# Performance Analysis of Industrial Gas Turbines for Engine Condition Monitoring

***By***

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# Assessing the Effects of Deposits on Turbine Blading in A Twin Shaft Gas Turbine

- Introduction
- Condition Assessment Principles
- Direct Termodynamic Analysis
- Analysis Employng Adaptive Modeling
- Implementation of Monitoring Method
- Test Cases
- Conclusions

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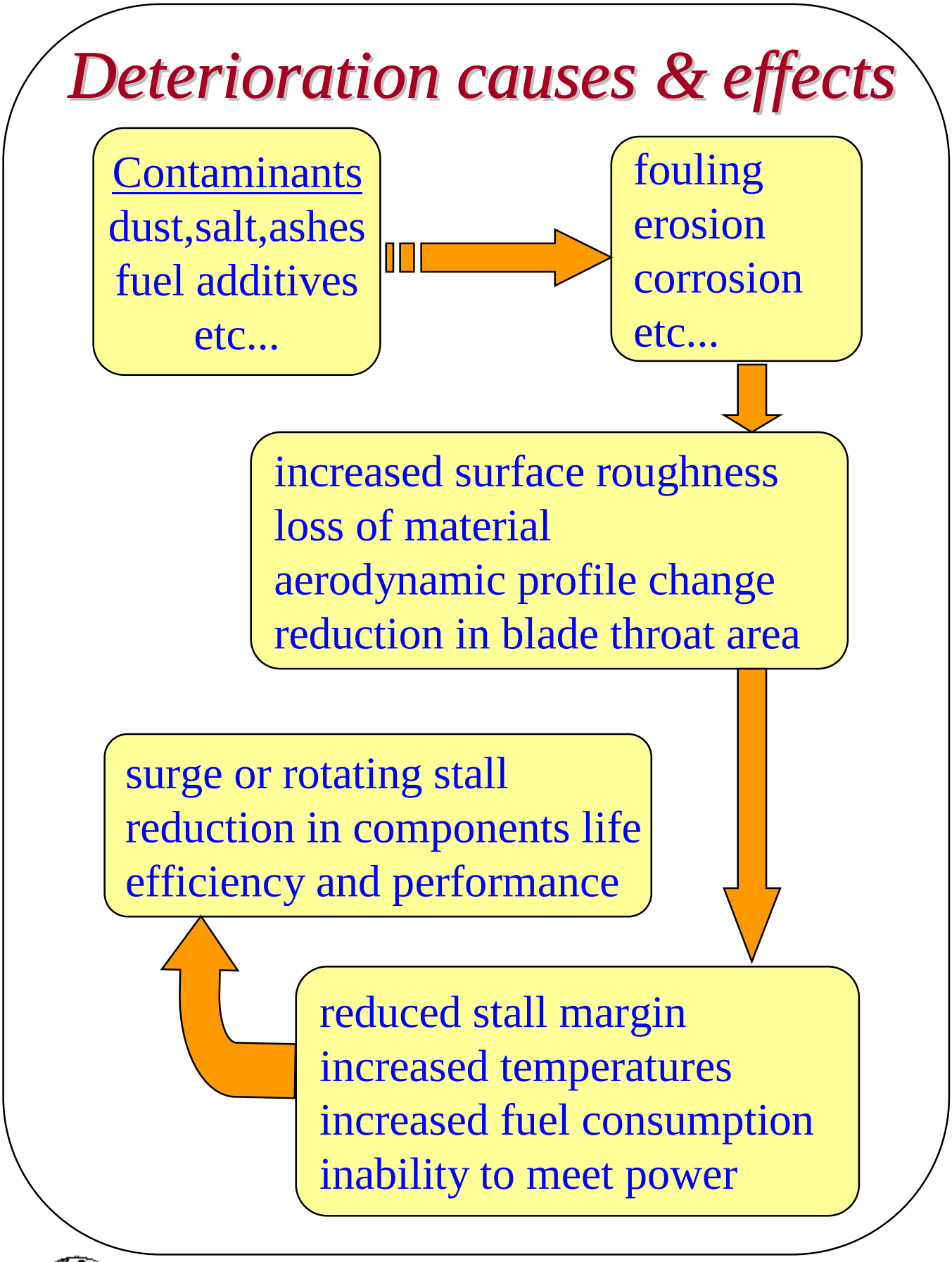
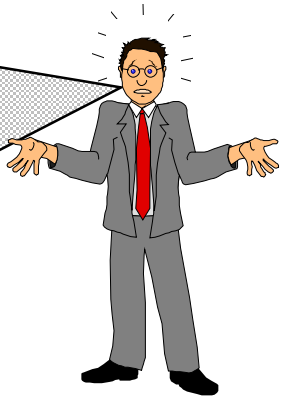
# *Deterioration causes & effects*



# *What about maintenance?*

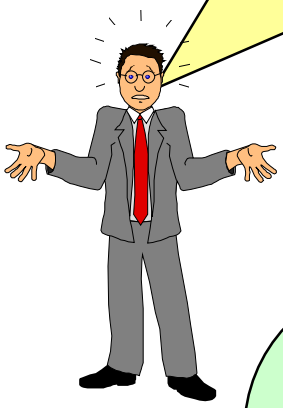
Early isolation of the root cause of problems allows the operators to better plan the corrective maintenance actions and to avoid harmful operating conditions.

For modern engines of modular construction, need to detect faults to the module level.



# *What about tools?*

Appropriate methods for fouling and/or performance deterioration detection have been proposed (for example Diakanchuk, 1991, Dundas 1992, 1993)



These methods cannot in general quantify the condition of the engine components and the contribution of each module to performance shortfall.

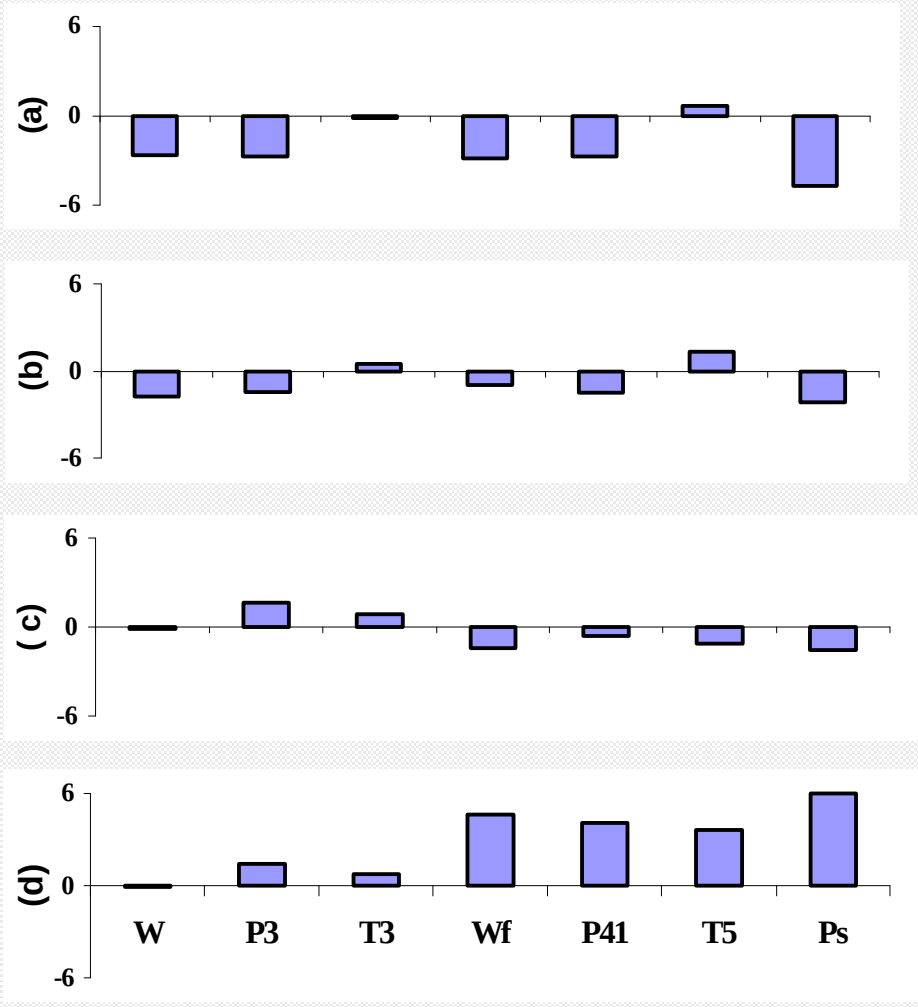
# Maintenance decision levels

- A maintenance decision is usually taken in two levels:
  - (a) **Fault Detection**. must be judged whether the machine is healthy or not
  - (b) **Fault Identification**: specifies fault location, kind and severity.

