Integrated Approach for Direct Calculation of Off-design Performance of Gas Turbine Engine

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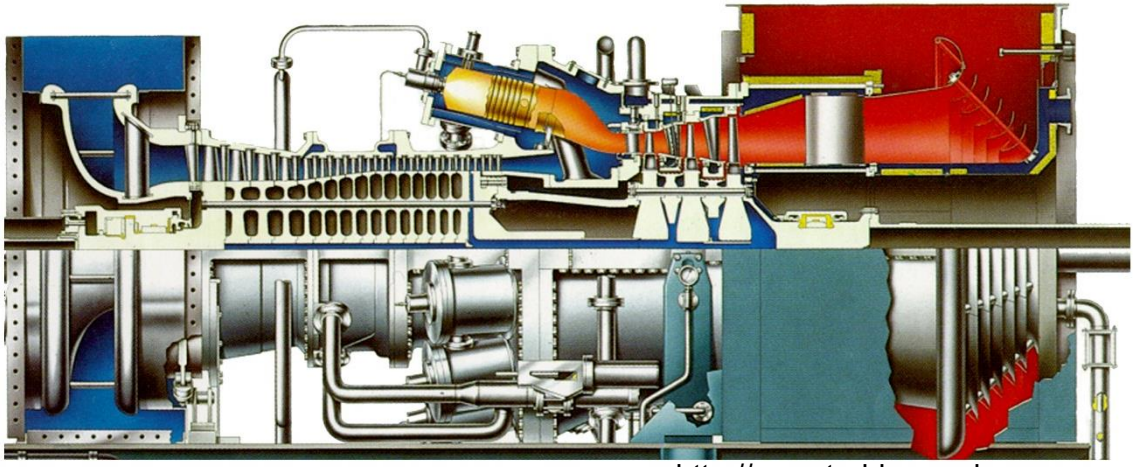
Plan of Presentation

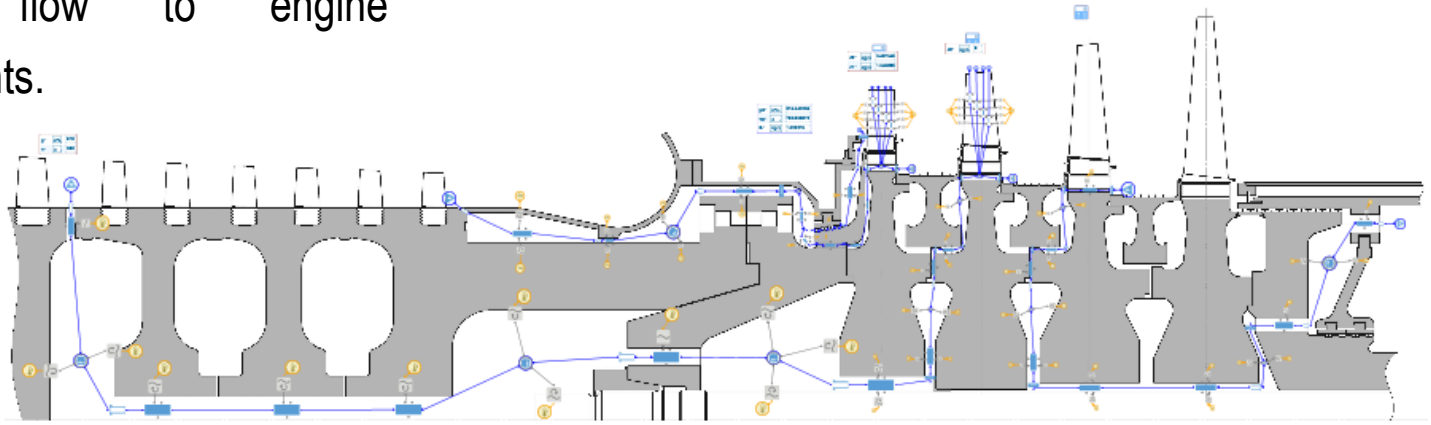
- ✓ Introduction
- ✓ Gas turbine design
- ✓ Gas turbine off-design performance
- ✓ Virtual Test Facility for gas turbine performance
- ✓ Conclusion

Introduction

- ✓ Gas Turbines are used as shaft or propulsive power
- ✓ GT's are required to operate in off-design modes
- ✓ Secondary flows has the main function of providing cooling and sealing flow to engine components.

