Gas Turbine Components and Simulation

GT Performance Short Course

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Topic Overview

- Overview of dimensionless parameters
- Understanding Component characteristics (maps)
- Design Point Simulation
- Off-Design point simulation.

Components of a Gas Turbine

- Intake
- Compressor/Fan/Booster
- Combustor
- Turbine/Power Turbine
- Nozzle
- Jetpipe/Reheater
- Intercooler
- Recuperator

Dimensionless Analysis

- Engine performance ➔ described by many variables + operating envelope
- E.g. mass flow W is a function of:

Parameters
Tamb
Pamb
Ma
N
D-engine
R (working fluid)
γ (working fluid)
Viscosity

Dimensionless group
Dimensionless group for N
Ma
Dimensionless group for viscosity (2^{nd} order effect)

Parameters definition

	Full-dimensionless	Semi-dimensionless (quasi-dimensionless)	Referred (corrected)
Mass flow W	$\frac{W\sqrt{R\,T_1/\gamma}}{\mathrm{D}^2\,P_1}$	$\frac{W\sqrt{T_1}}{P_1}$	CM = $\frac{W\sqrt{\theta}}{\delta}$
Rotational speed (N)	$\frac{N}{\sqrt{\gamma\,R\,T_1}}$	$\frac{N}{\sqrt{T_1}}$	$\frac{N}{\sqrt{\theta}}$

Delta (δ) = P_1 / 101.325 kPa

Theta (θ) = T_1 / 288.15 K

$$CN = \frac{\frac{N}{\sqrt{T_1}}}{\left(\frac{N}{\sqrt{T_1}}\right)_{design}}$$

CN: relative to the DP value

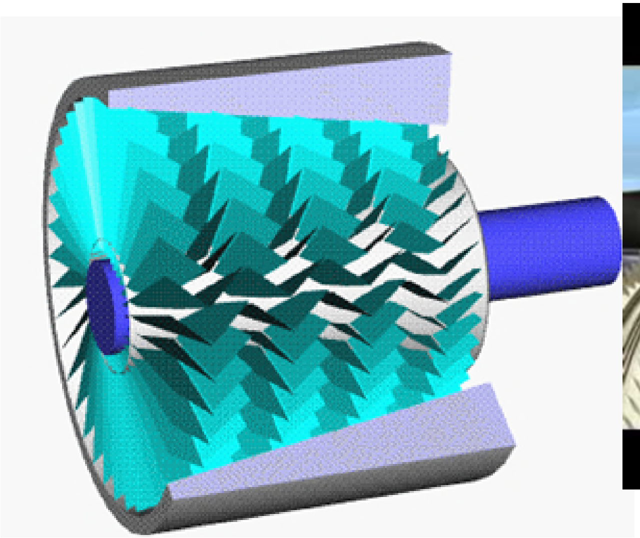
PCN=N / N_{design}

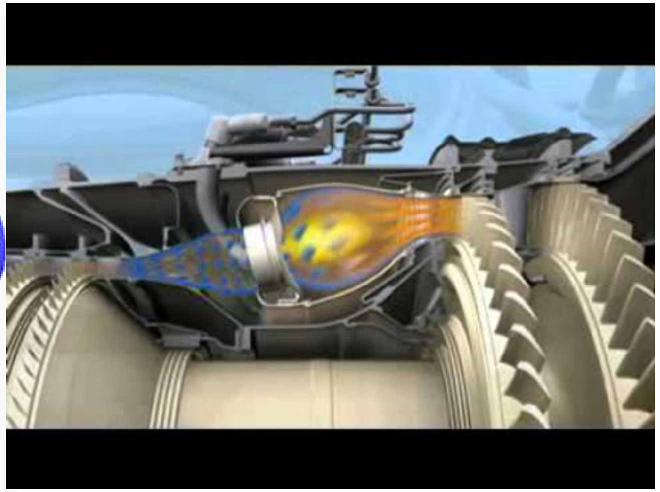
Design Point Definition

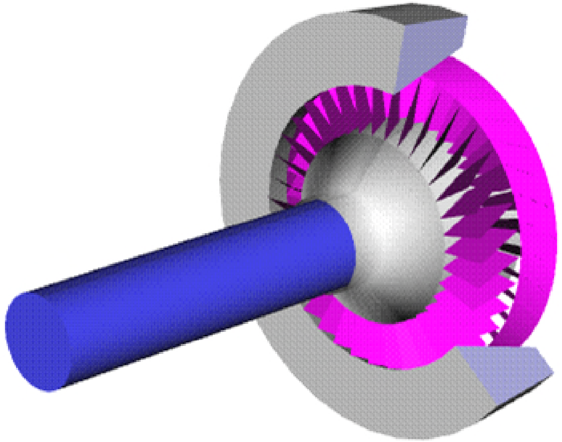
- The “size” of a gas turbine engine is usually defined by W and PR.
- W, PR, TET can be determined for a given power output from preliminary calculations.
- The engine components are designed in detail to give required **Design Point (DP)** performance.
  - the particular **point** in the **operating range** of a gas turbine when the engine is running at the particular **speed, pressure ratio and mass flow** for which the engine components where **designed**.
- Baseline Vs DP performance?

Off-Design Point Definition

- Off-Design performance (OD): its overall performance over the entire operating range of speed and power output.
- OD performance:
  - o determined by the interaction of the components (i.e. matching)
  - o Each component ➔ wide operating range ➔ interaction (matching) ➔ this will restrict the operating range