- Engine manufacturers normally provide users with performance specifications for a nominal engine.
- As engines deteriorate or are subjected to specific faults operator has no capability of identifying the cause of the problem

**Condition Monitoring and Diagnostics** : *use measurements to infer the present and future status of the engine and its components in order to help maintenance decision making.*

| | $W_a$ | $p_3$ | $T_3$ | $W_f$ | $p_{41}$ | $T_5$ | $P_S$ |
|---|---|---|---|---|---|---|---|
| (a) Mistuned IGVs | – | – | ≈ | – | – | - | – |
| (b) Compressor Fouling | – | – | - | – | – | - | – |
| (c) Compressor-Turbine Fou | ≈ | - | - | – | – | – | – |
| (d) Power Turbine Fouling | ≈ | - | - | - | - | - | - |



# Adaptive Performance Model

## Modification factor definition

$$f = \frac{X_{act}}{X_{ref}}$$

$X_{ref}$ parameter value on the reference map

$X_{act}$ parameter value on the actual "on engine" map

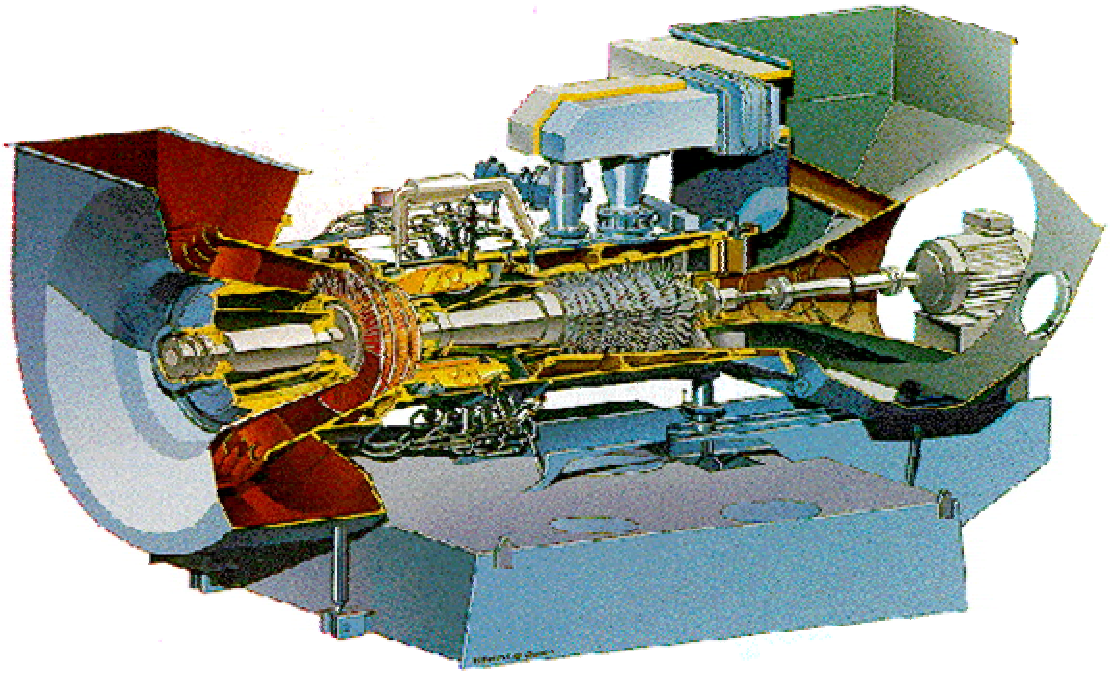
***Define*** full set of factors for all engine components

***Calculate*** factors by solving an optimization problem

***Target**: measured quantities on the engine are identical to the corresponding calculated ones*

# The Case of a malfunctioning Industrial Gas Turbine

## A twin shaft gas turbine (ABB GT10)



The engine was installed and its first runs were performed on June 96.
During efficiency testing, (November 96) an **increased EGT** was observed.

Analysis of the data was made at two levels :

- "common sense" thermodynamic analysis
- adaptive performance modelling

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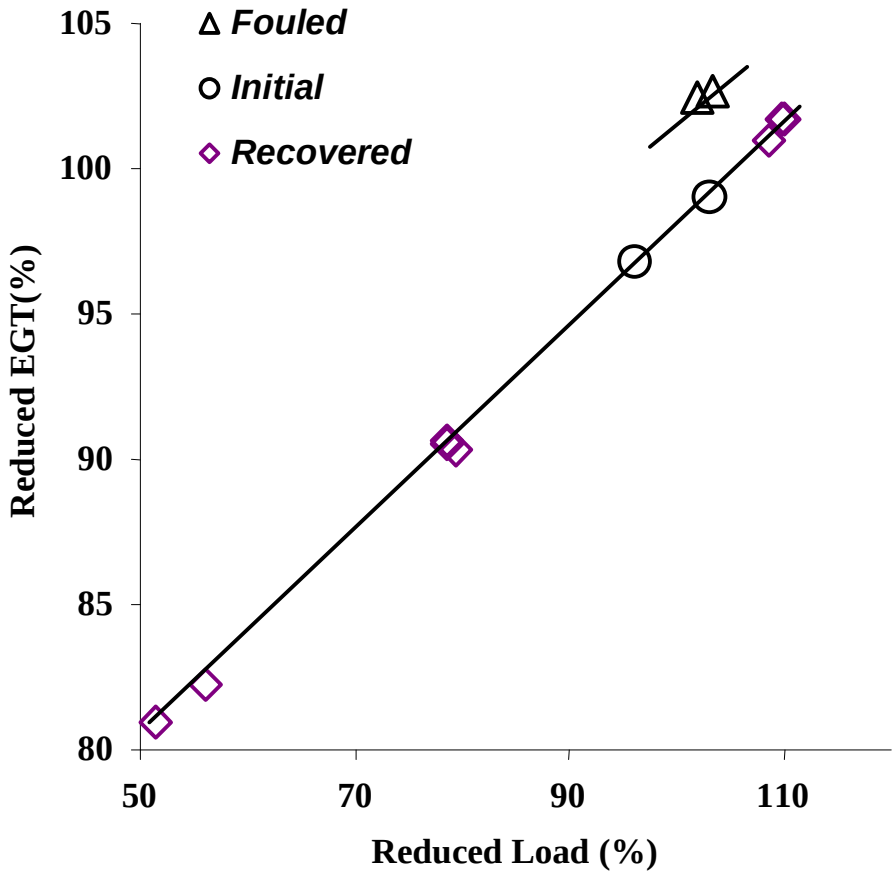
# Diagnosing the problem