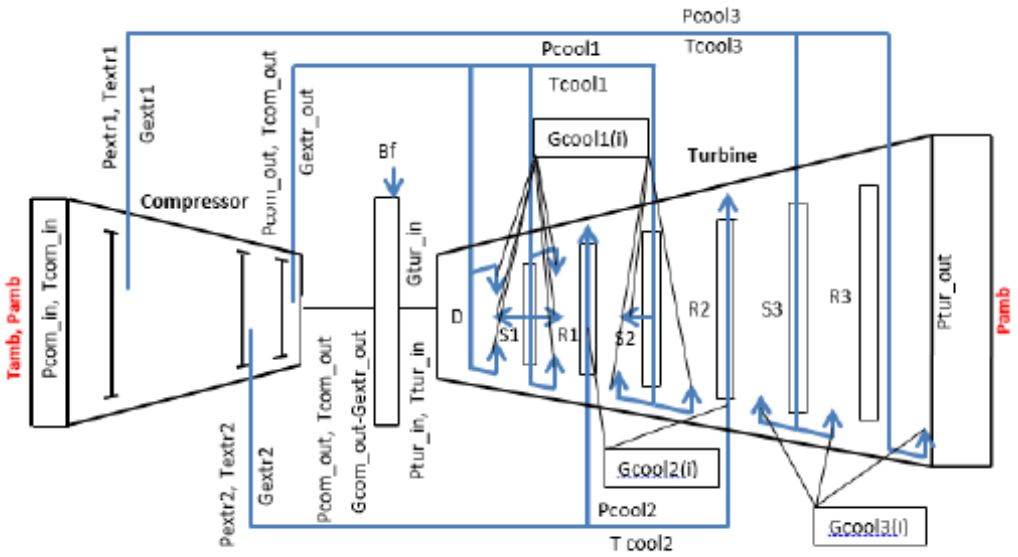


http://www.turbinecowboy.com



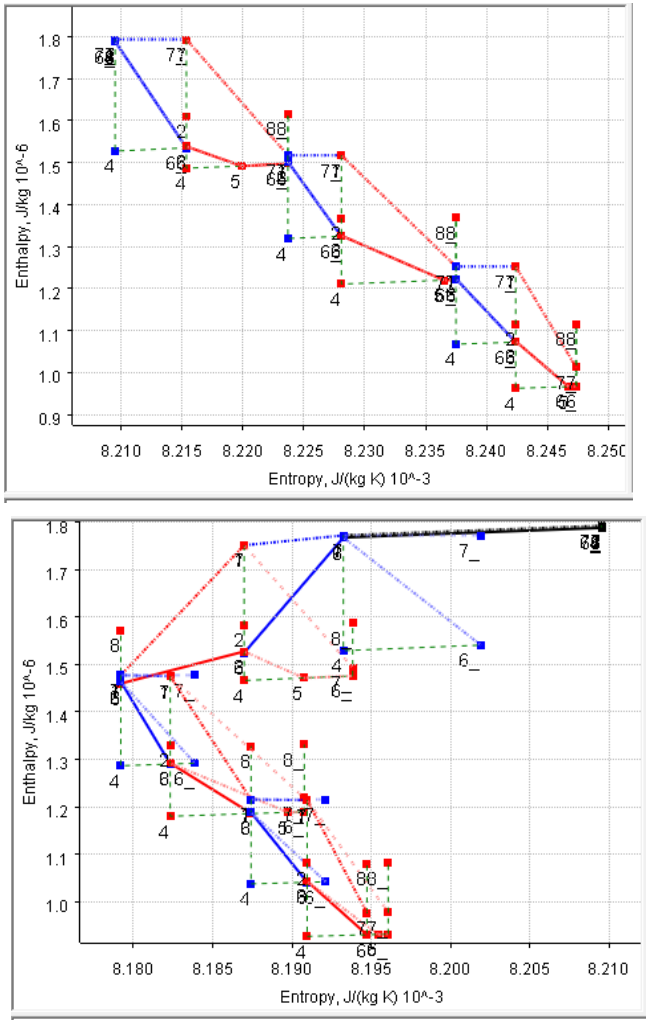
Scheme of secondary flows in a gas turbine engine

Introduction



Gas Turbine cooling system

- ✓ The cooling air extracted from the compressor affects the gas turbine performance
- ✓ The mixing of the cooling flow with the main flow in a gas turbine significantly influences the aero-thermodynamics of the turbine

