



LABORATORY OF THERMAL TURBOMACHINES
NATIONAL TECHNICAL UNIVERSITY OF ATHENS

**INCREASING DIAGNOSTIC EFFECTIVENESS BY
INCLUSION OF
FUEL COMPOSITION AND WATER INJECTION EFFECTS**

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Increasing Diagnostic Effectiveness By Inclusion Of Fuel Composition And Water Injection Effects



**Increasing Diagnostic Effectiveness By Inclusion Of
Fuel Composition And Water Injection Effects**

- Reasons for performance alterations
- Modeling Fuel composition and water injection effects
- Effect of Water injection on quantities used for monitoring
- Effect of Fuel change on quantities used for monitoring
- Summary - Conclusions



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Reasons for Performance Alteration

Change of fuel

Change in hot gas properties
↳ Change in turbine power
Different heating value *↳*
different fuel/air ratio and
flow rate

Water Injection

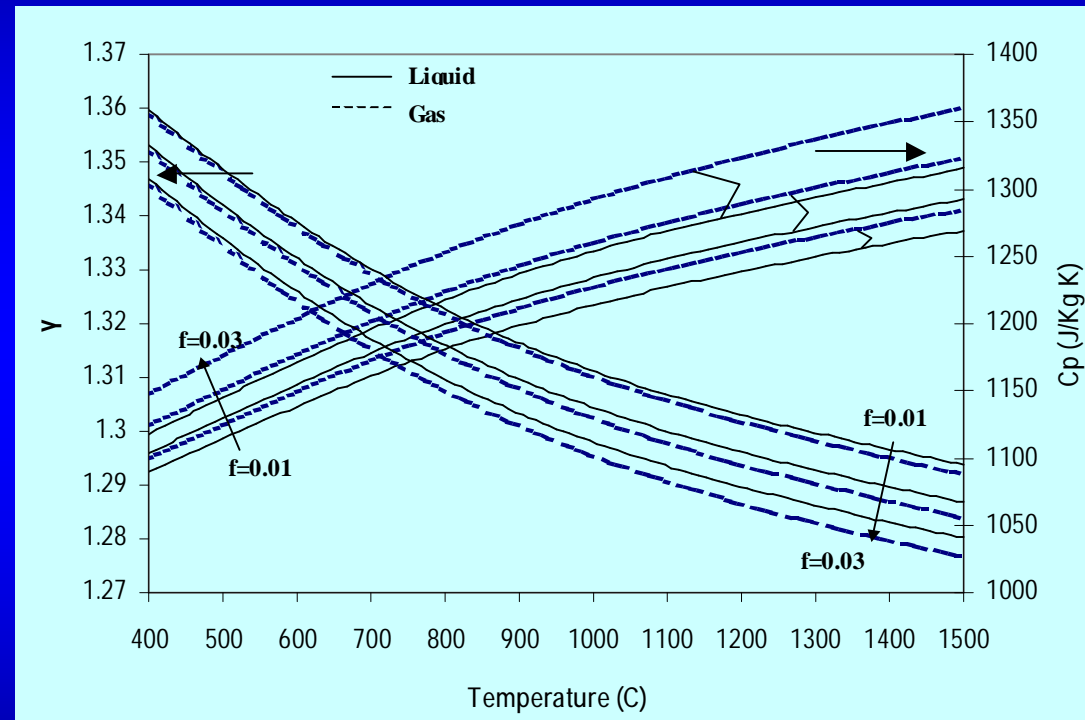
Change in hot gas properties
↳ Change in turbine power
Increase of hot gas flow rate

Change of fuel or Water Injection

Change in compressor operating point



Change in hot gas properties for Change of fuel



Example: Hot gases Variation of C_p and γ , for gas and liquid fuels.

