Aerospace Vehicle Design & Systems Integration

Propulsion 1

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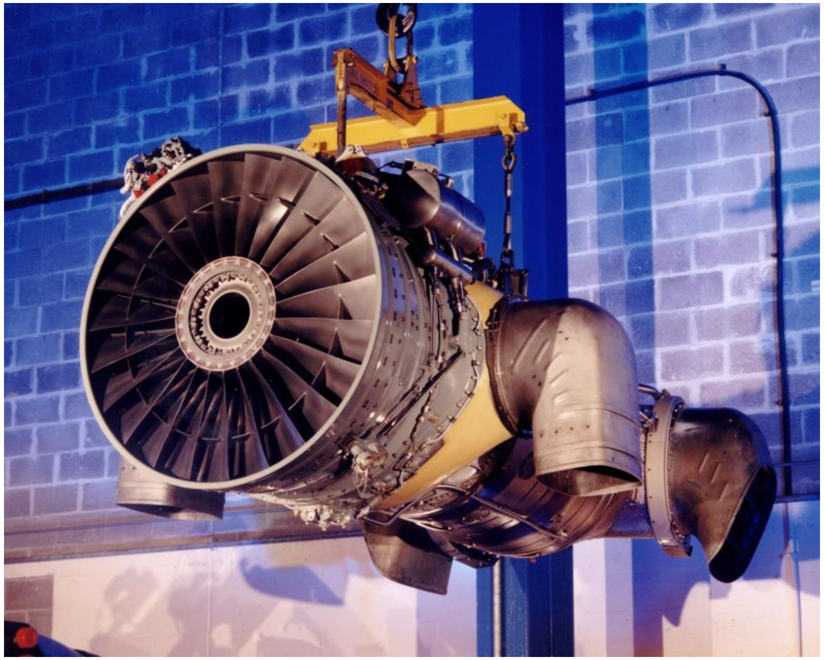
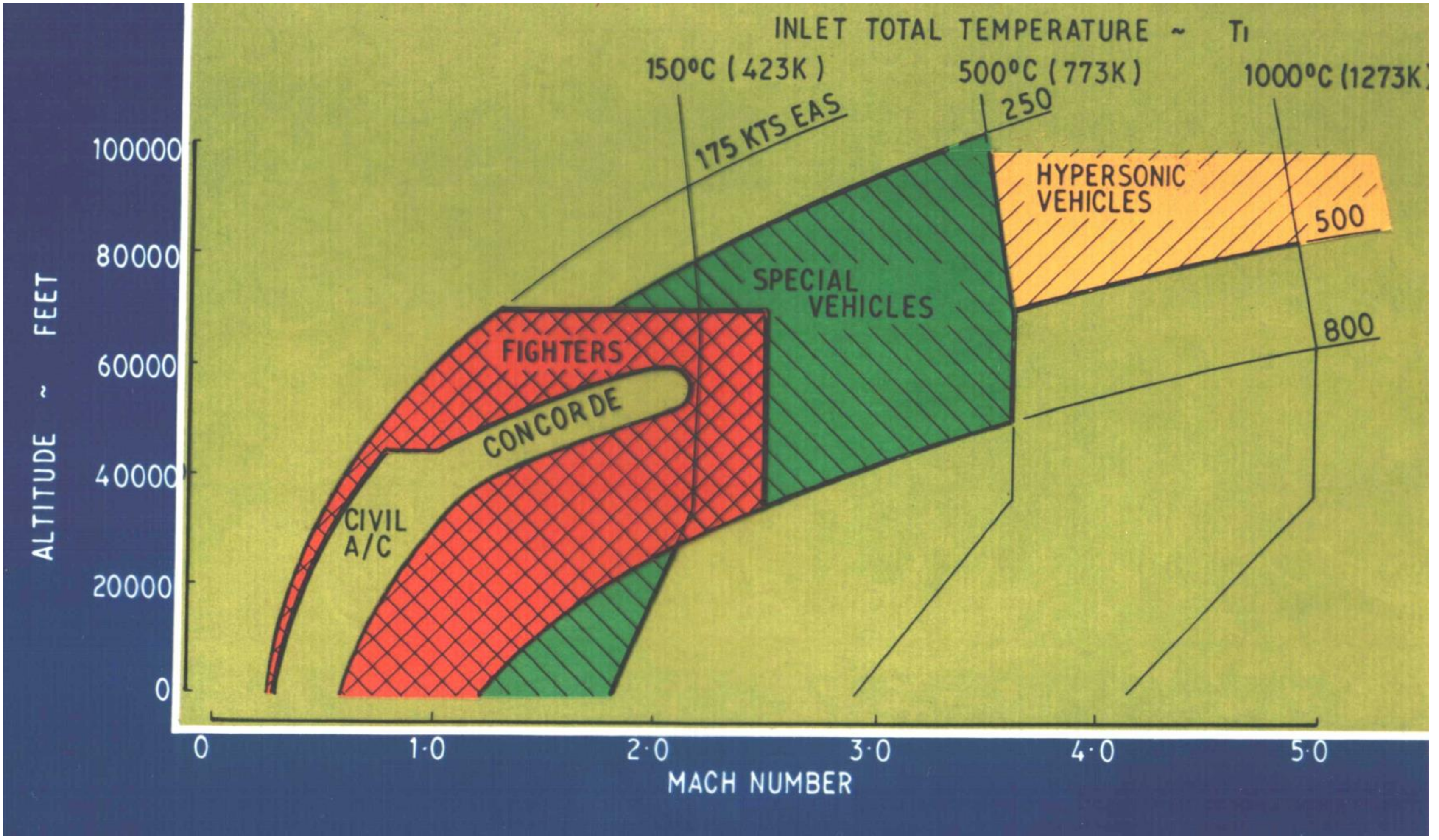
Systems Integration ~ Propulsion

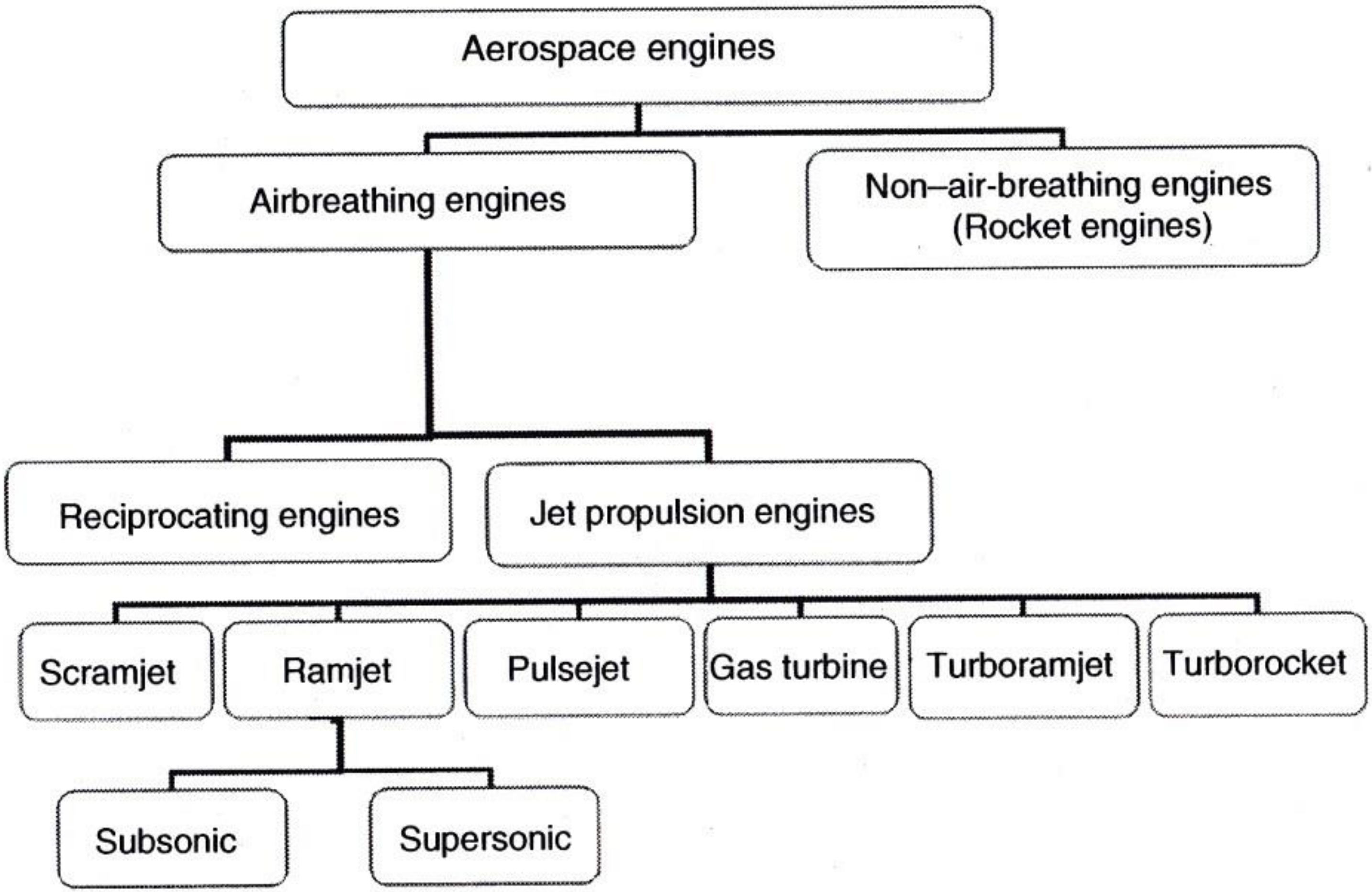
- Introduction
- Fundamentals
- The Turbojet
- The Turbofan
- Technology
- Conclusions



