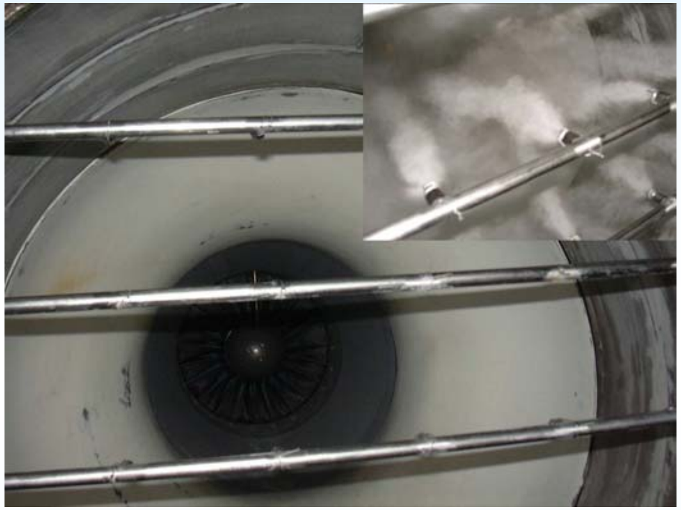
Water Injection Effect on Compressor Stage Operation

- Experimental Set-Up
- Effect of Water Injection on Stage Characteristic
- Detailed Aerodynamic Measurements
- Effect on Stage Power Consumption
- Conclusions

Experimental Set - Up



One Stage Axial Compressor

- $N_{C,nom}$=18000rpm
- $\pi_{C,nom}$=1.57
- $m_{C,nom}$=27.5 kg/s

Impaction Pin Nozzles (Mee Industries)

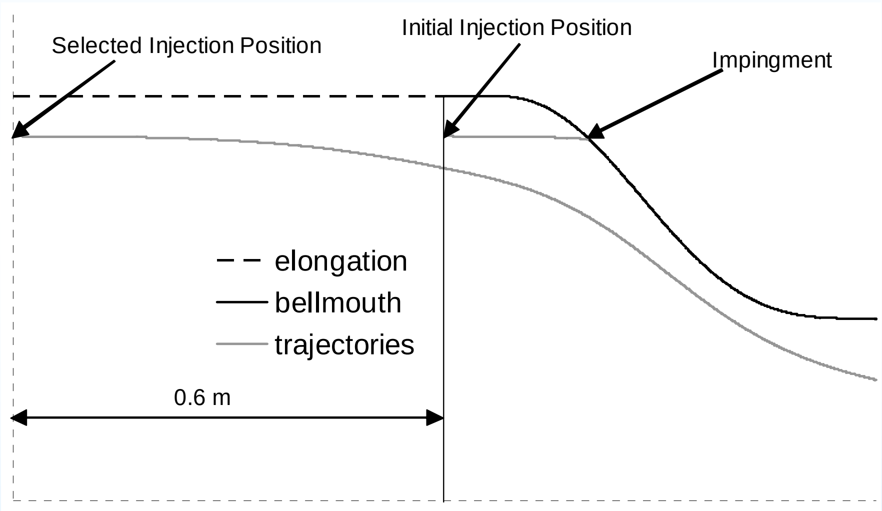
- Axisymetrically Distributed at Bellmouth Inlet
- Maximum Injected Water Mass Flow: 2%

Experimental Set - Up

Bellmouth Configuration

Droplet Trajectories Analysis

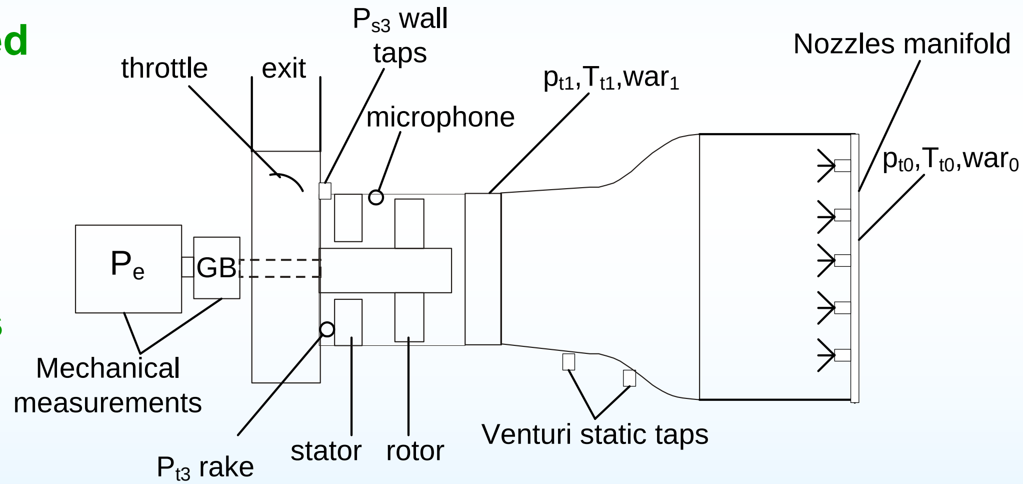
- **Lagrangian Framework**
- **Droplet Evaporation Model**
- **Meridional Flow Solver (2D)**



Experimental Set-Up

Test-Rig Measurements

1. The flow rate of water
2. The pressure at nozzle manifold
3. Compressor Rotational Speed
4. Torque 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

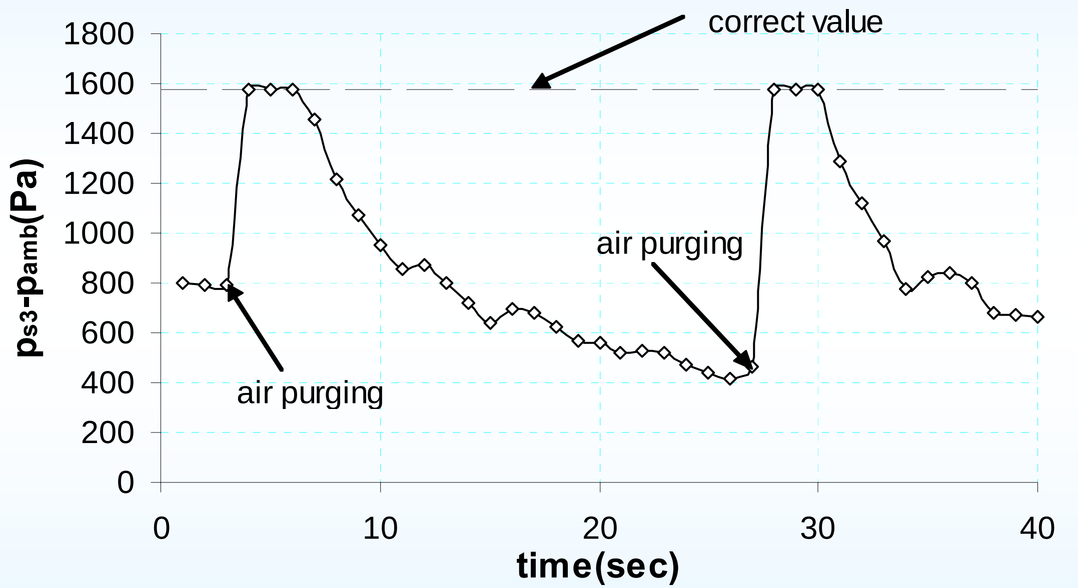
Measurements Considerations

- **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 Measurements 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

