EFFECTS OF ANTI-ICING SYSTEM OPERATION ON GAS TURBINE PERFORMANCE AND MONITORING

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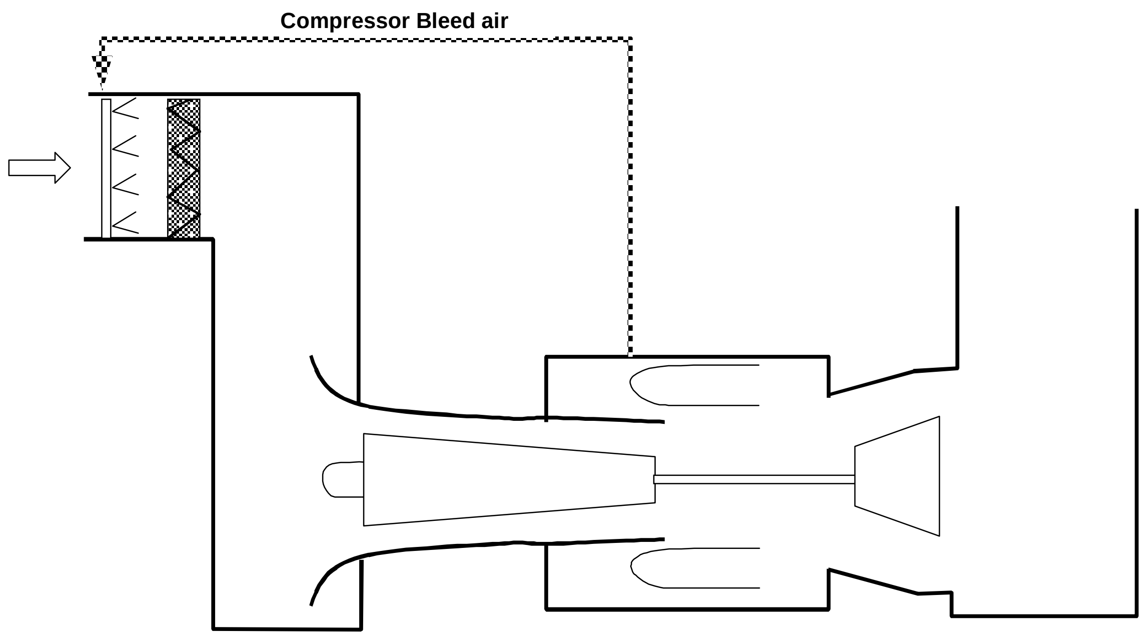
Effects Of Anti-Icing System Operation On Gas Turbine Performance And Monitoring

- **Effects on Performance**
- **Impact on Monitoring**
  - **Measurement observation**
  - **Derived parameters**
- **Propose a way to improve diagnostic capability**
- **Present supporting data from an industrial gas turbine**
- **Discussion-Conclusions**

Hot bleed anti-icing

Anti-icing with compressor delivery air.



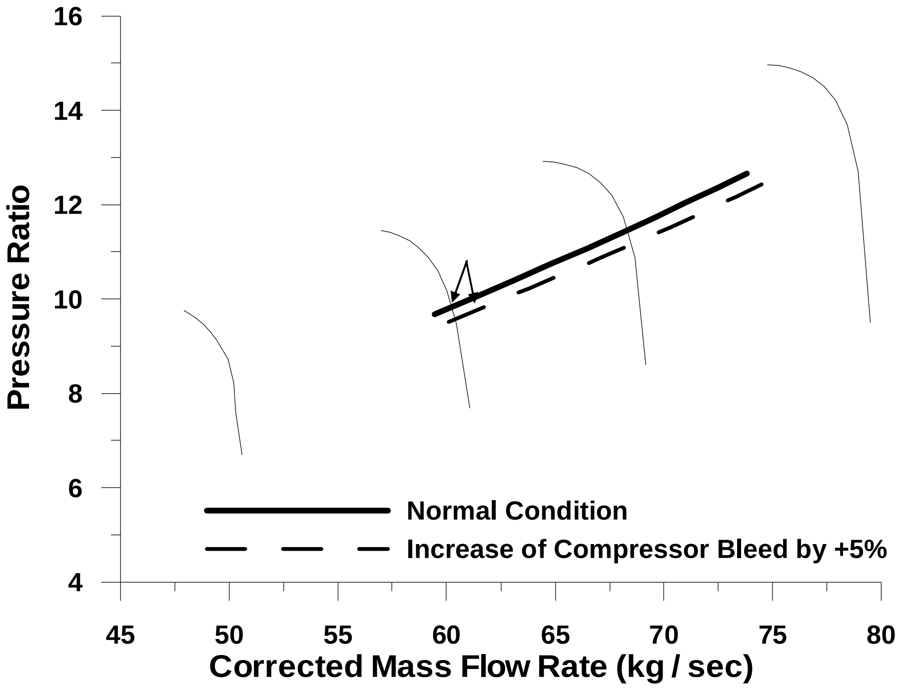
Effects of hot-bleed anti-icing on performance.

Mechanisms:

