GTEN 2019 Symposium
October 21-23, 2019 | Banff, Alberta

GAS TURBINE PERFORMANCE FOR MECHANICAL DRIVE APPLICATIONS

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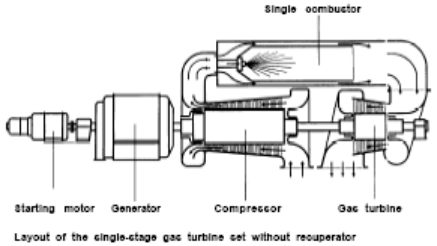
Industrial Gas Turbines

- Drivers for
  - Compressors
  - Pumps
  - Generators

Outline

- Components
- Working Principles
- Off Design Performance

Power Generation in 1939



Layout of the single-stage gas turbine set without recuperator

Worlds first simple cycle industrial gas turbine in industrial use

4000kW

Neuchatel, Switzerland

BBC

1939

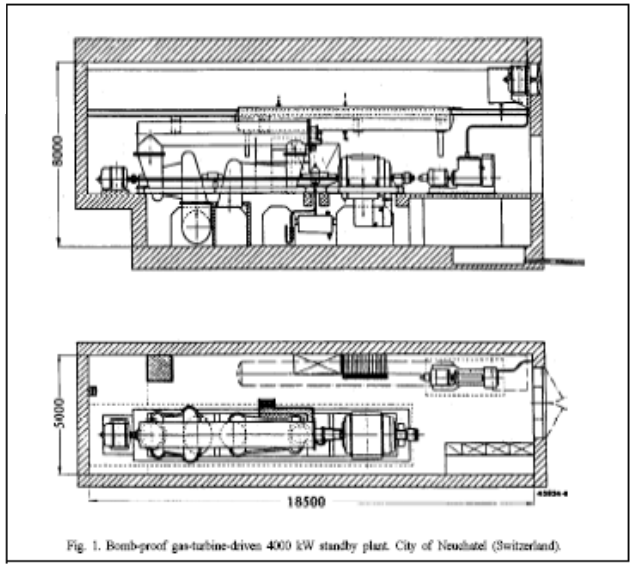
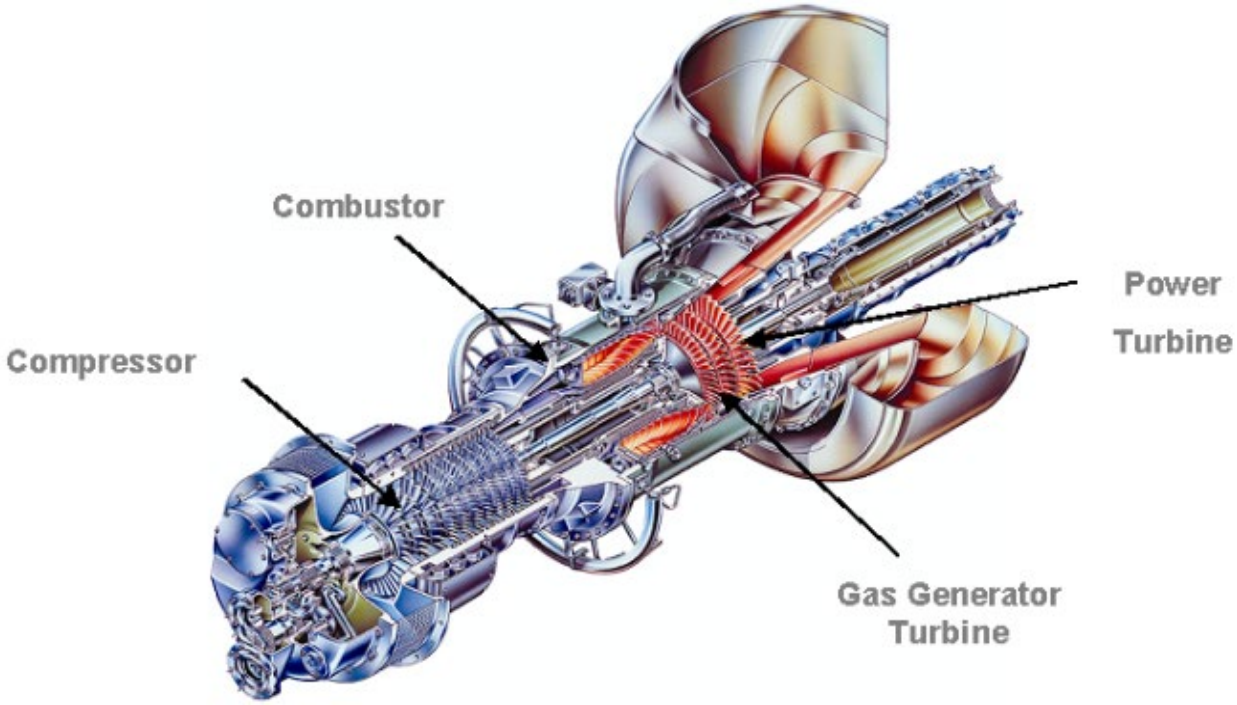
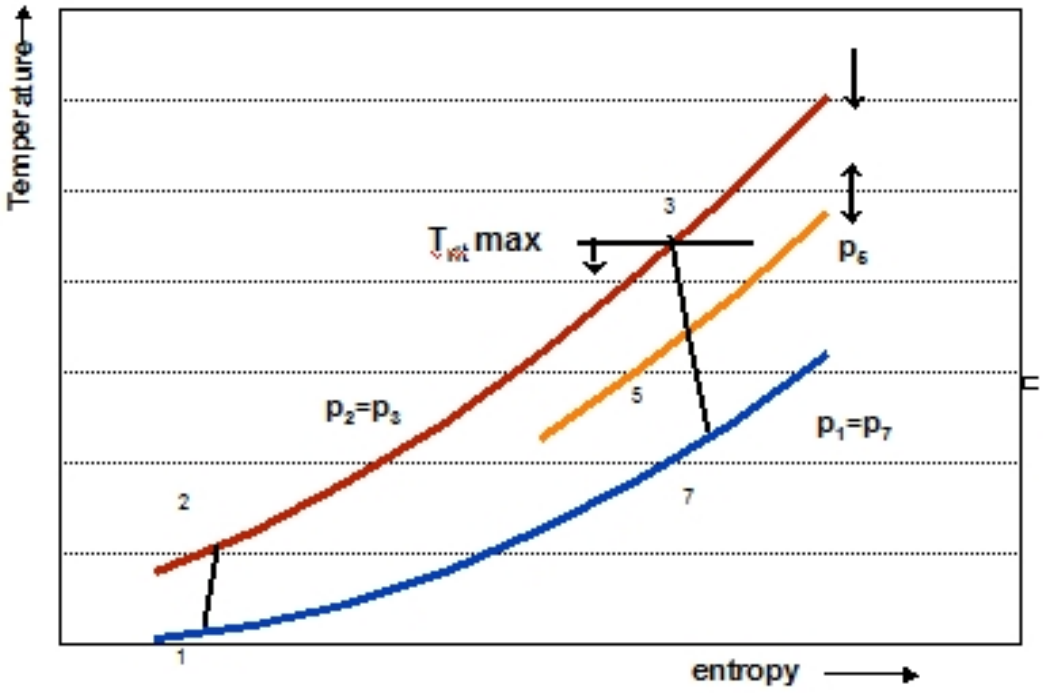


