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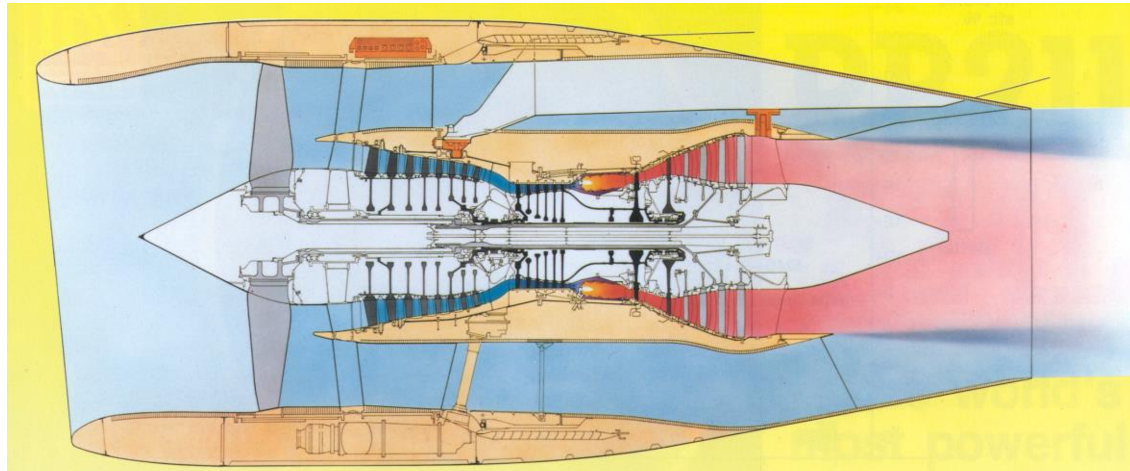
GAS TURBINE ENGINES AND PERFORMANCE

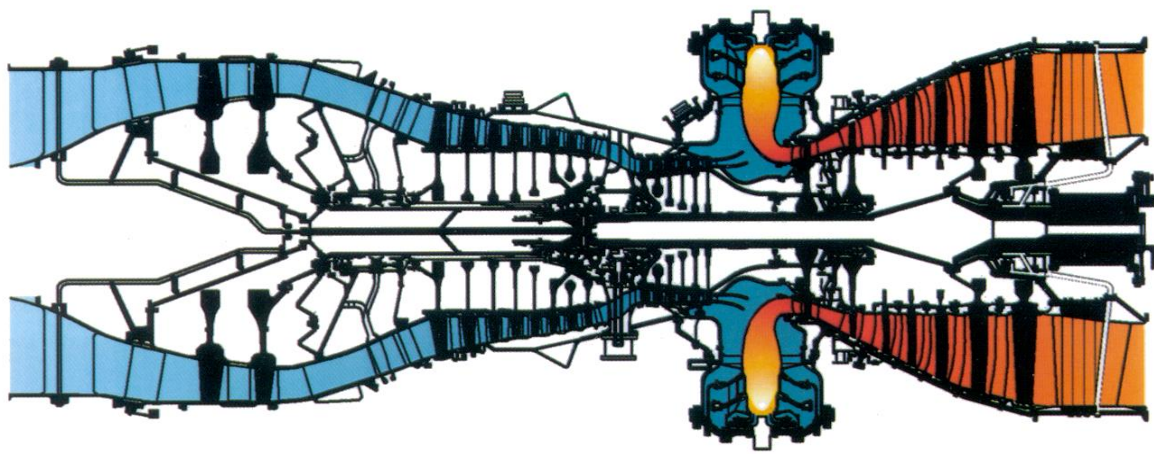
Professor Pericles Pilidis
Thermal Power & Propulsion

Jet Engines



A VERSATILE PRIME MOVER

Shaft Power



Images Courtesy of Rolls-Royce

THE GAS TURBINE IS A HEAT ENGINE

Input:	Heat	(Qcc)
Output:	Heat	(Qr)
	Work	(UW)

Qcc = UW + Qr

Thermal Efficiency η_{th} = UW / Qcc

PRIME MOVER COMPARISON

+ Small - Continuous Flow
  - Internal Combustion

  Emissions

- Higher Fuel Costs

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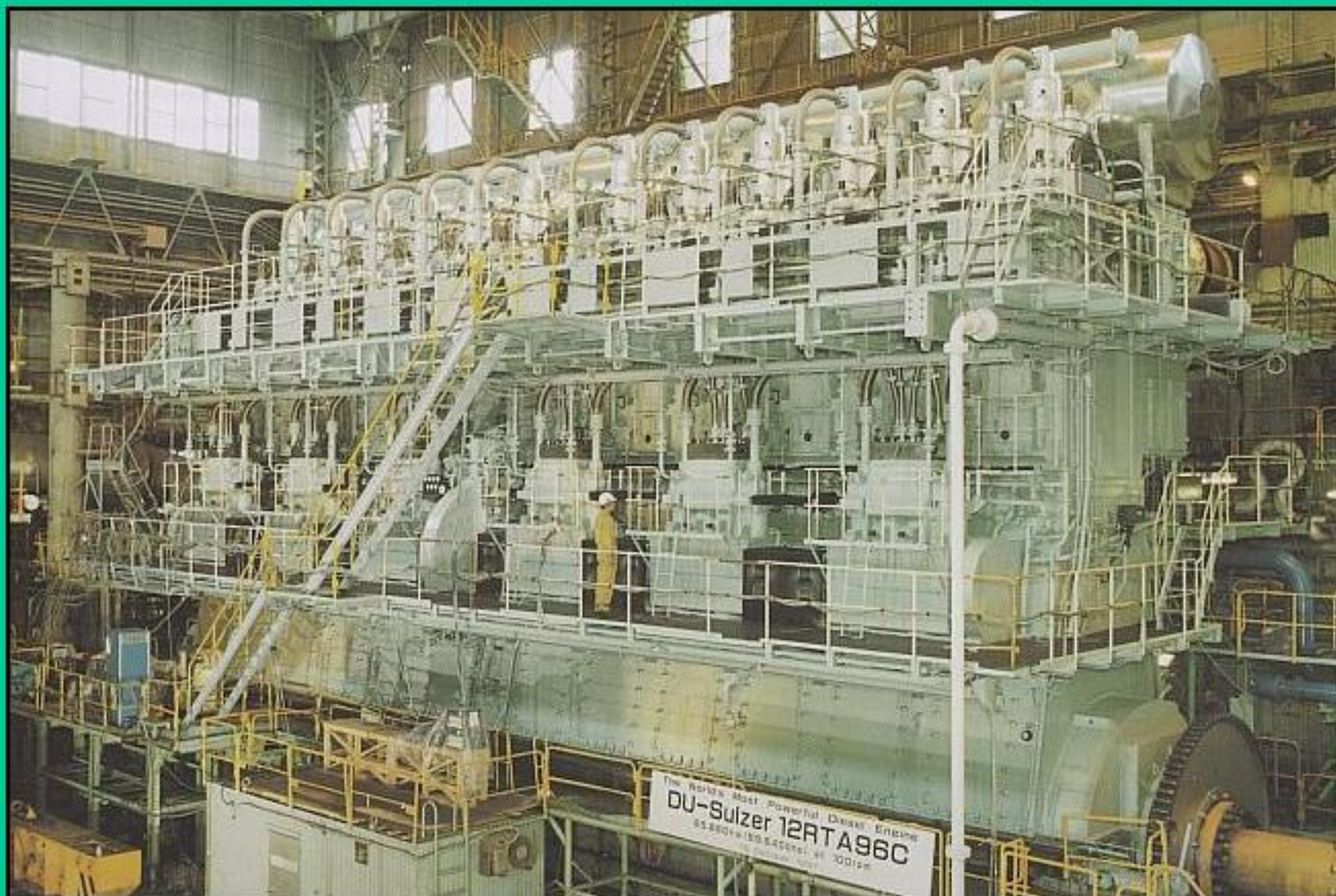


Courtesy of: Wartsila-Sulzer

Siemens multi-shaft combined-cycle power plant turnkey (with cooling tower).

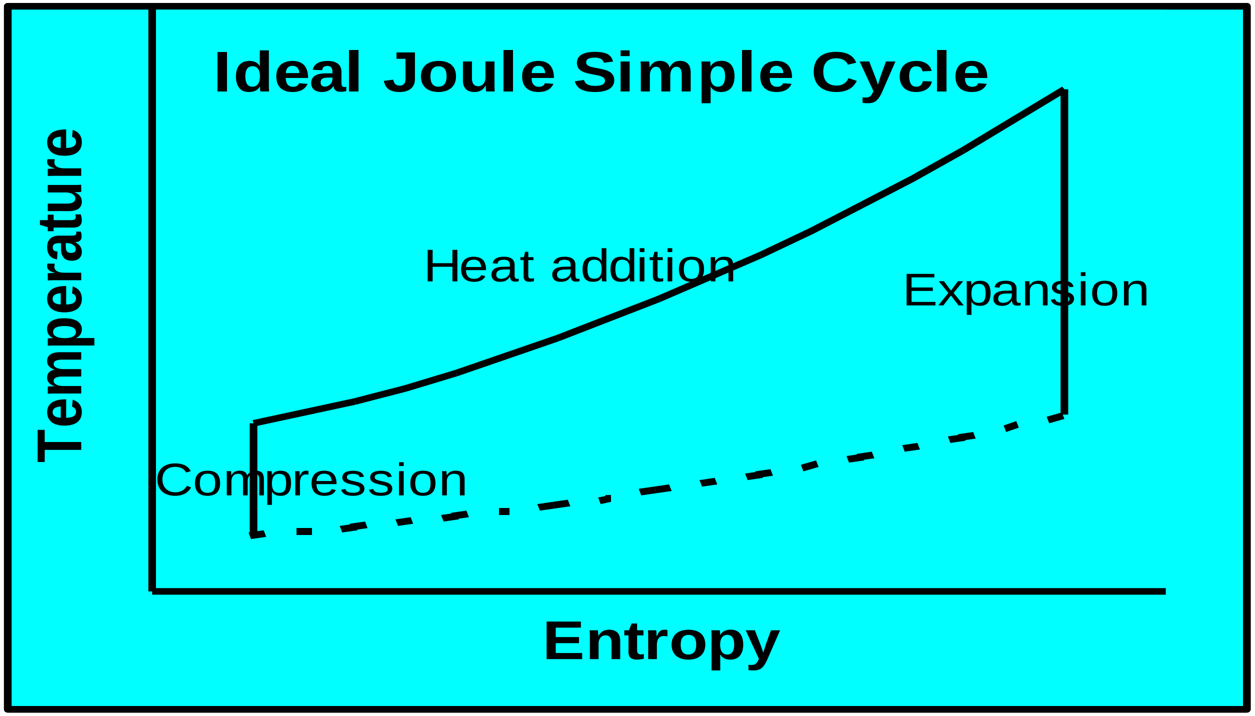
APPLICATIONS

Aircraft Propulsion - Civil - Military - Helicopters

Power Generation - High Efficiency CCGT
- Peak Load

Oil, Gas, Process - Gas Pumping, Electricity,

Marine Fast Ships - High Productivity
- Fuel Costs



Heat is added to compressed air at (nearly) constant pressure.

Thus expansion work is greater than compression work.

The surplus is the useful work.

