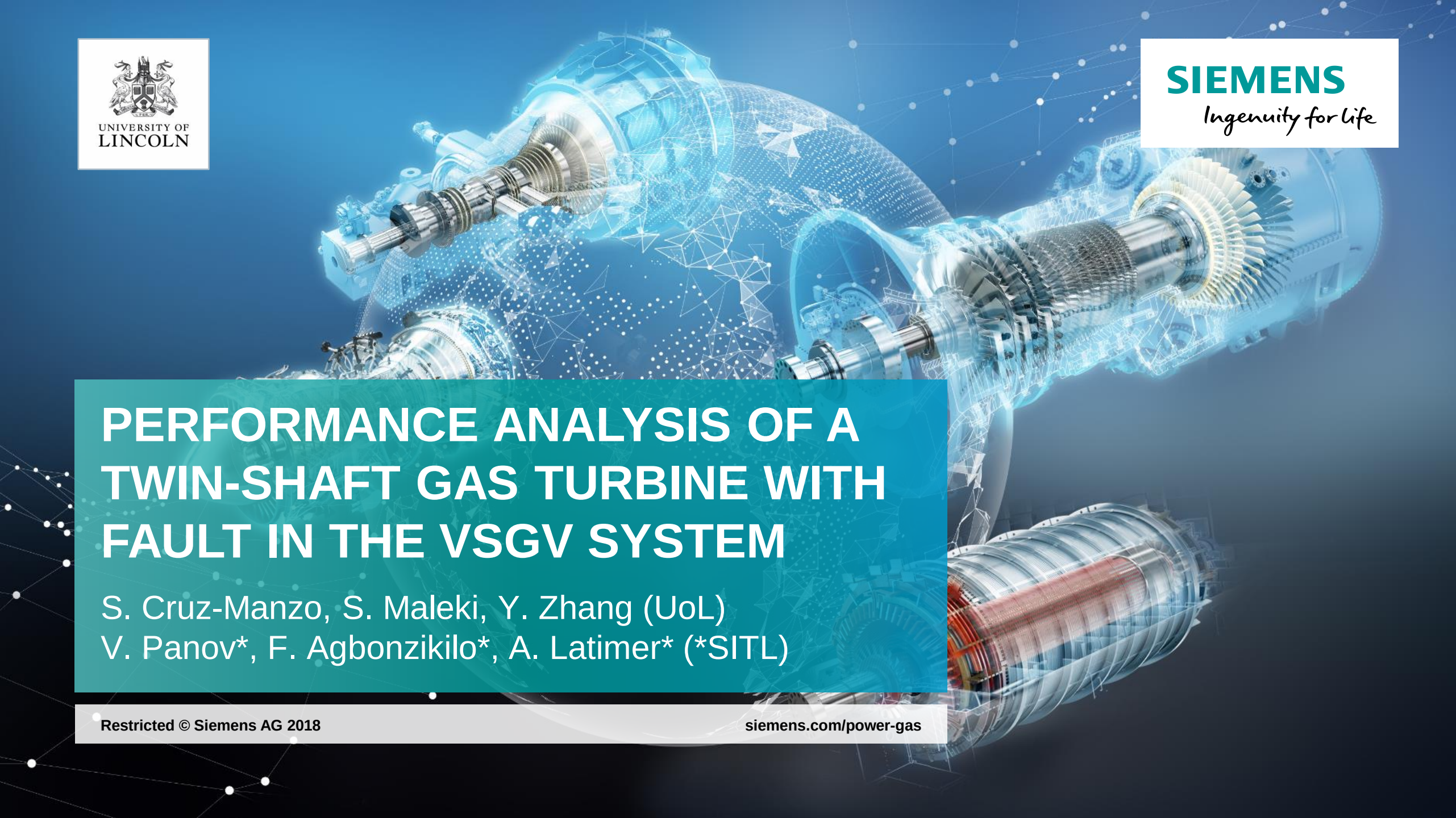

PERFORMANCE ANALYSIS OF A TWIN-SHAFT GAS TURBINE WITH FAULT IN THE VSGV SYSTEM

S. Cruz-Manzo, S. Maleki, Y. Zhang (UoL)
V. Panov*, F. Agbonzikilo*, A. Latimer* (*SITL)

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Introduction

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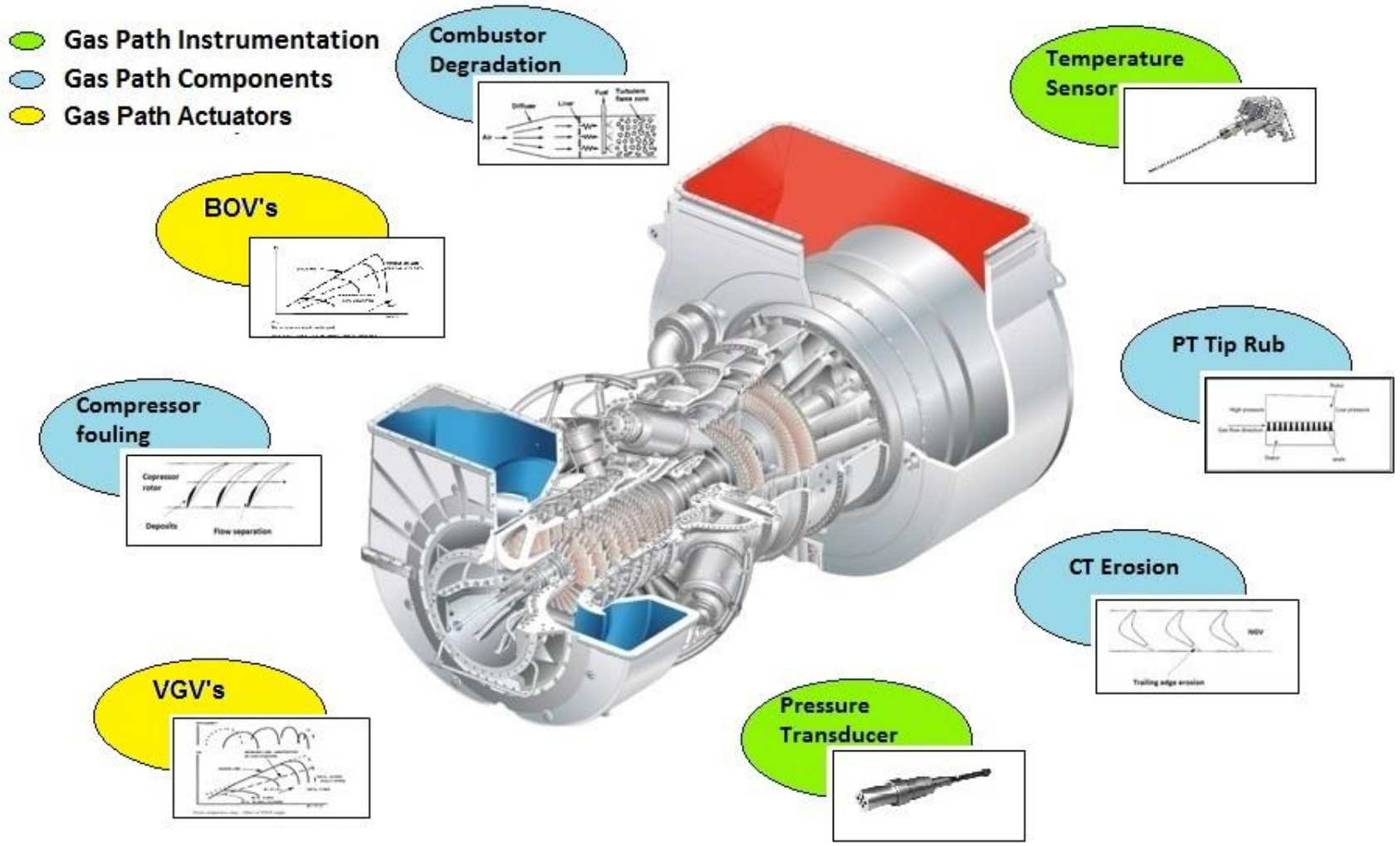
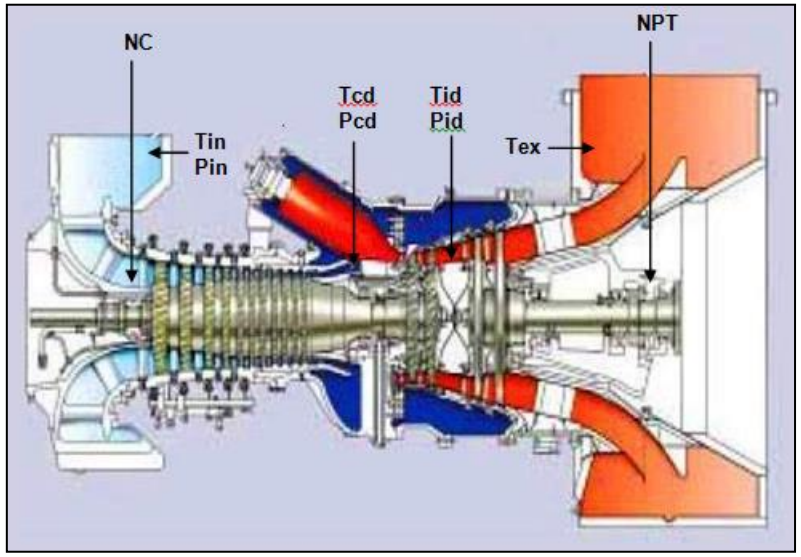
2. Gas Turbine Engine – Industrial Twin Shaft Turbine operated in the field as a Power Generator Unit
3. Numerical Analysis via dynamic simulation based on non-linear gas turbine model
4. Example - case study for slow rate degradation process: Compressor Fouling
5. Example - case study for moderate rate degradation process: Compressor Turbine Damage
6. Case study for fast rate process: VGV offsetting

Gas Path Monitoring

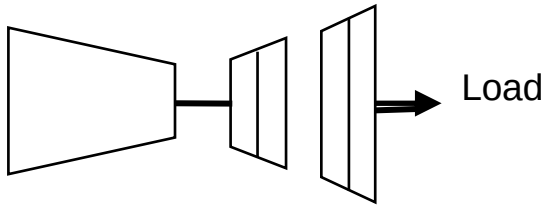


Engine Instrumentation

Measurement stations



Twin-shaft gas turbine



Measured engine parameters

No	Description	Sensor Type	Notation
1	Compressor inlet	Pressure	P_{in}
2	Compressor inlet	Temperature	T_{in}
3	Compressor delivery	Pressure	P_{cd}
4	Compressor delivery	Temperature	T_{cd}
5	Inter-duct	Pressure	P_{id}
6	Inter-duct	Temperature	T_{id}
7	Exhaust	Temperature	T_{ex}
8	Gas generator shaft	Speed	n_{gg}
9	Power turbine shaft	Speed	n_{pt}