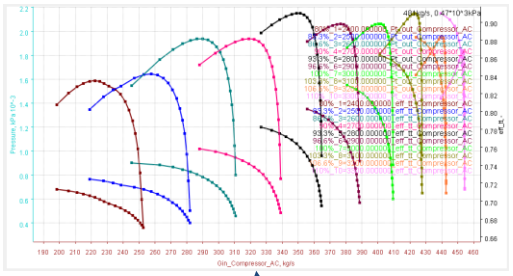


Enthalpy-Entropy Diagram of uncooled & cooled turbine

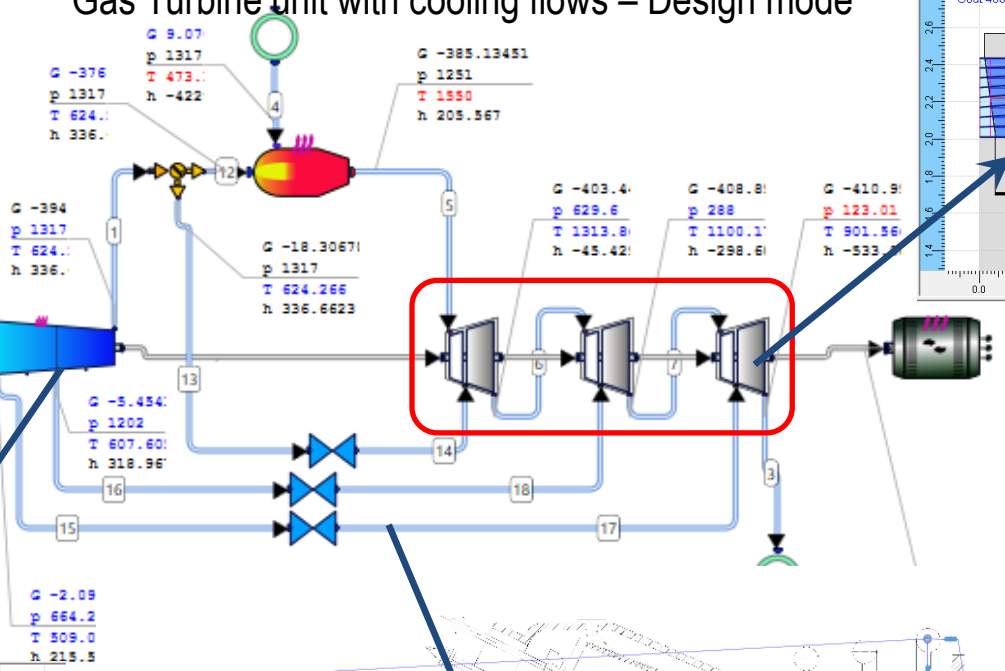
Objectives for Gas Turbine Design

- ✓ The objective is to design a gas turbine unit for a power output of 166 MW
- ✓ The turbine inlet temperature and pressure ratio is to be determined for maximizing the efficiency.
- ✓ Detailed design of the components is to be done considering secondary flows and turbine blade cooling requirements.
- ✓ The off-design performance is to be evaluated considering the gas turbine control as in actual machine using Virtual Test Facility.
- ✓ To compare the results of the off-design performance predicted using Virtual Test Facility and conventional thermodynamic cycle calculation.

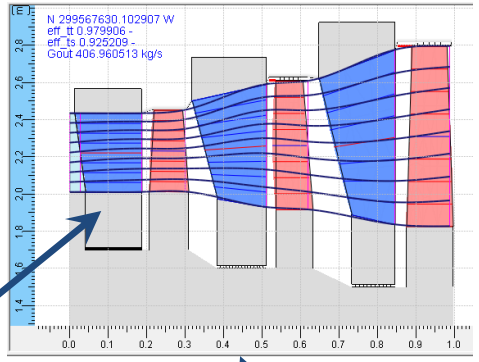
Gas Turbine Design and Performance

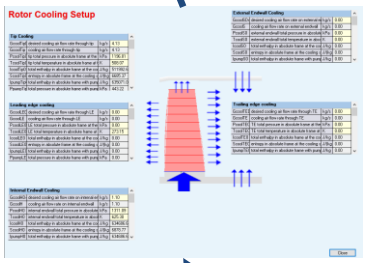


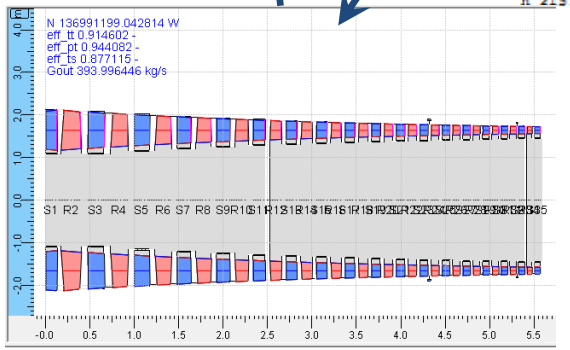
Gas Turbine unit with cooling flows – Design mode