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THERMODYNAMICS - Θερμοδυναμικη

Thermal Efficiency η_{th}

Spec Fuel Cons (SFC) = Fuel Flow / Power

Heat Rate = Qcc / UW

Specific Power = Power / Air Flow

- **THERMODYNAMICS** - Θερμοδυναμικη

Some Useful Approximations

Compressor Work = CW = Wc c_p (T_{out} - T_{in})

Turbine Work = TW = Wt c_p (T_{out} - T_{in})

Useful Work = TW - CW

Heat Input = Qcc = Wcc c_p (T_{out} - T_{in})

Fuel Flow = Qcc/FCV

Density = ρ = p/Rt

Mass Flow = W = ρAv

THERMODYNAMICS - Θερμοδυναμικη

Ideal compression and expansion

$P_{out}/P_{in} = (T_{out}/T_{in})^{(\gamma/(\gamma-1))}$

Real compression - $P_{out}/P_{in} = (T_{out}/T_{in})^{\eta p\,(\gamma/(\gamma-1))}$

Real expansion - $P_{out}/P_{in} = (T_{out}/T_{in})^{(\gamma/(\gamma-1))/\eta p}$

ηp is the polytropic efficiency, a measure of losses.

THERMODYNAMICS - Θερμοδυναμικη

Losses: ηp is a measure of losses

Isentropic efficiency is also used.

For a given pressure ratio: $\eta ise_c = CW_{id} / CW_{real}$

For a given pressure ratio: $\eta ise_t = TW_{real} / TW_{id}$

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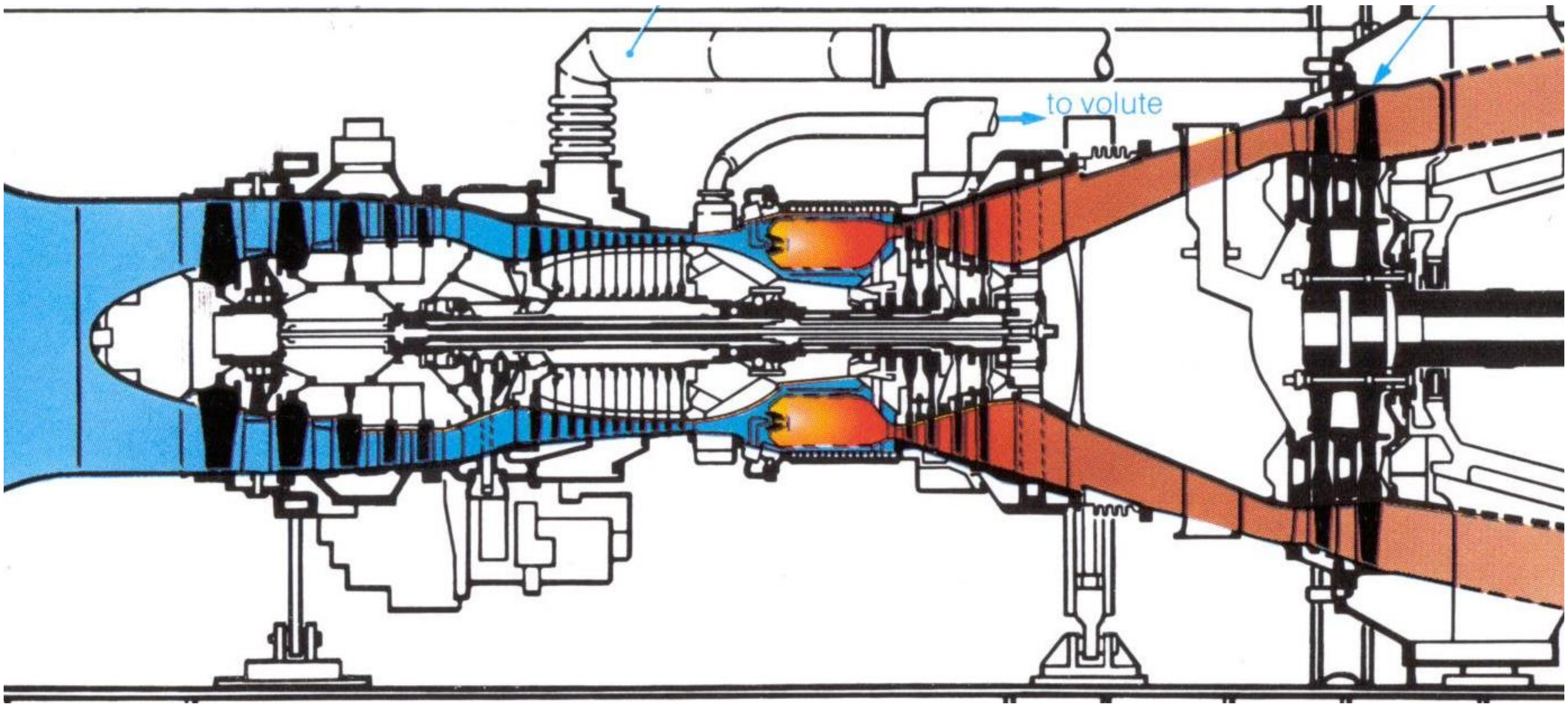
SIMPLE CYCLE GT



Pressure Rise Add Heat Expansion

Compressor/s Combustor/s Turbine/s

Image Courtesy of Rolls-Royce

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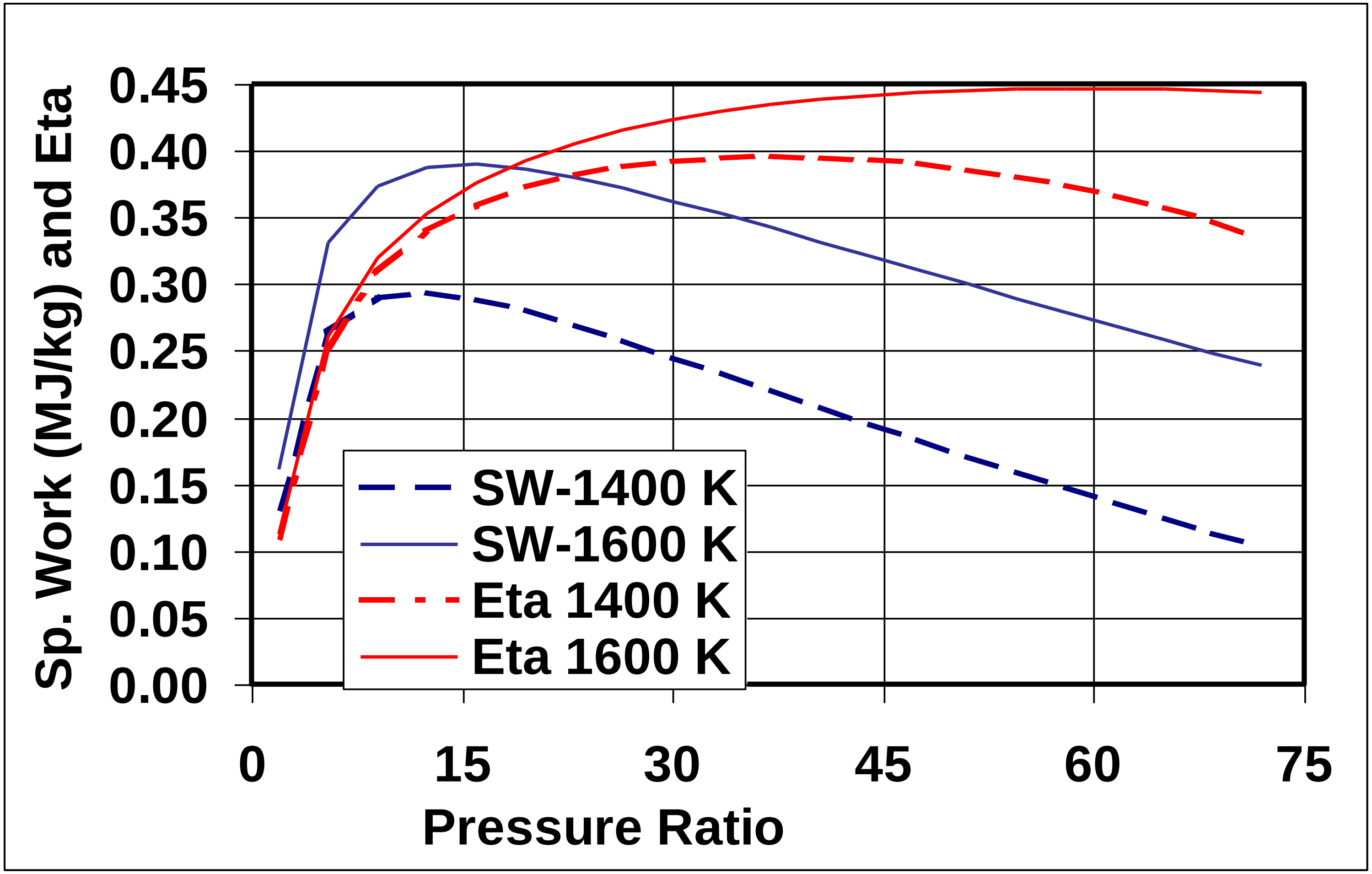
EFFICIENCY VS SPECIFIC POWER