Temperature sensors

Pressure sensors

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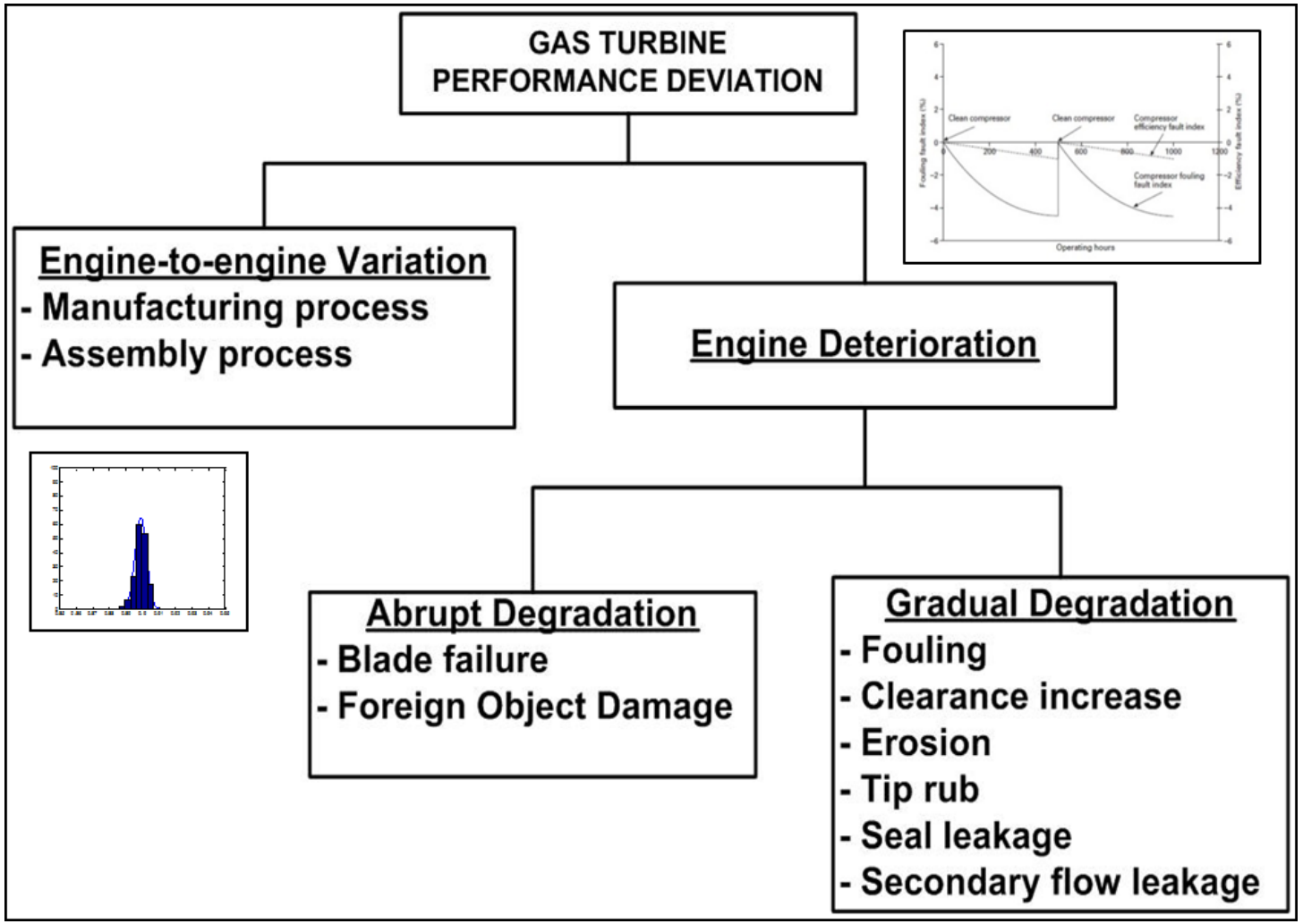
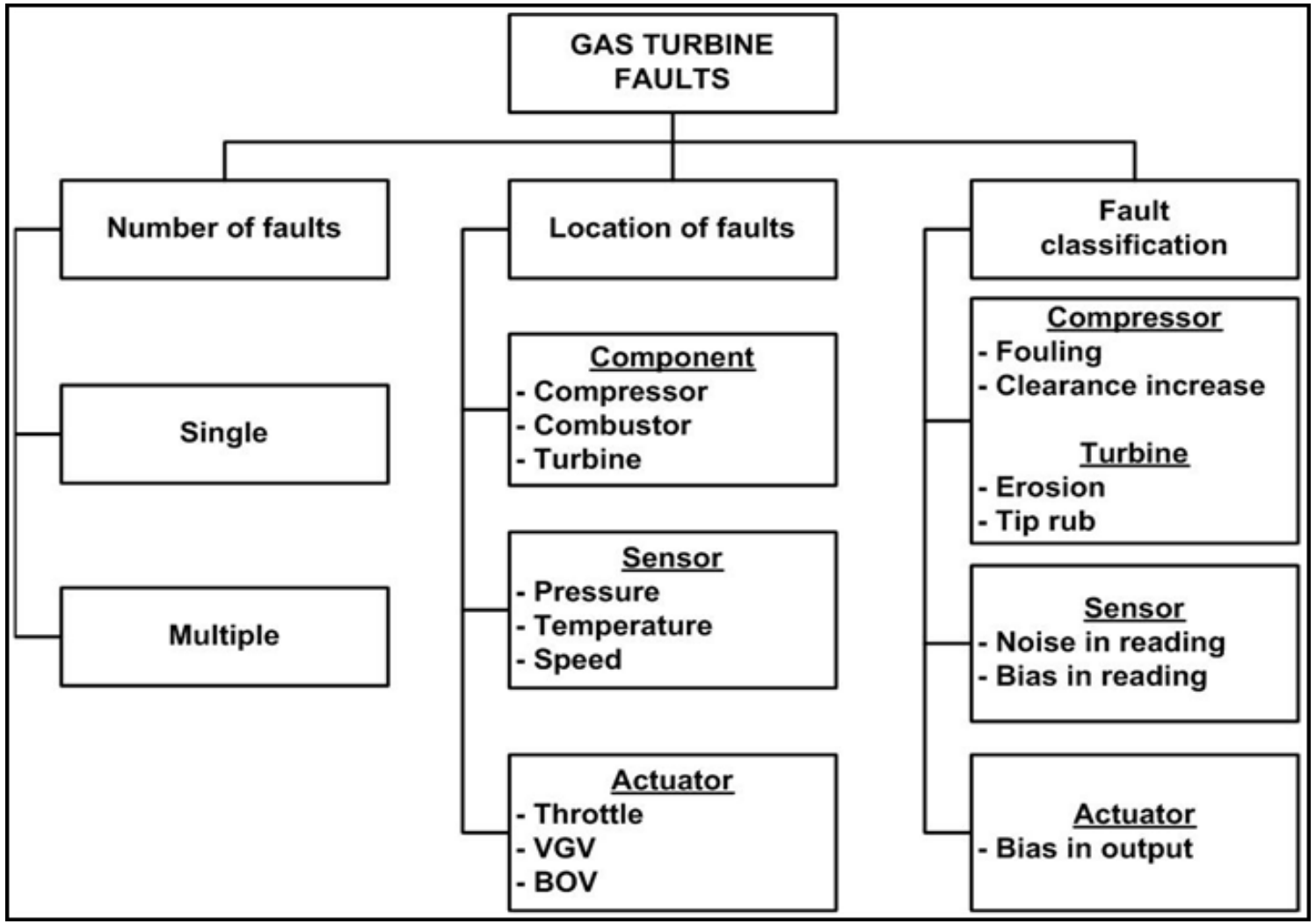
Section 2

Gas Path Faults and Degradation Modes

Gas Turbine Performance Deviation



Fault & Degradation Modes



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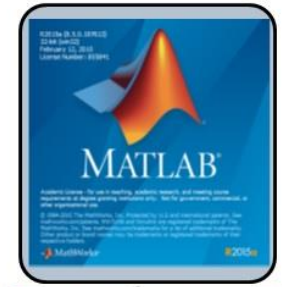
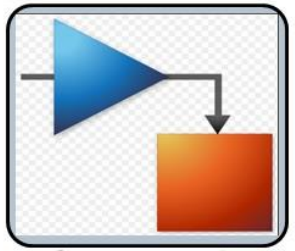
Section 3