## ISO Analysis

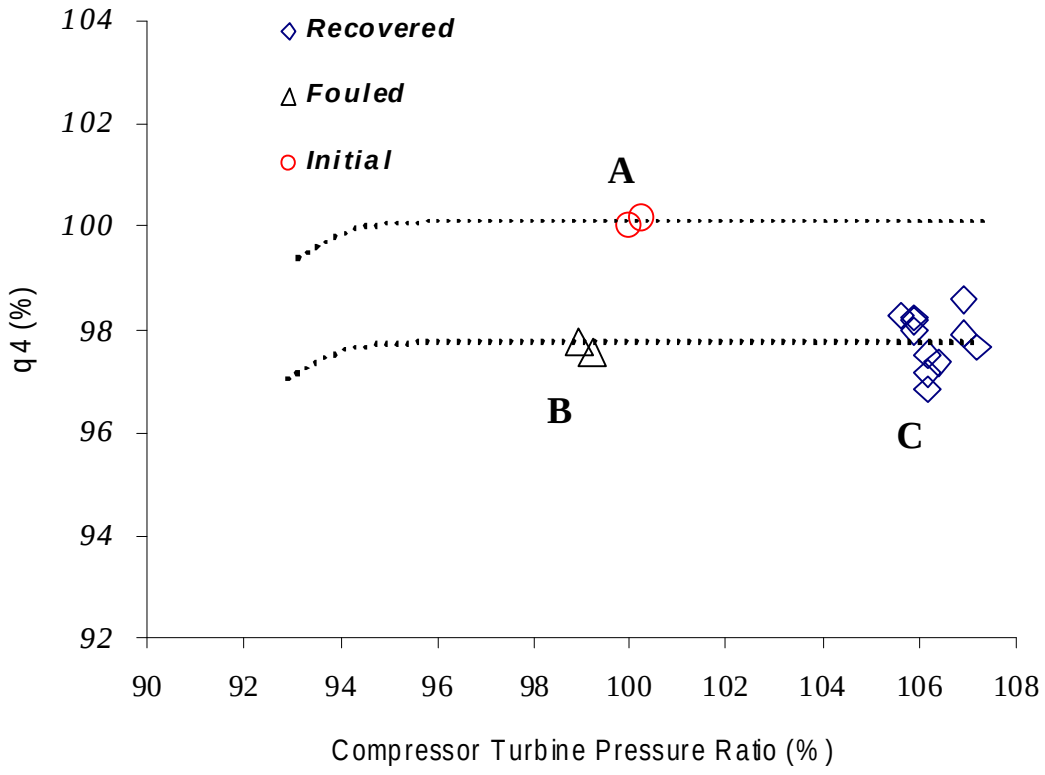
*The guidelines of ISO 2314 correction and calculation procedures were applied*

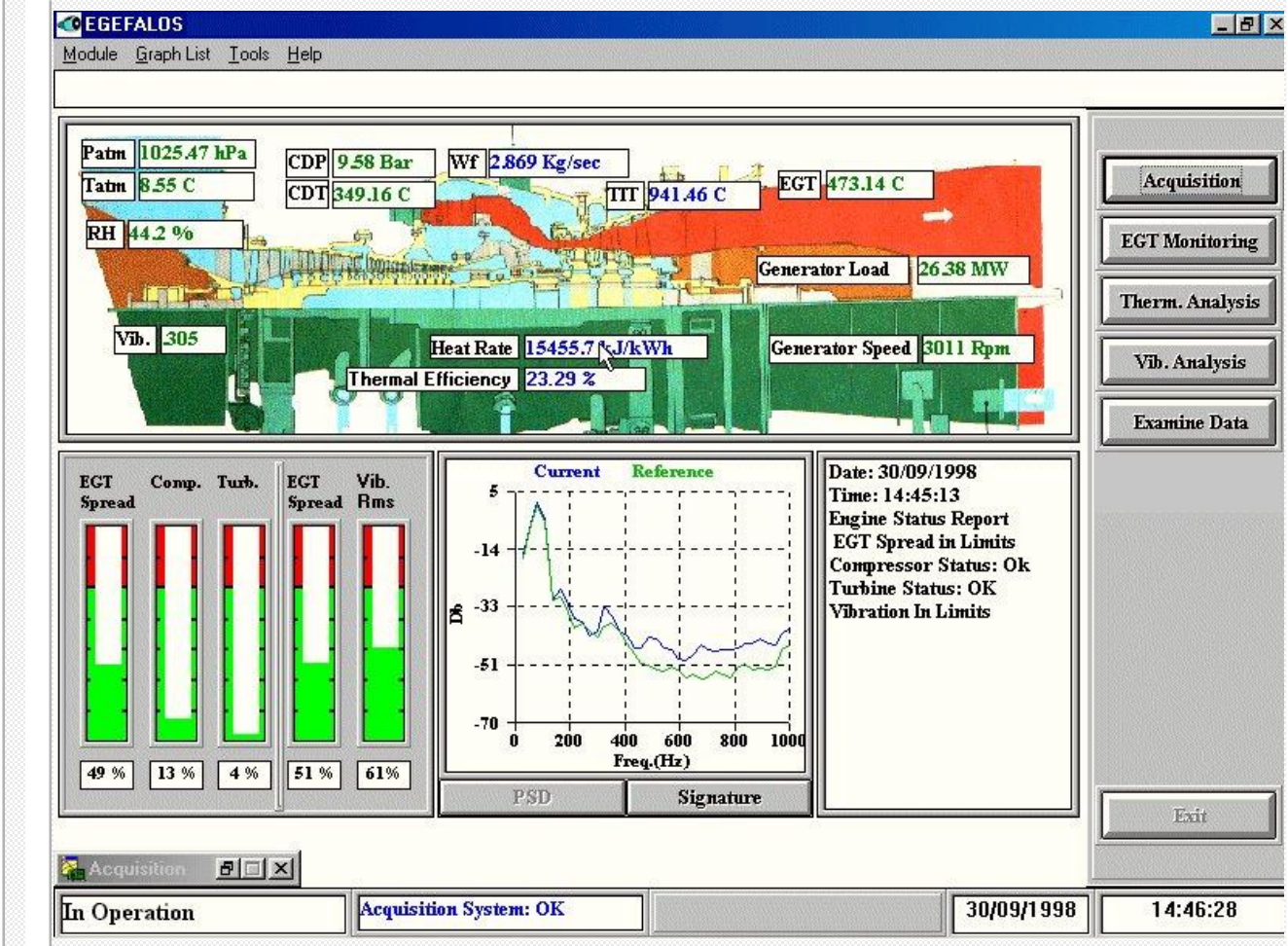


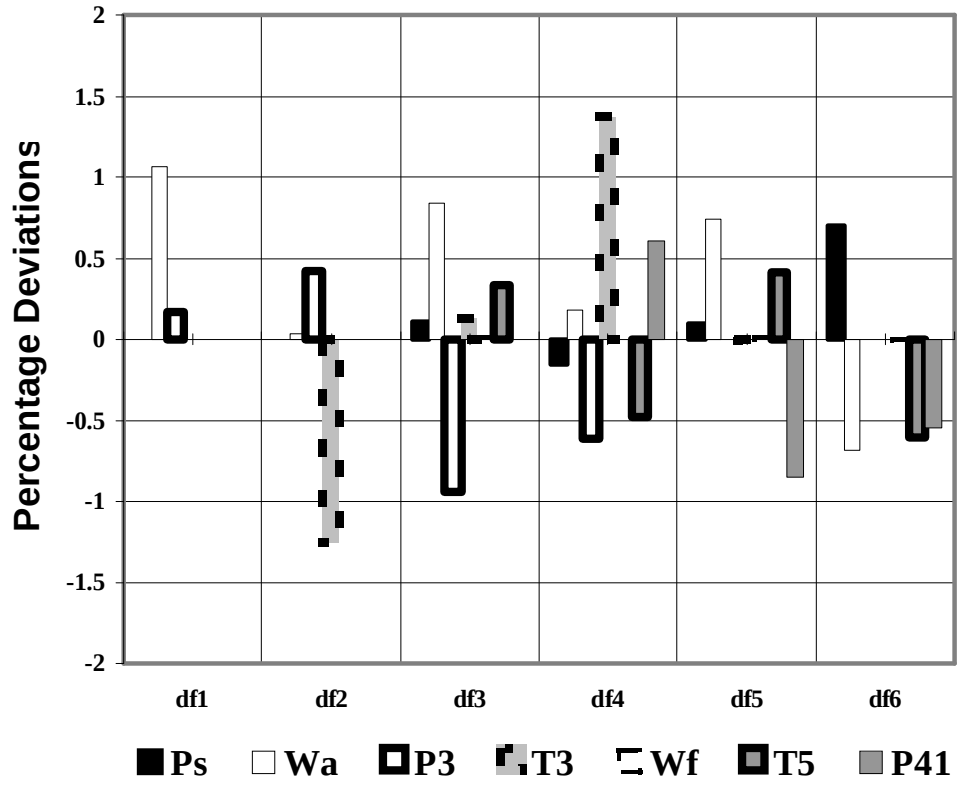

Corrected EGT vs Corrected Load (Before and after intervention)

