Aerospace Vehicle Design & Systems Integration

Propulsion 2

The birth & development of the Jet Engine

Lecturer: *Mr N A (Sandy) Mitchell MSc, CEng, FRAeS*

Aviation in the 1920's

IMPERIAL AIRWAYS 1924–1939
Top: Britain's trimotor, the DH 66 Hercules, the first new type ordered by the new airline in 1927, for use on the Cairo to Basra section of the route to India.
Above: The 20-passenger Armstrong-Whitworth Argosy.
Right: The backbone of the Imperial fleet in the 1930s were eight 4-engined Handley Page 42s which could carry 38 passengers in great style; no passenger was ever lost.

Sir Frank Whittle

The Germ of an Idea

Breguet Range Equation

$$dR = \frac{V}{w_f} dW_{fuel}$$

speed

fuel flow

$$R = V(L/D)\eta_{prop} \frac{H}{g} Log_e\{W_{Take-off}/(W_{Payload} + W_{empty})\}$$

fuel calorific value

Aerodynamic Efficiency

lift to drag

overall power plant efficiency

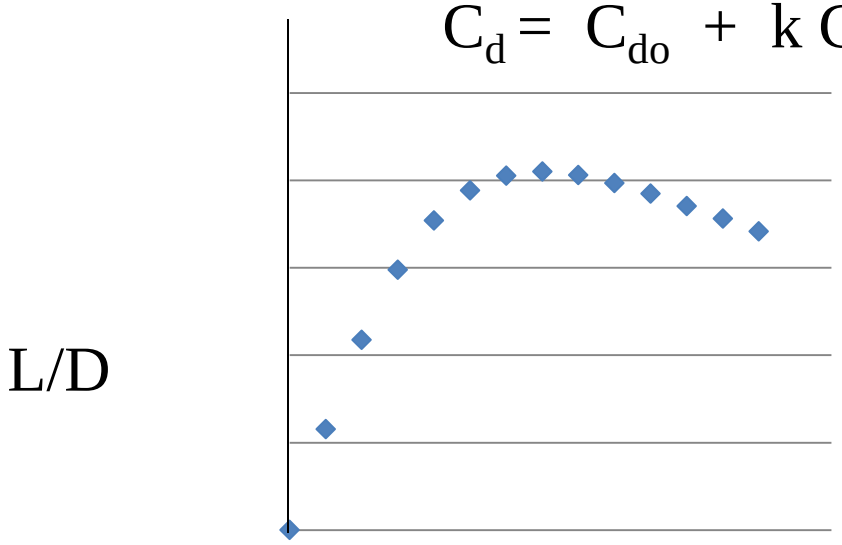
Whittle's Cranwell Thesis
Future Developments in Aircraft Design

Lift to Drag ratio

C_d or C_L = (Drag or Lift) /1/2 x density x V^2 x Area

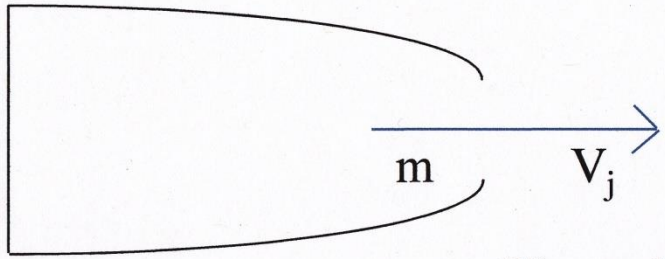
Basic Drag Equation

$C_d = C_{do} + k C_L^2$



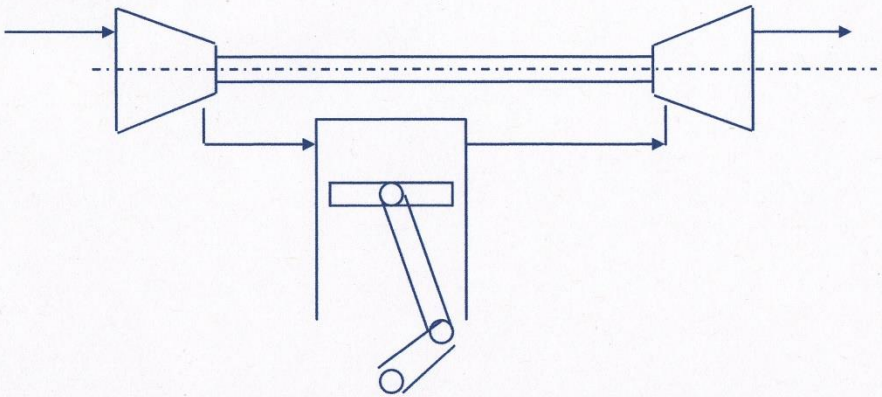
Two ideas combined by Sir Frank Whittle

Rocket propulsion



$$X_g = mV_j$$

Supercharging



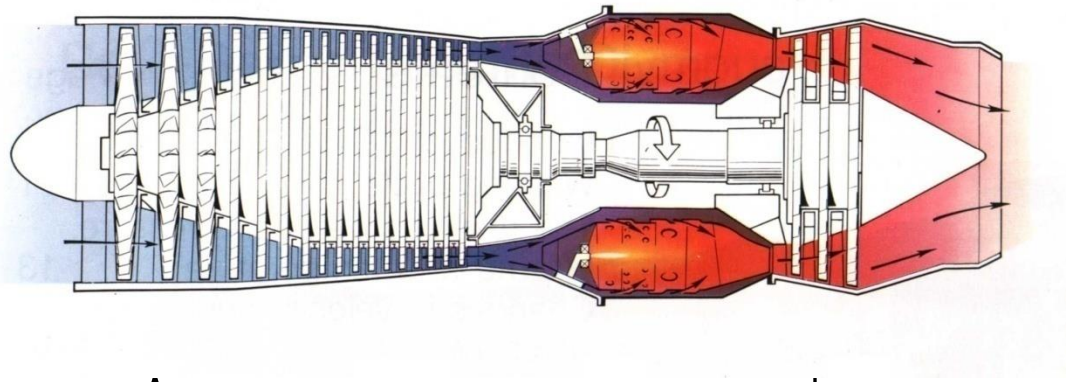
The turbojet engine - an energy converter