GT CYCLES: EFFICIENCY VS SPECIFIC POWER

Simple Cycle

Recuperated

Intercooled

Reheat

GAS TURBINE CYCLES - SIMPLE CYCLE

Single Shaft vs Multi Shaft

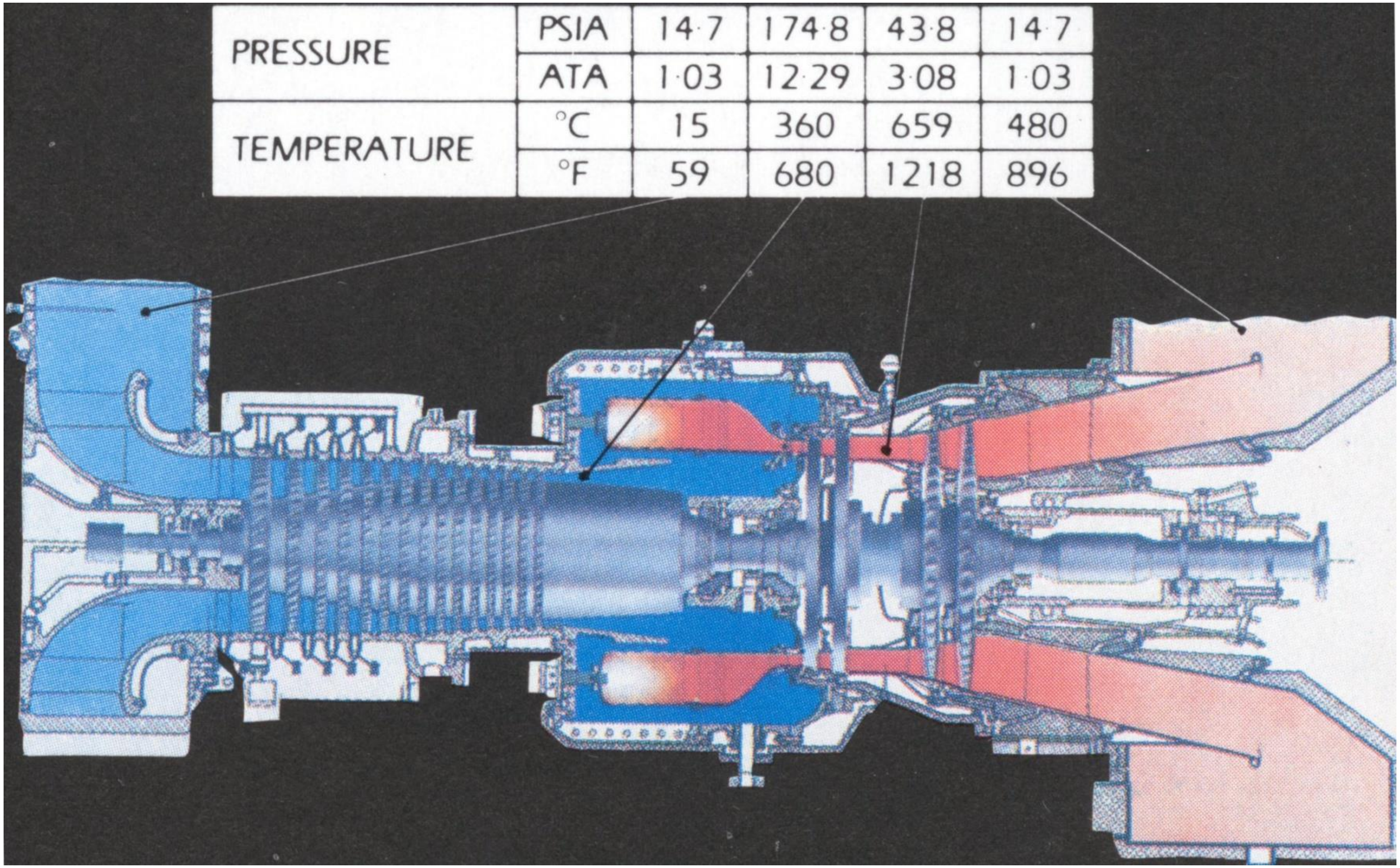
- Independent / Coupled Power Turbine

- Surge Prevention

SINGLE VS MULTI SHAFT

Independent - Coupled Power Turbine

Image courtesy of Alstom



PRESSURE	PSIA	14·7	174·8	43·8	14·7
	ATA	1·03	12·29	3·08	1·03
TEMPERATURE	°C	15	360	659	480
	°F	59	680	1218	896

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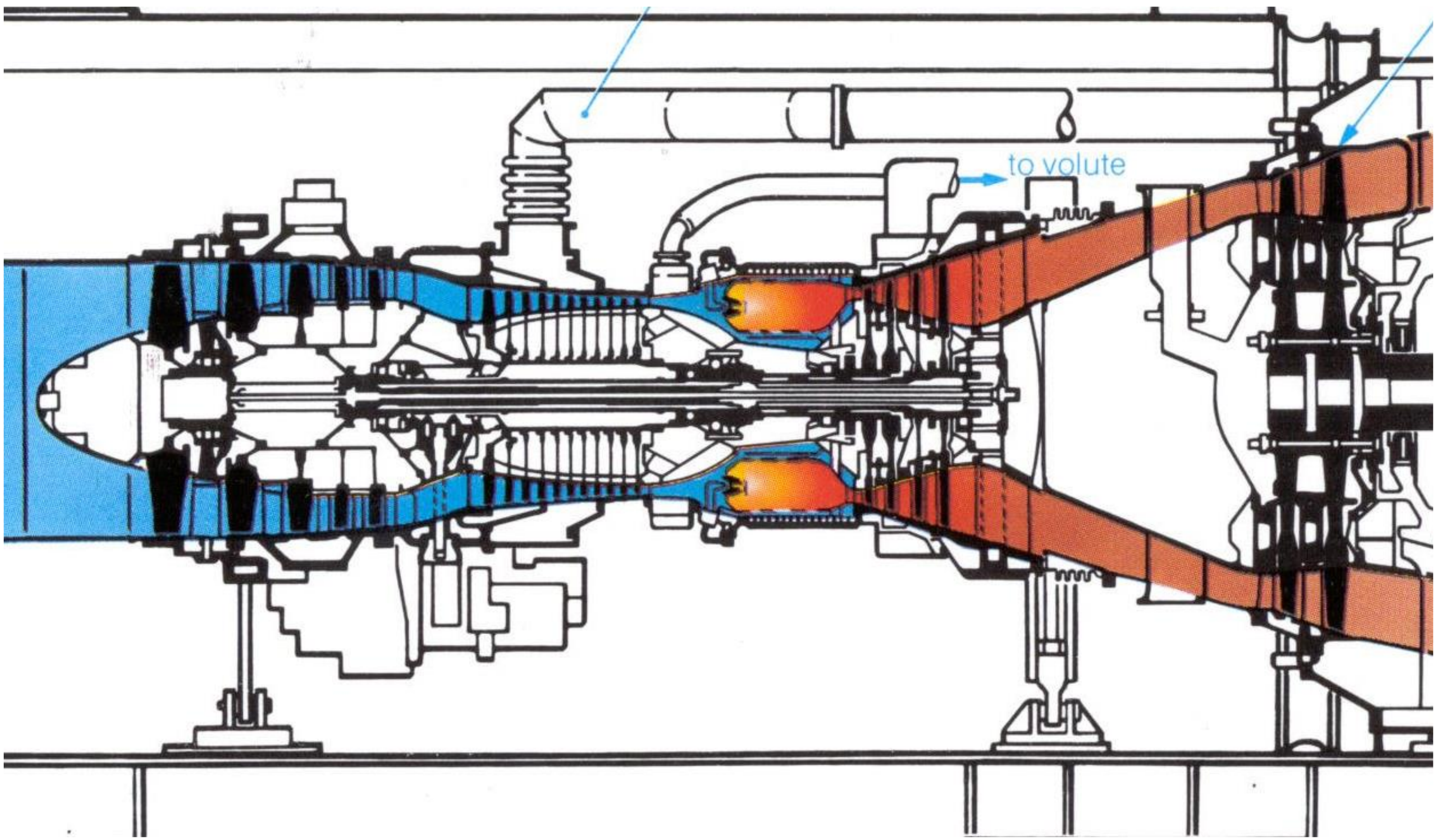
SINGLE VS MULTI SHAFT

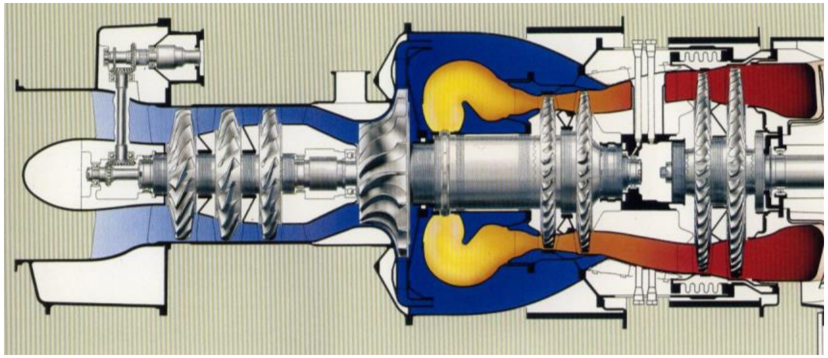
Surge Prevention

Image courtesy of Rolls-Royce



THE JET ENGINE

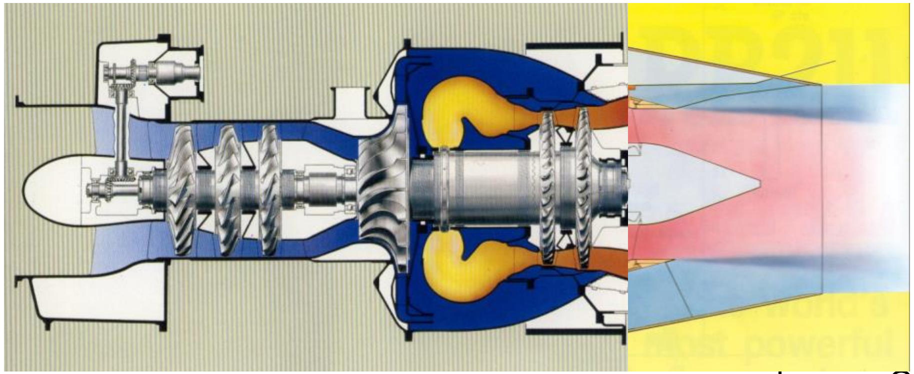
Convert Pressure Energy into Kinetic Energy



Mechanical Power

Power Turbine

<---Gas Generator--->



Thrust

Propelling Nozzle

Images Courtesy of TurboMeca and Rolls-Royce

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THE JET ENGINE - Θερμοδυναμικη

Some Useful Principles

Density = ρ = p/Rt

Mass Flow = W = ρAv

Total energy of the flow = wCpt + wv^2/2 = w CpT

Speed of sound = a = $(\gamma Rt)^{0.5}$

$(P/p_i)^{(\gamma-1/\gamma)}$ = T/t = 1 + (g-1)M^2/2

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THE JET ENGINE - PROPULSIVE EFFICIENCY