# Diagnosing the problem

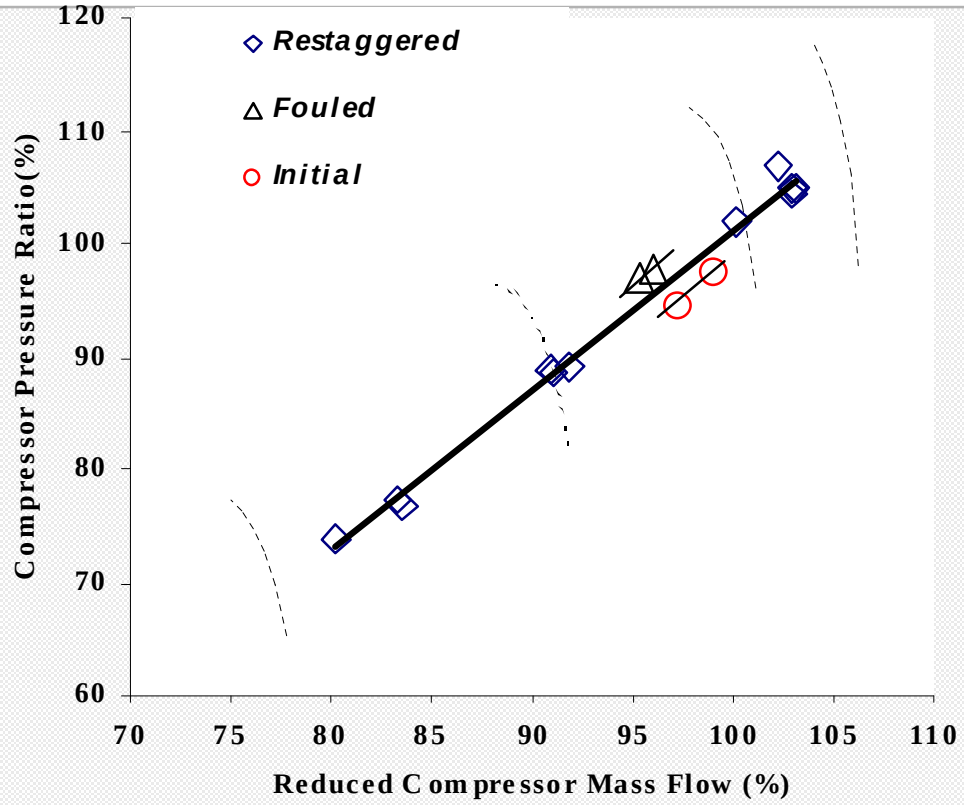
## ISO Analysis



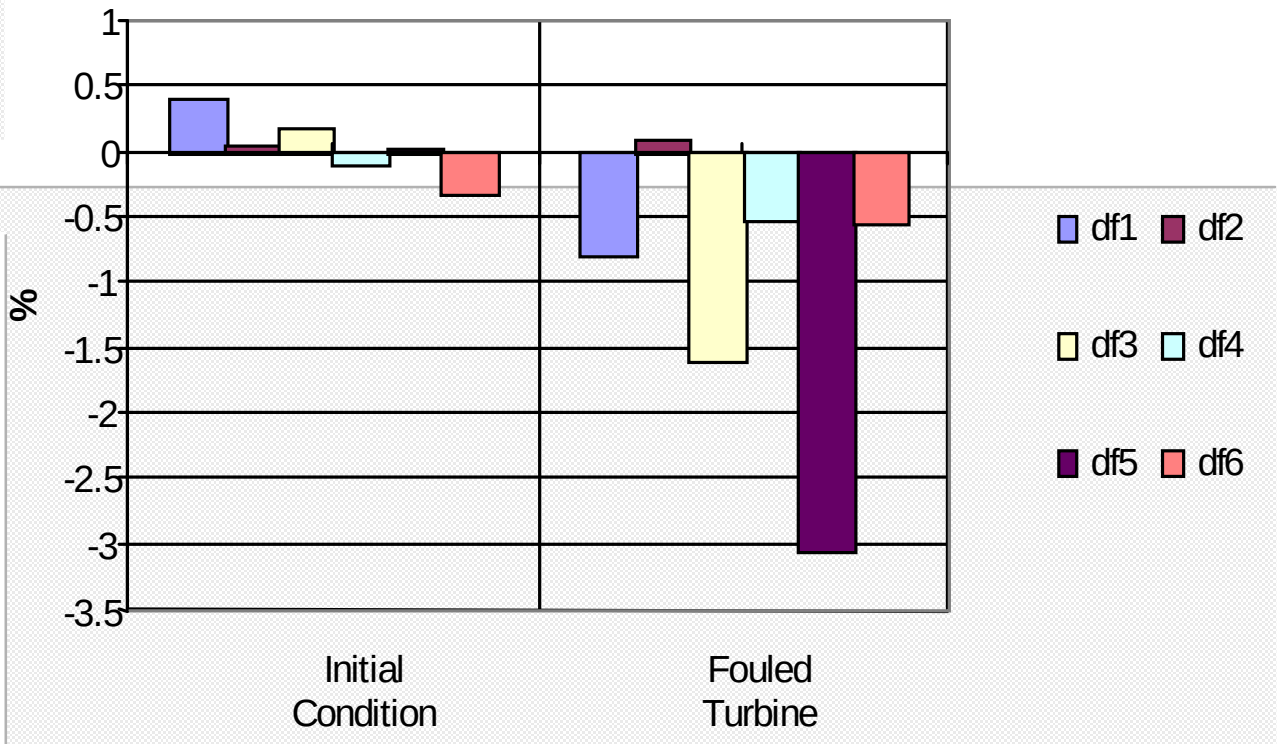

EGEFALOS
Module
Graph List
Tools
Help
Patm 1025.47 hPa
Tatm 8.55 C
RH 44.2 %
CDP 9.58 Bar
CDT 349.16 C
Wf 2.869 Kg/sec
ITT 941.46 C
EGT 473.14 C
Generator Load 26.38 MW
Vib. .305
Heat Rate 15455.7 kJ/kWh
Thermal Efficiency 23.29 %
Generator Speed 3011 Rpm
Acquisition
EGT Monitoring
Therm. Analysis
Vib. Analysis
Examine Data
EGT Spread
Comp.
Turb.
EGT Spread
Vib. Rms
49 %
13 %
4 %
51 %
61%
Current
Reference
Db
5
-14
-33
-51
-70
0
200
400
600
800
1000
Freq.(Hz)
PSD
Signature
Date: 30/09/1998
Time: 14:45:13
Engine Status Report
EGT Spread in Limits
Compressor Status: Ok
Turbine Status: OK
Vibration In Limits
Exit
Acquisition
In Operation
Acquisition System: OK
30/09/1998
14:46:28