- air extracted from compressor delivery

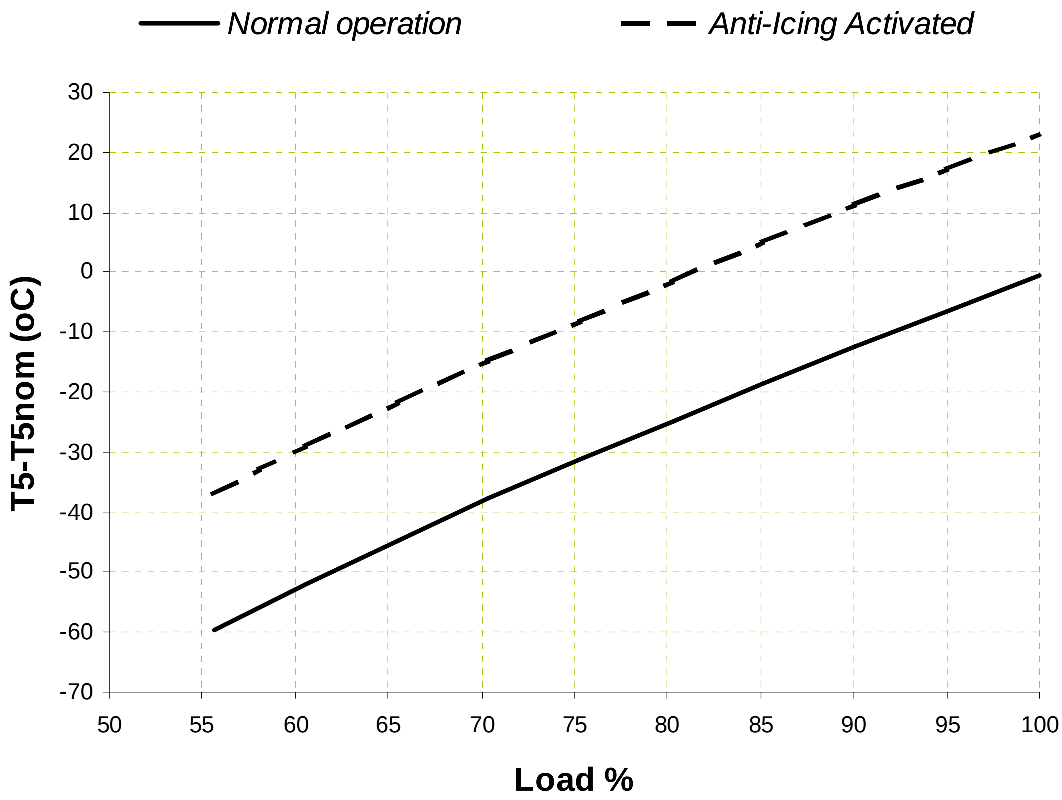
- compressor inlet temperature > ambient

Shift of operating line because of compressor delivery (additional) bleed.



Change of the interrelations between operating parameters.

Effect of hot bleed anti-icing operation on EGT versus load dependence.



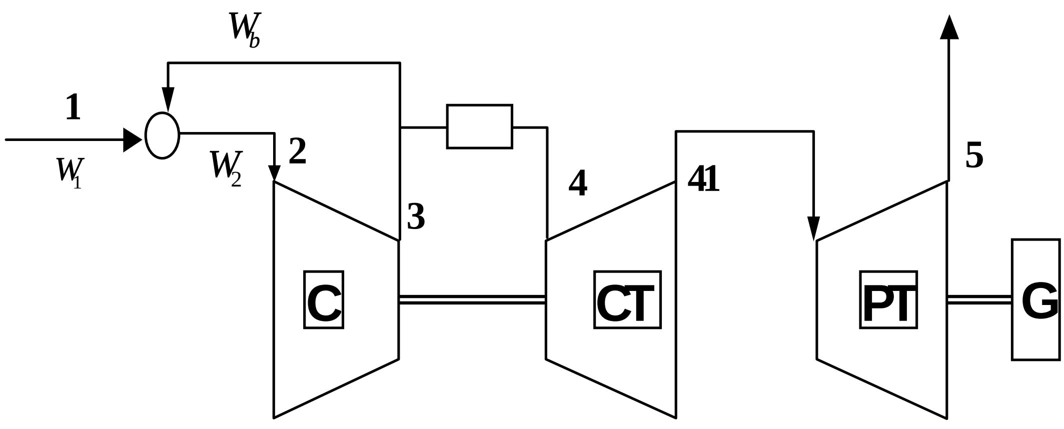
(when variation of operating parameters is monitored, their change may be misinterpreted as indication of a malfunction)

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

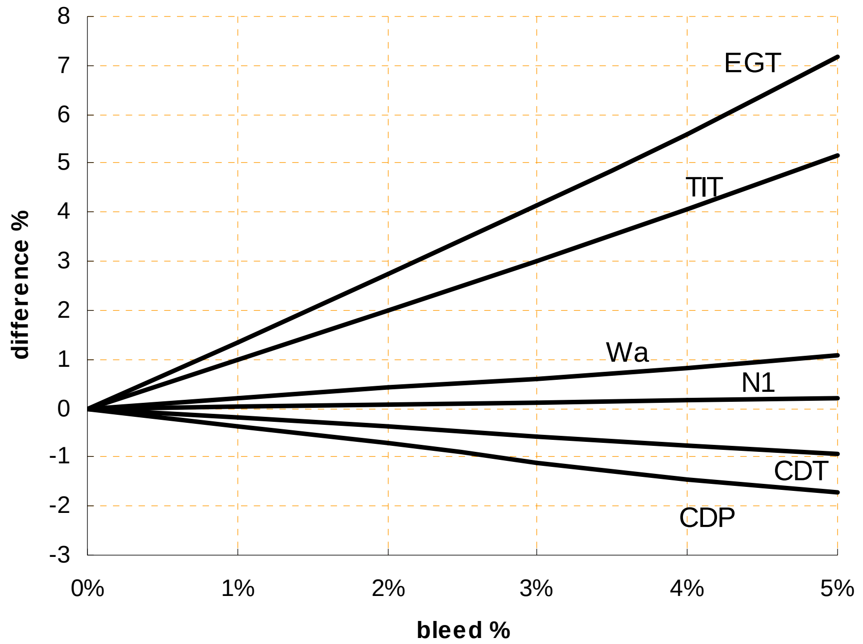
"Signatures" can be estimated using engine models



Engine subdivision into components for simulation of hot bleed anti-icing operation.