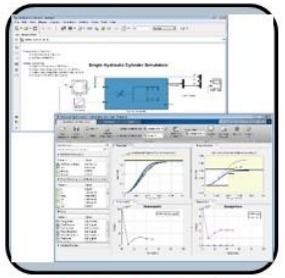
Gas Turbine Numerical Simulation

Simulation Toolchain

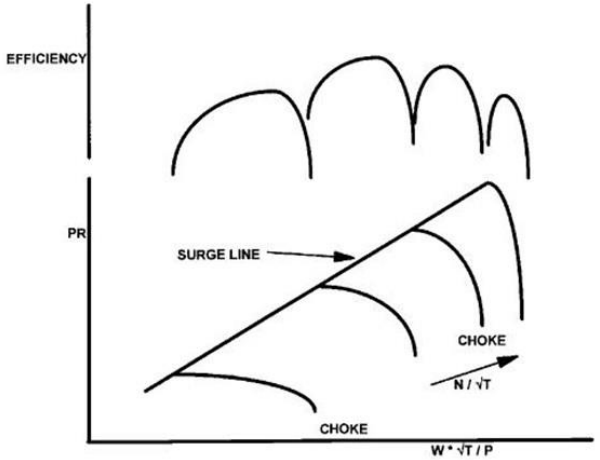


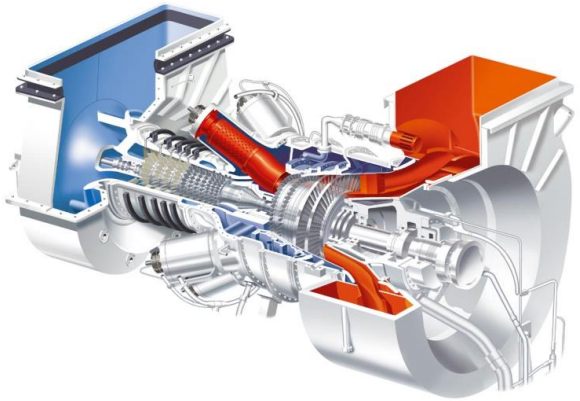
Matlab





Parameter Optimization





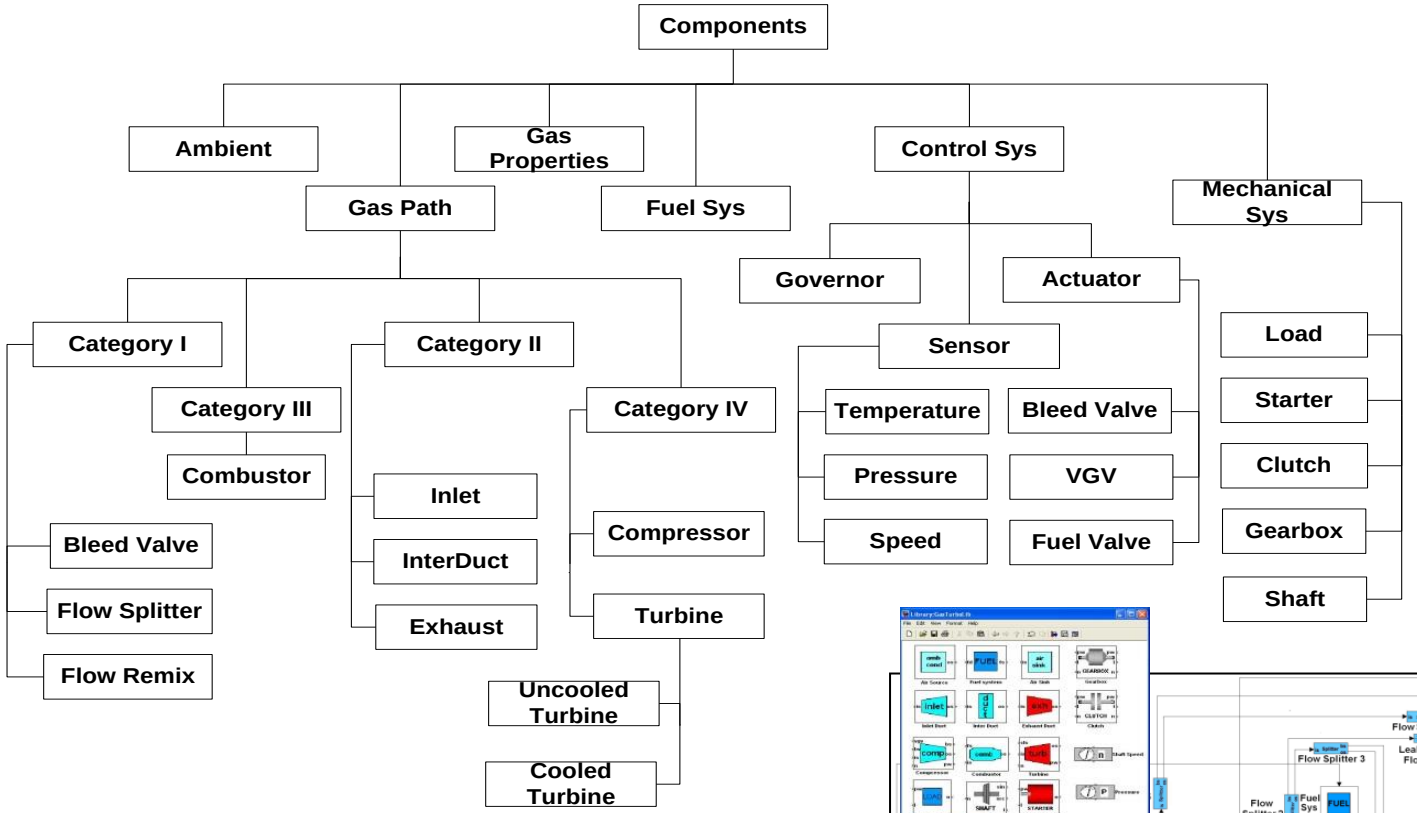
Parameter Optimization Toolbox in Simulink