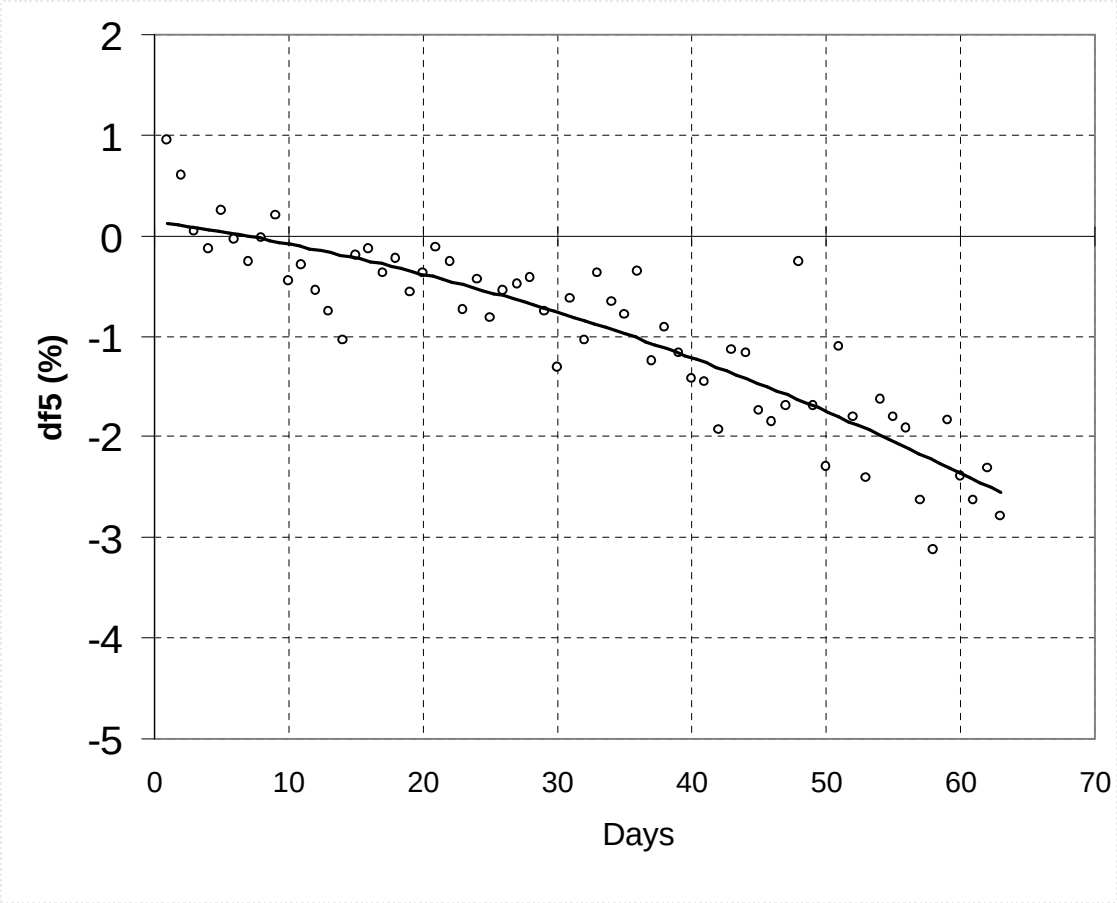

Deviations of measured quantities for 1% reduction of each individual modification factor.



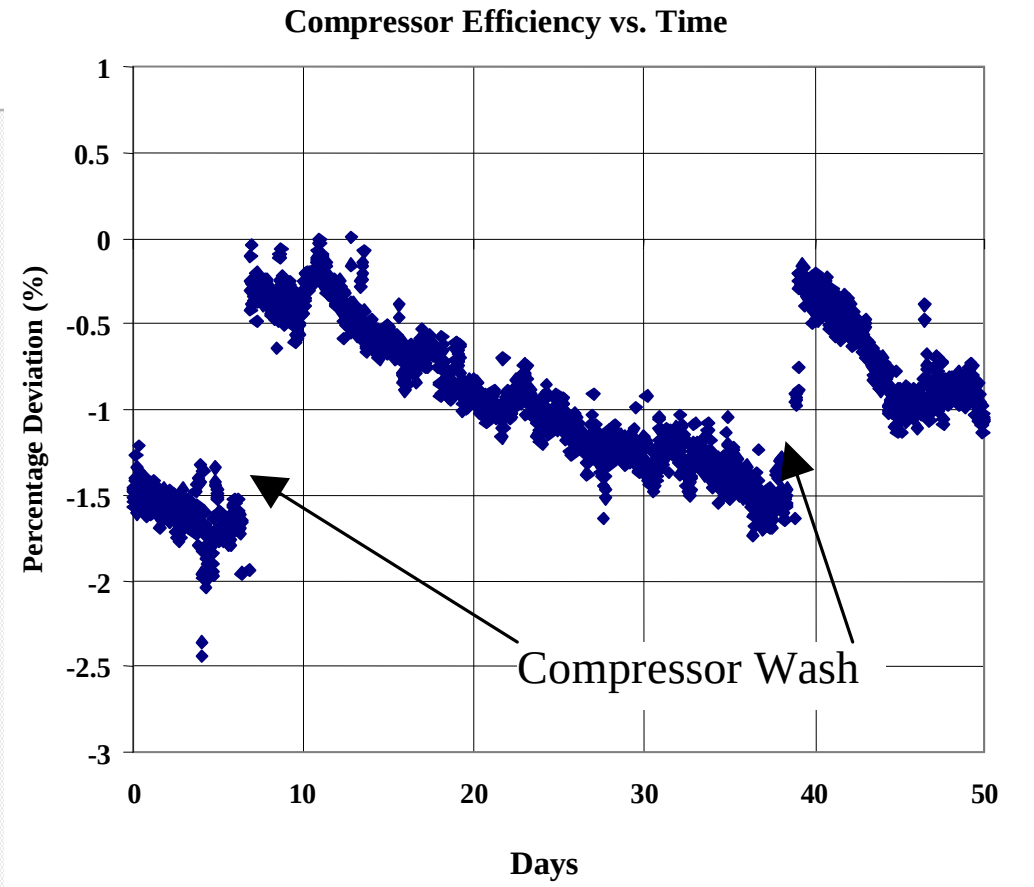

Compressor Map Operating Points for different “health” conditions of the twin shaft gas turbine.




Health Indices Percentage deviation, for a gas turbine, which has suffered severe turbine fouling, caused by fuel additives.




Evolution of power turbine degradation over the initial period of engine operation


Compressor Efficiency vs. Time
Percentage Deviation (%)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
0
10
20
30
40
50
Days
Compressor Wash

# Diagnosing the problem

## Setup of the engine adaptive model

### Compressor:

$$f_1 = \frac{q_C}{q_{C\,ref}} \qquad f_2 = \frac{n_{P_C}}{n_{P_C\,ref}}$$

### Core Turbine:

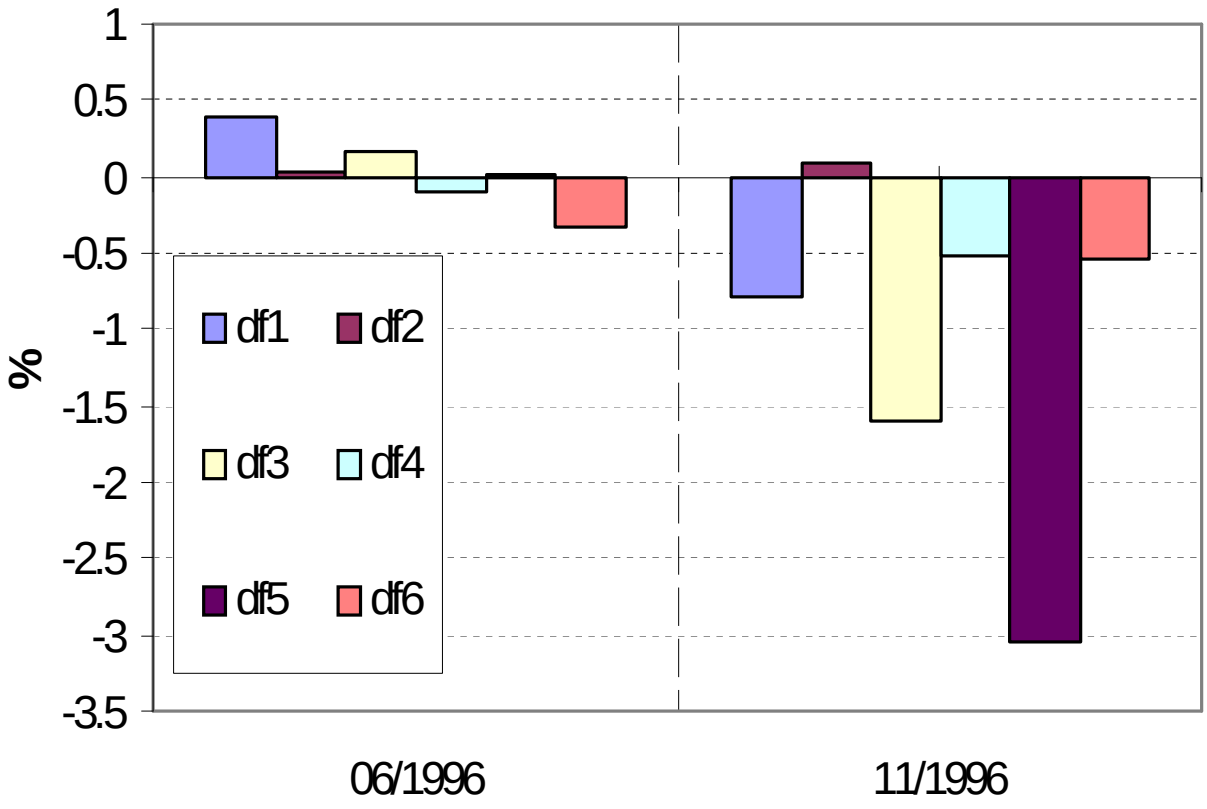
$$f_3 = \frac{q_{CT}}{q_{CT\,ref}} \qquad f_4 = \frac{n_{is_{CT}}}{n_{is_{CT\,ref}}}$$

### Power Turbine:

$$f_5 = \frac{q_{PT}}{q_{PT\,ref}} \qquad f_6 = \frac{n_{is_{PT}}}{n_{is_{PT\,ref}}}$$

