Lecture 8

Cycle Choice ~ Military & Supersonic Transports

Objective: To outline the reasons for the choice of engine cycle for combat aircraft & supersonic transports.

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Propulsion System Requirements

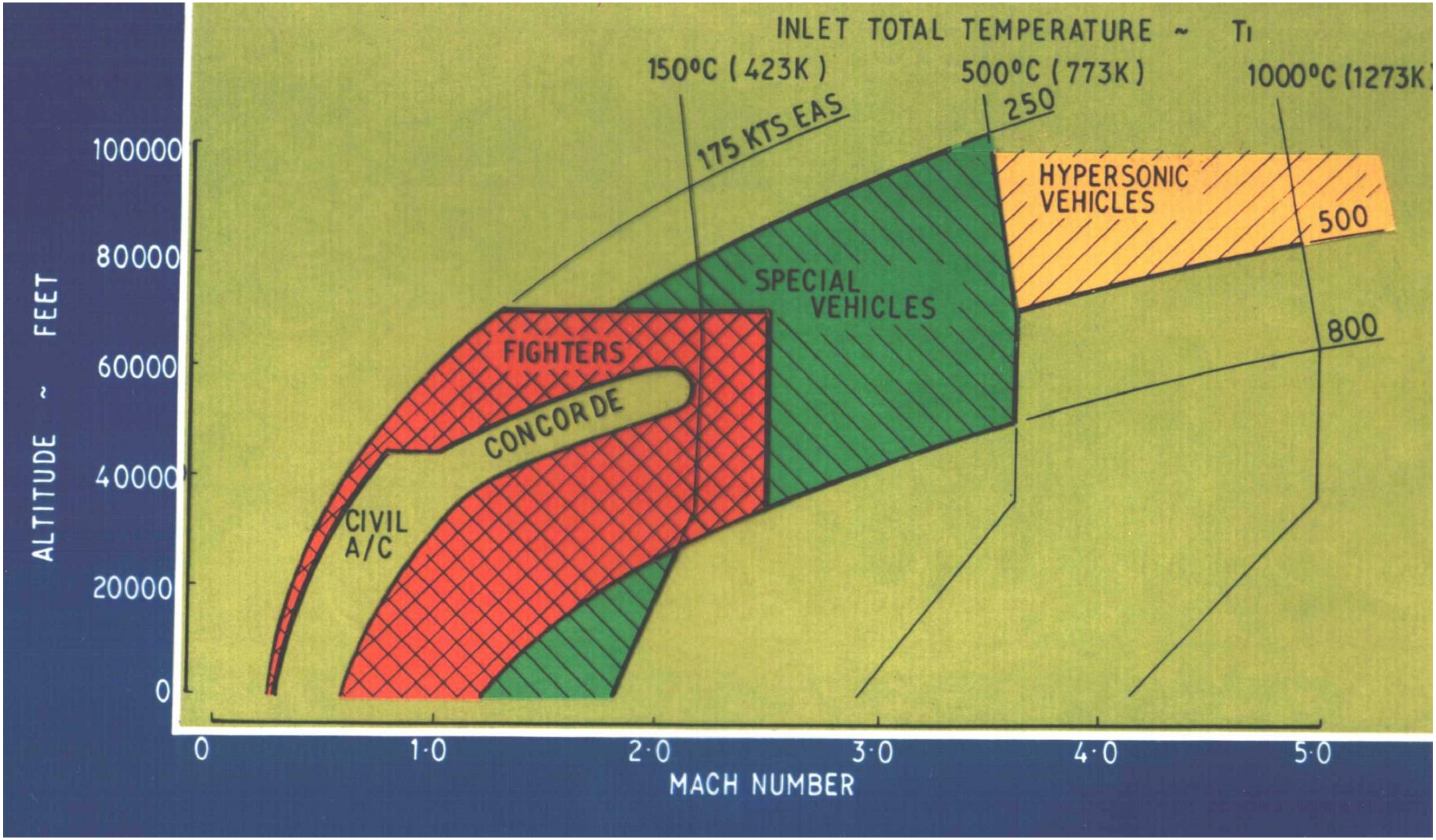
Optimum for Airframe Manufacturer:

- 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

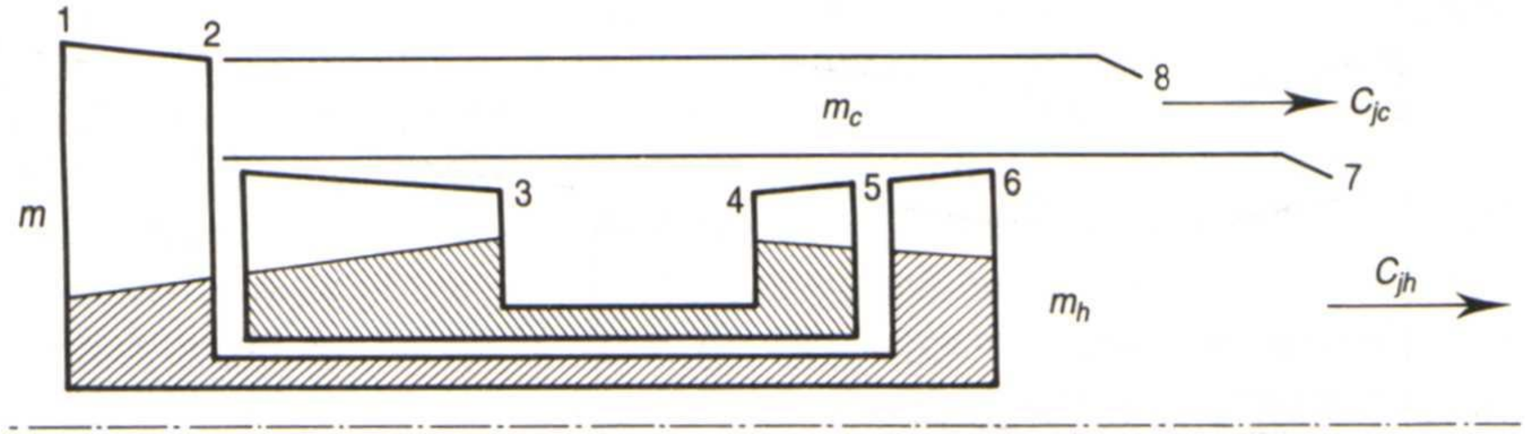
Optimum for Customer (Airline, Air Force etc.):