$$Fn = WeVj - WiVo + An(p_n - p_a)$$

$\eta_{ov} = \eta_{th} \times \eta_{pr}$

η_{th} - Heat to KE

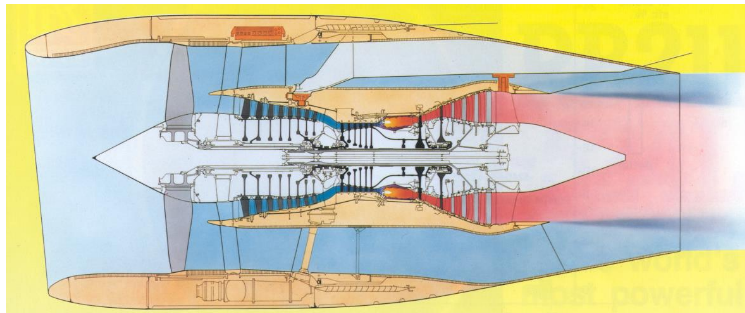
η_{pr} - KE to Thrust

$\eta_{pr} = FnVo / (KEj+FnVo) = FnVo / (KE)$

$\eta_{pr\ ideal} = 2 / (1+Vj/Vo)$

THE JET ENGINE - PROPULSIVE EFFICIENCY

Vo--->



Images Courtesy of Rolls-Royce

-------->Vj

Vm = 0

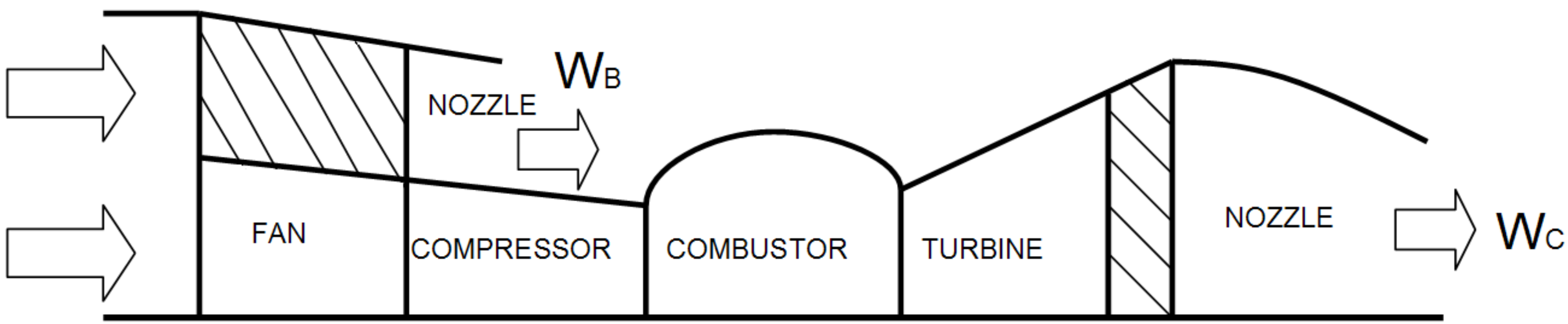
Vm = Vj-Vo

$KEj = W\,(Vj-Vo)^2 / 2$

----------------------------------- Ground --------------------------

η_{pr} = Thrust Work / KE from engine

THE TURBOFAN ENGINE



Bypass Ratio = Wb/Wc

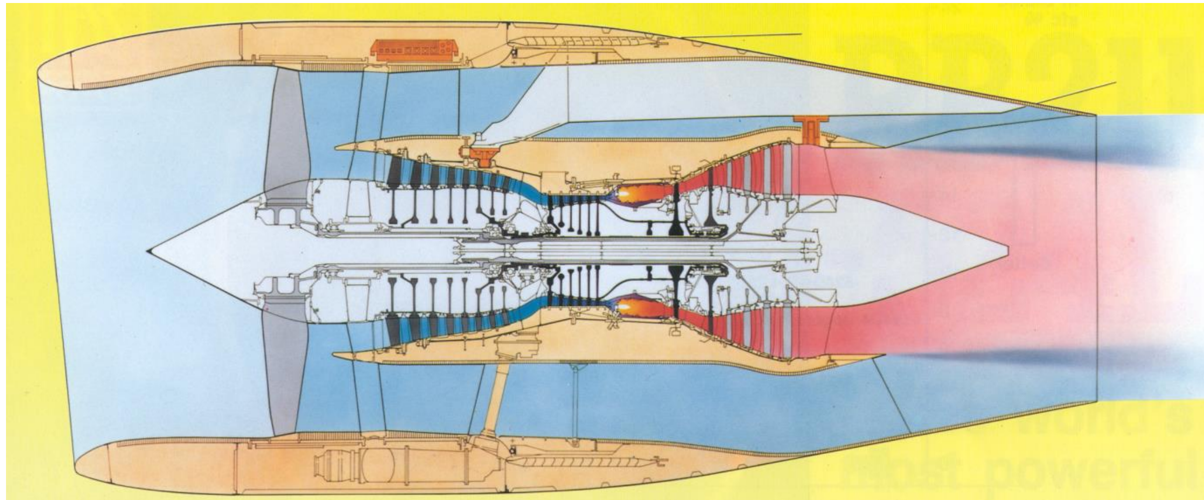
Reduces SFC and Spec. Thrust but increases diameter

Civil and military applications

TURBOFANS

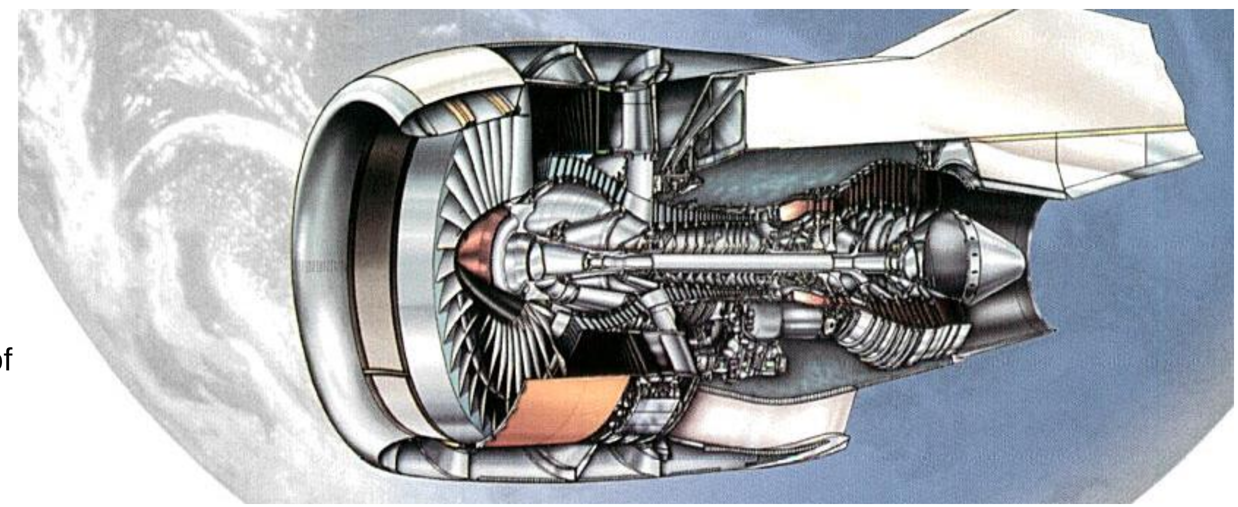
Mixed Exhaust High Bypass Turbofan

Image Courtesy of Rolls- Royce



HBP Turbofan with Separate Exhausts

Image Courtesy of Pratt+Whitney



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Aircraft Engine Design

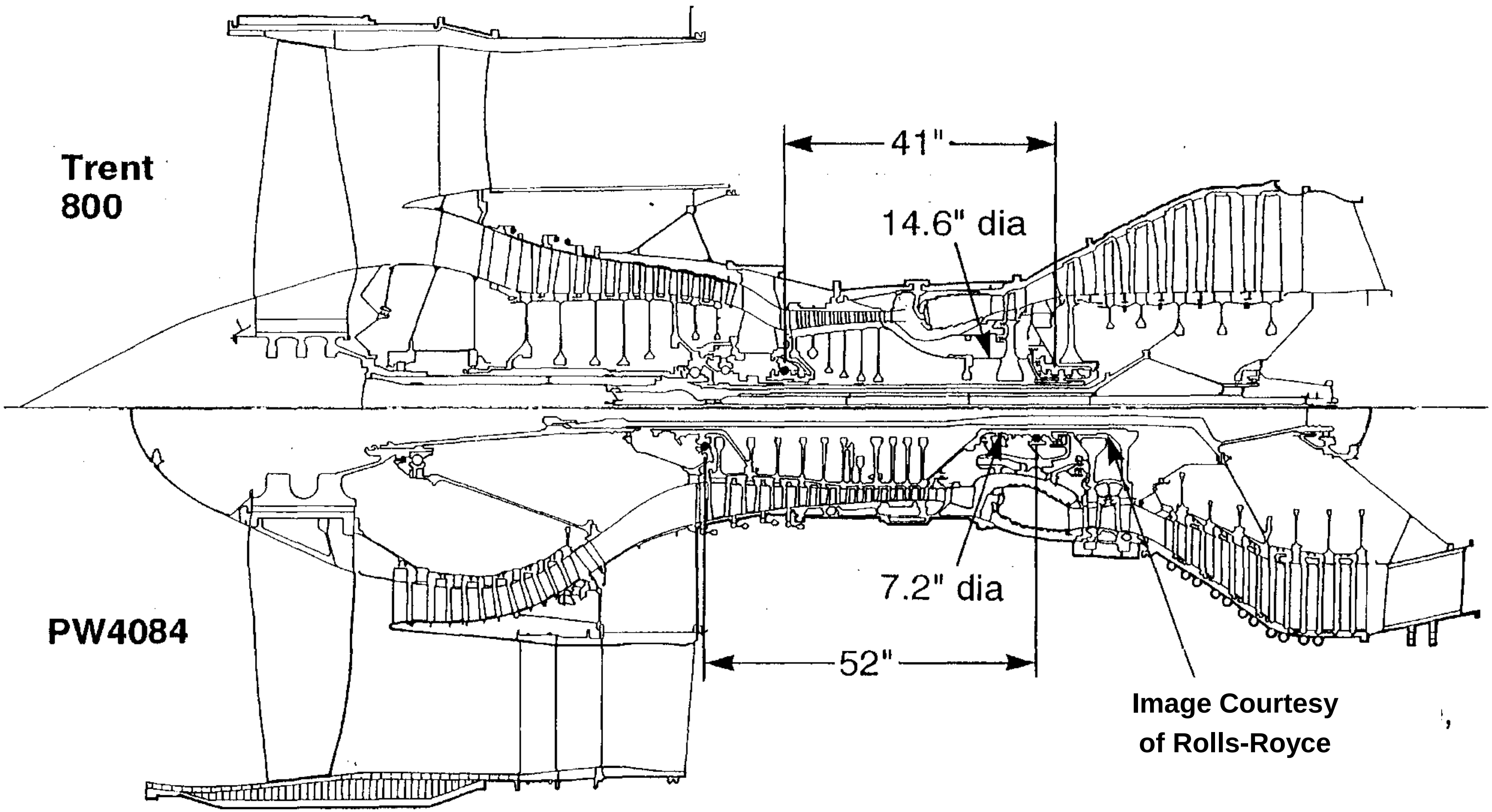

Image Courtesy
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Aircraft Engine Design