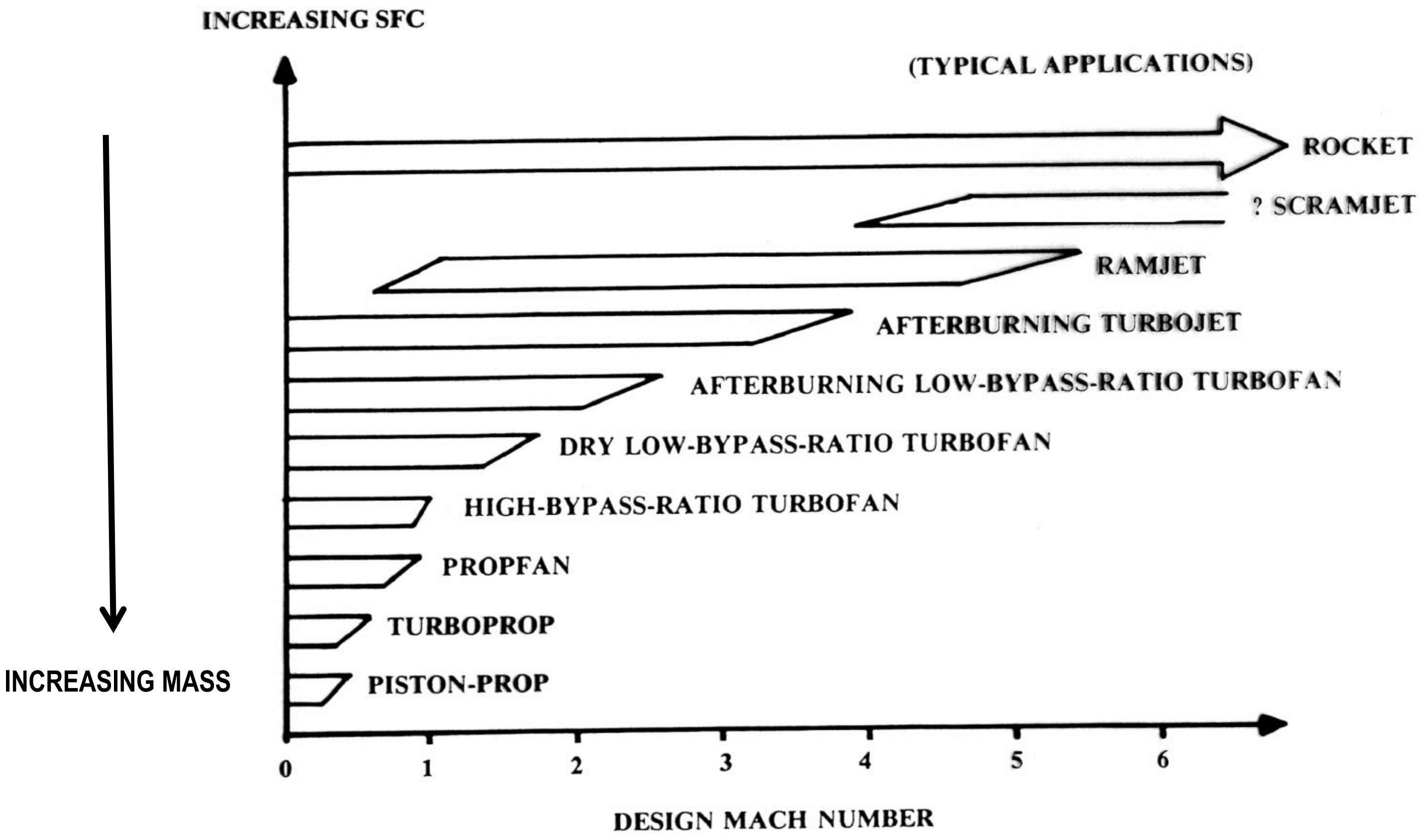
Aircraft Operating Envelopes



Propulsion System Classification



Propulsion system speed limits



SPECIFIC FUEL CONSUMPTION (SFC) *Fuel flow per unit of Thrust*

Propulsion System Requirements

Optimum for Airframe Manufacturer:

- **Sufficient Thrust to meet all Aircraft Requirements (Take-off, climb, Manoeuvre etc.)**
- **To use the minimum amount of fuel (low sfc, weight & drag)**
- **To have the lowest purchase price**
- **To have thrust growth for change in requirements**

Optimum for Customer (Airline, Air Force etc.):

- ***All of above, plus***:
- **High Reliability**
- **Low Unscheduled removal rates**
- **Long time between overhauls**
- **Maintenance - low cost, easy to carry out & predictable.**

Piston Engines

Four stroke, two stroke Turbochargers and Propellers

Four Stroke Piston Engines:

- **Mainly used by General Aviation, Unmanned Aerial Systems & light helicopters.**
- **Power levels generally in the 100 – 500 HP class**
- **Typical of type ~ Lycoming O-235-L2C, flat four 85kW (115hp), driving a two blade fixed pitch propeller.**

Two Stroke:

- **Offer more power at the expense of fuel economy & noise**
- **Technological developments in this field are addressing this issue.**

Turbochargers:

- **An externally driven compressor driven by a turbine using exhaust gases.**
- **The device is designed to maintain the sea level power to altitude.**
- **Above the critical altitude the engine-supercharger combination is no longer capable of delivering full power.**

Aero Diesel Engines

Advantages:

- Excellent Fuel economy.
- No complicated ignition system.
- Diesel is a lot safer, as it is much less flammable than petrol.
- Diesel fuel easily available.
- High Reliability

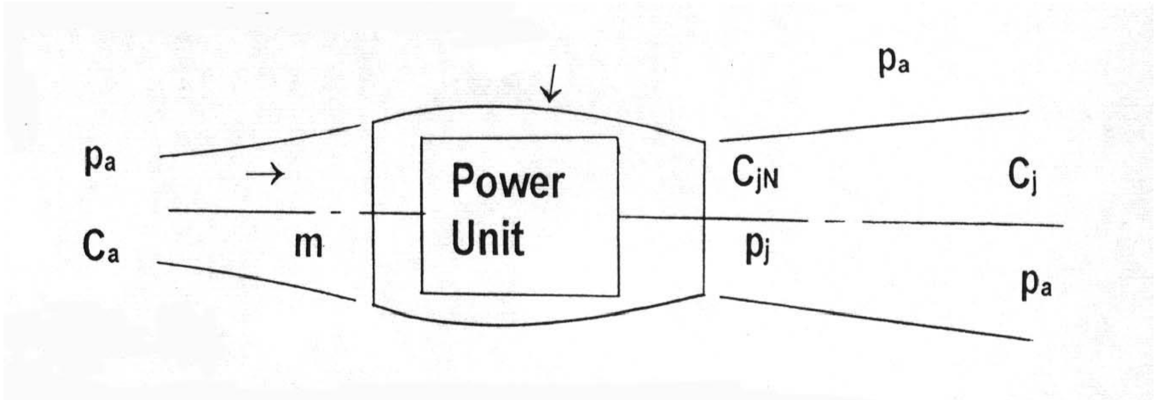
Disadvantages:

- Weight

CessnaC-172 Delta Hawk A4TB

Analysis of Gas Turbines

Aircraft moving through stationary air



Wind Tunnel Analogy ~ Fixed Aircraft moving air flow

The gas turbine engine - an energy converter

Hydrocarbon energy into air

Compressor

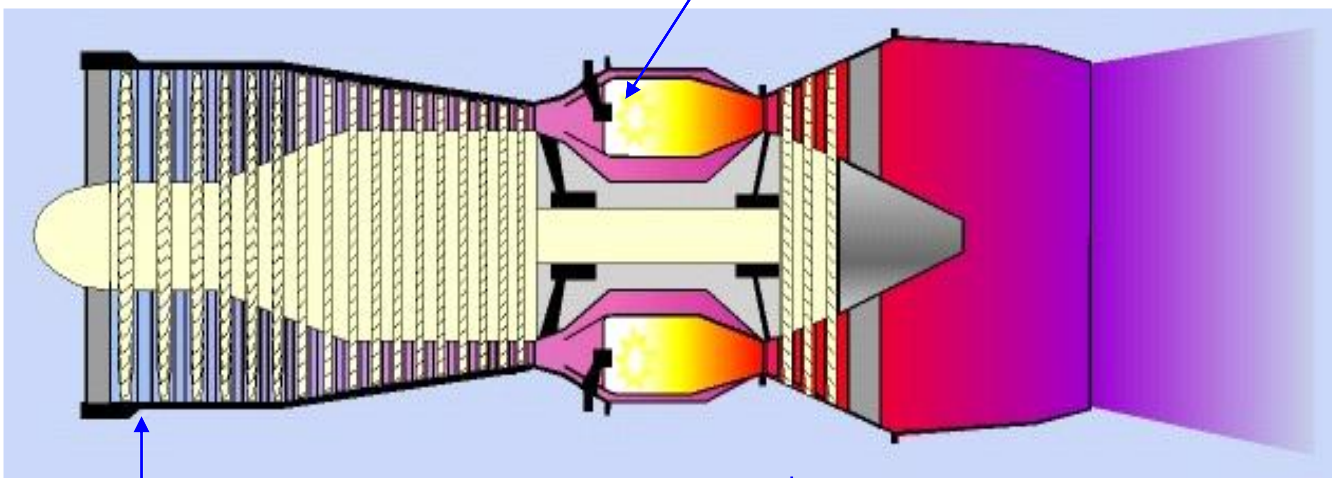
Combustion Chamber

Turbine

Nozzle

m_o

Vel_{in}



m_j

Vel_{FEout}

Work into air

Extract thermal energy from the products of combustion to produce power to drive compressor

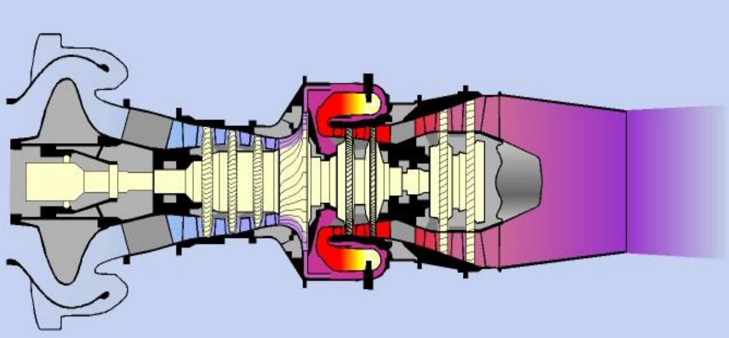
Via shaft

$$\text{Thrust} = m_j \times Vel_{FEout} - m_o \times Vel_{in}$$

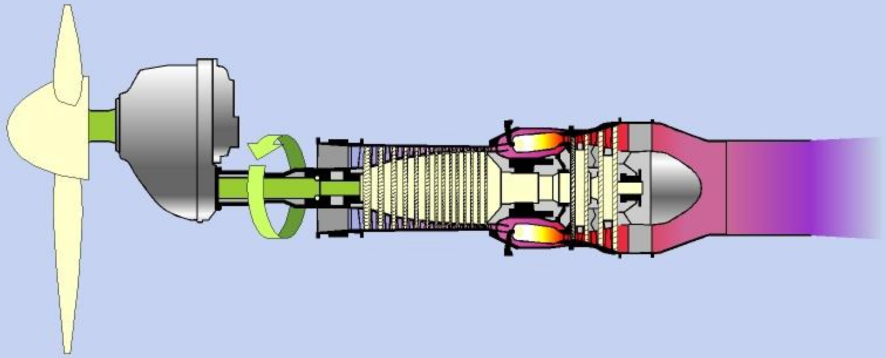
Definitions

- **OVERALL EFFICIENCY = useful work (thrust x velocity) / energy supplied by fuel** = ***Thrust x V_a / m_f x Q_{net}***
- ***Fuel flow = m_f ; Q_{net} (net calorific value of fuel)***
- **OVERALL EFFICIENCY** is the product of ***Efficiency of Energy Conversion and Propulsive Efficiency***
- **Efficiency of Energy Conversion: = useful mechanical energy/ energy supplied by fuel**
- **Propulsive (Froude) Efficiency = useful work/ useful work + unused KE in jet =** $2 / (1 + V_j / V_a)$
- **Specific Fuel Consumption (SFC) =** ***Fuel flow per unit of Thrust = m_f / F ; kg/hr/N ~ a measure of overall efficiency***
- **SPECIFIC THRUST** (Thrust per unit Mass Flow) **= (V_j - V_a)**
  (*N/ kg/hr* or Unit of velocity)