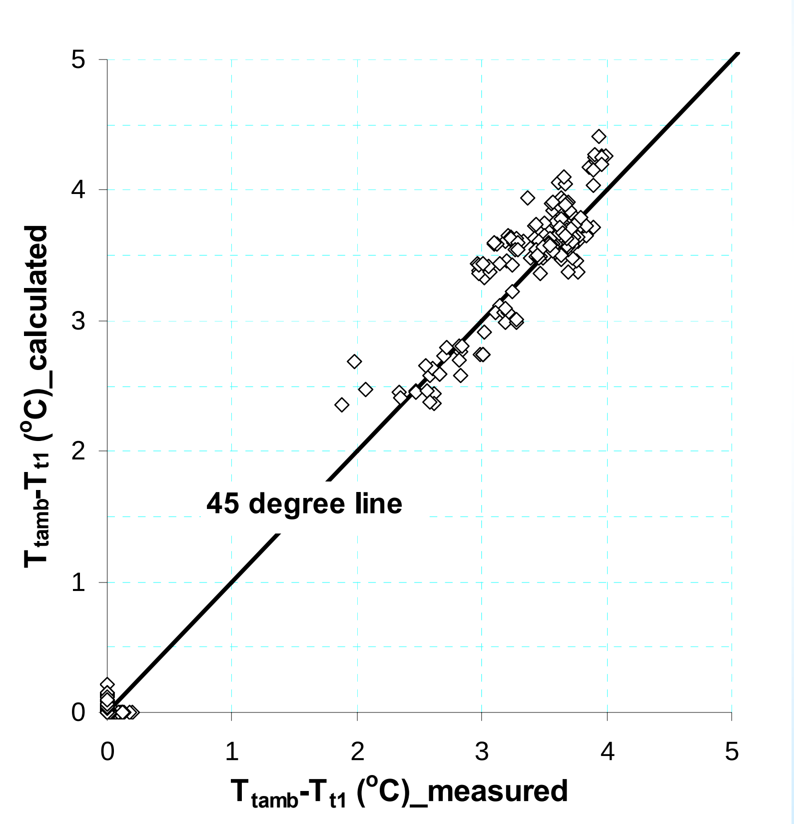
- Increased Measuring Wall Taps Diameter to 1.5mm
- Total Pressure Probe of Kiel Type with 3mm Hole
- Purging System using Pressurized Air and Electronic Vanes
- Defining of Acquisition Time to 1 sec



Experimental Set-Up

Inlet Water to Air Ratio and Temperature Measurement

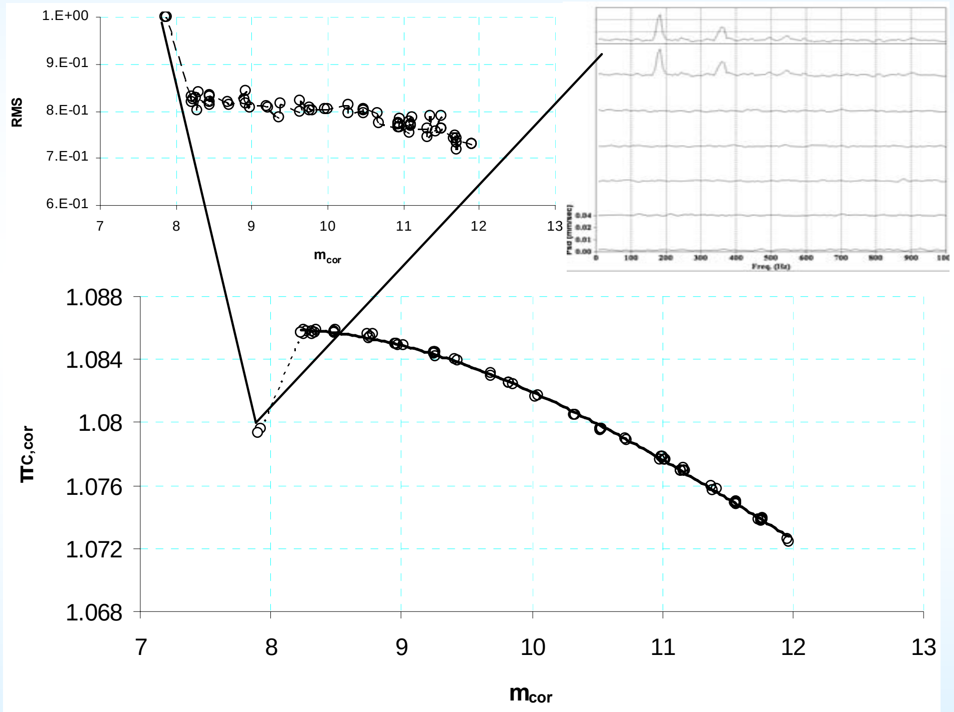
- Bleeding Air from the Stage Inlet introducing a bent tube facing downstream
- Humidity Chamber incorporating a RH Sensor and a Pt100 Thermometer
- Measuring Temperature with a Pt100 Thermometer in the bent tube (insulated)
- Air Movement Imposing Pressure Difference at the Humidity Chamber



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



Water Injection Effect on Compressor Stage Operation

- **Experimental Set-Up**
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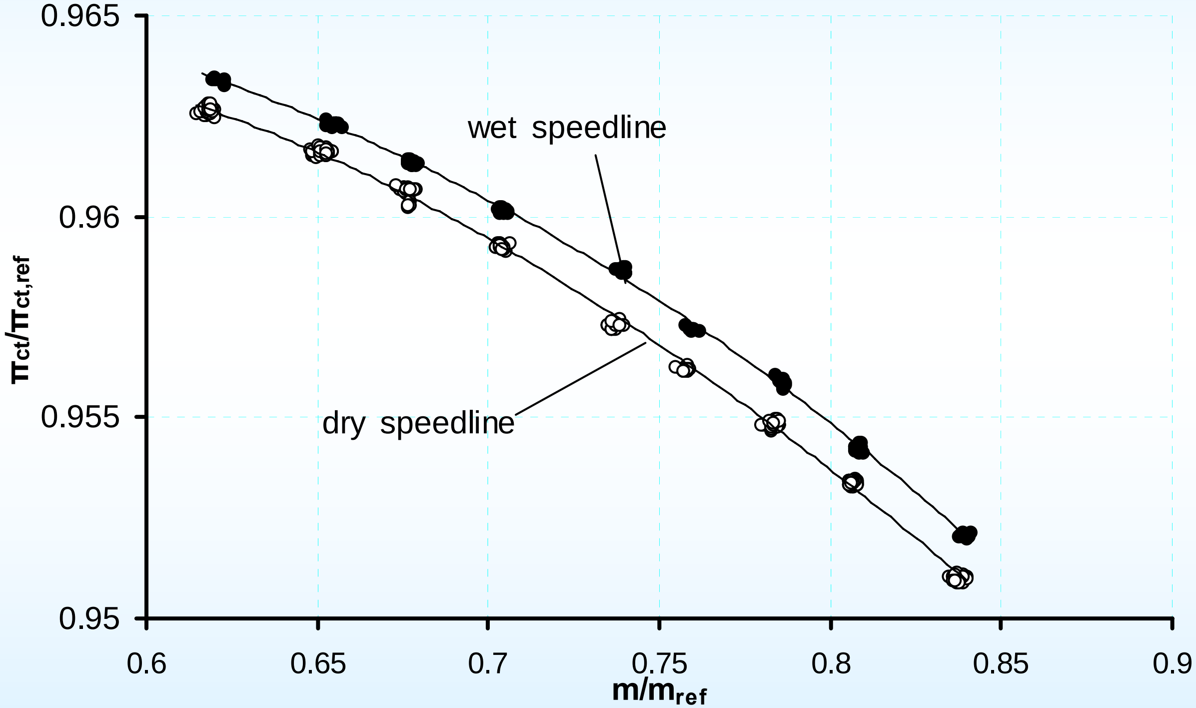
Effect of Water Injection on Compressor Performance