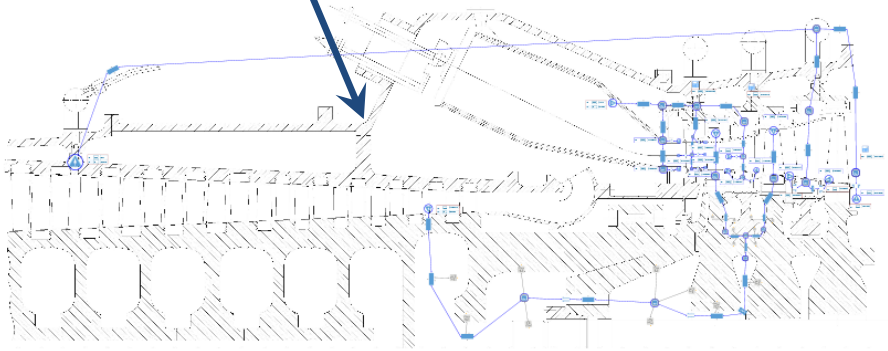
3 stage gas turbine flow path



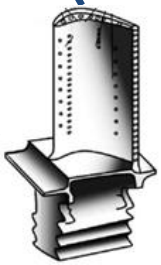




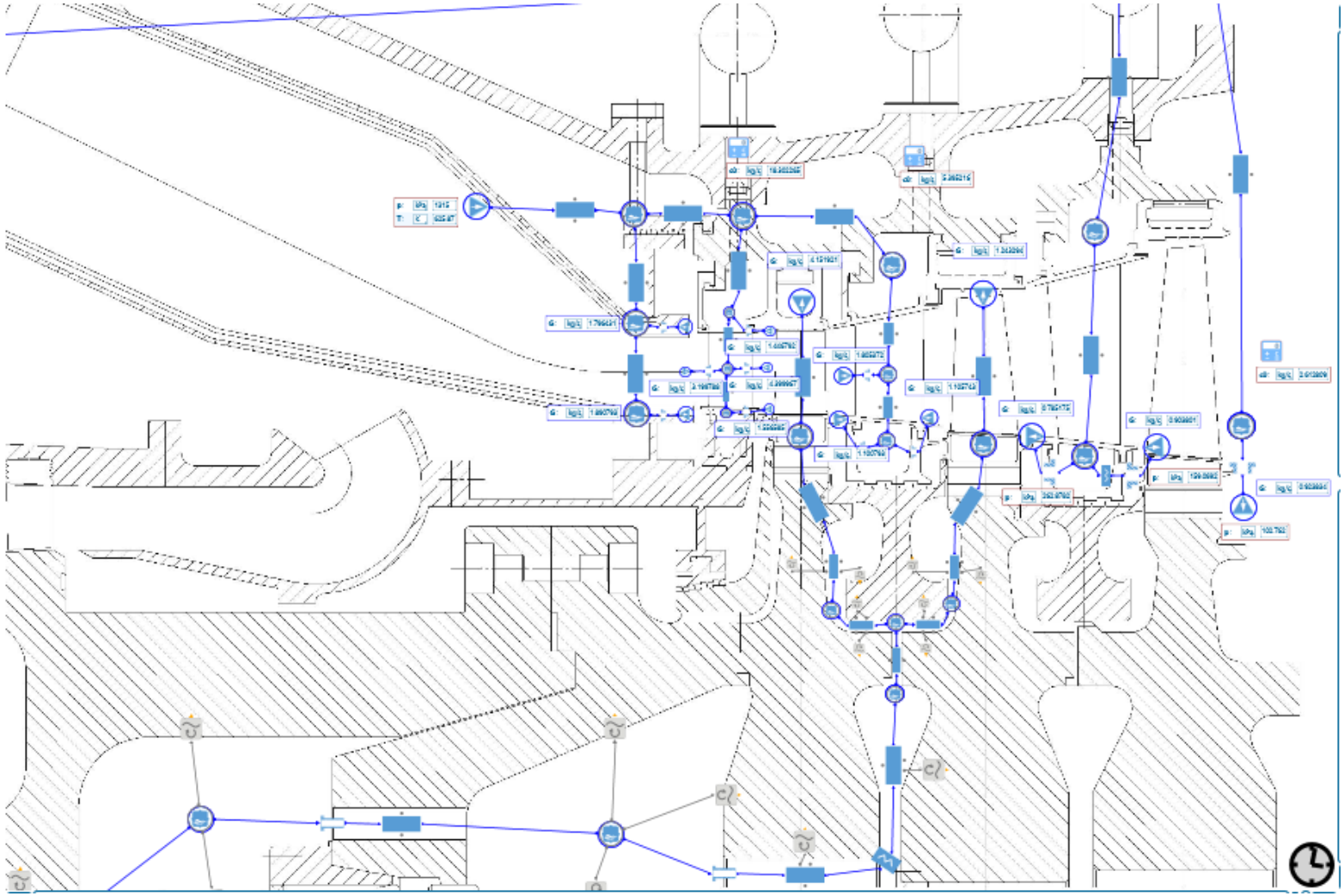
17-stage compressor with bleed



Secondary flow system of the gas turbine



Secondary Flow in AxSTREAM NET™



Gas Turbine Technical Data

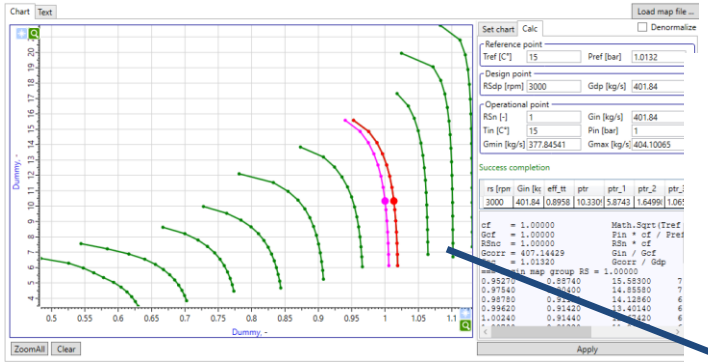
Compressor parameter	Value	Unit
Pressure ratio	12.93	-
No of stages	17	-