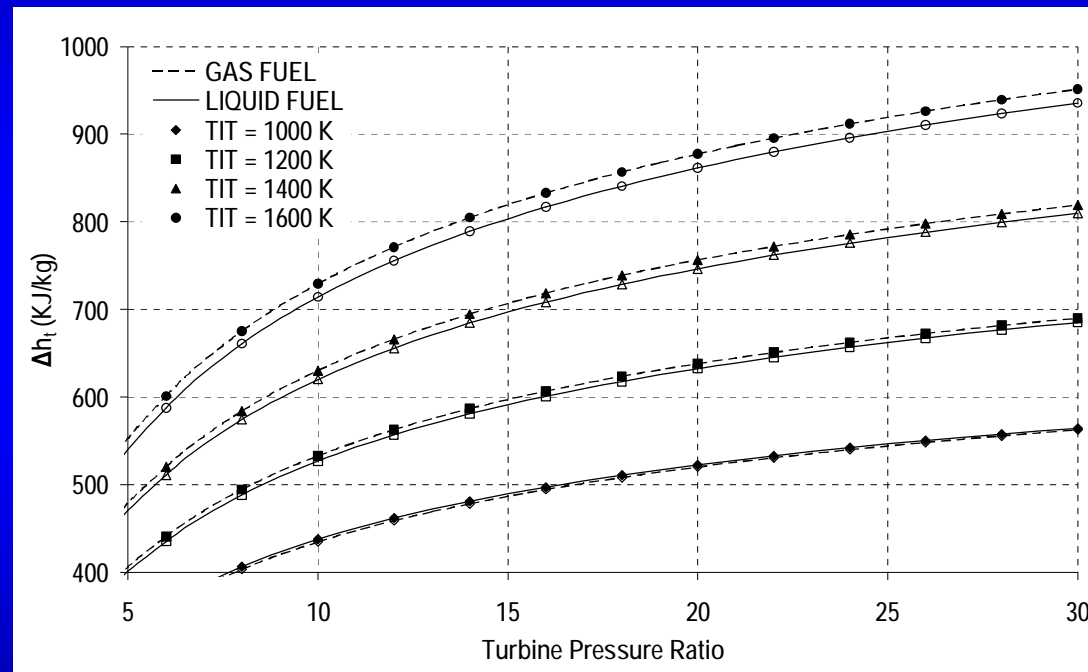


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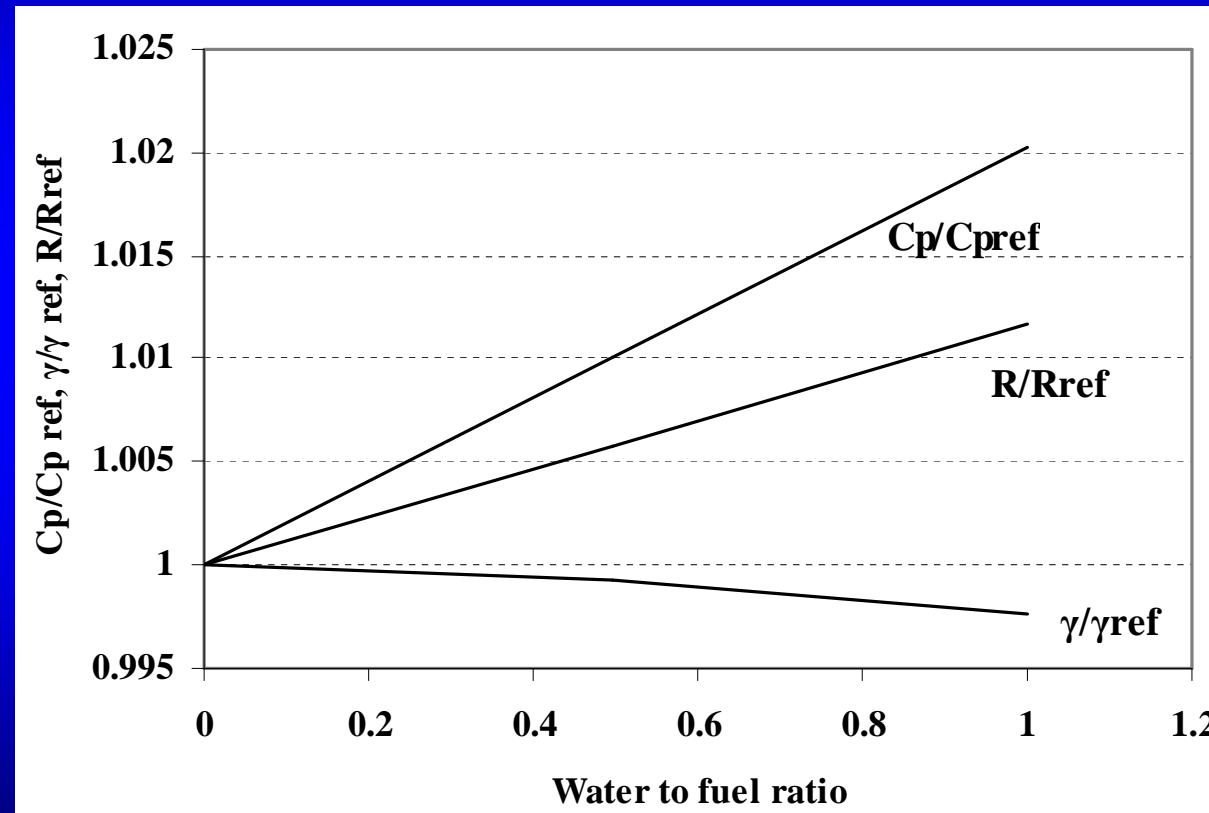


Influence of fuel on Turbine enthalpy drop





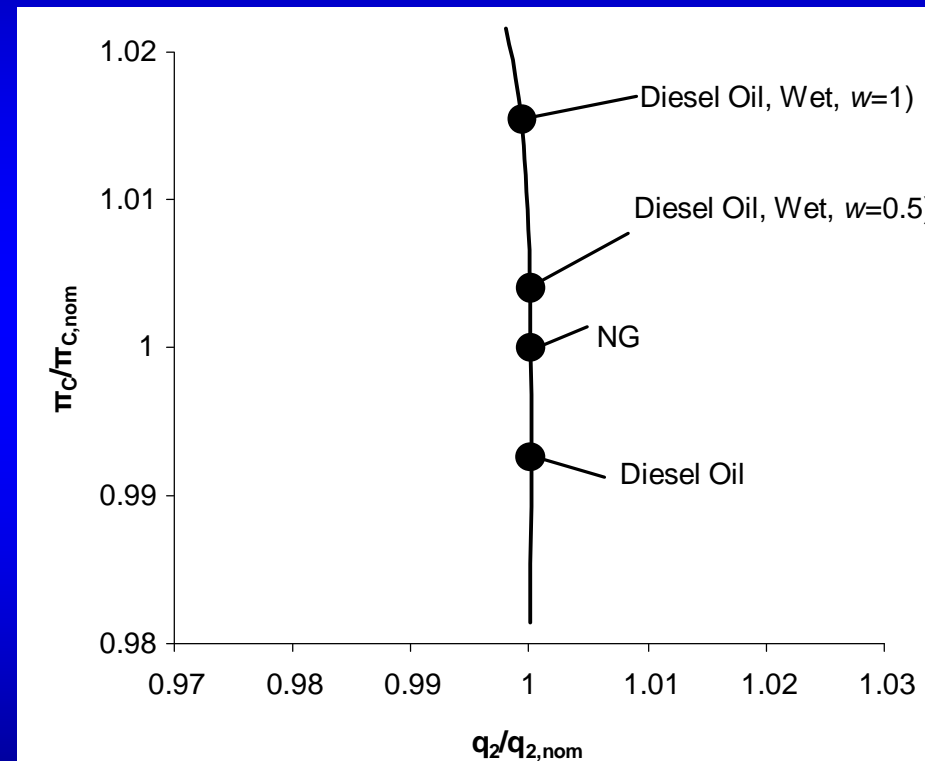
Change in gas properties in function of
amount of injected water



(f=0.02).