Performance Parameters Deviations,

(In function of bleed air amount)

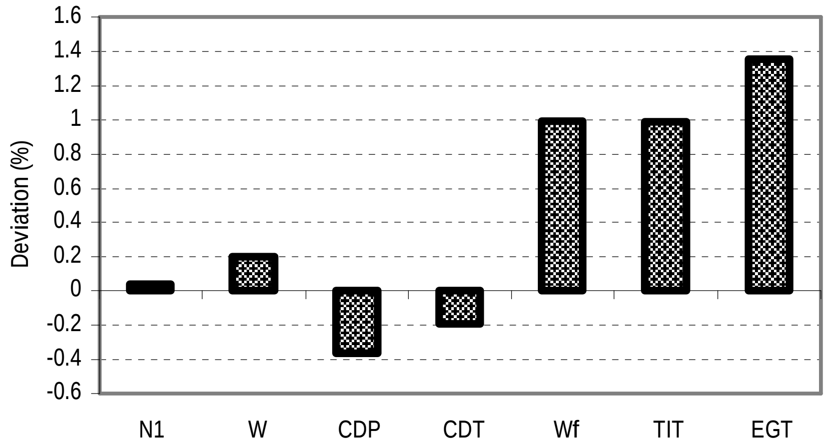


$\Delta Y=(Y-Y_o)/Y_o \times 100$

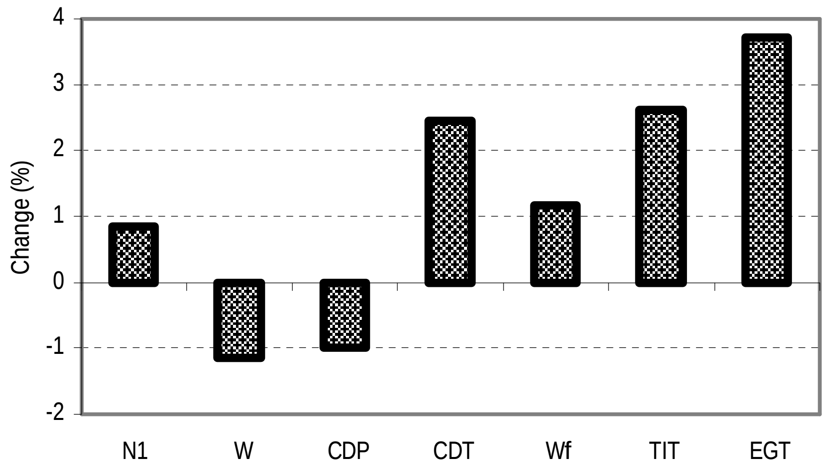
Differences formed for operation at the same engine inlet temperature, which is not necessarily equal to ambient temperature.

"Signature" of compressor delivery bleed, on measurements

(a) simple bleed



(b) bleed redirected to inlet for anti-icing



Constant load operation

Effects On Monitored Parameters

II. Model Based Methods

Technique used "**ADAPTIVE MODELLING**"

"***HEALTH INDICES***"

Compressor

$$f_1 = \left(W_2\sqrt{T_2}/P_2)\right)/\left(W_2\sqrt{T_2}/P_2\right)_{ref} \quad ,$$

$$f_2 = h_C / h_{C,ref}$$

Gas Generator Turbine

$$f_5 = \left(W_4\sqrt{T_4}/P_4\right)/\left(W_4\sqrt{T_4}/P_4\right)_{ref} \quad ,$$

$$f_6 = h_{GGT} / h_{GGT,ref}$$

Power Turbine

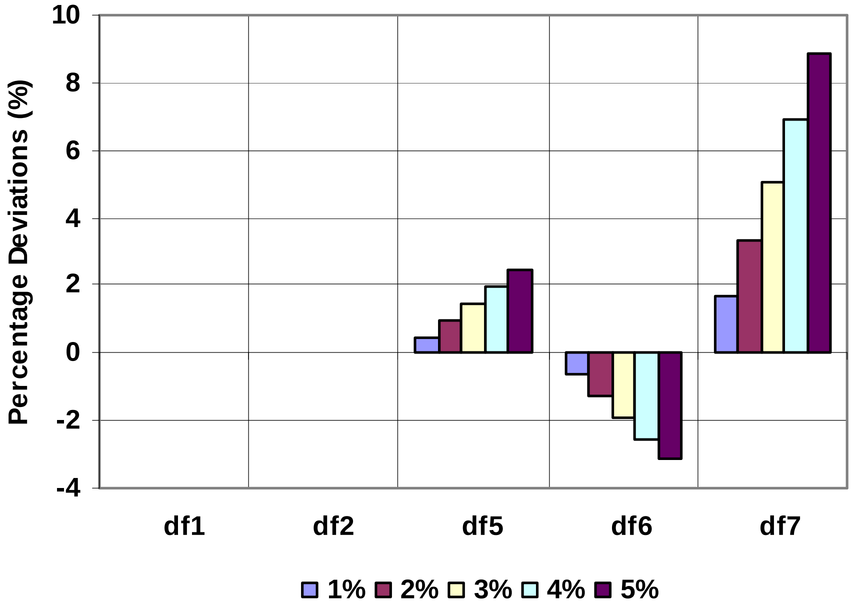
$$f_7 = \left(W_{4.1}\cdot\sqrt{T_{4.1}}/P_{4.1}\right)/\left(W_{4.1}\cdot\sqrt{T_{4.1}}/P_{4.1}\right)_{ref}$$

$$f_8 = h_{PT} / h_{PT,ref}$$

Measurements collected from the engine operating with the anti-icing system activated, fed to the adaptive model, without altering the layout to reflect the presence of a bleed, produce health parameters different form their nominal values.

"Signatures" of extra bleed on health indices

(different amounts of bleed)



Bleed presence ≈ increase in turbines flow capacity, drop of compressor turbine efficiency.

TEST data from a gas turbine with anti-icing in operation.

