Moisture Condensation Effect on Turbine Performance Tests

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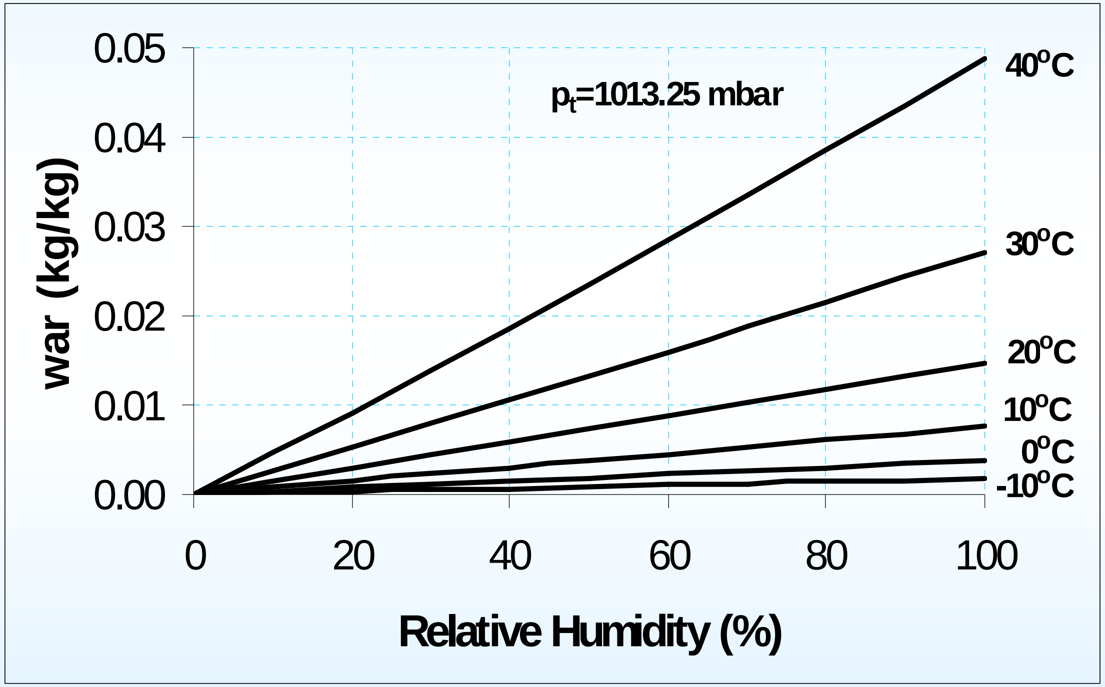
Moisture Condensation Effect on Turbine Performance Tests

- §Ambient Humidity and Condensation
- §Test Rig Model
- §Test Case
  - §Condensation Prediction
  - §Measurements Correction
- §Condensation Avoidance
- §Conclusions

