GAS TURBINE DEGRADATION, CONDITION MONITORING & GAS PATH DIAGNOSTICS

Presented by

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Gas Turbine Performance Degradation

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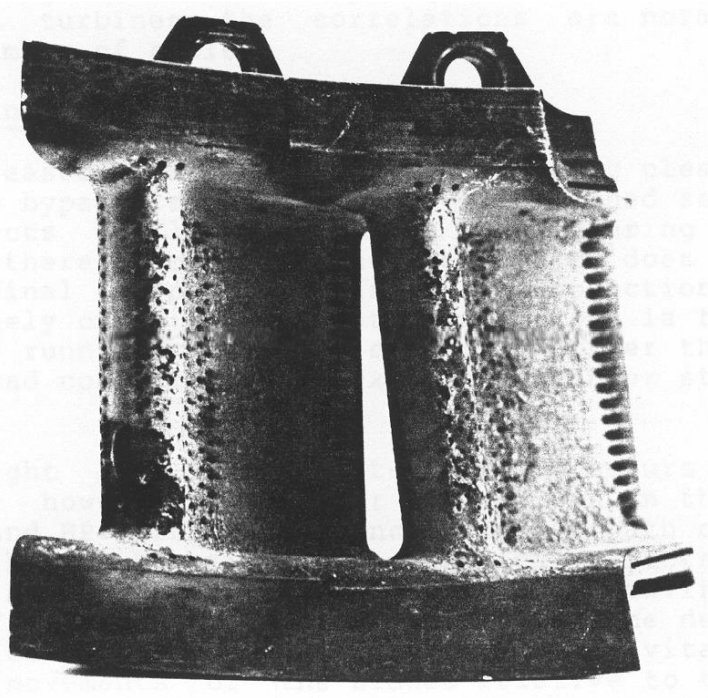
Fouling

Compressor Fouling (deposition)

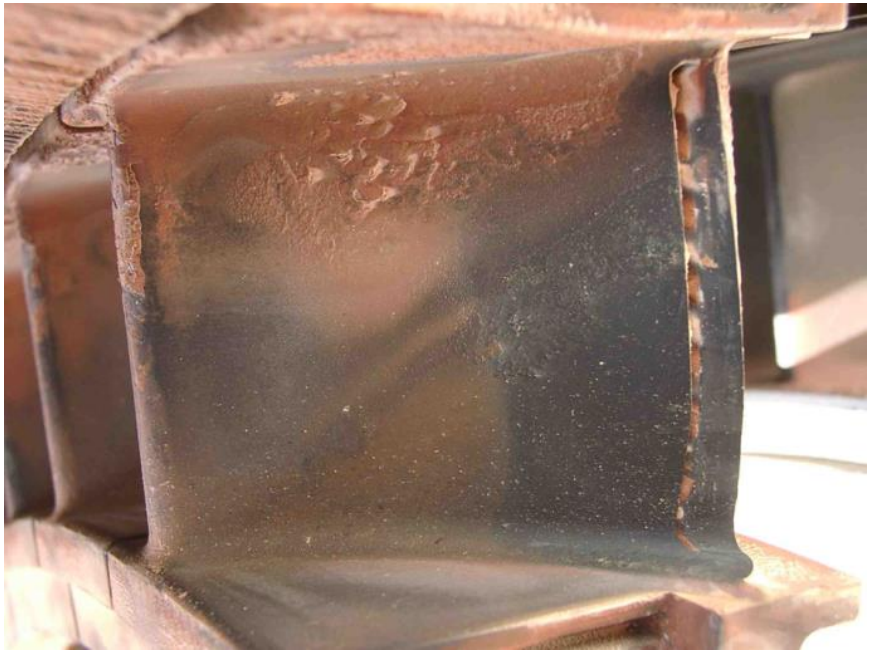
Common particles & size in atmosphere

Particles	Size (μm)
Sand	20 - 2000
Ground dust	1 - 300
Oil smokes (oil and gas plants)	0.02 - 1
Salt particles – in mist/on spray	<10 / >10
Insects Swarms	>1000
Pollens	10 - 100

- Frame 9 (ISO airflow of 650 kg/s) would ingest, in a year of operation at 10ppm foulant loading rate, 225 tons of foulant per year.
- Around 70% performance loss for industrial gas turbines could be contributed by fouling

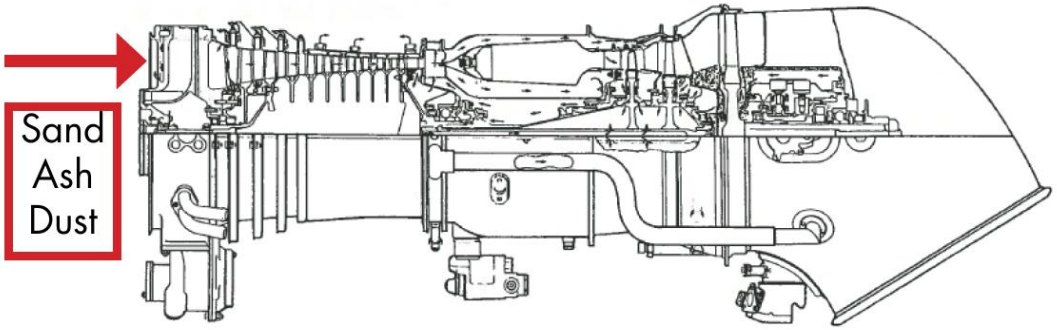


(Saravanamuttoo, 1985)

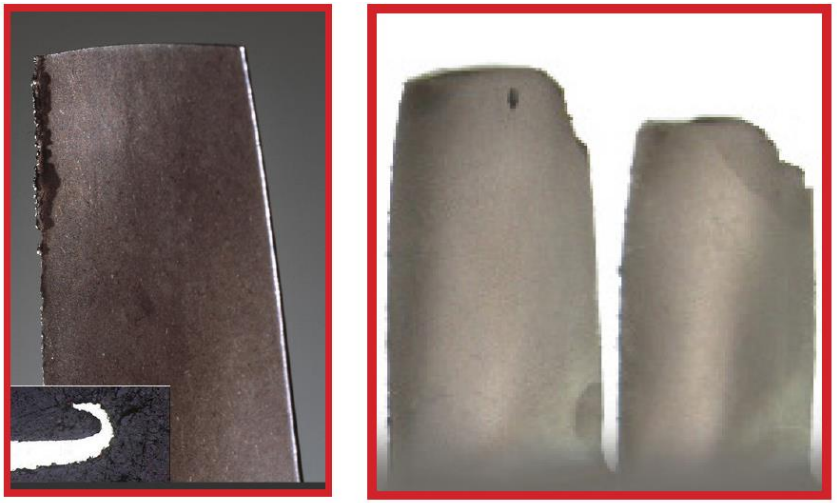


Turbine Fouling (deposition)