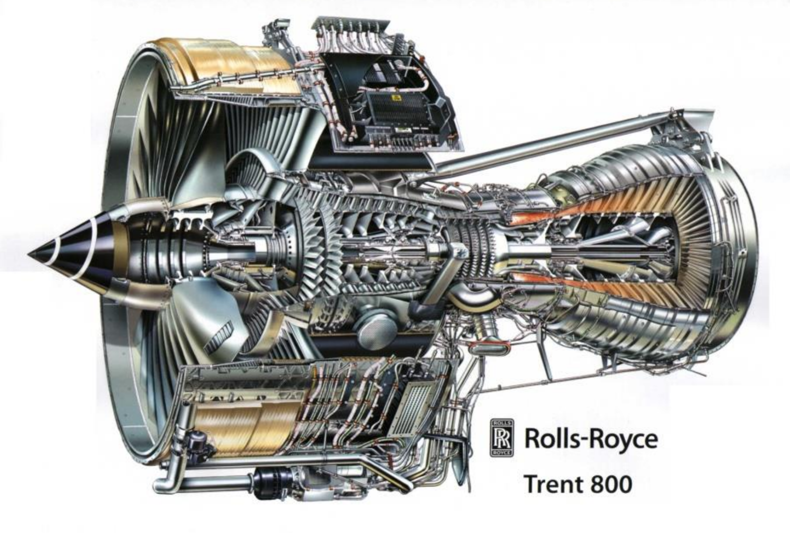
Gas Turbine Propulsion System Types



RTM322

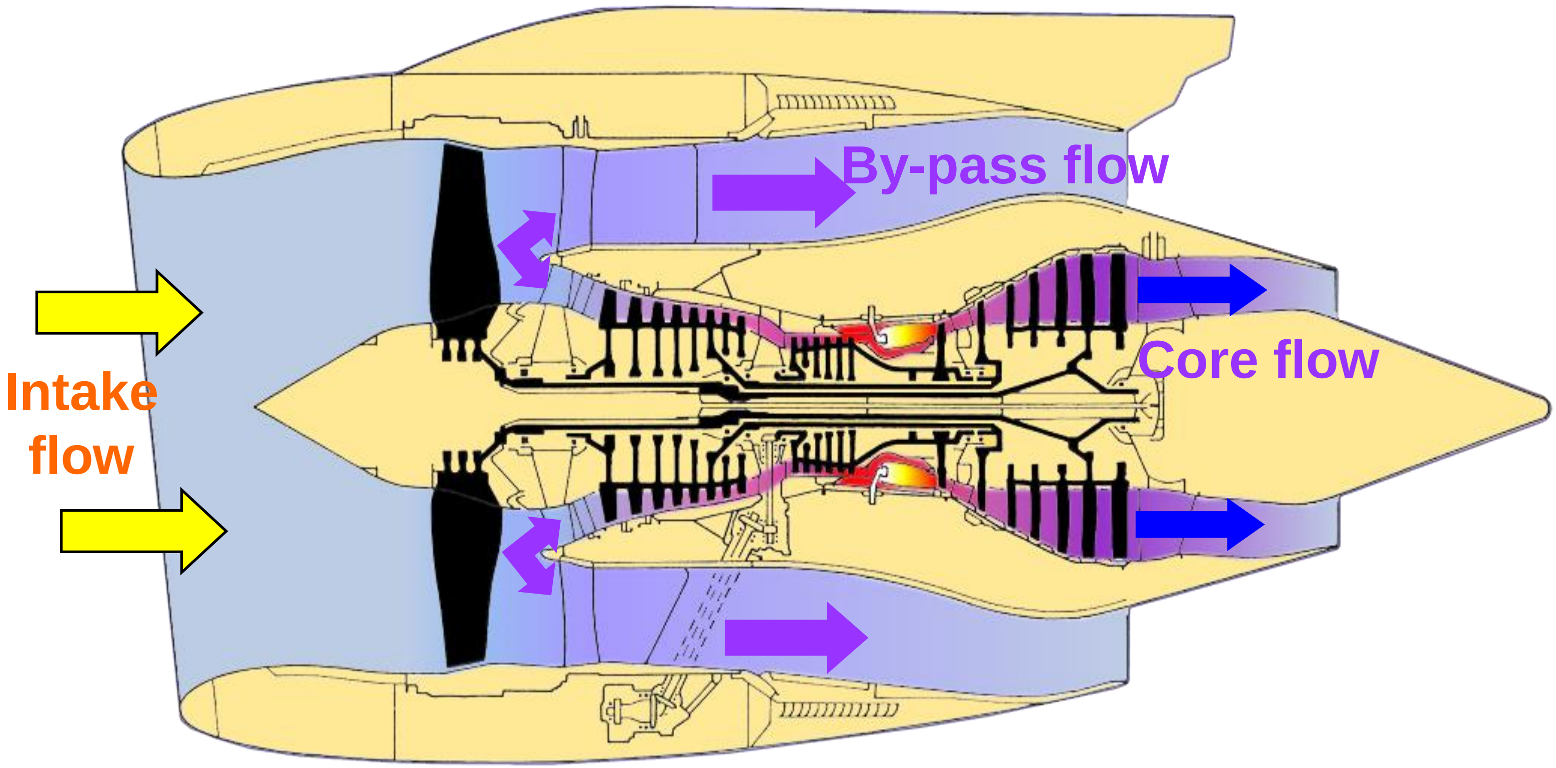


Turboprop - AE 2100



EJ200

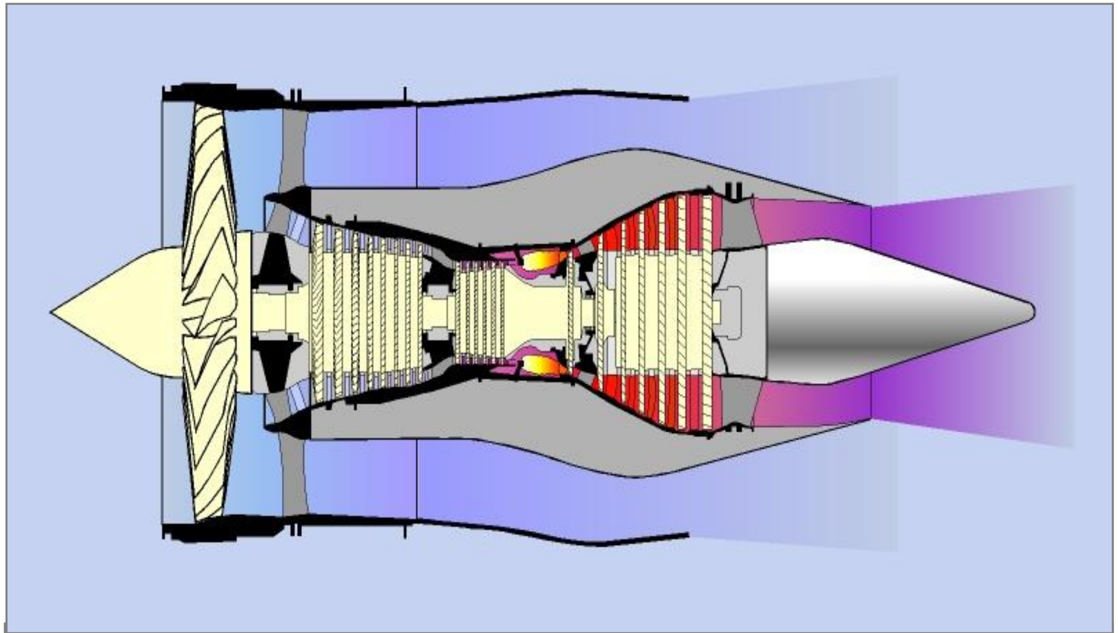
Propulsion System Layout



Different Turbofan Types

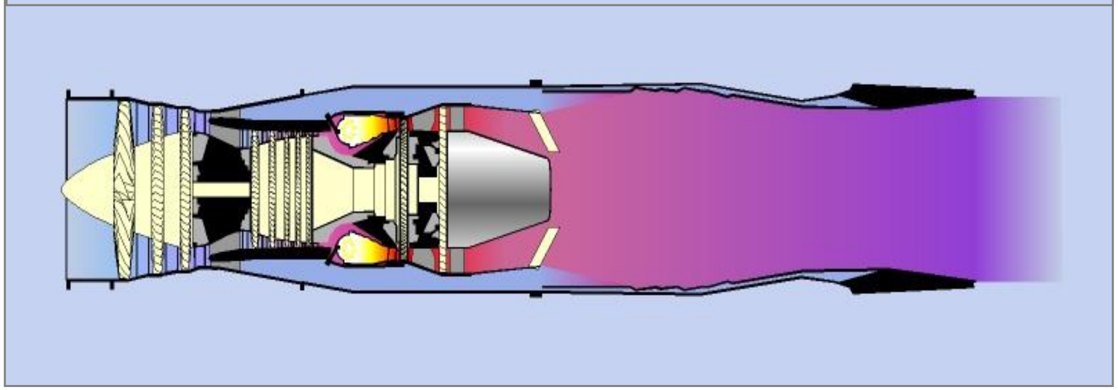
Civil Turbofan~ Trent

High by-pass ratio Turbofan
Thrust ~2000 to 120,000 lb
By-pass ratio 4 – 13
OPR ~ 60
Fan PR ~ 1.9
Specific Thrust ~ 25 – 35 lb/lb/sec



Military Turbofan ~ EJ200

Low by-pass ratio Reheated Turbofan
Thrust ~10,000 to 40,000 lb (inc R/H)
By-pass ratio 0.3 – 1
OPR ~ 25 – 30
Fan PR ~ 3 – 5
Specific Thrust ~ 120 lb/lb/sec (inc R/H)