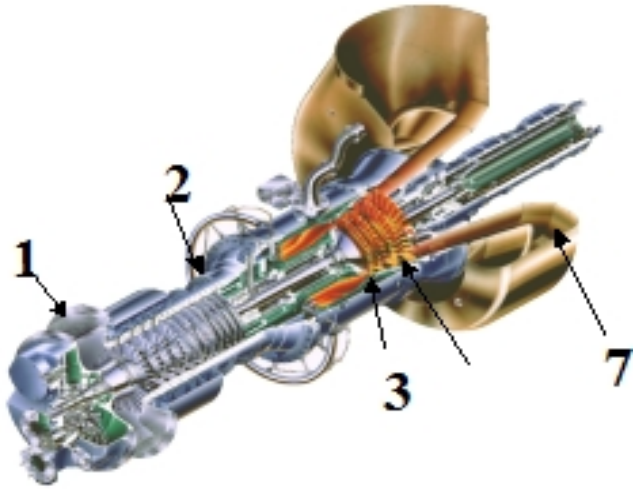
Fig. 1. Bomb-proof gas-turbine-driven 4000 kW standby plant. City of Neuchatel (Switzerland).

Components of a typical industrial gas turbine

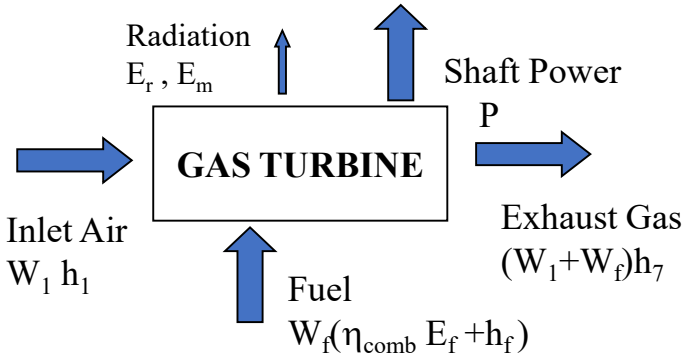


The Brayton Cycle





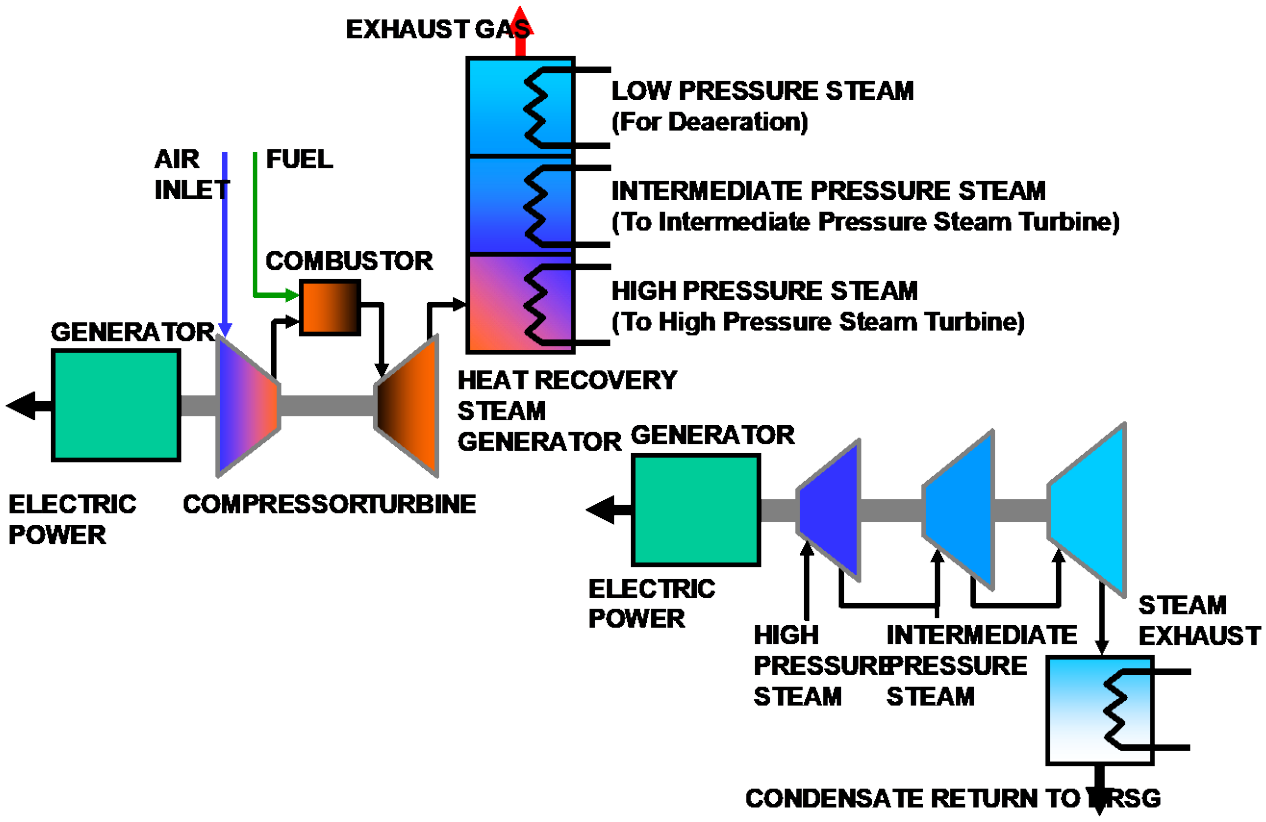
1st Law of Thermodynamics: Energy In = Energy Out



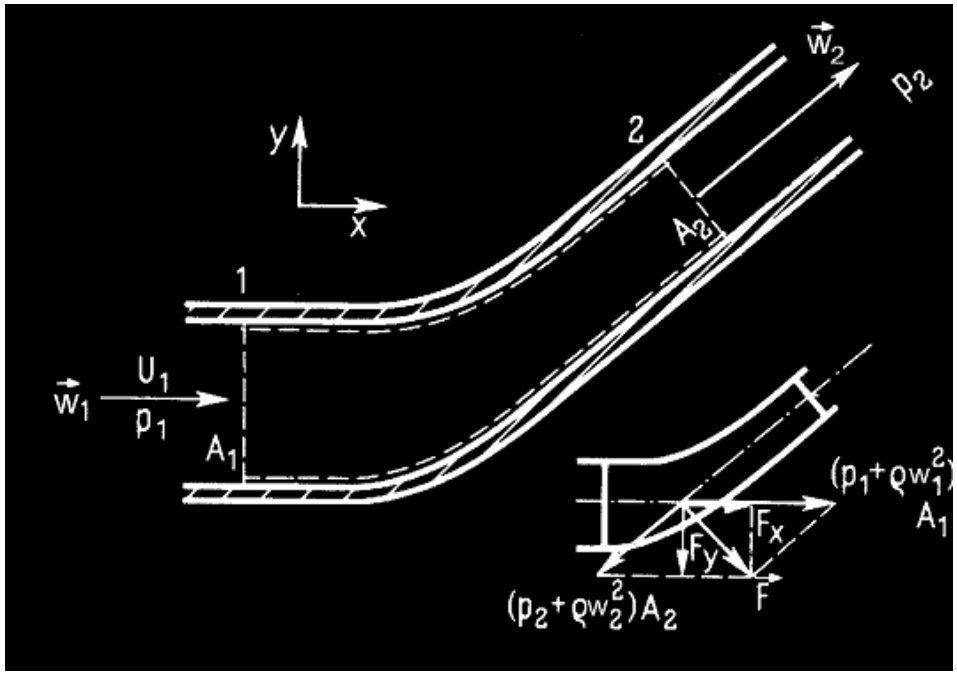
$$\eta_{th} = \frac{P}{W_{fuel} \cdot LHV_{fuel}}$$