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

Aircraft Flight Envelope



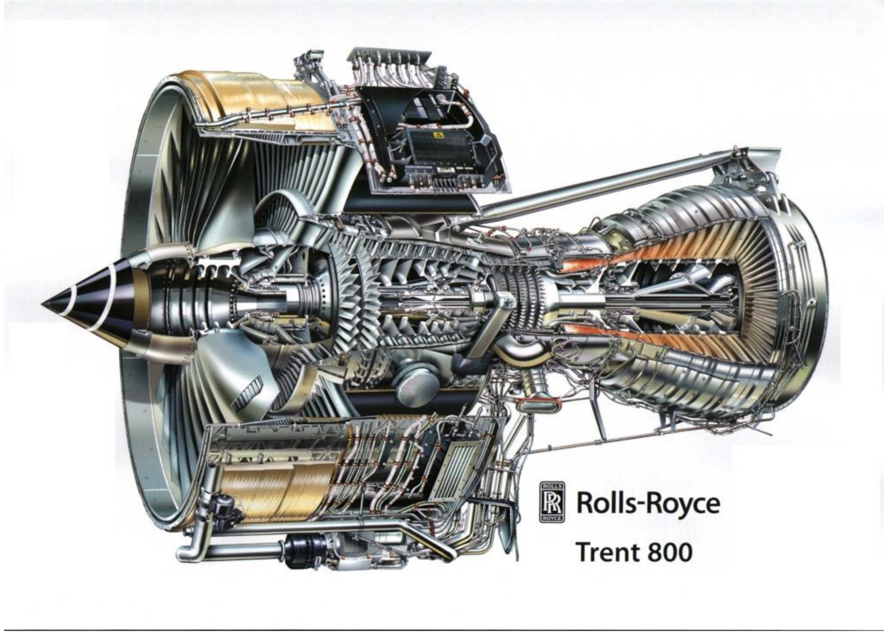
Key Cycle Parameters

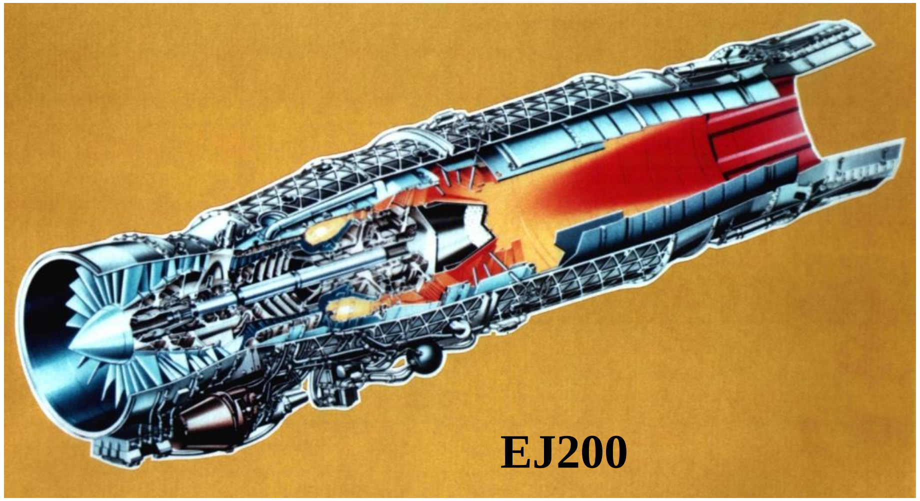


- Overall Pressure Ratio $OPR = P_{03}/P_{01}$
- Fan Pressure Ratio $FPR = P_{02}/P_{01}$
- Stator Outlet Temperature $SOT\ K = To_4$
- Specific Thrust $ST = F/\dot{m}$
- By-pass Ratio $\lambda = \frac{m_c}{m_h}$ (by-pass flow/core flow)

Note for mixed flow engines p_{sh}/p_{sc} is also important

Propulsion Systems for Transport & Combat Aircraft





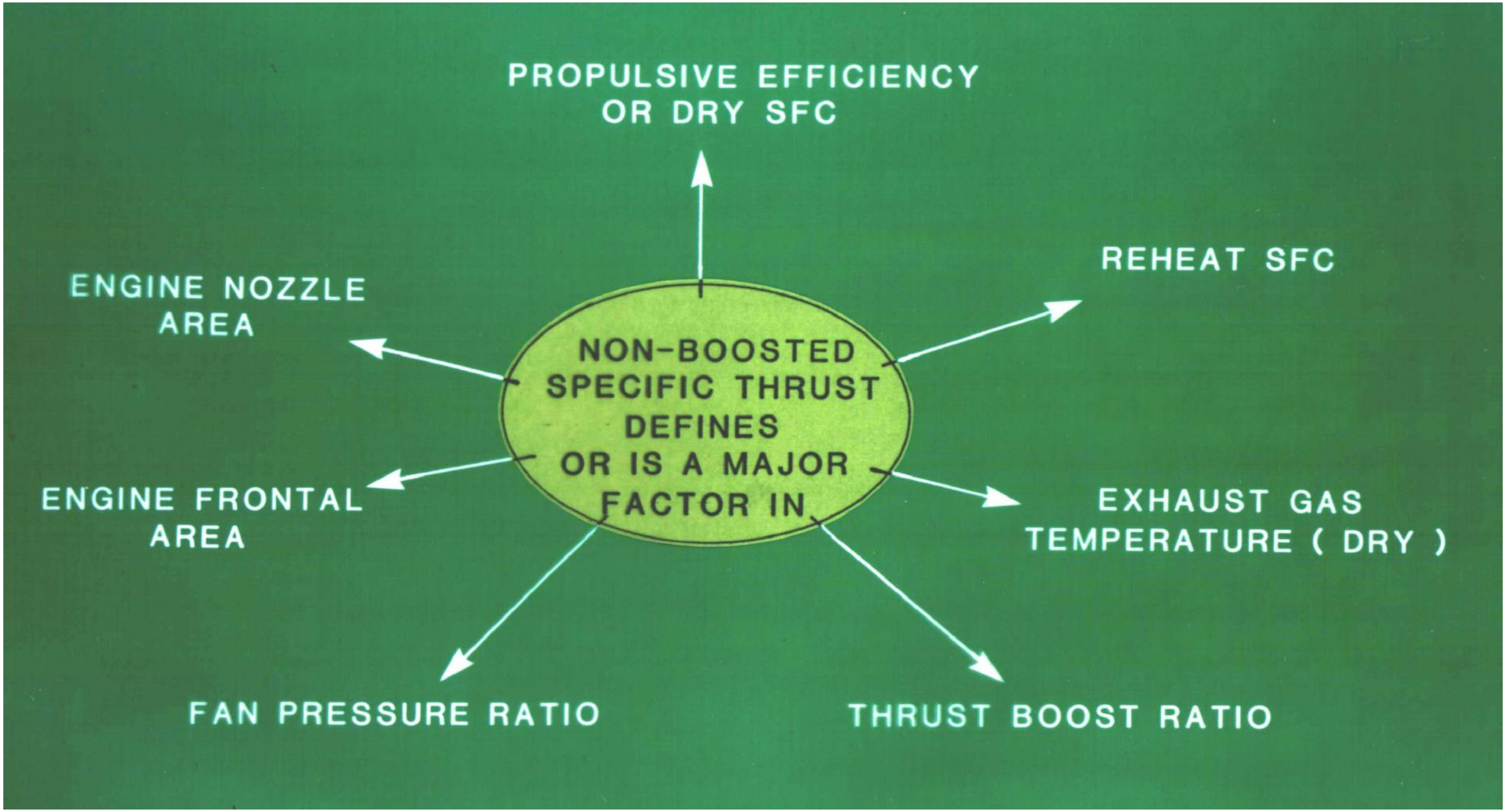
<u>High by-pass ratio Turbofan</u>

Thrust ~2000 to 100,000 lb
By-pass ratio 4 – 10
OPR ~ 40
Fan PR ~ 1.9
Specific Thrust ~ 25 – 35 lb/lb/sec

