



ECATS

Network of
Excellence

A network for an
environmentally compatible
air transport system

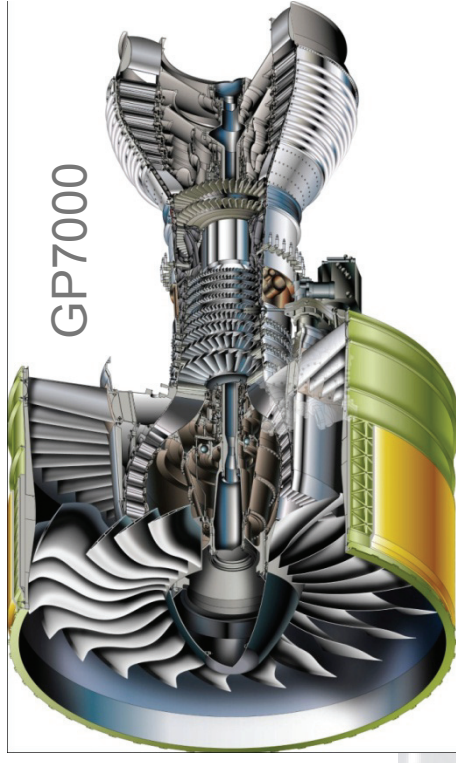


Engine technology and aircraft emissions



Outline

- Introduction
- Generating thrust
- Energy considerations
- Requirements
- Atmosphere
- Engine cycle
- Engine types
- Combustion & Emissions
- Engine performance models



Introduction

Why do we need engines?

- Changing the kinetic energy of an aircraft
 - Speed
- Changing the potential energy of an aircraft
 - Altitude
- Overcome drag
 - Non-conservative forces

What is drag really?

- Leaving energy behind
 - Moving air
 - Hot air and exhaust gases

Vortex – induced drag



Form drag and lift induced drag

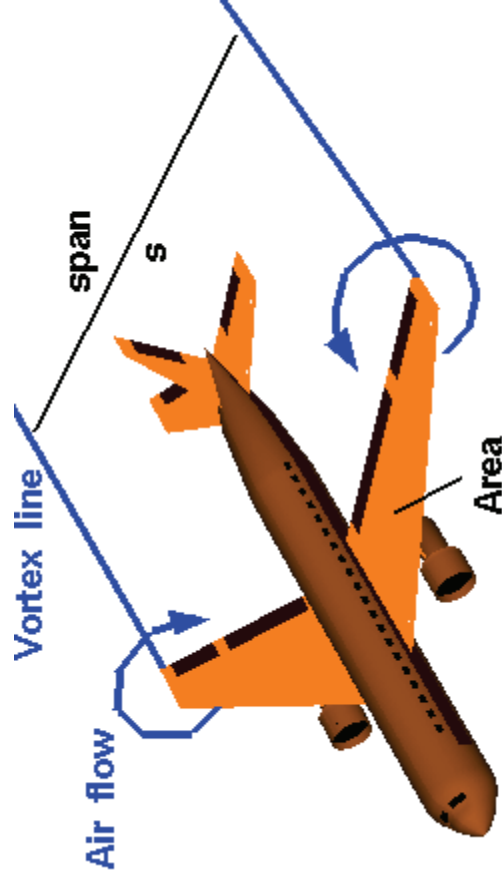
$$D = C_D \cdot A \cdot \frac{1}{2} \cdot \rho \cdot v^2$$

$$L = C_L \cdot A \cdot \frac{1}{2} \cdot \rho \cdot v^2$$

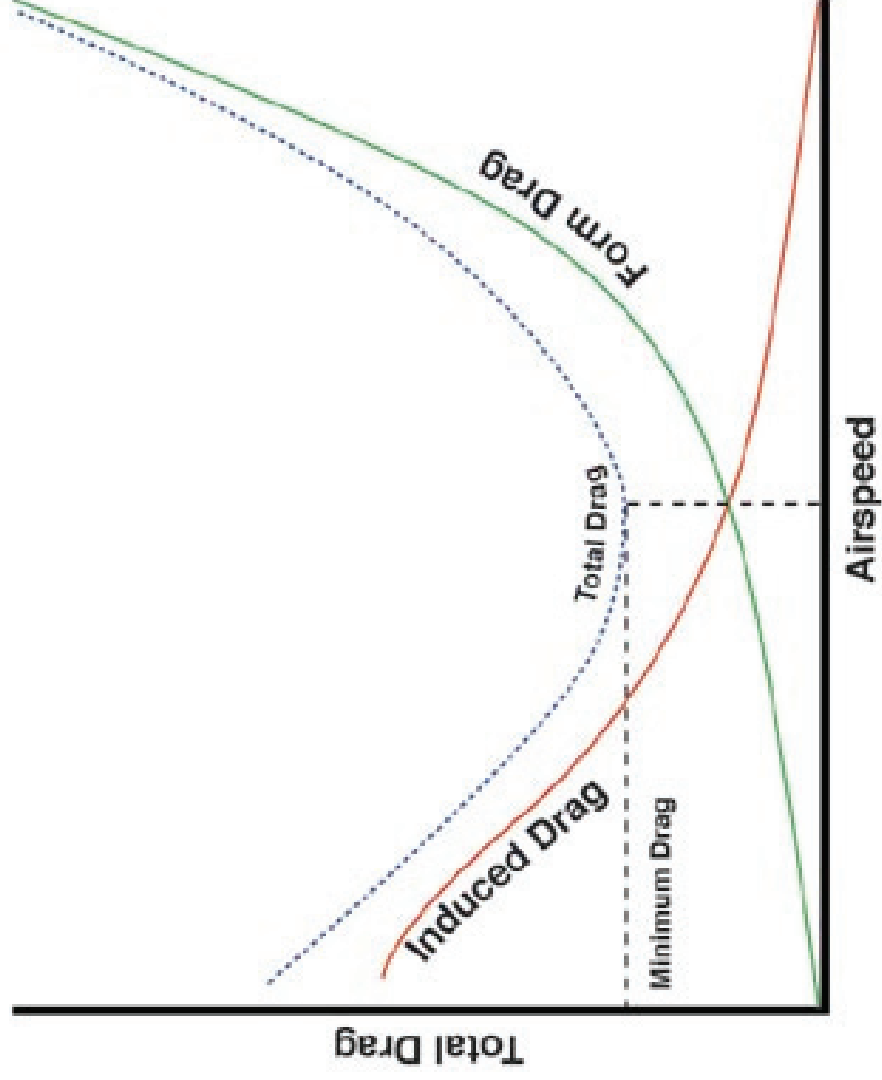
$$C_D = C_{D_0} + C_{D_i}$$

$$C_{D_i} = \frac{C_L^2}{\pi \cdot AR \cdot e}$$

$$AR = \frac{s^2}{A}$$



Drag vs speed



Generating Thrust

Accelerating a body:

Force required
Causes reaction
The reaction force accelerates the
reaction mass



After acceleration:

Energy in both bodies

$$E = \frac{1}{2} \left(1 + \frac{m}{M} \right) v^2$$

Jumping straight up

- Acceleration relative to Earth
- Earth mass some 6×10^{24} kg
- Jumper mass, say 85 kg
- m/M about 0
- $\Rightarrow$ All energy in jumper!

$$E = \frac{1}{2} \left(1 + \frac{m}{M} \right) v^2 \approx \frac{1}{2} v^2$$



Some other reaction masses

- Moon 7×10^{22} kg
- Boat some 100 kg and up
Think about what happens when you move
relative to a boat!
- Rockets: 50 – 95 % of initial mass
- Aircraft: reaction mass is air
Density 0,05 – 1,5 kg/m³