Component Module

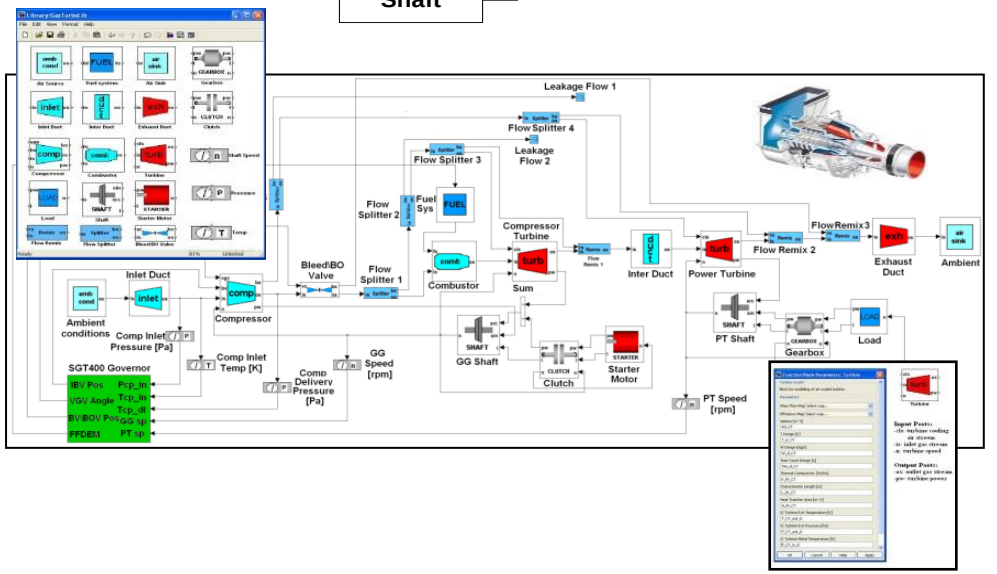
- Flow Rate
- Efficiency

Estimated Parameters

Generic Component Based Tool for Simulation of Gas Turbine Engines

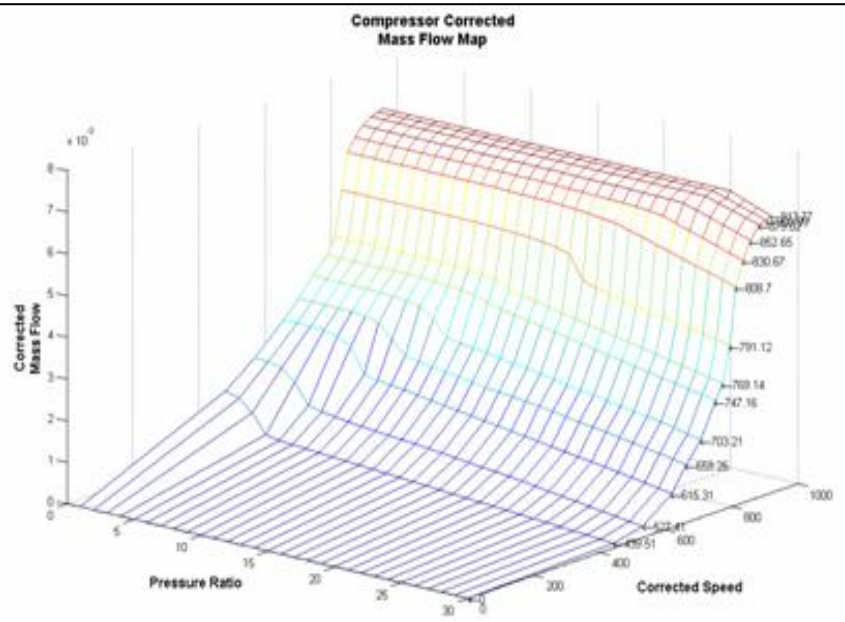


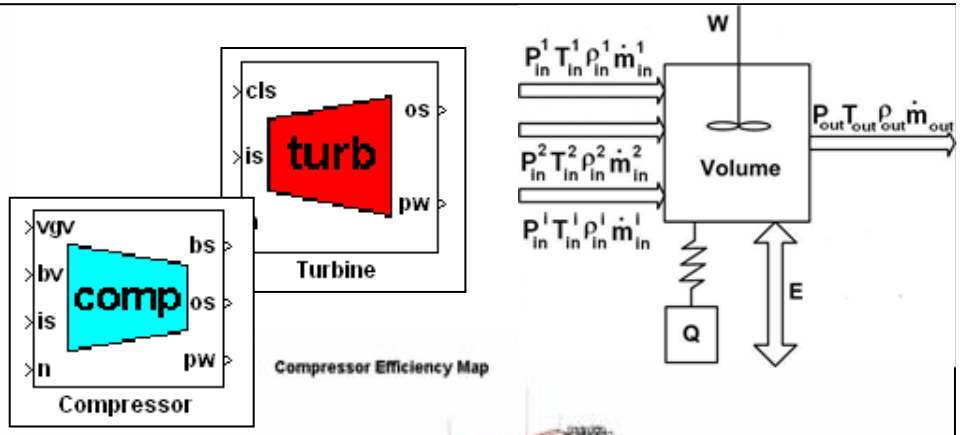
Component oriented architecture

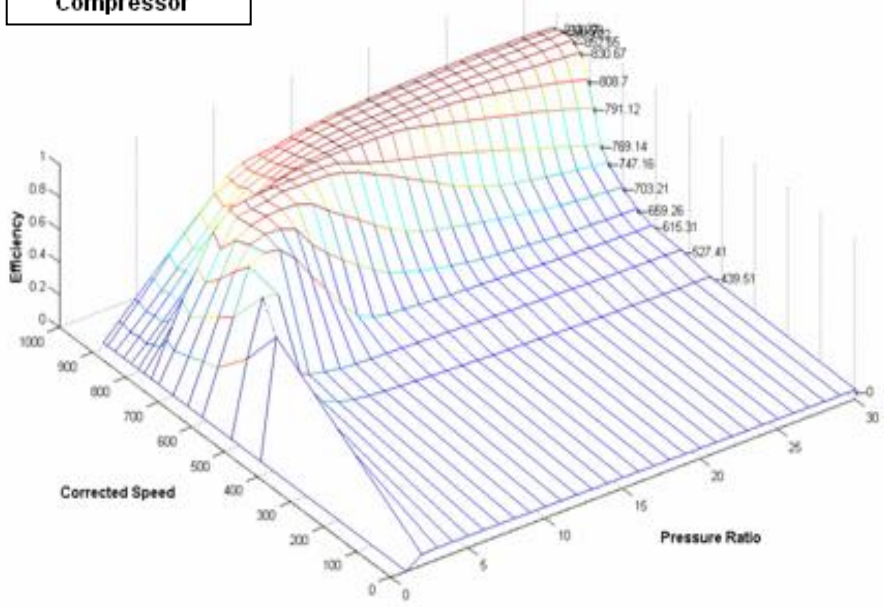


Based on standard SIMULINK block library

Component Characteristics – Predicted health parameters





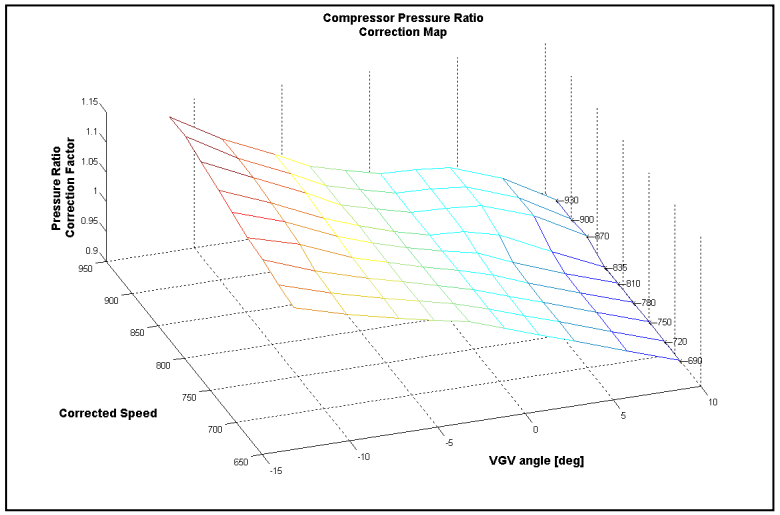


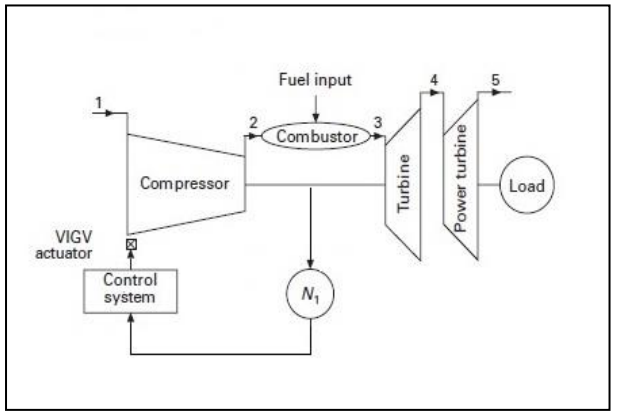
$$\Gamma_{comp} = f_{\Gamma}\left(\pi_{comp}, \bar{n}_{comp}\right)$$