Ambient Humidity

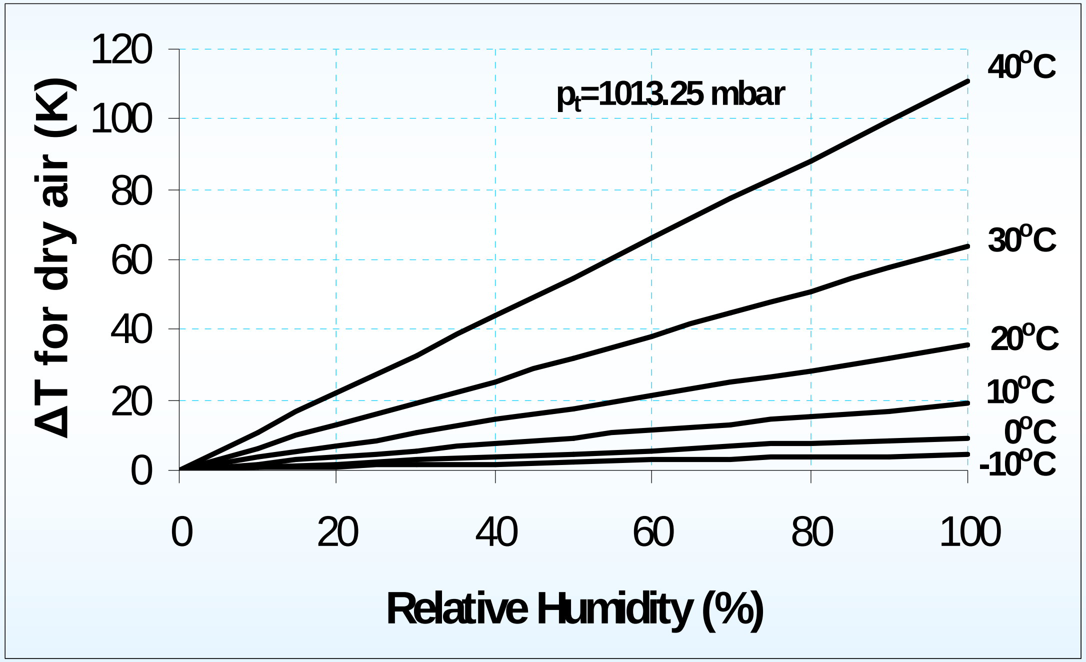


Moisture fraction is a function of ambient pressure, temperature and relative humidity

Humidity, Condensation and Temperature Rise

- Homogeneous and Heterogeneous Condensation
- Water droplets appear and two – phase flow with heat and mass transfer between water and the gas mixture occur
- Release of the latent heat of vaporization produces a temperature rise of the gas mixture
- Condensation is a thermodynamically irreversible process, resulting in loss of stagnation pressure

Temperature Rise



Heating of dry air by the latent heat of vapour.

Vapour quantity corresponding to various ambient conditions

Turbine Efficiency Determination

Thermodynamic Method

$$n_{T,is} = \frac{T_{t1} - T_{t3}}{T_{t1} \cdot \left[1 - \left(\frac{p_{t3}}{p_{t1}} \right)^{\frac{g-1}{g}} \right]}$$

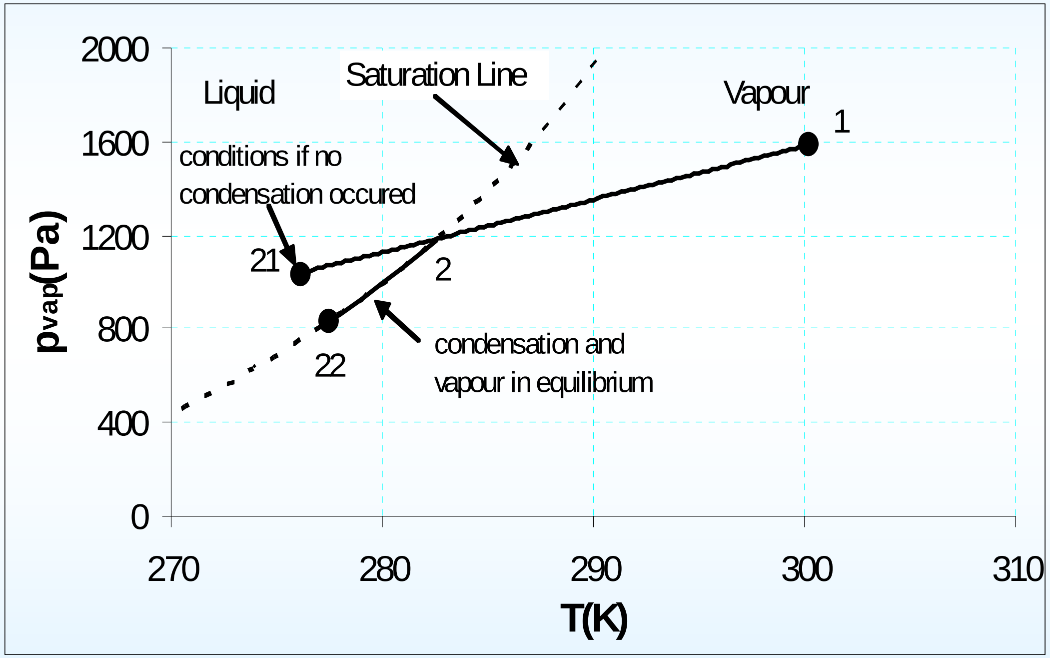
- §Temperature Measurement
- §Pressure Measurement
- §Gas Composition

Mechanical Method

$$n_{T,is} = \frac{t \cdot N}{c_p \cdot \dot{m} \cdot T_{t1} \cdot \left[1 - \left(\frac{p_{t3}}{p_{t1}} \right)^{\frac{g-1}{g}} \right]}$$

- §Flow Measurement
- §Torque Measurement
- §Shaft Speed Measurement
- §Gas Composition