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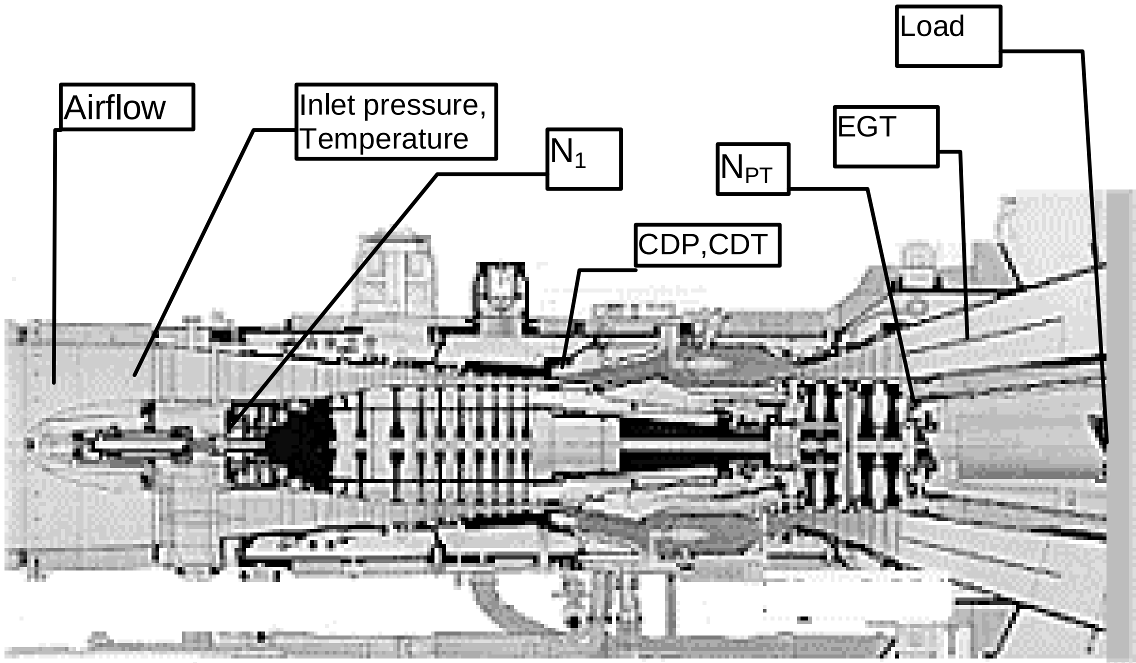
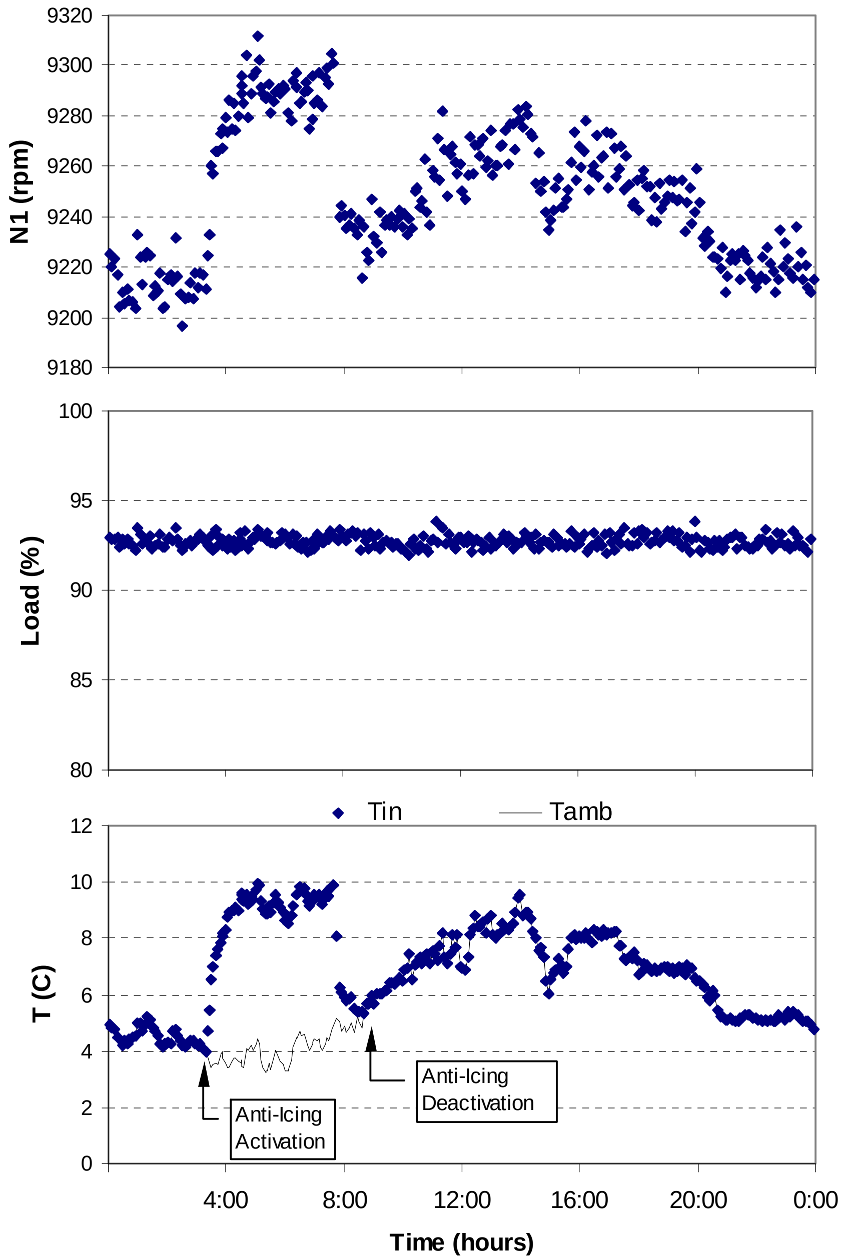