# Diagnosing the problem

## Adaptive Modeling Results



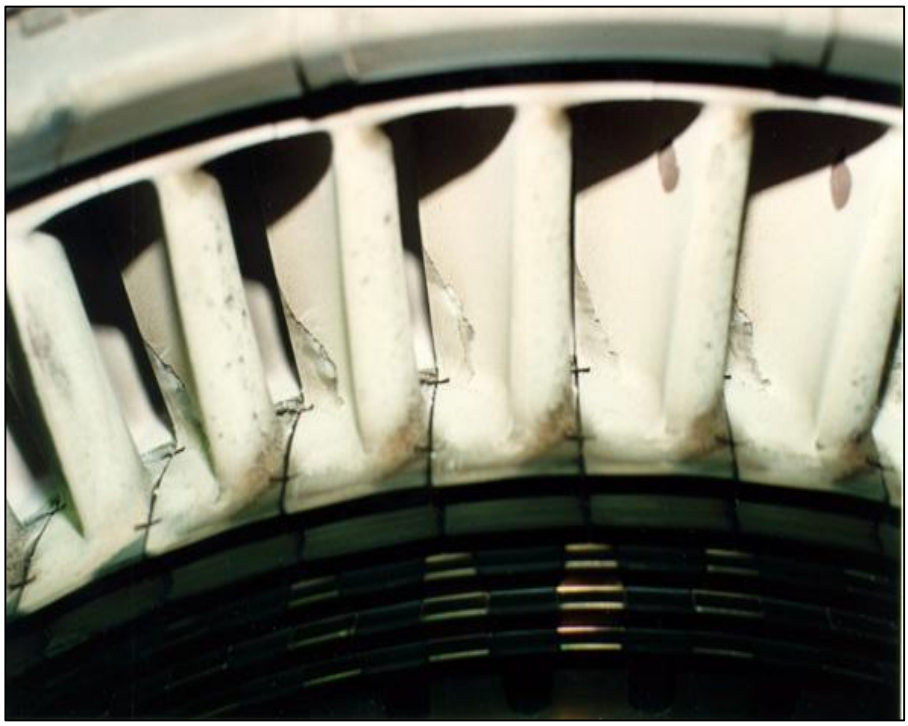

**Health Indices Percentage Deviation.**

*first period of operation* :deviations of small magnitude, within the uncertainty limits

*performance test* : evidence of an increased responsibility of the hot section for the existing deterioration

# Diagnosing the problem

## Inspection Results

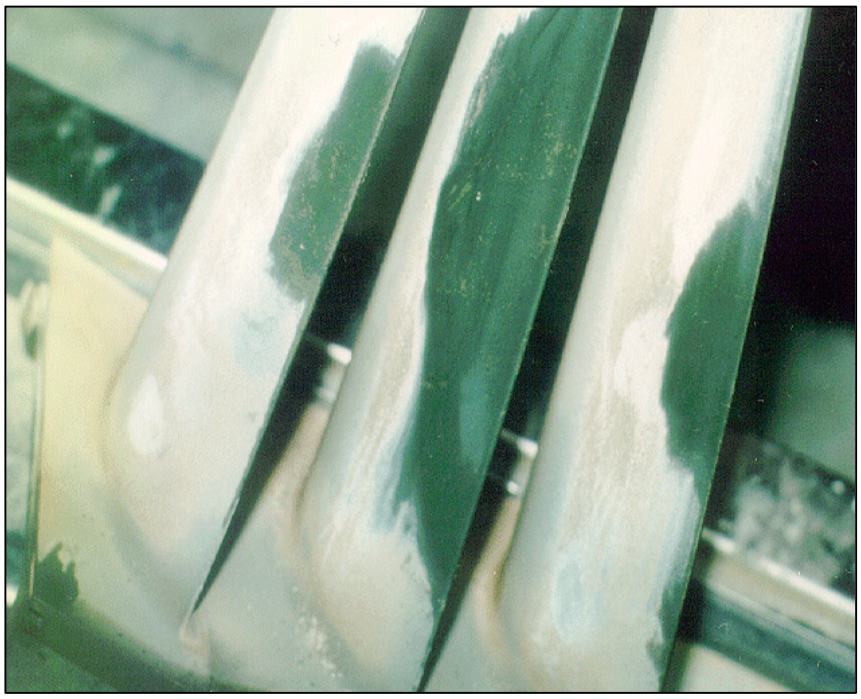


Compressor Turbine 1st rotor blades.

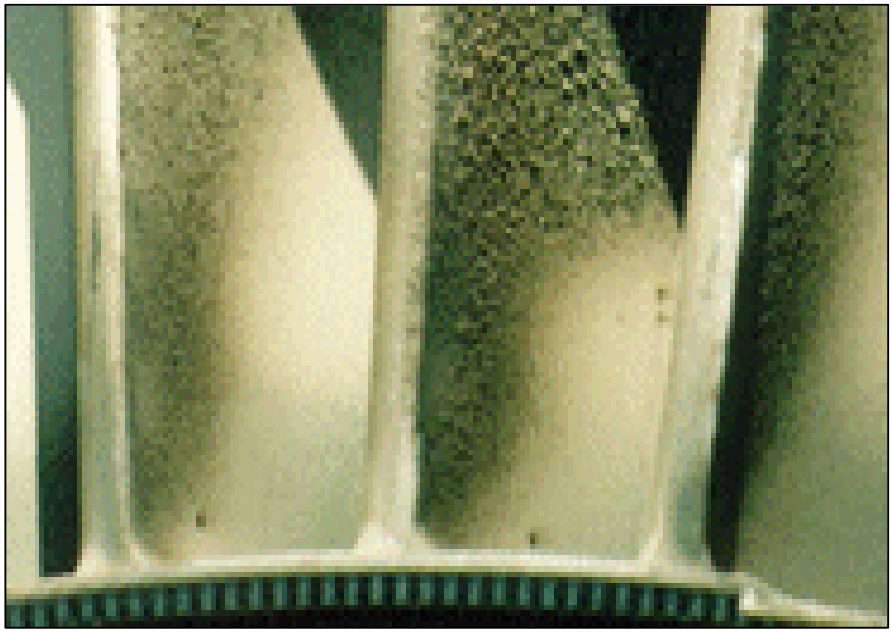
Compressor Turbine 1st Stator vanes.
Suction side view.

# Diagnosing the problem

## Inspection Results



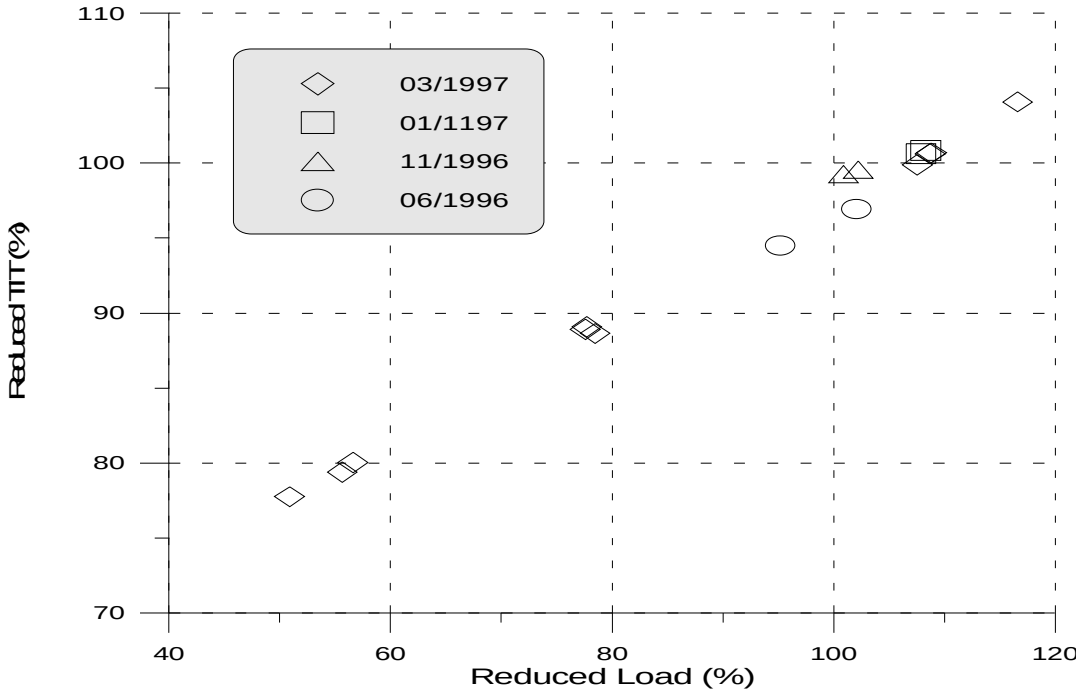
Power Turbine 2nd Stator vanes detail.