Condensation during Expansion



Phase Diagram for Water

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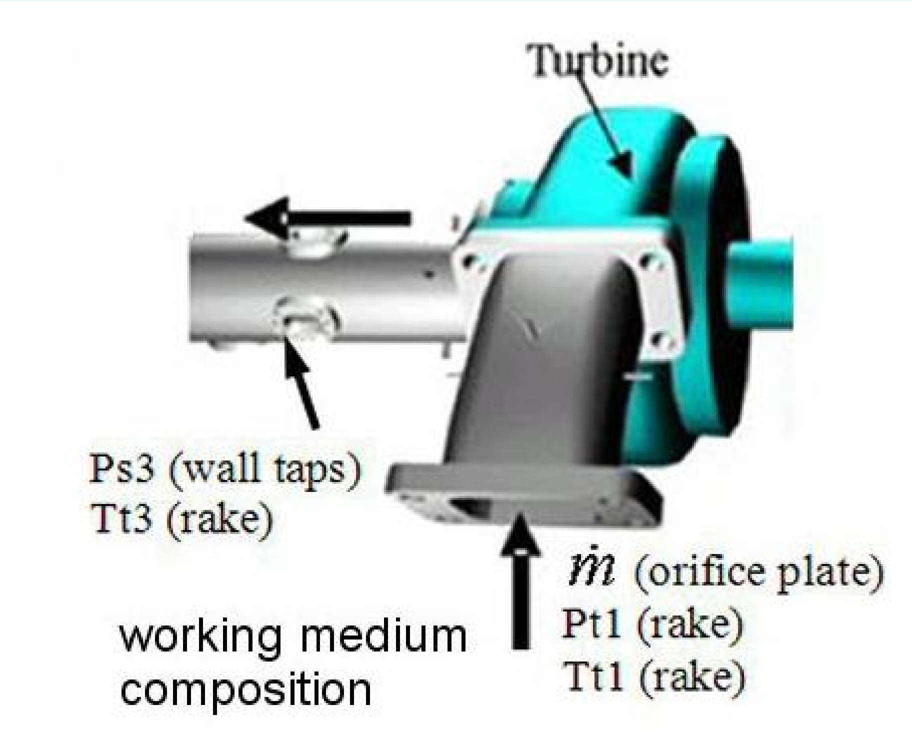
Test Rig Model



Typical Measurements

Test Rig Model

Objective

- **Evaluation of isentropic efficiency as if no condensation occurs**

Steps

- **Prediction of condensation**
- **Calculation of condensed water**
- **Calculation of the exit conditions as if no condensation occurs**

Test Rig Model

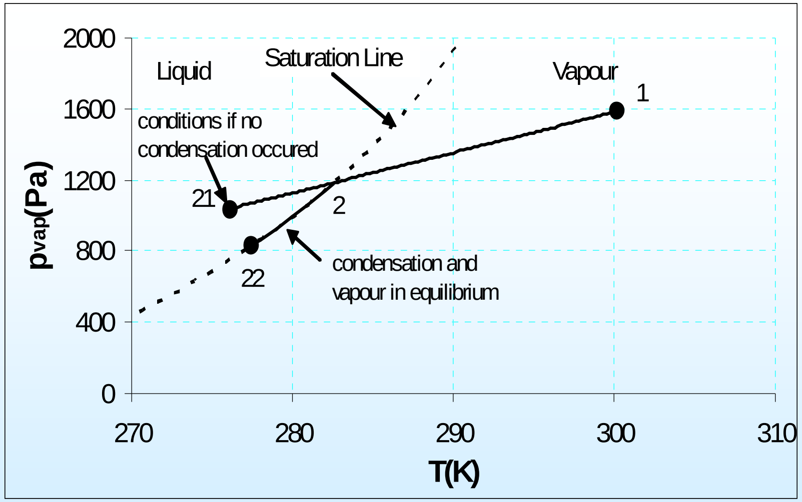
Calculation of Condensed Water

- §Assuming Equilibrium Saturation at Turbine Exit
- §Condensate Quantity Calculated based on Static Conditions
  - §Conservation of enthalpy (total to static)
  - §Conservation of entropy (total to static)
  - §Conservation of mass

Test Rig Model

Calculation of "Dry" Exit Conditions

- **§Assuming Instant Condensation**
- **§Calculation of Exit Conditions as if no Condensation had Occurred**
  - **§Conservation of Energy**
  - **§Conservation of Momentum**
  - **§Conservation of Mass**