Courtesy of Wikipedia

Simulation importance

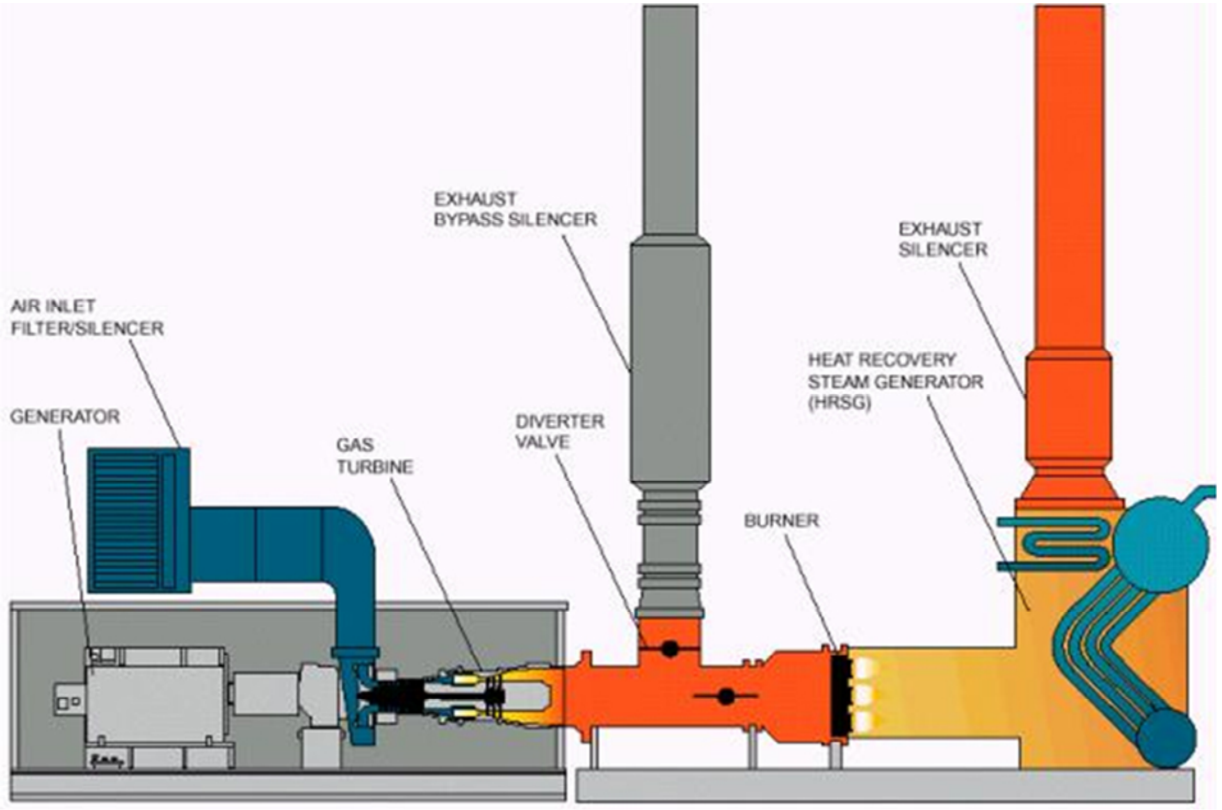
- Why is simulation important? (i.e. engine's performance under different operating conditions?)
- economic and safety, e.g.:

http://en.wikipedia.org/wiki/Boeing_767

Idle conditions
i.e. different power settings
SFC?

Simulation importance

- Why is simulation important? (i.e. engine's performance under different operating conditions?)
- economic and safety, e.g.:



http://www.coal2nuclear.com/s2_6-8_medium.htm

Part load
SFC?
£?
Life?

Simulation importance

- Why is simulation important? (i.e. engine's performance under different operating conditions?)
- economic and safety, e.g.:

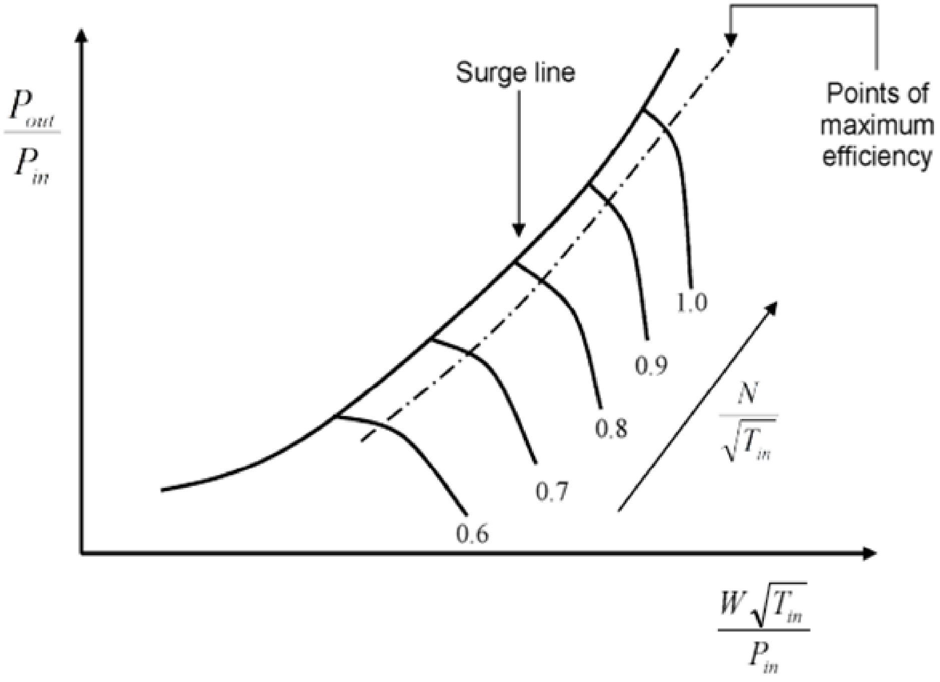
http://www.coal2nuclear.com/s2_6-8_medium.htm