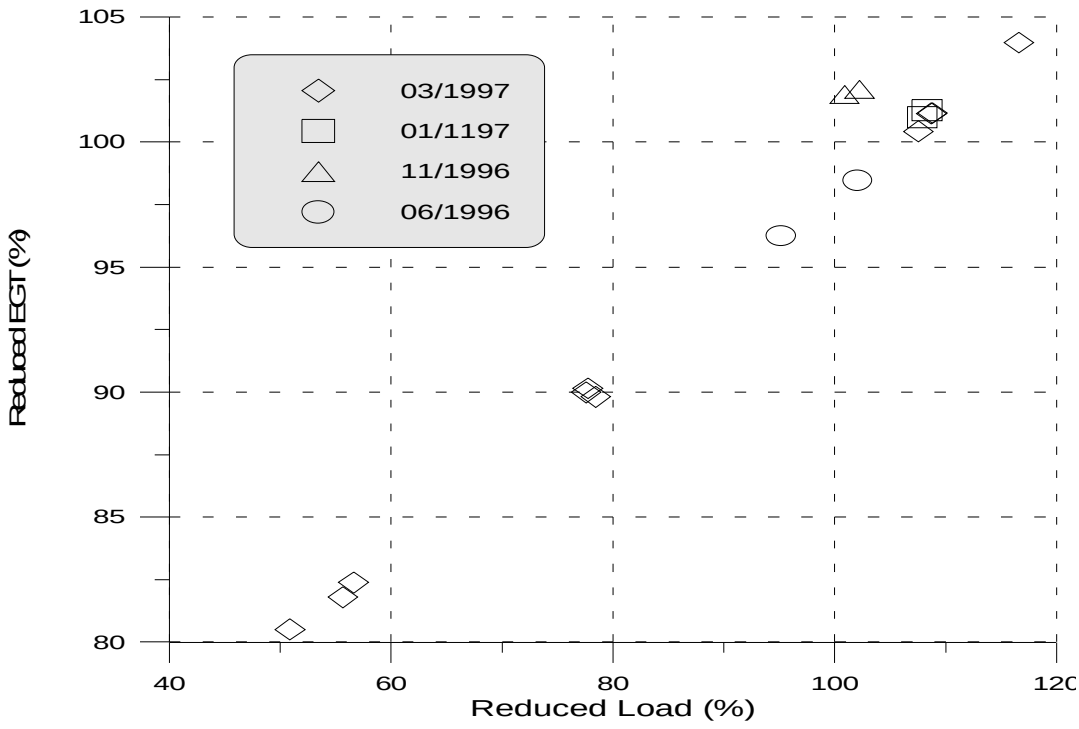
Power Turbine 2nd Stator vanes.
Leading edge Suction side view.

# Verification of Performance Recovery

## ISO Analysis (Before and after intervention)




**Turbine Inlet Temperature vs Corrected Load**




**Corrected EGT vs Corrected Load**

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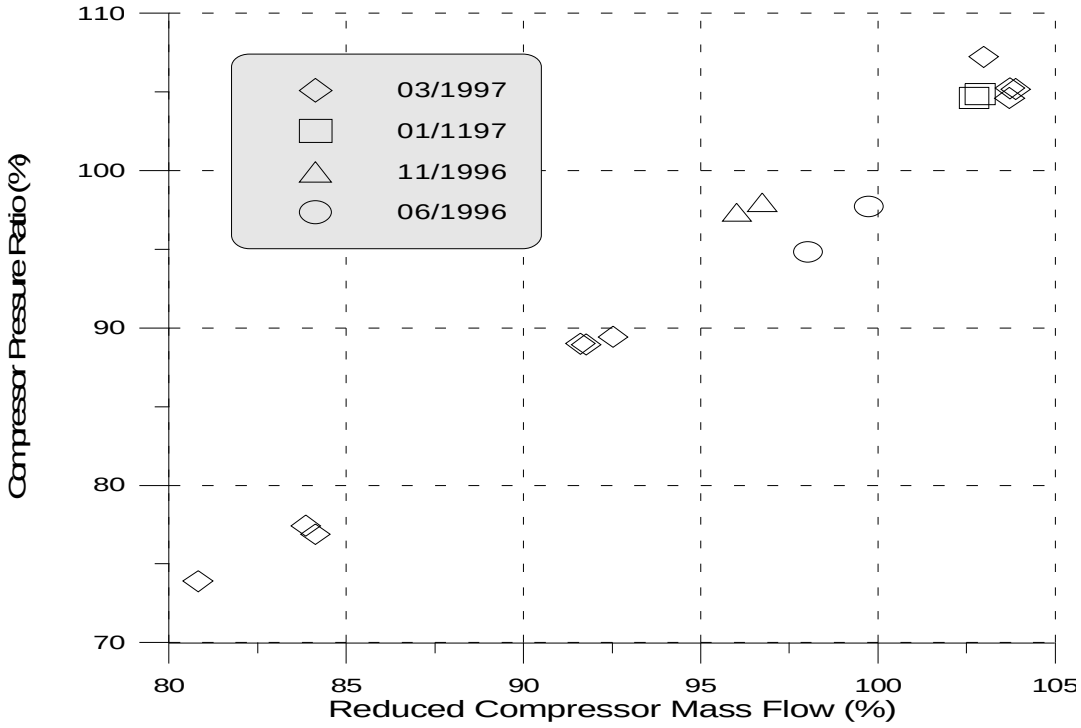
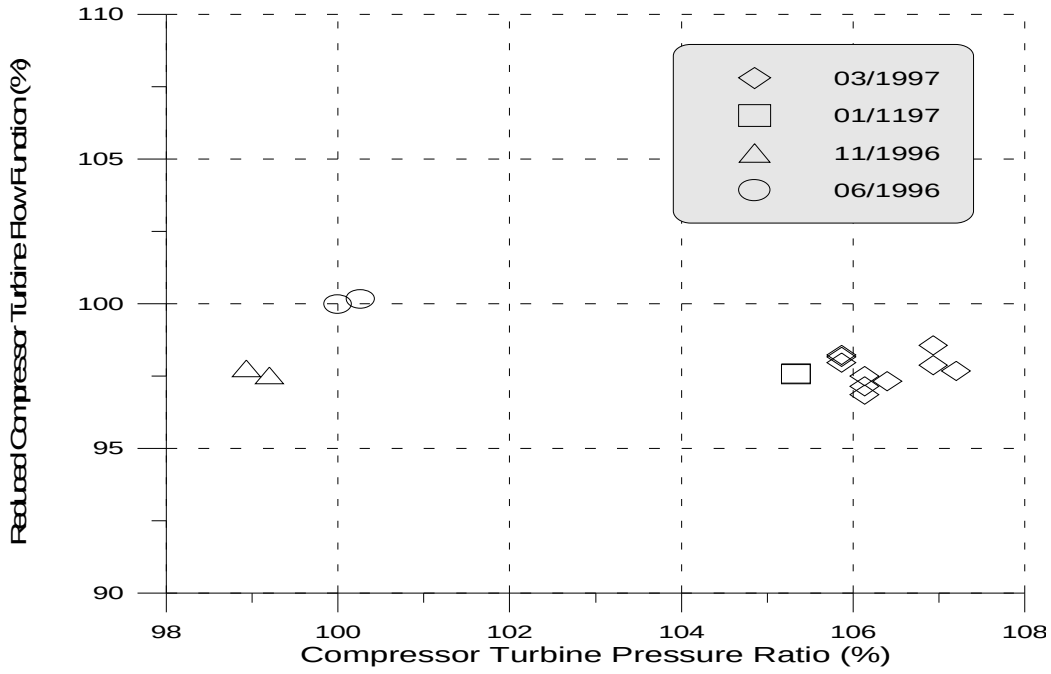
# Verification of Performance Recovery