<u>Low by-pass ratio Reheated Turbofan</u>

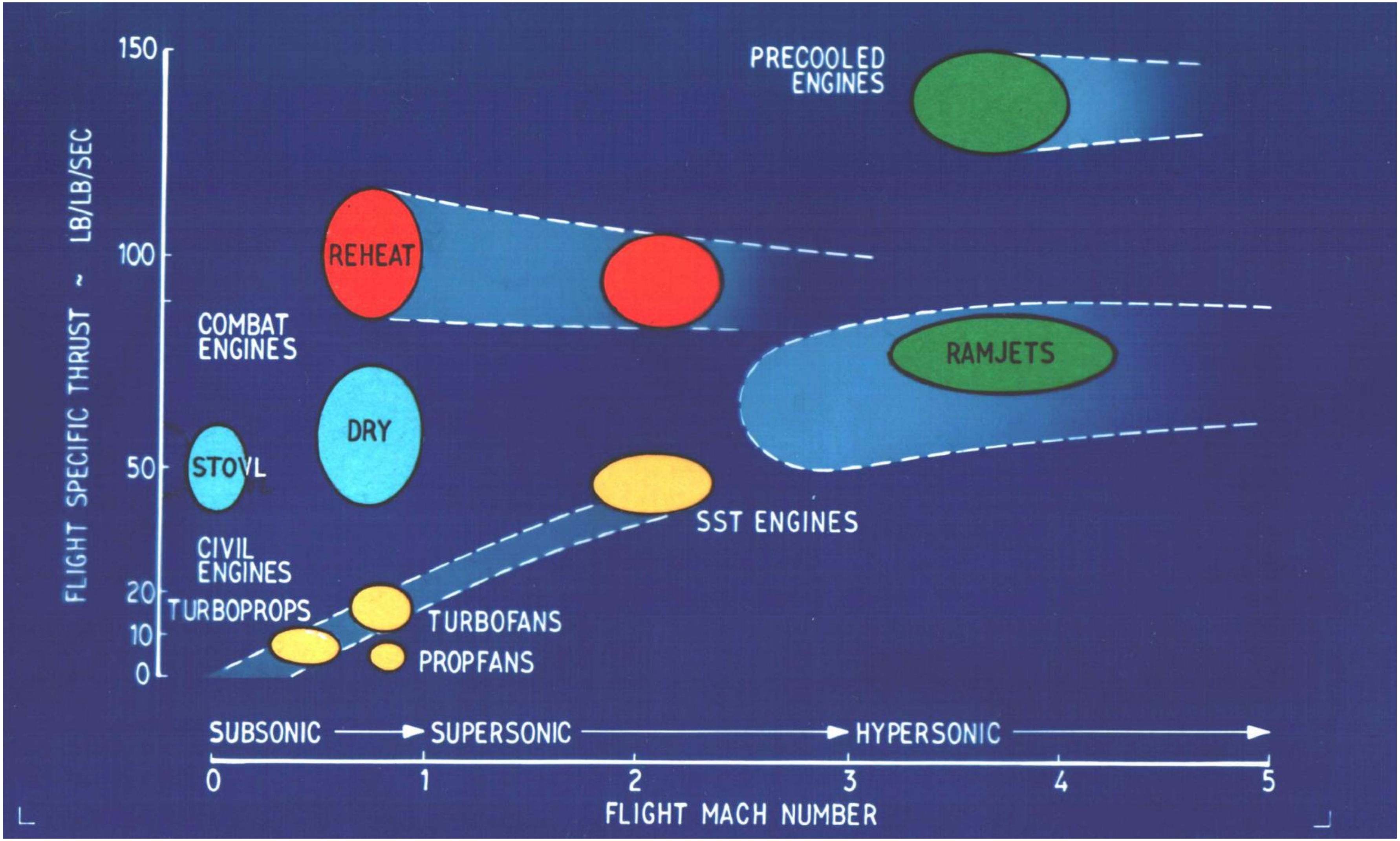
Thrust ~10,000 to 40,000 lb (inc R/H)
By-pass ratio 0.3 – 1
OPR ~ 25 – 30
Fan PR ~ 3 – 5
Specific Thrust ~ 120 lb/lb/sec (inc R/H)

Specific Thrust ~ the basic parameter



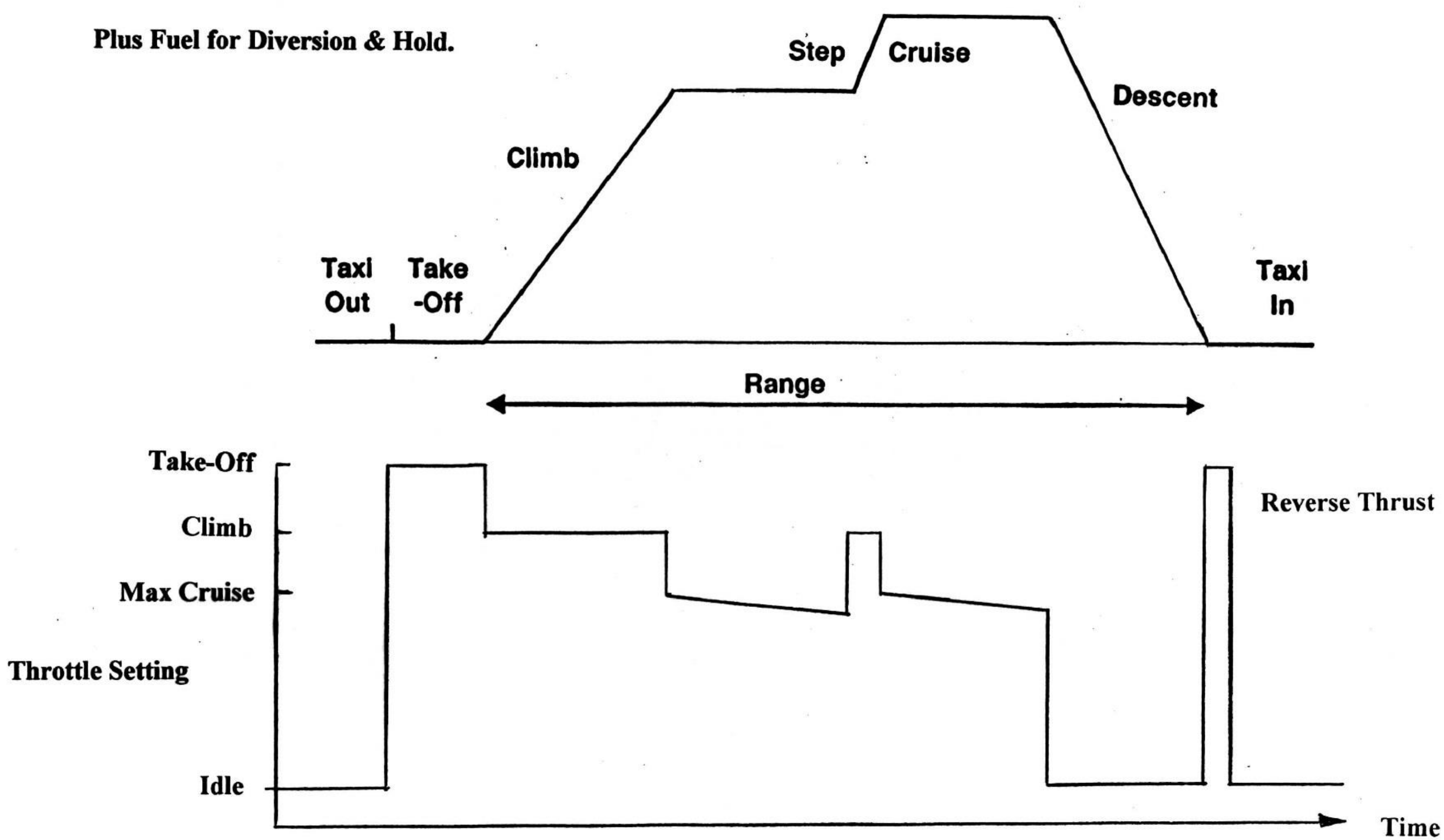
SPECIFIC THRUST (Thrust per unit Mass Flow) = $(C_j - C_a)$ **(Unit of velocity)**

Specific Thrust - Variation with design flight speed



Specific Thrust = $F/\dot{m}$ Units kN/kg/sec or m/sec (Lb/lb/sec or ft/sec)