Energy Considerations

Energy efficiency

- Propulsive efficiency

$$\eta_p = \frac{2}{1 + \frac{c}{v}}$$

- Cycle efficiency

$$\eta_c = \frac{T_H - T_C}{T_H}$$

- Limited by:
 - temperature differences
 - overall pressure ratio

- Total efficiency

$$\eta = \frac{Fv}{\dot{m}_f Q} \quad \eta = \eta_c \eta_p$$

- F thrust
- Q heating value of fuel

Requirements

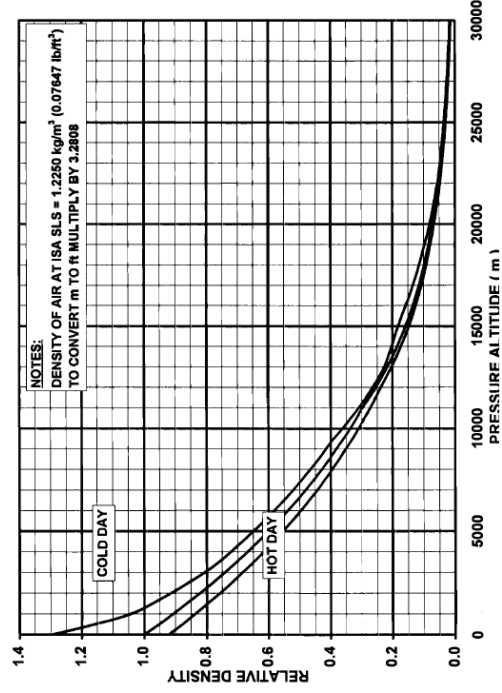
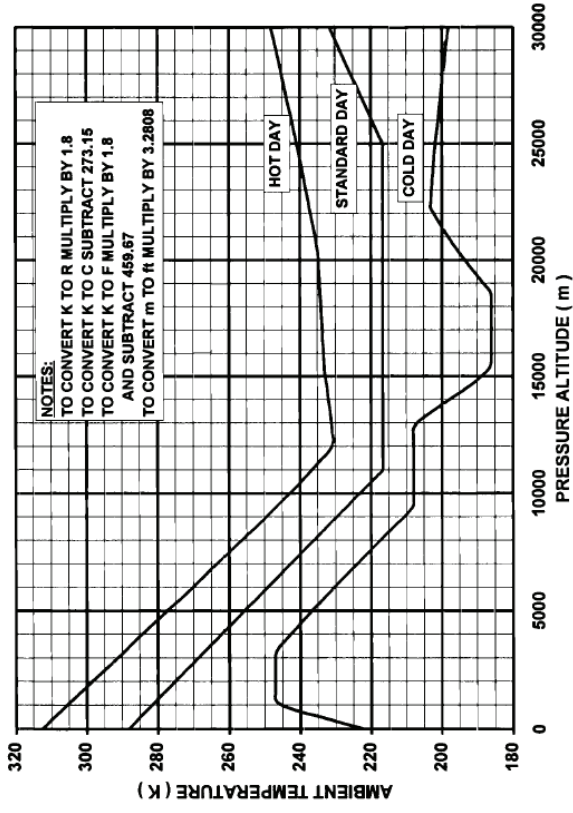
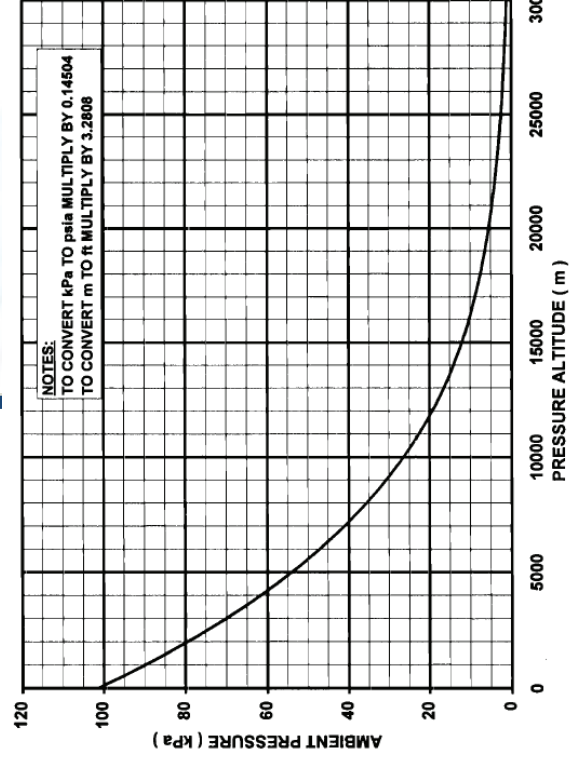
Operational requirements on engines

- Sufficient reliability
- Sufficient thrust at all parts of operational cycle
- Operational cycle
 - Taxi
 - Take Off
 - Climb
 - Cruise
 - Descent
 - Approach
 - Landing
 - Taxi

Additional requirements

- Producing electrical power
- Producing compressed air (bleed)
- Producing hydraulic power

Atmosphere



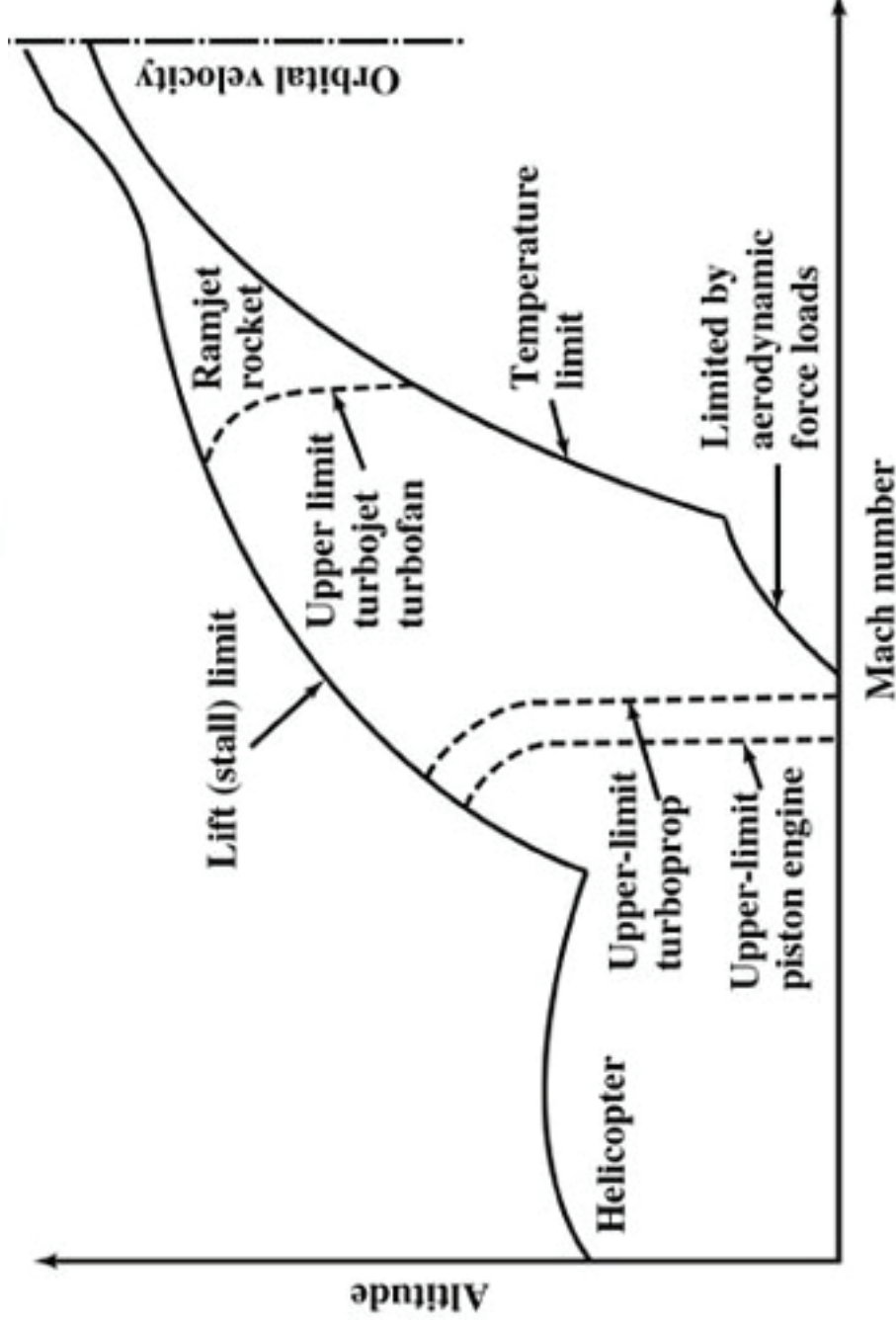
(Walsh & Fletcher, 2004)

Propellers are also wings

- Tip vortices occasionally condensate air



Propulsion envelopes



Engine Cycle

History:

Jet engine developed in 1930's



Frank Whittle

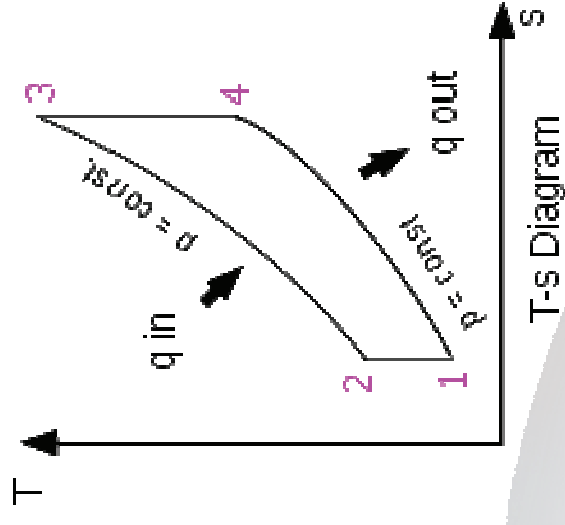
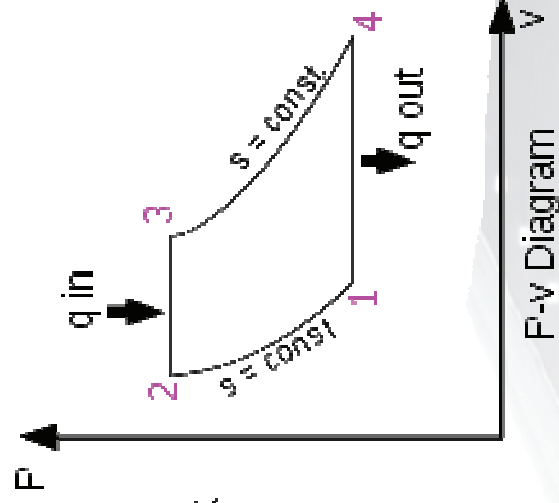
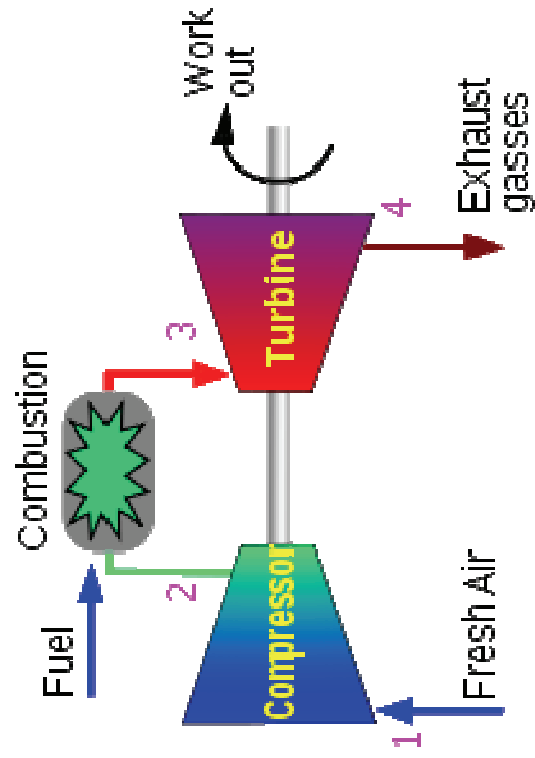