**Shift of Compressor operating point
for operation with different fuels and water injection.**



Single shaft gas turbine. Constant TIT



Modeling fuel composition and water injection effects

- Variable properties in thermodynamic calculations
- Alteration in the performance of turbomachinery components



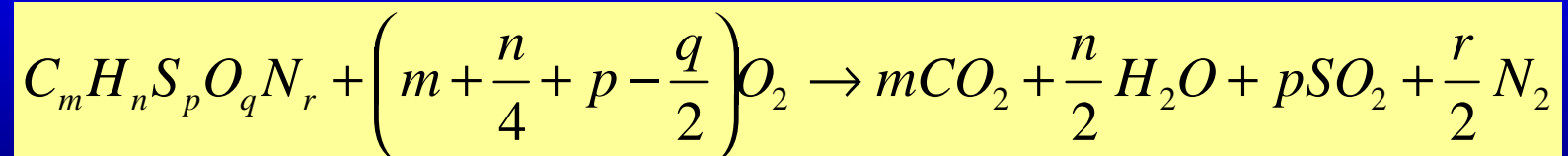
Modeling fuel composition and water injection effects

Alter gas properties in thermodynamic calculations

- Mixture properties

$$P = \sum_i X_i \cdot P_i$$

- Combustion Products constitution





Modeling fuel composition and water injection effects

Referring turbomachinery component performances

$$\left(\frac{N}{\sqrt{T}}\right) / \left(\frac{N}{\sqrt{T}}\right)_0 = \sqrt{R \cdot g \cdot (1+g_0) / R_0 \cdot g_0 \cdot (1+g)} \quad (3.1)$$

$$\left(\frac{W\sqrt{T}}{P}\right) / \left(\frac{W\sqrt{T}}{P}\right)_0 = \sqrt{\frac{R_0 \cdot g}{R \cdot g_0}} \cdot \left(\frac{2}{1+g}\right)^{\frac{g+1}{2 \cdot (g-1)}} \cdot \left(\frac{1+g_0}{2}\right)^{\frac{g_0+1}{2 \cdot (g_0-1)}} \quad (3.2)$$

$$\left(\frac{\Delta h}{T}\right) / \left(\frac{\Delta h}{T}\right)_0 = R \cdot g \cdot (1+g_0) / R_0 \cdot g_0 \cdot (1+g) \quad (3.3)$$

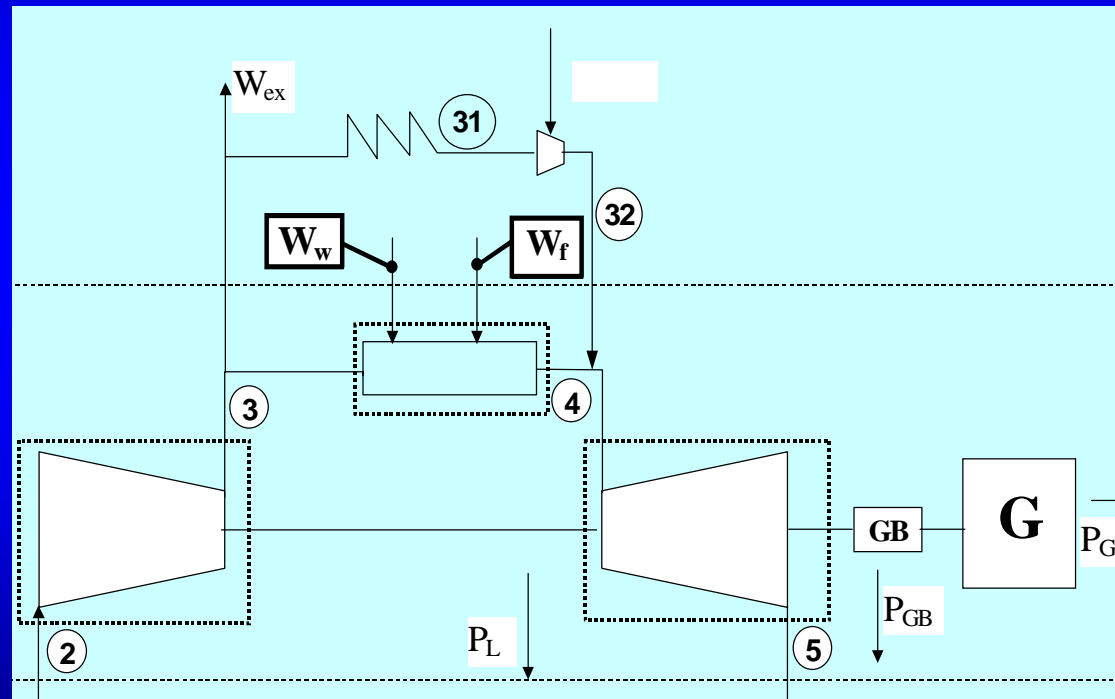
$$q_4 = \left(\frac{W_4 \sqrt{T_4}}{P_4}\right) \sqrt{\frac{R}{g}}$$