Ambient conditions
Temperature
Pressure
Altitude

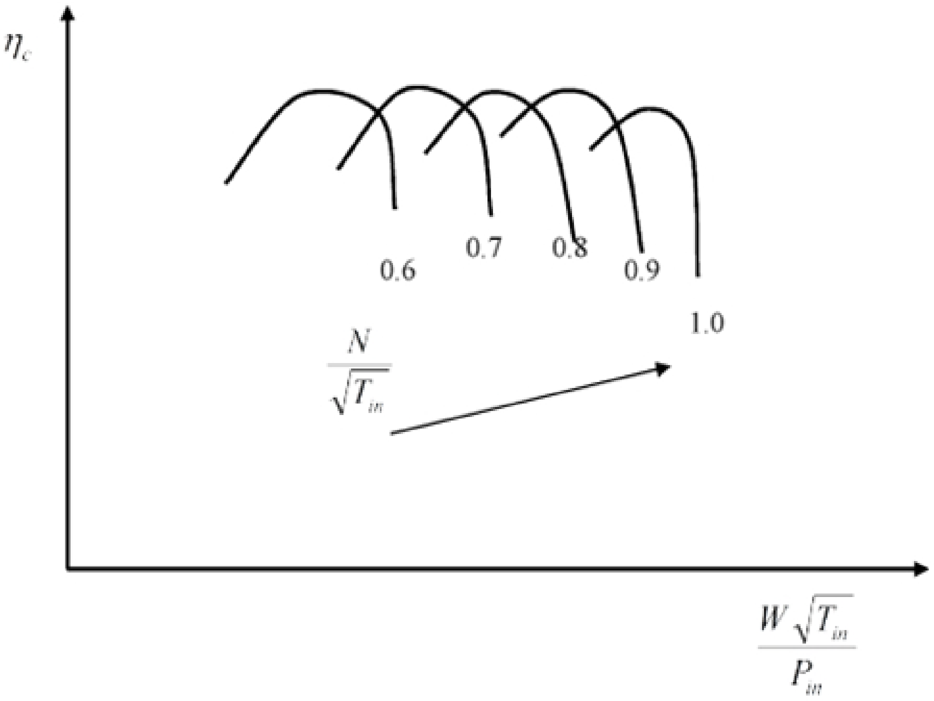
Component characteristics

- Component characteristics (maps) determine component's performance parameters
  - Compressor
  - Combustor
  - Turbine
  - Propelling nozzle
- Critical role in the OD "matching" of the engine.

Axial Compressor Characteristics



Pressure ratio Vs. non-dim. mass flow



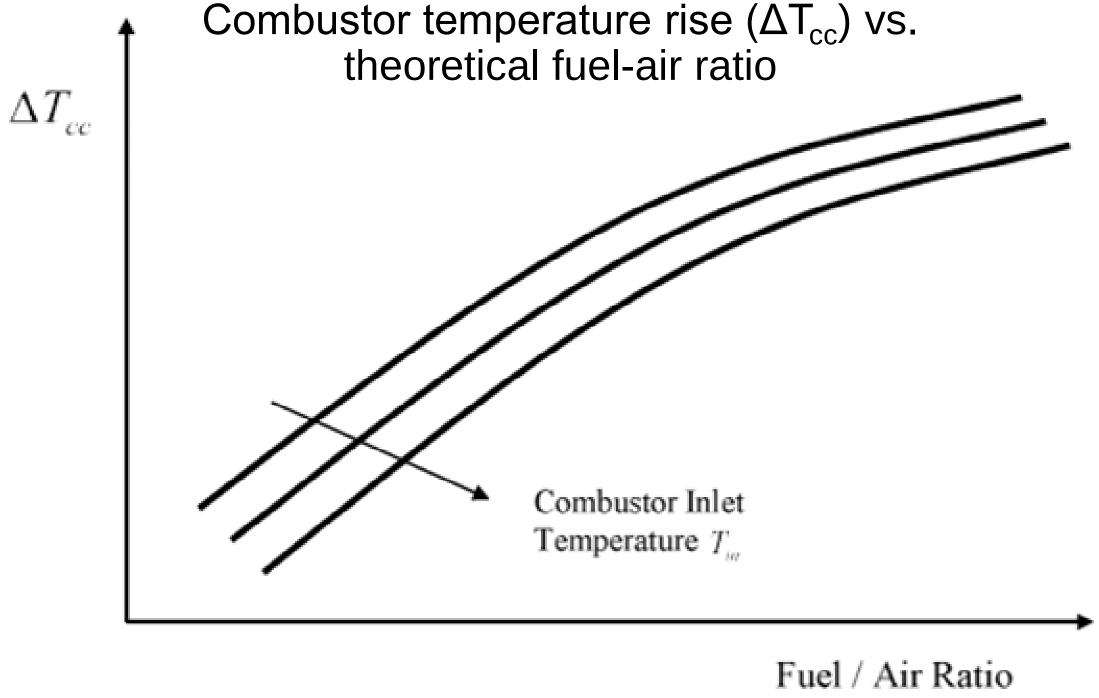
Efficiency Vs. non-dim. mass flow

- Narrow range of W for a given N/√T (vertical lines)
- DP is close to the surge line

N/√T is usually relative to design value

Combustor characteristics

Combustor temperature rise (ΔT_{cc}) vs.
theoretical fuel-air ratio



Fuel flow? (i.e. sfc)
COT: specified or guessed

Combustion Efficiency

- for a given ΔT : $\eta_{cc}=FAR_{theoretical} / FAR_{actual}$
- for a given FAR: $\eta_{cc}=\Delta T_{actual} / \Delta T_{theoretical}$