$$HR = \frac{W_{fuel} \cdot LHV_{fuel}}{P}$$

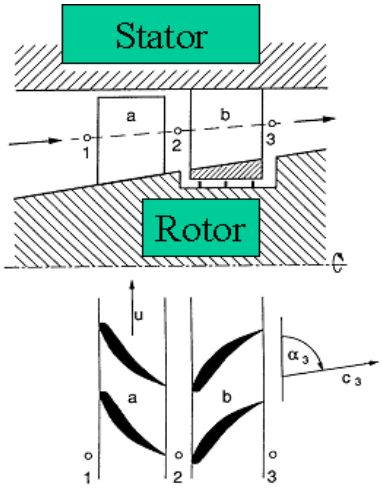
Combined Cycle (Brayton and Rankine)

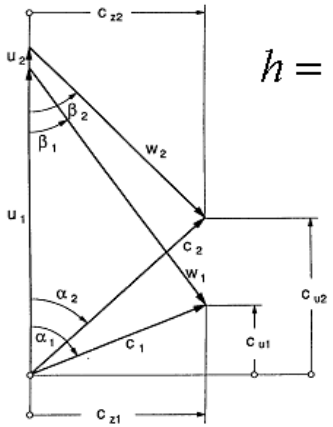


Momentum



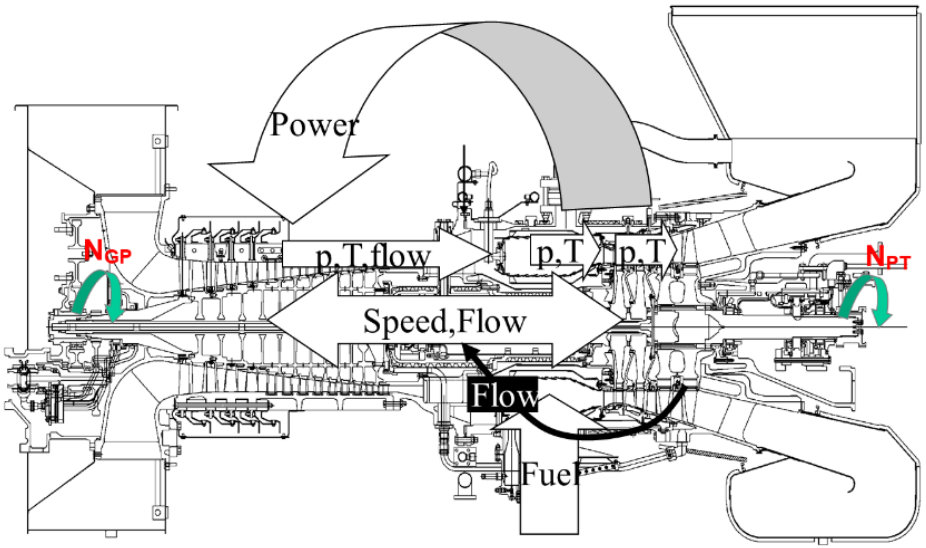
Working principles -Euler





$$h = c_{u2} \cdot u_2 - c_{u1} \cdot u_1$$

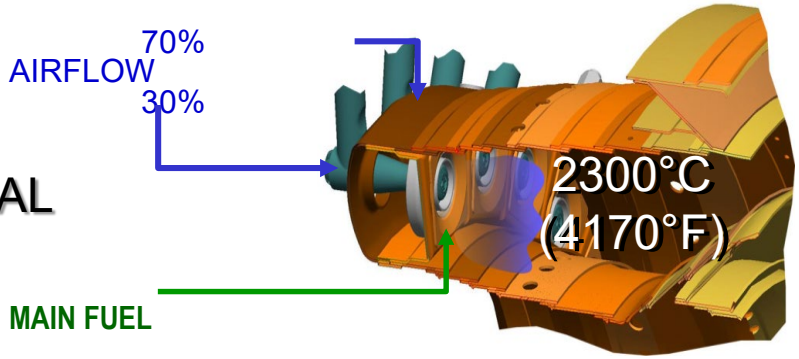
Component Interaction



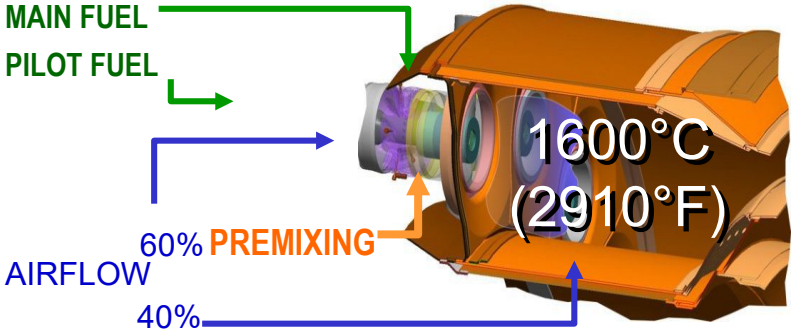
- Gas Generator Power Equals Compressor Power
- Gas Generator and Compressor Run at same speed
- Fuel Energy is converted into heat (almost completely)
- Turbine nozzles are ‘the bottleneck’ and determine the airflow/ pressure ratio through the engine
- Two Shaft: The Power Turbine can operate at arbitrary speed. Its flow characteristic determines the Gas Generator operating point.

Combustion Systems

CONVENTIONAL



SOLONOX



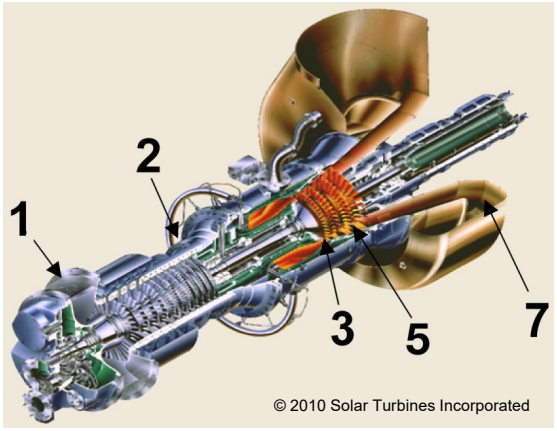
The Control of Gas Turbines

Engine Controls

- Fuel
- Variable Inlet Guide Vanes
  - During Start-Up: To avoid Surge
  - For Single Shaft SoLoNOx: To control Fuel/Air Ratio in the combustor
  - For Two Shaft: Control NGP such that engine will run at full mechanical speed even at temperatures above match
- Bleed
  - During Start-Up: To avoid Surge
  - For Two Shaft SoLoNOx: To control Fuel/Air Ratio in the combustor