Raw Effect on Compressor Performance



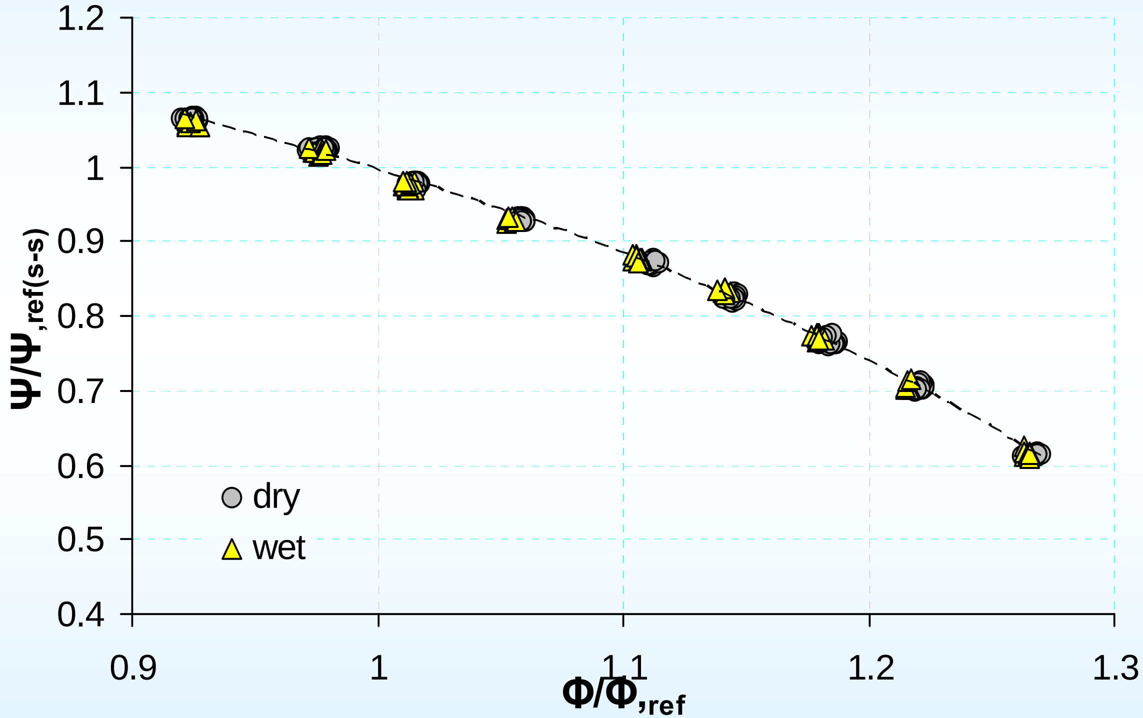
Tamb = 20.5°C RH=62% mwinj=1%

Effect of Water Injection on Compressor Performance

Effect on Pressure Rise Coefficient

- Assuming Incompressible Flow
- Pressure Rise Coefficient:

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

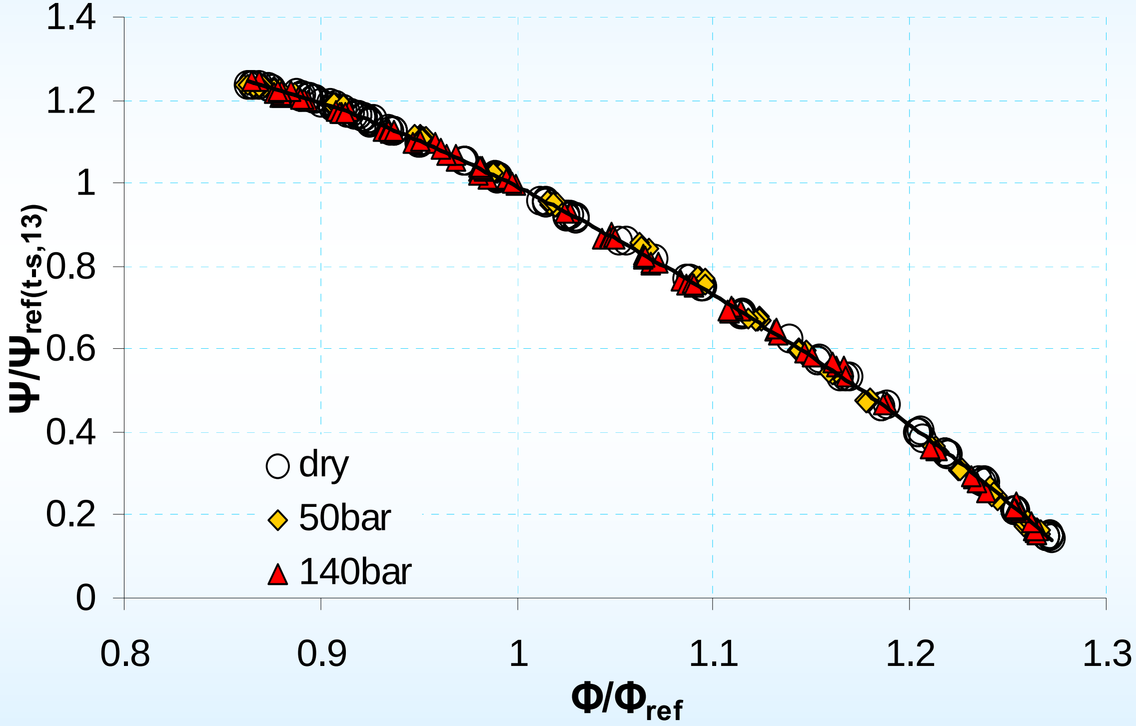


Tamb = 20.5°C RH=62% mwinj=1%

Effect of Water Injection on Compressor Performance

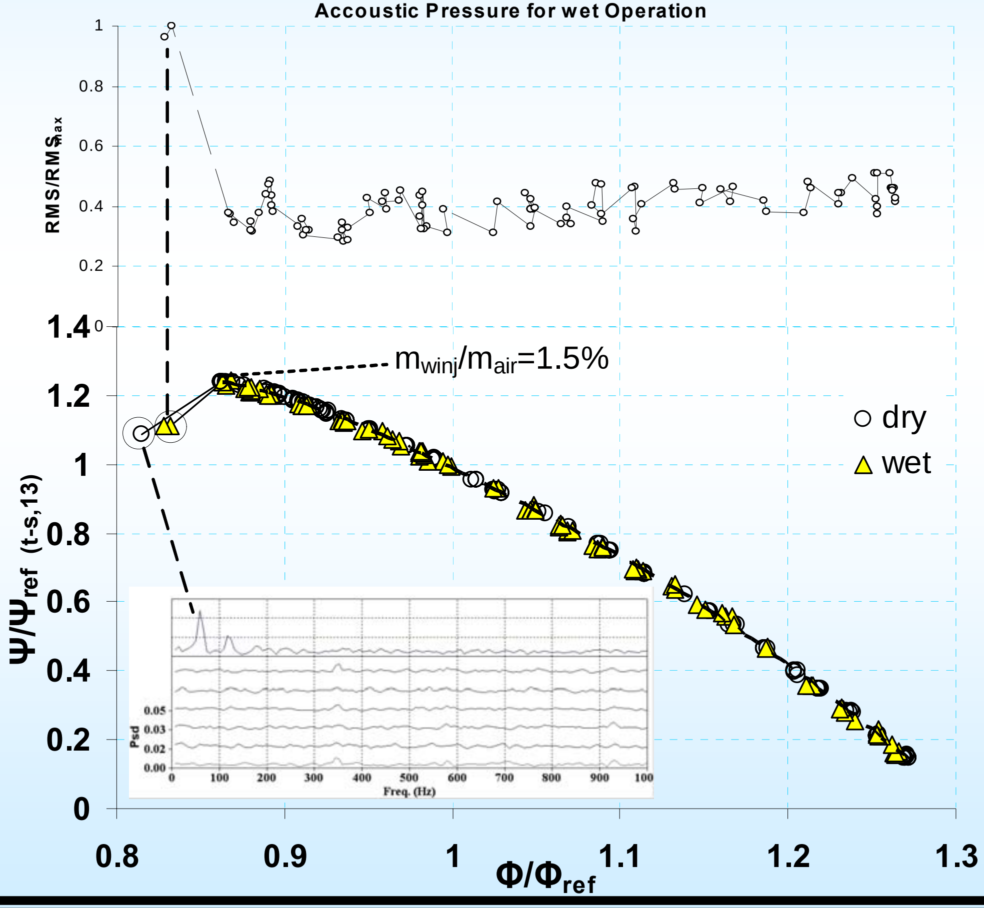
Effect on Pressure Rise Coefficient

- Assuming Incompressible Flow
- 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



Effect of Water Injection on Compressor Performance

Effect on Stall Margin



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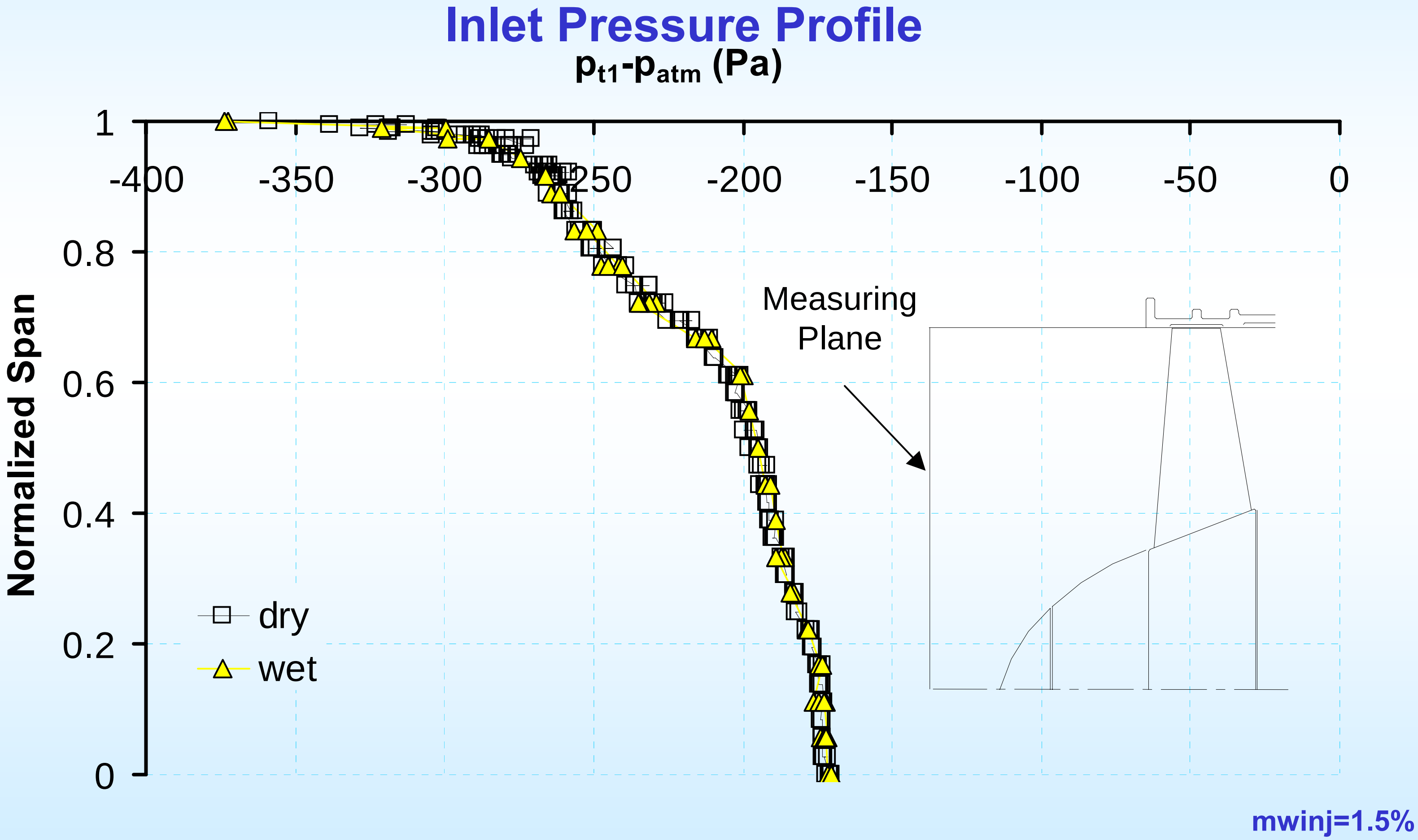
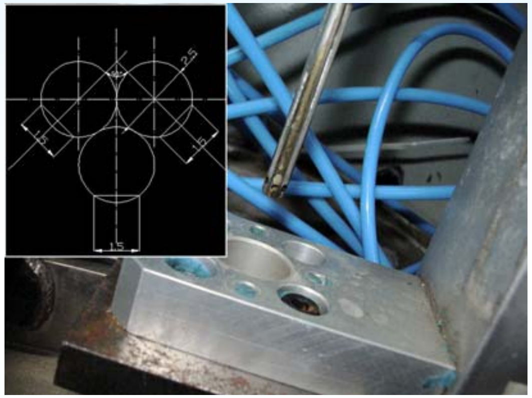
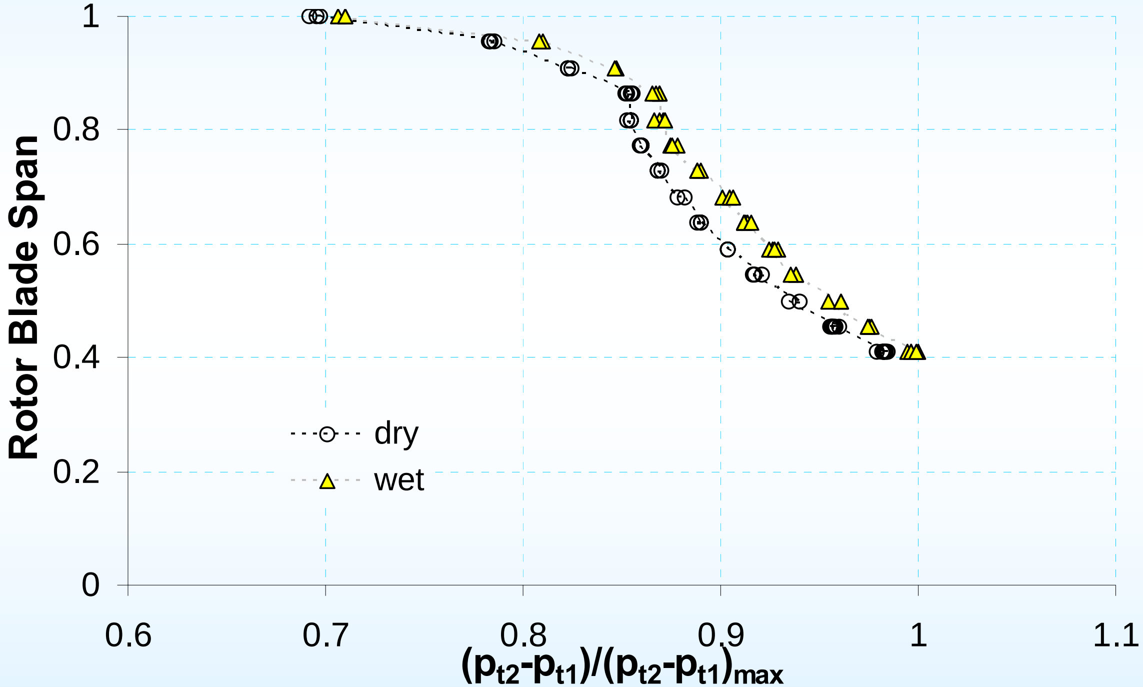
Detailed Aerodynamic Measurements