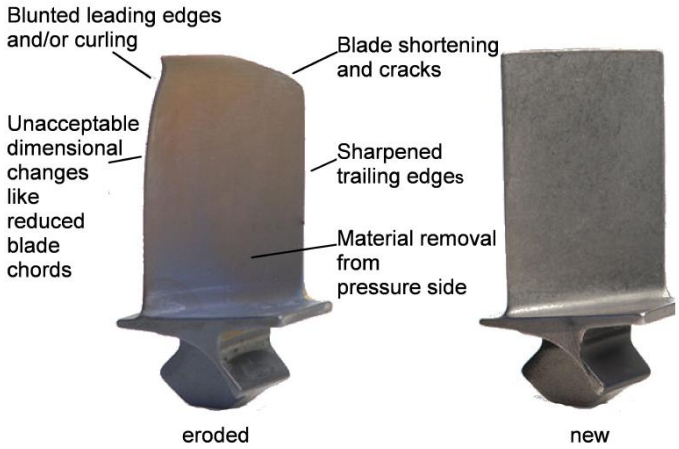
Erosion



(www.Heli-One.com)



LE CURL EXAMPLE AND CT58 BLADES WITH EROSION

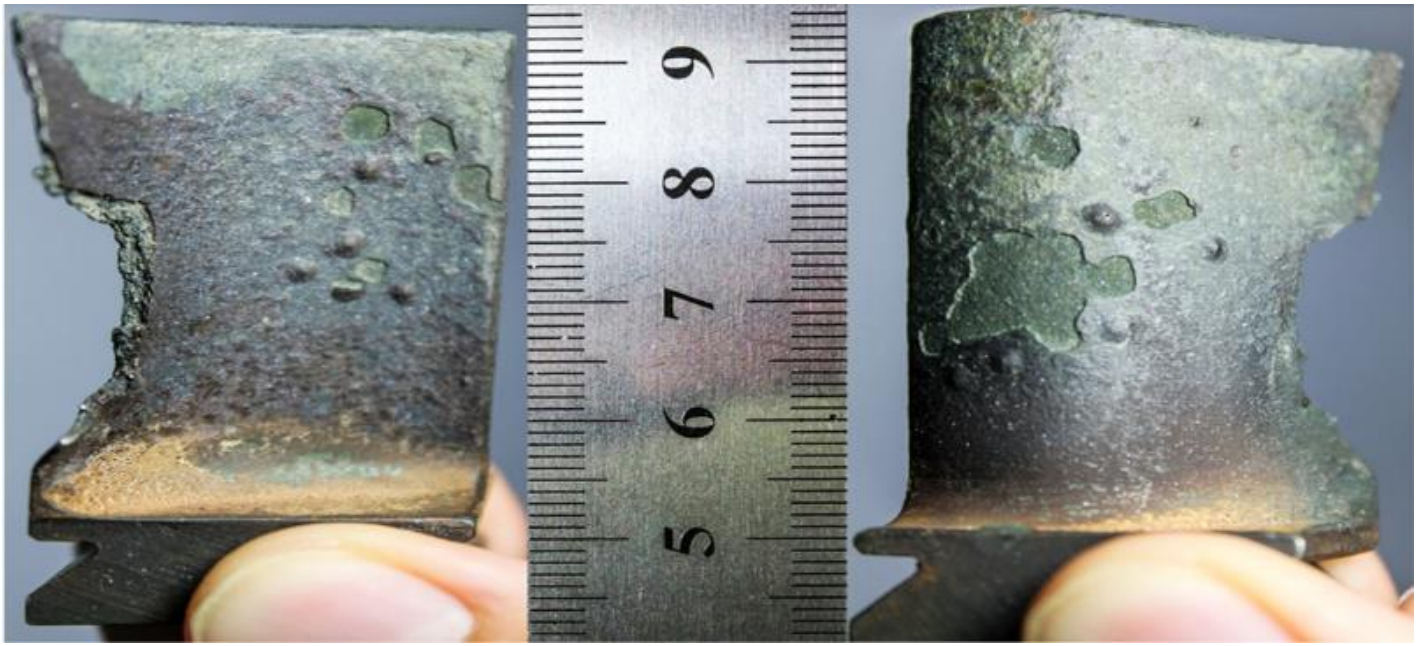


(Schrade & Staudacher, 2014)

RAF Puma Helicopter in Sahara Desert Morocco

Erosion Damage

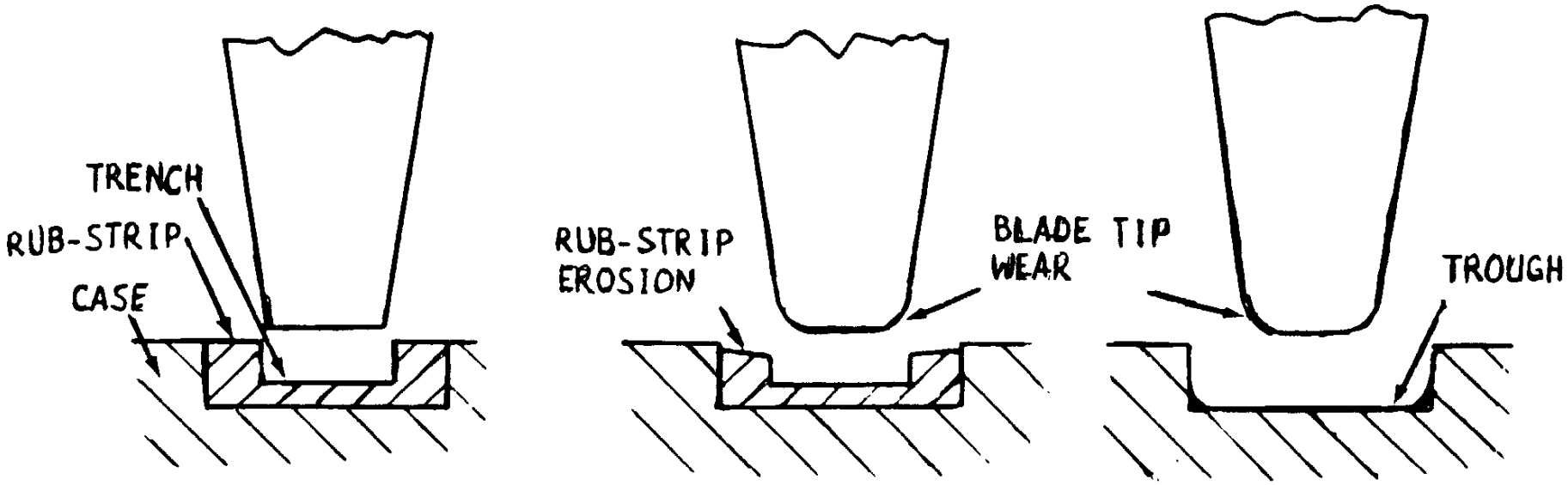
Corrosion



Sulphuric Corrosive Damage

Salehnasab B., Poursaeidi E., Mortazavi SA., Farokhian GH. Hot corrosion failure in the first stage nozzle of a gas turbine engine. EFA. Elsevier Inc.; 2016;