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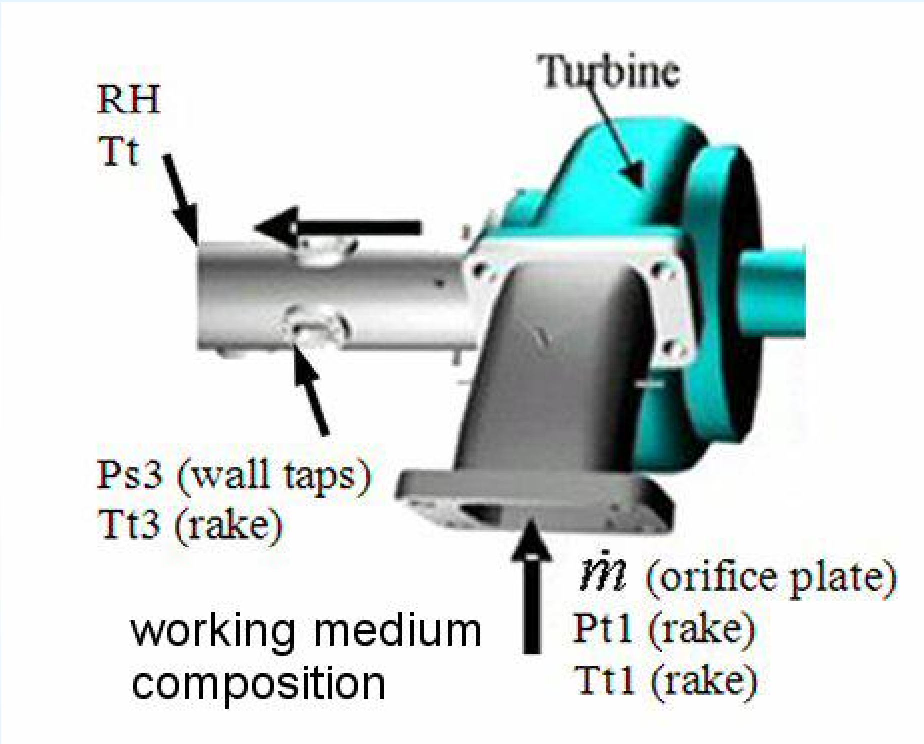
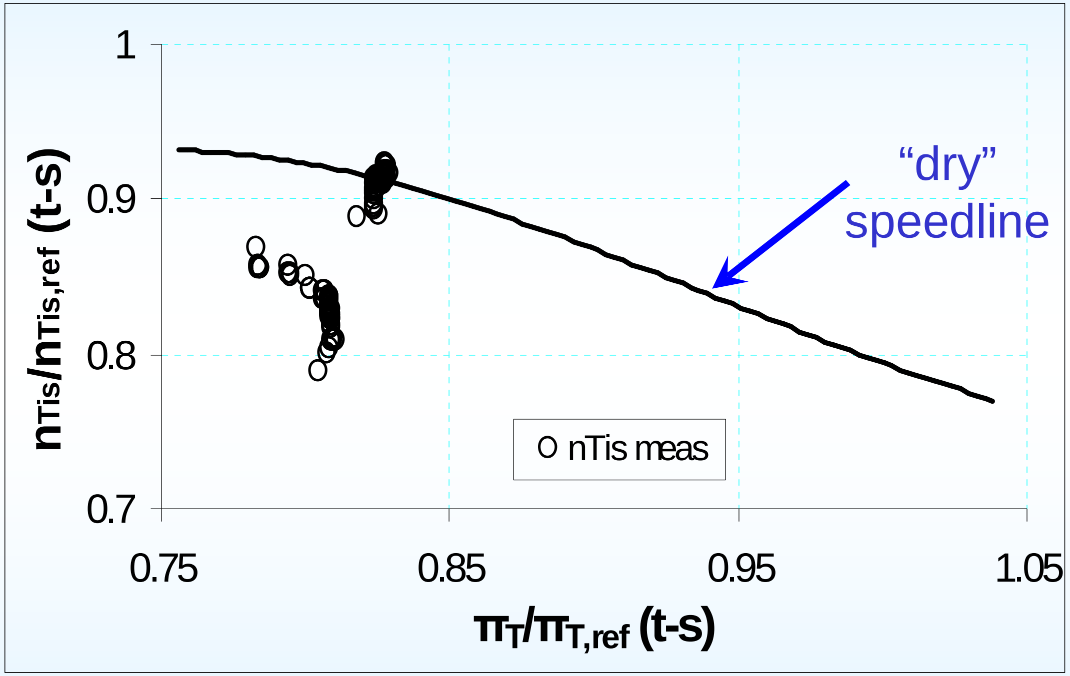
Test Facility