Gas turbine Layout and quantities measured for monitoring

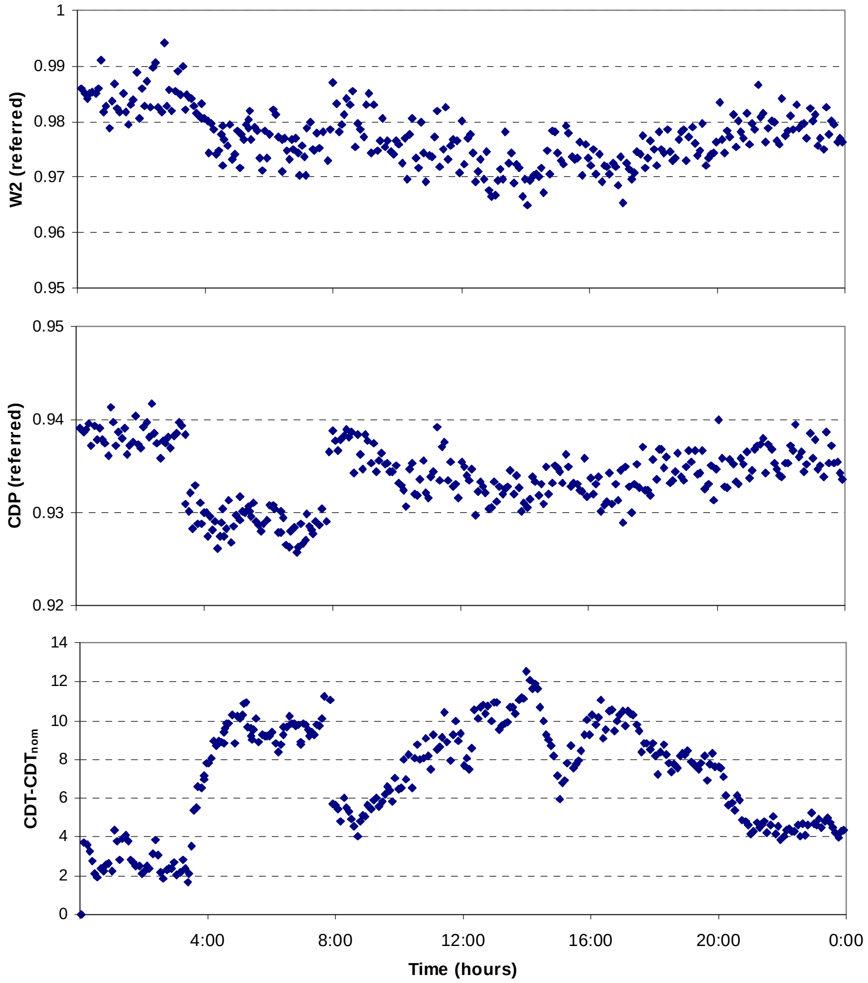
Inlet anti-icing when ambient temperature drops below 4 ^{o}Cr. The amount of air designed to increase inlet temperature by approximately 5 ^{o}C

Operating conditions, including operation with anti-icing



Effect of anti-icing operation on performance

(a) compressor related performance variables

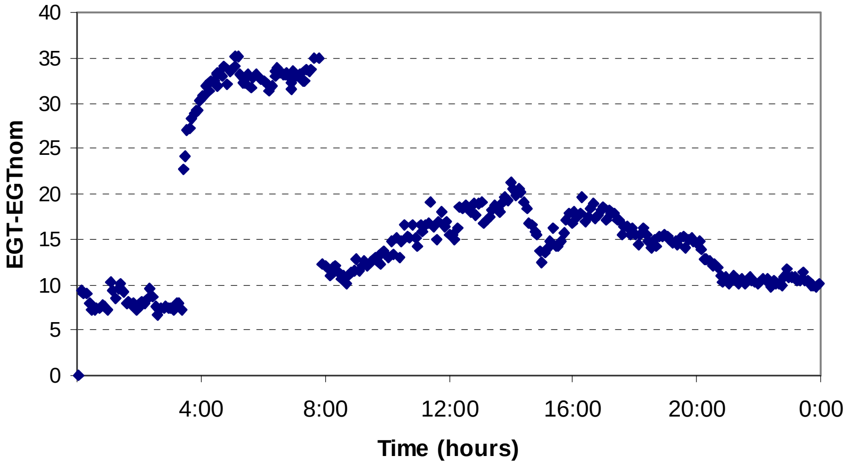


- compressor delivery temperature -
- compressor delivery pressure ¯
-air mass flow drops ¯

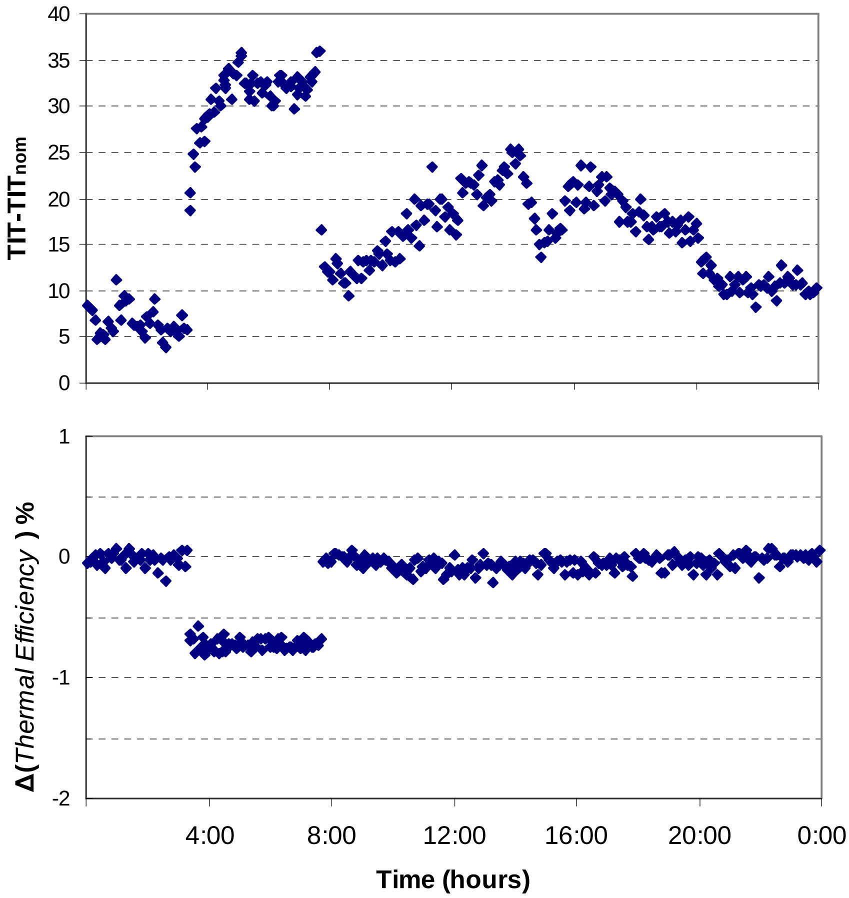
In agreement with trends predicted by the engine model

Effect of anti-icing operation on performance

(b) exhaust gas temperature.