Hydrocarbon energy into air

Thrust = m_j x Vel_{out} – m_o x Vel_{in}

m_o

Vel_{in}



Useful work in form of a jet

m_j

Vel_{out}

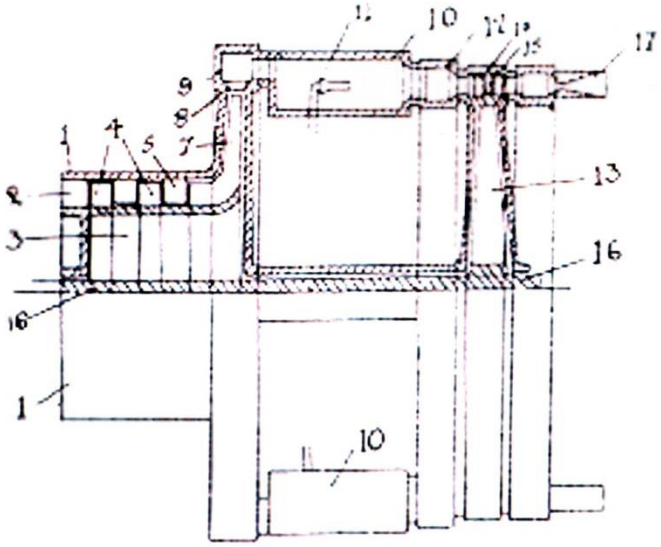
Work into air

Extract thermal energy from air to produce power to drive compressor

Via shaft

Propulsive Efficiency = $2/(1+ Vel_{out}/Vel_{In})$

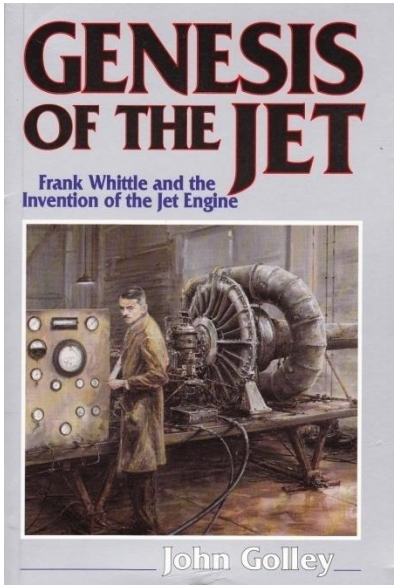
Sir Frank Whittle

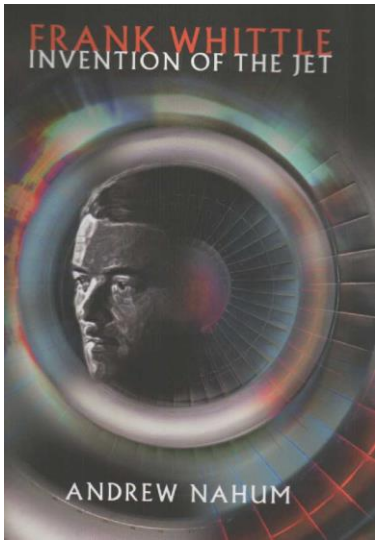


Whittle's 1930 Patent Application
~ allowed to lapse in 1935

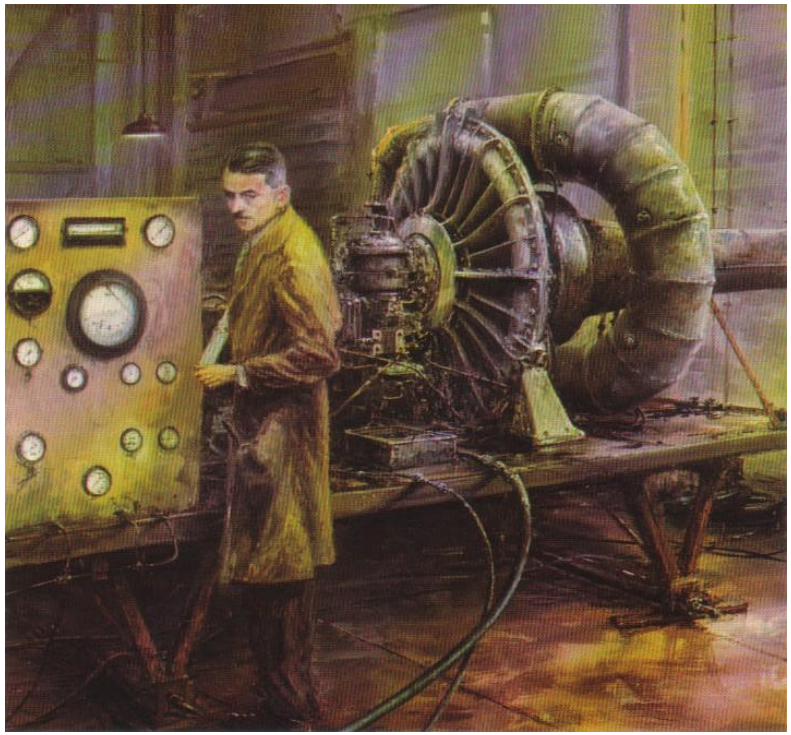
"Scientific investigation into the possibilities of jet propulsion has given no indication that this method can be a serious competitor to the airscrew/engine combination"