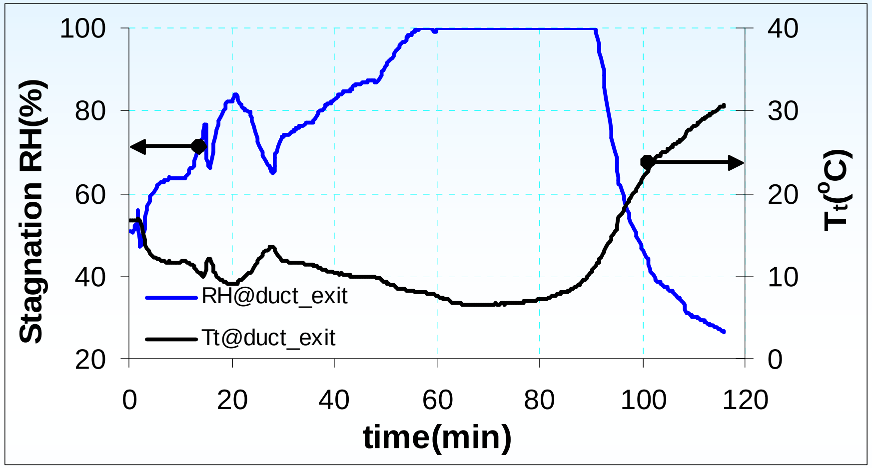
Typical Test Rig with two additional measurements at duct exit (RH, Tt)

Raw measurements



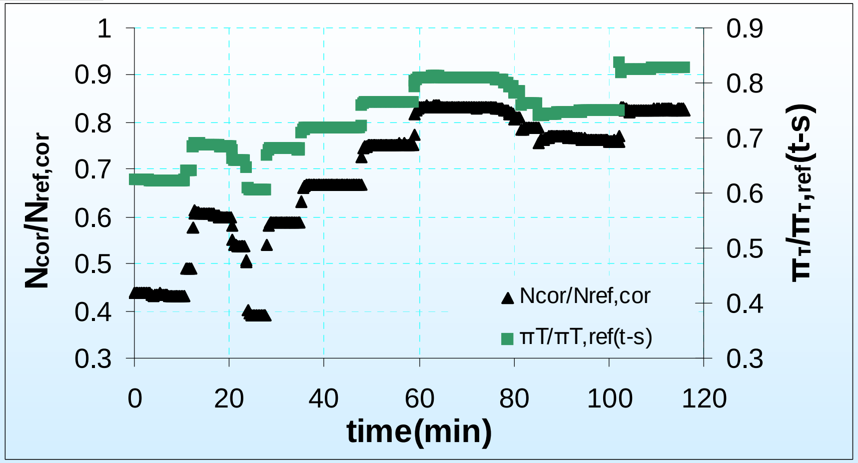
Deviation of measured efficiency from no condensation speedline

Test Case



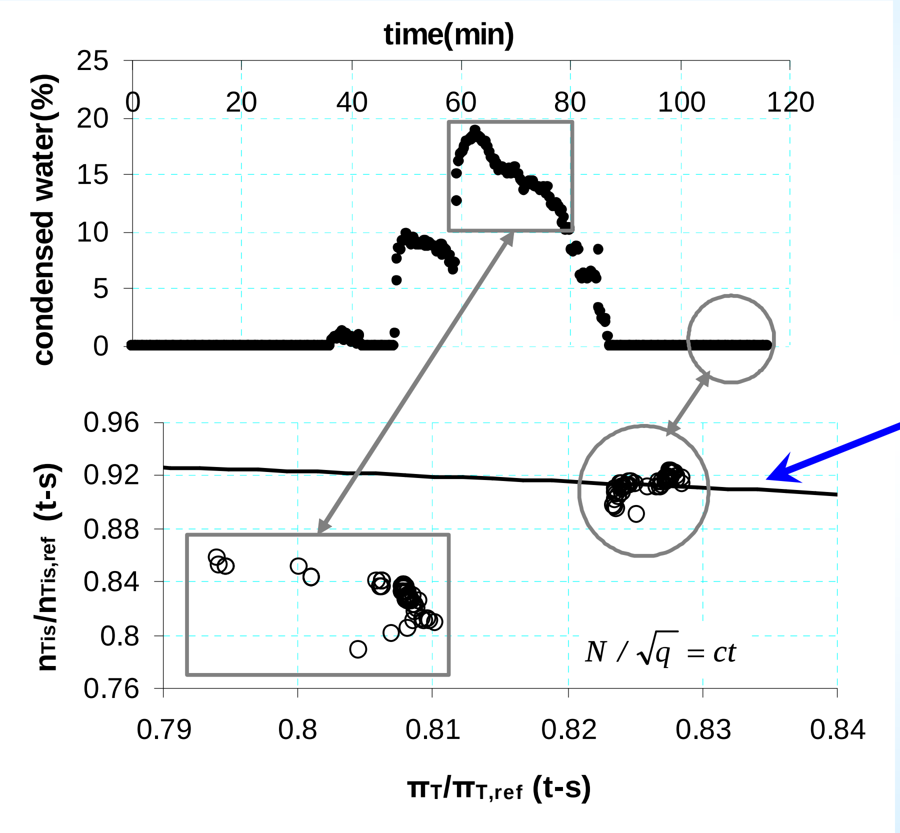
Variation of Measured Temperature and Relative Humidity at duct exit