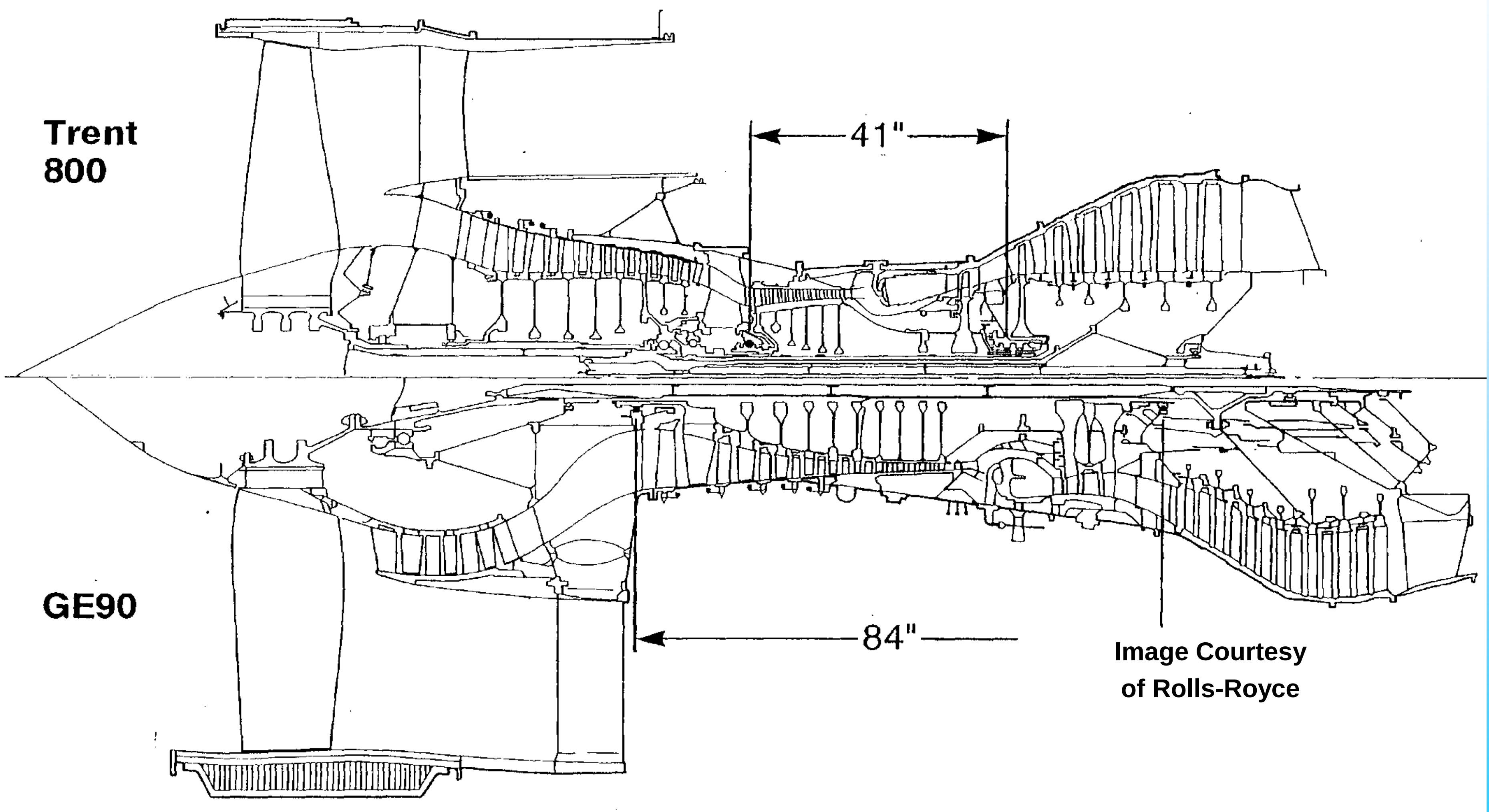
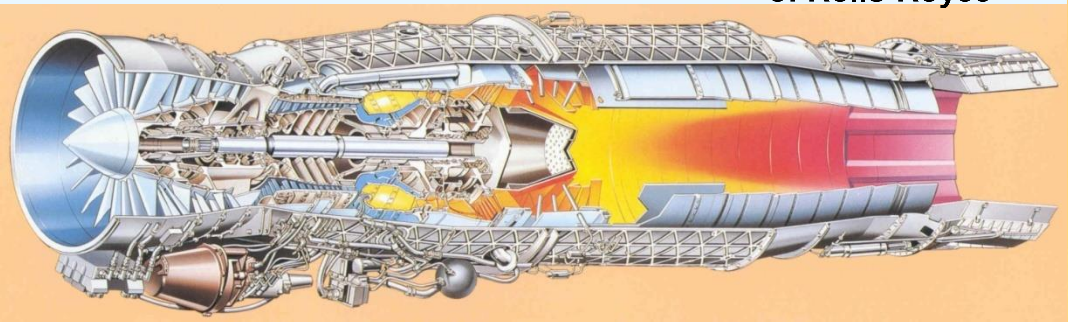


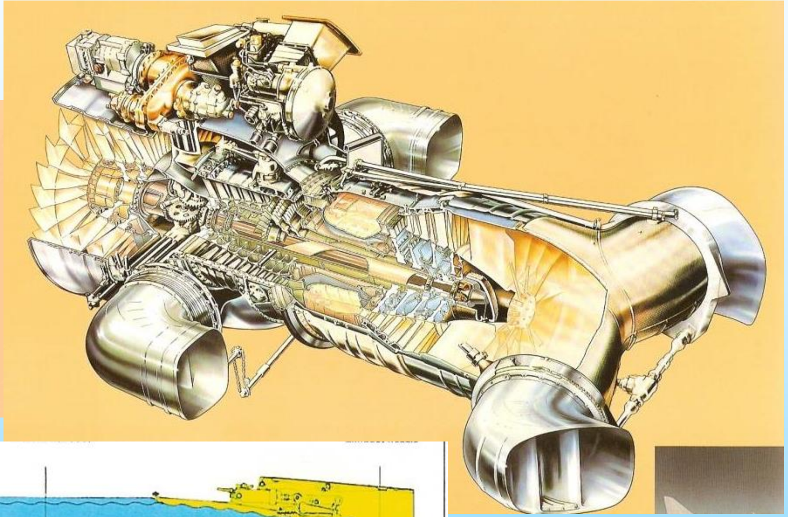
Image Courtesy of Rolls-Royce

Aircraft Engine Design - Unducted Fan

Aircraft Engine Design - Low Bypass Turbofans

Images Courtesy
of Rolls-Royce





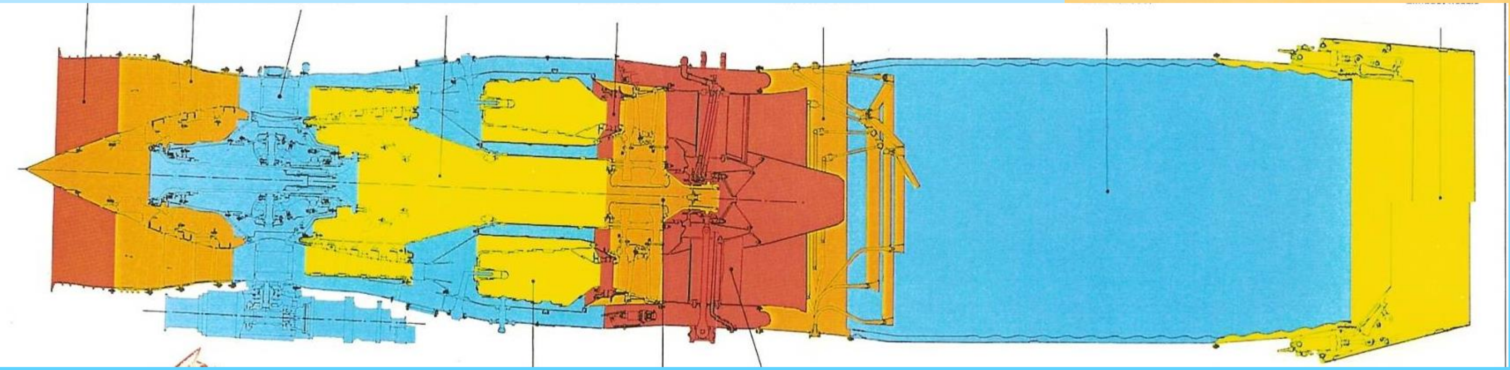


Image Courtesy
of SNECMA

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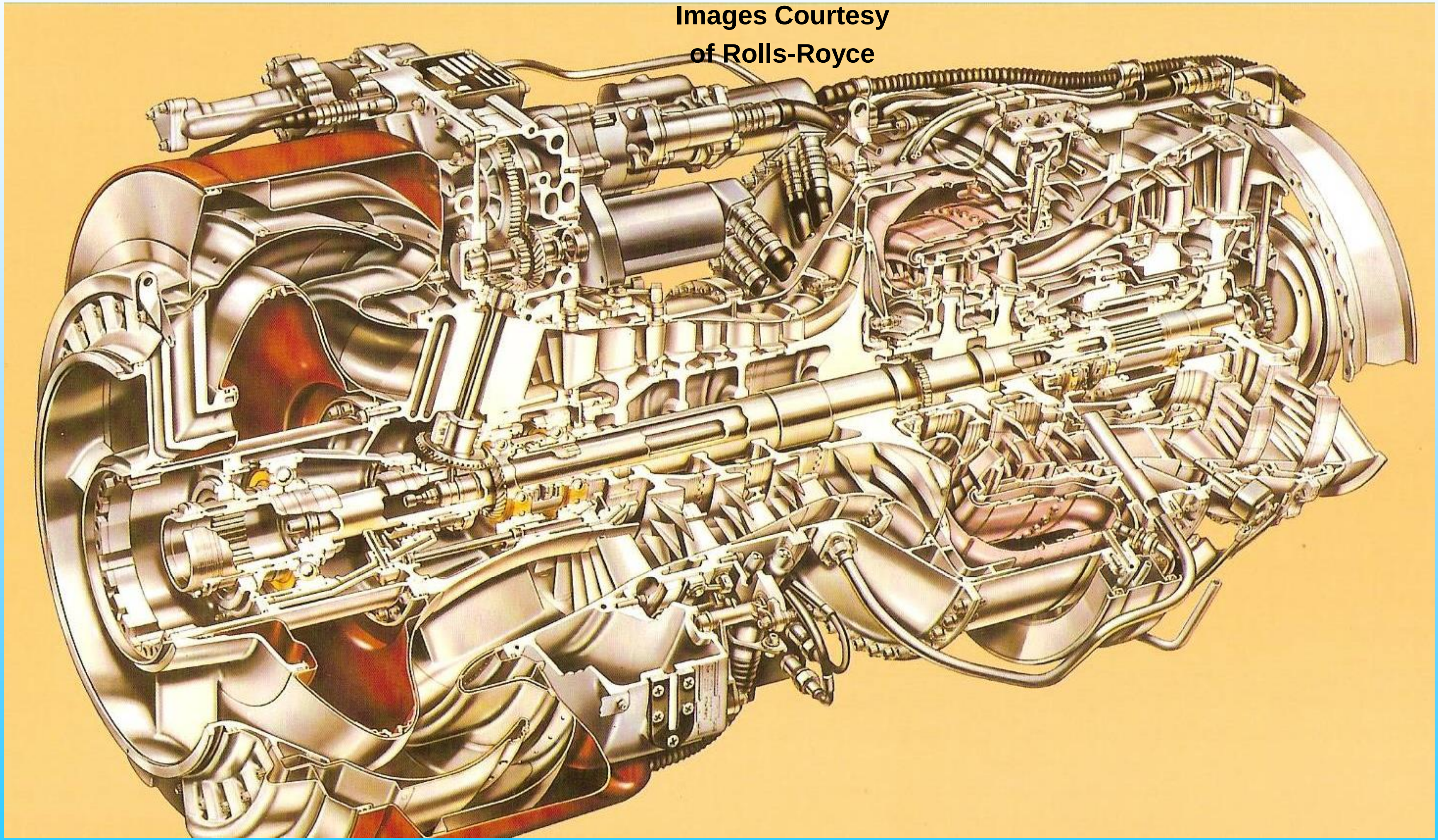
Small Gas Turbine

Images Courtesy of Rolls-Royce



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The Future?

Open Rotors - η_{prop}

Advanced cores - $\eta_{thermal}$

Combustion with Pressure Rise - $\eta_{thermal}$

Biofuels - Hydrogen - CO_2 mitigation

Integration - Distributed Propulsion?