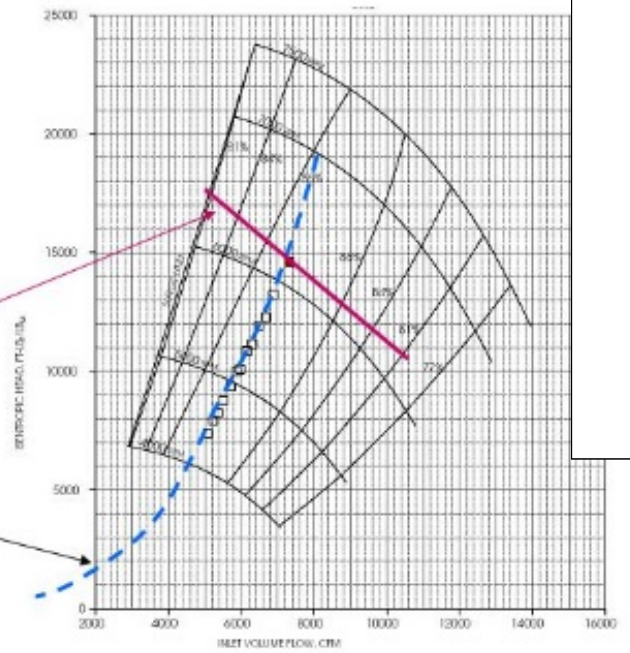
Engine Controls Pt 2

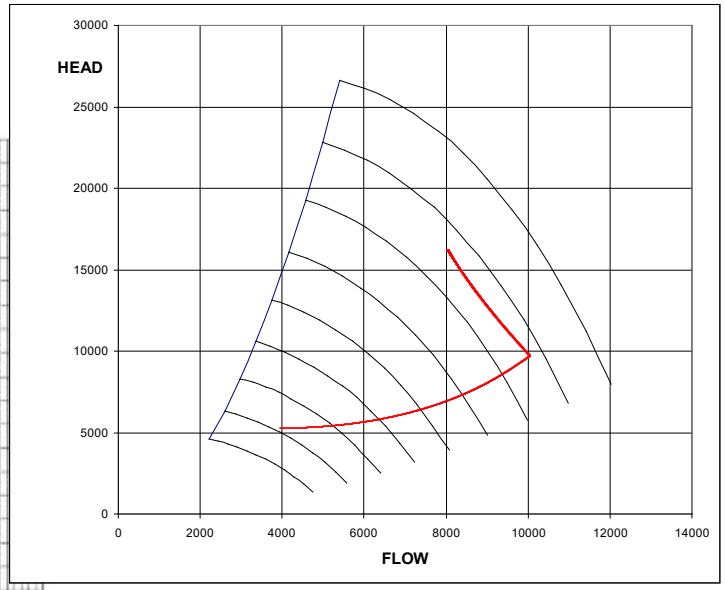
- Controlling the Temperature
  - **T_3 needs to be controlled, but usually, either T_5 or T_7 are measured**
  - **T_7 : Ok for Single shaft, Problematic for two shaft (var. PT speed)**
  - **T_5 : T_3/T_5 relationship determined by test (air flow necessary for energy balance), however some dependency on T_1.**



Process Control

For Given Load Setting (eg NGP), Compressor Will Operate at Point Determined By Available Power and Pipeline Characteristic