$$\eta_{comp} = f_{\eta}\left(\pi_{comp}, \bar{n}_{comp}\right)$$

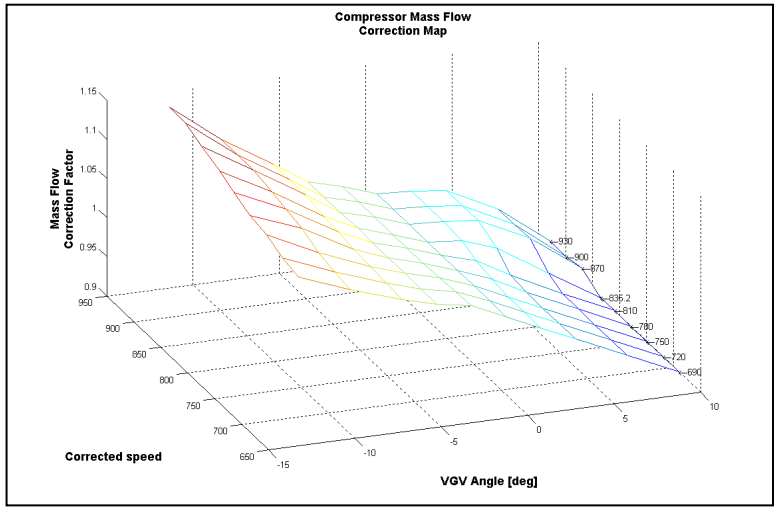
Compressor VGV offset correction

Pressure Ratio Correction Map

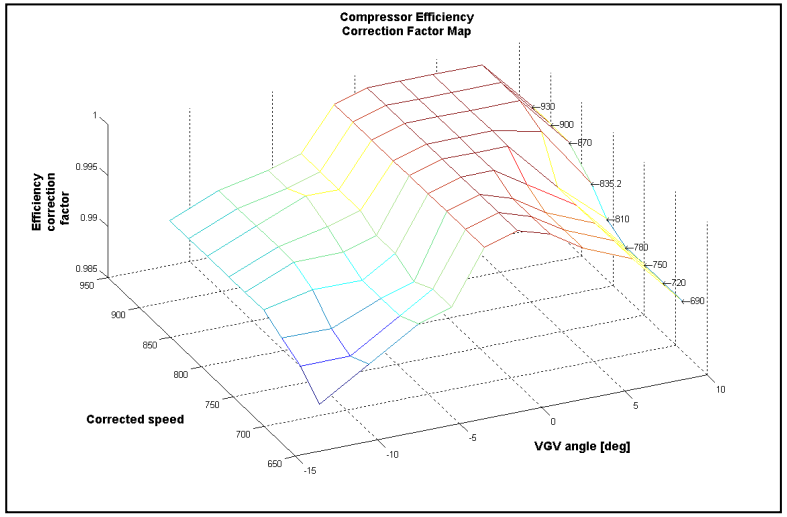




Mass Flow Correction Map



Efficiency Correction Map

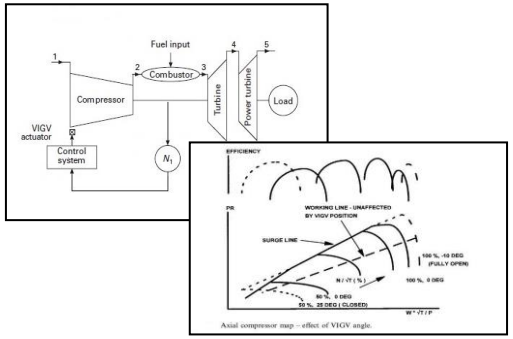


Section 4

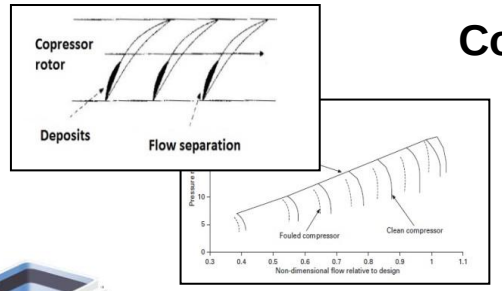
Gas Path Degradation Simulation

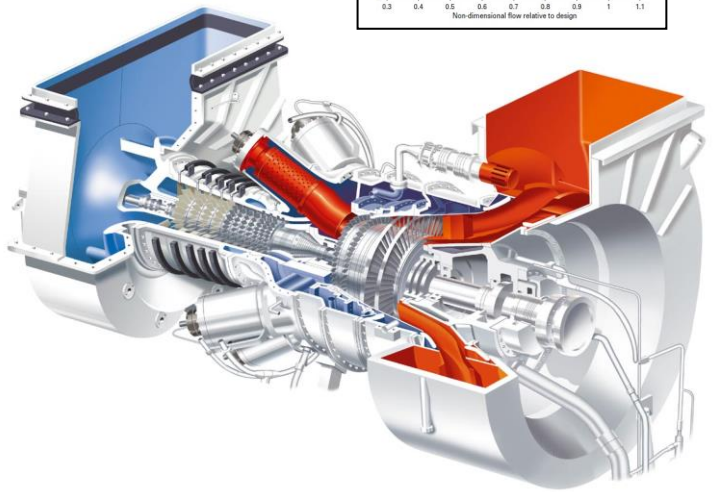
Gas Path Faults

VGV's position offset

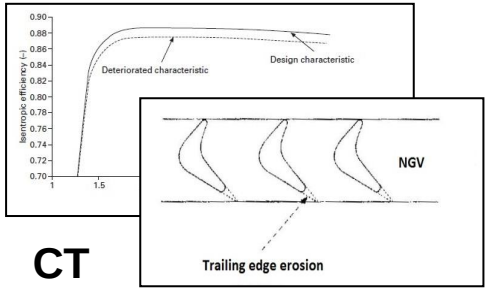


Compressor fouling

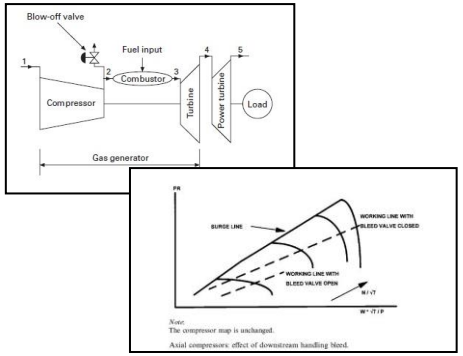




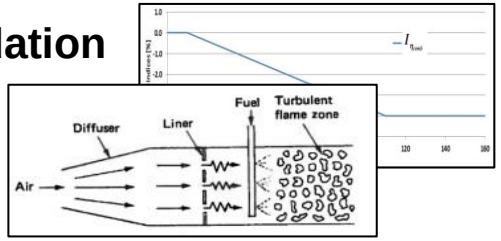
CT erosion



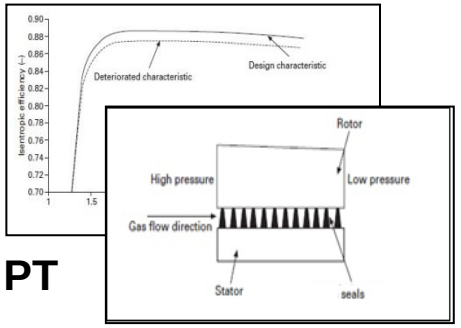
BOV's position fault



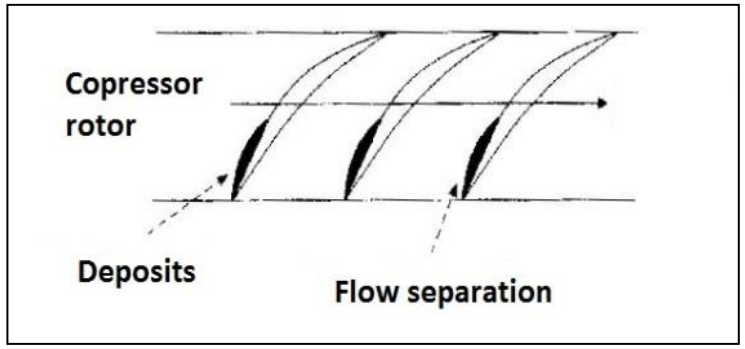
Combustor degradation



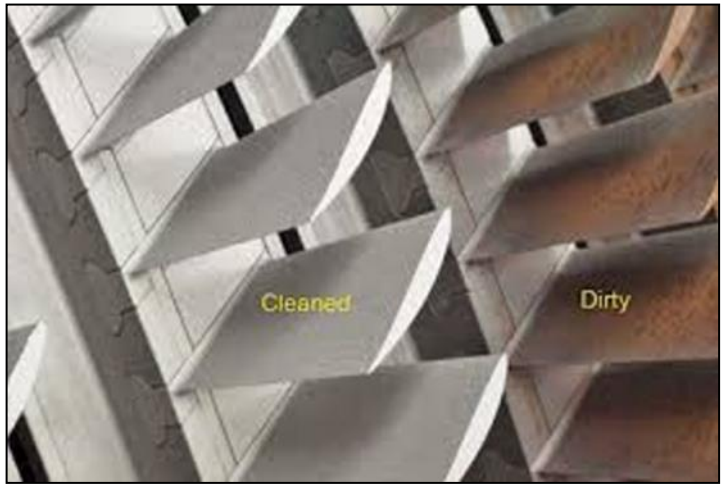
PT Tip/Seal Rub



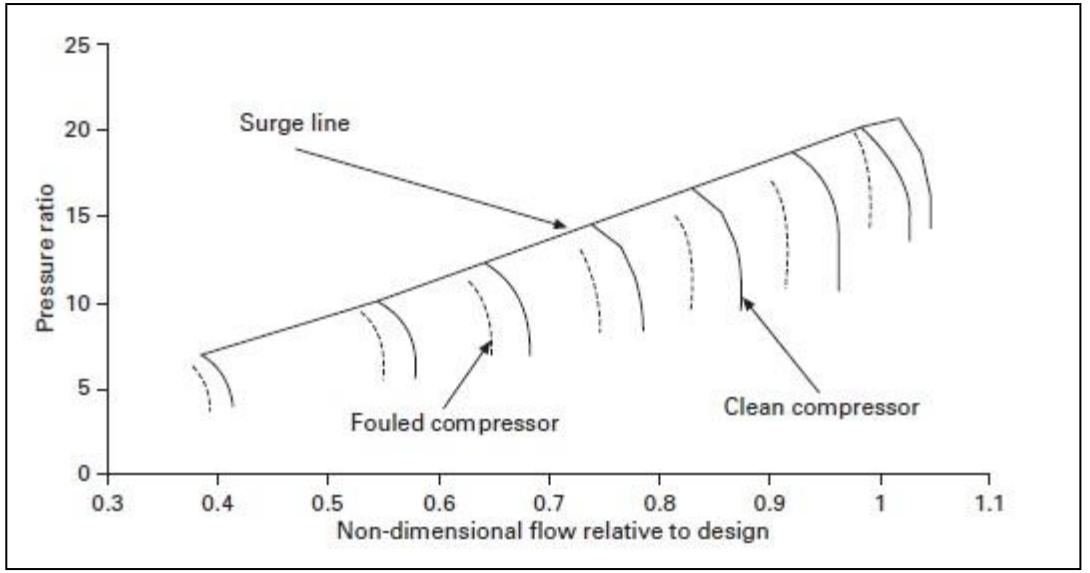
Compressor Fouling



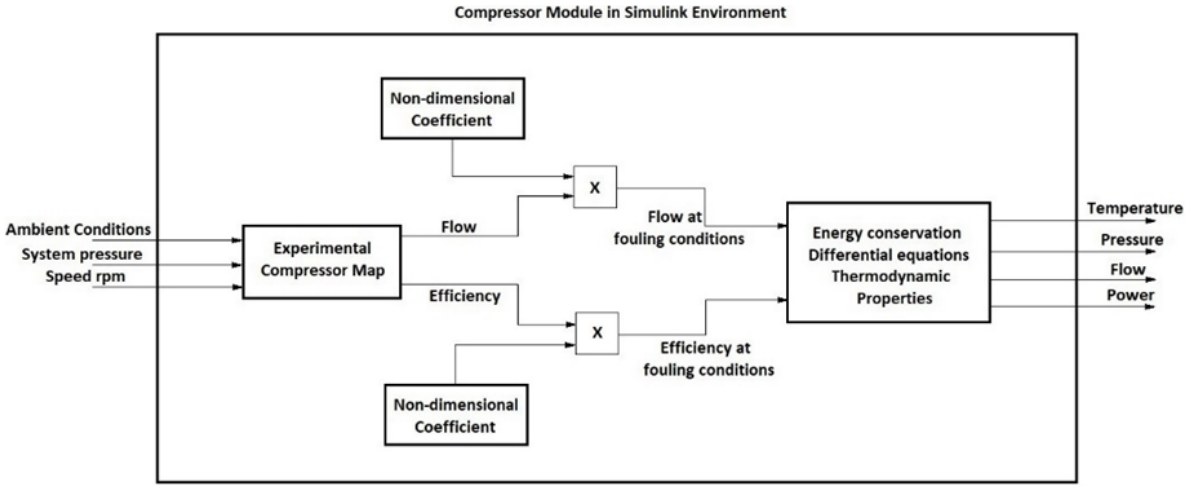
Compressor blades fouling



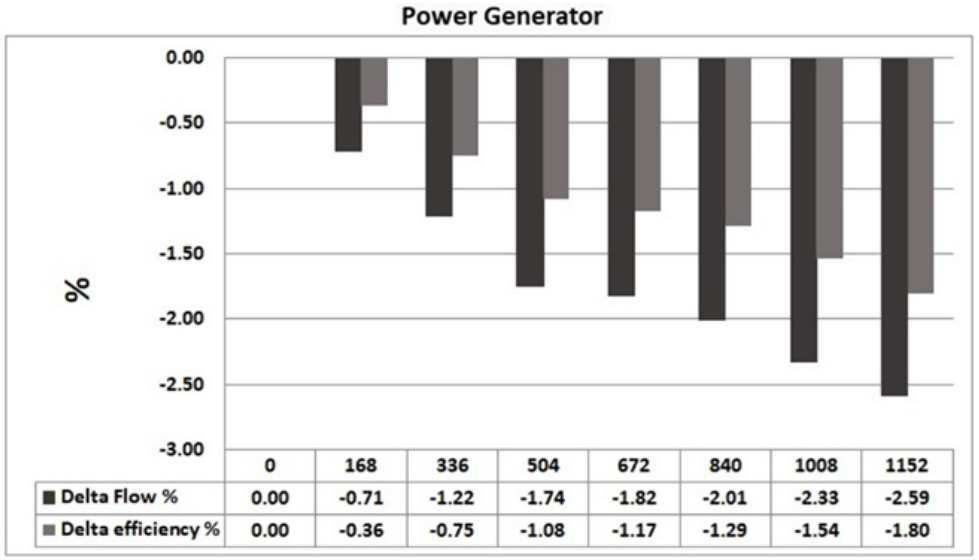
Compressor characteristics



Implementation of non-dimensional coefficients

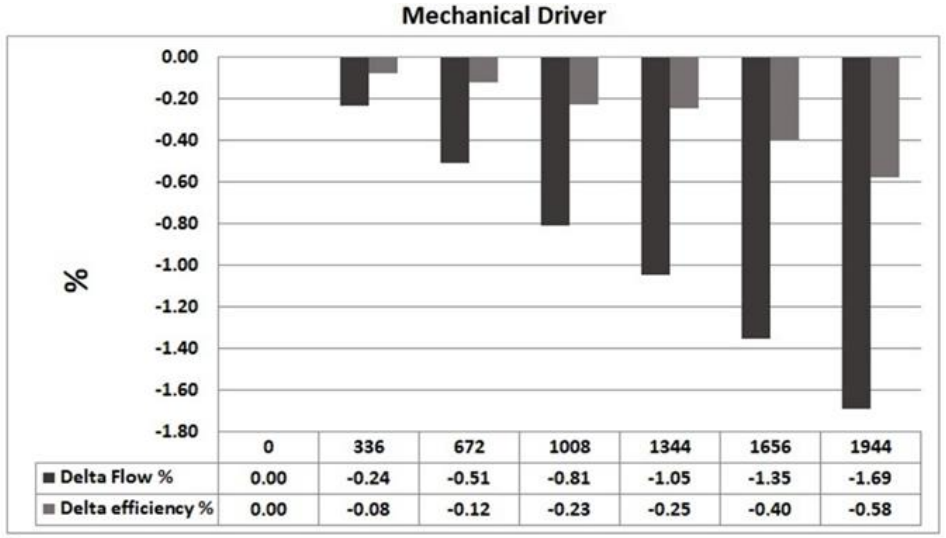


Compressor Fouling



a)

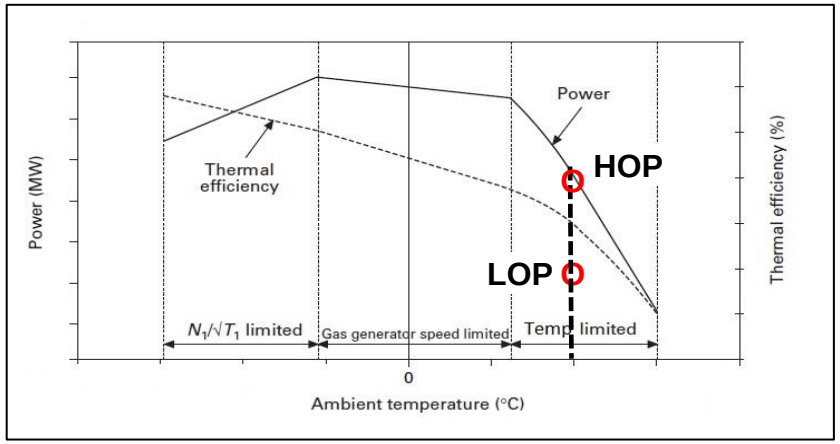
Compressor fouling for power generation unit running @ high operating point



