Lecture 14

The Engine Control System

To describe how the engine is controlled

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The control of Engine behaviour

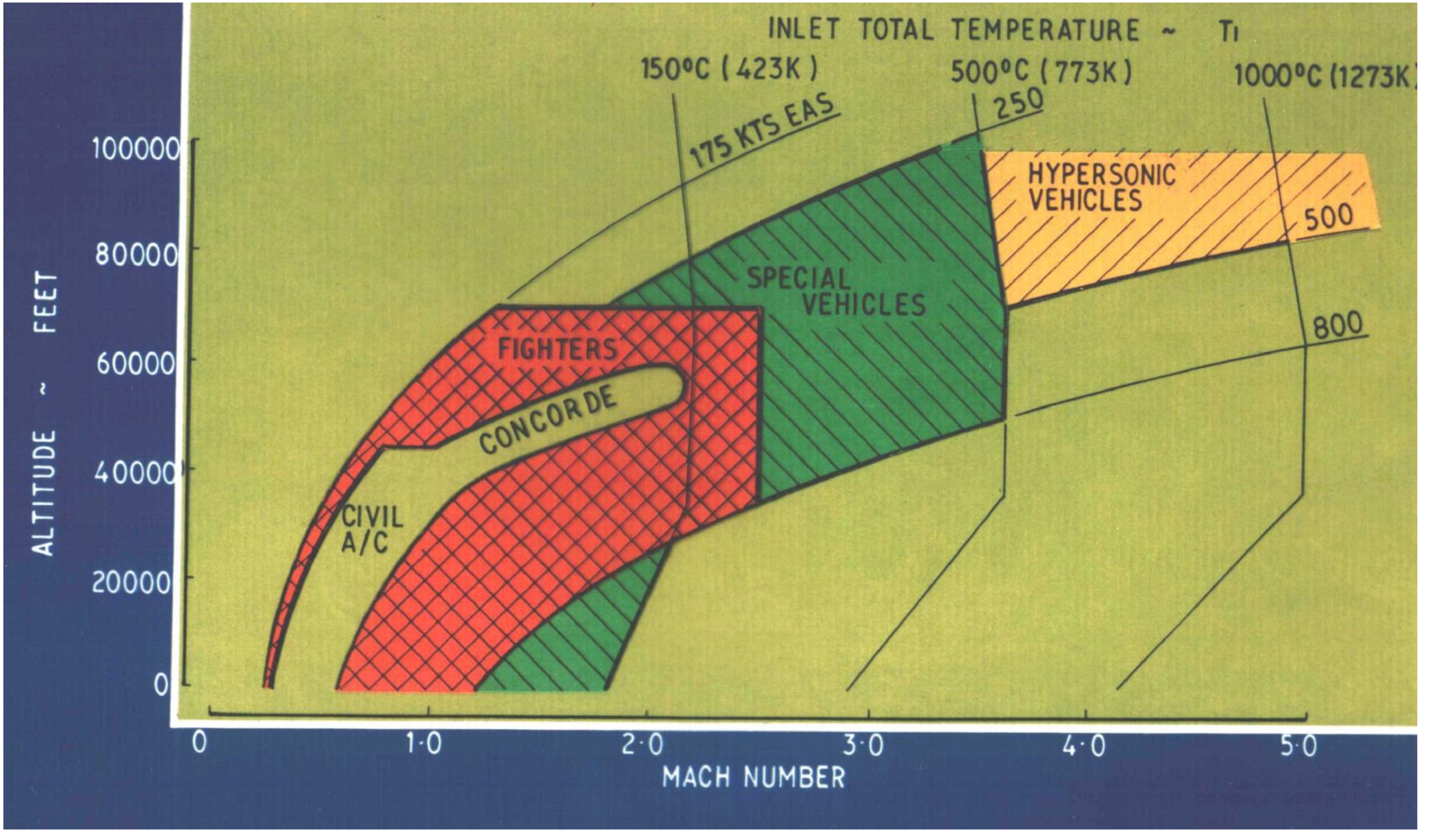
A control system is required to maintain Engine Safety & minimise Pilot workload irrespective of the way that the throttle is moved & for all inlet conditions. This includes:

- Starting & stopping
- Smooth acceleration & deceleration without incursion into unstable regimes
- Controlling critical mechanical parameters:
  - Rotational speeds
  - Compressor delivery pressure & temperature
  - Turbine Entry & Exit temperatures & pressures
- Sampling & collecting of Engine Conditions for Health & Safety purpose, (Engine Health Monitoring , Life usage, Diagnostics etc.)