Fundamentals

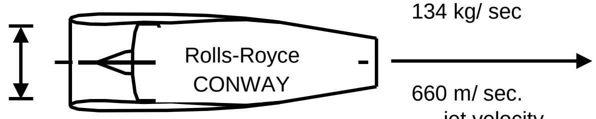
Based upon Rolls-Royce plc Data

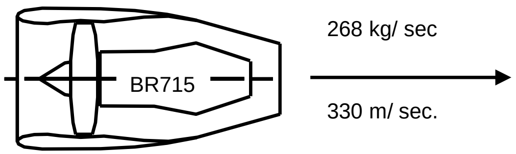
SFC is improved by:

HIGHER PROPULSIVE EFFICIENCY and **HIGHER THERMAL EFFICIENCY**

Means -
- Reduced jet velocity
- Larger fan moving more air at lower speed
- Increasing bypass ratio

Higher
- Overall pressure ratio (OPR)
- Turbine temperatures (TET)
- Component efficiencies



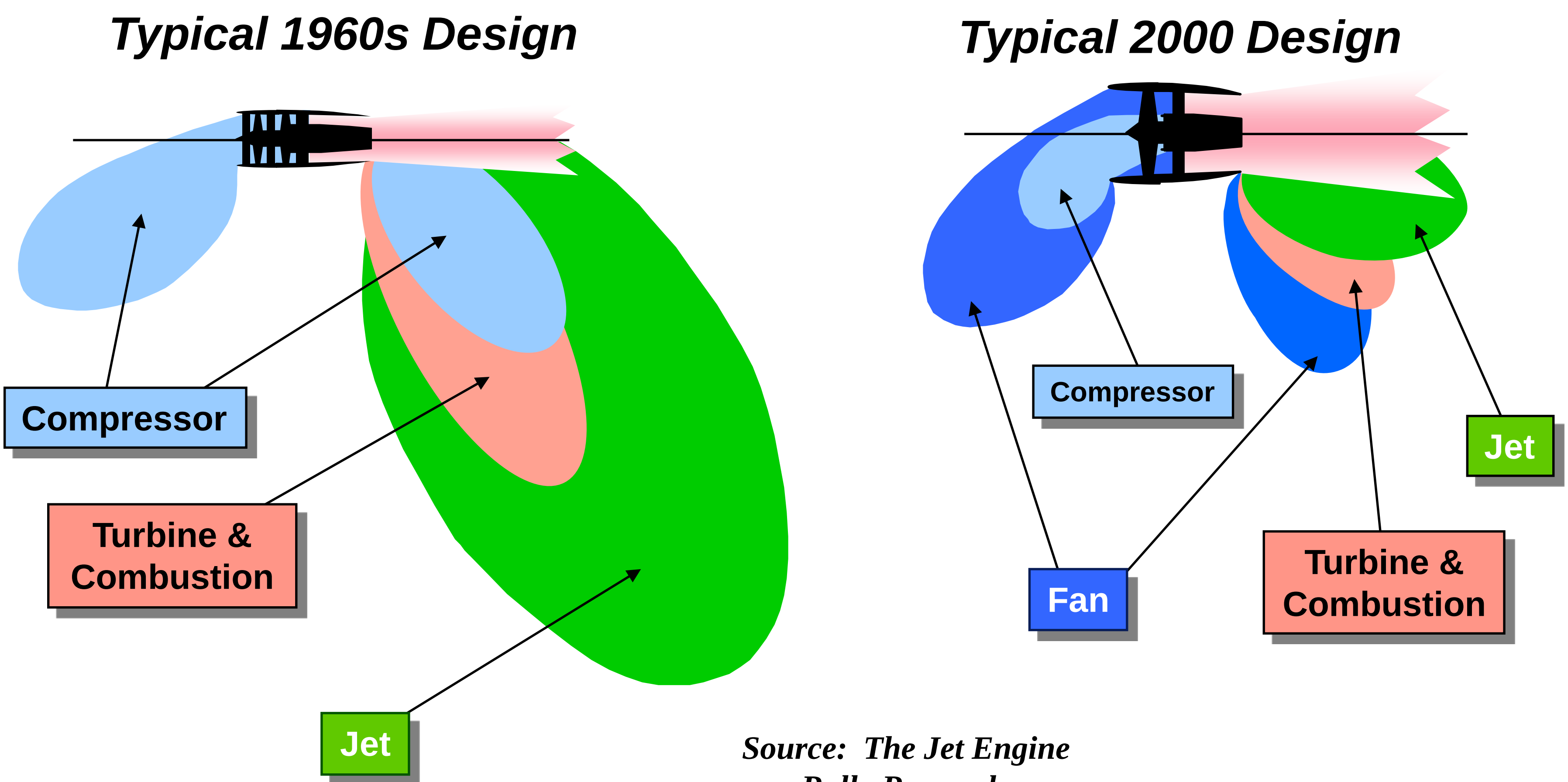


	Conway	BR 715
Specific Thrust Lb/lb/s	67	33
OPR	15	32
By-pass Ratio	0.3	4.6
TET	1400K	1600K
SFC lb/hr/lb	~ 0.85	~ 0.6

The Conway entered airline service in 1960.

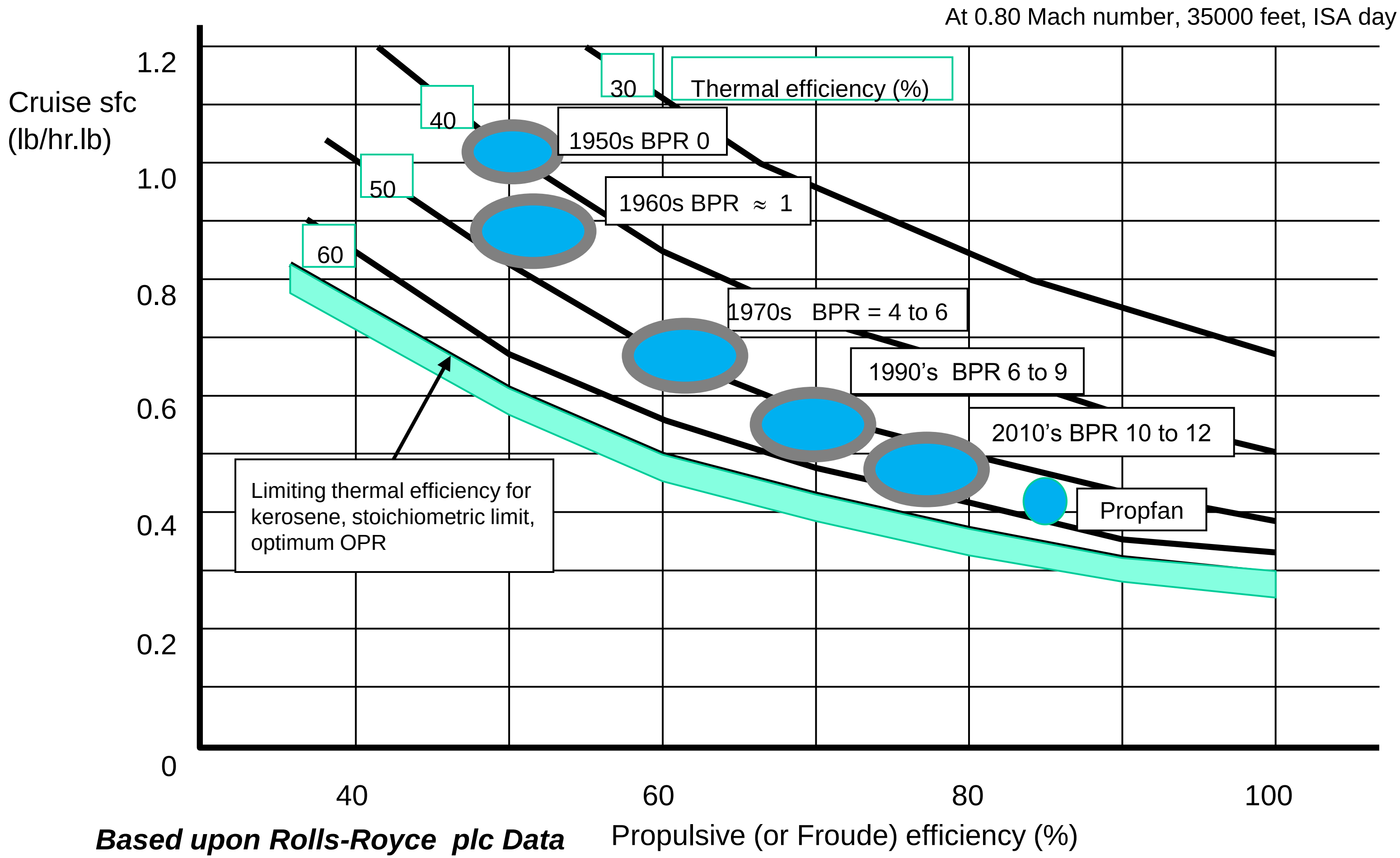
The BR 700 series entered service in 1996

Gas Turbine Propulsion Systems
Comparison of Component Noise Sources



Source: The Jet Engine
Rolls-Royce plc

Cycle Efficiency Trends



Based upon Rolls-Royce plc Data

Some Conclusions

- For Aircraft where fuel efficiency & emissions are important i.e. Commercial Transport Aircraft:
- It is best to move a large mass flow of air to a low jet velocity ~ also reduces jet noise;
- But at the expense of size and weight of the powerplant.