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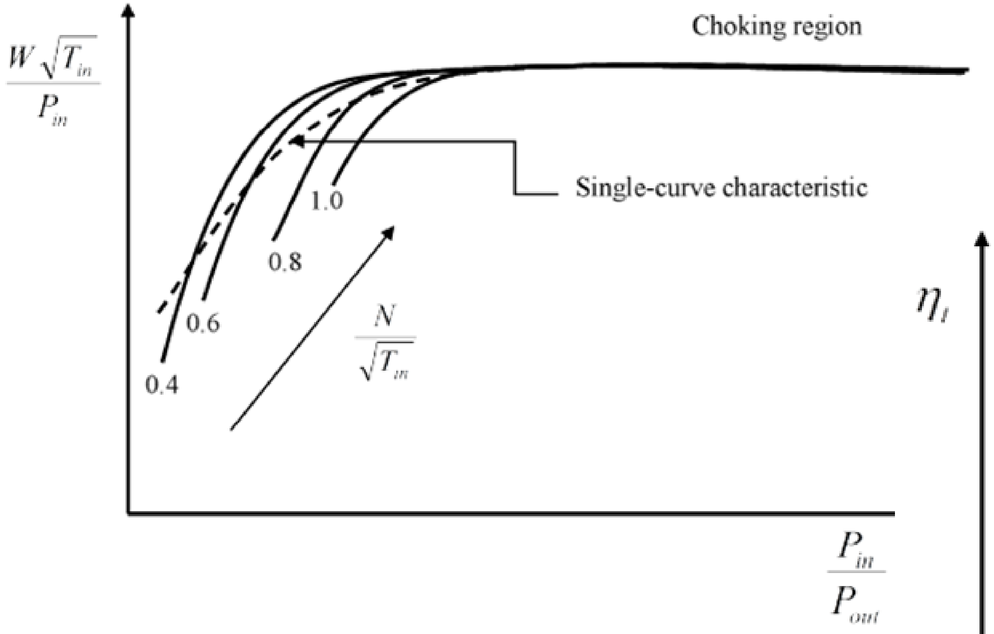
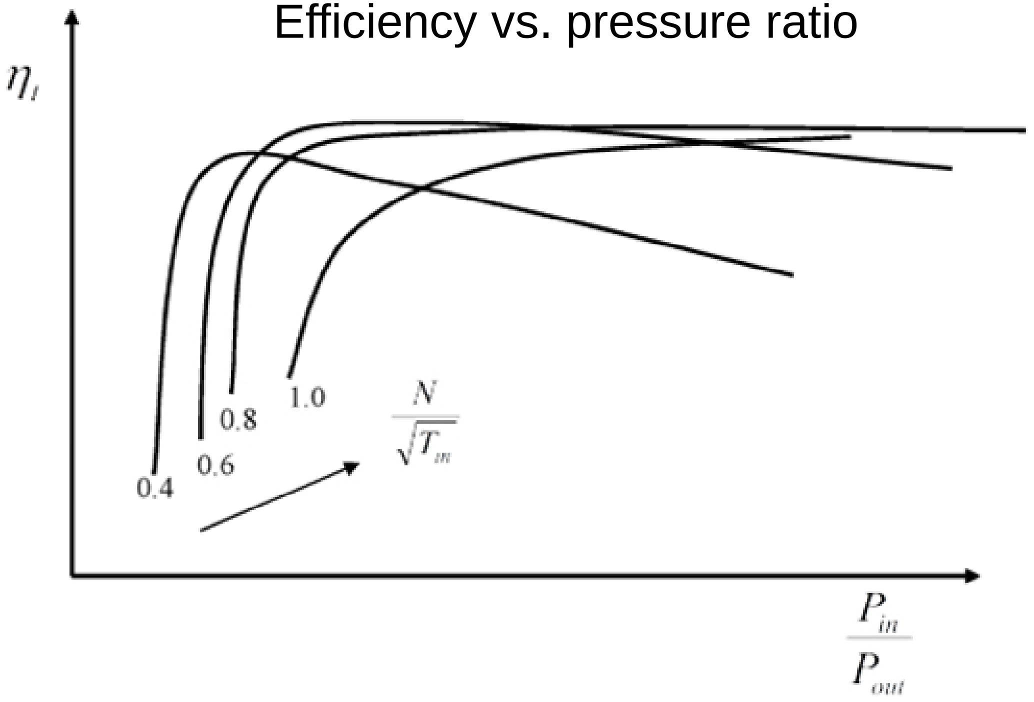
Turbine characteristics