Typical Civil Mission

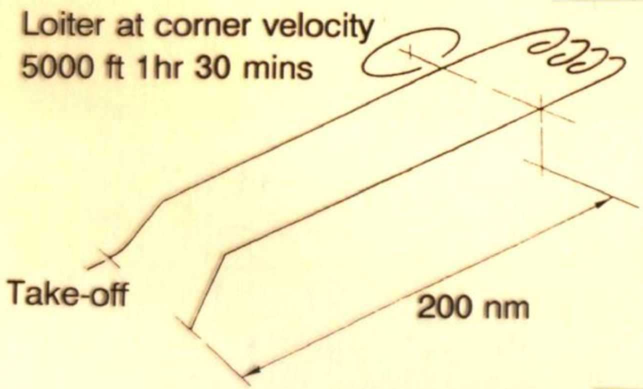


Combat Aircraft Roles

Role	Mission Requirements	Aircraft Type
Air Superiority	Highly manoeuvreable	F15/F16/F18
Interceptor	Combar Persisitence	F22 F35
	Supersonic Performance	Typhoon Rafale
	Short T/O &Landing	
	STOVL	
Interdictor	Long range	F111
	Low obervables	TornadoF111
	Sophisticated weapons carriage	F117
	Self Defence Capability	B2
Battlefield Support	Survivable	Harrier AV8B
	Large stores carriage	A10
	Highly Manoeuvrable	F35
	Short T/O &Landing	Apache
	STOVL or Rotary	

Typical Military Missions for Combat Aircraft

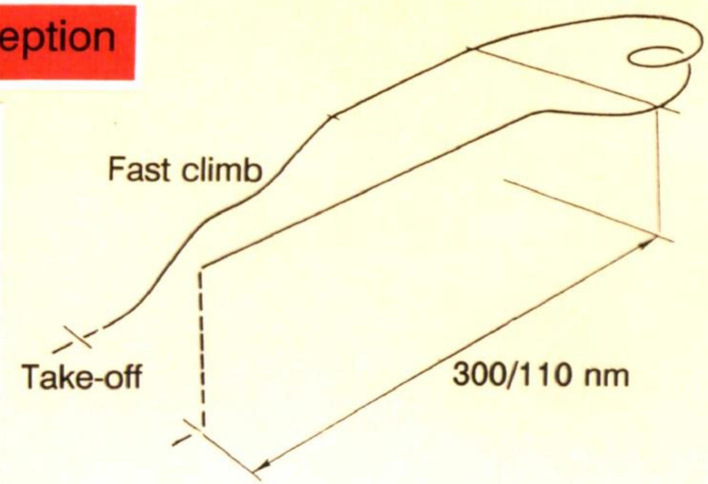
Air superiority



- Low altitude air superiority
- 8 submerged missiles
- Internal fuel
- Mach 0.9, 5000 ft, 8 x 8 g, combat
- 420 kts, 5000 ft, return
- 10% reserve fuel

Interception

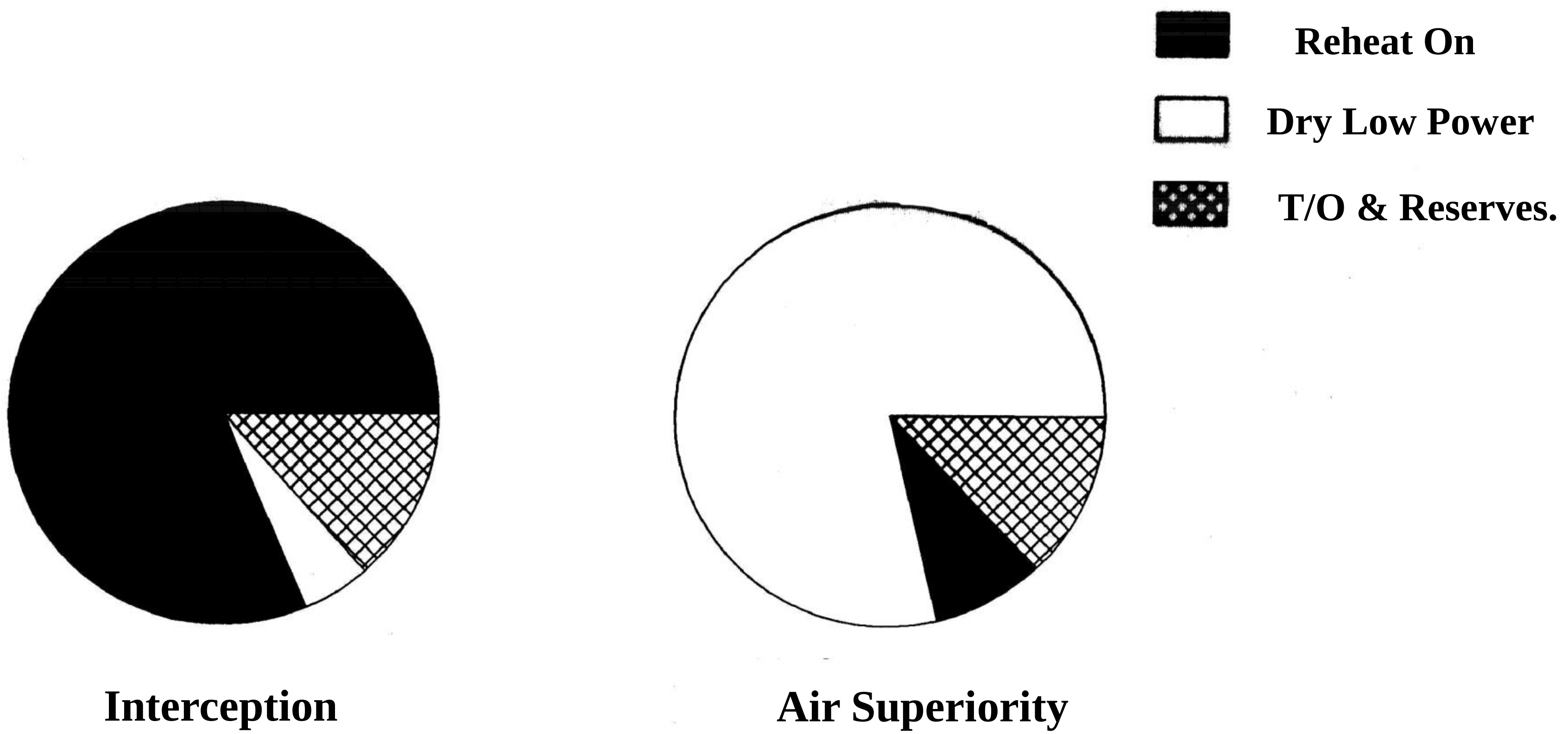
- Point and long range intercept
- 8 submerged missiles
- Mach 1.5, 36000 ft, dry cruise
- Mach 1.8, 36000 ft, combat
- Mach 0.9, Tropopause, 7 x 360 combat
- Optimum return
- 10% reserve fuel