Inlet Mass Flow	401.96	kg/s
Shaft rotation speed	3000	rpm
Power	136.99	MW
Polytropic Efficiency	94.4	%

Turbine parameter	Value	Unit
Pressure ratio	12.13	-
No of stages	3	-
Inlet Mass Flow	384.35	kg/s
Shaft rotation speed	3000	rpm
Outlet mass flow	410.52	kg/s
Power	303.87	MW
Cooled Efficiency (T-S)	89.76	%
Turbine Inlet Temp.	1550	K

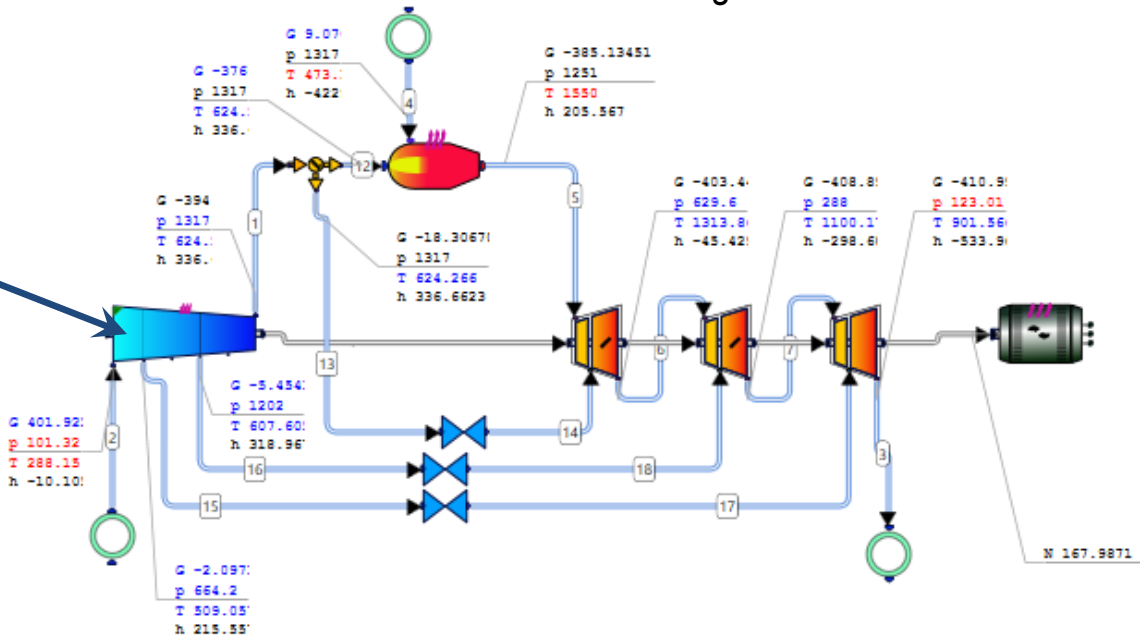
- ✓ The thermal efficiency of the gas turbine unit is 37. 03%