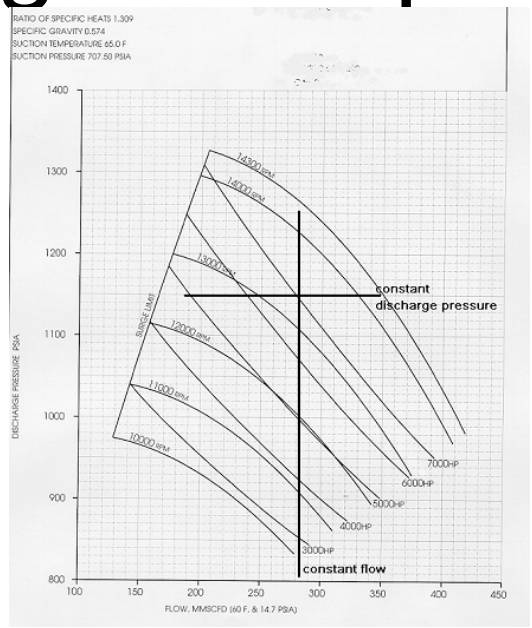


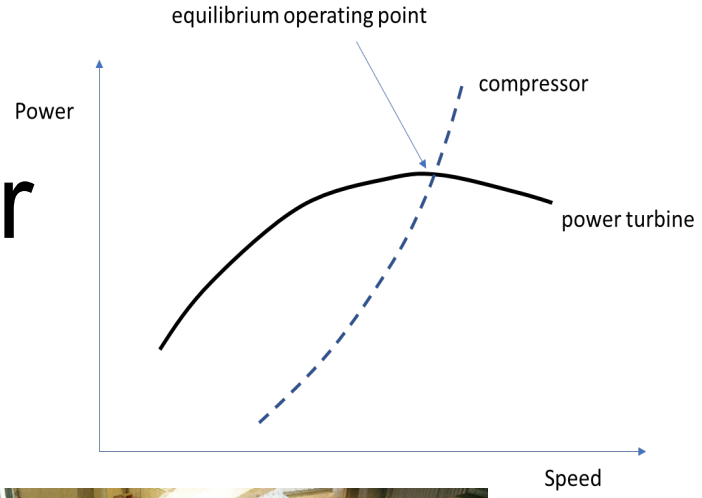
Steady state

Transient

Gas Turbine Driven Centrifugal Compressor

- Variable speed, controlled by power input

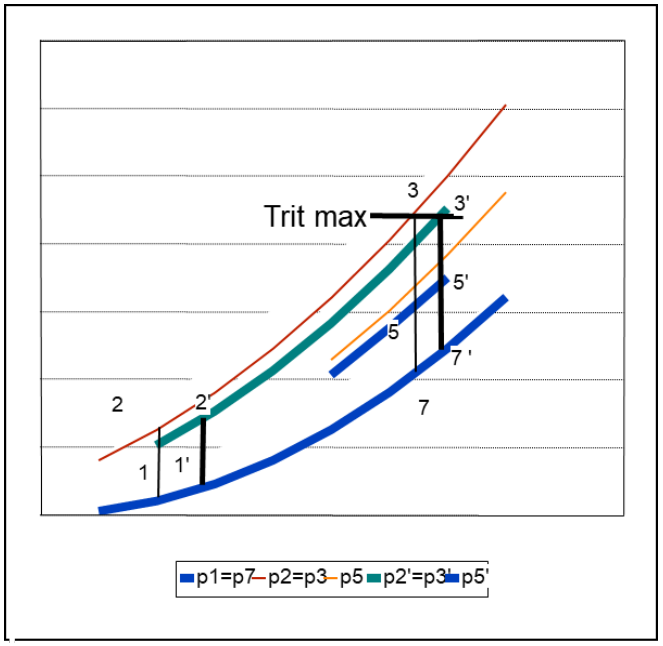




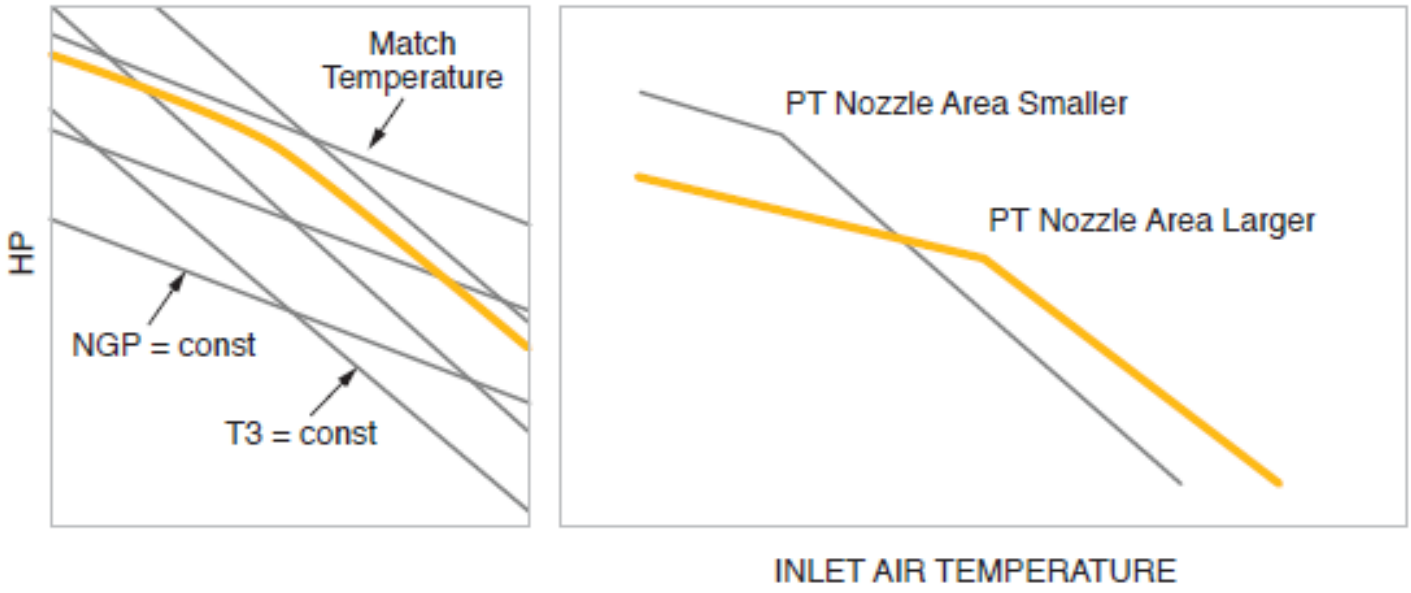
Off Design Performance

- Ambient Temperature
- Ambient Pressure
- Inlet / Exhaust Pressure Losses
- Accessory Loads
- Relative Humidity
- Load
- Power Turbine Speed
- Fuel
- Accessory Loads

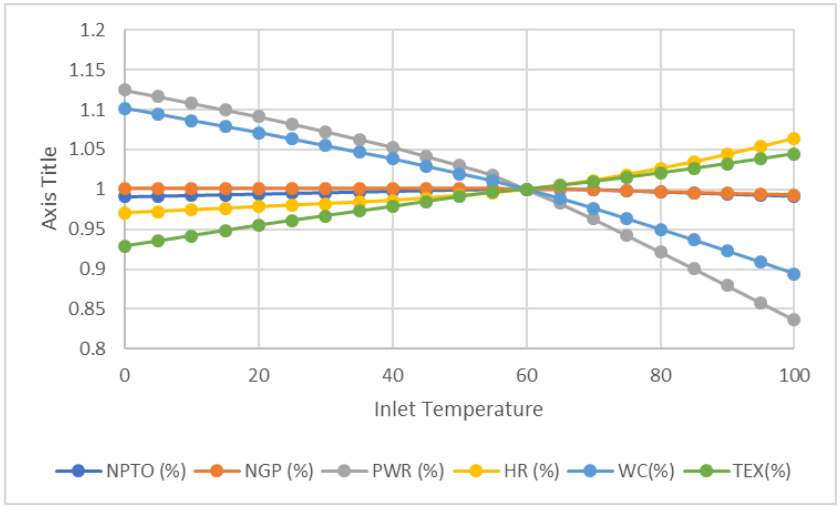
Ambient Temperature



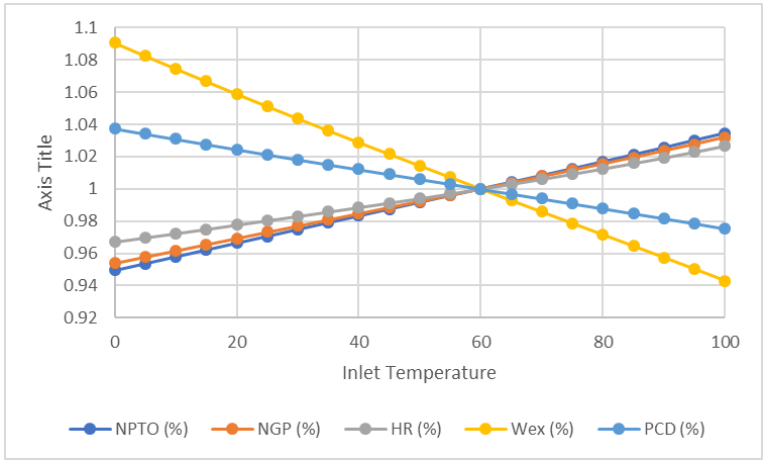
Matching


Match
Temperature
HP
NGP = const
T3 = const
PT Nozzle Area Smaller
PT Nozzle Area Larger
INLET AIR TEMPERATURE