British Under-Secretary of State for Air, 1934

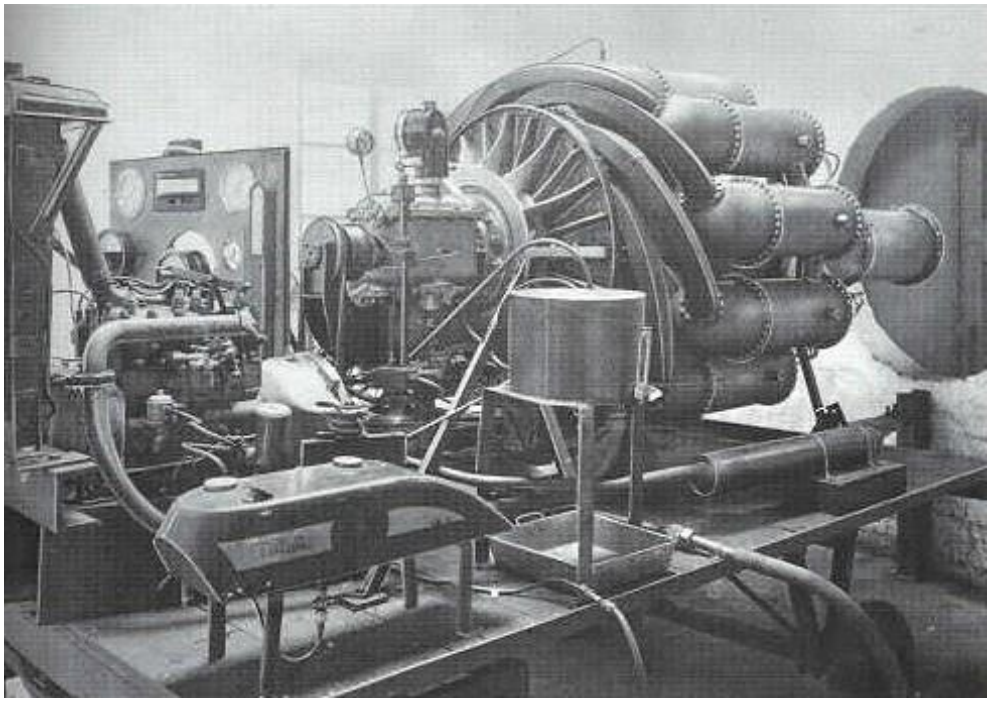




The Whittle Unit (WU) on Test

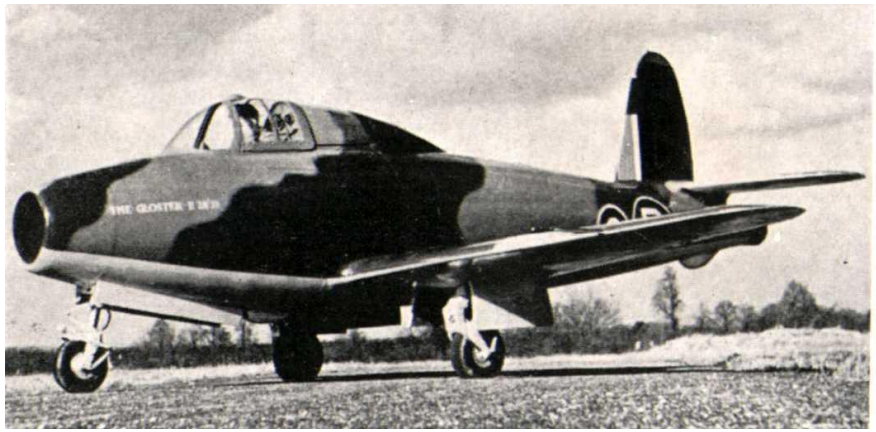


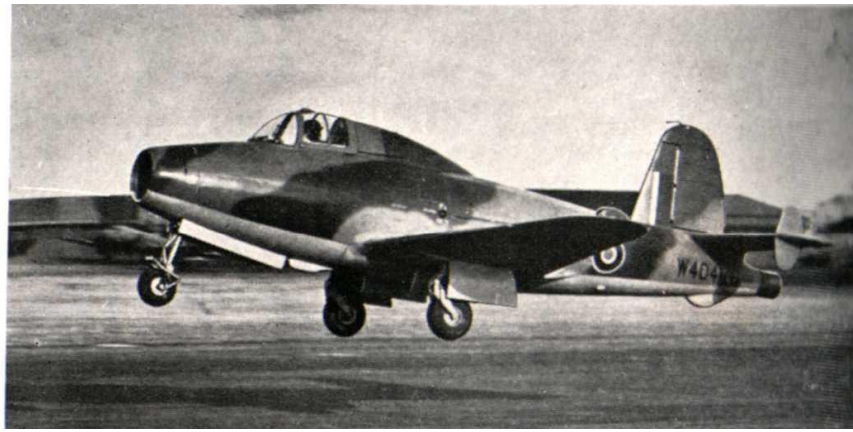
Painting



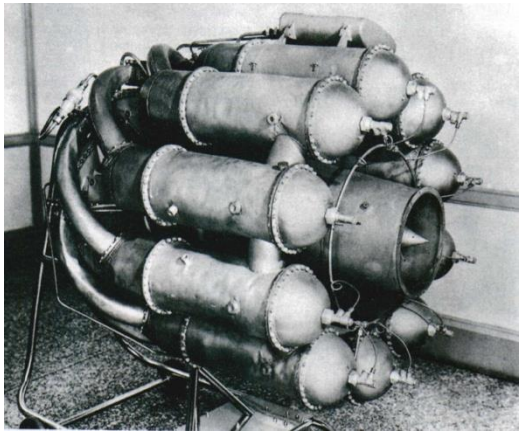
On test 1939

The first flight in the UK



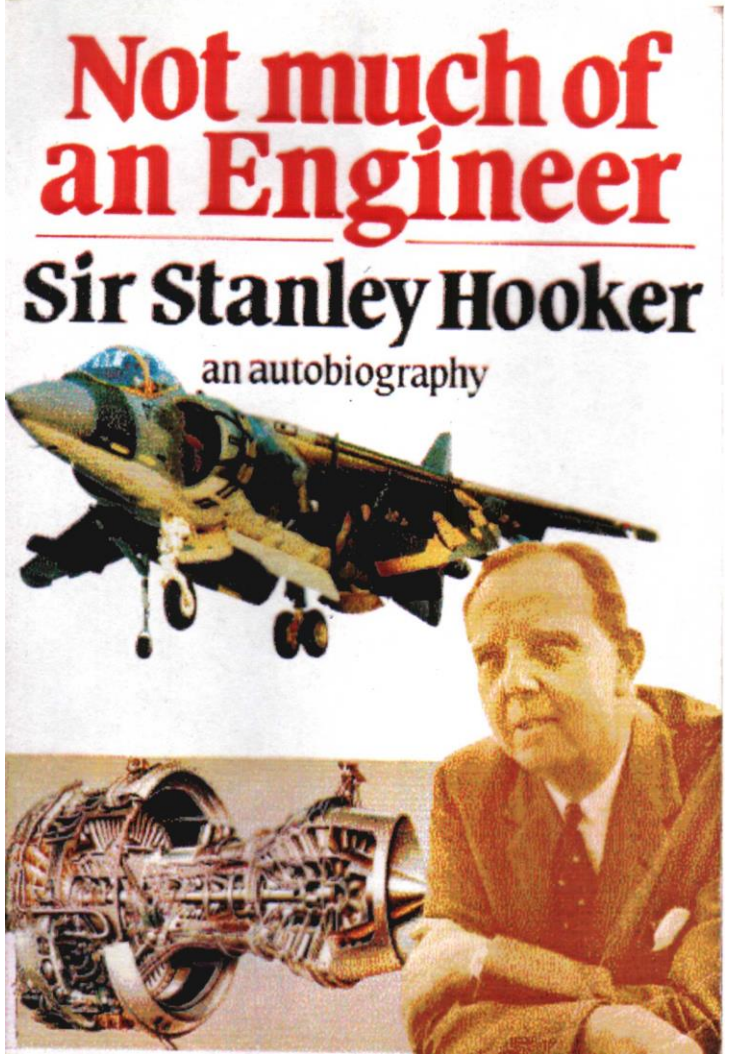


Gloster E28/39 powered by the W1 ~ 15th May 1941



The Whittle Unit

Sir Stanley Hooker



Hooker's first job at RR was the development of turbo-chargers for the Merlin

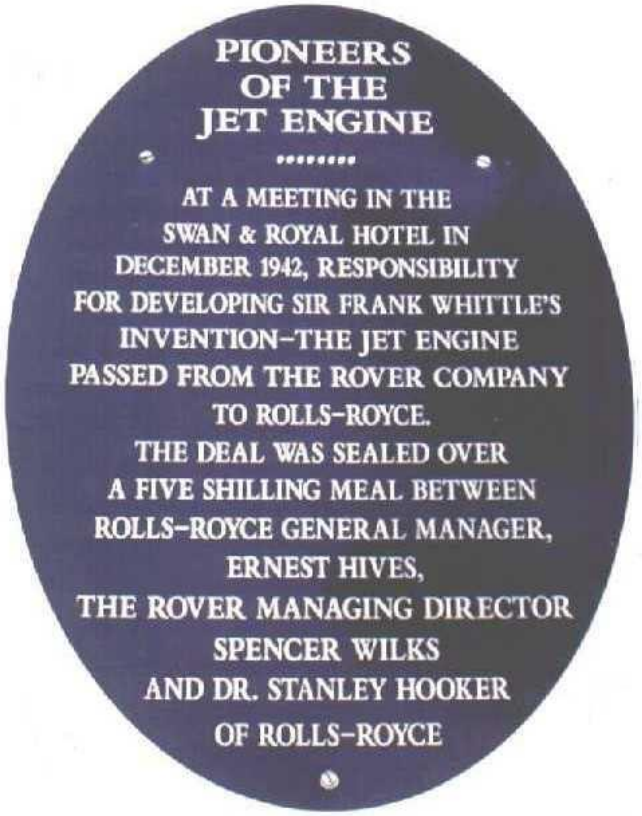
Equivalence of Propulsion SHP to Jet Thrust

- Engine Power = 1000 shp = 750 kW
- Propulsive Power of Prop. = 525 kW = $X.V_a$

- At V_a= 300mph = 135 m/s,
- $X = 525.10^3/135 = 3890$ N = 870 lbf

Don't worry, we will soon design the simplicity out of that"
- Lord (Ernest) Hives, Rolls-Royce

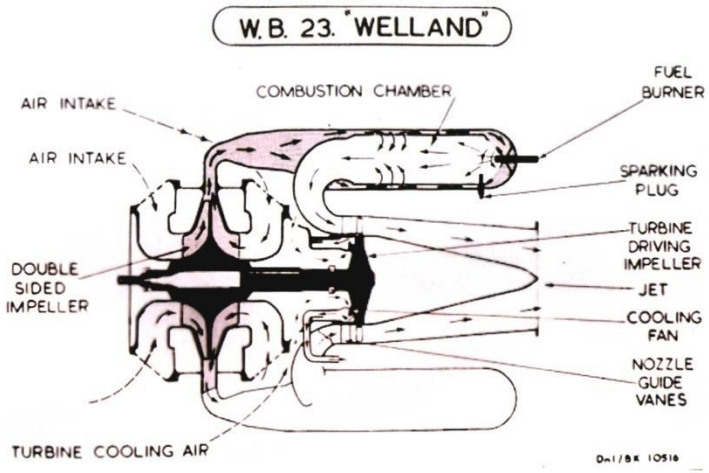
The UK Pioneers

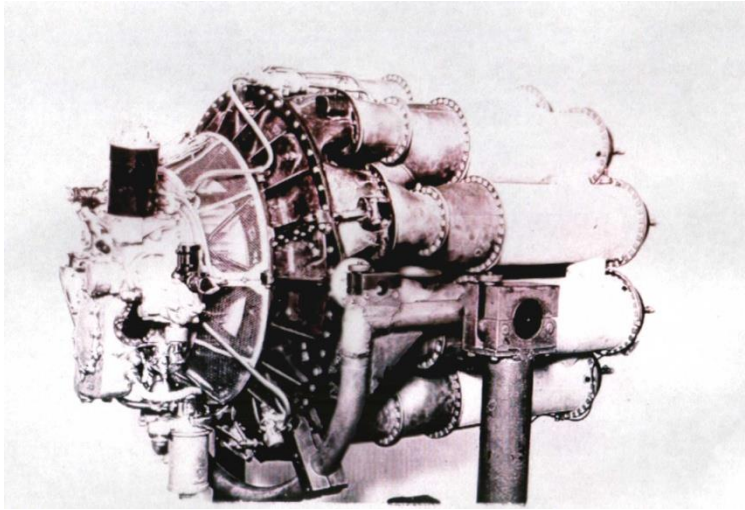


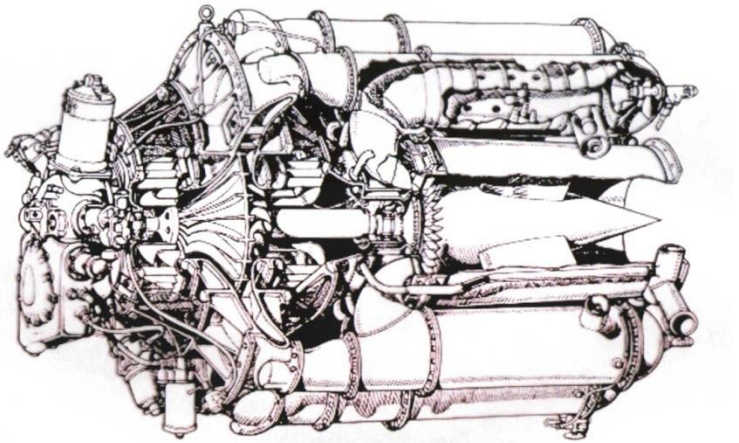
John Herriott Sir Frank Whittle Sir Stanley Hooker