Gas Turbine off-Design Performance

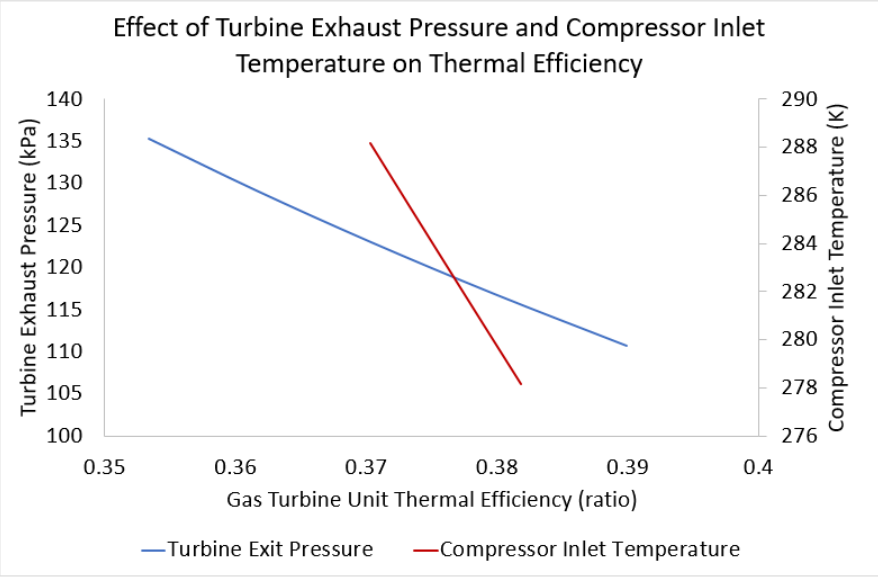
- ✓ The off-design simulation is performed using maps obtained from component design that are matched for common operating points.
- ✓ AxCYCLE™ provides special tool to preview compressor maps and calculate performance using corrected parameters and reference values.

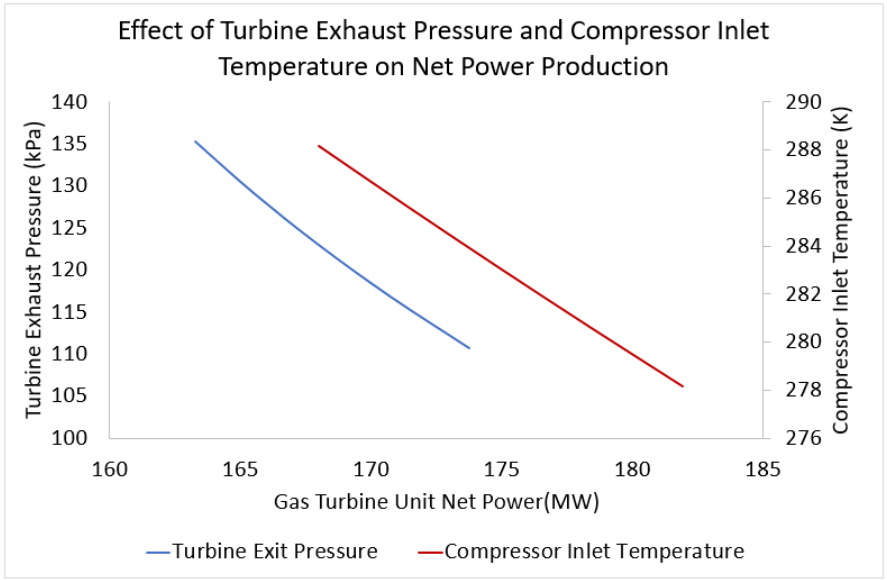


Gas Turbine unit for off-design calculation



Gas Turbine off-Design Performance





- ✓ The off-design performance using AxCYCLE™ can be generated with custom selecting the variables and objectives. The component maps are used for the thermodynamic cycle off-design calculation.
- ✓ Any number of parameters can be studied, here inlet temperature of compressor and exhaust pressure of turbine is varied and presented as an example.