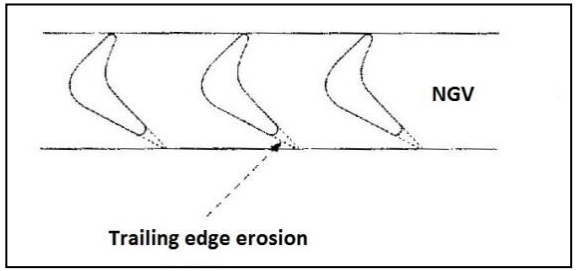
b)

Compressor fouling for mechanical drive unit running @ low operating point

Twin shaft - operating envelope

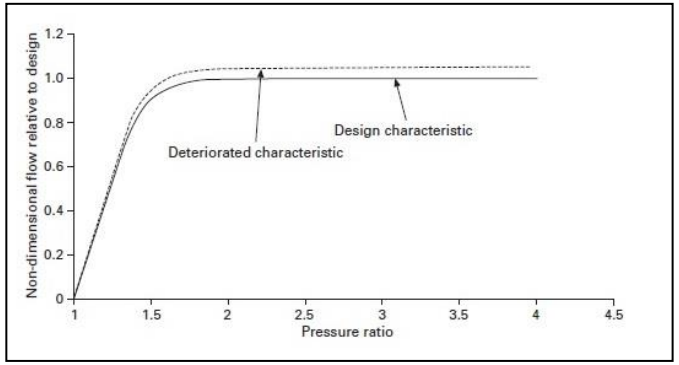


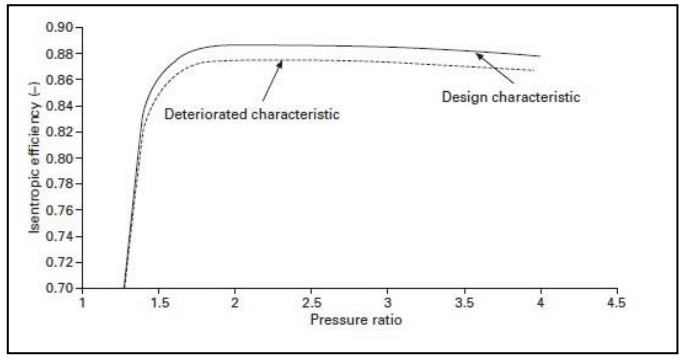
Compressor Turbine Damage

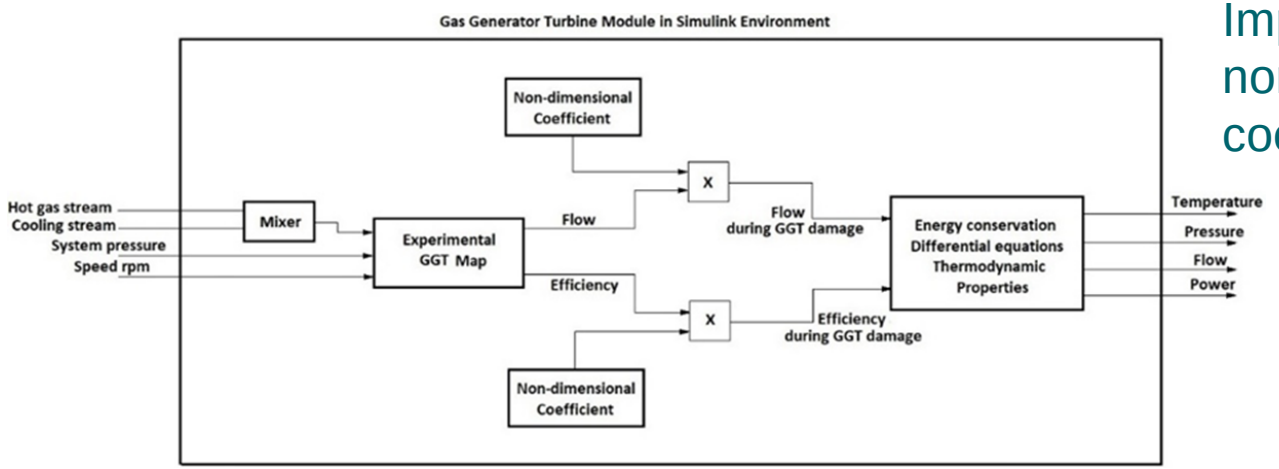


High Pressure Turbine Blade Damage

Turbine characteristics

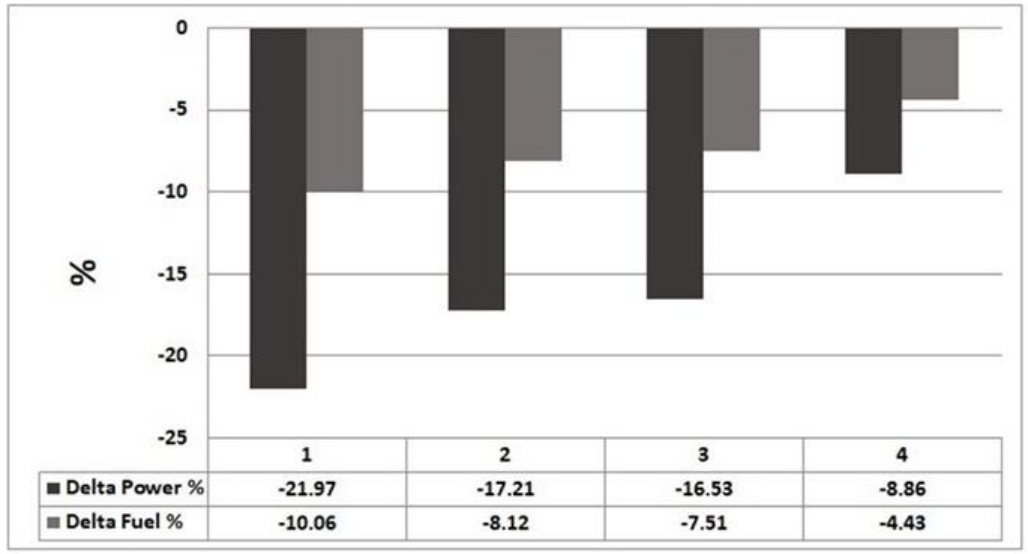






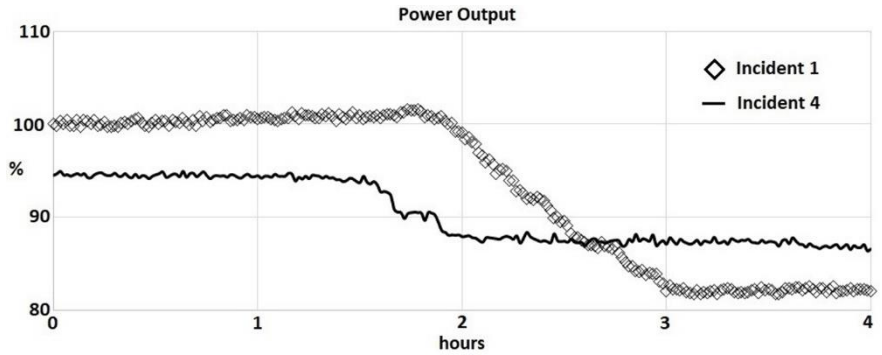
Implementation of non-dimensional coefficients

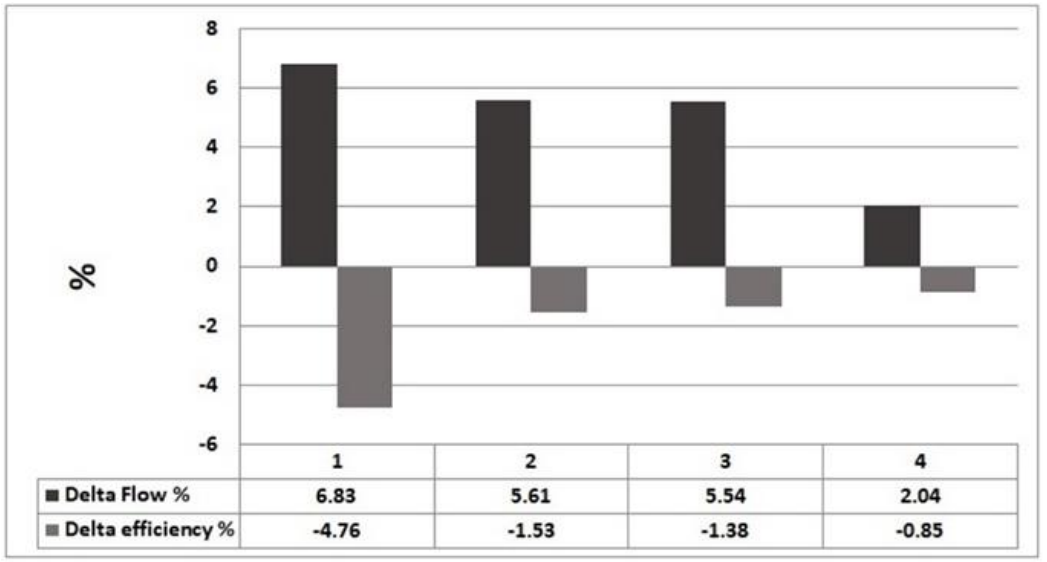
Compressor Turbine Damage



	1	2	3	4
Delta Power %	-21.97	-17.21	-16.53	-8.86
Delta Fuel %	-10.06	-8.12	-7.51	-4.43

Power output and fuel demand for power generation unit running @ high operating point





	1	2	3	4
Delta Flow %	6.83	5.61	5.54	2.04
Delta efficiency %	-4.76	-1.53	-1.38	-0.85

CT damage for power generation unit running @ high operating point

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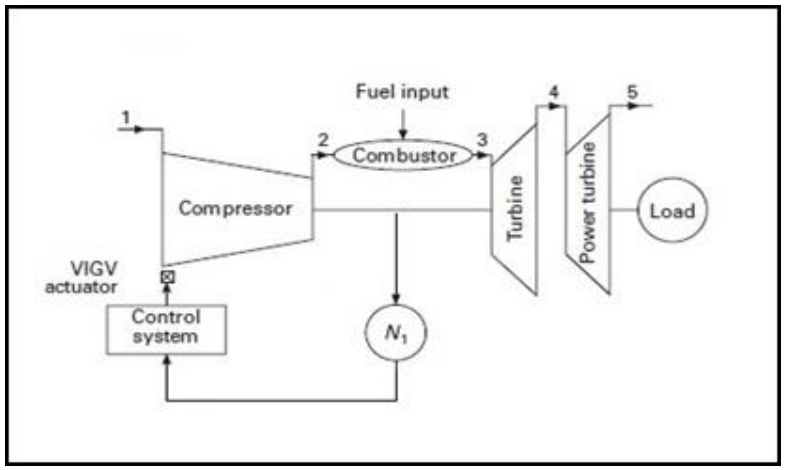
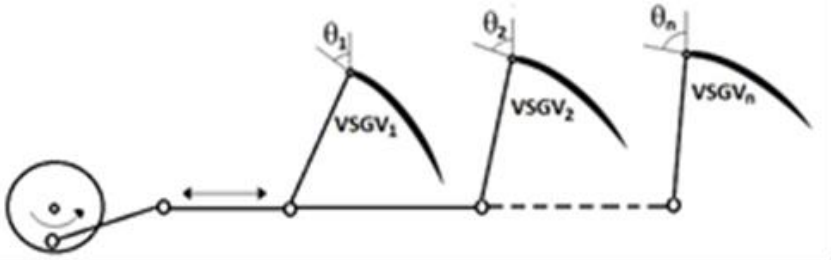
Section 5