Tip Clearance Damage

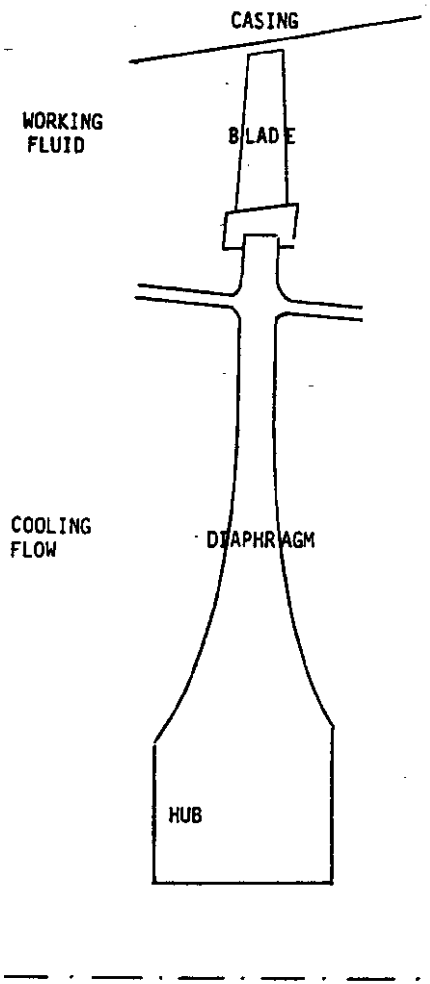


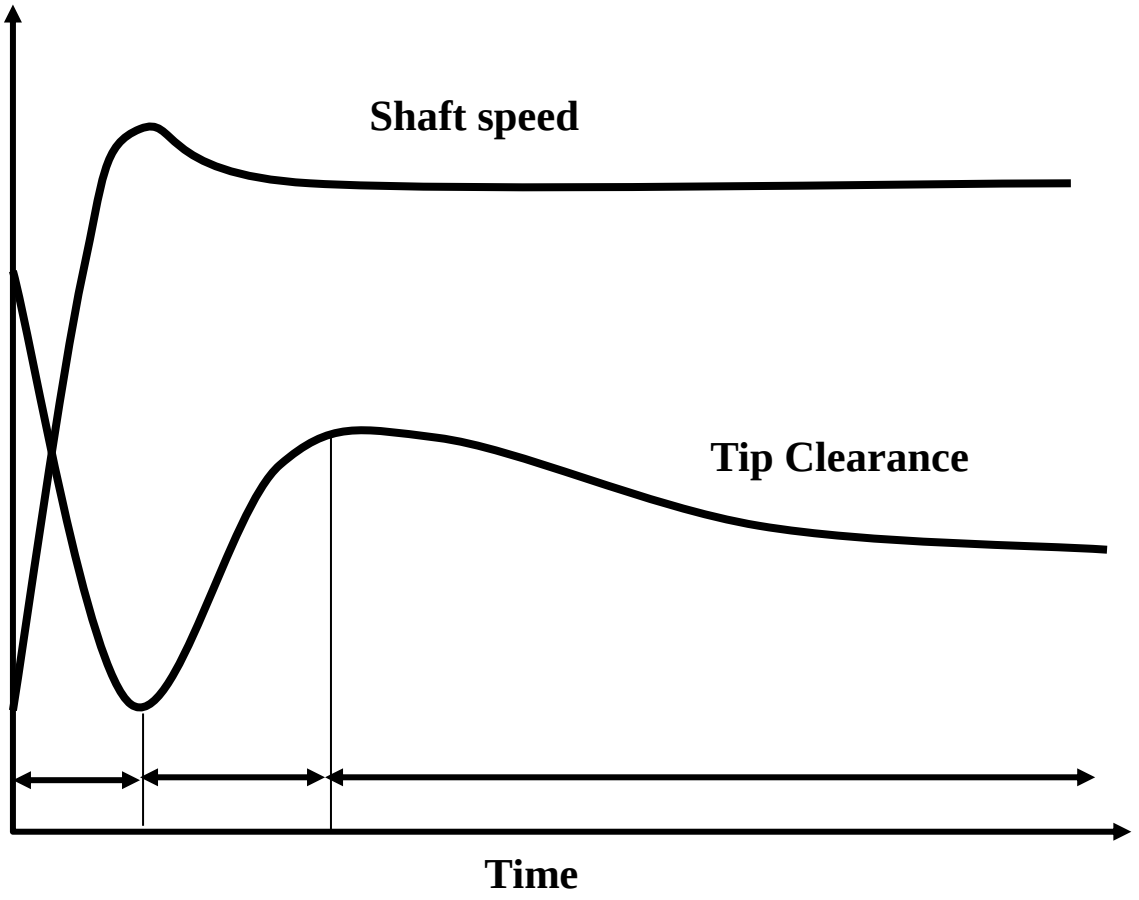
(Sallee GP, NASA CR-135448, 1980)