Hans von Ohain

Engine function

- Engine cycle
 - Compression
 - Combustion
 - Expansion and energy collection/use
- Overall pressure ratio, OPR, typically 15 – 32
 - Pressure ratio
 - Overall pressure ratio

Engine cycle



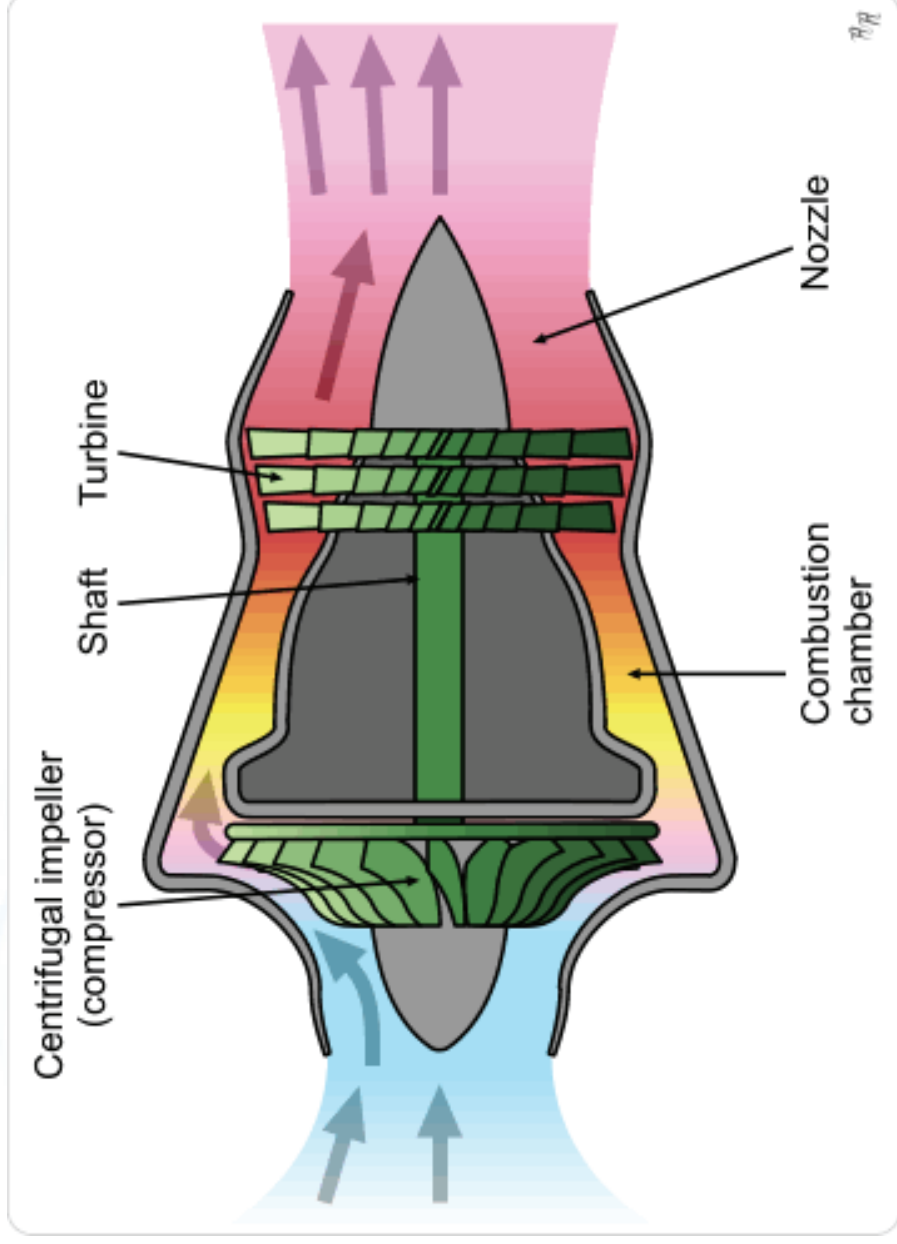
Idealized Brayton Cycle

Engine Types

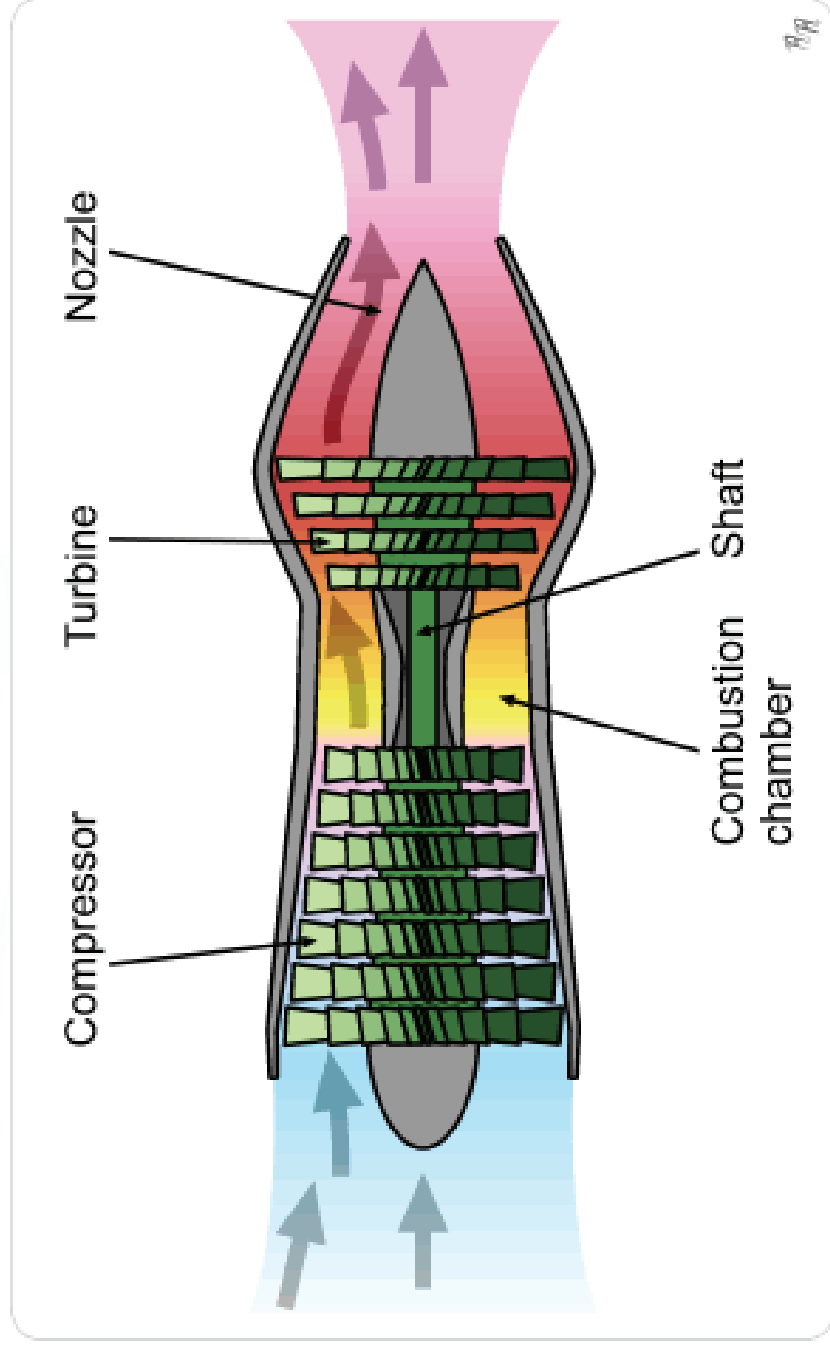
Jet engine types

- Turbojet
- Turbofan
 - By pass ratio
- Turboprop