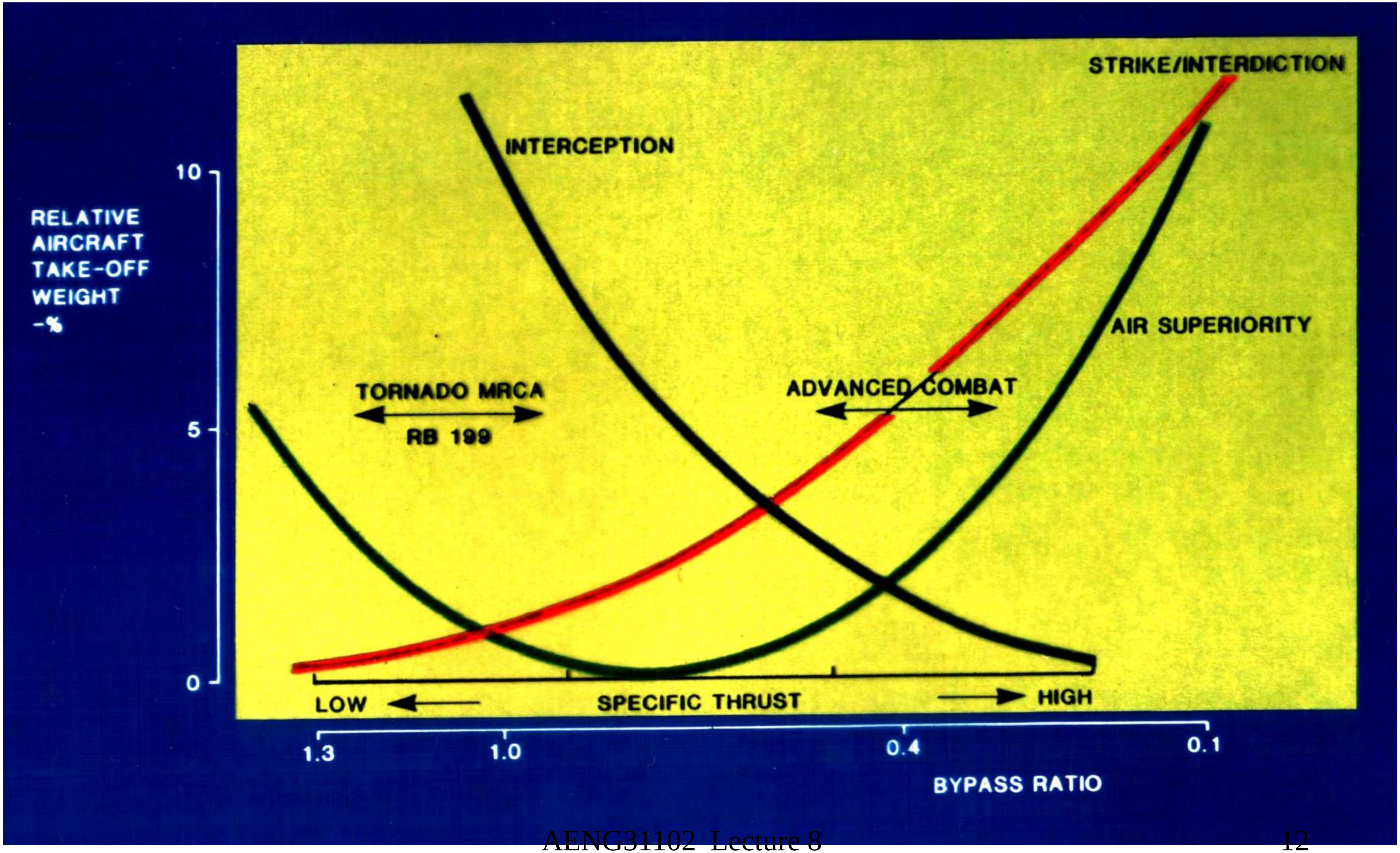
Flexible, fast, far reaching

Fuel Breakdown

Military Missions



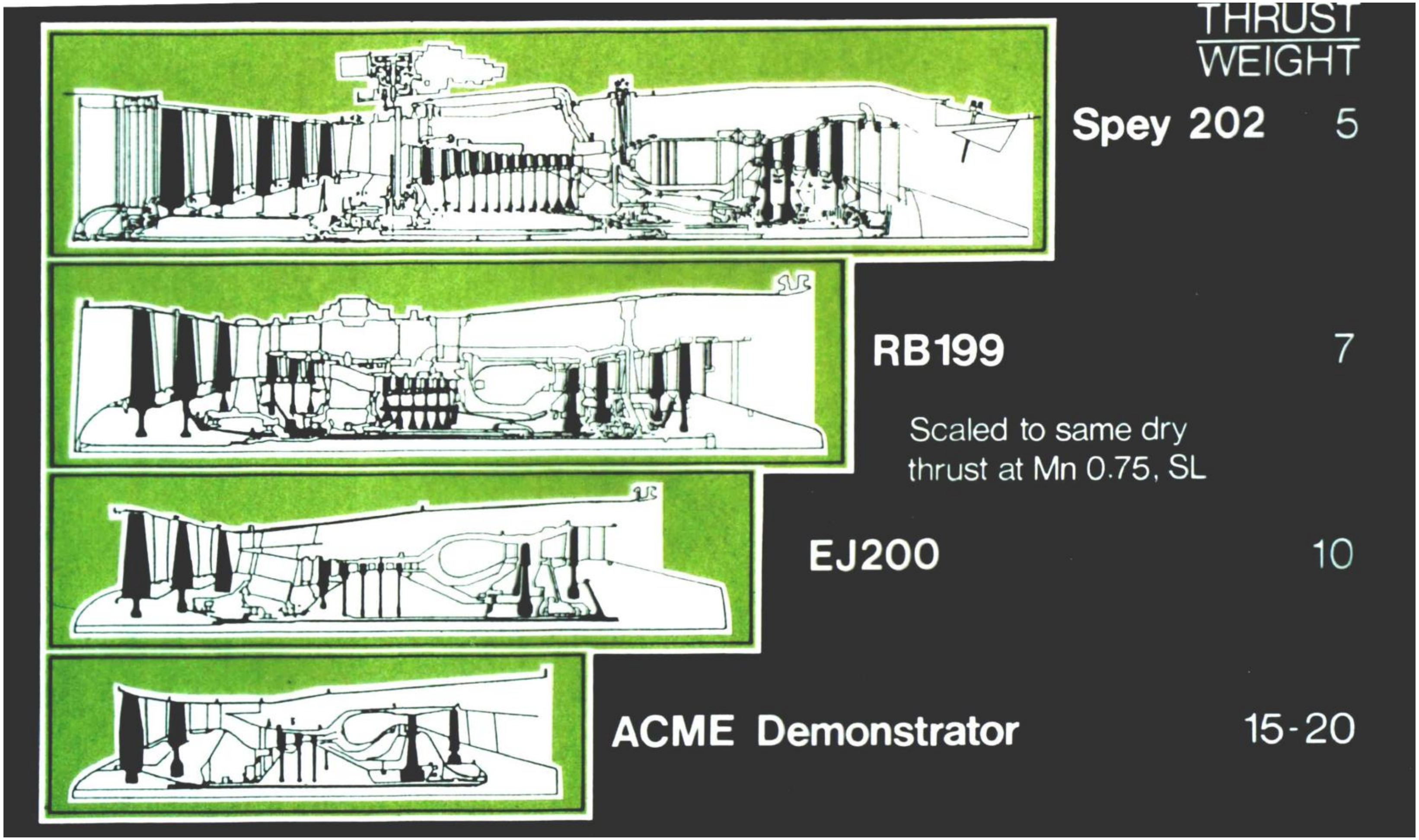
Cycle Options for Combat Aircraft



Engine Cycles for Combat Aircraft

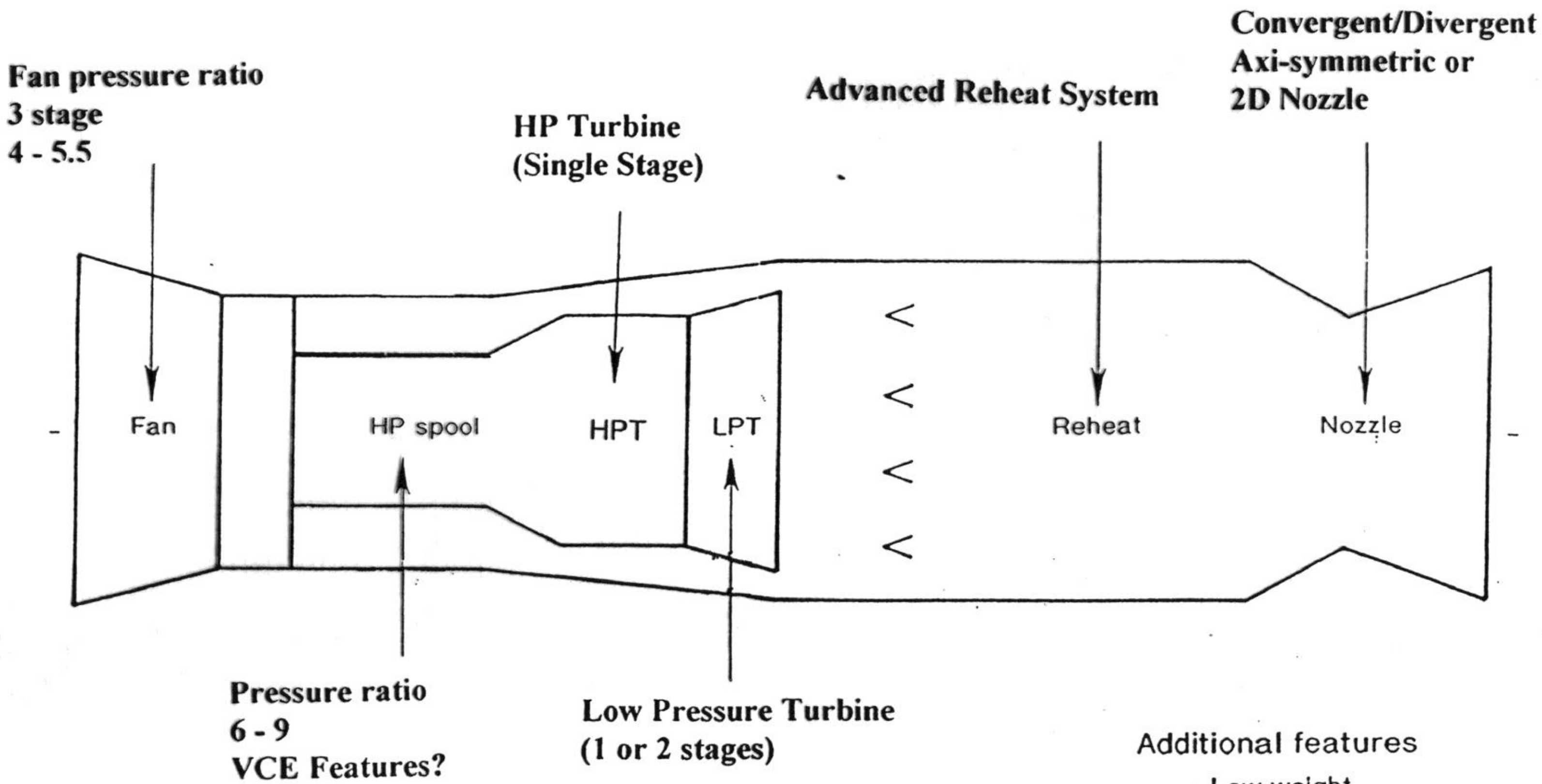
- Over the past 30 years, the trend has been for the engine cycle for Supersonic CTOL Aircraft to have increasing values of specific thrust (reheat-off)
- This has been driven by the need for:
  - High Non-reheat to Reheat thrust ratios
  - Low SFC Reheat on
  - Low cross-section & weight
  - Adequate SFC Reheat off
- Long range attack aircraft, STOVL & other requirements may well modify the need for high specific thrust but studies have shown that for combat persistence, high specific thrust is the most fundamental parameter.

The trend in Supersonic Fighter Engines



Based upon Rolls-Royce plc Data

Future Combat Engines



Additional features

- Low weight
- Low manufacturing cost
- Controls

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UTILISATION

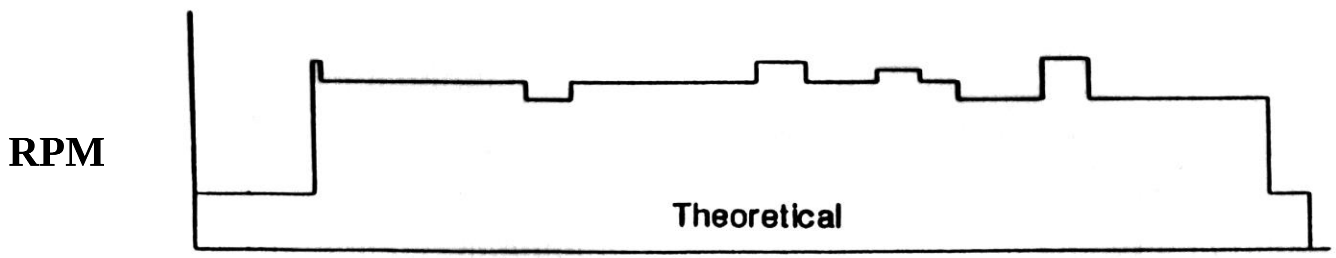