Compressor and turbine tip clearance damage

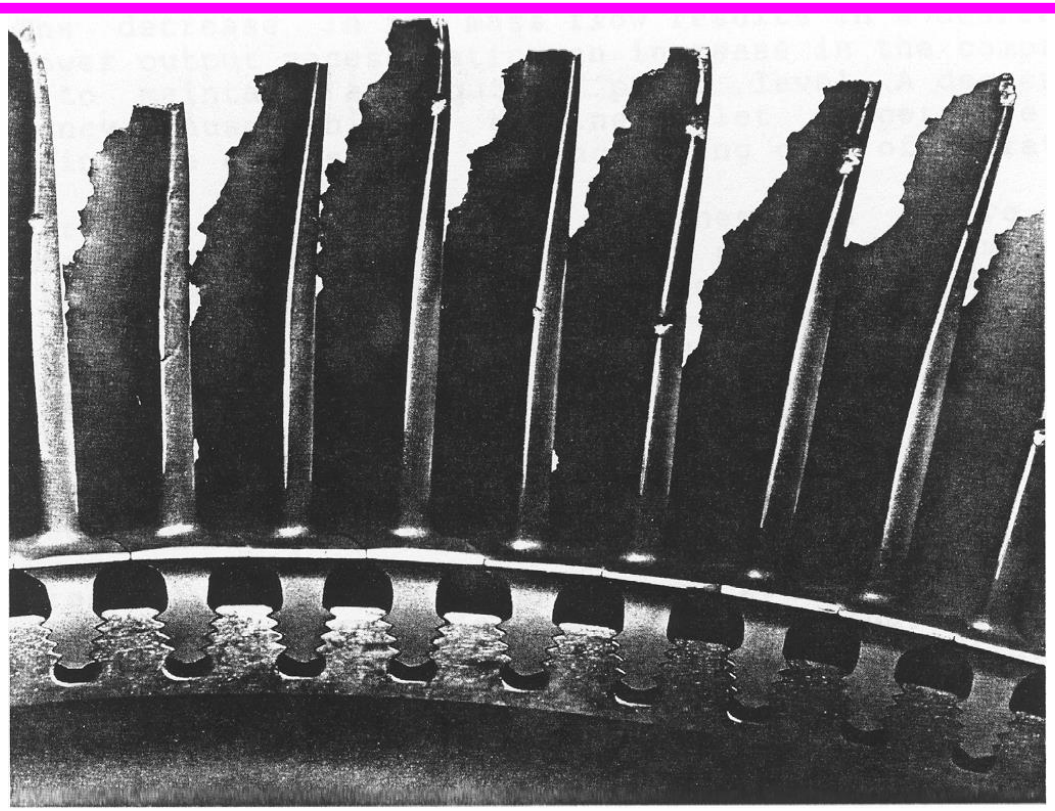
How does it happen?

Compressor & Turbine Tip Clearance Change





Turbine Damage

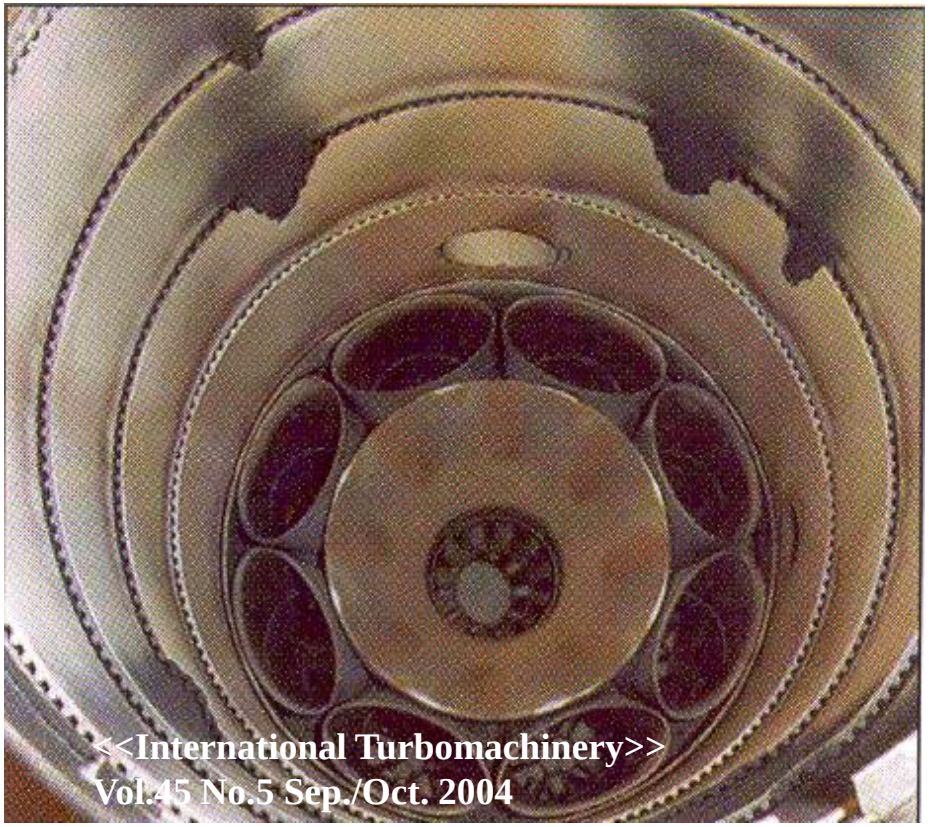


(Peterson RC, 1986)

Hot end component damage (overheating)

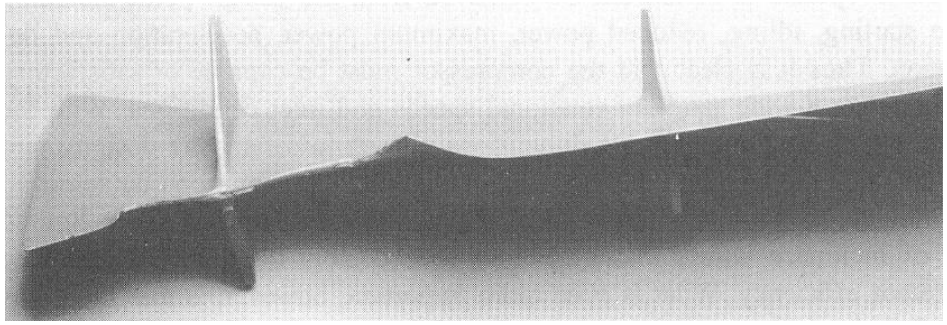
When does it happen?