Terminology

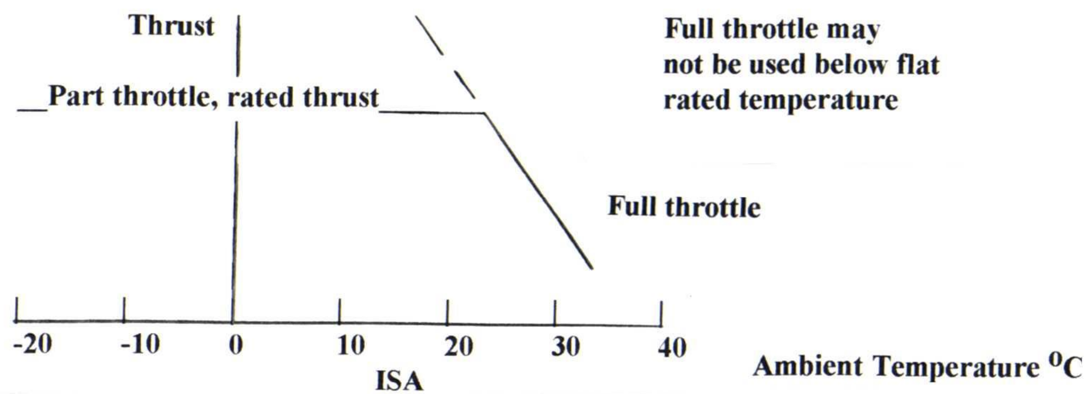
- FADEC = Full Authority Engine Control
- EEC = Electronic Engine Controller
- FMU = Fuel Metering Unit
- HCU = Hydraulic Control Unit
- EHSV = Electro-Hydraulic Servo Valve
- LVDT = Linear Variable Differential Transformer
- EMU = Engine Monitoring Unit

Flight Envelope



Civil Rating Definitions

Take off: Maximum thrust available for take-off. Often flat-rated to ambient temperatures above ISA. Thrust can be boosted water injection. Time limit generally 5 min & only available for take-off &, if required, for reverse thrust for landing.