- For Supersonic Military Aircraft size & weight of powerplant are important:
- It is best to move a small mass flow of air through to a high velocity;

- Both need as high an efficiency of energy conversion as possible:
- So the temperature that the air is raised to in the combustion should be as high as possible ~ 1800K – 2200K.
- The exhaust gas leaving the combustion chamber is higher than the melting point of the best material available.

Emissions

Chemistry of Combustion

$$C_{12}\,H_{24} + 18O_2 + 67.7N_2 \rightarrow 12CO_2 + 12H_2O + 67.7N_2 + \text{HEAT}$$

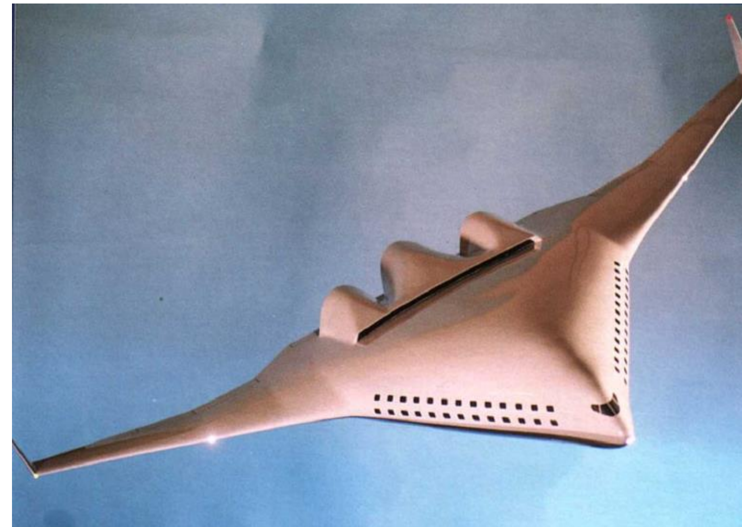
Major Unwanted Pollutants

- **Oxides of Nitrogen** ~ ***Dependant on Flame Temperature***
- **Carbon Monoxide** ~ ***Negligible problem except at idle conditions***
- **Unburnt Hydrocarbons (unburnt fuel)**

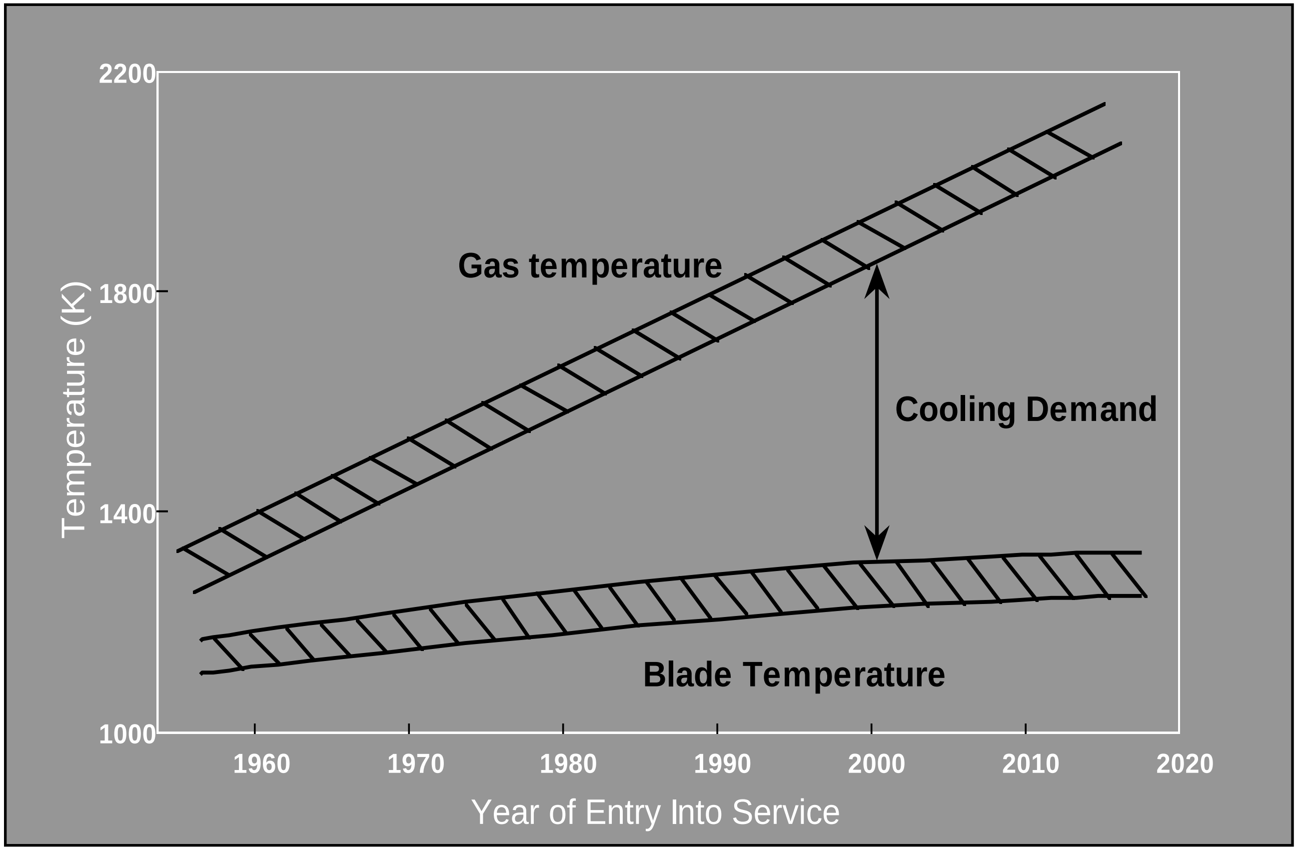
  ~ ***Negligible problem except at idle conditions***
- **Smoke (carbon particles)**
- **Sulphur Dioxide**

The Challenges for Air Transport

- ***Global Warming, Pollution & the Environment***
  - *Emissions*
  - *Noise*
  - *Fuel efficiency*
- ***Long range – little alternative to aircraft***
- ***For short range operations – there are alternatives.***
- ***How will the Industry & in particular the Low Fare Airlines respond ?***