Non-dim. mass flow vs. pressure ratio

N/√T is relative to design value

Efficiency vs. pressure ratio



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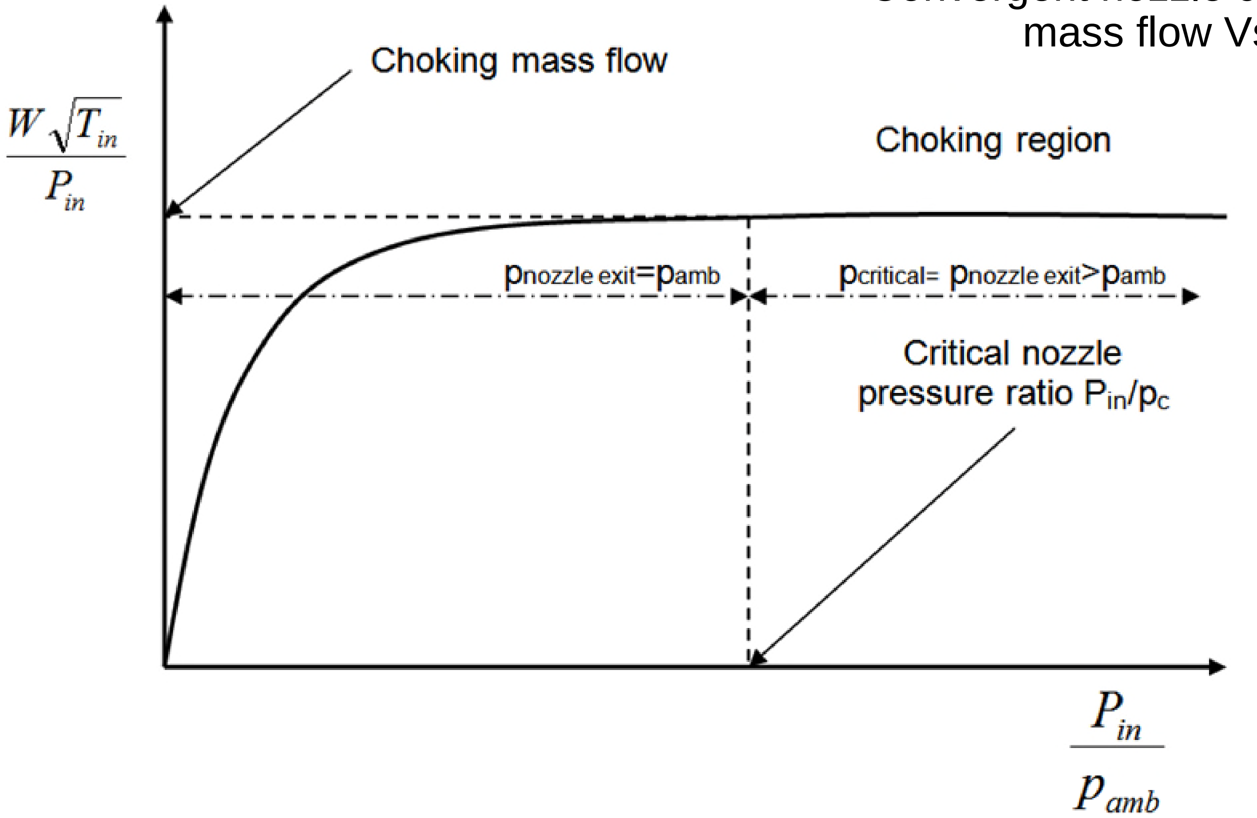
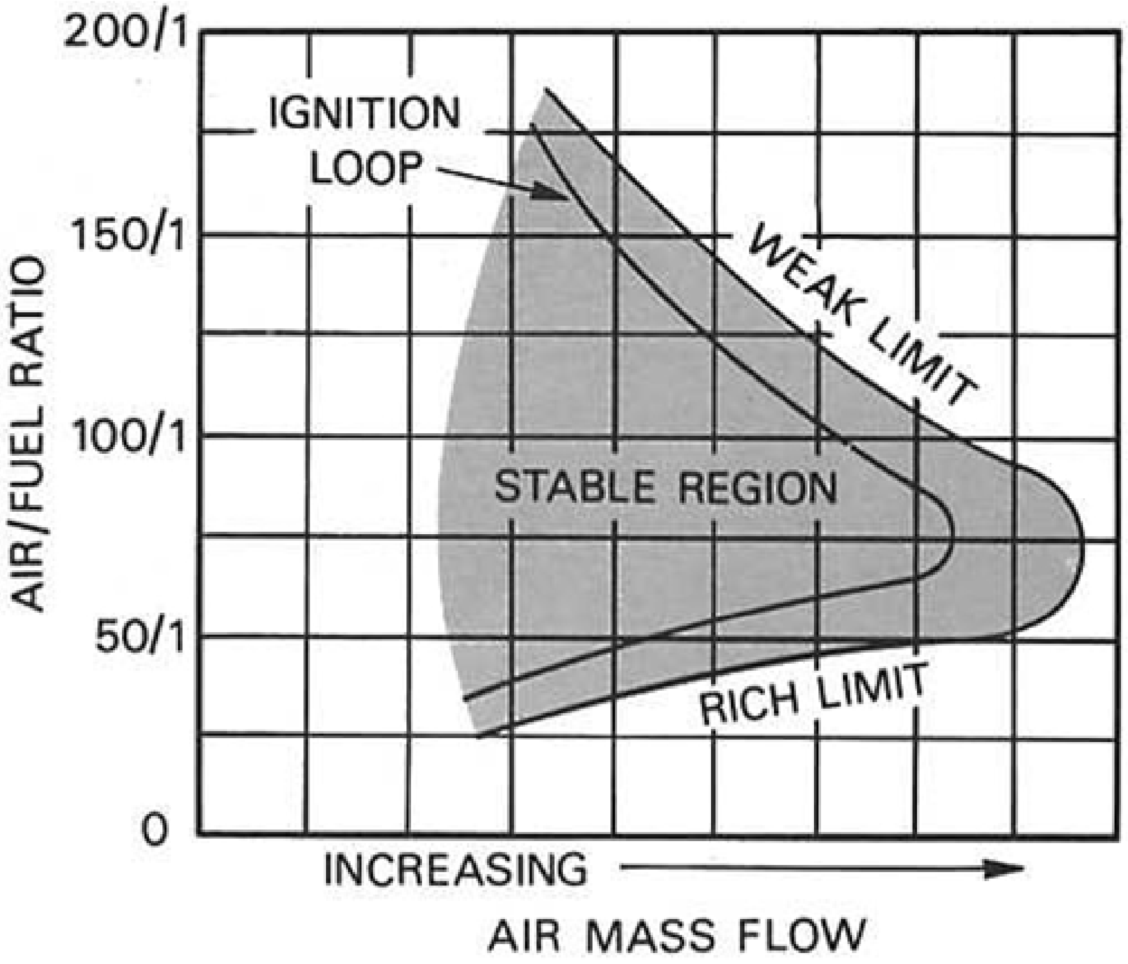
Propelling nozzle

Convergent nozzle characteristic of non-dim. mass flow Vs. pressure ratio



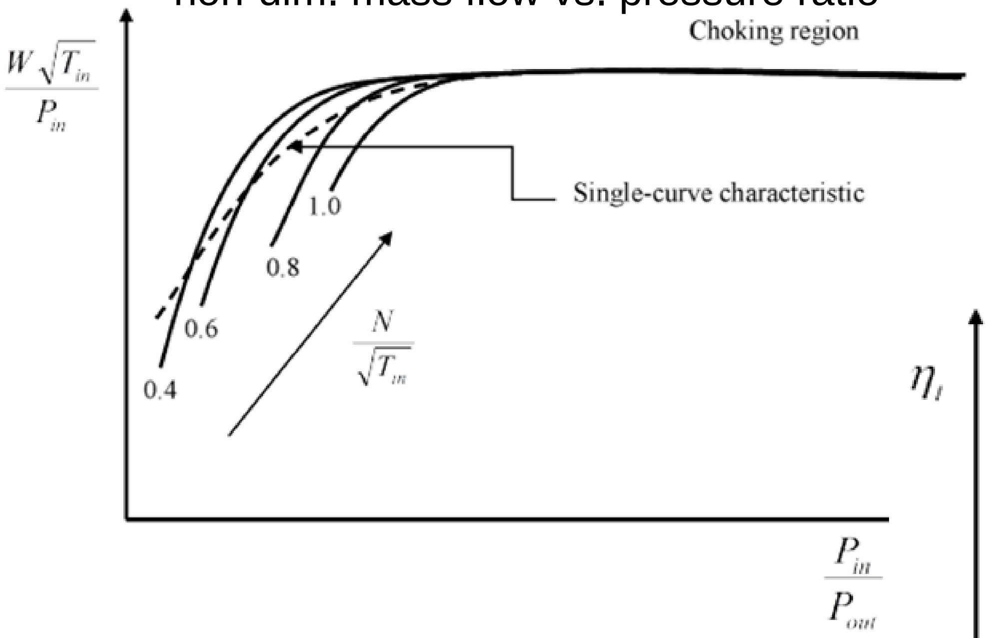
- Nozzle area is obtained from the DP calculations and remains fixed in OD calculations (not in variable-area nozzle)
- Exit static pressure **=**, or **>** ambient pressure (con nozzle).