- Turboshaft

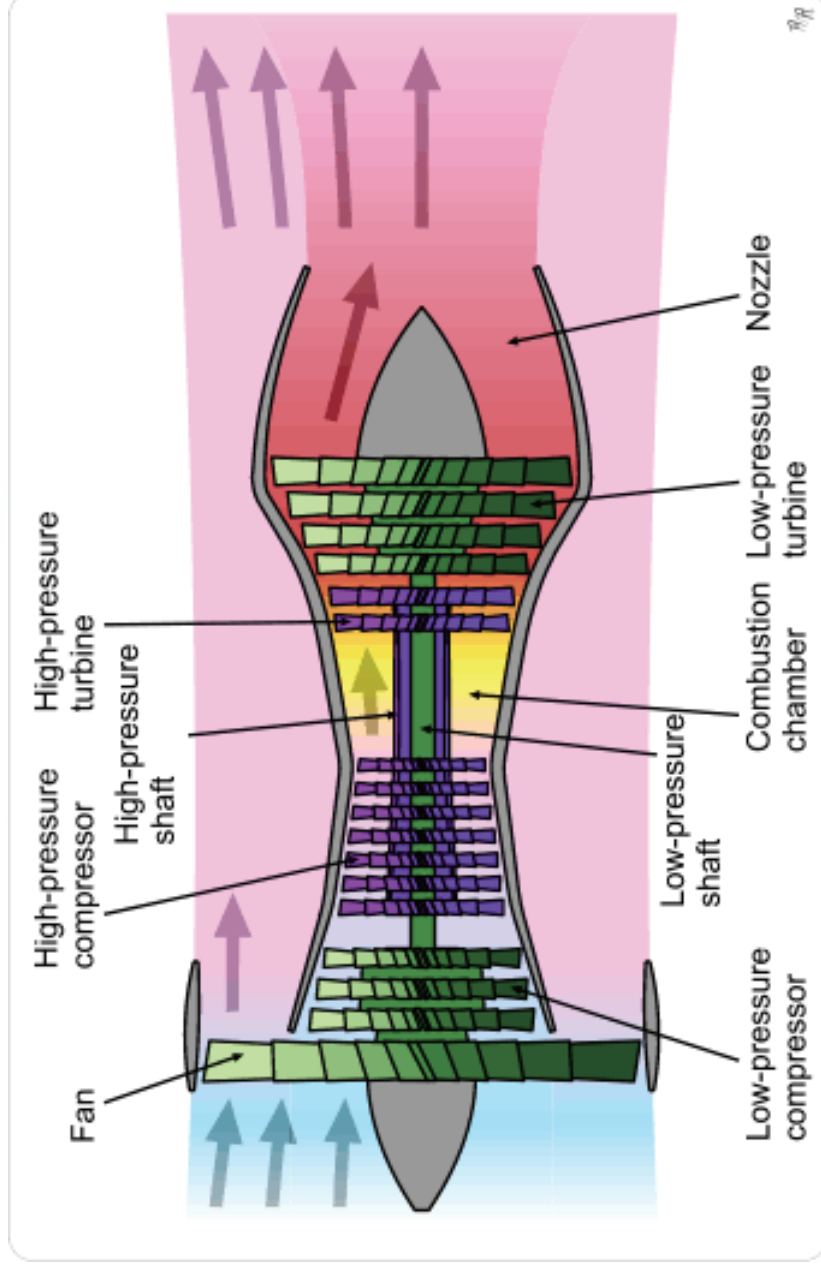
Turbojet with radial compressor



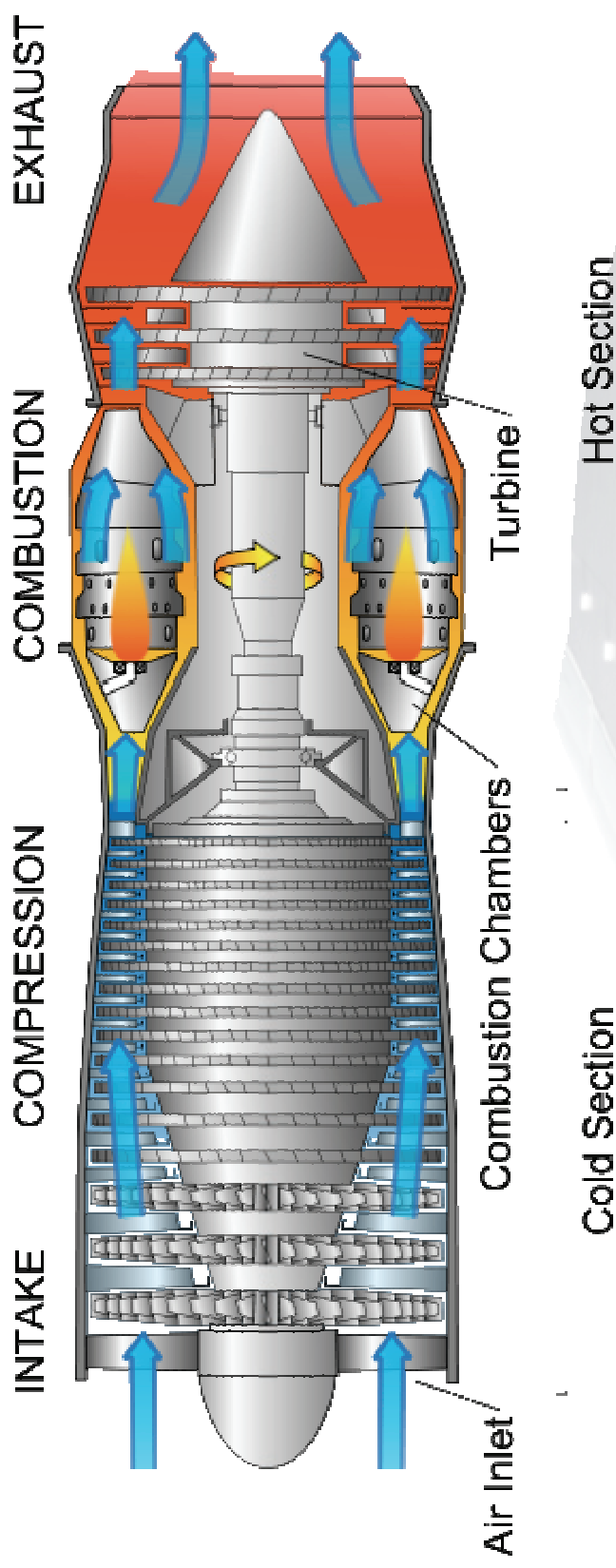
Turbojet



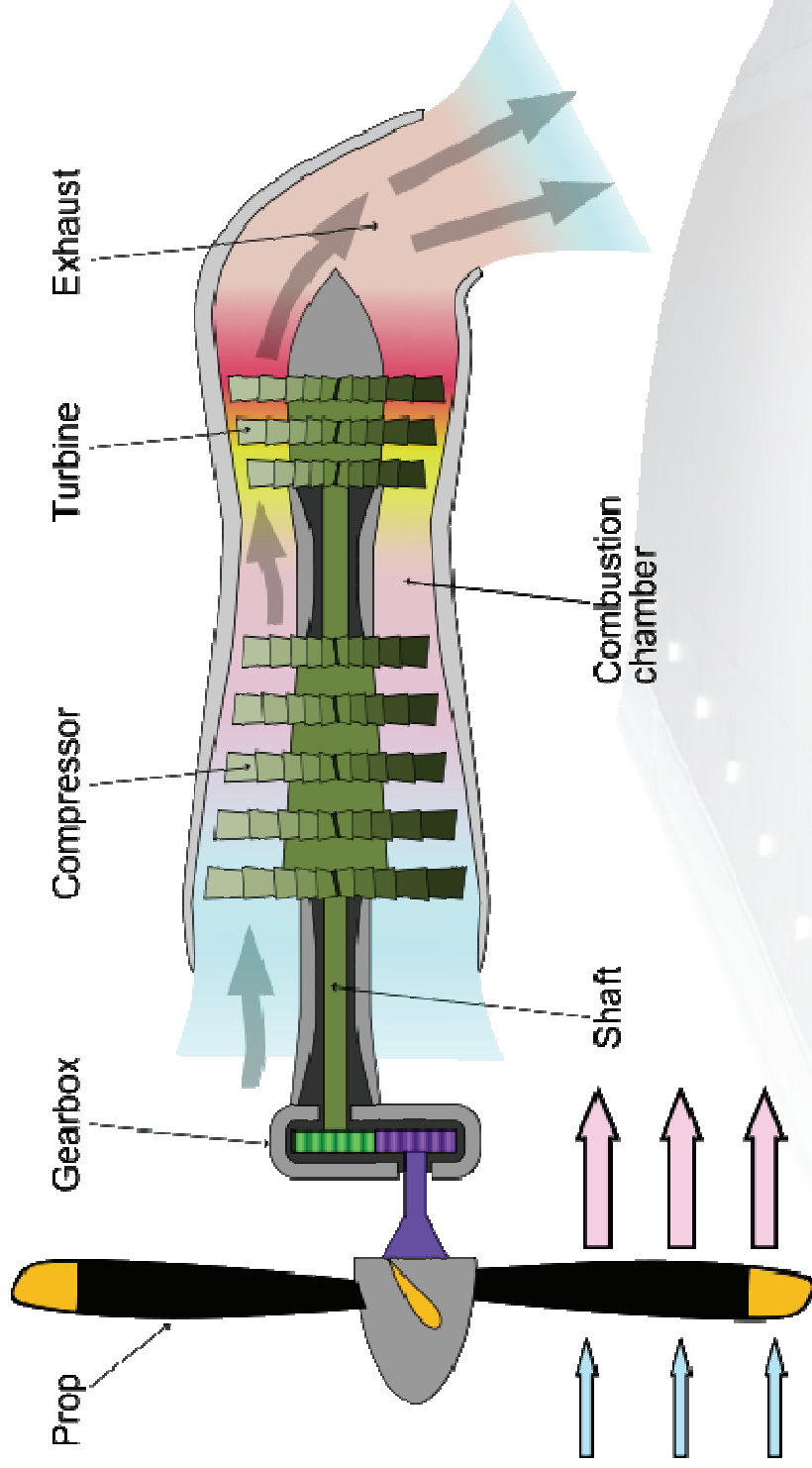
Turbofan engine principle



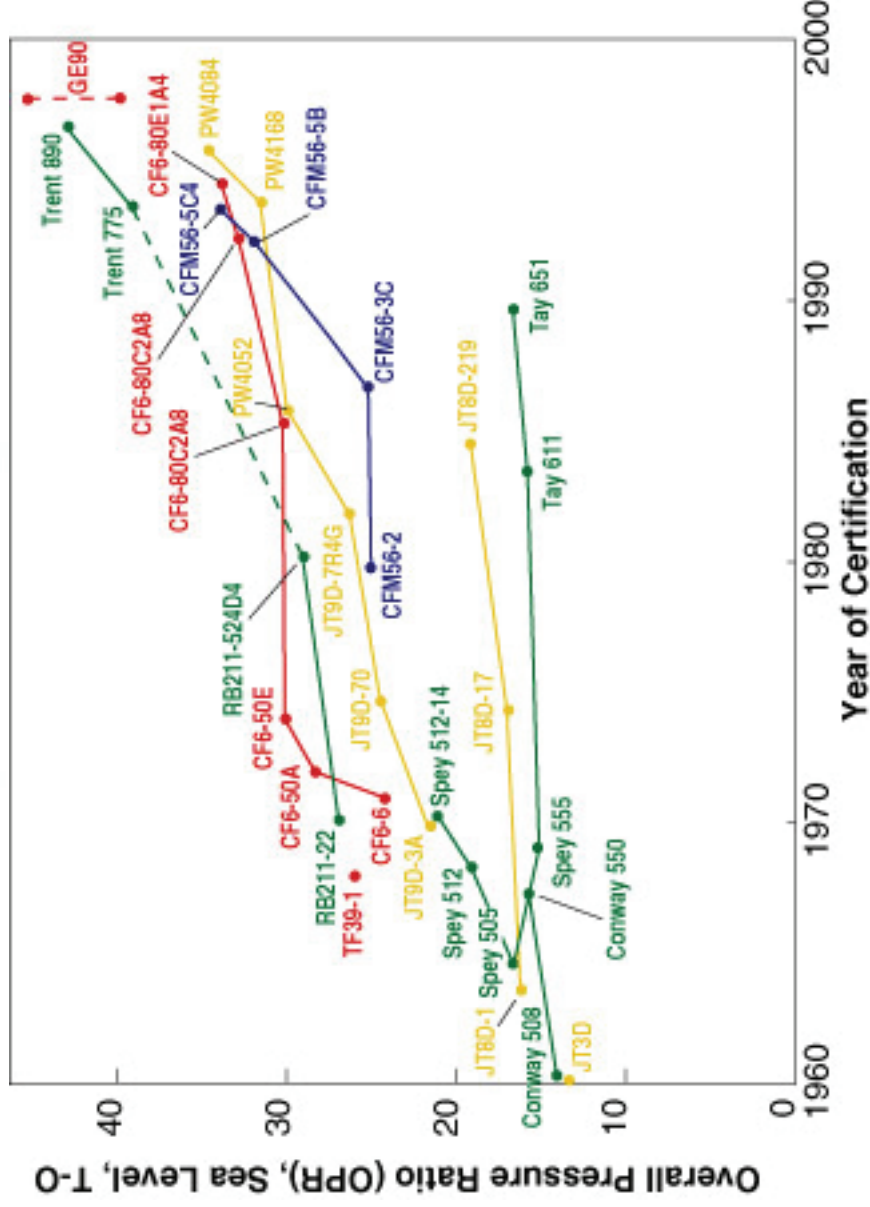
Turbofan



Turboprop



Overall Pressure Ratio examples



Some jet engine manufacturers

- Rolls Royce
- General Electric
- Pratt & Whitney
- MTU
- Snecma
- Ivchenko Progress