Expression for turbine
flow function useful for
interpretations



Constitution of component-based models

To support Diagnostic procedures



Layout of a single shaft gas turbine



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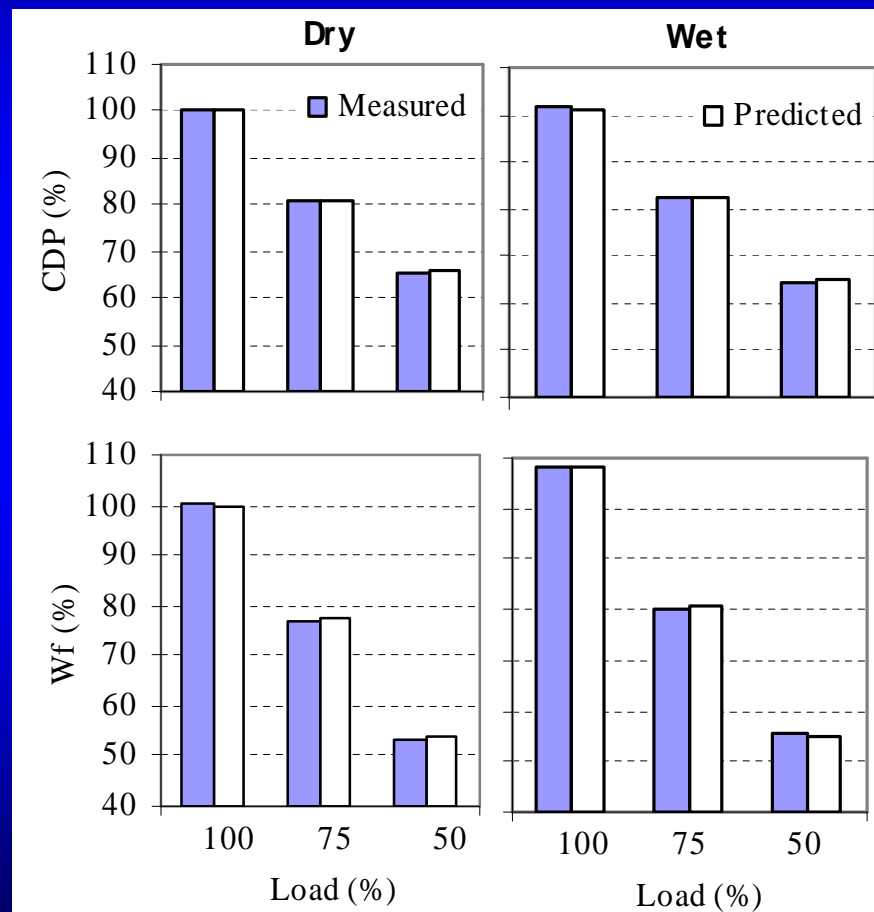


Effects On Monitored Parameters

- I. Methods based on measurements observation
- "Signatures" of measurement deviations from nominal values are used to monitor performance and diagnose malfunctions
- "Signatures" can be estimated using engine models



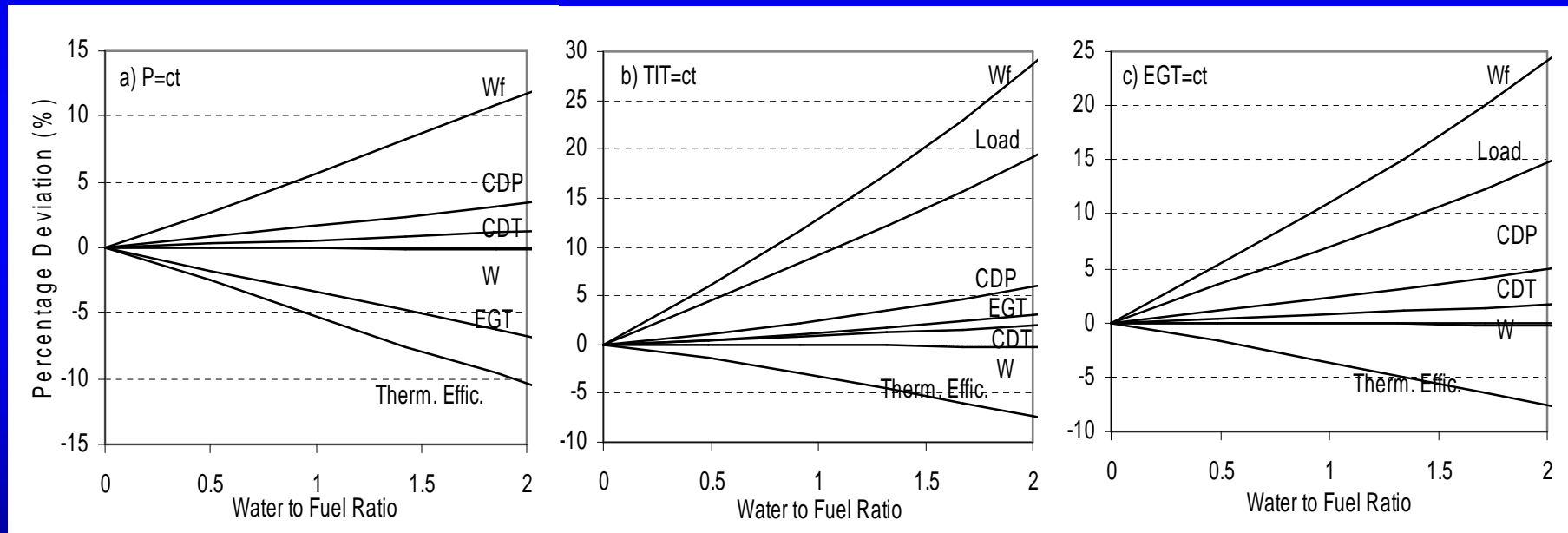
EFFECT OF WATER INJECTION ON QUANTITIES USED FOR MONITORING



Measured and predicted values of gas turbine performance parameters for dry and wet operation