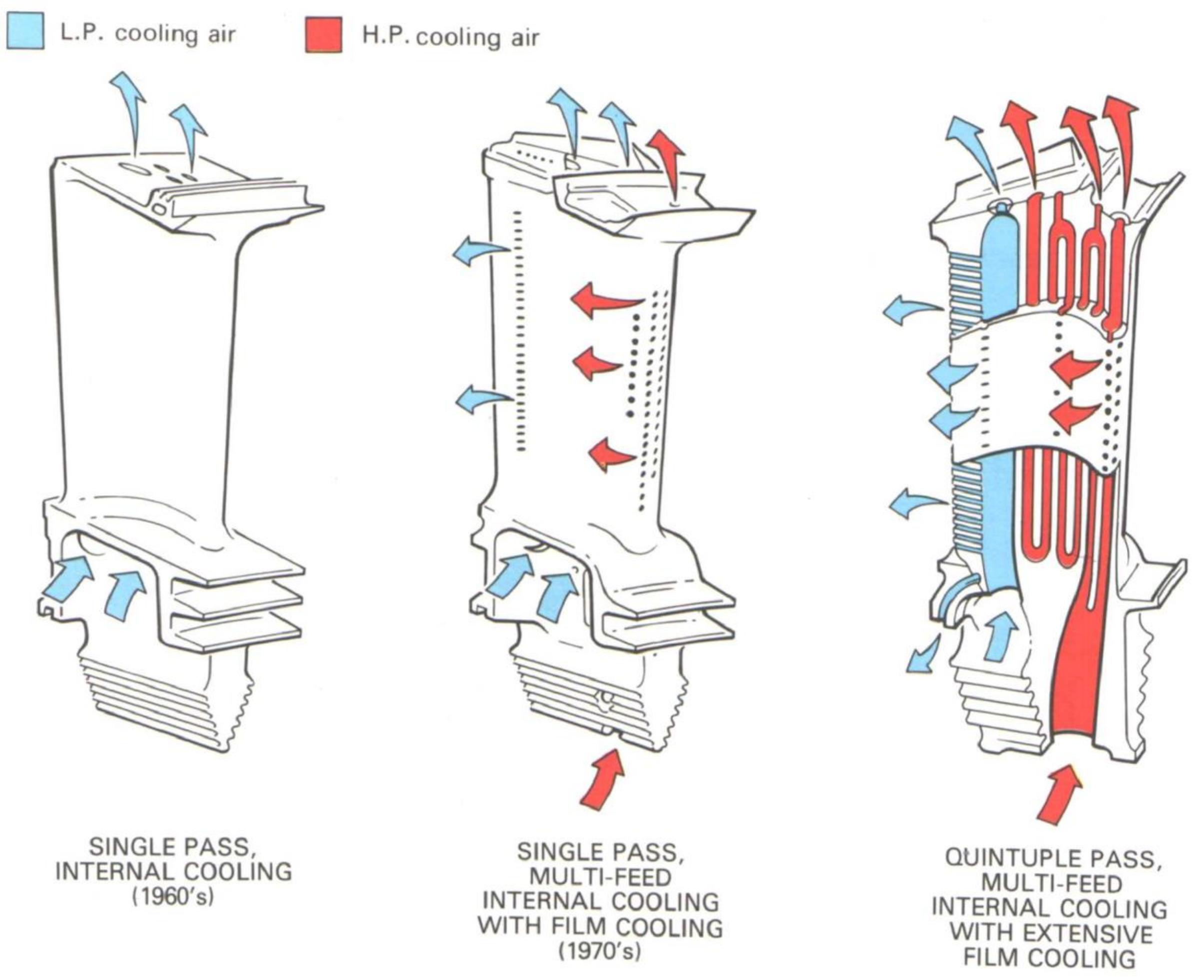


Turbine cooling



- **High temperature gives high thermodynamic efficiency**
- **Blades must be cooled**
- **Balance between efficiency cost and life**