Combustion & Emissions

Combustion

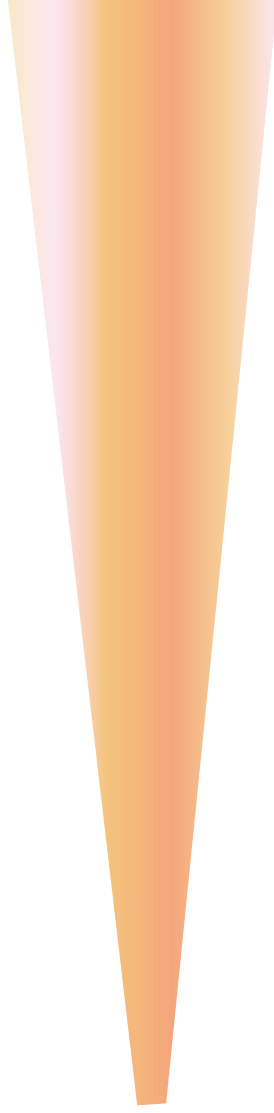
Fuel $C_nH_m (+S)$



Air



$N_2 + O_2$

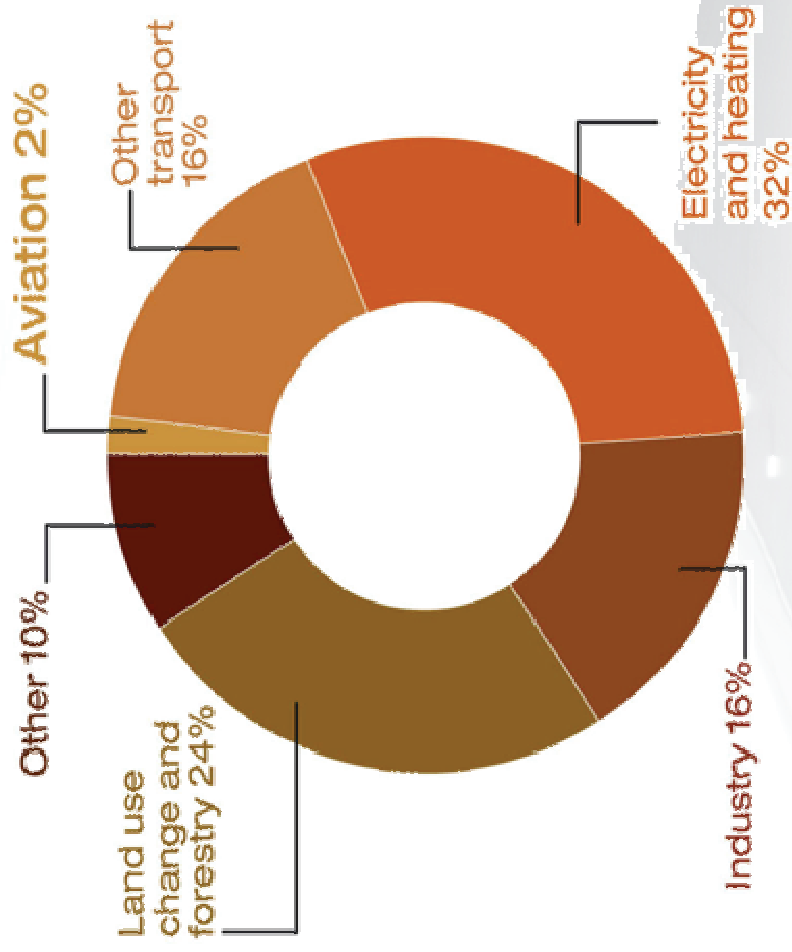


$CO_2 + H_2O + N_2 + O_2 + NO_x + UHC + CO + C_{soot} + SO_x$

Emissions

- CO₂ Carbon dioxide
- NO_x Nitrogen oxides
- HC Hydrocarbons, unburnt fuel
- CO Carbon monoxide
- S Sulphur (FSC, Fuel sulphur content)
- O₃ Ozone
- H₂O water
- Particles