## ISO Analysis (Before and after intervention)




**Compressor Map Operating Points.**




**Compressor Turbine Operating Points.**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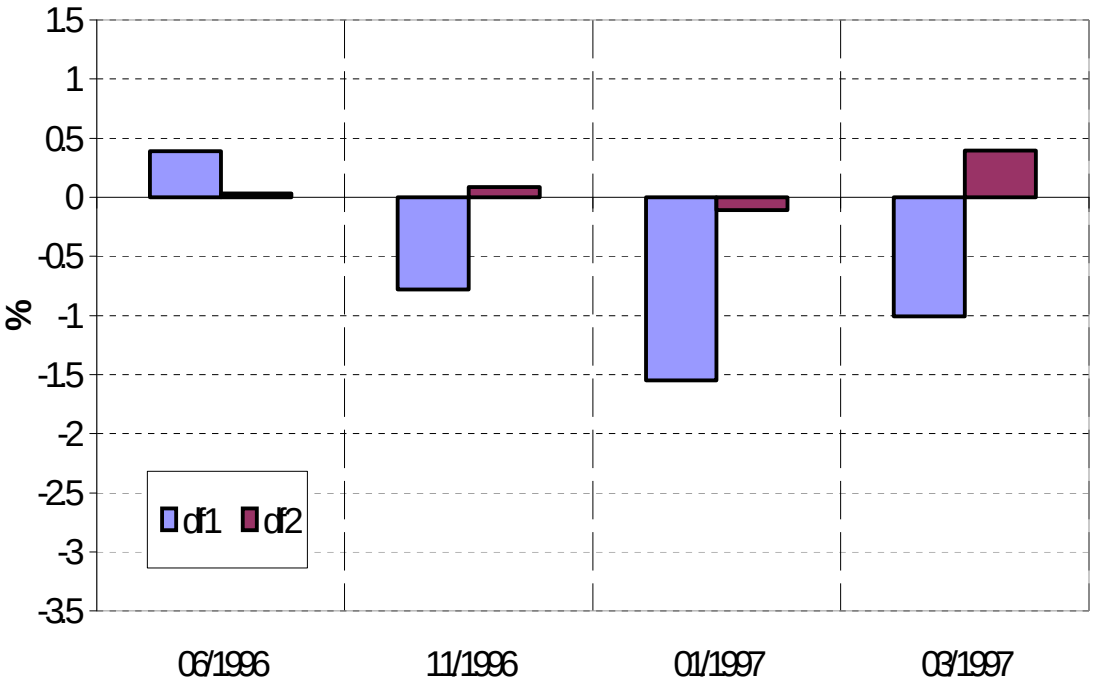
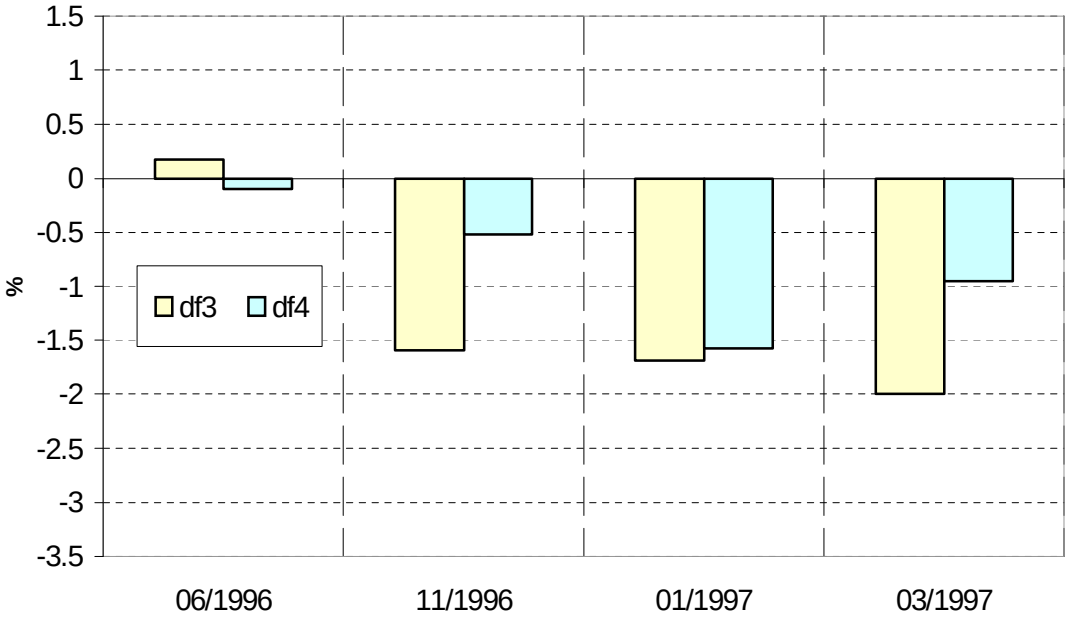
# Verification of Performance Recovery

## Adaptive Modeling Results




**Compressor Health Indices Deviation.**




**Compressor Turbine Health Indices Deviation.**

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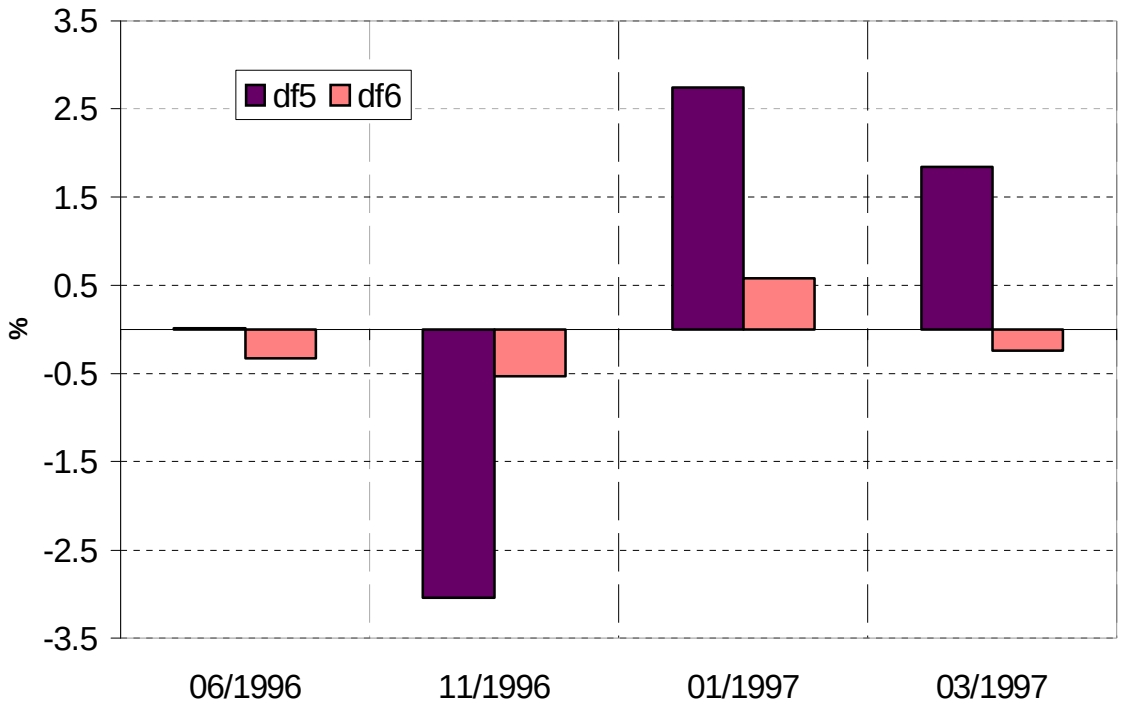
# Verification of Performance Recovery

## Adaptive Modeling Results




**Power Turbine Health Indices Deviation.**

Flow capacity has clearly increased as a result of the re-staggering, while efficiency has been insignificantly influenced

In addition to the diagnostic ability,ability to verify the condition of the components after an intervention for modifications.

# Conclusions

Procedures for characterizing the condition of gas turbines have been presented.

An industrial gas turbine, which exhibited some problems in the hot section, was employed as a test vehicle.

Standard thermodynamic analysis can point out some aspects of malfunction

however

***only the application of a component level diagnostic technique can provide detailed insight about the condition of the engine components.***

Using information available to the user, it is possible ***to predict the effects of geometry changes to its performance, with a good accuracy.***