Detailed Aerodynamic Measurements

Rotor Exit Pressure Profile





mwinj=2%

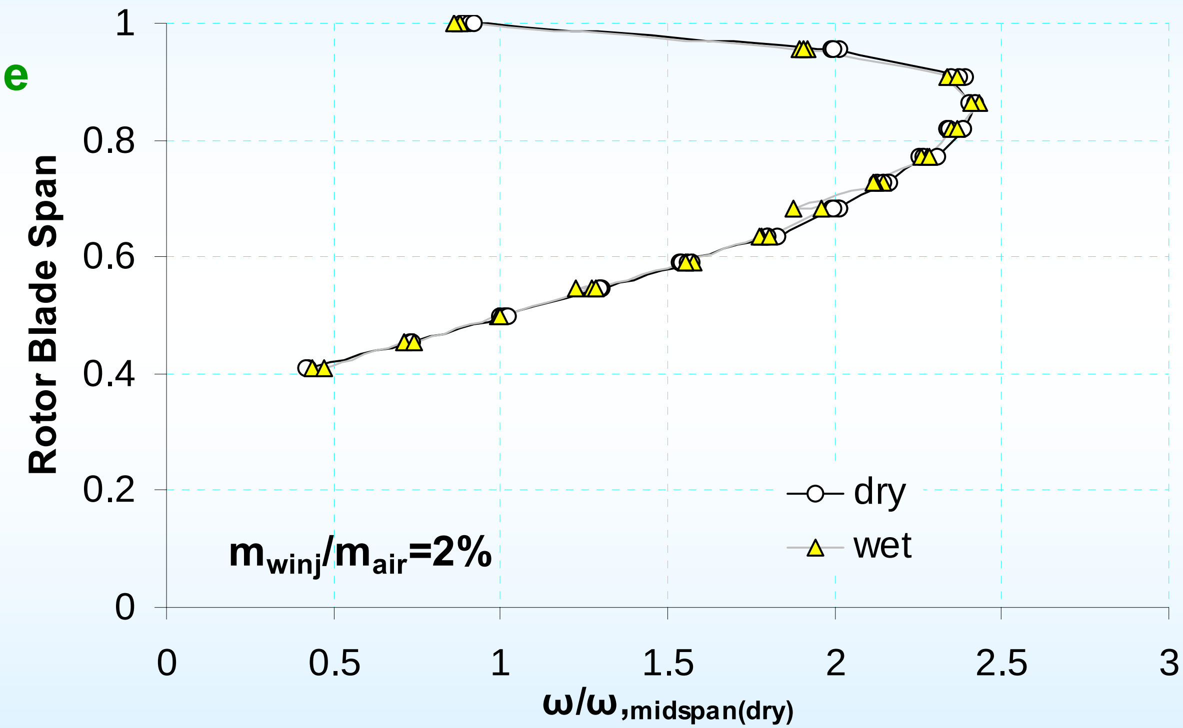
Effect of Water Injection on Compressor Performance

Total Pressure Loss Coefficient Profile

- Assuming Incompressible Flow
- Total Pressure Loss Coefficient:

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

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

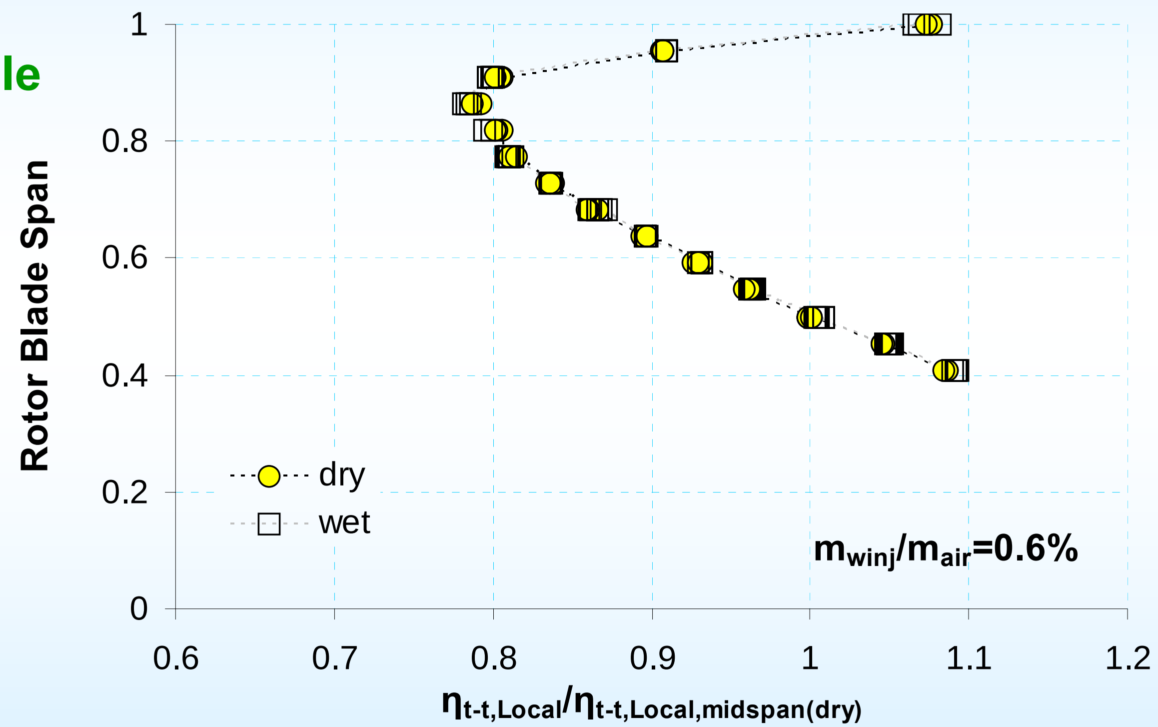


Effect of Water Injection on Compressor Performance

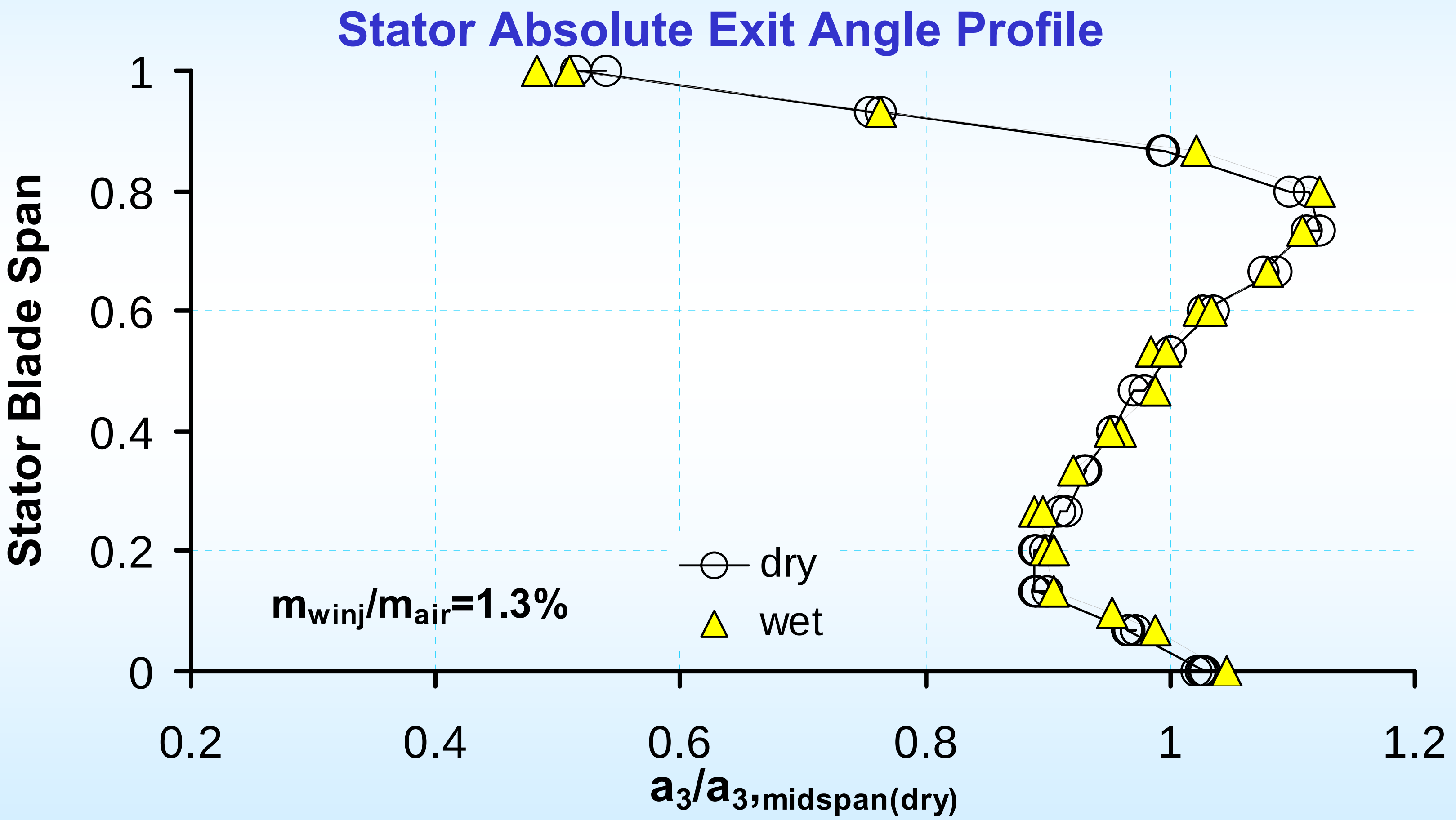
Total to Total Efficiency Profile

- Assuming Incompressible Flow
- Local Total to Total Efficiency:

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



Detailed Aerodynamic Measurements



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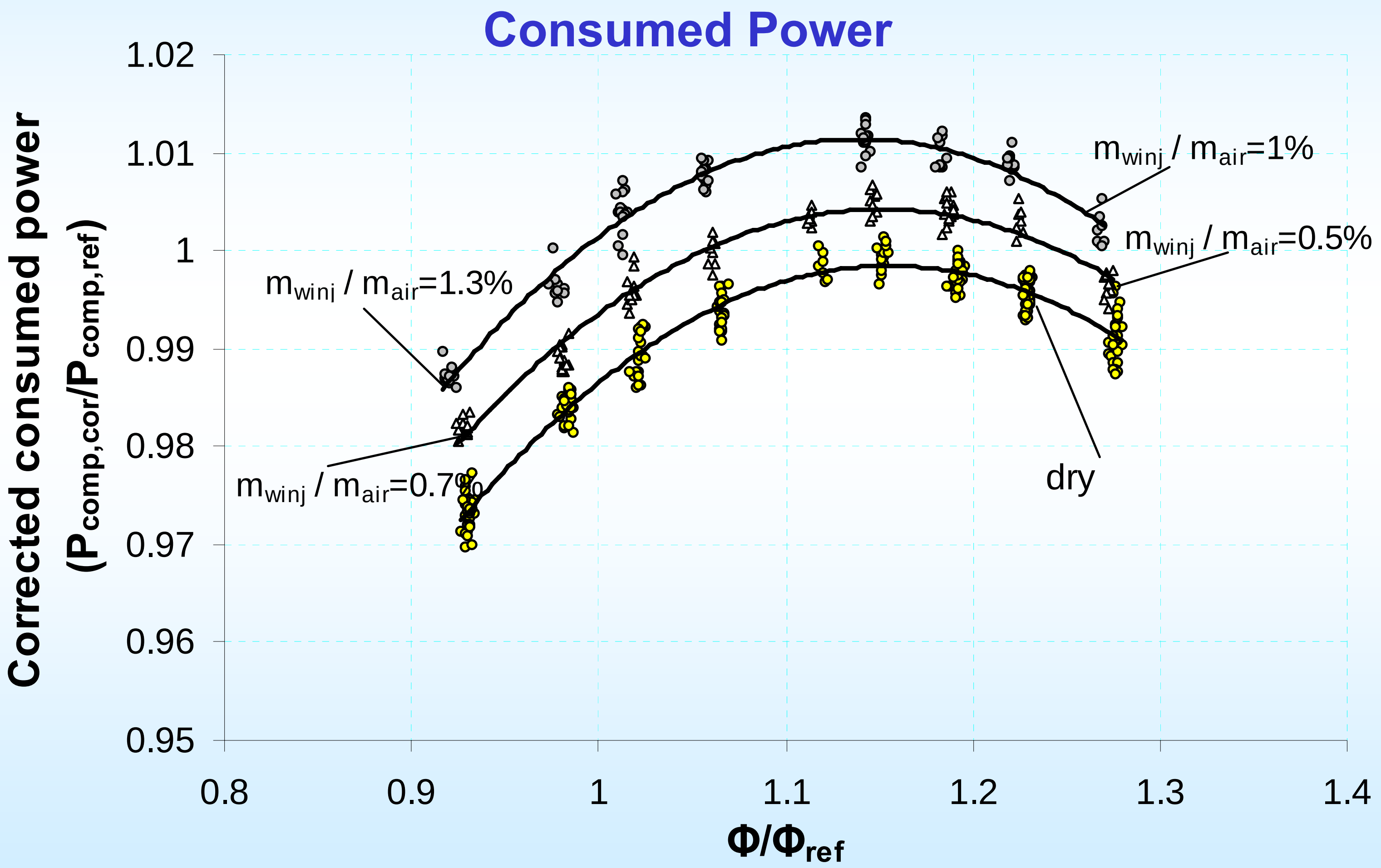
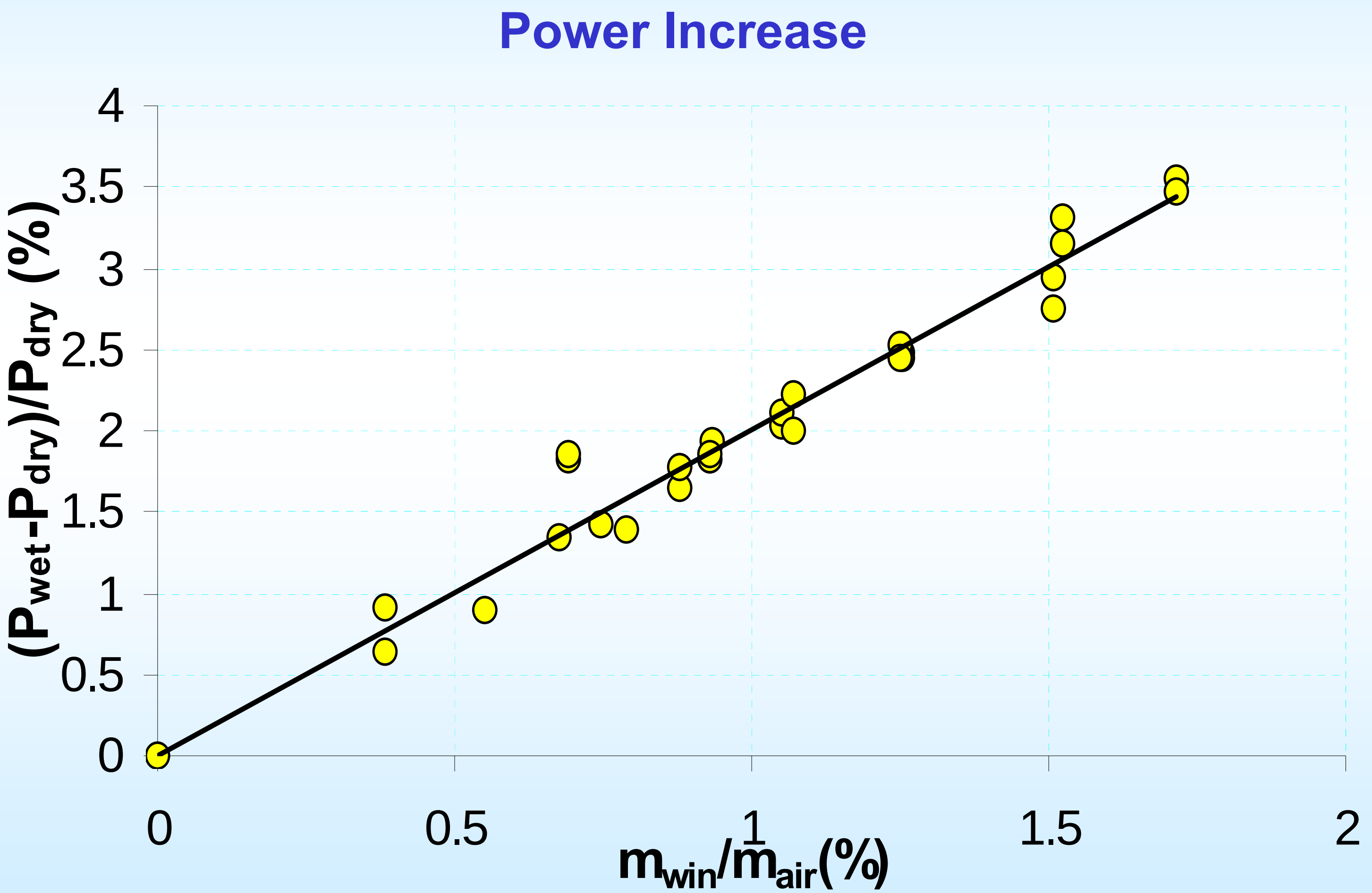
Effect on Compressor Power Consumption