Combustor Faults



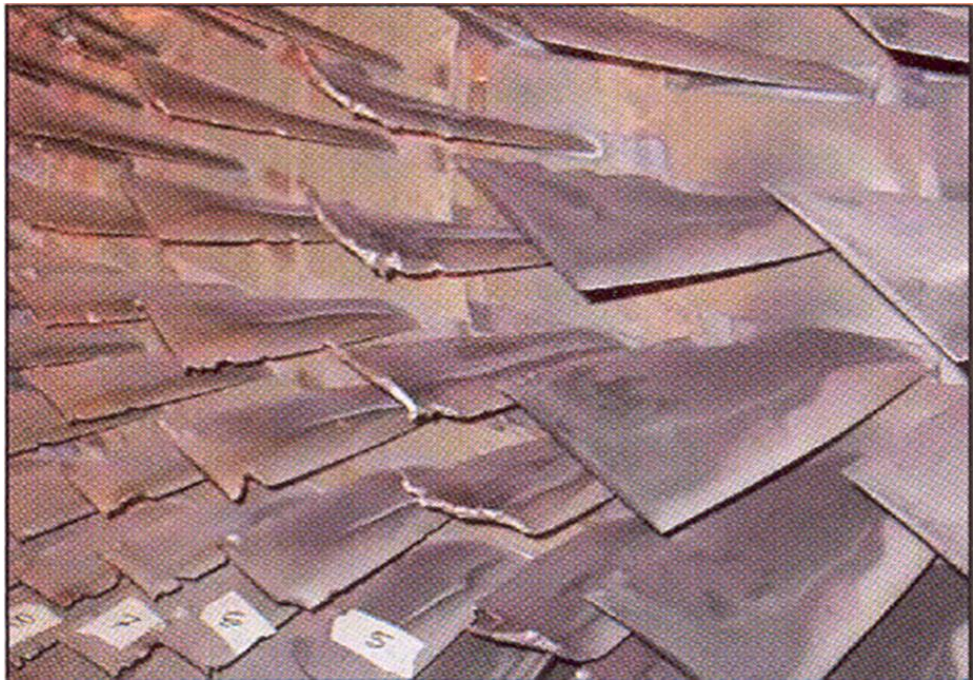
Combustion system deterioration

FOD & DOD



<<Gas Turbine Theory>> by HIH Saravanamuttoo etc.

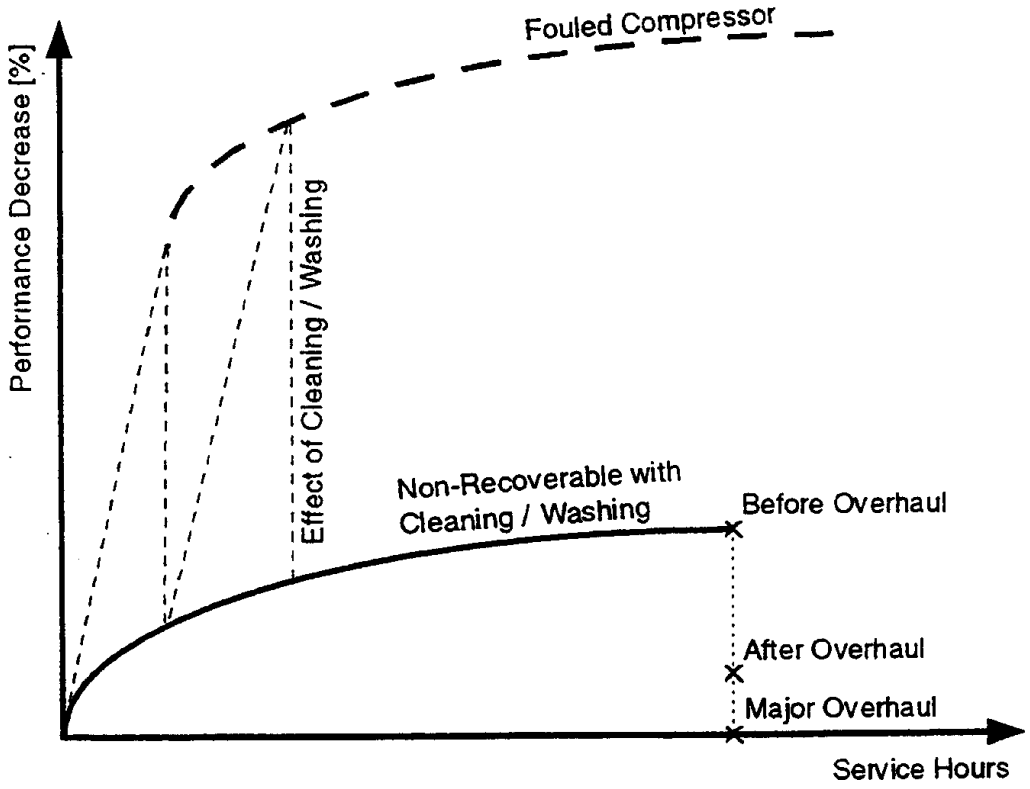
Effect of seagull strike on a large turbofan blade



<<International Turbomachinery>> Vol.45 No.5, Sep./Oct. 2004

Foreign object damage (FOD) & Domestic object damage (DOD)

Recoverable & non-recoverable performance



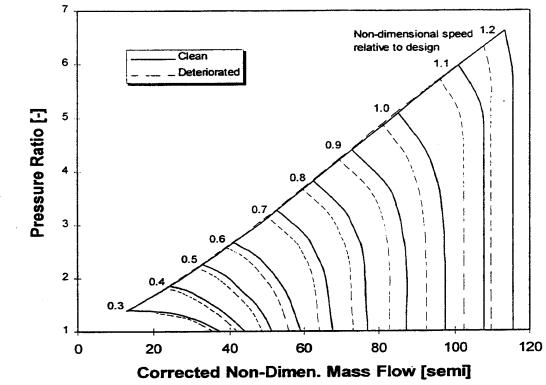
- Recoverable
- Non-recoverable
- Cumulative effect

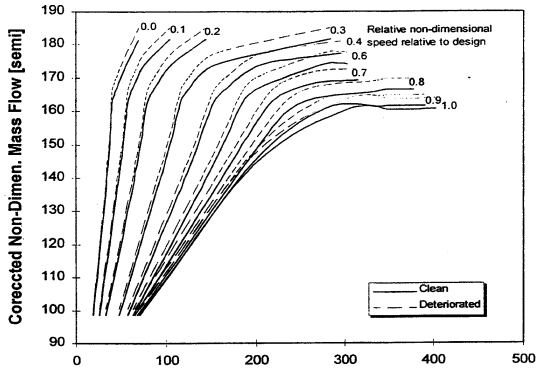
Typical gas turbine degradations

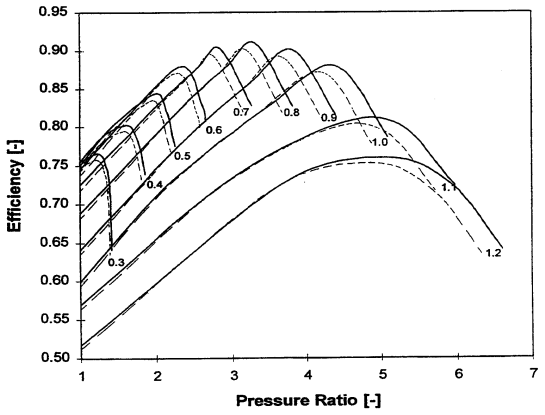
Degradation on

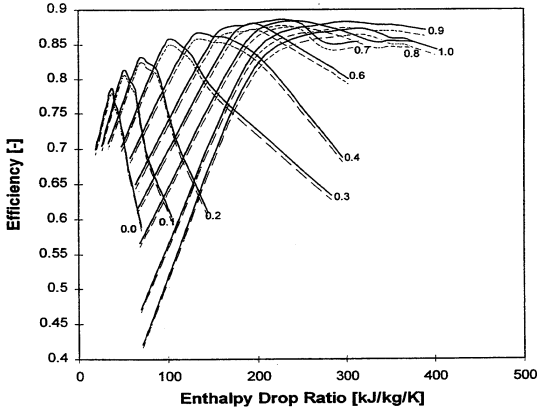
- **Compressor:** drop in isentropic efficiency drop & flow capacity
- **Combustor:** drop in combustion efficiency
- **Turbine:** isentropic efficiency drop, flow capacity change
- **Nozzle:** change in flow capacity
- **Seal & flange:** change in flow capacity

Compressor and Turbine Degradation









A fault is characterised as changes in a component characteristics (ΔP, $\Delta \Gamma$, $\Delta \eta$) from its base line or design condition.