Combustion Stability

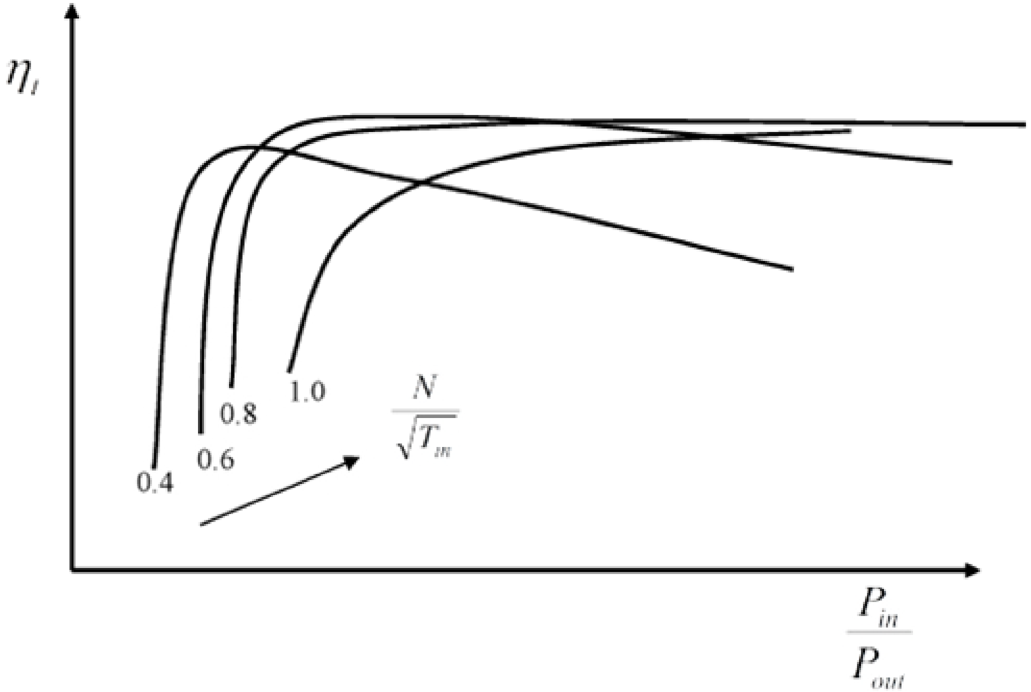


Component Characteristics

Turbine characteristic of
non-dim. mass flow vs. pressure ratio

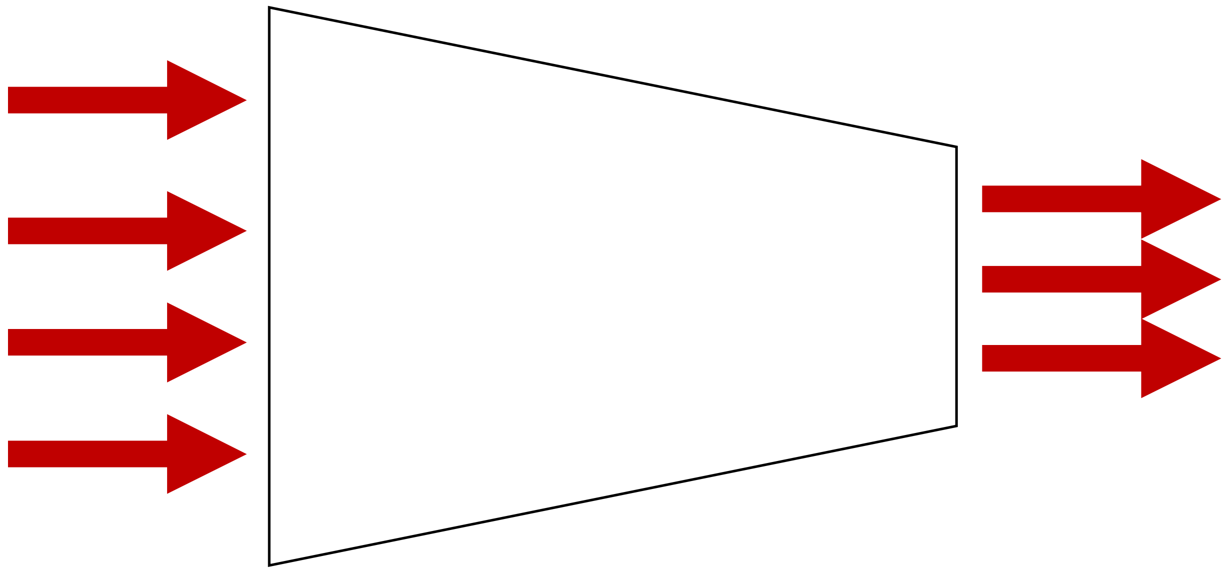


Turbine characteristic of
efficiency vs. pressure ratio



They are sufficient to describe turbine performance under different operating conditions.