- The Military Customer utilises his systems in order to maintain the minimum level of readiness, train new personnel and, all the while, keeping a Military Capability in reserve for use in times of conflict.
  - Utilisation low in order to preserve capability & minimise costs. (Typically 300 hours per year e.g. one flight of one hour per day)
- The Airline maximises utilisation (if there are sufficient passengers) in order to maximise revenue.
  - Utilisation high. (Typically 3000 hours per year e.g. 10 one hour flights per day or 1 ten hour flight per day)
- For some operations e.g. military transport and primary training the Military will behave more like an Airline

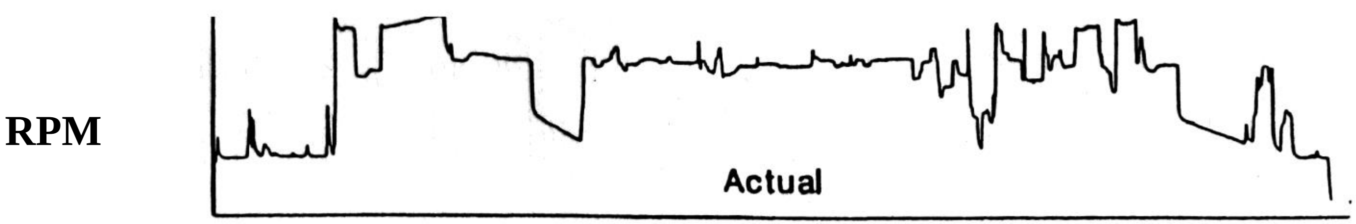
Intensity of Usage

- The Airline Pilot will keep excursions from the norm e.g. "g" loadings, engine throttle movements… to a minimum for reasons of passenger comfort & to keep costs as low as possible.
  - Typically one engine throttle cycle (idle- max. thrust – idle) per flight.

- The Military Pilot is training for combat and hence there will be many excursions from the norm in terms of g" loadings, engine throttle movements etc.
  - Can be as high as ten engine throttle cycles (idle- max. thrust – idle) per flight.