Compressor Health Parameters

Degradation Scaling Factors:

Flow Capacity Scaling Factor

$$SF_{c,FC} = FC_{c,\deg} / FC_c$$

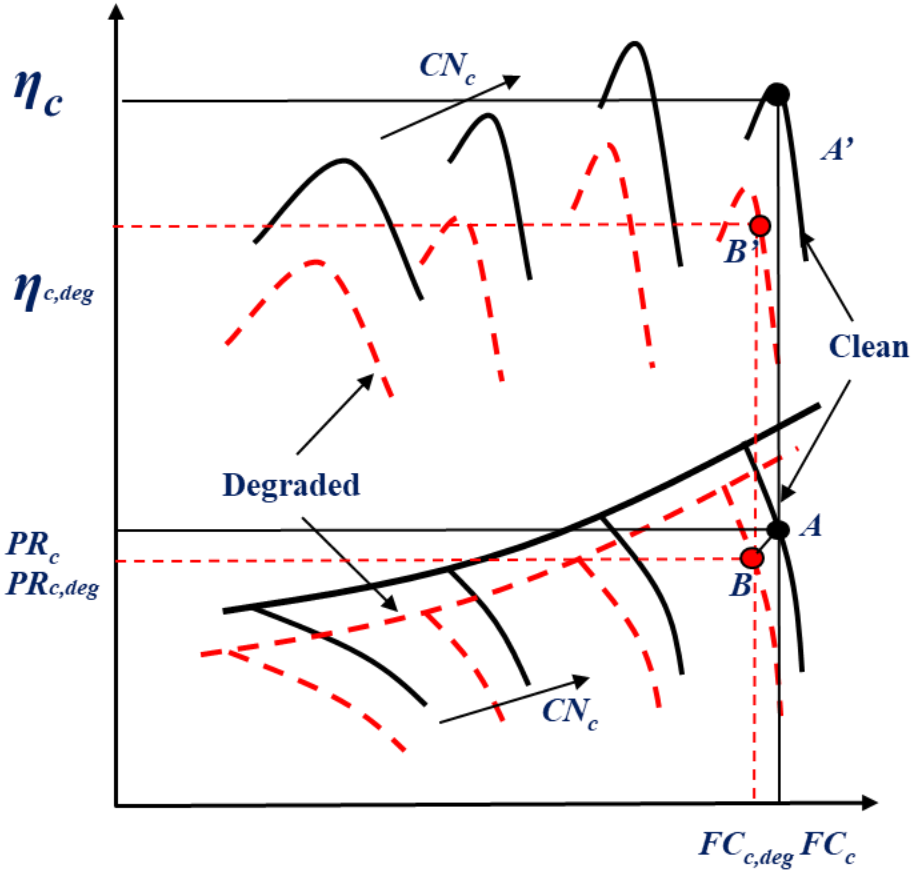
Efficiency Scaling Factor

$$SF_{c,Eff} = \eta_{c,\deg} / \eta_c$$

Pressure Ratio Scaling Factor

$$SF_{c,PR} = PR_{c,\deg} / PR_c$$

Assumption: $SF_{c,FC} = SF_{c,PR}$



Health Indices:

Flow Capacity Index = $SF_{c,FC}$ - 1

Efficiency Index = $SF_{c,Eff}$ - 1

Pressure Ratio Index = $SF_{c,PR}$ - 1

Turbine Health Parameters

Degradation Scaling Factors:

Flow Capacity Scaling Factor

$$SF_{t,FC} = FC_{t,deg}/FC_t$$

Efficiency Scaling Factor

$$SF_{t,Eff} = \eta_{t,\deg} / \eta_t$$

Enthalpy Drop Scaling Factor

$$SF_{t,DH} = DH_{t,deg}/DH_t$$

Assumption:

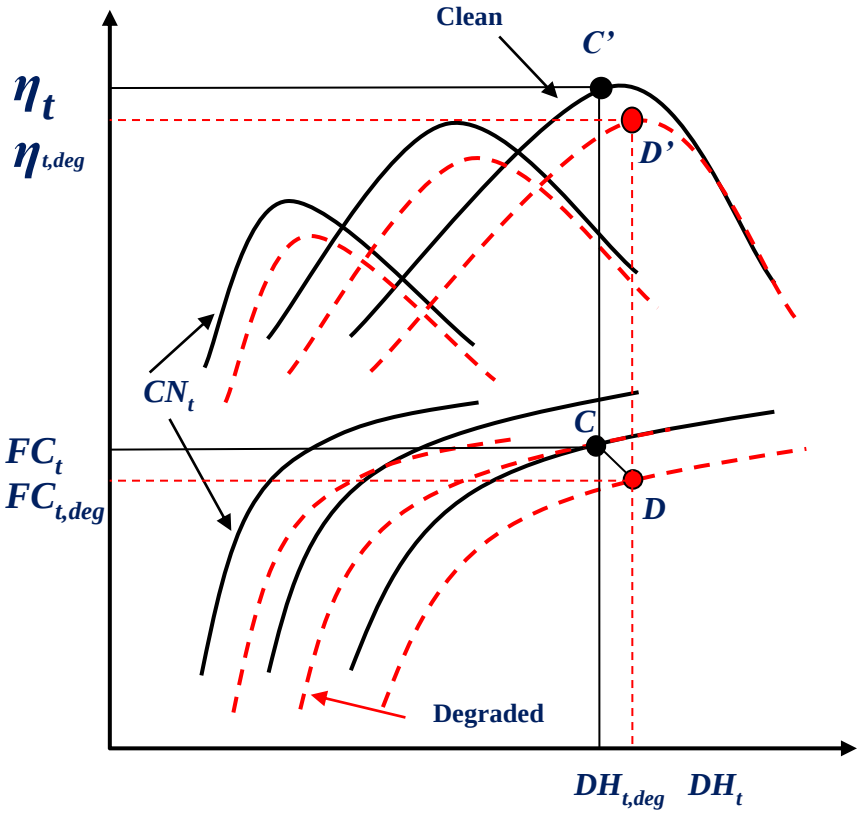
$$SF_{t,FC} = -SF_{t,DH}$$

Health Indices:

Flow Capacity Index = $SF_{t,FC}$ - 1

Efficiency Index = $SF_{t,Eff}$ - 1

Pressure Ratio Index = $SF_{t,PR}$ - 1

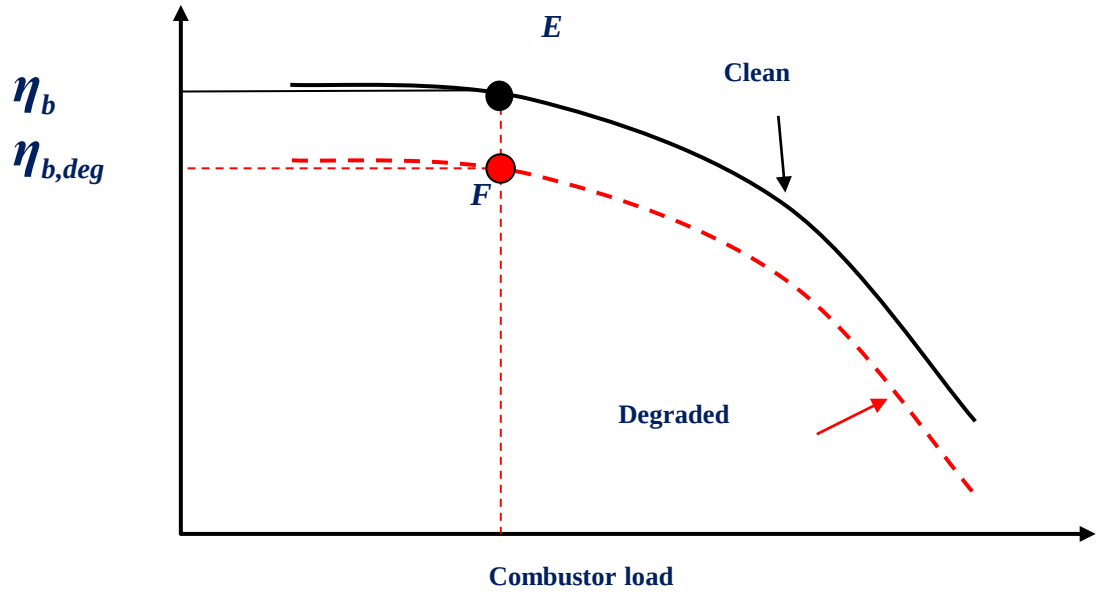


Combustor Health Parameter

Degradation Scaling Factors:

Efficiency Scaling Factor

$$SF_{b,Fff} = \eta_{b,deg}/\eta_b$$



Health Index:

$$Efficiency\ Index = SF_{b,Eff} - 1$$

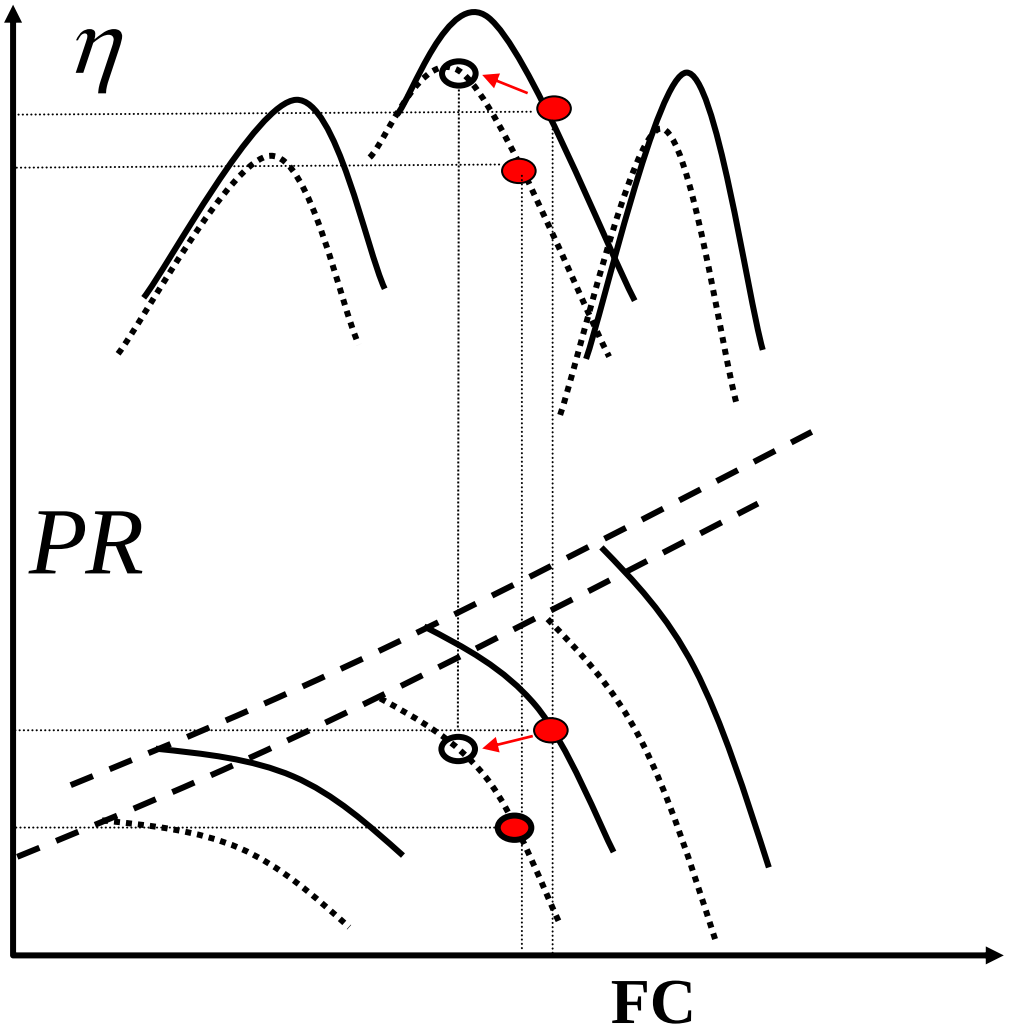
$$Combustor\_Load = f\left(P_b, \Delta T_b\right)$$

Health Parameters

Change of efficiency (move of operating point)

vs

Deviation of efficiency Index (deviation of map)