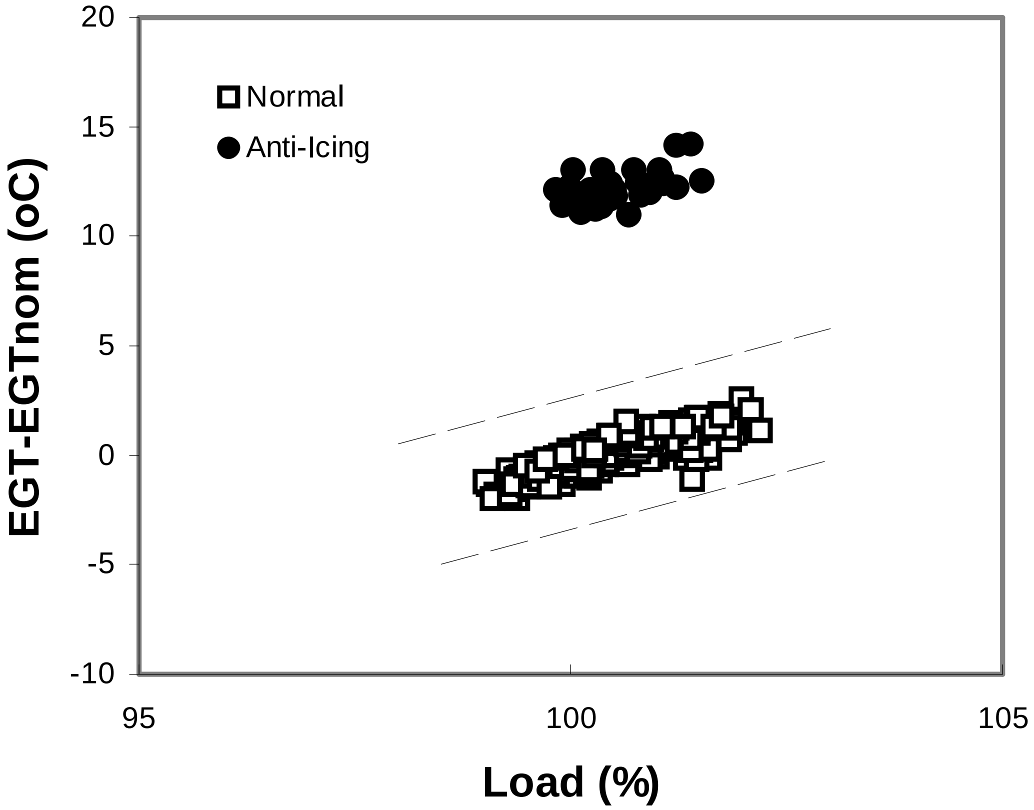


(c) Estimated quantities



Anti-icing operation and performance parameters interrelations

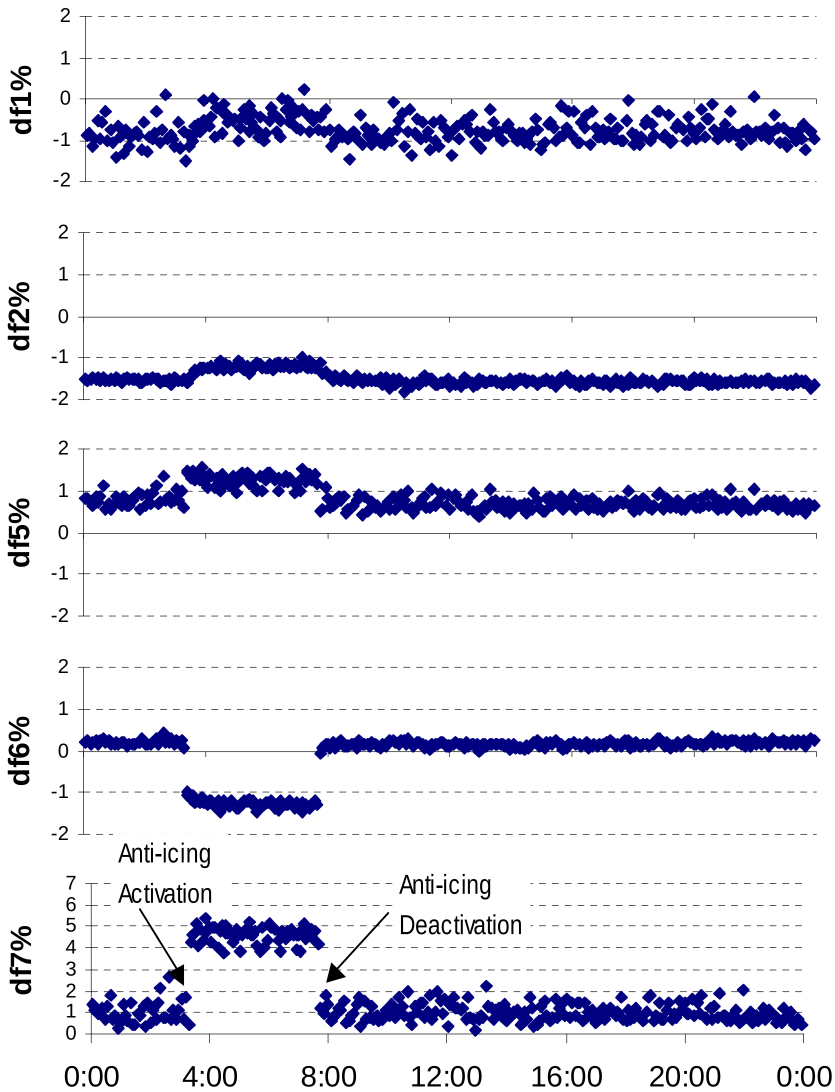
EGT - Load (operation with and without anti-icing)



EGT gets values larger than expected for given load. Could lead to a false alarm. Turn-off the EGT checking function, when the anti-icing system is in operation.