VGV System Fault Analysis

VGV System Fault

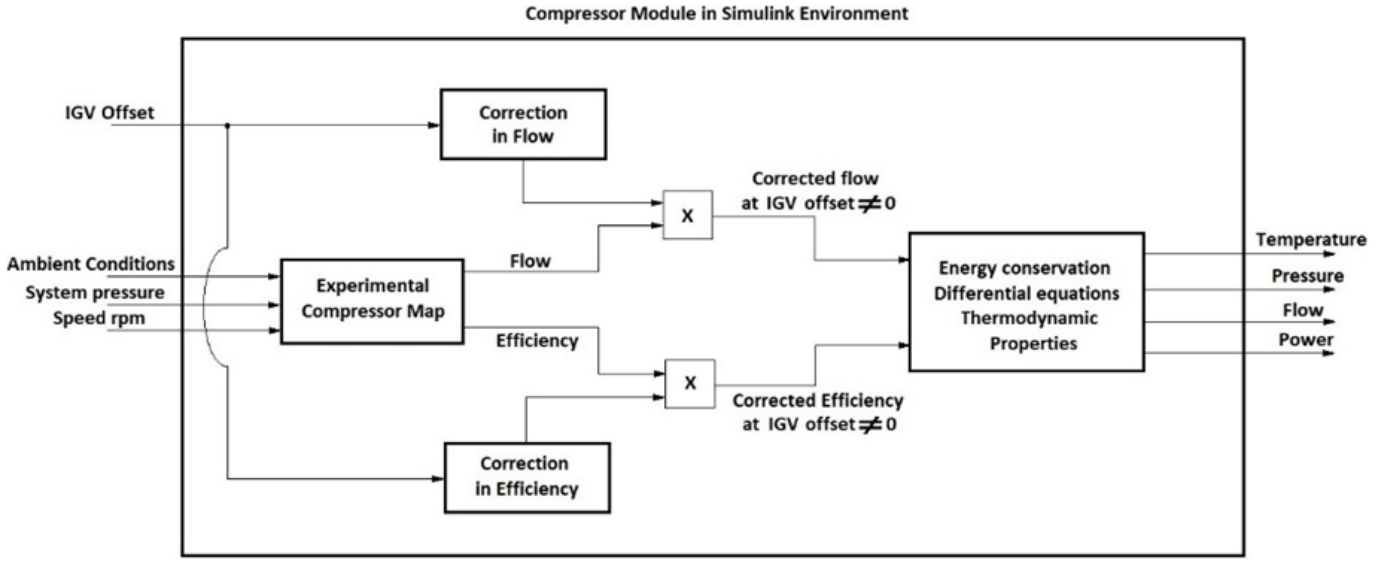


VGV position feedback for position of linear actuator

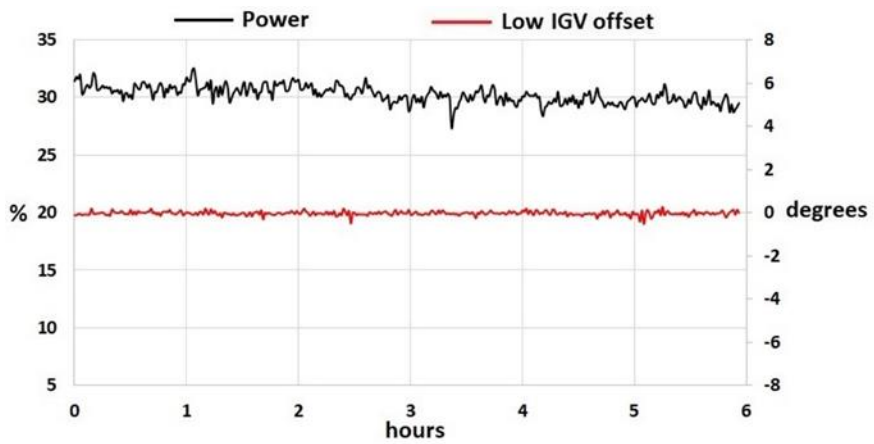


VGV Loose Connected Ram Fault

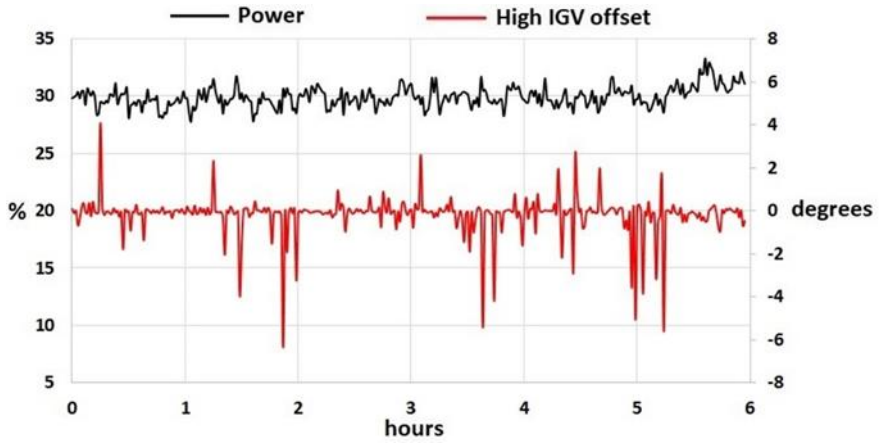
Implementation of non-dimensional coefficients



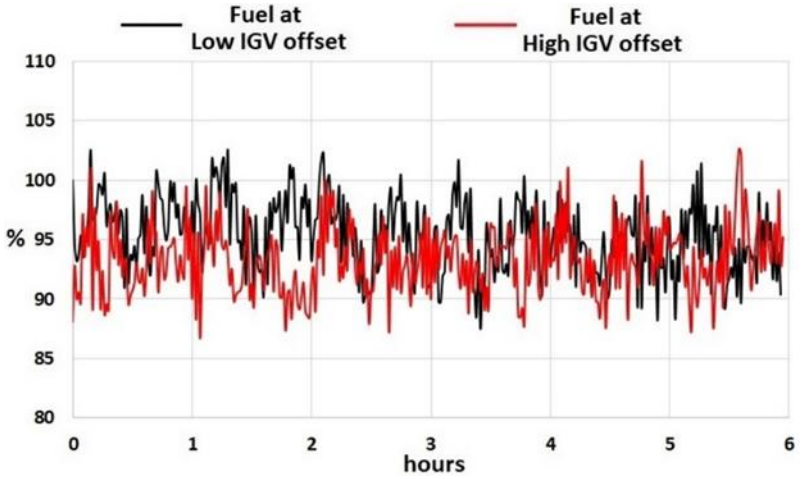
Low vs High VGV offset



Measured power and at low IGV offset

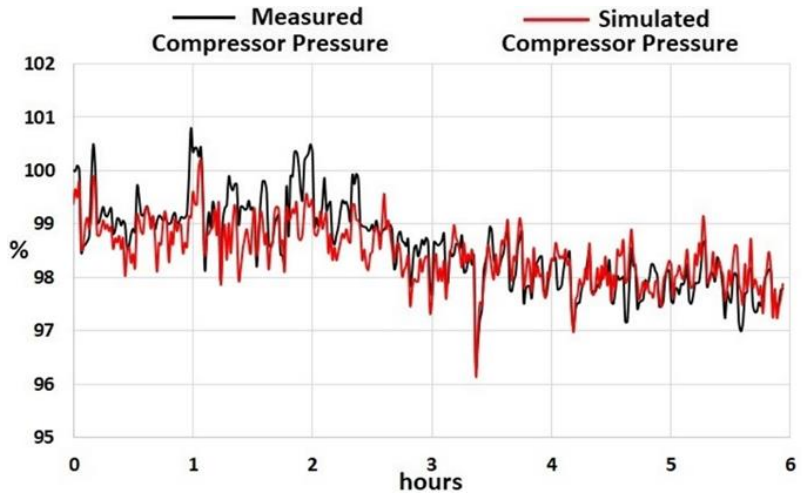


Measured power and at high IGV offset

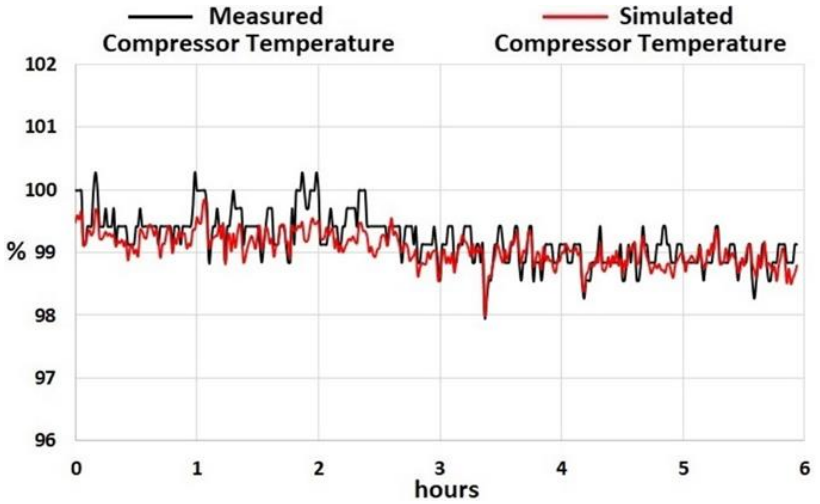


Fuel demand for low and high IGV offset

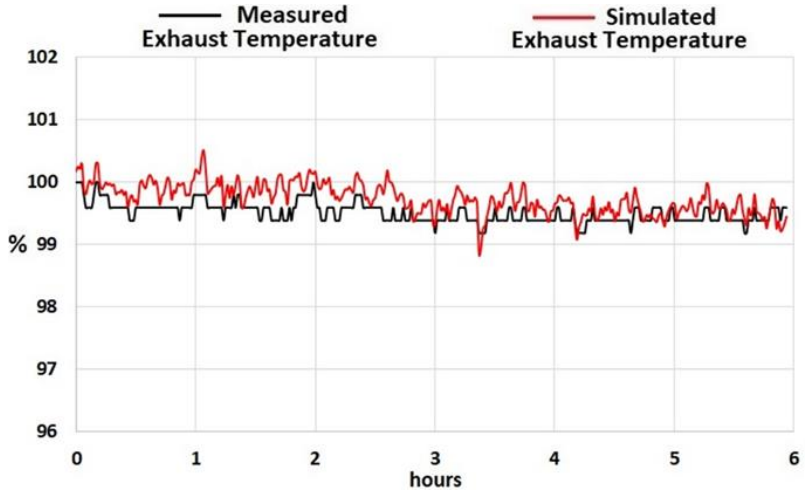
Measured vs simulated data at low IGV offset