Aviation CO₂ Emissions



Source: UN IPCC

Emission index

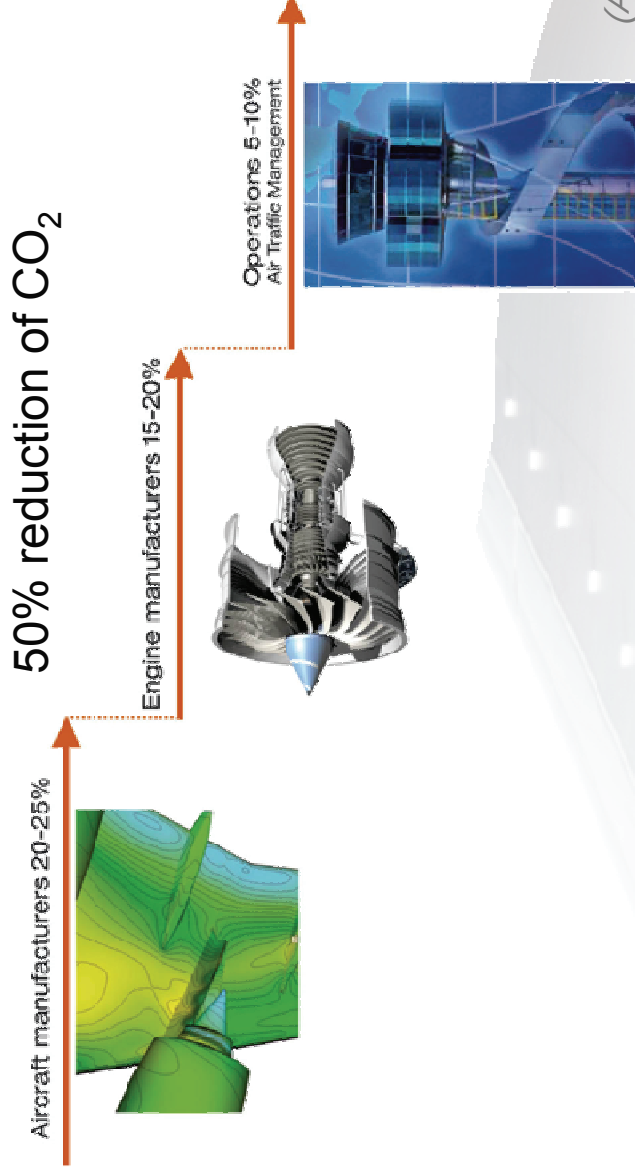
- ICAO Database
- Manufacturer data

Fuel flow and emission indices for the PW126A as a function of power setting (P_{rel}), and the corresponding ICAO application times.		Take Off	Climb Out	Approach	"Idle"	Flight Idle	Ground Idle
P_{rel}		1	0.81	0.3	0.07	0.038	0.015
Power [hp]		2662	2145	799	186	101	40
FF [kg/s]		0.1607	0.137	0.0766	0.047 ₉	0.0277	0.0222
EIHC		0	0	0	0	0	0
EICO		2.2	2	3.5	8.4	24.5	36.4
Data from the manufacturer		18.9	16.3	10	7.1	4.6	4.1
(Pratt & Whitney).		0.7	2.2	4	26		

New Engine Types

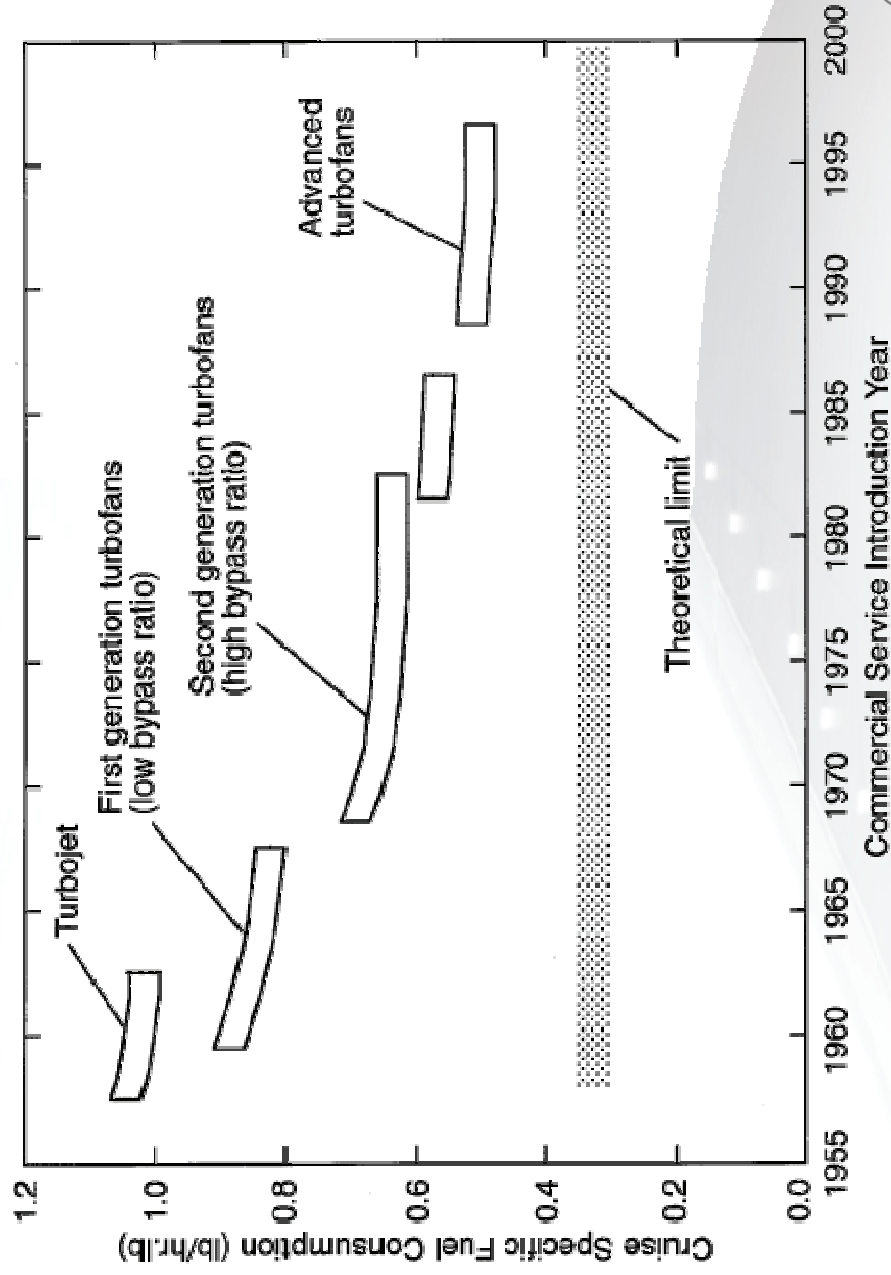
ACARE 2020

- 50% reduction of CO₂ per passenger and kilometer
- 80% reduction of NO_x
- 50% reduction of noise



ACARE:
Advisory Council for Aeronautics Research in Europe

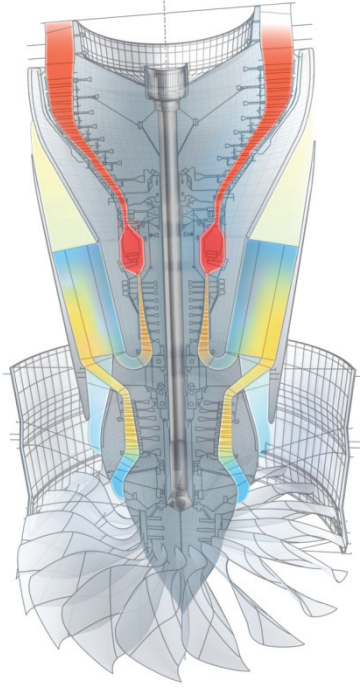
Engine Technology Level



(Brasseur et al., 1998)

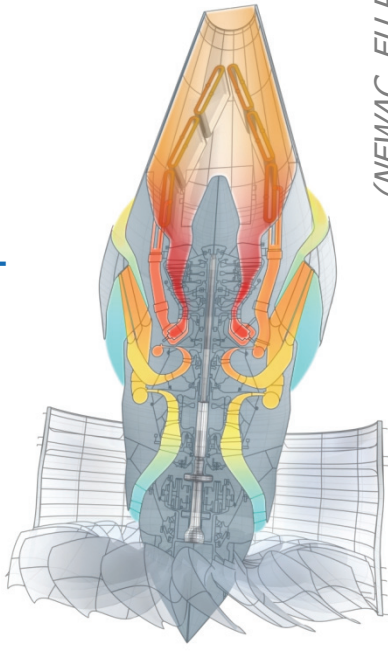
New Engine Configurations

Intercooled core configuration

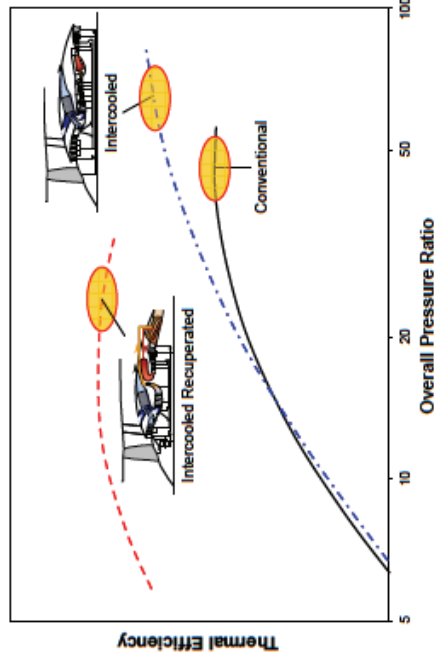


(NEWAC, EU Project)

Intercooled recuperative core



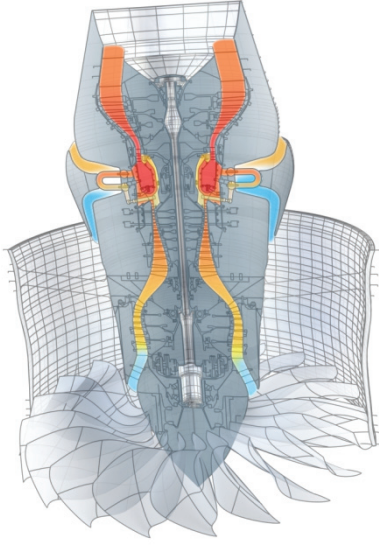
(NEWAC, EU Project)