Operating point variation during test



Condensation Prediction

F Speedline 1

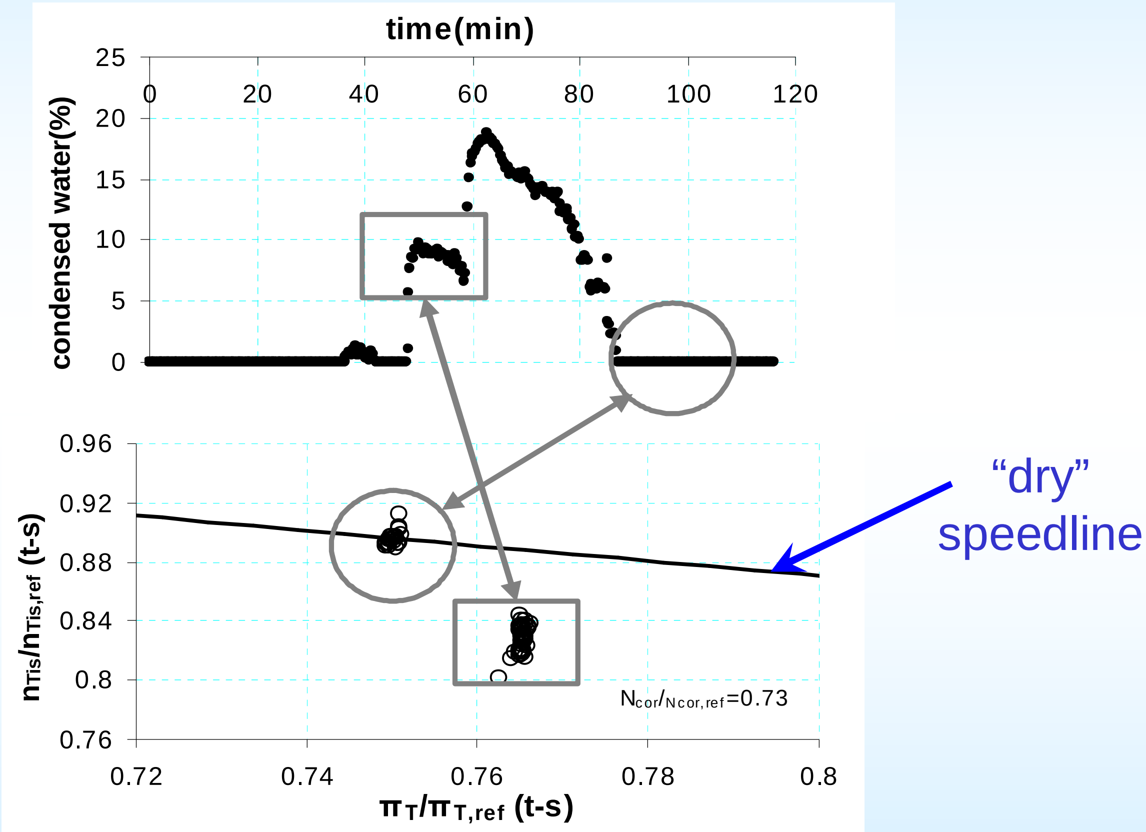


"dry" speedline

Correlation of erroneous efficiency calculations with condensation

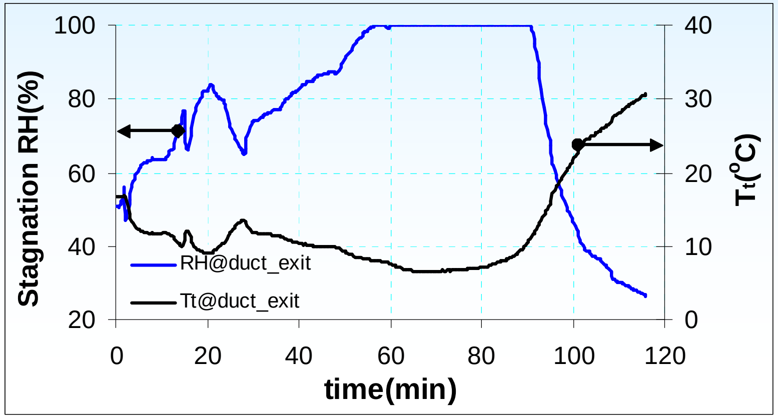
Condensation Prediction

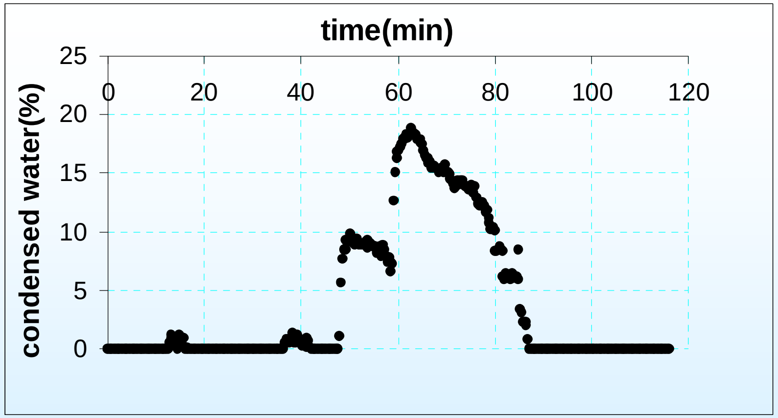
- Speedline 2



Correlation of erroneous efficiency calculations with condensation

Condensation Prediction

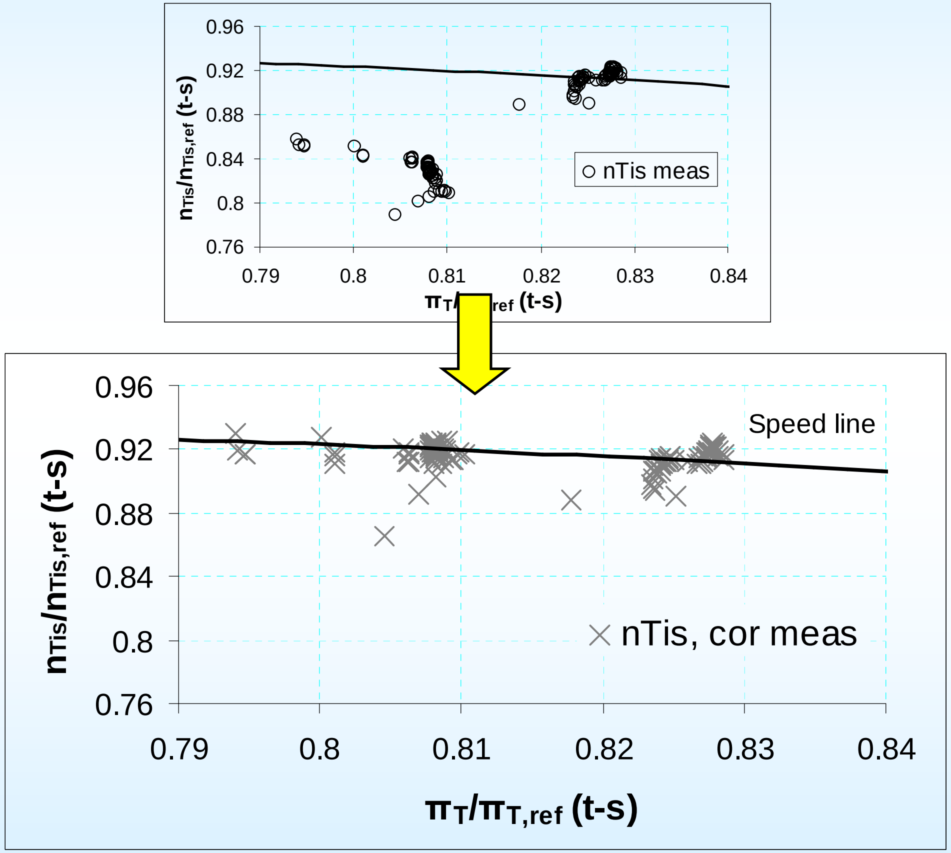