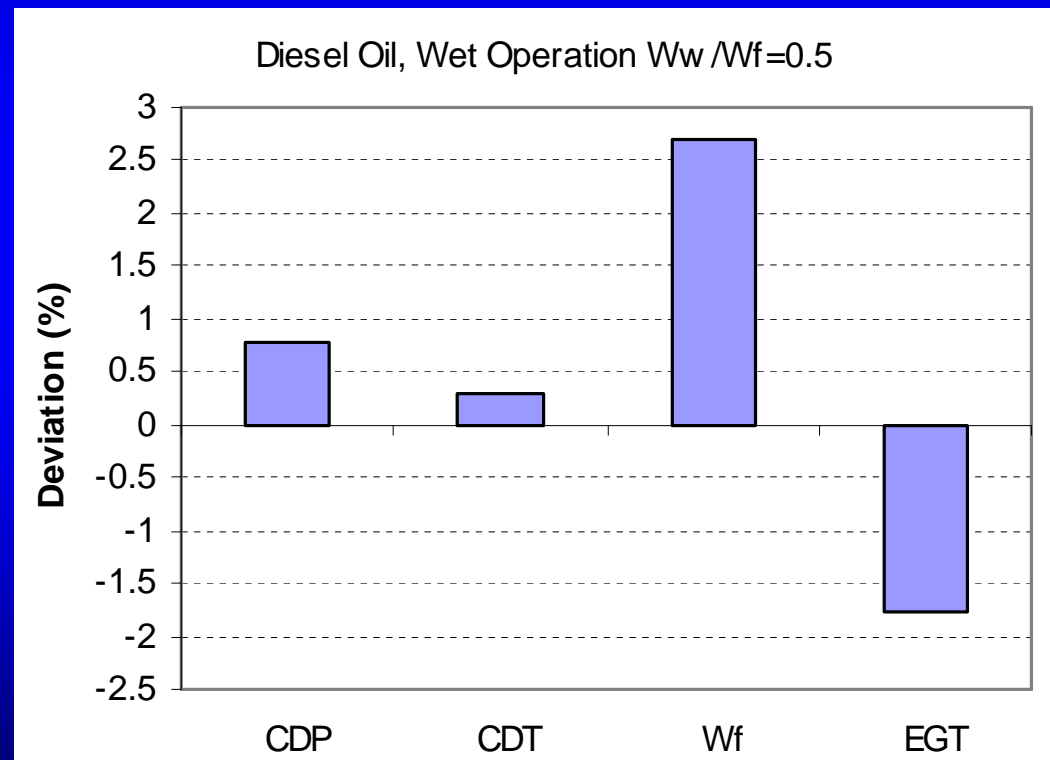


Percentage change of performance related quantities, in function of water/fuel ratio. Changes evaluates at constant (a) Power output, (b) TIT, (c) EGT



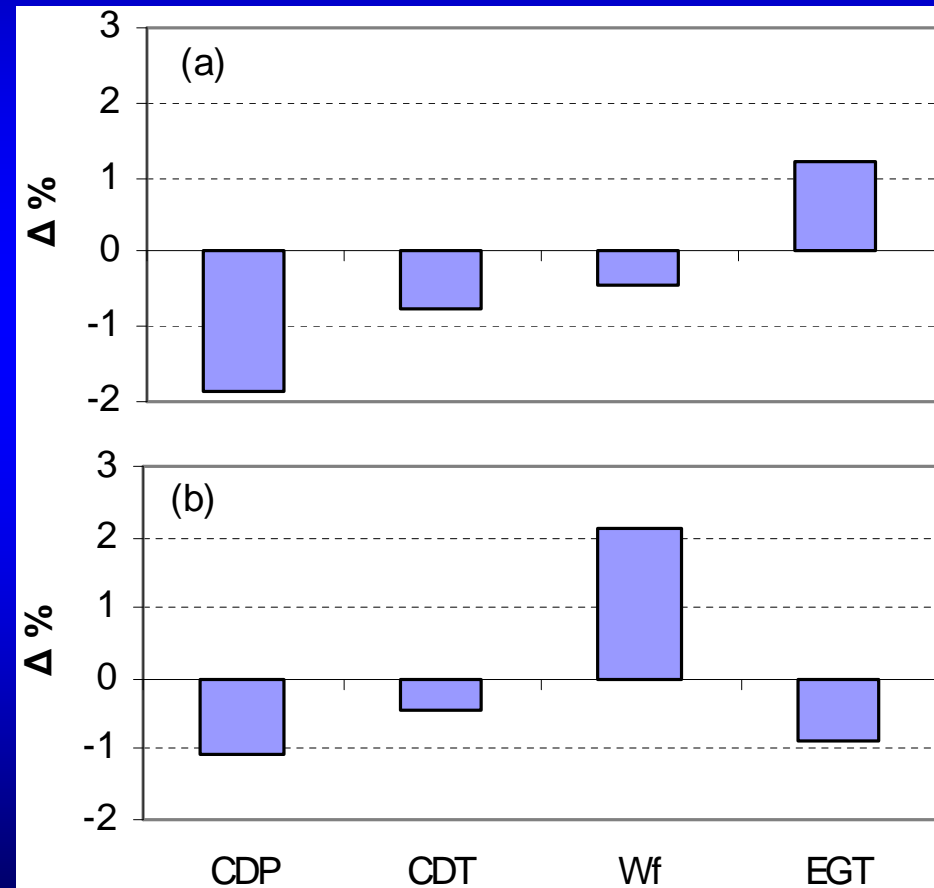


Deviations of measurements for Diesel oil wet operation
w=0.5, with respect to dry operation (constant power
output)