Compressor discharge temperature at low IGV offset

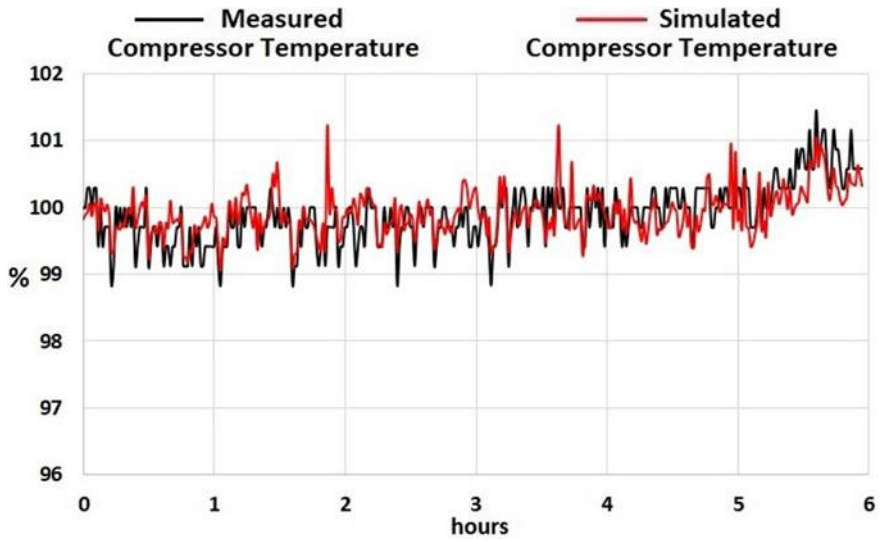


Compressor discharge pressure at low IGV offset

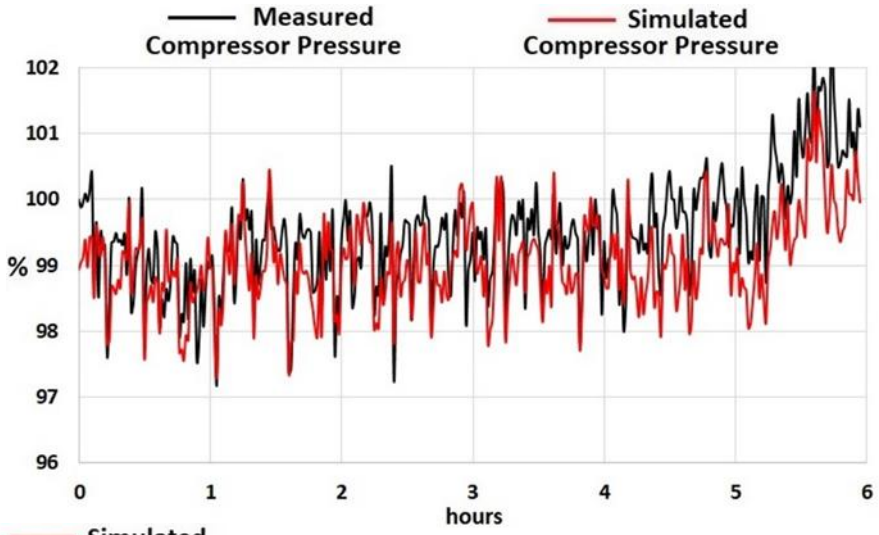


Power turbine exhaust temperature at low IGV offset

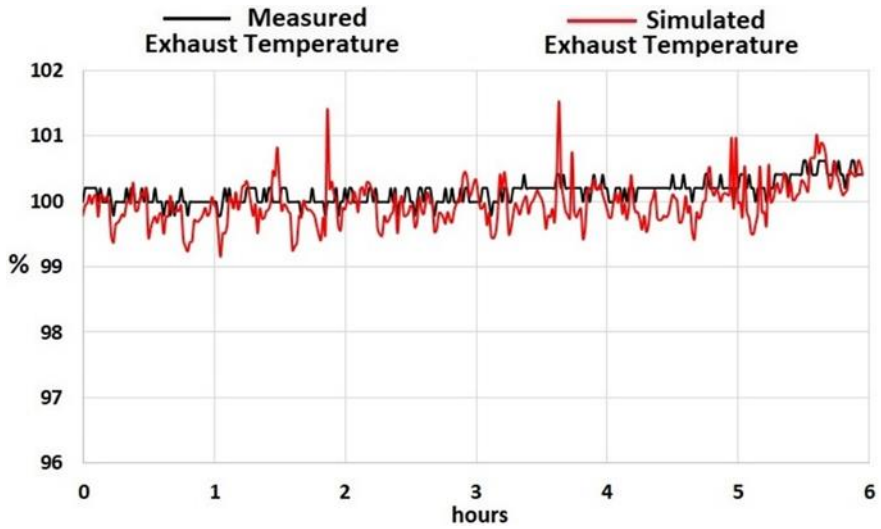
Measured vs simulated data at high IGV offset



Compressor discharge temperature at high IGV offset

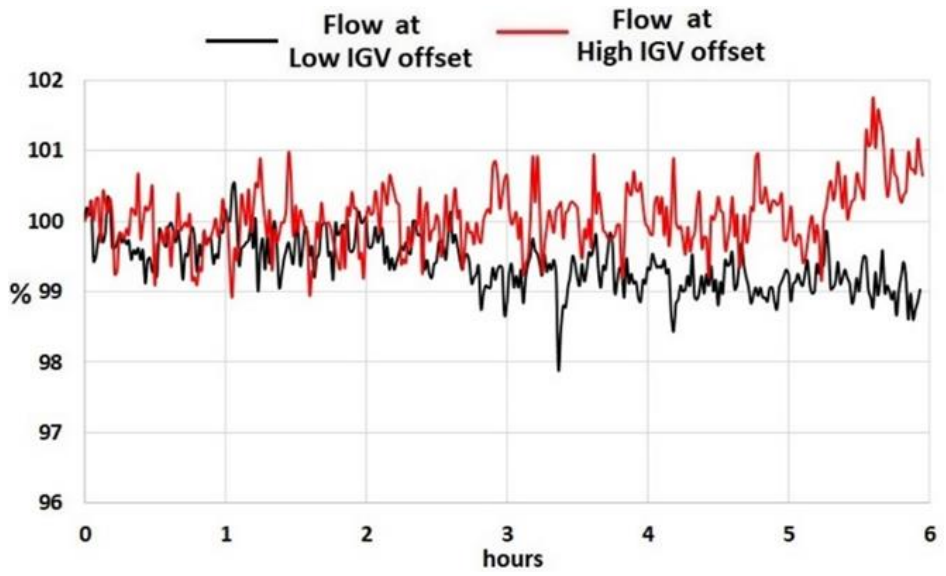


Compressor discharge pressure at high IGV offset

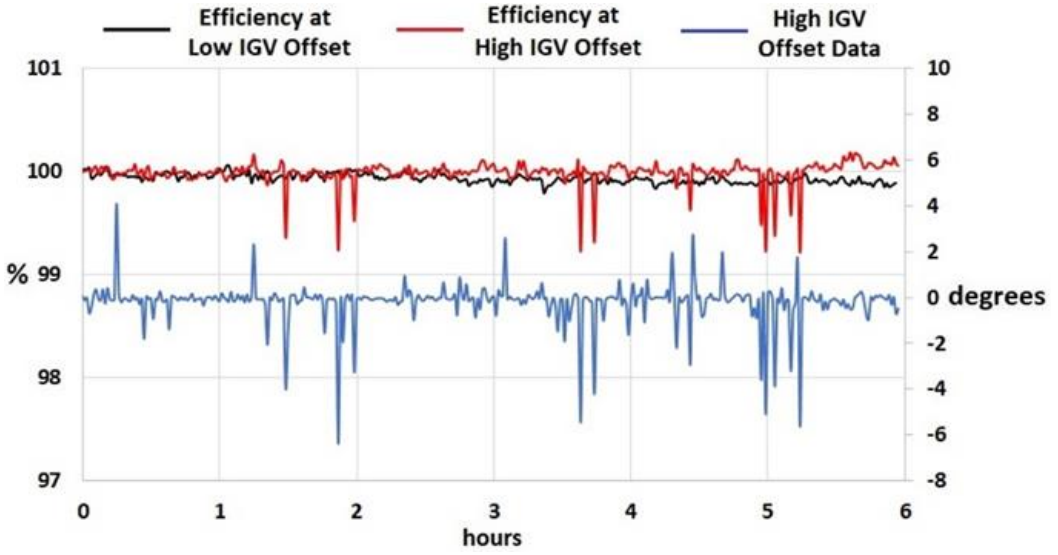


Power turbine exhaust temperature at high IGV offset

Health Parameters – Low vs High VGV offset conditions



Simulated flow discharged by compressor



Simulated compressor efficiency

IGV Offset	% GGS	% CDT	% CDP	% ET
4.1	0.298	0.299	0.663	0.351
2.3	0.079	0.342	0.052	0.102
-3.98	0.700	0.673	0.527	0.816
-6.4	0.739	1.506	0.322	1.387

Error between measured and simulated data

Section 6

Summary & Outlook

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Summary

Performance analysis of Twin-shaft Gas Turbine with a fault in Variable Guide Vane system

- Application of dynamic non-linear physics based model
- Simulation of gas path related degradation/ fault modes
- Deterioration rates ranging from slow & moderate to very fast

Outlook

Future development of Gas Turbine Systems analysis

- Model-based monitoring and diagnostics techniques
- Transition from steady-state towards transient modelling tools
- Advent of on-line & real-time monitoring model-based systems as an enabler of functional digital twin technology

Final page

Thank you for your attention!

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