Ambient Temperature

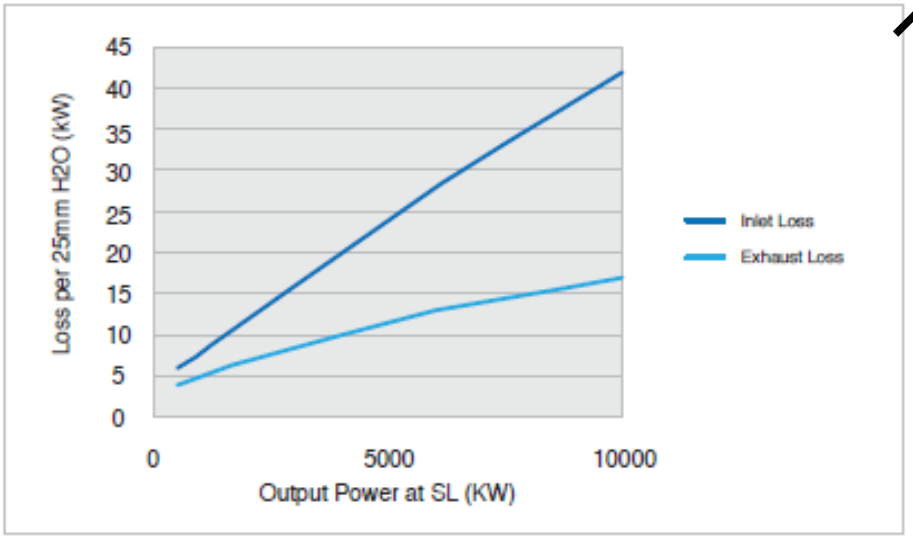


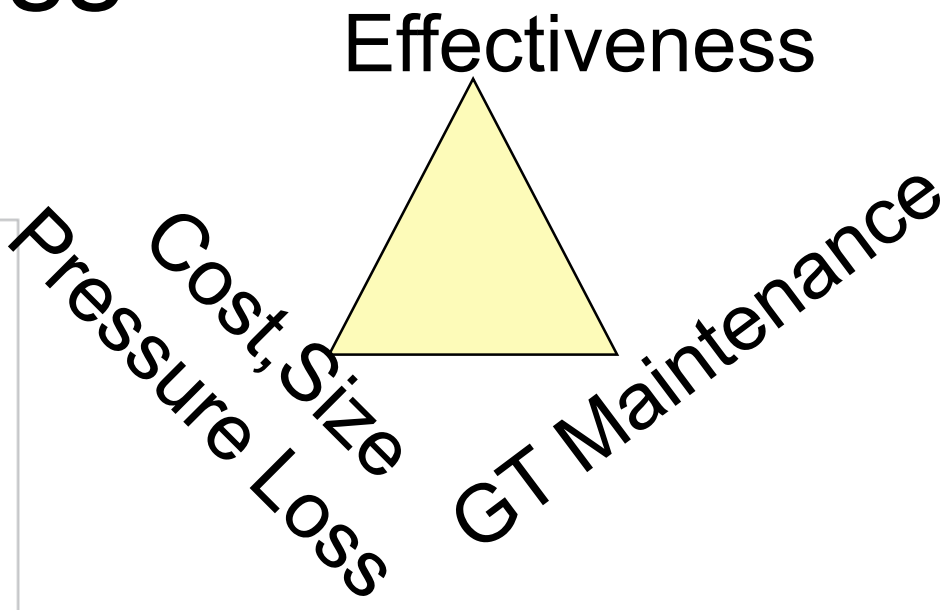
2 Shaft Full Load



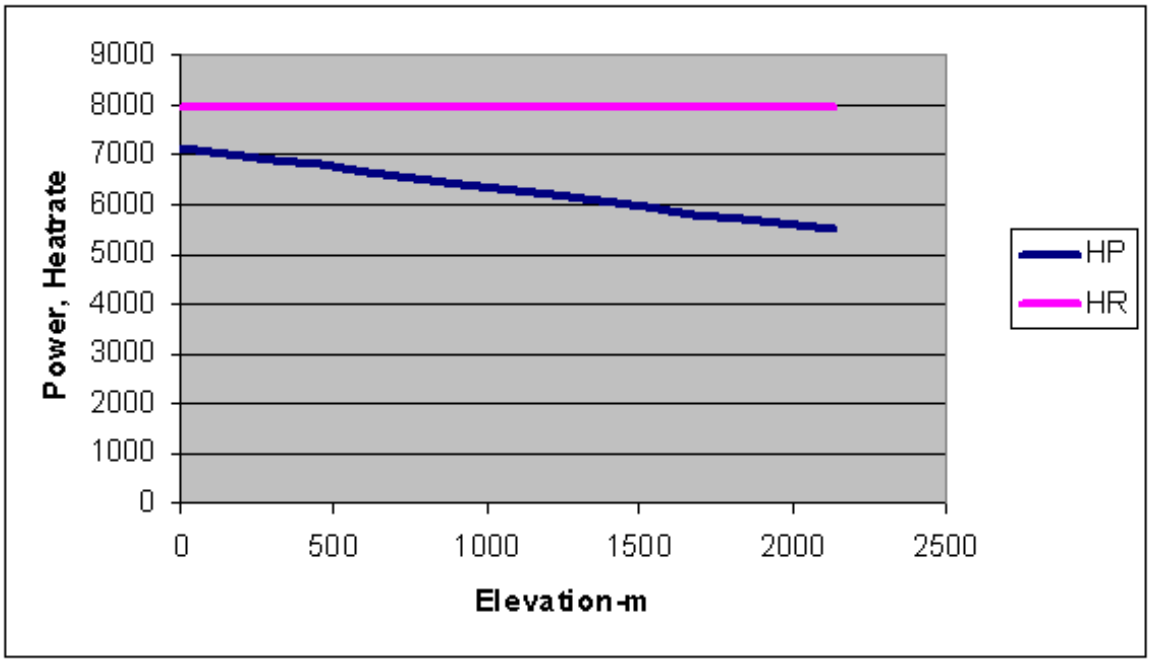
2 Shaft Constant Load

Inlet/Exhaust loss

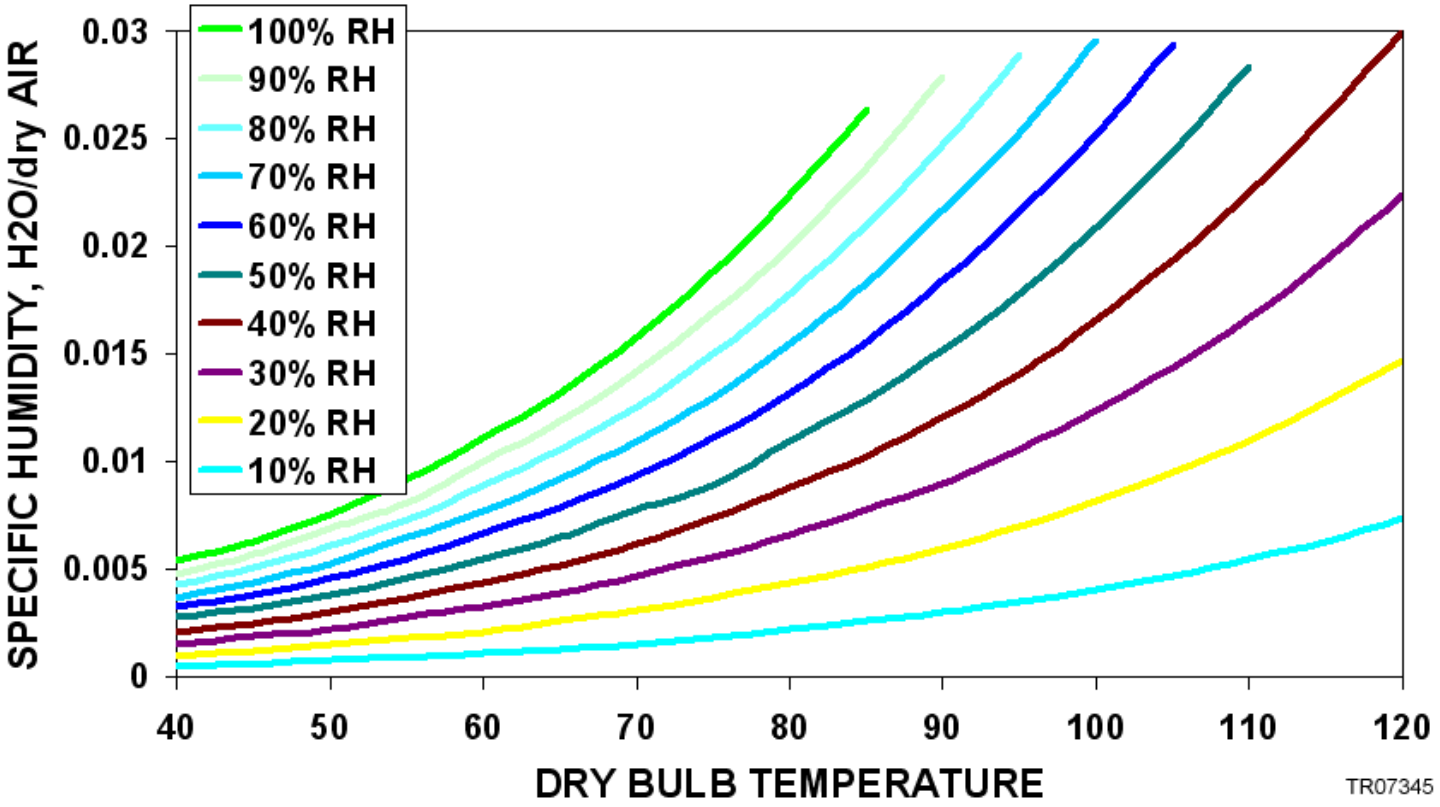




Site Elevation



Humidity


100% RH
90% RH
80% RH
70% RH
60% RH
50% RH
40% RH
30% RH
20% RH
10% RH
SPECIFIC HUMIDITY, H2O/dry AIR
0.03
0.025
0.02
0.015
0.01
0.005
0
40
50
60
70
80
90
100
110
120
DRY BULB TEMPERATURE
TR07345