Time evolution of health indices

(anti-icing operation no taken into account)



-Flow capacity of power turbine changes by about four times the change in compressor turbine
-Actual turbine problem could be overshadowed
-Behavior in agreement with prediction

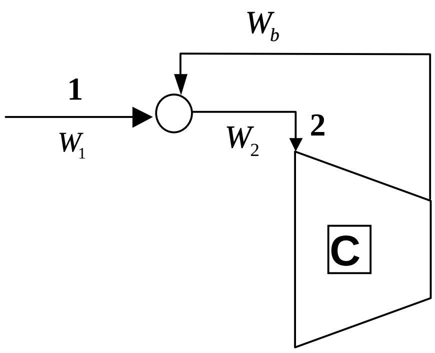
Accounting For Anti-Icing Operation In Monitoring

Bleed air fraction estimation

Full mixing assumed

$$W_2 \cdot h_2 = W_1 \cdot h_1 + W_b \cdot h_b$$

$$b = W_b / W_2, \quad W_2 = W_1 + W_b$$



Bleed air fraction:

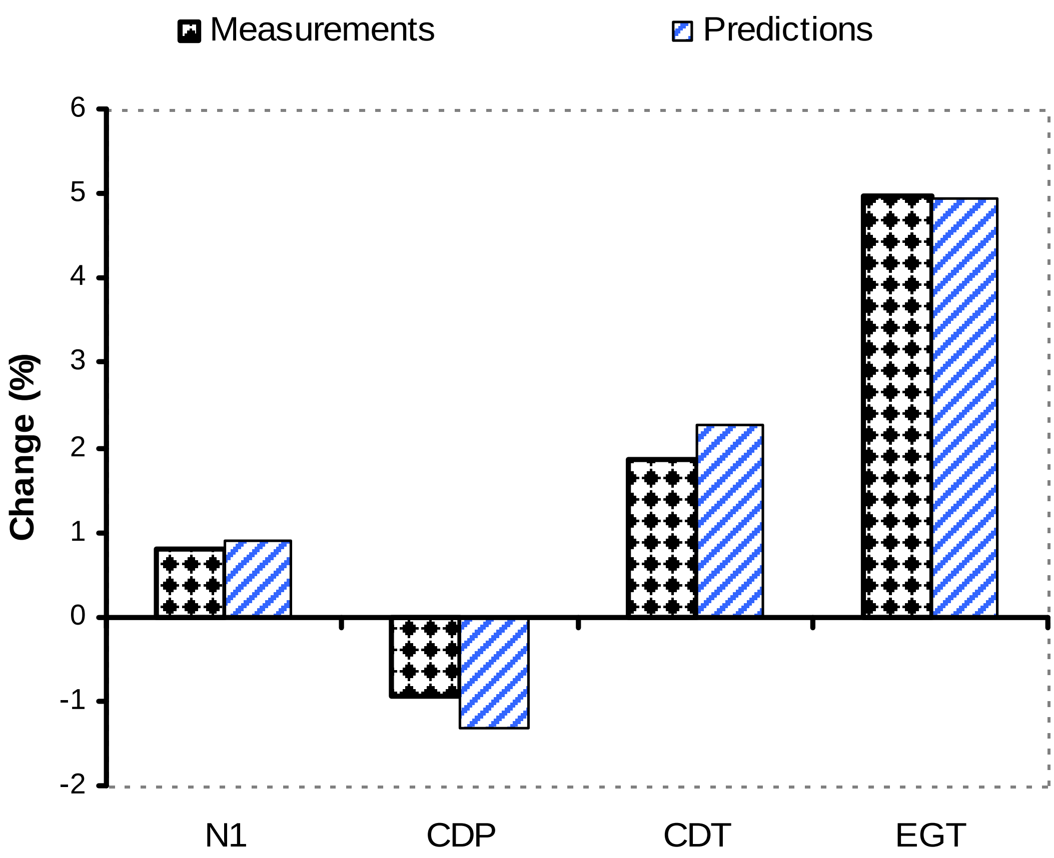
$$b = \frac{h_2 - h_1}{h_3 - h_1} \approx \frac{T_2 - T_1}{T_3 - T_1}$$

-Evaluated from ambient, compressor inlet and compressor delivery temperatures
-Applicable for a steady state condition

Direct Observation Method

Measurement Changes when anti-icing is activated.

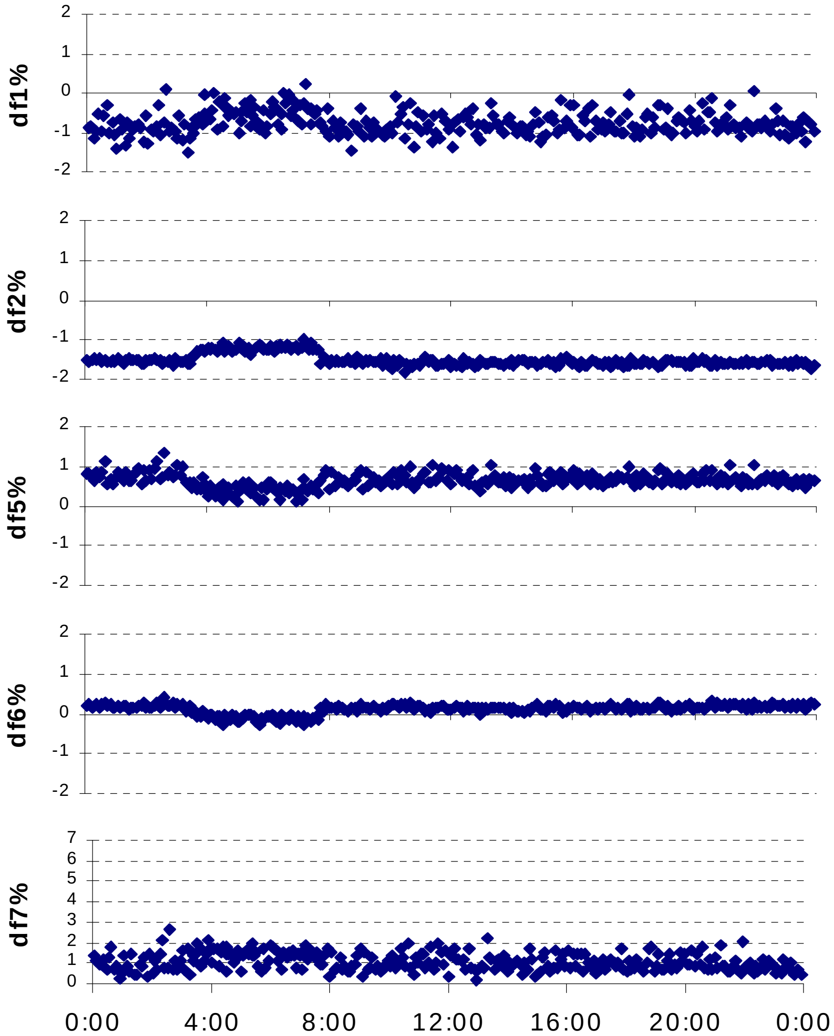
Comparison of measured to estimated values.