Gas Turbine Nozzle



A_1, P_1, ρ_1, V_1

A_2, P_2, ρ_2, V_2

Image courtesy GE

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Gas Turbine Nozzle

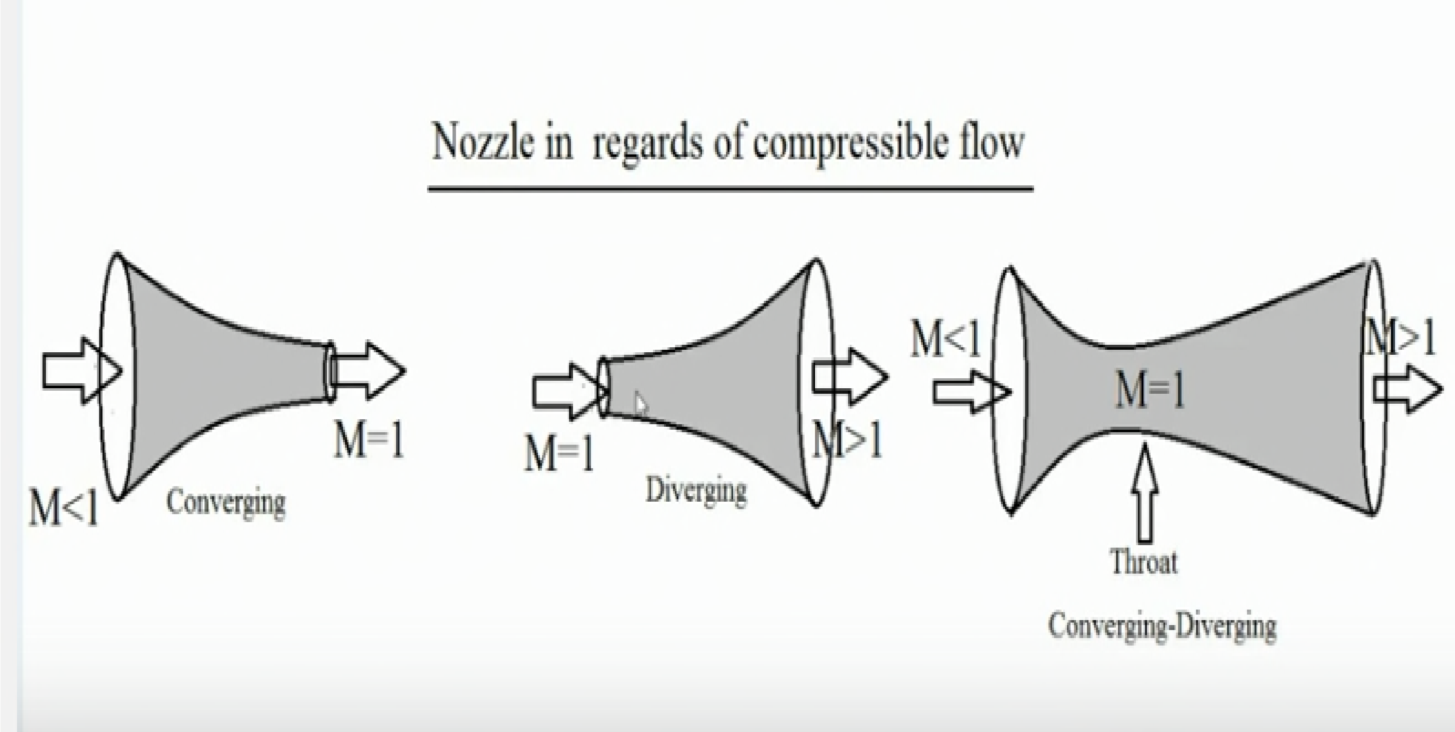

Image courtesy GE

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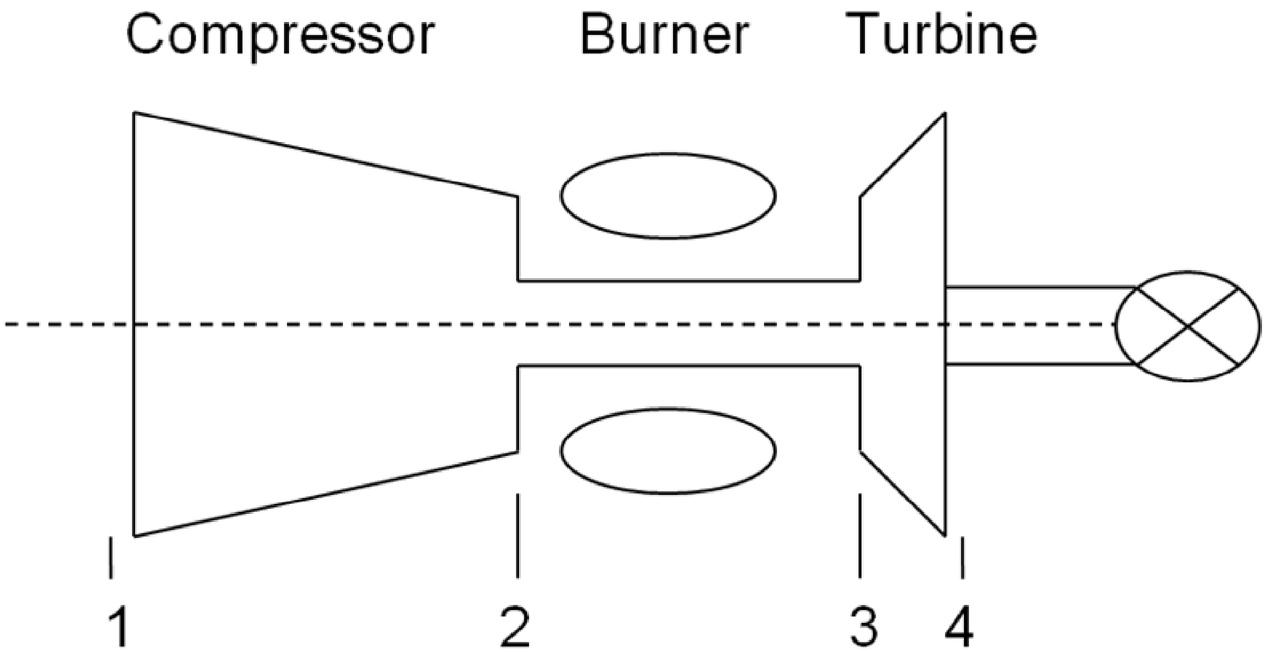
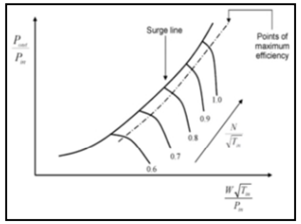
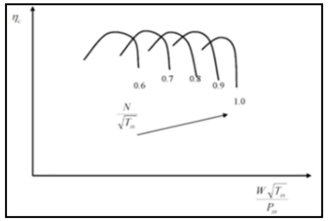
Engine Steady State Conditions