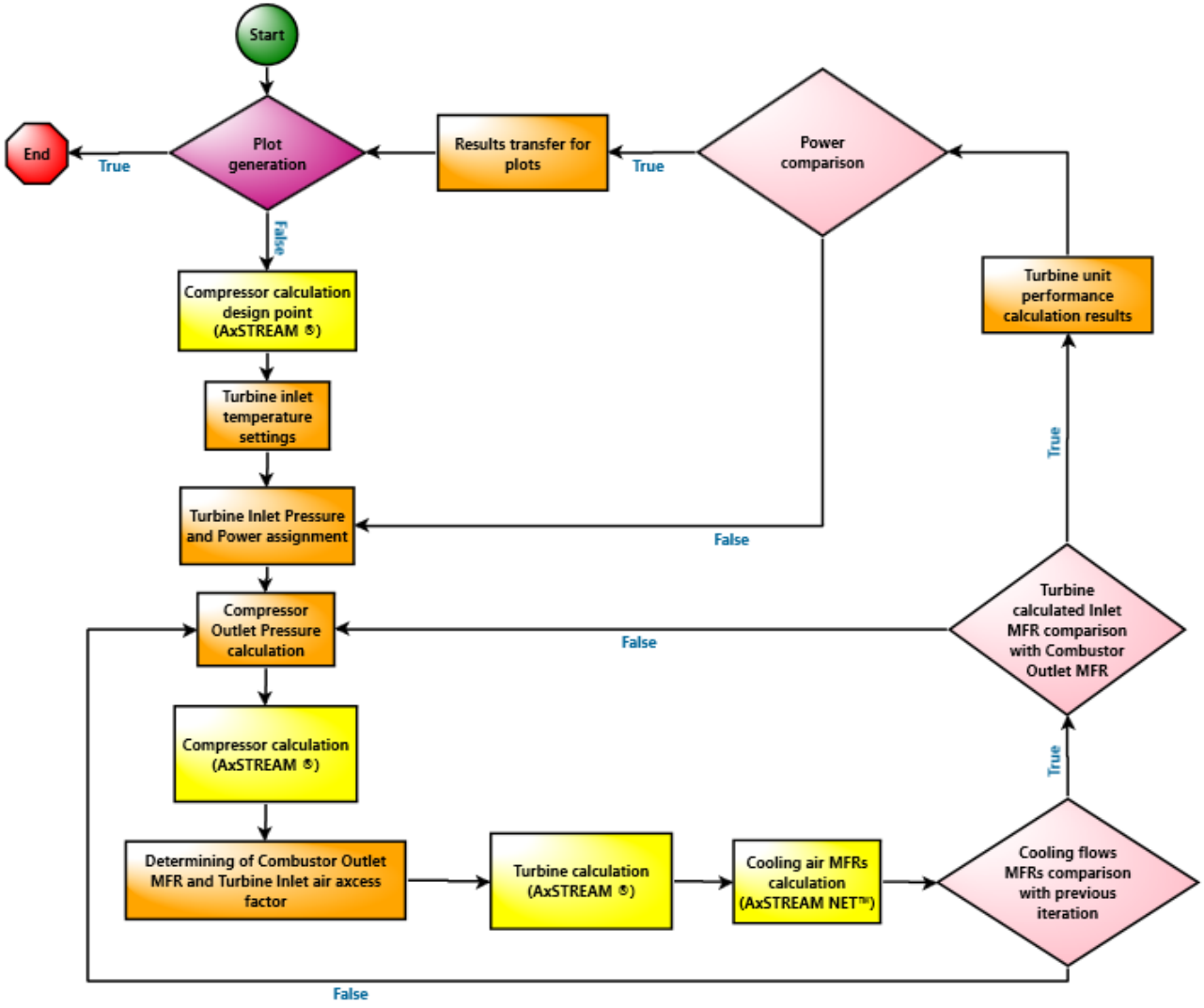
Accuracy of Off-design Calculation

- ✓ Traditionally the component maps are generated and used to calculate the off-design performance of the gas turbine unit.
- ✓ The component maps can be generated using 3D analysis or streamline analysis and can account most of the parameters / variables (like stator re-stagger).
- ✓ The secondary flows and its variation during off-design operation is not accounted which may lead to inaccuracies in off-design performance of the gas turbine unit.
- ✓ When unit performance for different operating modes is predicted without accounting for the actual secondary flows and cooling flows, it affects not only efficiencies but also reliability of the system due to premature failure, blade burnout etc.
- ✓ More accurate prediction is possible when unit performance for design and off-design operational modes are done using direct calculation without usage of component maps.
- ✓ Virtual Test Facility proposed here is a direct calculation method for gas turbine off-design performance prediction.

Introduction to Virtual Test Facility

- ✓ Virtual Test Facility (VTF) is essentially an algorithm for performing the full simulation of a gas turbine unit as in an actual gas turbine operation.
- ✓ The VTF is performed in AxSTREAM® platform powered by AxSTREAM ION™. AxSTREAM ION™ brings multi-disciplinary integration and optimization capabilities to AxSTREAM® Platform.
- ✓ The gas turbine operation is controlled by adjusting inlet guide vanes and/or stator guide vanes and turbine inlet temperatures which is by adjusting the fuel flow.
- ✓ In the presented case only turbine inlet temperatures are changed for power control.
- ✓ The Virtual Test Facility consists of different blocks such as computational blocks, condition blocks, scripting blocks, waiting blocks, optimizing blocks, off-design map generating blocks etc.