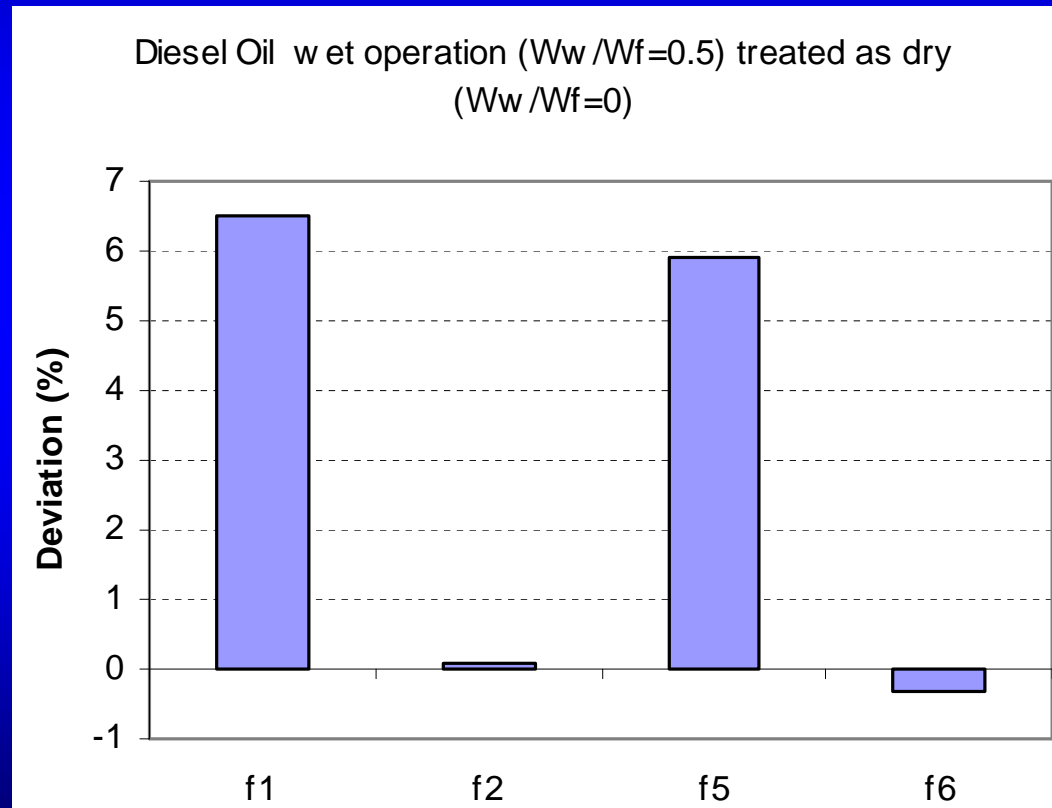


Signature of IGV fault (a) for dry operation, (b) for wet operation ($w=0.5$), using the dry operation as baseline.



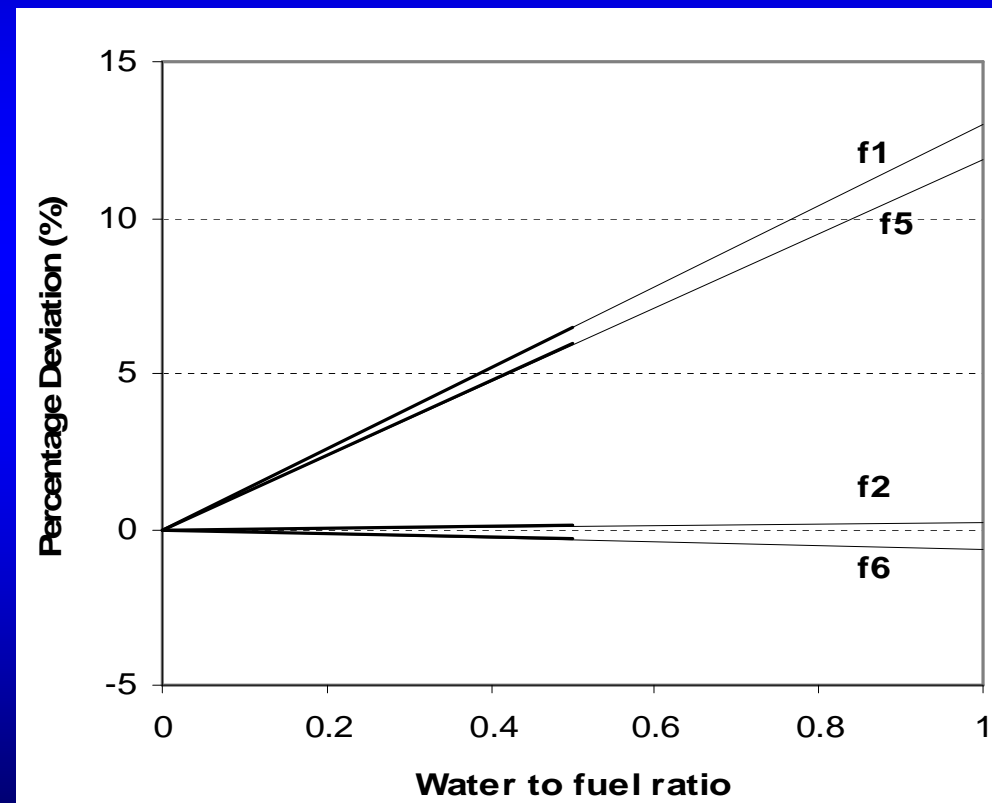


Deviation of modification factors if wet operation ($w=0.5$)
data are processed by adaptive model with dry air.





Deviation of modification factors if data from operation with injected water are processed by adaptive model with dry operation.