Effect on Compressor Power Consumption

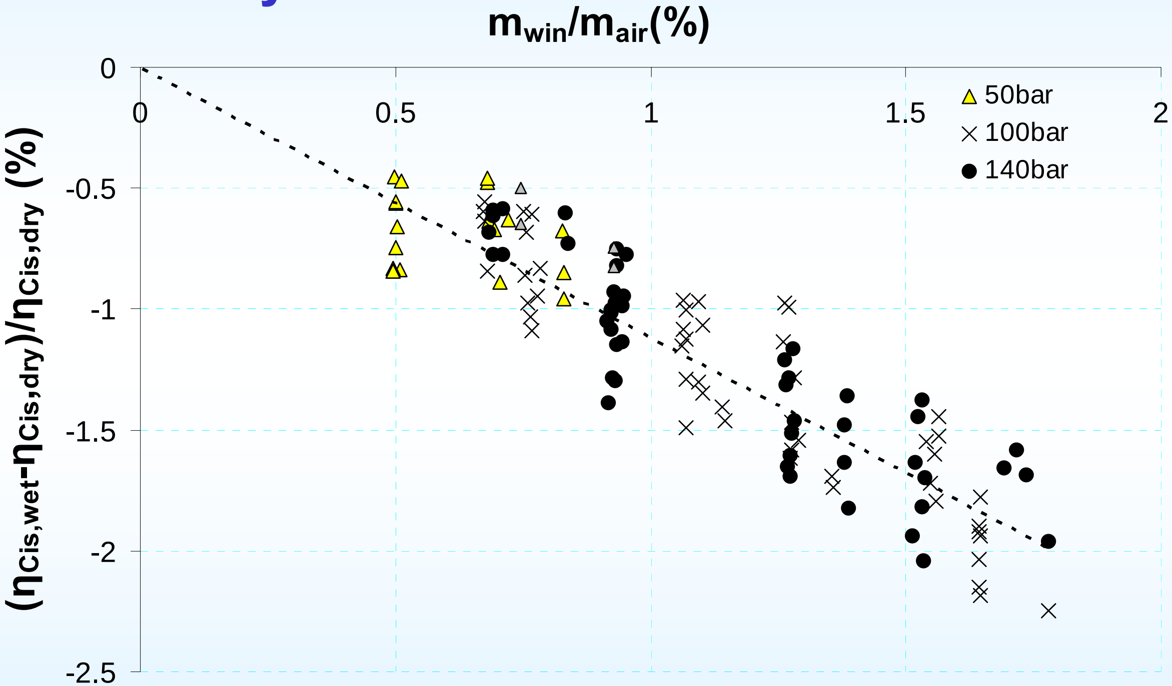


Effect on Compressor Efficiency

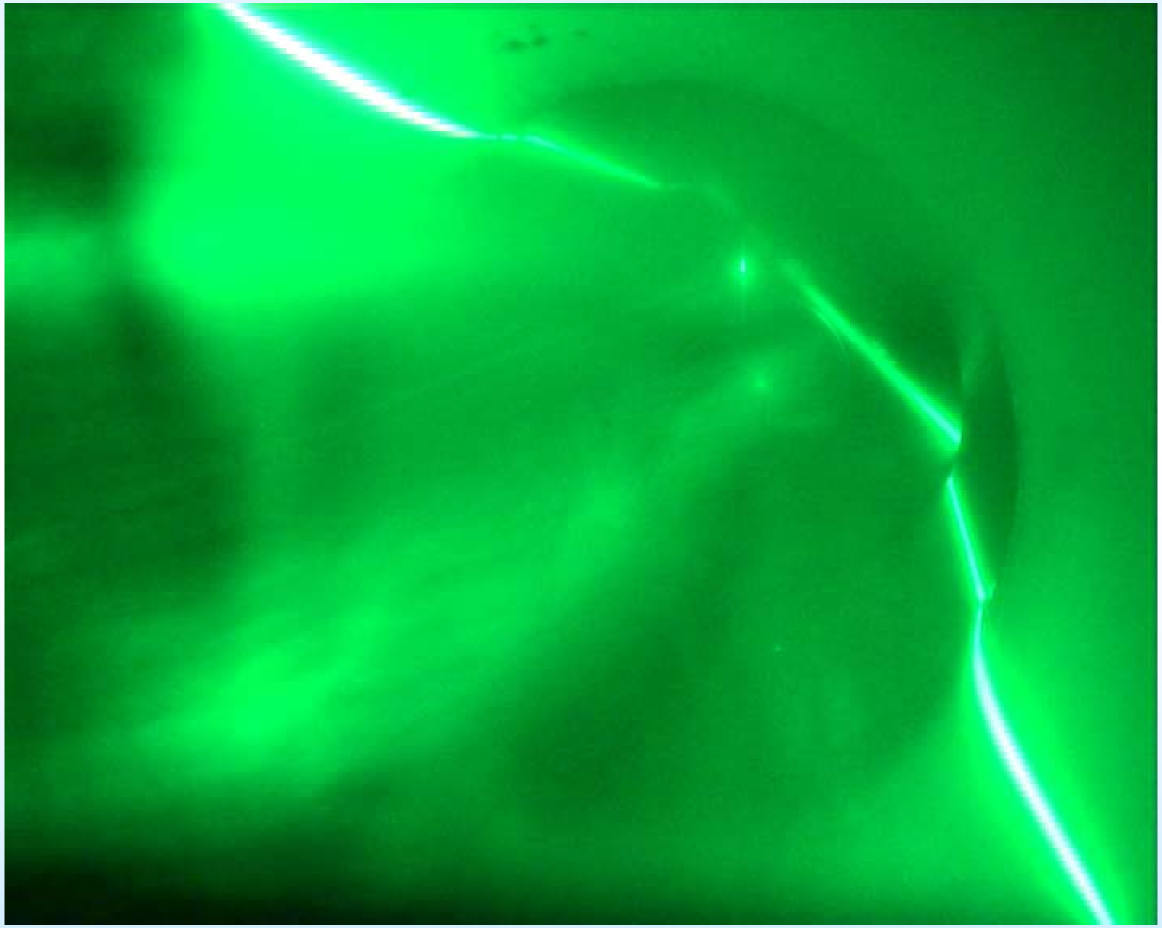
Efficiency Decrease

- Assuming Incompressible Flow
- Isentropic Efficiency via Mechanical Measurements :

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



Preliminary Flow Visualization



Conclusions

- Special Techniques should be used in order to obtain data from a Wet Compressor
- The pressure rise coefficient presented no measurable deviation with water injection up to 2%
- The point where initial stall occurs presented no change with droplet laden flow
- Aerodynamic measurements indicate that the stage flowfield 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 decrease of stage efficiency is a strong function of the water quantity entering the engine and droplet size (from 12μm to 20μm) seems to have no effect

Future Work

- Further examination of the mechanism resulting to the increase of consumed power 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 effect of injection position at power consumption

Acknowledgments

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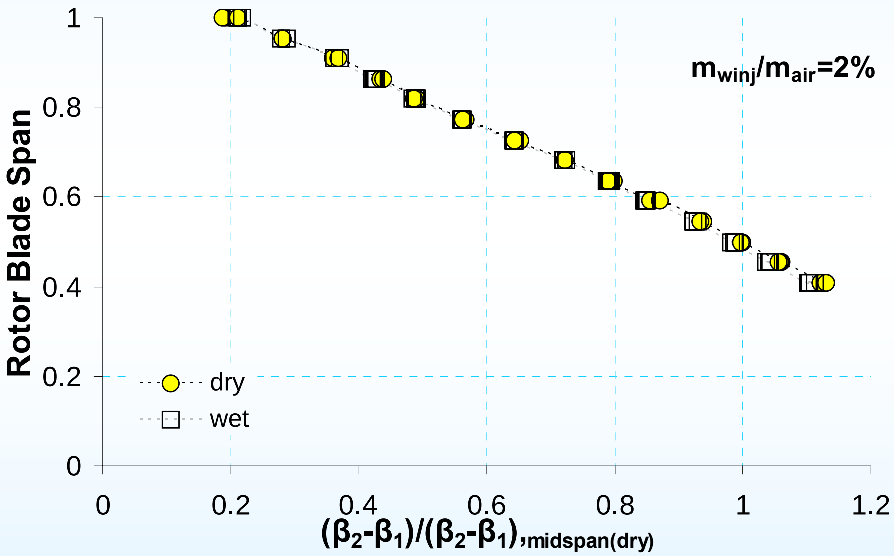
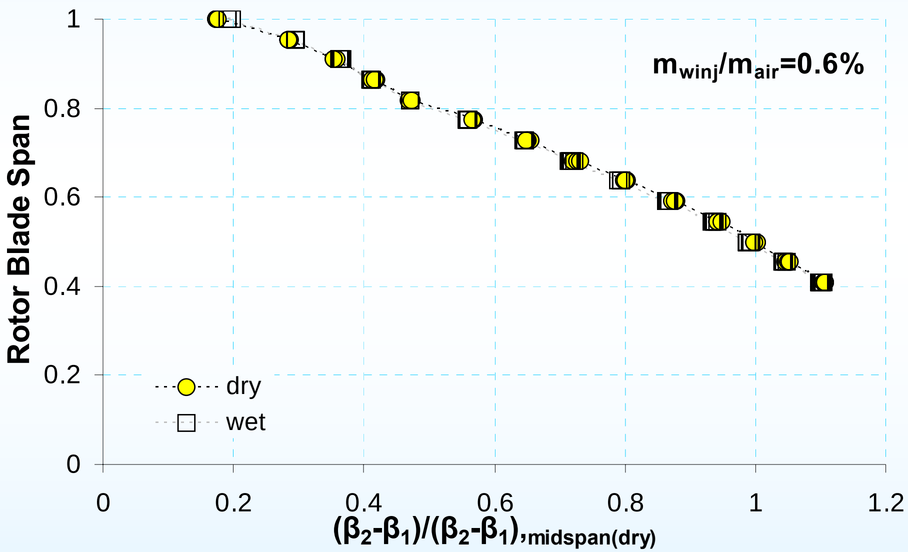
Effect of Water Injection on Compressor Performance

Rotor Relative Angle Turn Profile



N/N_d=27%



N/N_d=50%