Welland

The first RR production jet engine







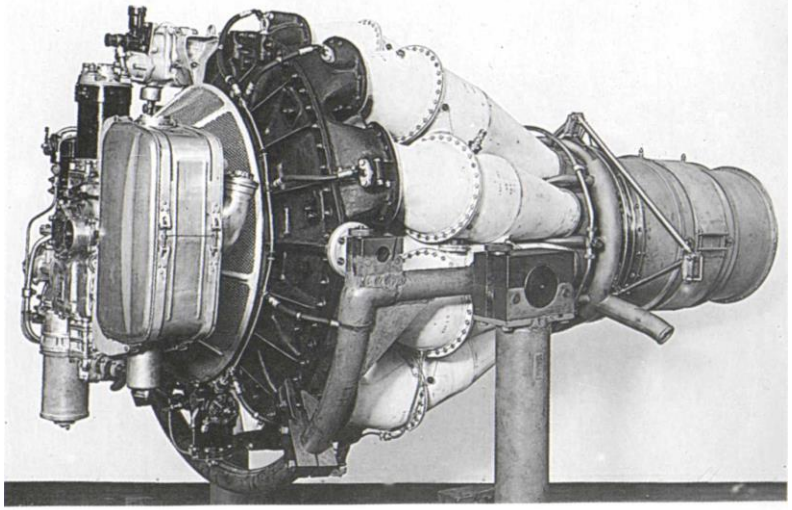
THE WELLAND Mk. I AERO ENGINE

de Havilland
Frank Halford

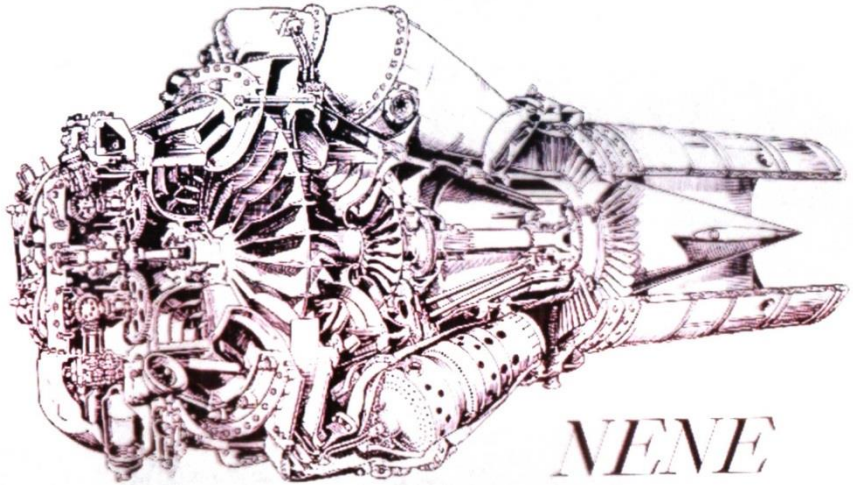
First flight of Gloster Meteor

- Frank Halford, de Havilland's engine designer, simplified Whittle's design to produce the deH Goblin at 2700Lb thrust
- The first flight of a prototype Meteor flew on 5 March 1943 with the Goblin
- It was flown in the single engined deH Vampire on 20th September 1943.

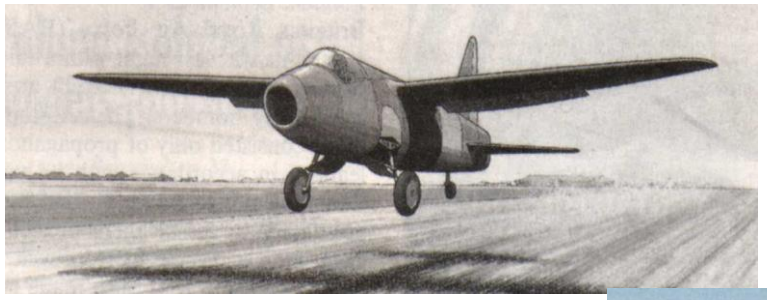
Derwent & Nene



The B.37 Derwent I introduced 'straight through' chambers which transformed the appearance. This engine was made at Newcastle-under-Lyme for the Meteor III.

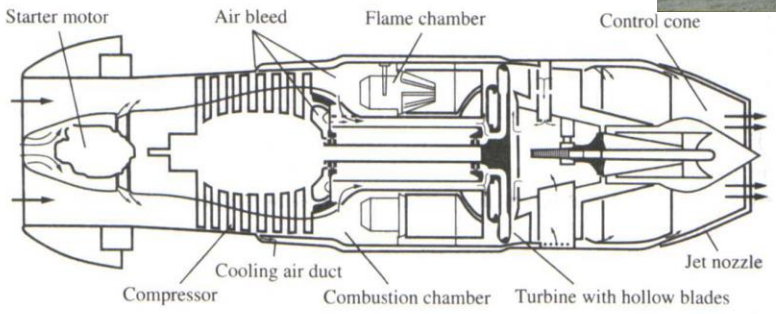


German Wartime Achievements



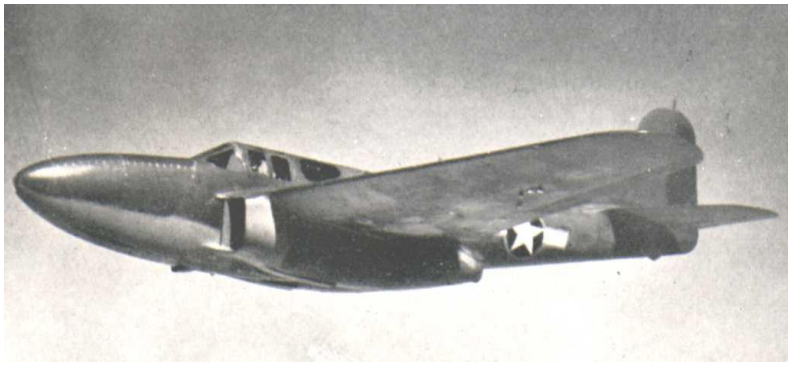
Heinkel 178 first flew in 1939

Me262A

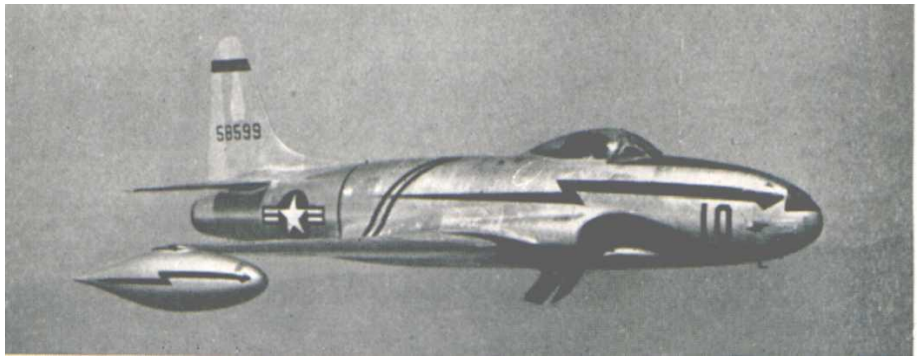


Jumo 004b which demonstrated many novel features.

The situation in the USA



Bell P59 Aircomet



Lockheed P80 Shooting Star

"In its present state, and even considering the improvements possible when adopting the higher temperatures proposed for the immediate future, the gas-turbine engine could hardly be considered a feasible application to airplanes."

Committee on Gas Turbines, US National Academy of Sciences, June 1941

End of World War 2

Sir Frank Whittle

Sir Stanley Hooker

Technological Revolutions

- Engineering in the main develops in a series of incremental steps.
- Really radical ideas are few & far between.
- Generally occur outside the mainstream.
- Those with new ideas often ridiculed.
- Once proven - embraced with great enthusiasm & control passes from innovator to more traditional companies.

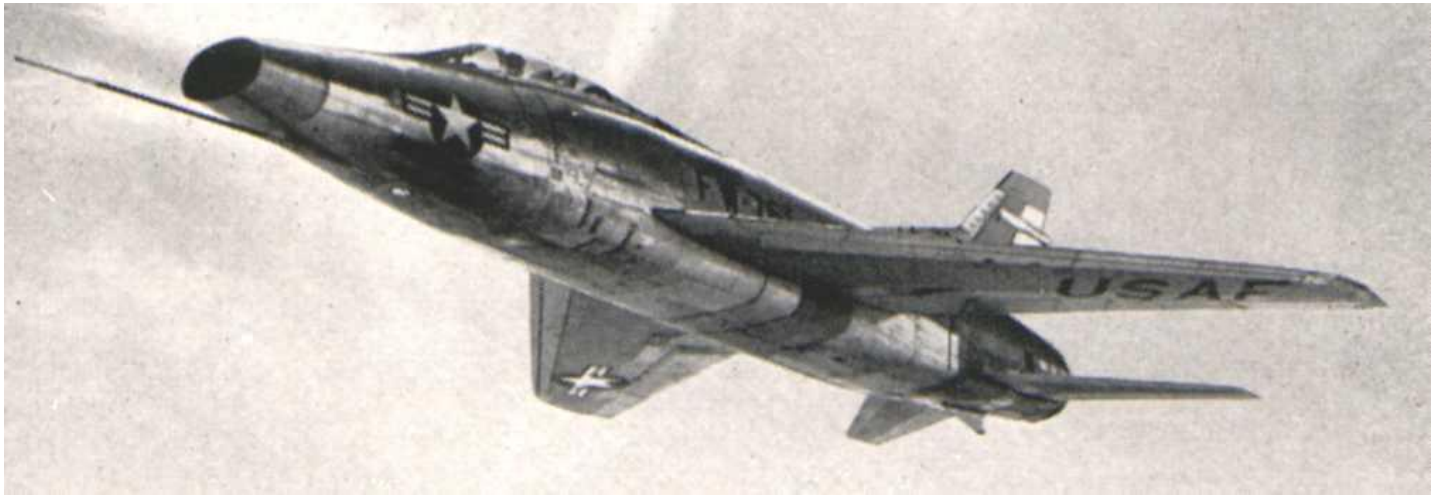
Supersonic Flight

Chuck Yaeger flying the rocket powered Bell X1 in the first supersonic flight 14th October 1947