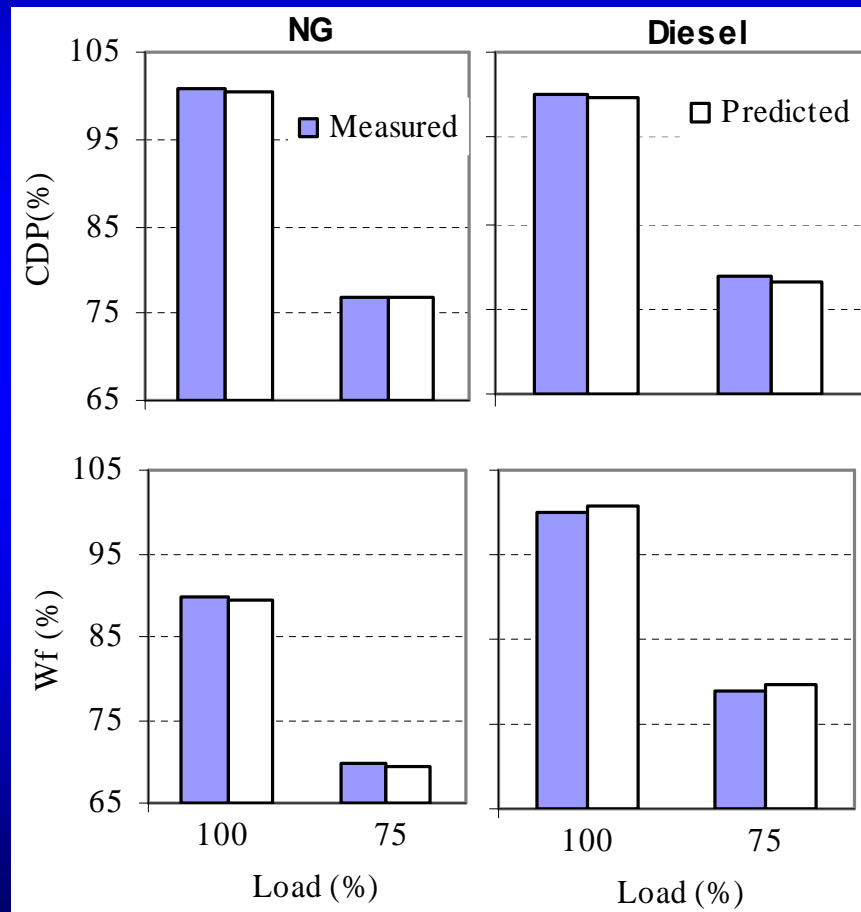


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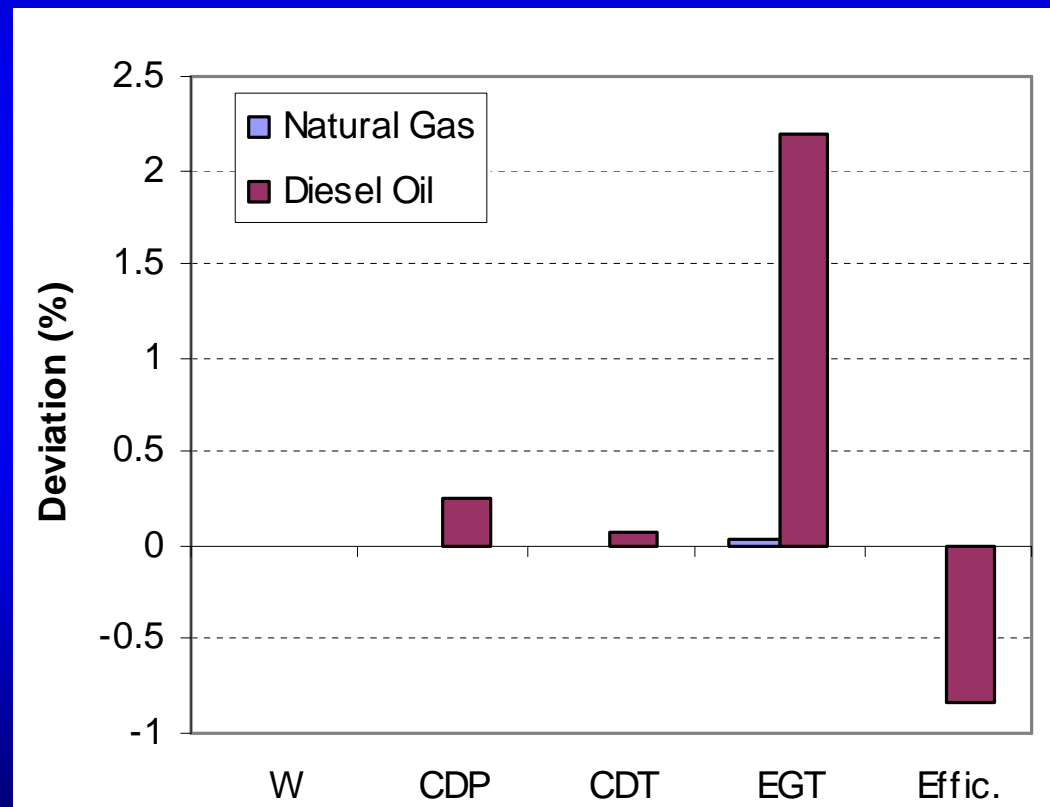
EFFECT OF FUEL CHANGE ON QUANTITIES USED **FOR MONITORING**



Measured and predicted values of gas turbine performance parameters for different fuels