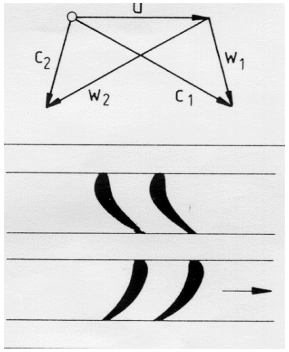
Variable Power Turbine Speed

Design

$$c_{u2} \approx o$$

$$c_{u1} \approx u$$

$$h \approx u^2$$

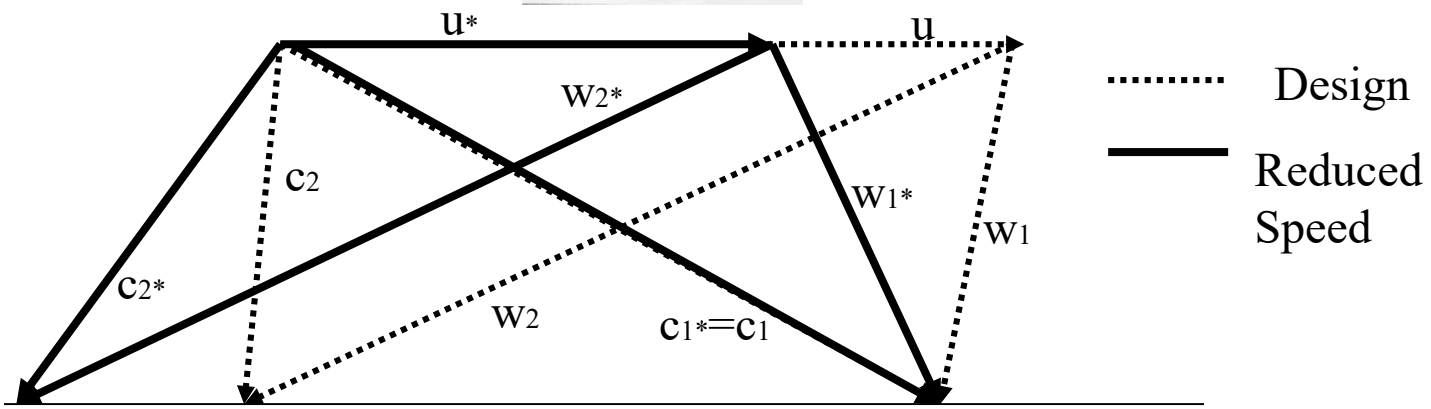


Off-Design

$$c^*_{u2} \approx u^* - u$$

$$c^*_{u1} \approx c_{u1} \approx u$$

$$h^* \approx u^*(2u - u^*)$$



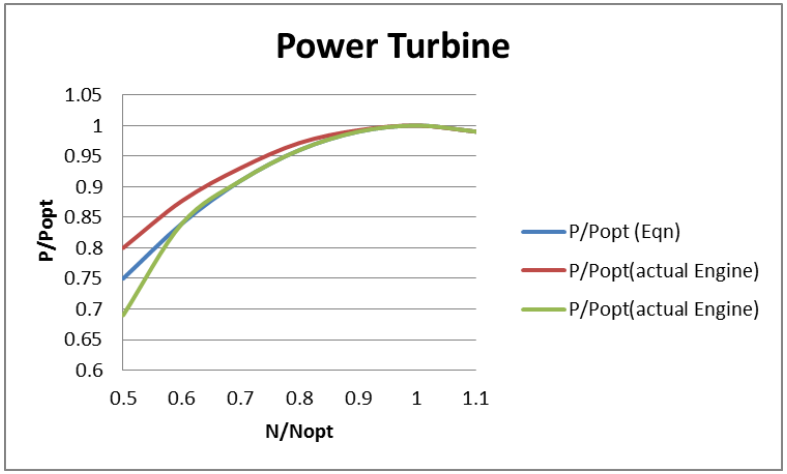
cax*=cax (Choke condition)

Power Turbine Characteristic

$$h^* \approx u^*(2u - u^*)$$

$$\frac{P*}{P} = \frac{h*}{h} = \frac{u^*(2u - u^*)}{u^2}$$

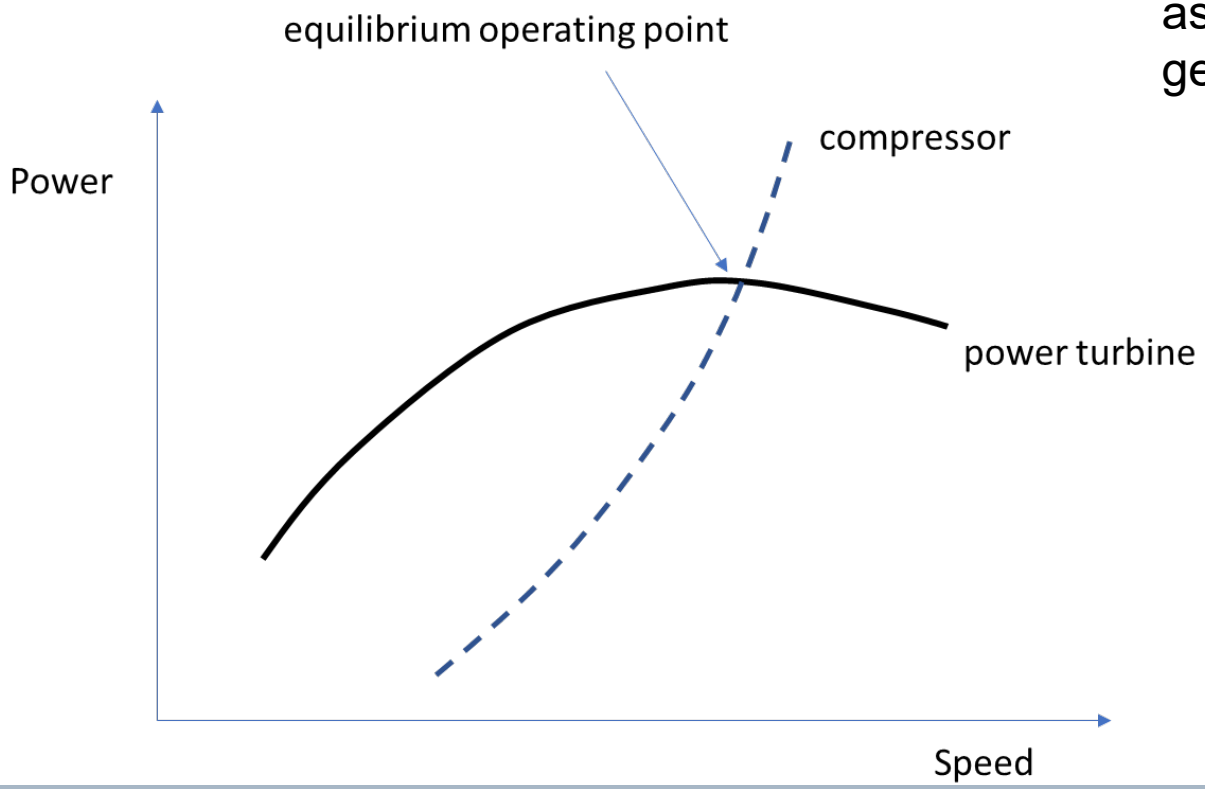
$$= \frac{2N^*}{N} - \left(\frac{N^*}{N}\right)^2$$