GAS TURBINE CYCLES

Recuperated - Heat Recovery

- Heat Exchanger

- Steam Injection

- Combined Cycles

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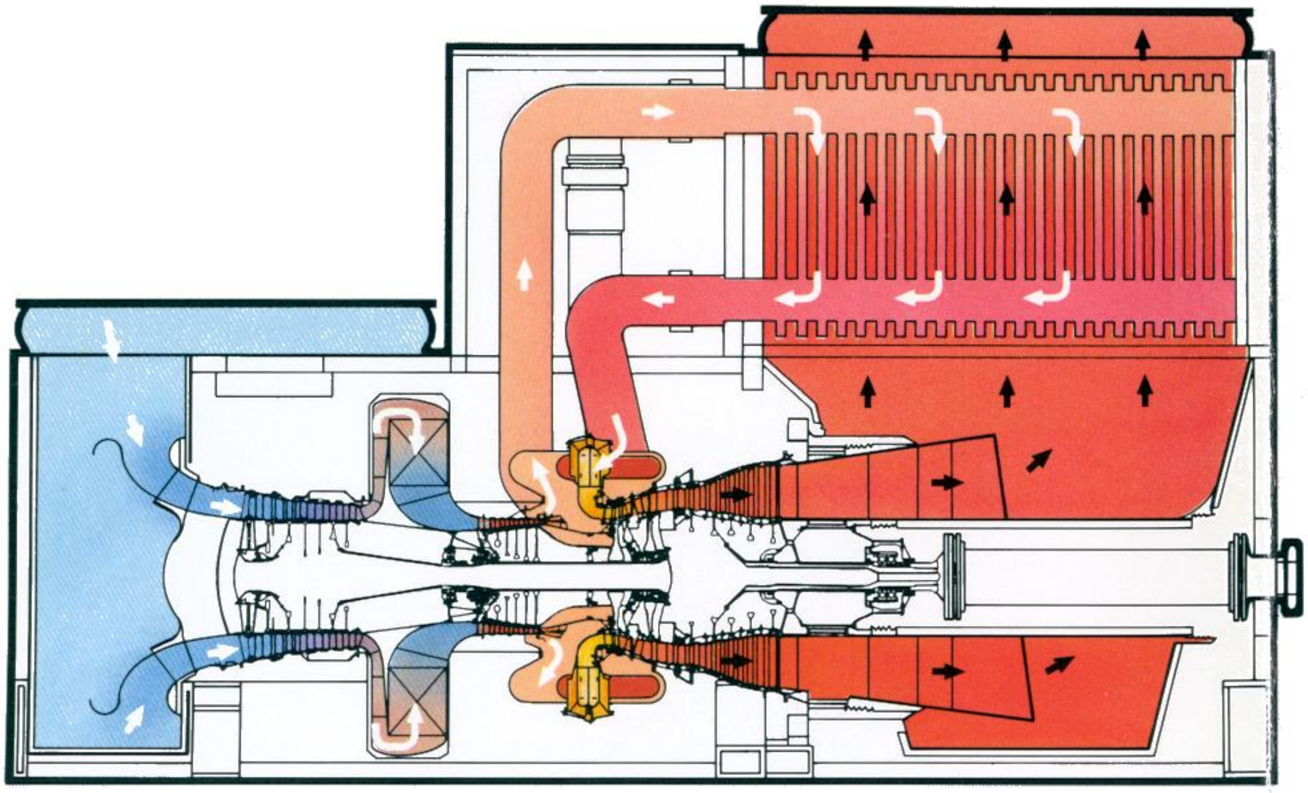
GAS TURBINE CYCLES- RECUPERATED

Image courtesy of Rolls-Royce



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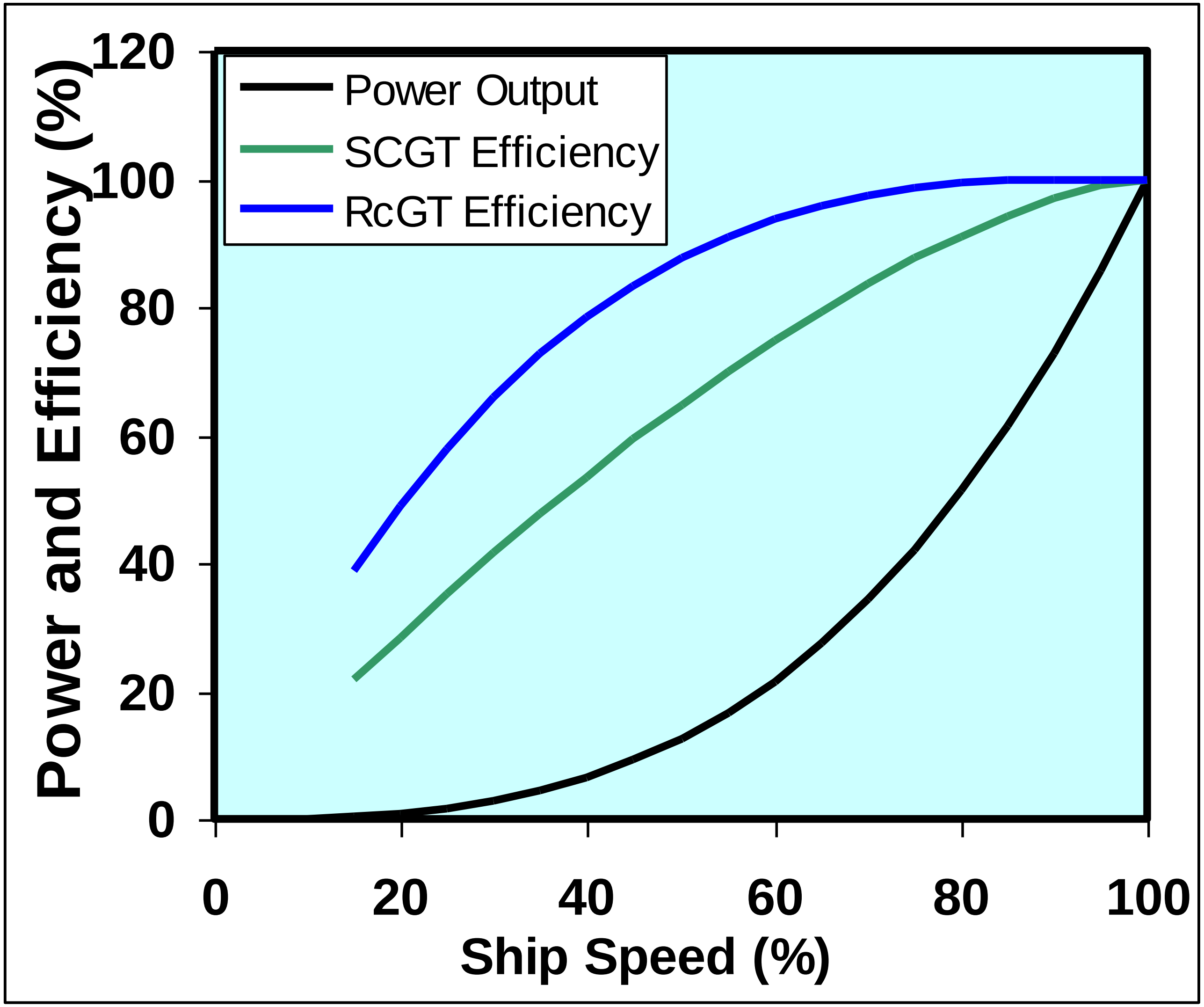
GAS TURBINE CYCLES- RECUPERATED



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GAS TURBINE CYCLES - STEAM INJECTION

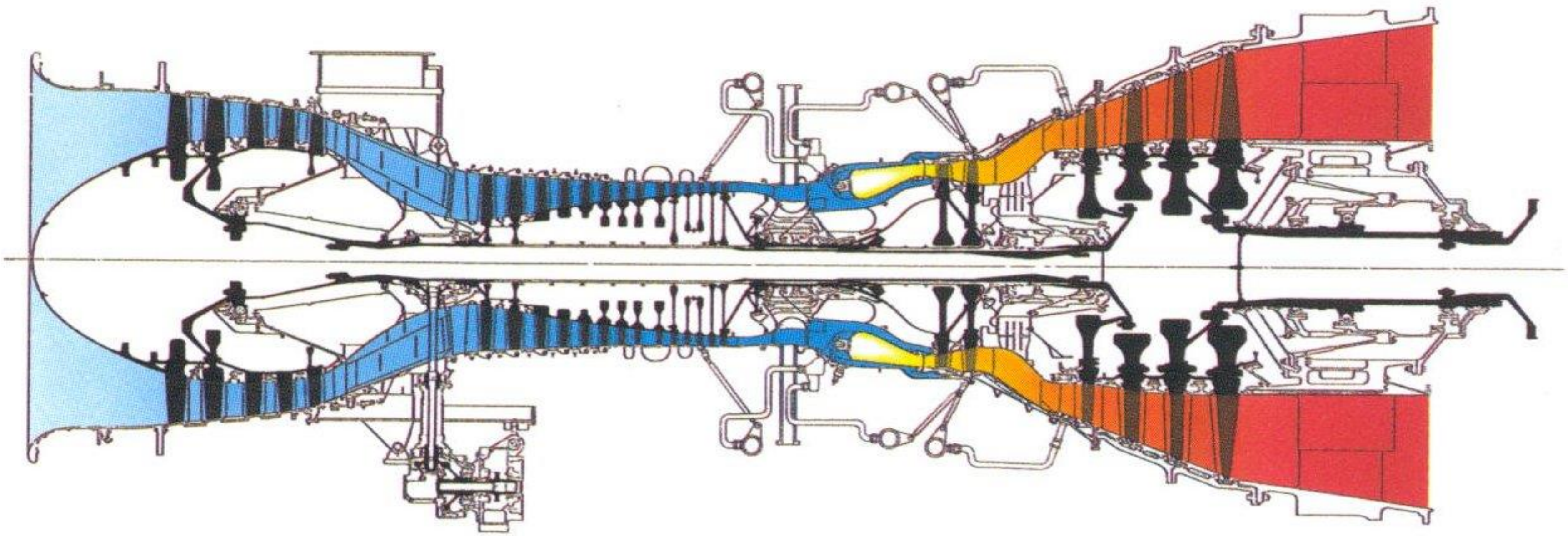

Image courtesy of General Electric

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GAS TURBINE CYCLES - COMBINED CYCLES