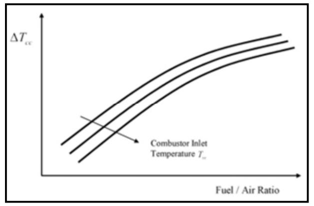
- Essential conditions of compatibility must be satisfied between the various components of an engine:
  - Mass flow
  - Work
  - Rotational speed
- OD performance simulation: **a “handle” is needed**

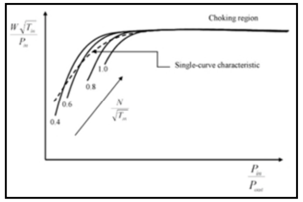
Engine Simulation

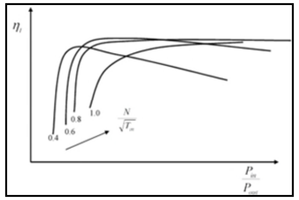












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Engine steady state conditions

- A direct solution to obtain the OD performance is not possible.
- It requires:
  - Iterative procedure
  - All engine variables are consistent with the “handle”
  - Some engine parameters are **guessed**
  - Checks are carried out to ensure that the results are compatible with the engine characteristics (“errors” should tend to 0).

Iterative methods

- Drawbacks:
  - Loops are nested (inner loop repeated for outer loops – increased number of iteration)
  - computationally inefficient

Matrix solution method is more common

Newton Raphson Method

Matrix Iteration

- The equations are formed by changing one variable and calculating the errors it produces.

- In matrix iteration the equations are solved simultaneously.

- Error= (calculated value-map value)/(map value)

Iterative methods

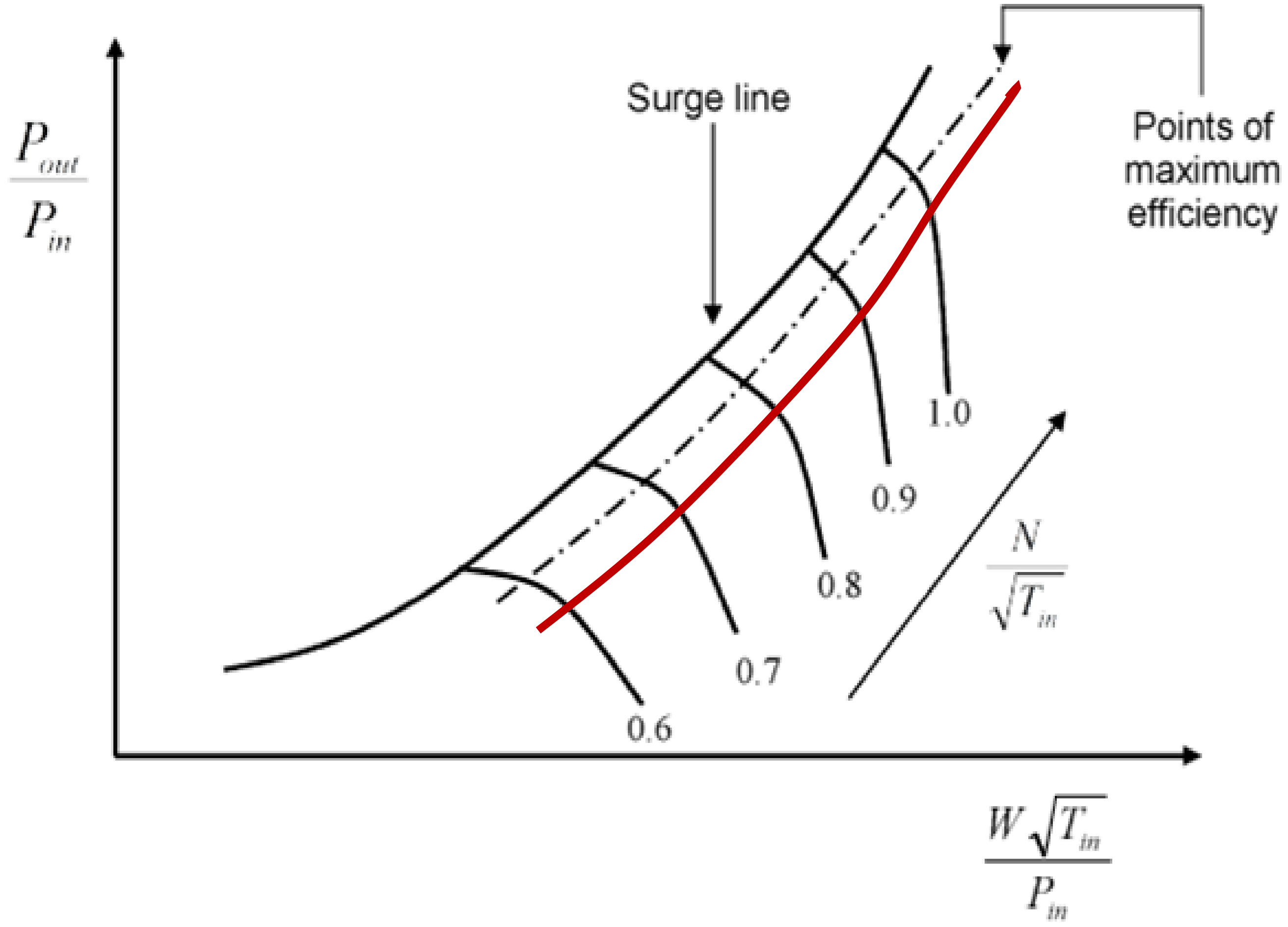
$$i = number\ of\ variables$$
$$j = number\ of\ errors$$

$$EB_1 = E_{11}dV_1 + E_{12}dV_2 + \cdots + E_{1j}dV_j$$
$$EB_2 = E_{21}dV_1 + E_{22}dV_2 + \cdots + E_{2j}dV_j$$
$$\dots\ \dots$$
$$\dots\dots\dots$$
$$EB_j = E_{i1}dV_1 + E_{i2}dV_2 + \cdots + E_{ij}dV_j$$

Eij: change in error Ei caused by a change in variable Vj

Always: i=j

Engine Working Line



Thank You

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