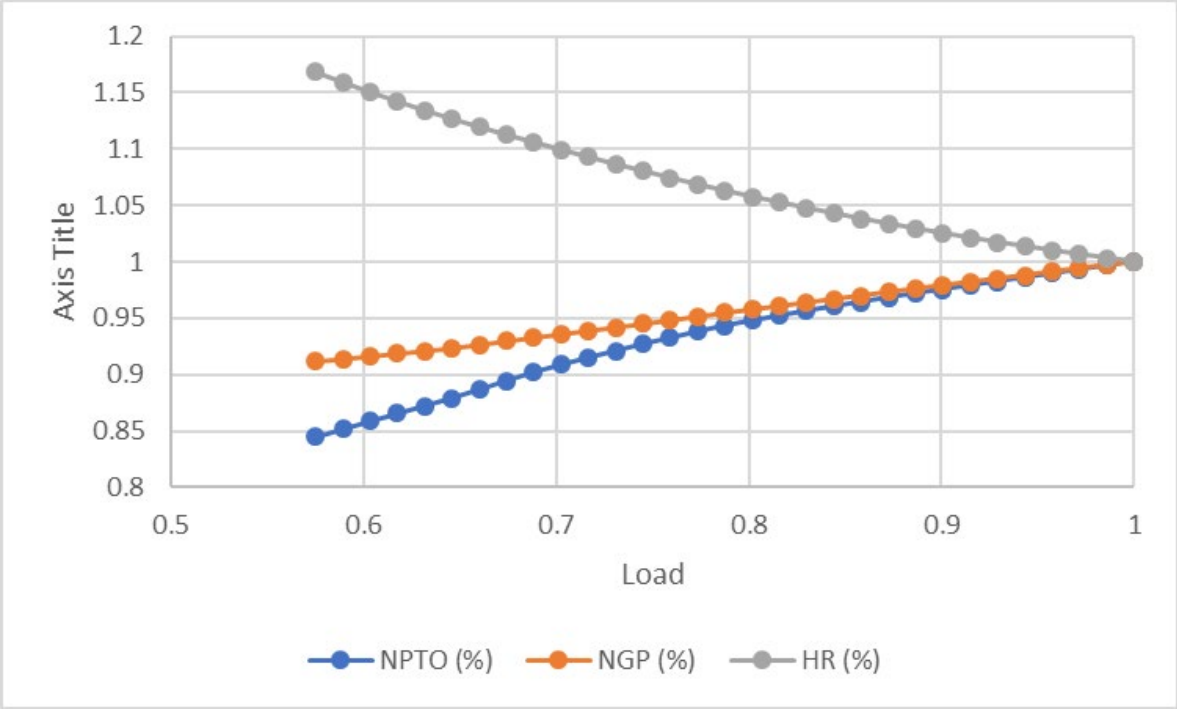
W*=W (Choke condition, Same Gas Generator Operating Point)

Speed-Power relationship for a driven centrifugal compressor and the power turbine.

The power turbine curve assumes a constant gas generator operating condition.

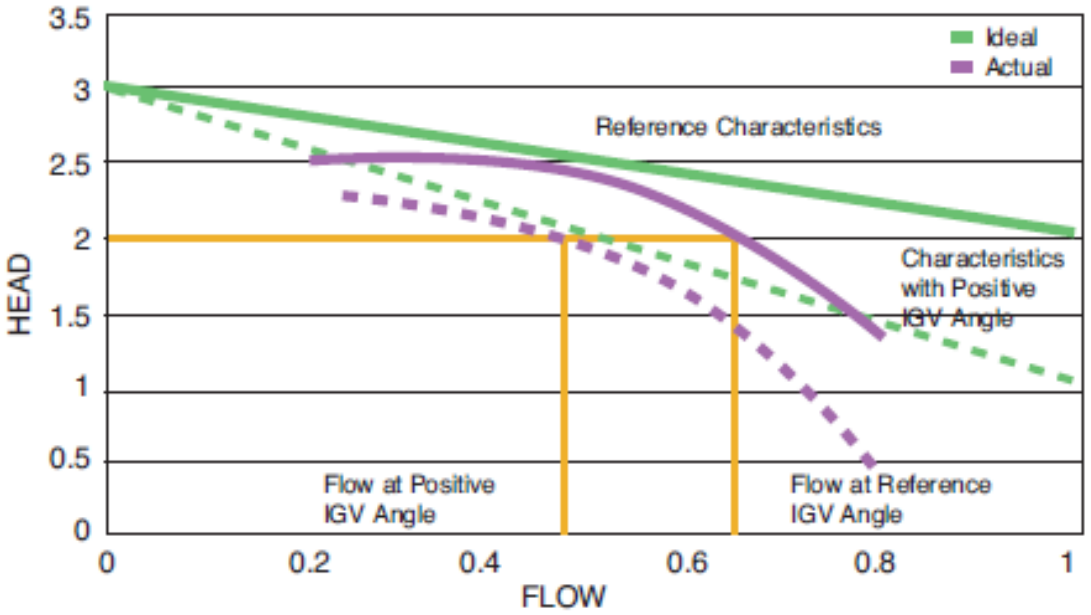


Part Load



2 shaft

Variable Guide Vanes



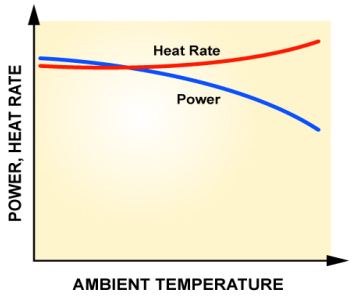
Constant speed (Single shaft): Adjust Flow

Variable Speed (2 Shaft): Constant Head/Flow

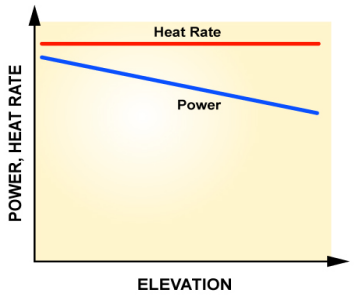
Summary

Performance Characteristics

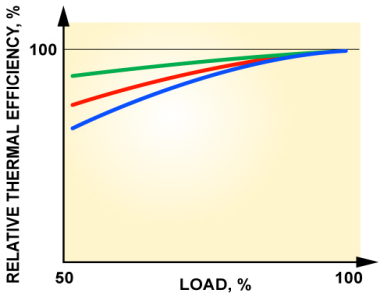
Performance vs Ambient Temperature



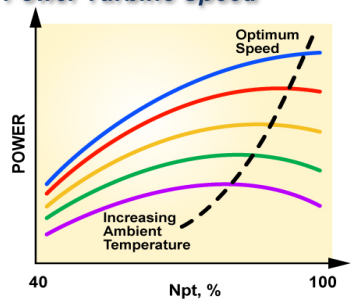
Power and Heat Rate vs Elevation



Efficiency at Part Load Operation



Power Turbine Speed



Thank You!
Questions?