Correlation of measured Relative Humidity with Condensation

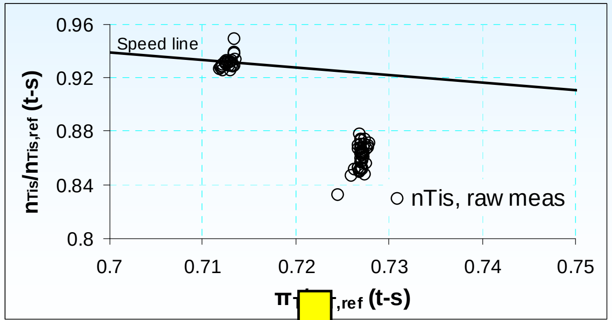
Measurements Correction

F Speedline 1

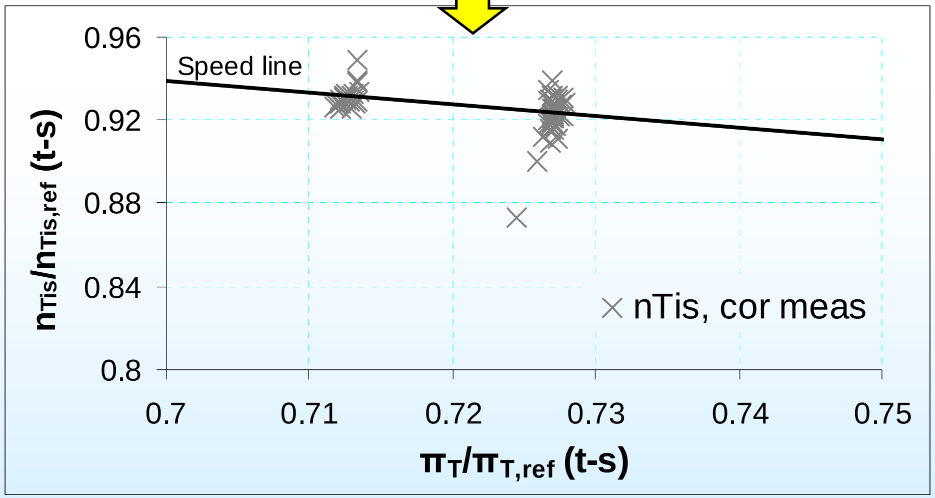


Calculated Isentropic Efficiency corrected for Condensation

Measurements Correction



Speedline 2



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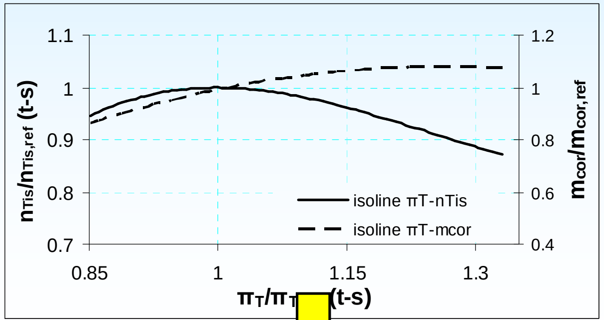
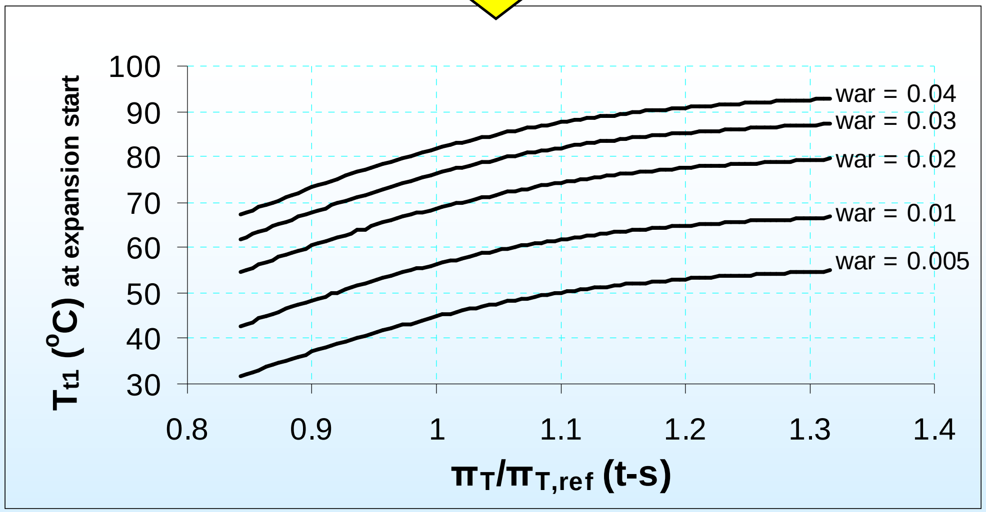
Condensation Avoidance

Test case used isolines





Minimum Temperature at Expansion Start

Conclusions

- **Condensation in cold flow turbine testing alters significant the measurements**
- **Condensation regions may be predicted accurately without additional measurements**
- **The efficiency corrected for condensation is consistent with the efficiency calculated from dry measurements**
- **The implementation of the method is possible to assure condensation free tests**