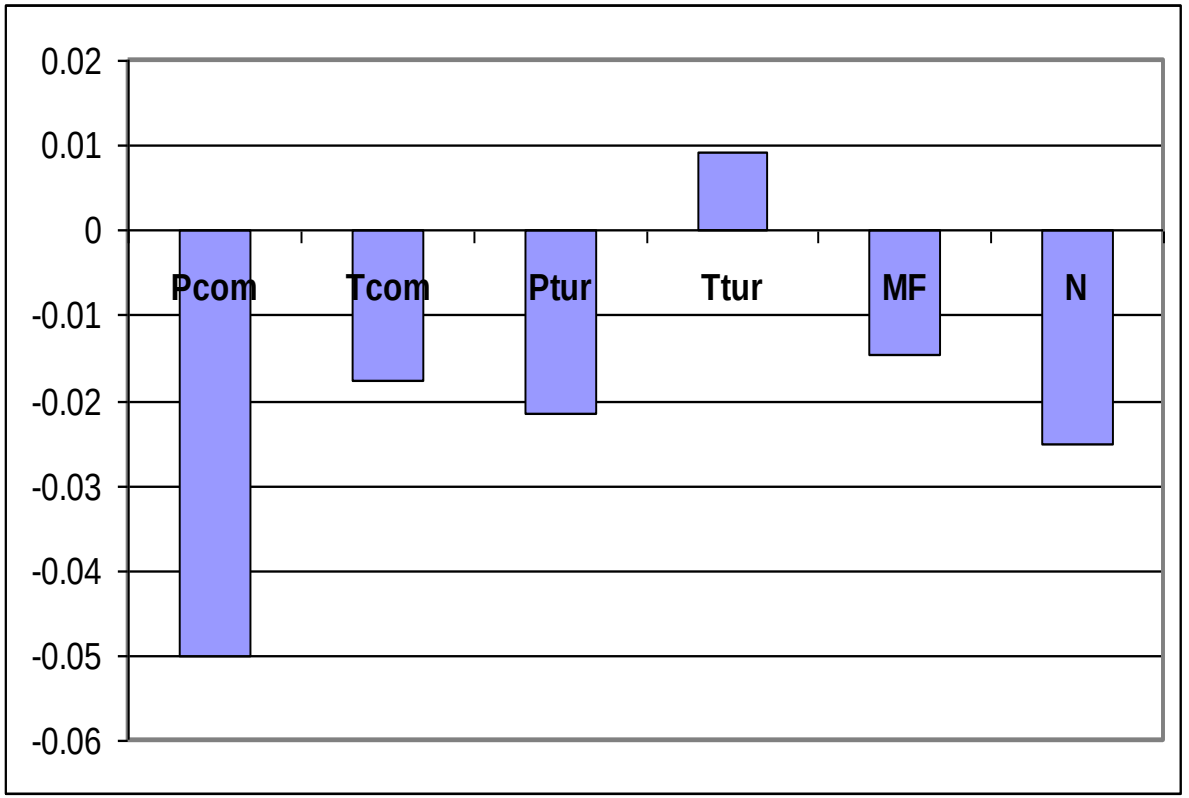


Performance deviation and fault signature

Fault Signature:

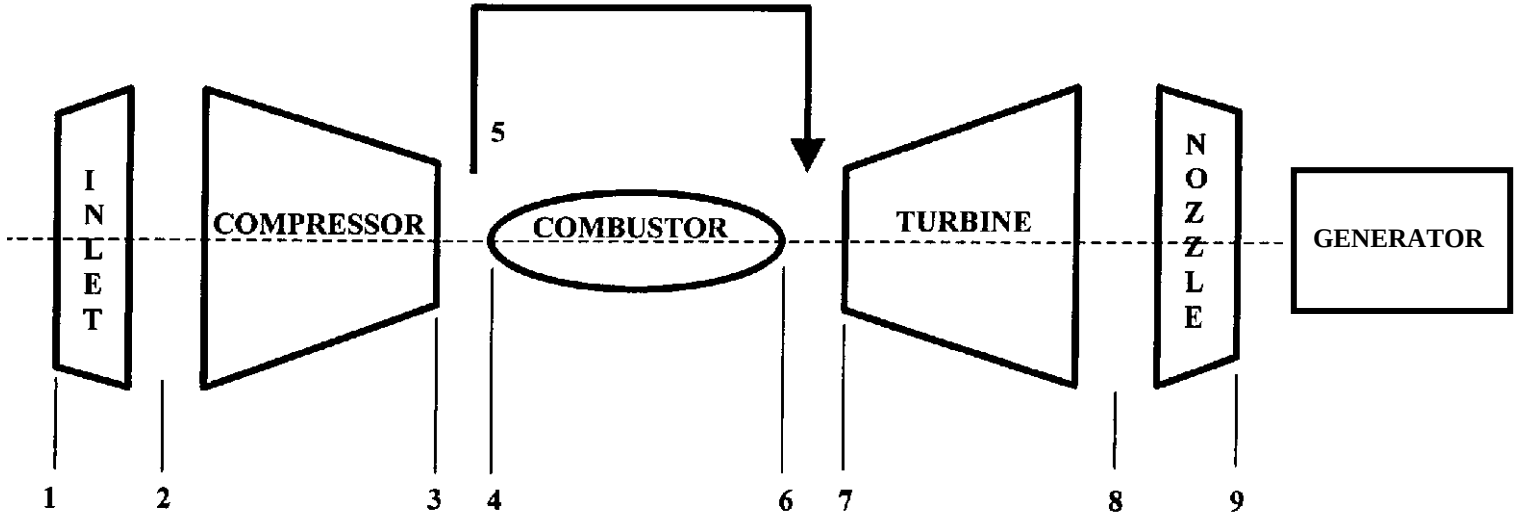
Measurement Deviations

$$\Delta z = \frac{z_{deg} - z_{cln}}{z_{cln}}$$



Fault signature of a single shaft industrial engine

Example of performance deterioration



Inlet mass flow:		**408.66 kg/s**
Compressor pressure ratio	**15.2**	
Turbine entry temperature	**1697.8 K**	
Exhaust temperature		**871.24 K**
Net power output	**165.93 MW**	
Overall thermal efficiency	**35.57 %**	

Example of performance deterioration

Fault	Represented By	Range
Compressor Fouling	Drop in Γ Drop in η_C	0.0 – (-5.0%) 0.0 – (-2.5%)
Compressor Erosion	Drop in Γ Drop in η_C	0.0 – (-5.0%) 0.0 – (-2.5%)
Turbine Fouling	Drop in Γ Drop in η_T	0.0 – (-5.0%) 0.0 – (-2.5%)
Turbine Erosion	Rise in Γ Drop in η_T	0.0 – (+5.0%) 0.0 – (-2.5%)
FOD	Drop in η_C and η_T	0.0 – (-5.0%)

Example of performance deterioration