Virtual Test Facility Setup



VTF Results

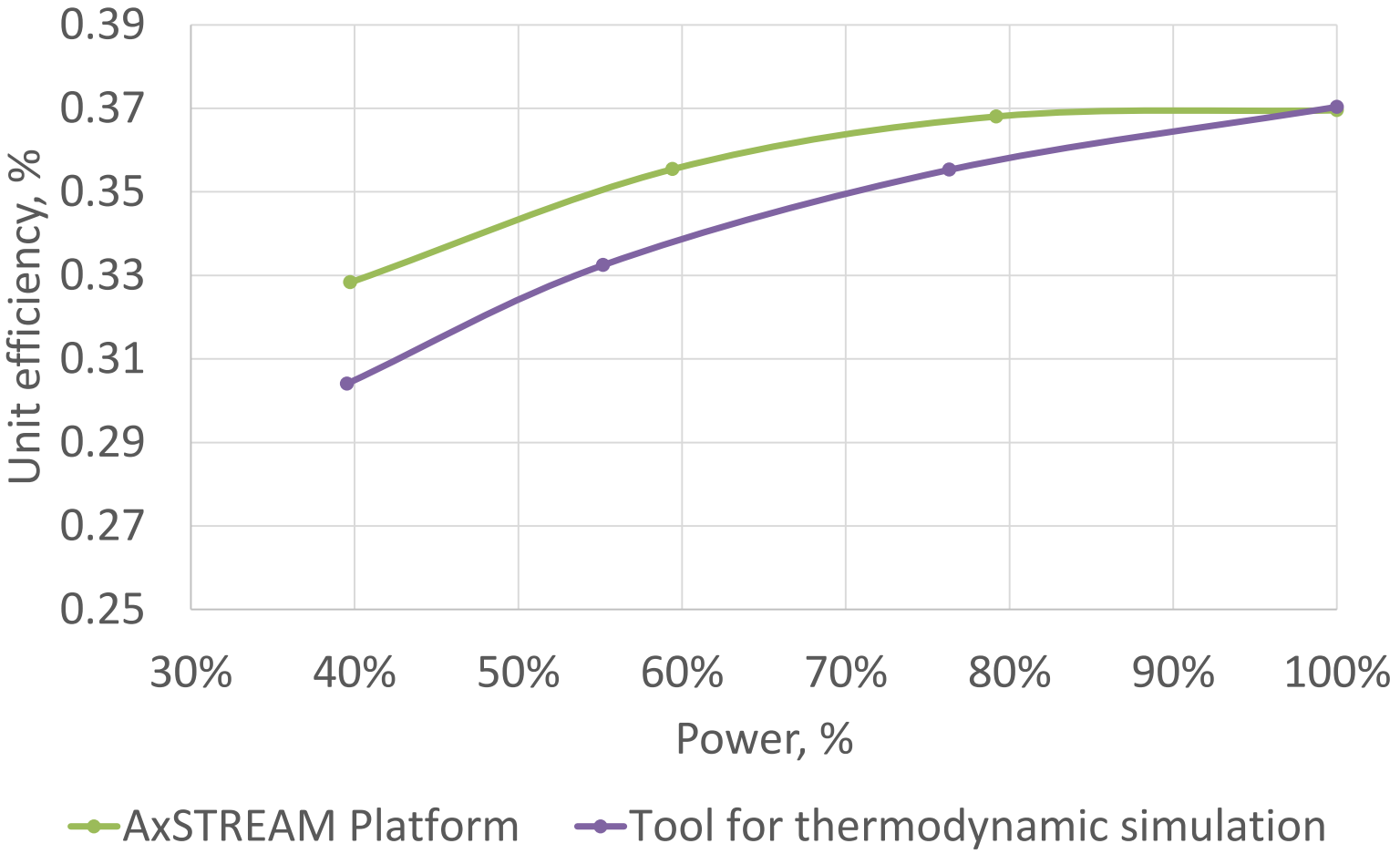


Figure -The dependency of unit efficiency from power level

Conclusion

- Integral characteristics of turbine and compressor are estimated based on detailed calculation with accounting flow path geometry (AxSTREAM® Meanline/ Streamline solver);
- Detailed calculation of cooling system parameters (AxSTREAM NET™).
- Performance calculations were executed using the AxSTREAM® Platform powered by AxSTREAM ION™ and compared with results received with the thermodynamic tool for heat balance calculation.
- The proposed approach with 1D solvers usage results in 2.42% difference in efficiency value at 40 % of unit power in comparison with results obtained with the conventional thermodynamic solver.

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