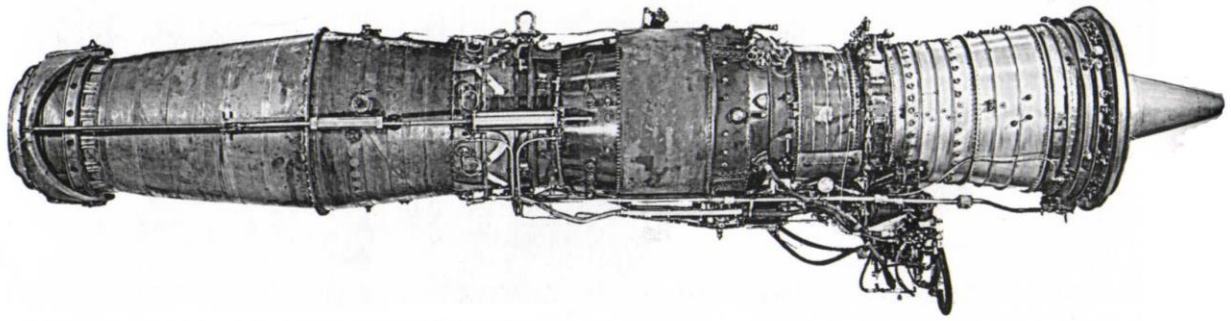
Miles M52 rocket aircraft.
Cancelled in 1946
Models flew at M= 1.38
Many unique features validated
Bi-convex wing; all moving tailplane etc.

"....the idea supersonic flight is just around the corner is quite erroneous ....
we have not the heart to ask pilots to fly it."
British Ministry of Supply, Jan 1946

Sustained Supersonic Flight

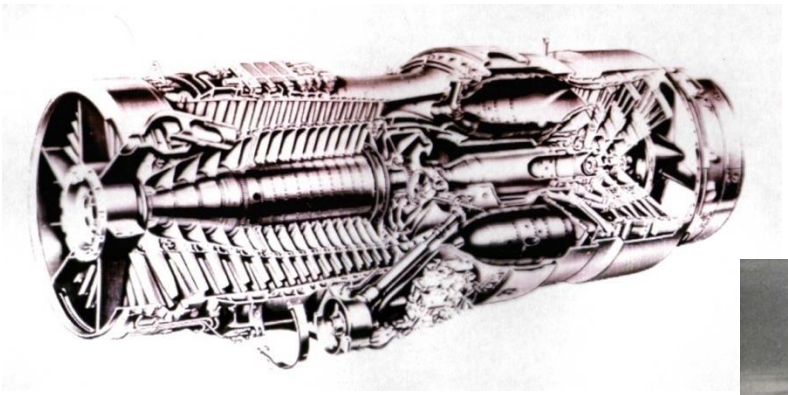


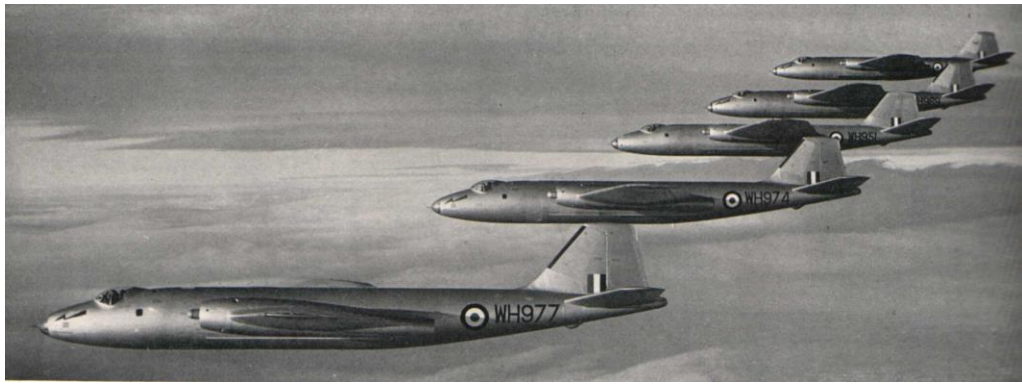
North American F100 Super Sabre



J57 with Reheat (Afterburner)