(Günter Wilfert ,2007)

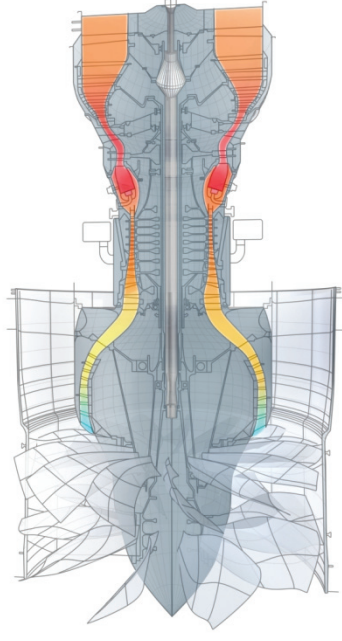
New Engine Configurations

Active core configuration

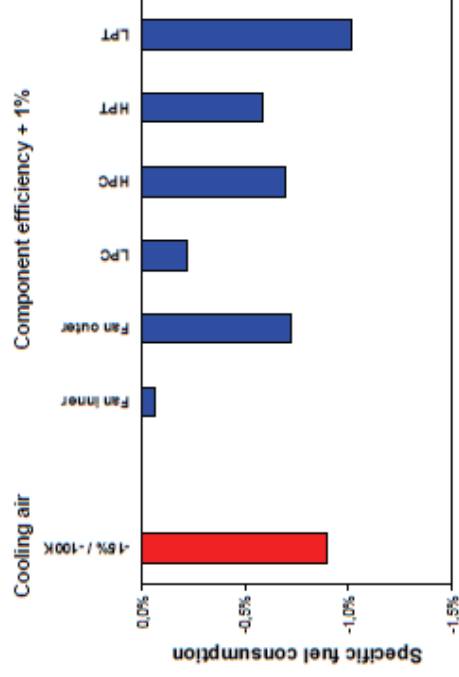


(NEWAC, EU Project)

Flow controlled core



(NEWAC, EU Project)



(Günter Wilfert ,2007)

Engine Performance Models

Engine Performance Models

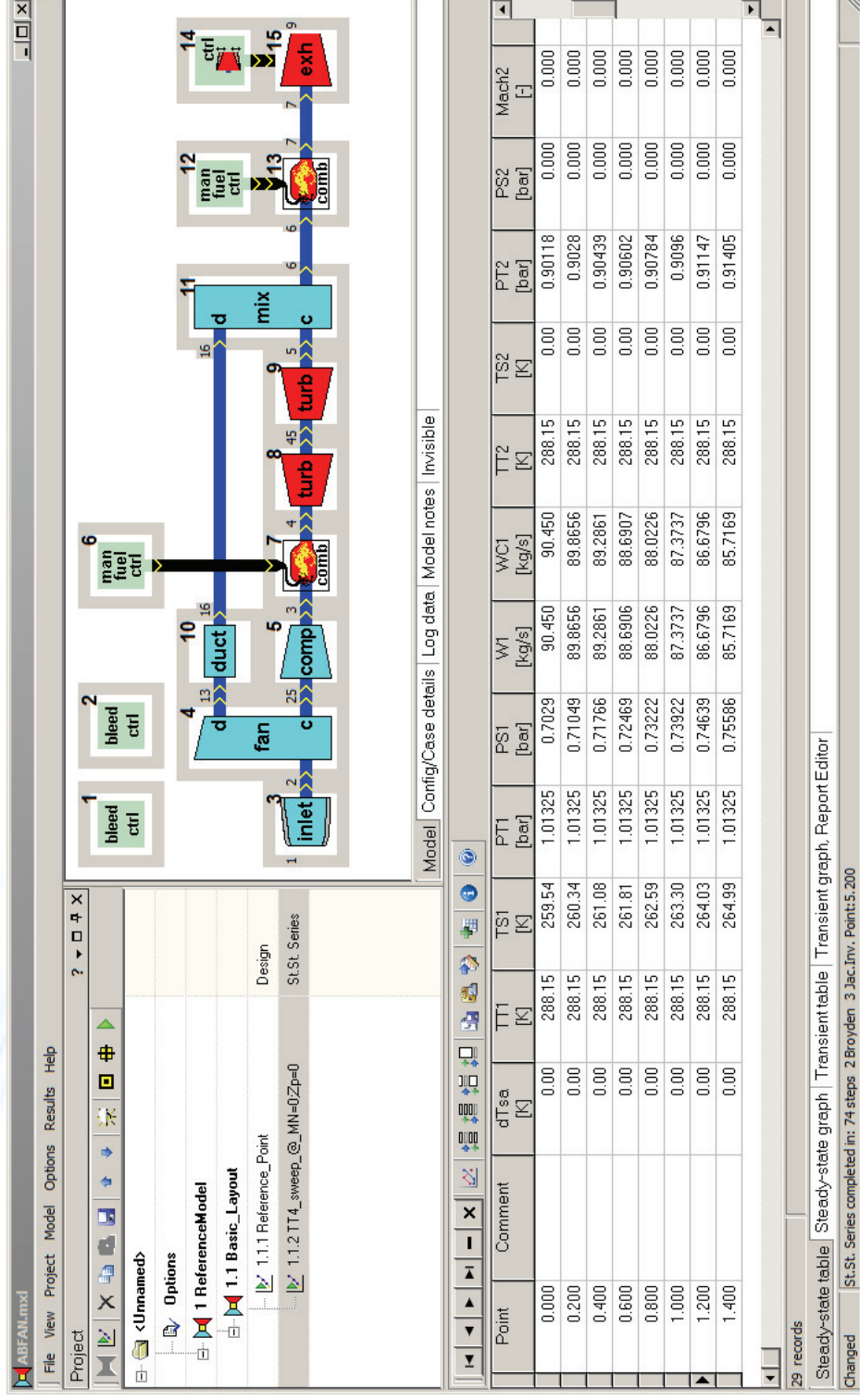
- Gas turbine engine performance models have evolved to a wide range of applications, providing support from the early stages of preliminary design through to in-service support.
- Engine models of various fidelity levels are used for design and verification of an engine, support its development and validation, while they play an important role in post-certification and in-service support.