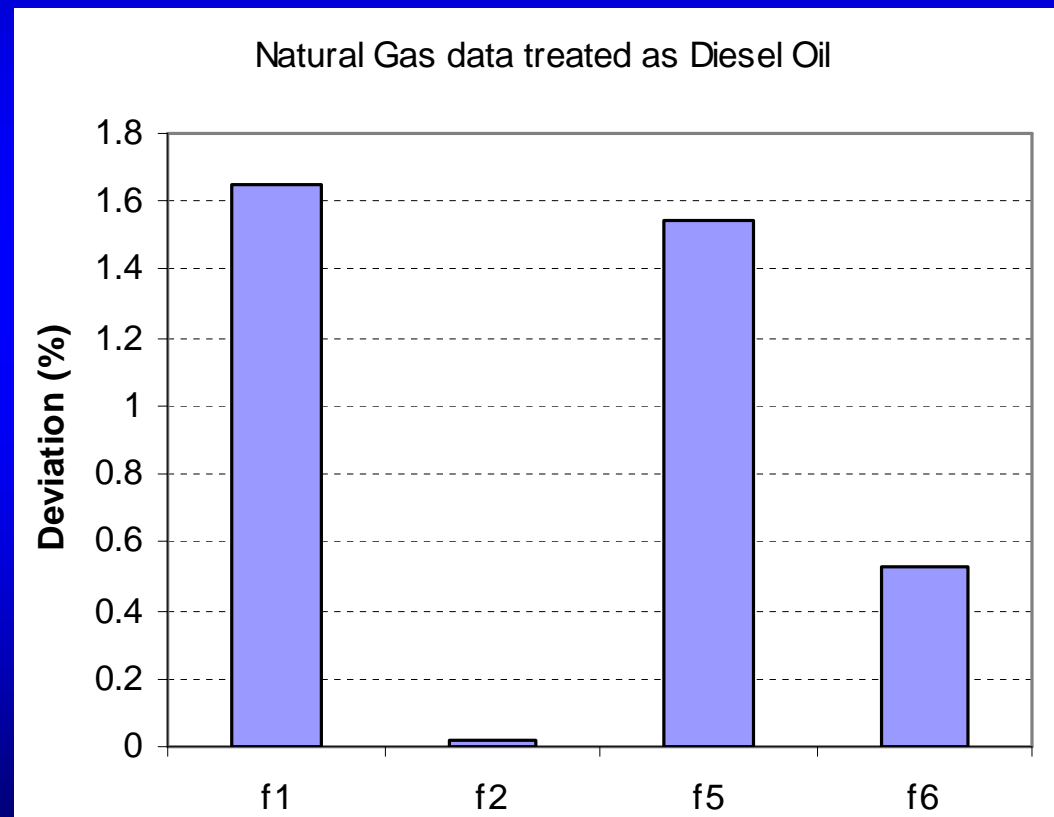


Measurements deviation for typical natural gas and diesel oil operation (baseline values corresponding to 100% CH₄).



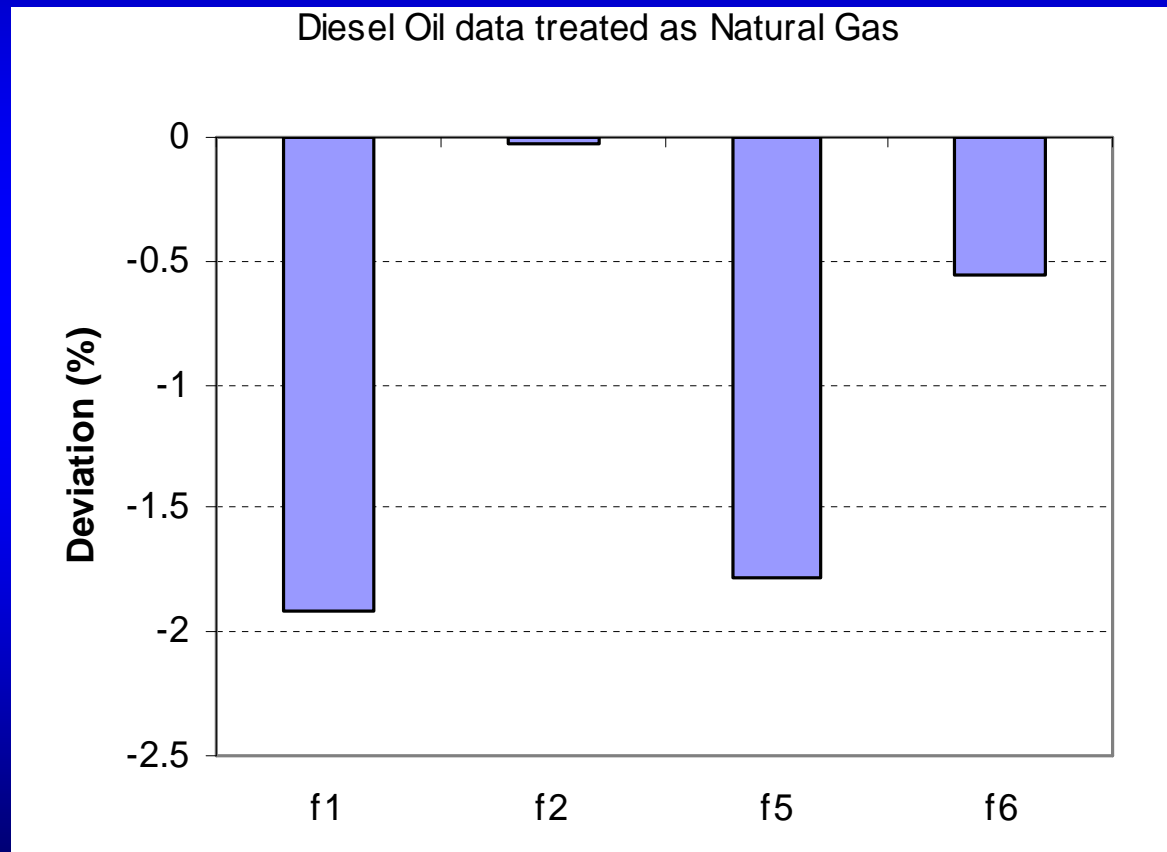


Deviation of modification factors if natural gas data are processed by adaptive model with diesel oil.





Deviation of modification factors if diesel oil data are processed by adaptive model with natural gas.





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Conclusions

- **The effect of water injection and fuel change on quantities related to gas turbine performance monitoring has been analyzed.**
- **For that purpose an industrial single shaft gas turbine model was used.**
- **Both examined cases produce deviations at measured quantities similar to the ones caused by faults.**
- **Effects are also significant on methods using component health parameters for monitoring.**
- **Incorporating water injection and fuel composition effects in a model supporting diagnostic procedures give the possibility for accurate engine condition assessment.**