The Avon in Military guise





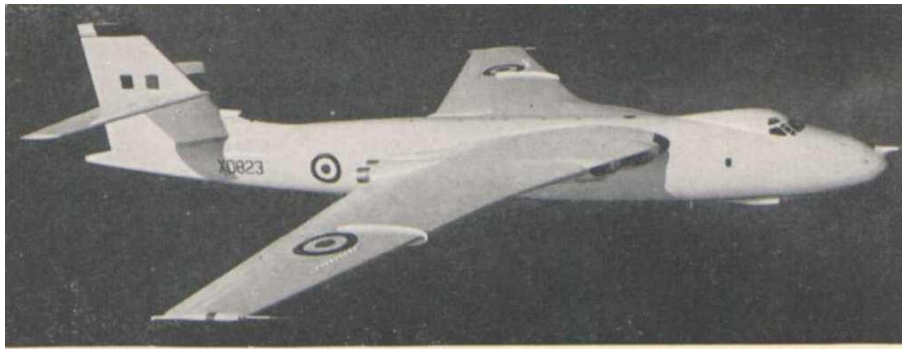
Canberra

Hunter

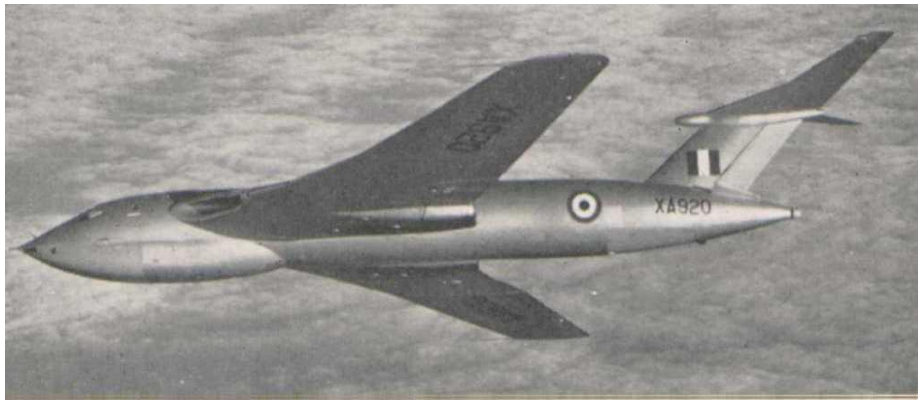
Valiant

The V Bomber Force

Avro Vulcan

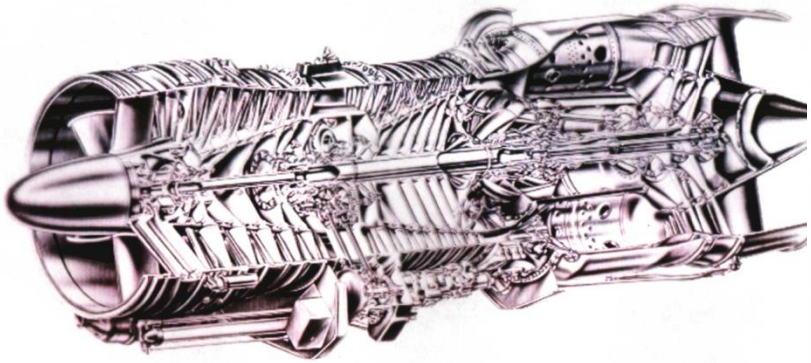


Vickers Valiant



Handley Page Victor

Olympus



TSR 2

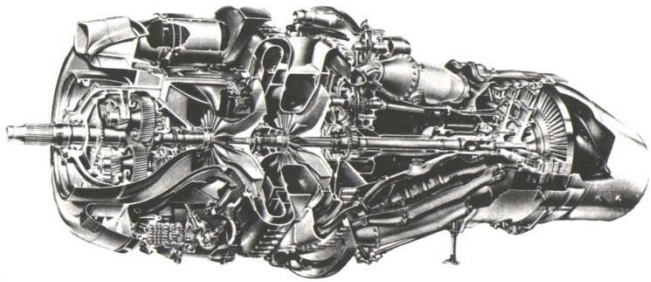
English Electric Lightning

Powered by 2 RR Avon Turbojets with reheat

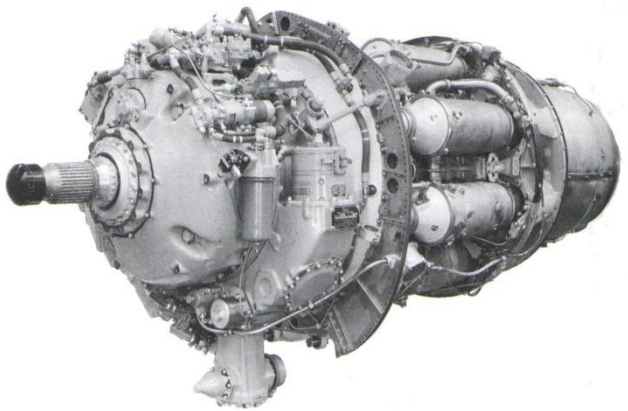
Brabazon Committee's 1944 recommendations for Transport Aircraft

- Type 1 Transatlantic — Bristol Brabazon
- Type 2 Short haul — Vickers Viscount
- Type 3 Long Range (Empire) — Avro Tudor
- Type 4 High Speed — De H Comet
- Type 5 Feederliner — De H Dove

Short-haul
Turbo-props ~ Viscount & Dart



Long-haul
Turbo-props ~ Brittania & Proteus



The first Jet Transport Aircraft

Comet & de Havilland Ghost

Comet Mk 1

36 passengers 1500 miles
Speed 450 mph at 35,000 ft
Cruise Mach Number = 0.68

de Havilland Ghost 50

Thrust 5,000 Lb
Pressure ratio 4.5
Mass flow 88lb/sec
Weight 2,200 lb

Intercontinental Travel Situation in early 1950's

- No leisure travel (except for mega-rich)
- Virtually no business travel
- Large scale emigration

Types of transport systems:

- Ship - *transatlantic/transpacific*
- Air - *small domestic US market*
  - *very small transatlantic*
  - *negligible transpacific*
- Rail- *transcontinental, local*

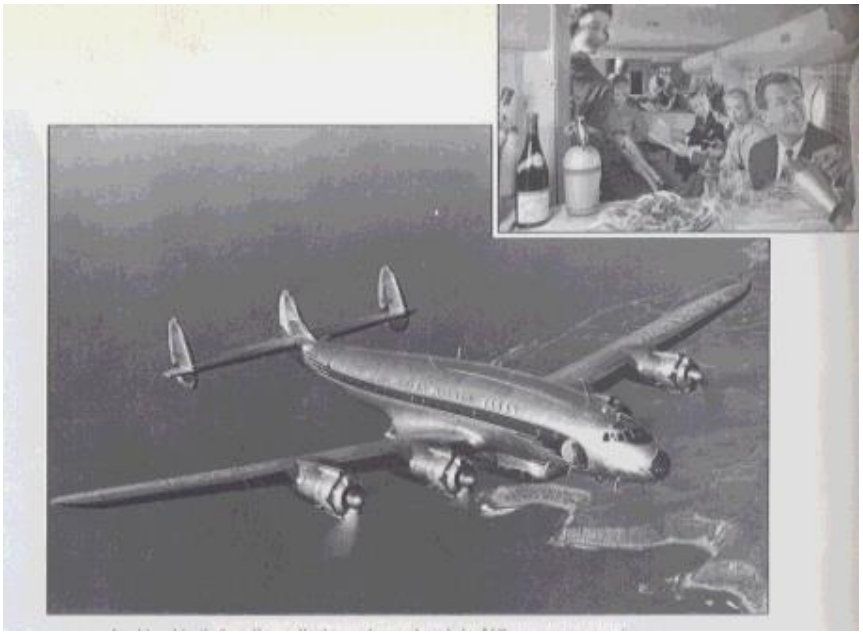
Reference: H I H Saravanamuttoo ICAS 2002

Transatlantic by Sea

Queen Elizabeth
1938 83676 tons

- **Queen Elizabeth and Queen Mary**
  - *London - New York* *4.5 days*
  - *Typical cruise* *30 kts*
  - *Passengers* *2200*
  - *Crew* *2000*
  - *Fuel per passenger* *4080 lb*

Post-War Long Range Aircraft Piston engined Airliners



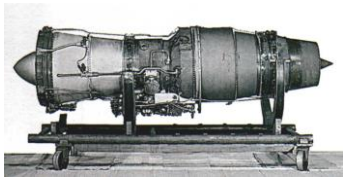
Lockheed Constellation

Boeing Stratocruiser

London - New York	
Typical Cruise	**275 kts**
Passengers	**74**
Flight Crew	**5**
Fuel per Passenger	**520 lb**

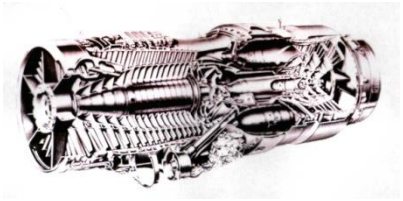
The first Jet-powered Transatlantic Airliners

Boeing 707



P&W JT3

De Havilland Comet 4



Avon

Ship versus Air

- Jet Transatlantic Service started Oct. 4, 1958 with BOAC, Comet 4
- In 1958 for the first time transatlantic passengers by air exceeded those by ship
- 1967 QE2 launched
- 1968 QE withdrawn from service
- 1975 United States withdrawn
- Transatlantic passenger traffic by ship virtually eliminated by the Jet Engine in 10 years

Situation at end of 1950's

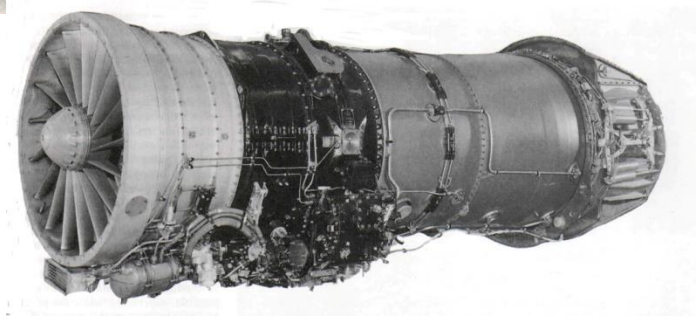
- A decade of great technological advance in both airframe & propulsion systems.
- Turbojets had become mature.
- Same engine could be used civil or military
- At high thrust levels axial compressors were established
- Turboprops, with centrifugal compressors, for short range
- Turboprops not used as the propulsion system for long range ~ speed & operating altitude too low.
- Noise & fuel economy (so long as range could be met) not an issue.

The next step ~ the emergence of the Turbofan

The development of by-pass engines

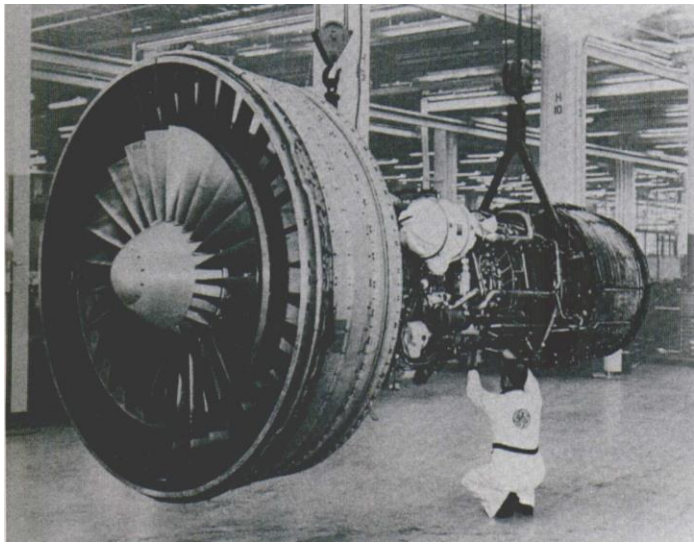
The VC 10 on it's first flight

Roll Royce Conway
"Low by-pass ratio"