Engine Performance Models

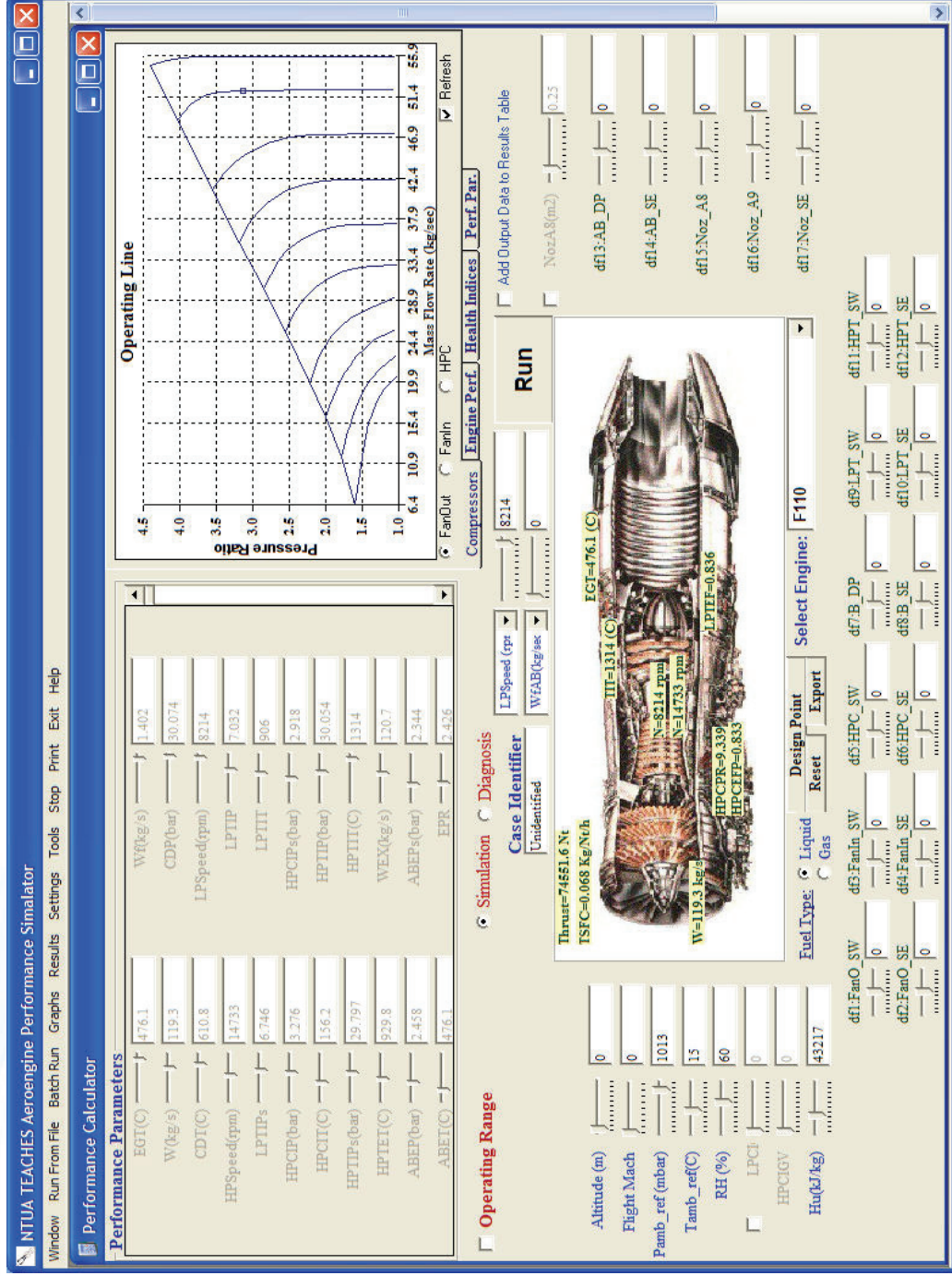
Software Packages

- A number of software packages with a user friendly interface are offered today (NLR's GSP, LTT/NTUA TEACHES, PROOSIS, GasTurb).
- These packages are using 0-D modeling techniques in which the performance of engine components (compressor, turbine, combustor) is predicted from corresponding performance maps.
- The emissions are predicted by methods of different fidelity. A multi reactor model is used in GSP, while in TEACHES and GasTurb the emissions are predicted by semi-empirical correlations.

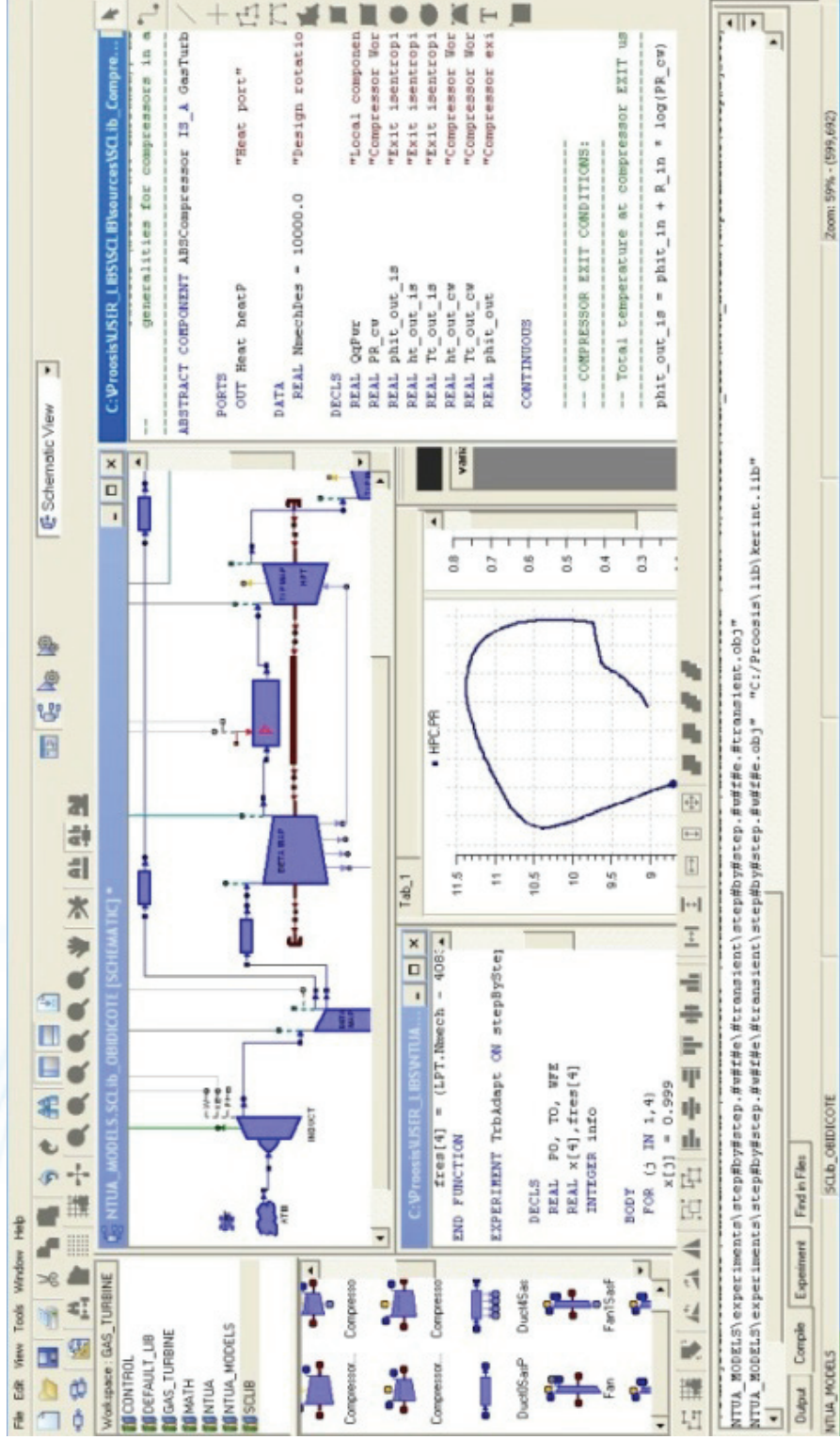
GSP Example



TEACHES Example

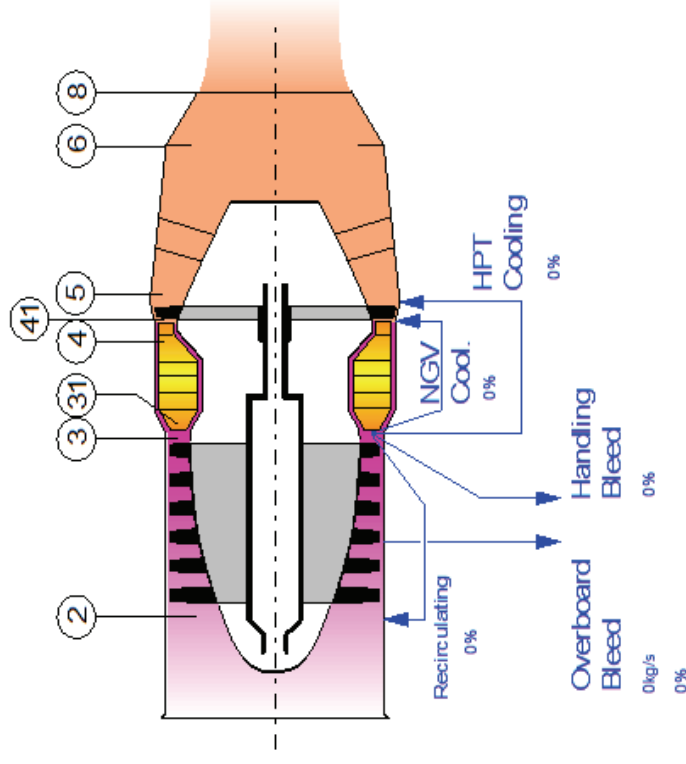


PROSIS Example



GasTurb Example

Station	W	T	P	WRstd	FN	
amb						
1	76.041	285.15	101.325		57.45 kN	
2	76.041	291.76	105.828		27.0727 g/(kN*s)	
3	76.041	291.76	104.770	74.000	FN/W2 =	755.48 m/s
31	76.041	647.54	1267.715	9.111	Prop Eff =	0.1872
4	76.041	647.54	1267.715		eta core =	0.3920
41	77.597	1370.00	1229.684	13.942	WF	= 1.55527 kg/s
49	77.597	1370.00	1229.684	13.942	s NOx	= 0.31952
5	77.597	1075.72	369.530	41.110	XM8	= 1.0000
6	77.597	1075.72	369.530	41.110	AB	= 0.1810 m²
8	77.597	1075.72	369.530	41.110	P8/Pamb	= 3.6470
Bleed	0.000	647.54	1267.710		WBld/W2	= 0.00000
					Ang8	= 20.00 °
P2/P1 = 0.9900	P4/P3 = 0.9700	P6/P5 = 1.0000			CD8	= 0.9600
Efficiencies:	isentr	polytr	RNI	P/P	W_NGV/W2	= 0.00000
Compressor	0.8300	0.8768	1.019	12.100	WCL/W2	= 0.00000
Burner	1.0000			0.970	Loading	= 100.00 %
Turbine	0.8700	0.8526	1.959	3.328	e45 th	= 0.87000
Spool mech Eff	1.0000	Nom Spd	7460 fpm		far7	= 0.02045
					PWX	= 0.00 kW
hum [%]	war0	FHV	Fuel			
0.0	0.00000	43.124	Generic			



References

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- Günter Wilfert, Joerg Sieber, Andrew Rolt, Nick Baker, Armel Touyeras , Salvatore Colantuoni, **'New Environmental Friendly Aero Engine Core Concepts'**, ISABE 2007
- GSP, Gas Turbine Simulation Program, www.gspteam.com
- GasTurb, Gas Turbine Software, www.gasturb.de
- PROOSIS: PRopulsion Object Oriented Simulation Software, www.proosis.com
- TEACHES, Turbine Advance Calculation Software, www.ltt.ntua.gr
- Walsh P., Fletcher P., 2004, 'Gas Turbine Performance', Blackwell Publishing