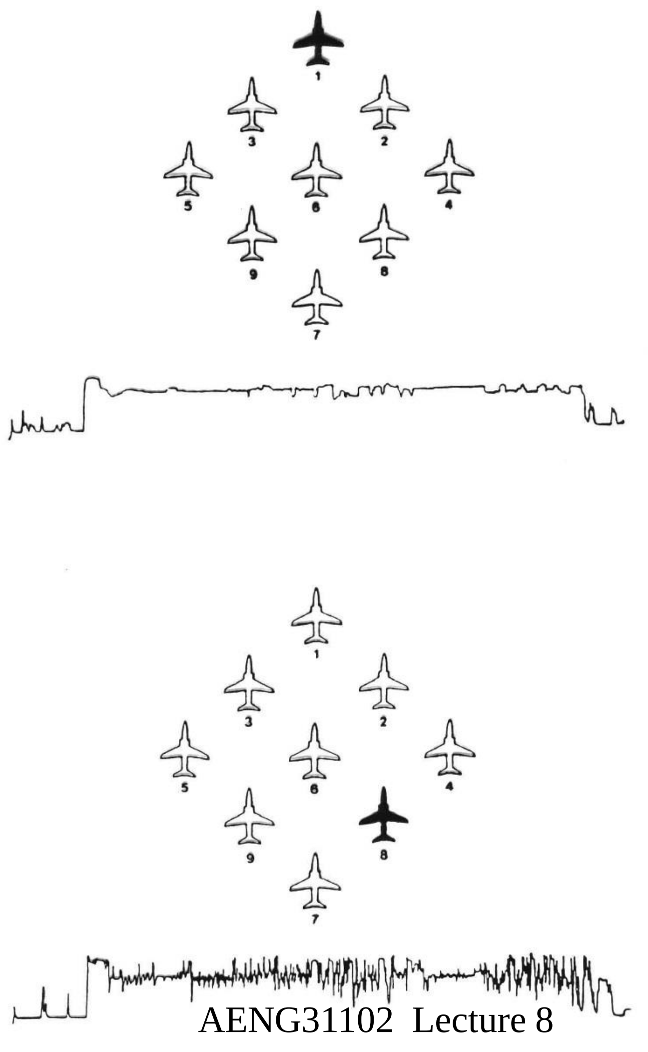
Peacetime Mission Throttle Movement





Based upon Rolls-Royce plc Data

Red Arrows Flight Data



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Based upon Rolls-Royce plc Data

Propulsion Units for Helicopters

Requirements:

- Power to drive rotor
- Adequate power to cater for engine failure
- Light weight
- Low fuel consumption
- Low price & Maintenance Costs
- High levels of reliability with low levels of maintenance

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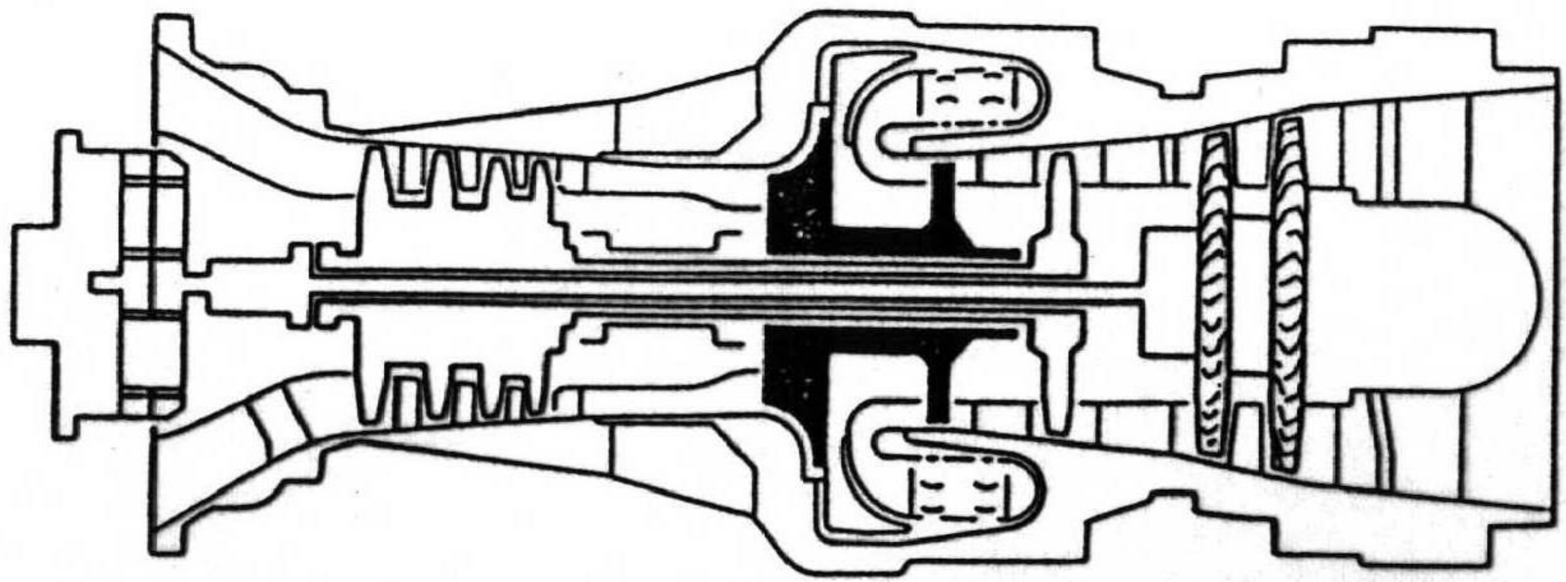
Shaft Power Cycles for Helicopters

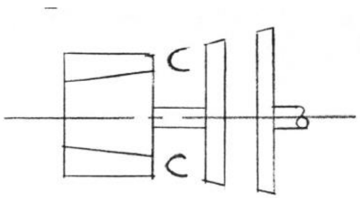
In general shaft power cycles for Aircraft & Helicopter applications are 'Open Cycle' i.e. air entering the engine is not re-circulated. The engine produces both shaft power & residual exhaust thrust

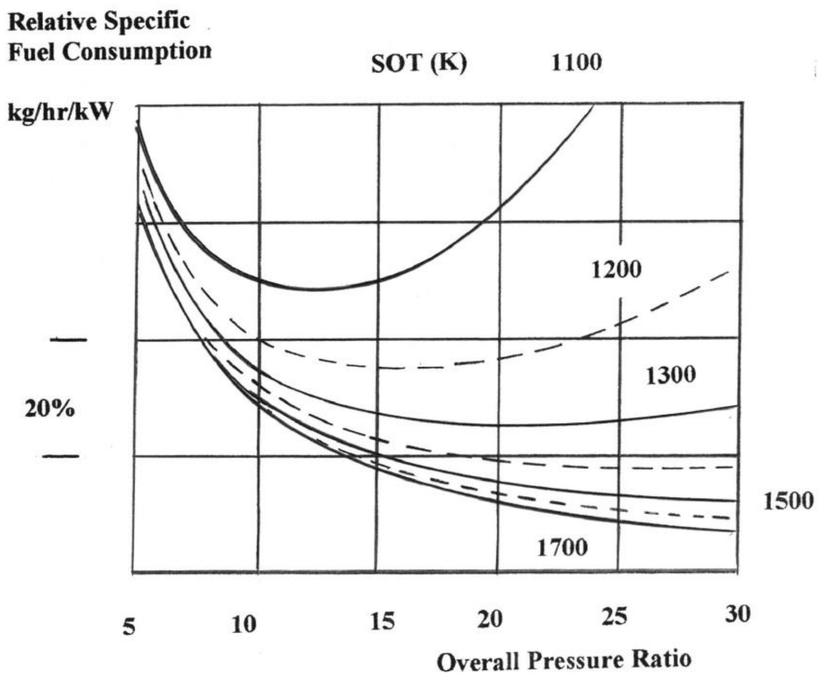


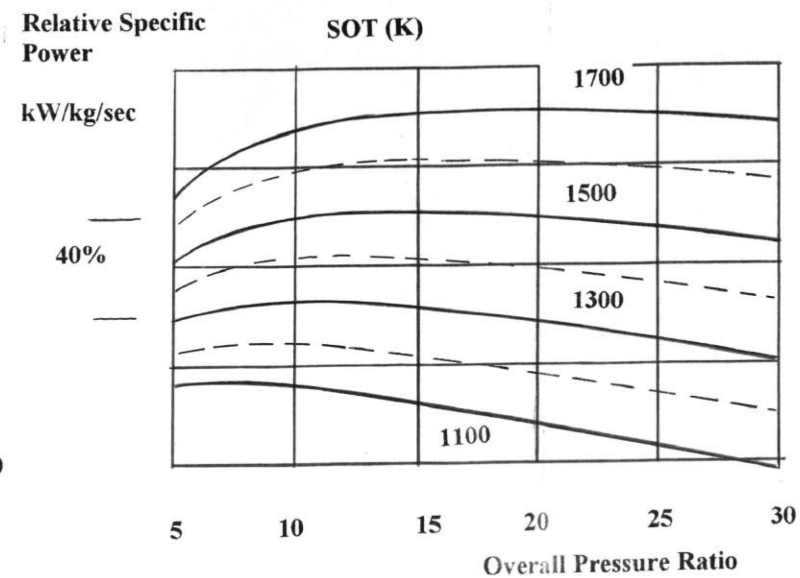
TWIN-SPOOL TURBO-SHAFT (with free-power turbine)