The development of high by-pass ratio turbofan

Lockheed C5A



GE TF39

The first wide-body Jets

Douglas DC10 ~ 1971

Lockheed 1011 ~ 1972

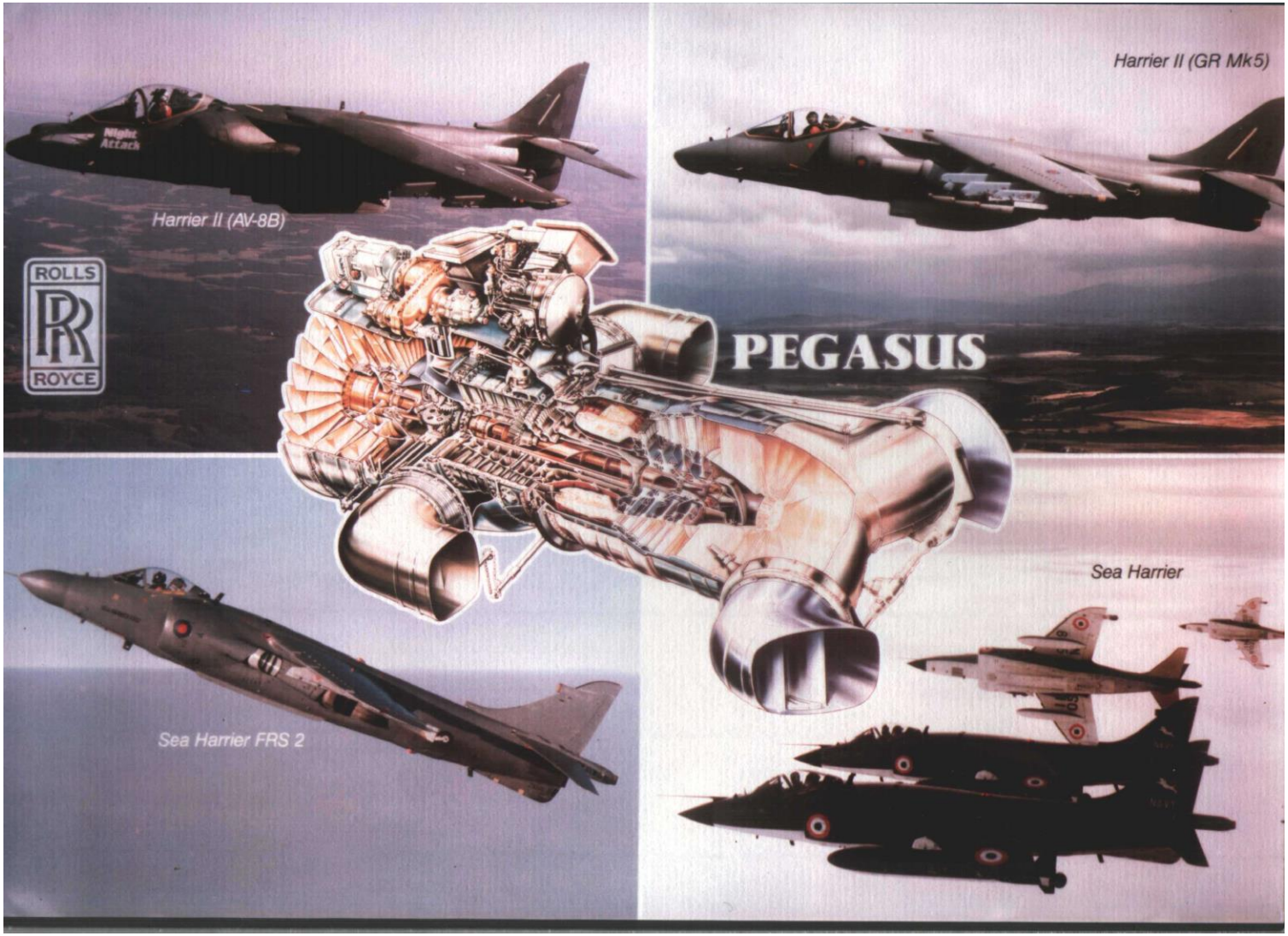
Boeing 747 ~ 1970

P&W JT9D	43,500 lbs	92 inch fan
GE CF6	40,000 lbs	86 inch fan
RB211-22B	42,000 lbs	85 inch fan
RB211-524B	50,000 lbs	85 inch fan