HP Turbine Cooling Arrangements



Fan Blade Technology

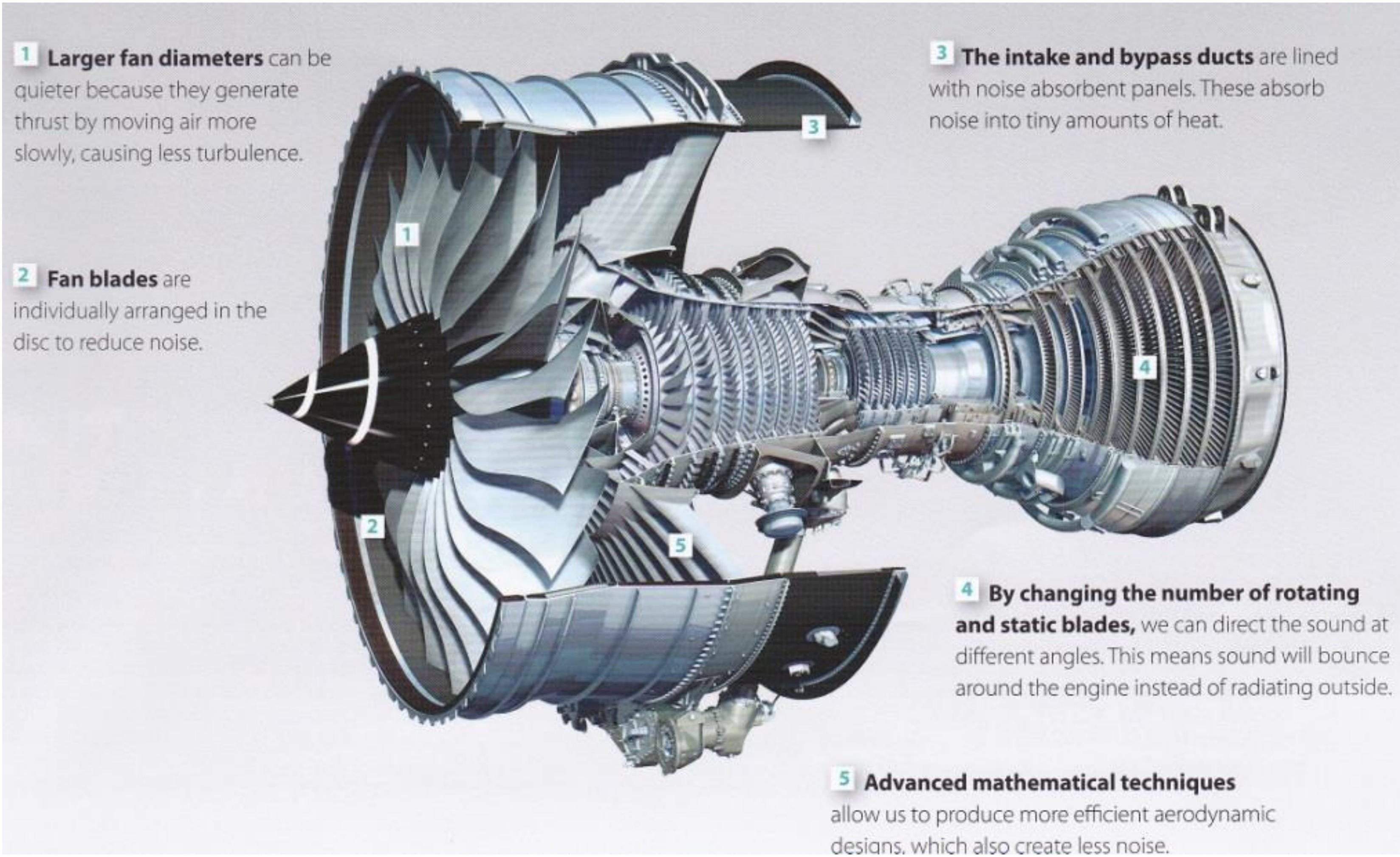
Clappered

Improved efficiency
reduced weight
reduced noise

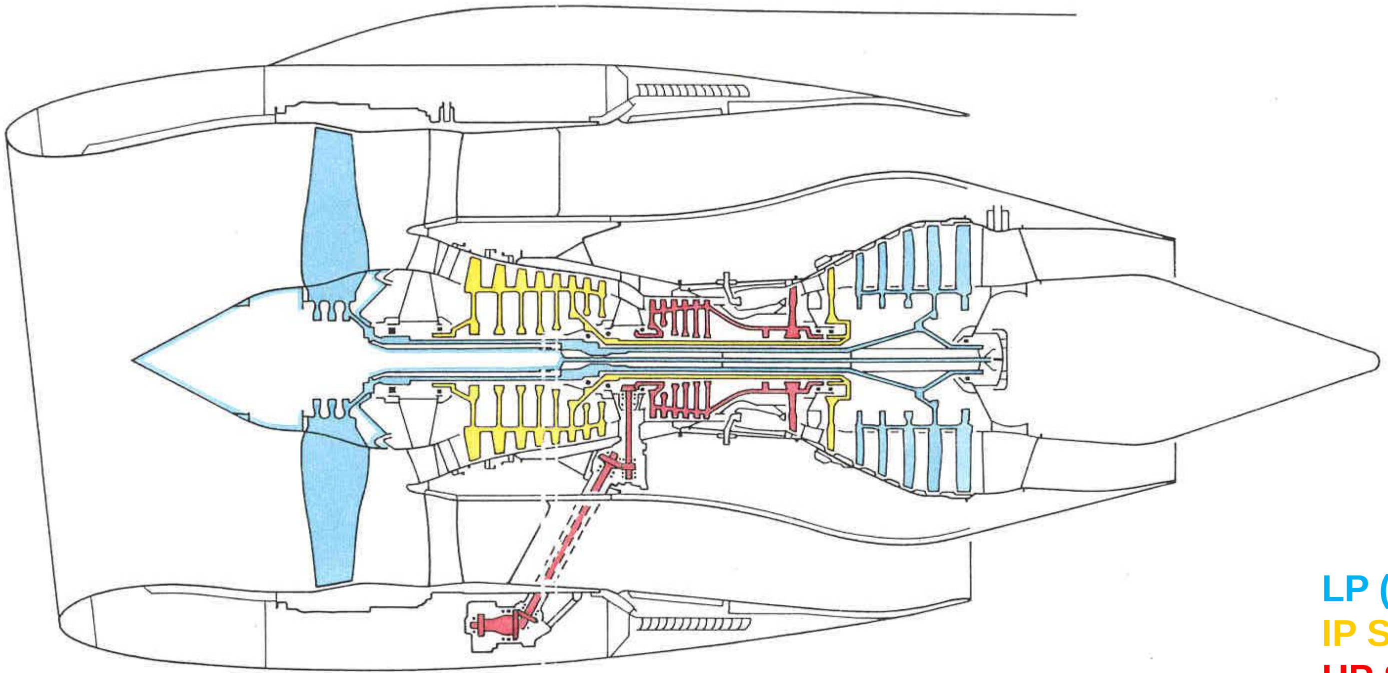
Wide-chord fan

The Next Step

Noise Technology



Engine Technologies & Materials



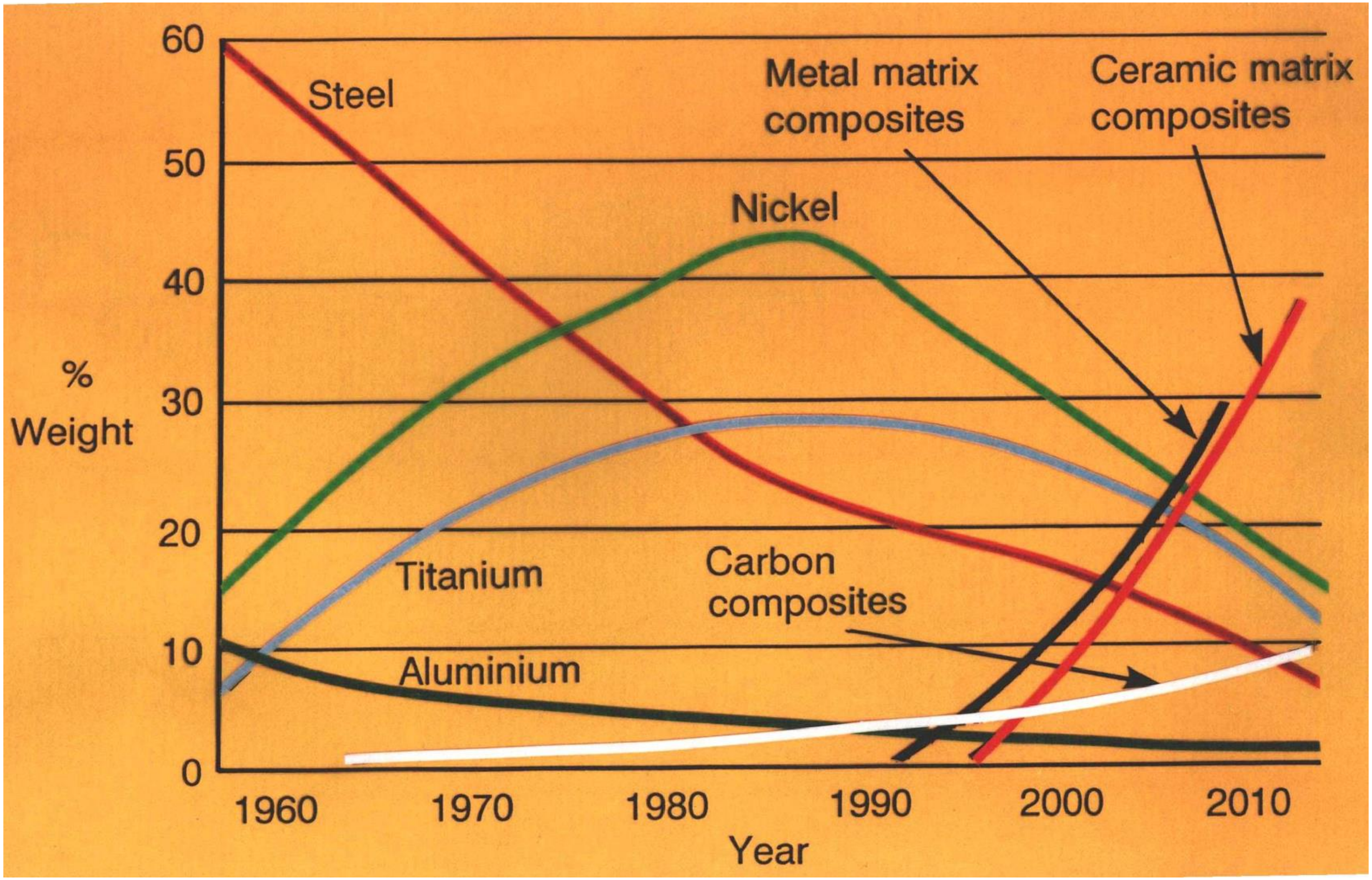
LP (Fan) Shaft
IP Shaft
HP Shaft

Fans *Compressors* *Combustor* *Turbines*

Titanium Nickel based alloys

→ Steel?

Trends in material usage



Based upon Rolls-Royce plc Data

Future Propulsion Technologies

- **Increased Operating Temperatures**
  - *New materials, improved cooling, control of emissions etc.*
- **Improved Methods**:
  - *Higher component efficiencies in less stages.*
- **New concepts:**
  - *Ducted Fans, Variable Cycle Engines etc.*
- **Alternative Fuels:**
  - *Bio-fuels, Hydrogen, etc.*
- **Advanced Digital Control Systems**
  - *Integration with the Aircraft Control System*
- **Engine/Airframe Installation:**
  - *Improved integration of propulsion system with airframe.*

Propulsion the key to advances in Aviation?

Many of the major advances in aviation have come about because of breakthroughs in Propulsion System design & Technology:

- **A light weight piston engine made the Wright Flyer possible**
- **Turbo superchargers enhanced high altitude capability**
- **Jet engines revolutionised Fighter Aircraft Design**
- **Reheat systems made sustained supersonic flight a reality**
- **High by-pass ratio engines ushered in the era of mass travel**
- **Powerplant design made Vertical Take-off & Landing possible**
- **Supersonic Transport made viable by propulsion design**

Aerospace Challenges for 21st Century

Aviation & the Environment.

- **Unmanned Aerial Vehicles for Military & Civil use.**
- **Vertical Take-off & Landing Transport Systems for Civil & Military use.**
- **Supersonic Short/Vertical take-off & Landing Military Aircraft.**
- **Low-cost Delivery System into Earth Orbit.**
- **Supersonic Airliner i.e. Concorde Replacement.**

Department of Aerospace Engineering

The Challenges for Propulsion

- *Global Warming, Pollution & the Environment*
  - *Emissions*
  - *Noise*
  - *Fuel efficiency*
- *Alternative fuels ~ Bio-fuels, Hydrogen?*
- *Novel Systems ~ can the gas turbine be further exploited?*

Airbus A380

Trent 900

Any Questions ?