Shaft Power Cycles

Specific Fuel Consumption & Specific Power versus Pressure Ratio & SOT







Reference: Gas Turbine Performance *by Walsh & Fletcher*

Major Features of Helicopter Powerplants

- Configuration and Cycle:
  - Single spool at smallest size for simplicity & low engine mass
  - For Medium/High power levels configuration as Turboprop
  - Levels of Pressure ratio ~ 15 - 20:1 (optimised for max. specific power & low sfc)
  - Stator outlet Temperatures ~ 1500K (cooled turbine blades required)

- Key Design Criteria:
  - Maximum power sized by hot/high operations and/or engine failure for multi-engined helicopters
  - Low Specific Fuel Consumption at normal operating conditions
  - Low engine mass
  - Frontal area not significant due to low flight speed &"buried" installation

- Piston Engines:
  - Used only at lowest power levels

Unmanned Aerial Vehicles

Tactical - Predator
100 - 900 lbs thrust

Reconnaissance - Global Hawk
2,000 - 15,000 lbs thrust

Target / Decoy
50 - 1,700 lbs thrust

Combat Vehicles - Boeing
4,000 - 12,000 lbs thrust

Piston Engines

Four stroke, two stroke Turbochargers with Propellers

Applications:

- Mainly used by General Aviation, Unmanned Aerial Systems & light helicopters.

Four Stroke Piston Engines:

- 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
- Pollution

CessnaC-172 Delta Hawk A4TB

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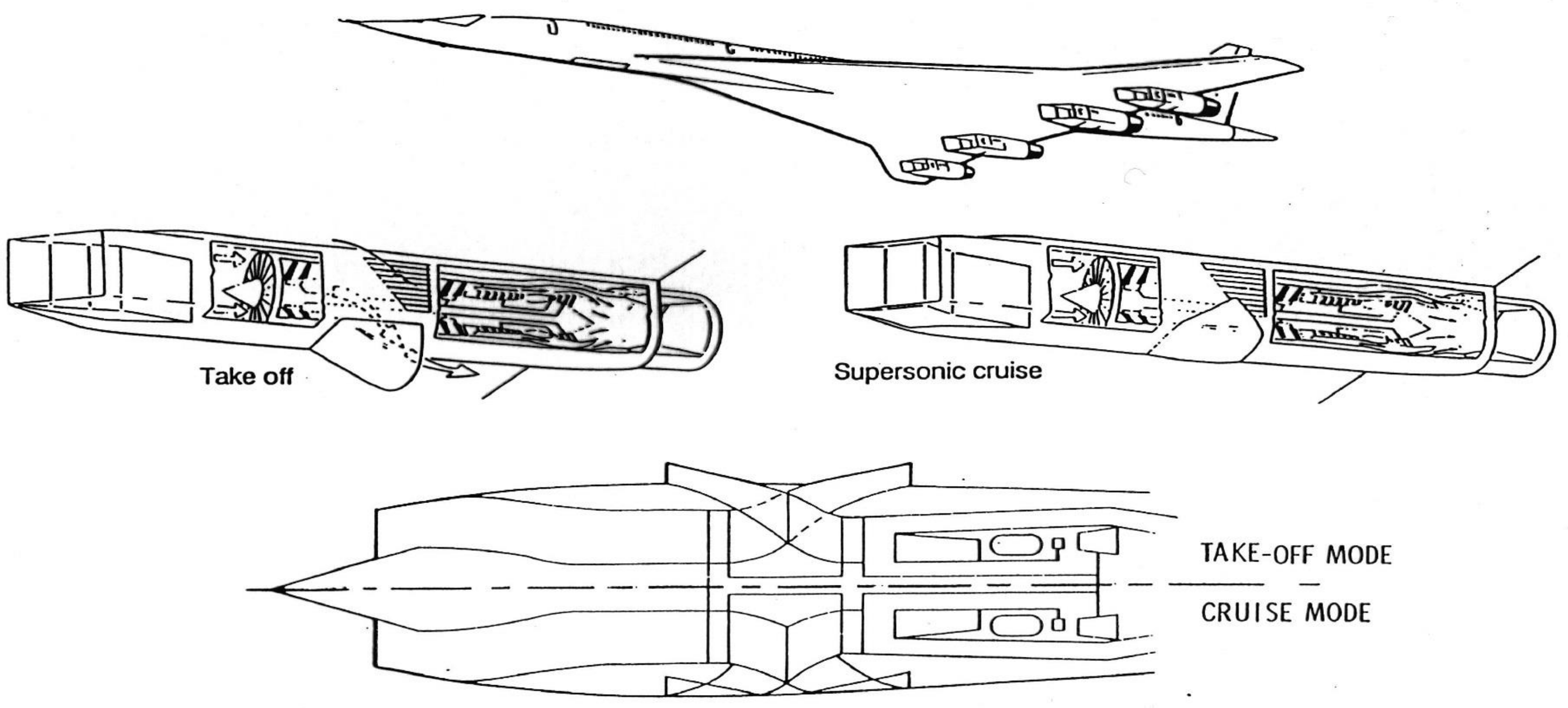
Future SST Propulsion Requirements

- High Specific thrust to give:
  - Sufficient supersonic thrust
  - Low installed drag supersonically
- SFC at Supersonic Cruise at least as good as the Olympus 593
- Low Specific Thrust at Take-off to meet noise requirements
- Good SFC subsonically (to give same range subsonic as supersonic)

Hence the need for a variable cycle engine

High Speed Commercial Transport



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Quiet Small Supersonic Transport

Aerion SSBJ

Specification:

12 Passengers | Powered by three engines ~ 15,000 Lb.
Range 5000 nm | L = 49 m   Span = 21 m
Cruise M = 1.4 - 1.6 No sonic Boom up to M = 1.1 – 1.2
Take off Mass – 54 tonnes | (Sonic Boom @ M =1.6 ~ 1/100 Concorde)

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:**
  - Hydrogen, etc.
- **Advanced Digital Control Systems**
  - Integration with the Aircraft Control System
- **Engine/Airframe Installation:**
  - Improved integration of propulsion system with airframe.

Key Lessons from Lecture 8

The choice of Engine Cycle for any Platform is a compromise between:

- **The Platform Requirements:**
  - Performance Thrust, SFC, Installed Drag
  - Geometric constraints, Mass etc.
  - Price, Maintenance Costs etc.
  - Reliability, maintainability, supportability etc.

- **The Propulsion System Design:**
  - Layout
  - Technology Levels
  - Mechanical Design & Material specification
  - Ease of Manufacture

- **For the best overall system design, the airframe & engine should not be treated as independent units.**

Lecture 9

Propulsion Systems for Super/Hypersonic Flight

Objective ~ Lecture 9

A review of the major propulsion systems for Supersonic & Hypersonic Flight.