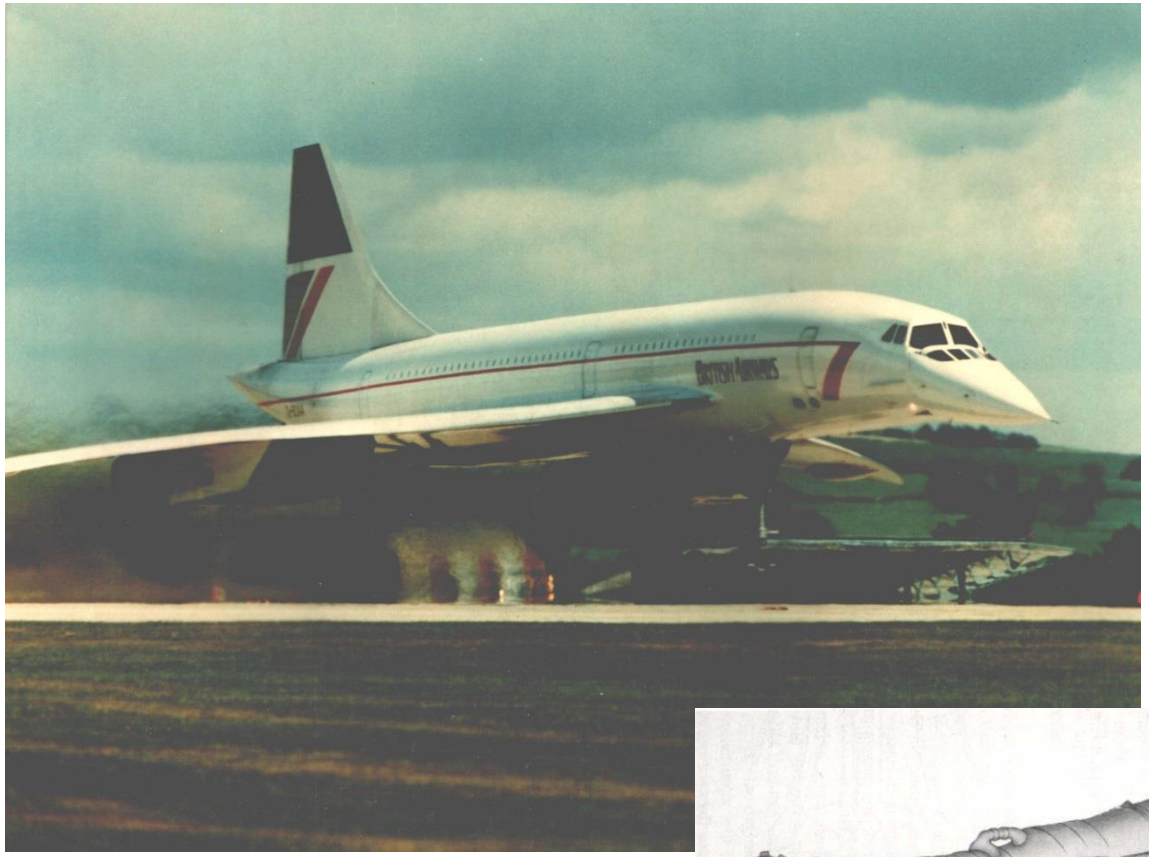
Jet Lift Experience

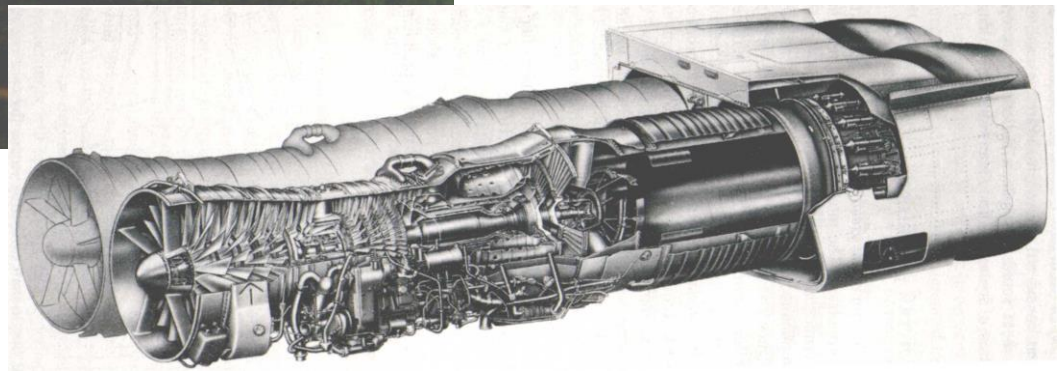
Vertical Take-off & Landing

Harrier and Pegasus



Concorde





Olympus 593

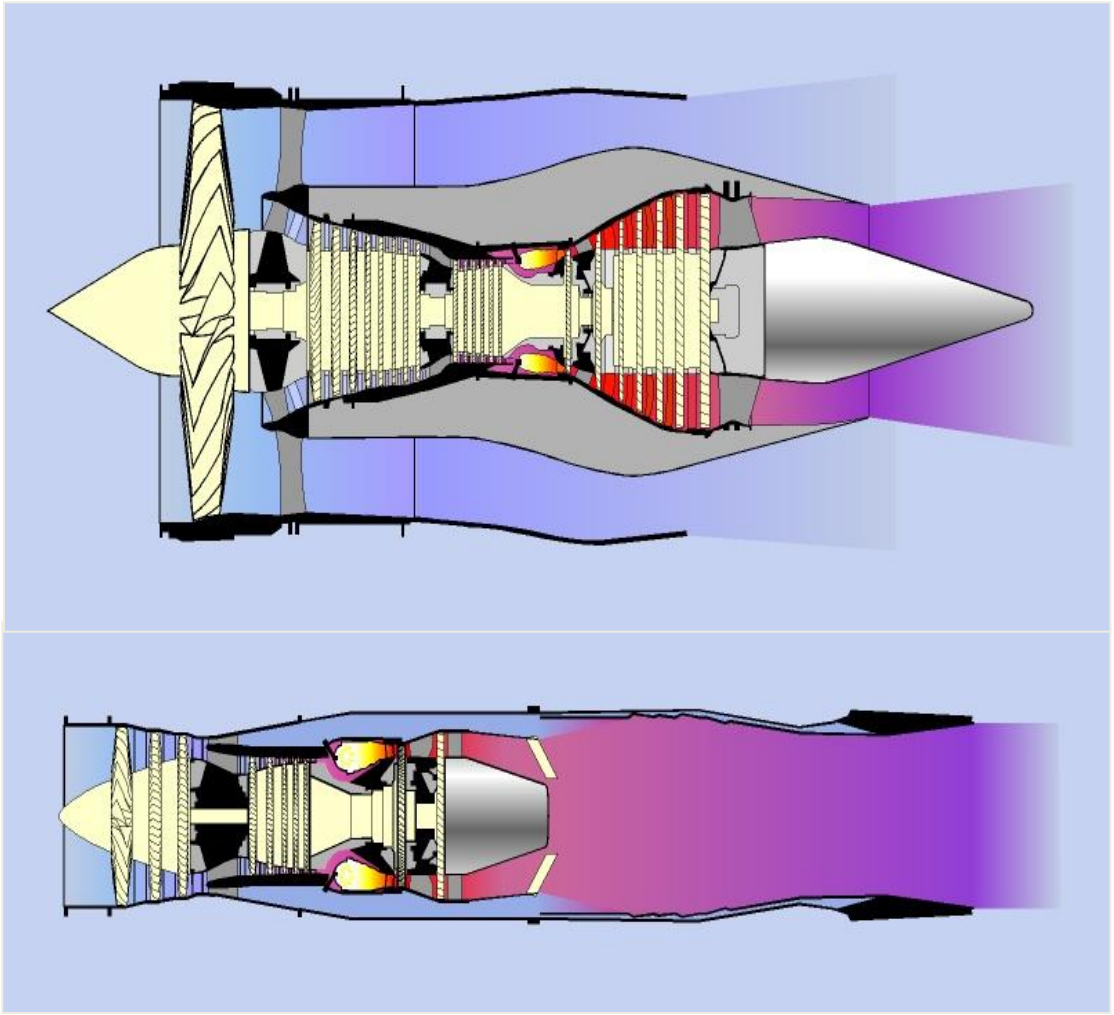
Turbofan Types

Civil Turbofans:

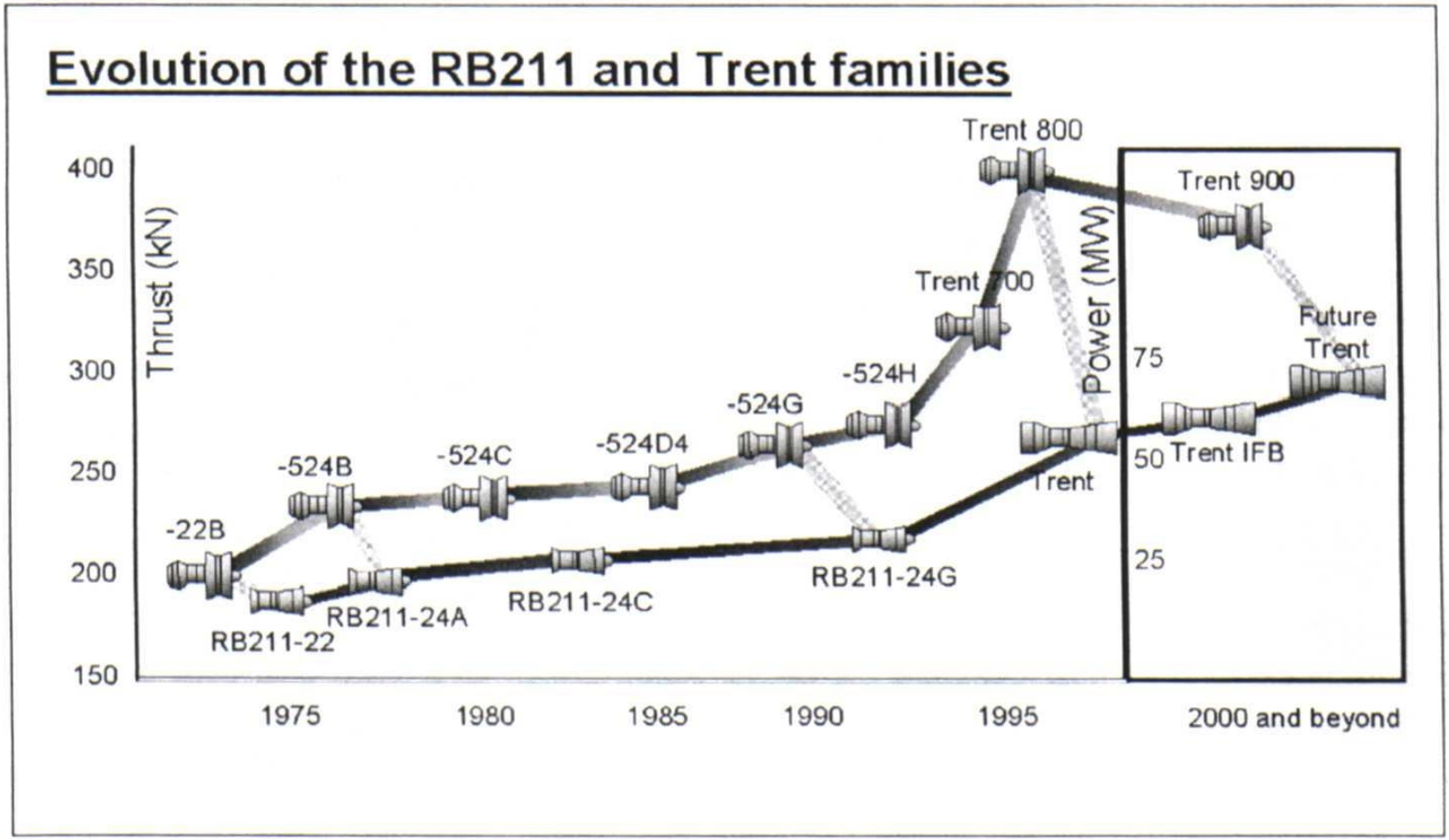
- RB211/Trent
- CF6/ CFM56/ GE 90
- P&W JT9

Military Turbofans:

- F100 / F110
- Adour/ RB199/ EJ200
- F119/F120
- F404/ F120



The Derivative Design Approach



Source - Rolls-Royce plc

What next for Propulsion ?

- ***Mature Technology with more than 50 years of experience.***
- ***Can the gas turbine can be further exploited with more advanced technology?***
- ***What novel Systems are there which will address the key issues of global warming & diminishing reserves of fossil fuels?***

The Challenges for Propulsion in 21st Century

- ***Global Warming, Pollution & the Environment***
  - ***Emissions***
  - ***Noise***
  - ***Fuel efficiency***
- ***Alternative fuels ~ Bio-fuels, Hydrogen?***
- ***Novel airframe & propulsion systems to exploit fully technology advances.***

Airbus A380

Trent 900

Any Questions ?