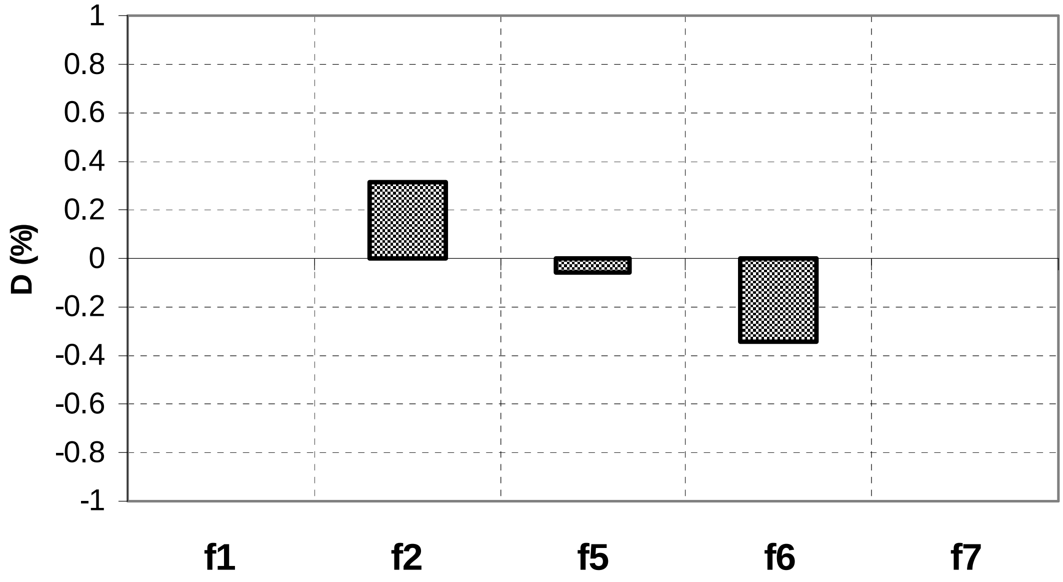
Expected changes of measured quantities can be calculated from the known amount of anti-icing bleed

Time evolution of health indices

Anti-icing bleed incorporated into model.



Signature of -1.5 ^{O}C bias on CDT reading,

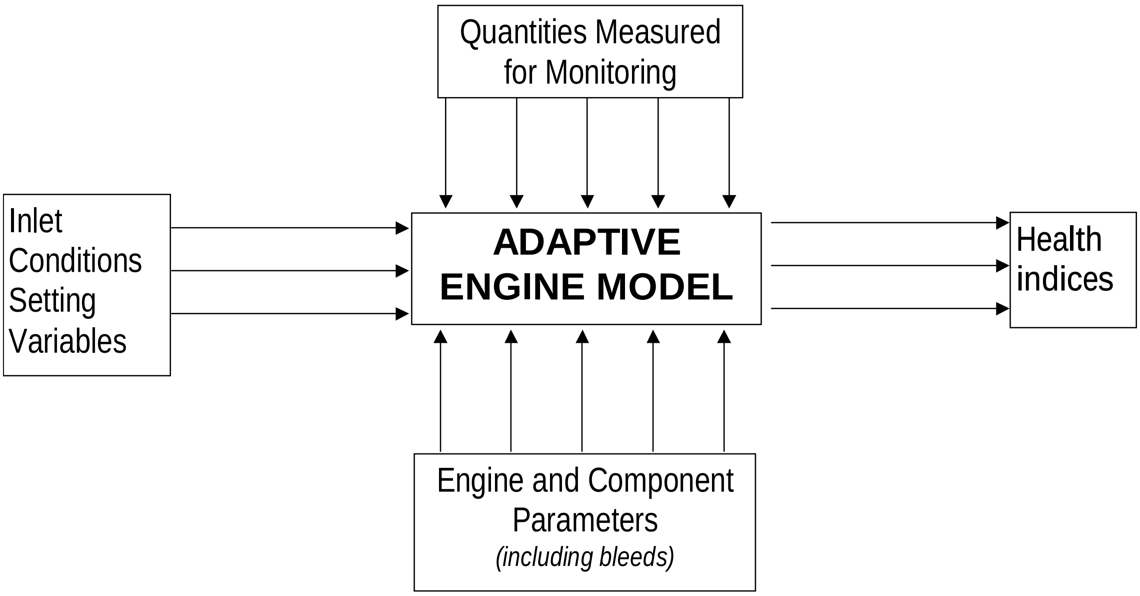


Derived by adaptive modelling the twin shaft engine

Remarks on General Applicability of Procedure

A known alteration during operation should be modeled, otherwise possible incorrect conclusions

A procedure to isolate faults in the presence of altered configuration.



- *Effect of parameters alteration separated from effect of faults..*
- *Requirement for successful implementation: correct modeling.*
- *Other types of alteration: variable customer bleeds, VGV's etc.*
- *Using an adapted engine model gives an additional advantage:*
  - *data for unmeasured quantities (e.g. TIT),*
  - *additional information on overall performance (e.g thermal efficiency)*

Summary - Conclusions

- *Effects of hot bleed anti-icing on the performance of an industrial gas turbine examined*
- *Behavior of different performance variables can be predicted using an engine performance model*
- *Influence of anti-icing operation on monitoring procedures analyzed. Uunless appropriate provisions are taken, difficulties may be introduced to the diagnosis and false alarms are possible*
- *A method to eliminate such possible shortcomings was introduced: information for altered configuration introduced into a supporting engine model*
- *Data from an industrial gas turbine, used to substantiate observations*
- *Generality of such an approach discussed. Approach useful for other types of altered configuration.*