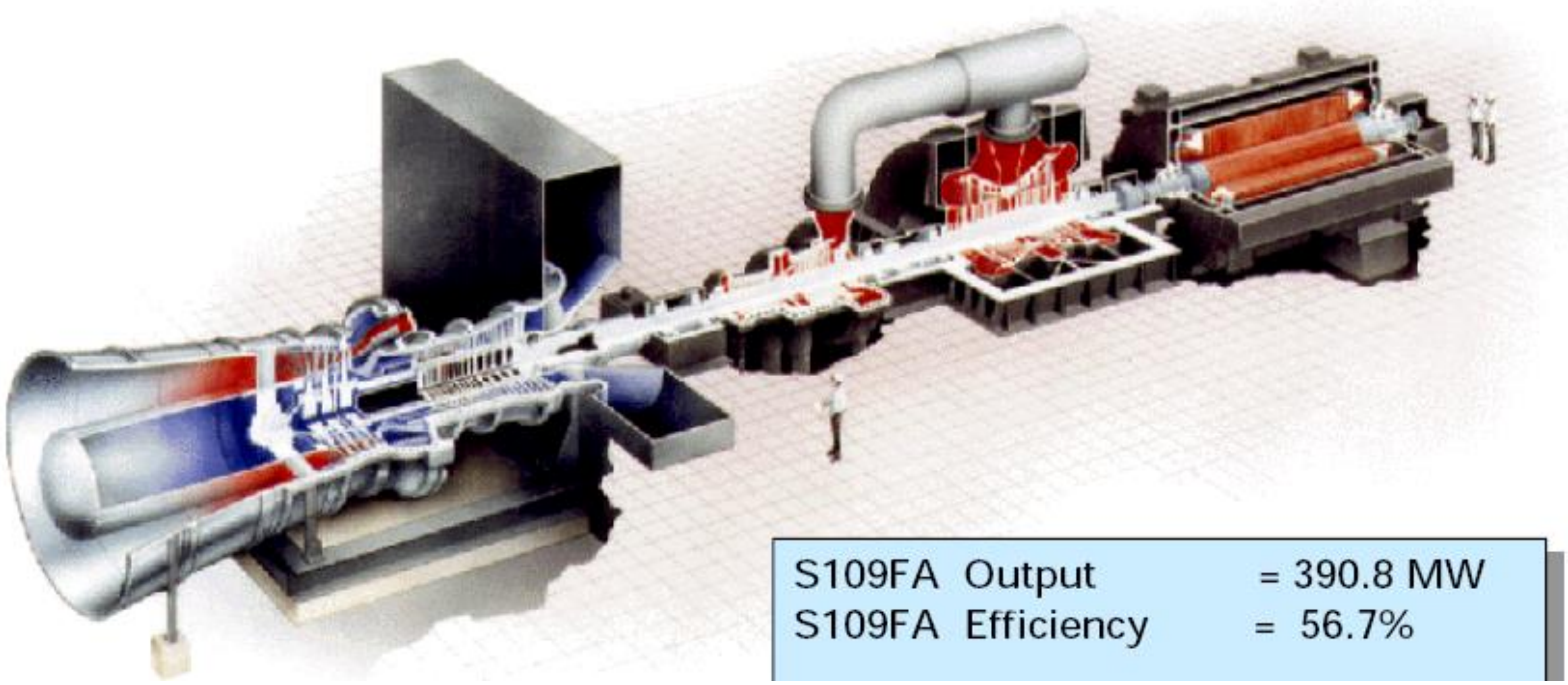
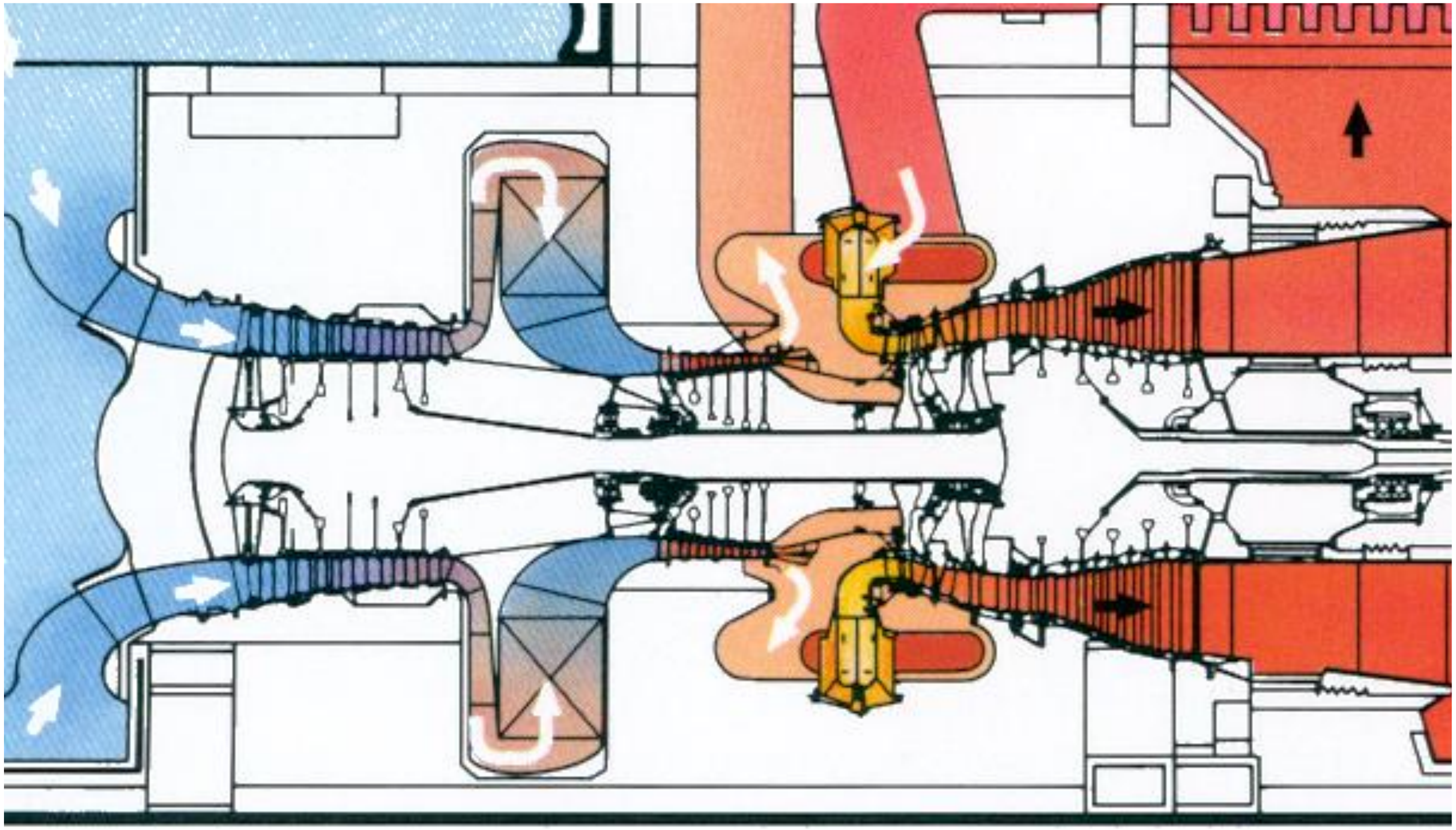


Image courtesy of General Electric

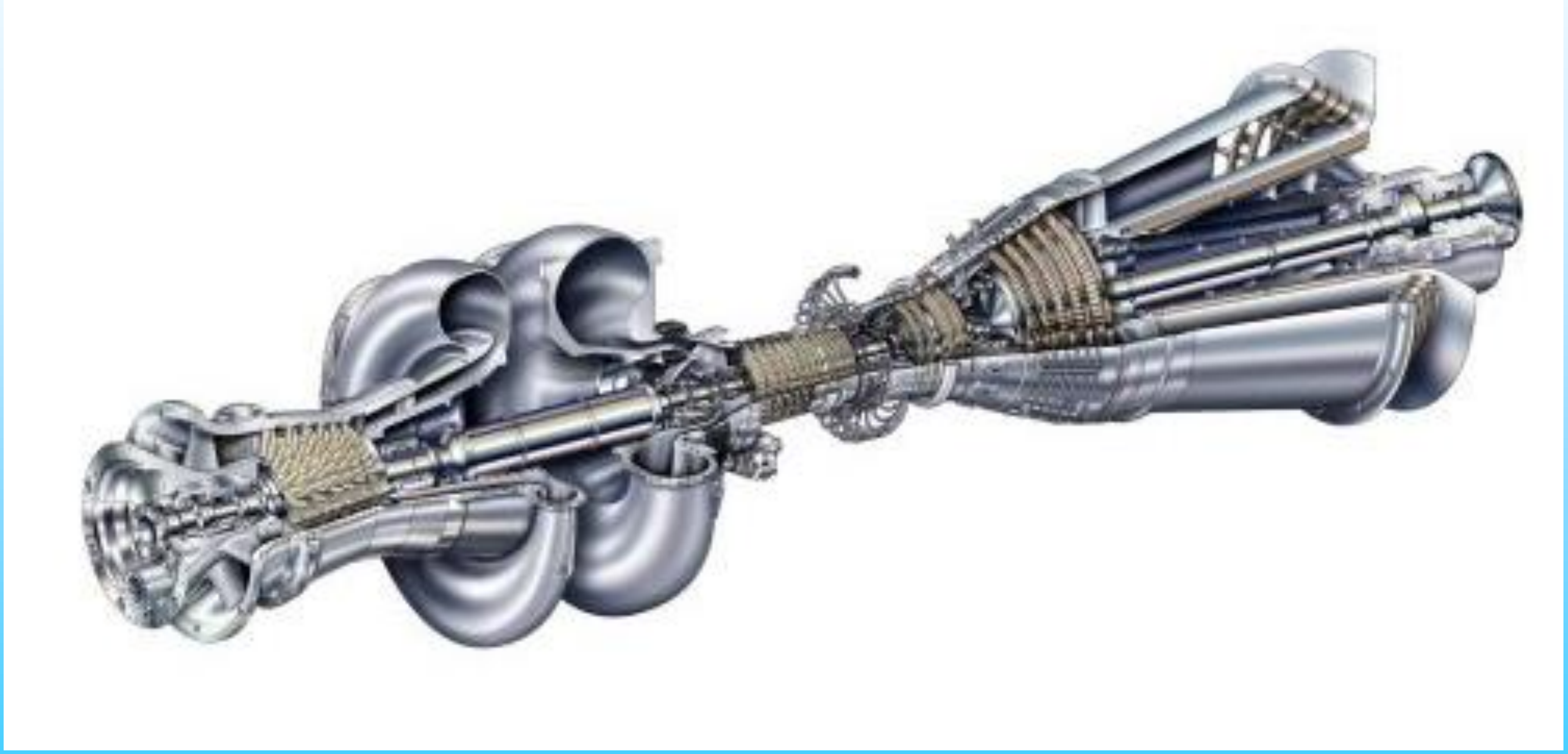
GAS TURBINE CYCLES - INTERCOOLING

Image courtesy of Rolls-Royce



GAS TURBINE CYCLES - INTERCOOLING

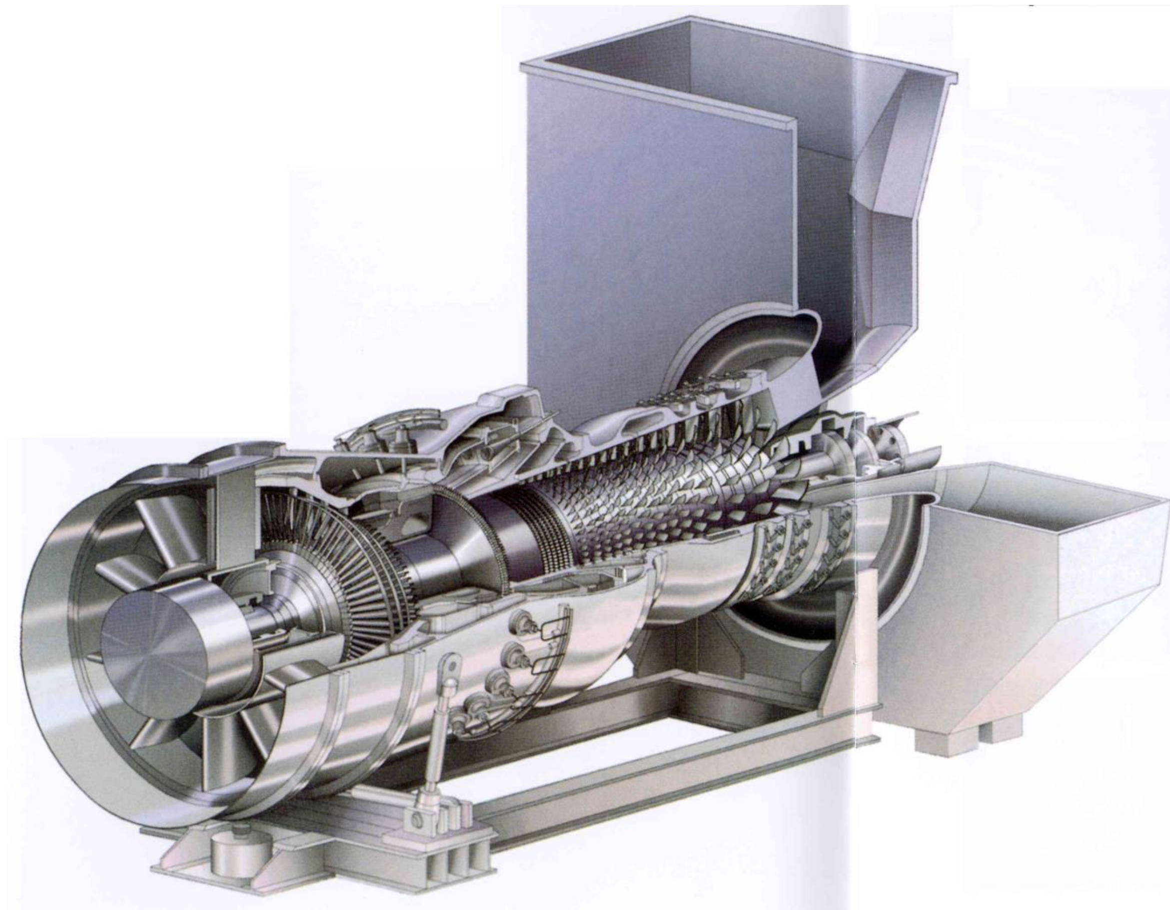
Image courtesy of GE



GAS TURBINE CYCLES:

REHEAT CYCLE FOR POWER GENERATION

Image courtesy of Alstom



GAS TURBINE CYCLES
LOW BYPASS REHEATED TURBOFAN

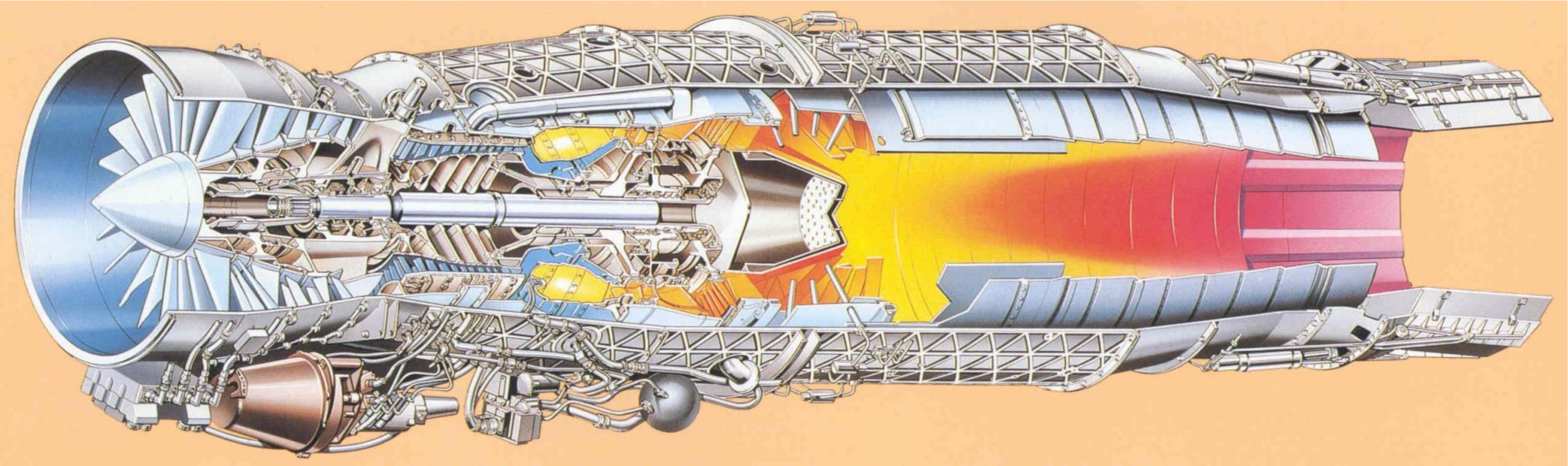


Image courtesy of Rolls-Royce

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GROWTH - ZERO STAGING

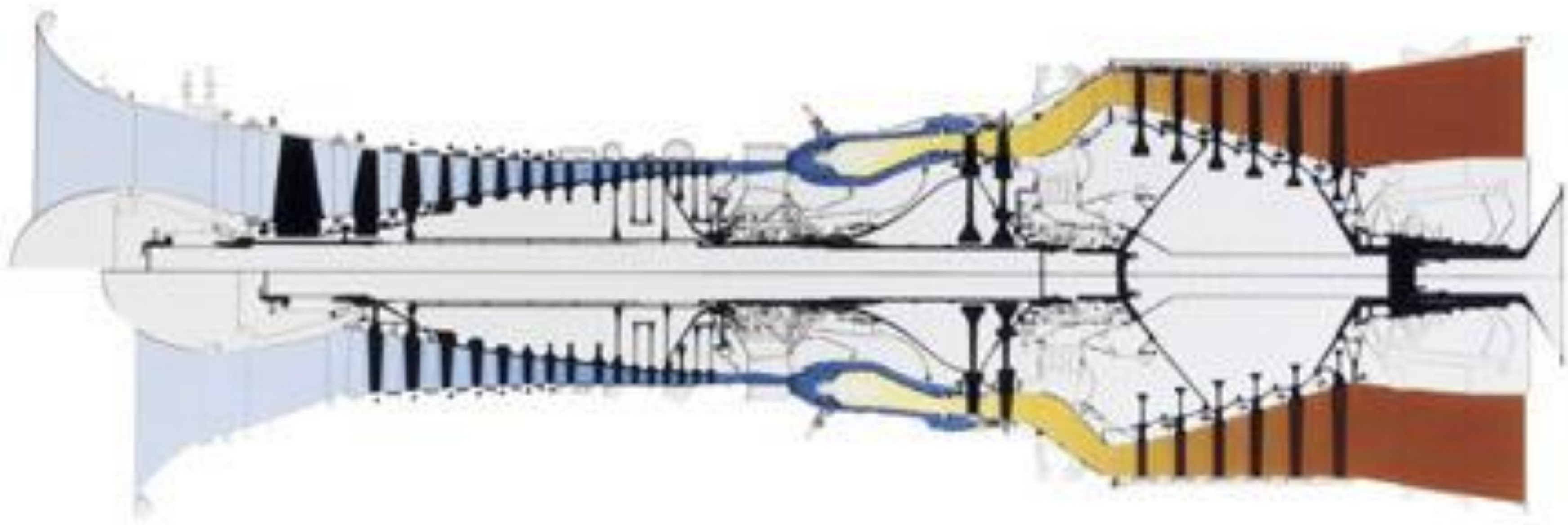


Image courtesy of General Electric

GROWTH - SCALING:

Vt = same = RxNxC

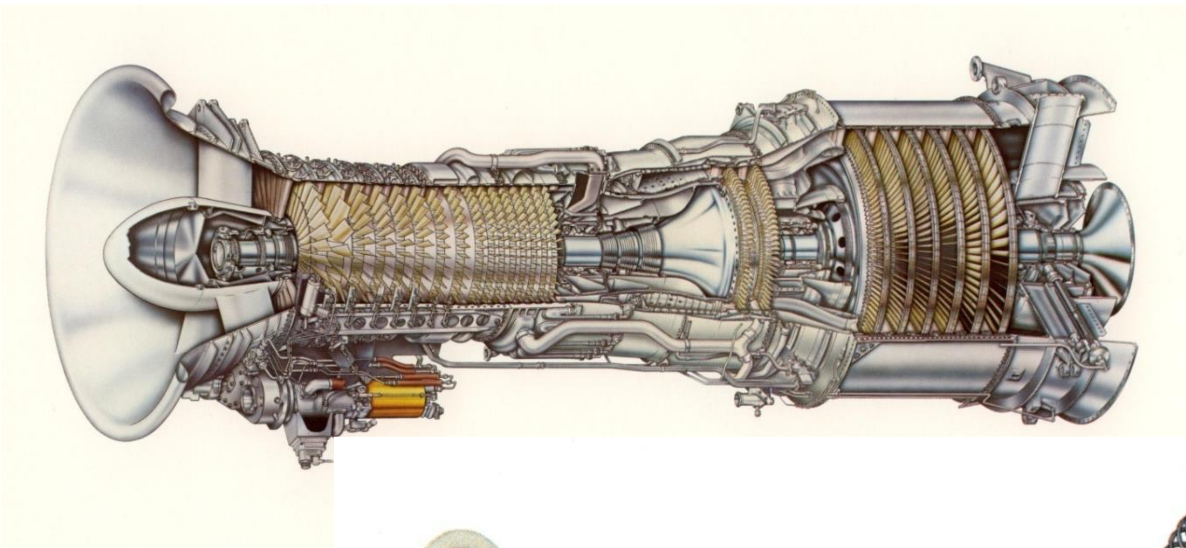
60 HZ RPM = 3600 (Direct Drive)

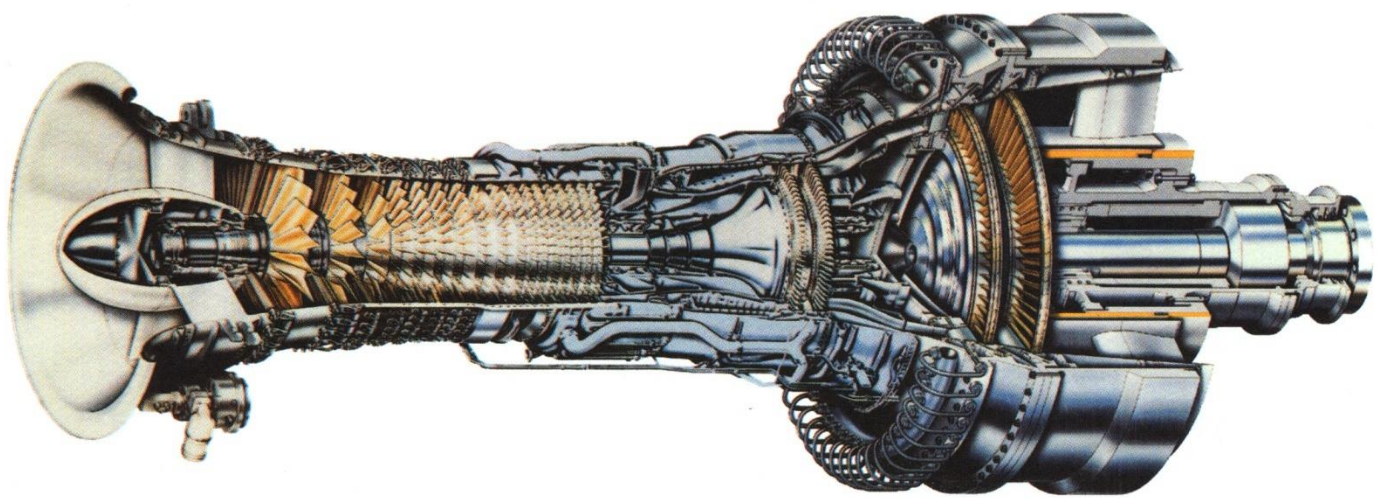
50 HZ RPM = 3000 (Direct Drive)

So $1.2 \times R_{60} = R_{50}$

And $1.44\ W_{60} \sim W_{50}$

POWER TURBINES





Images
courtesy
of General
Electric

Questions

&

Comments