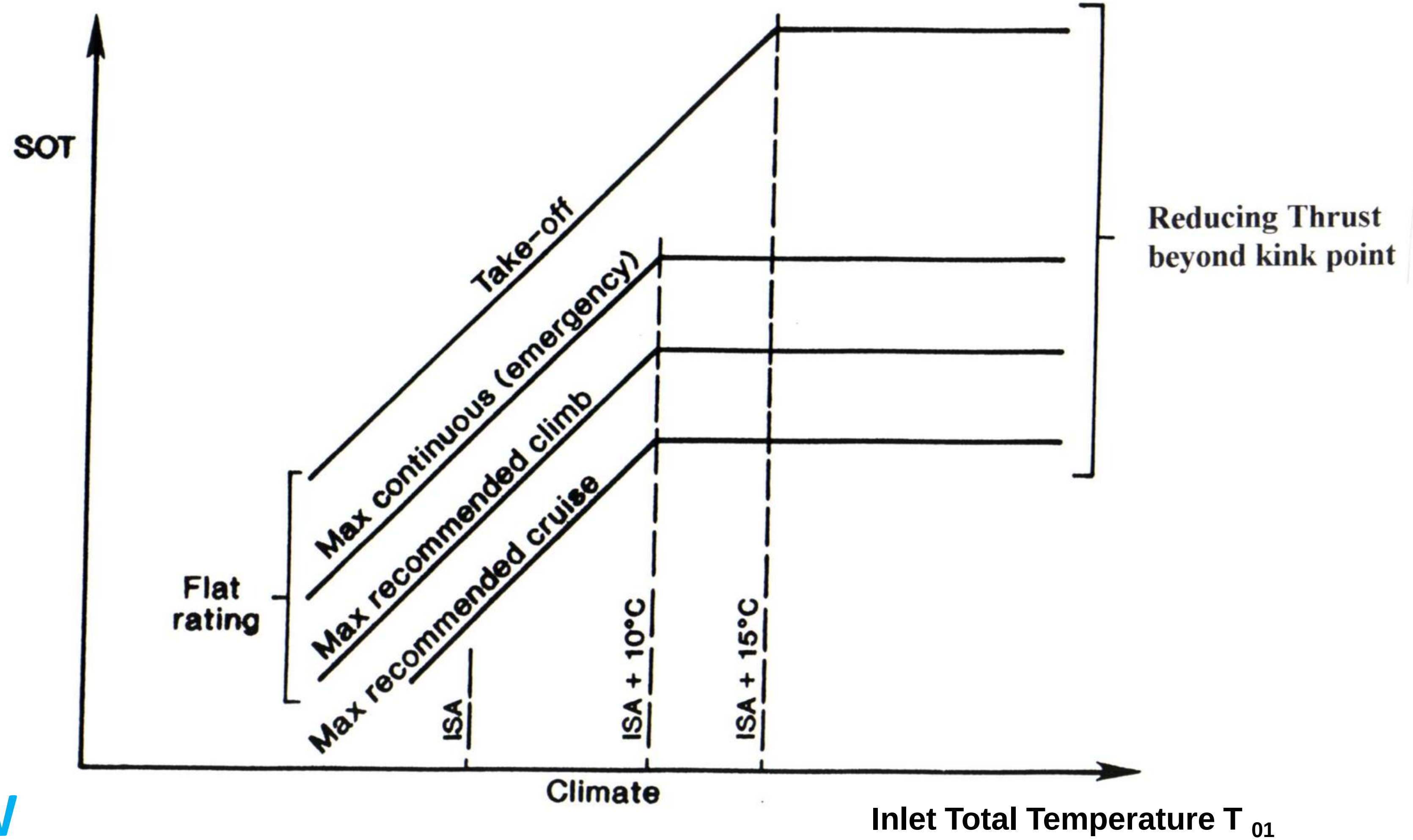
Civil Rating Definitions

Maximum Continuous Maximum thrust available for continuous use in flight. Intended to be used in emergency at the discretion of the pilot

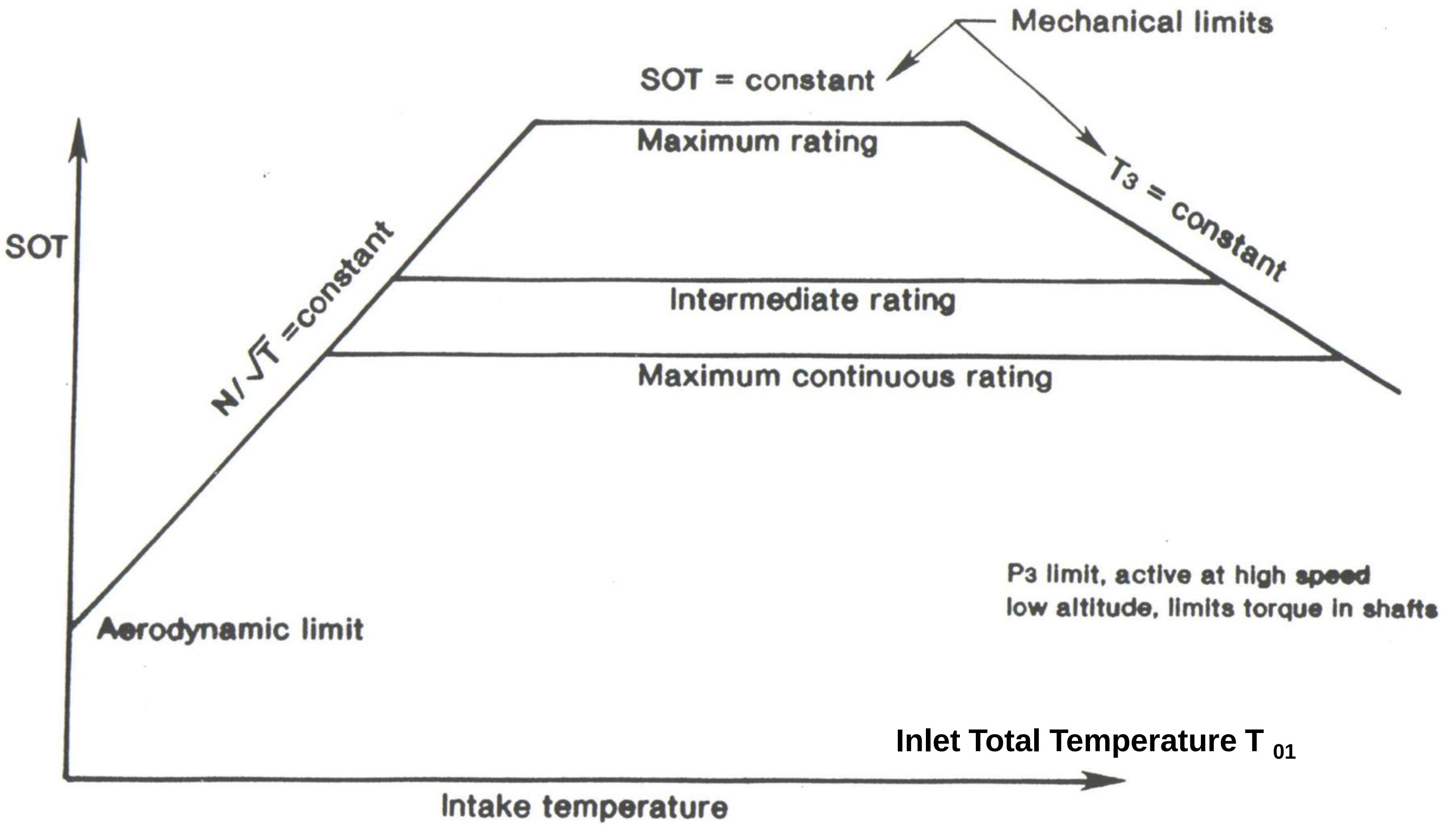
Maximum Thrust Maximum thrust available for unlimited operation in climb and Cruise. On some engines Max. Cont. & Max. Thrust are the same.

Note: Rating structures & definitions can vary with Manufacturer, Engine type and application.

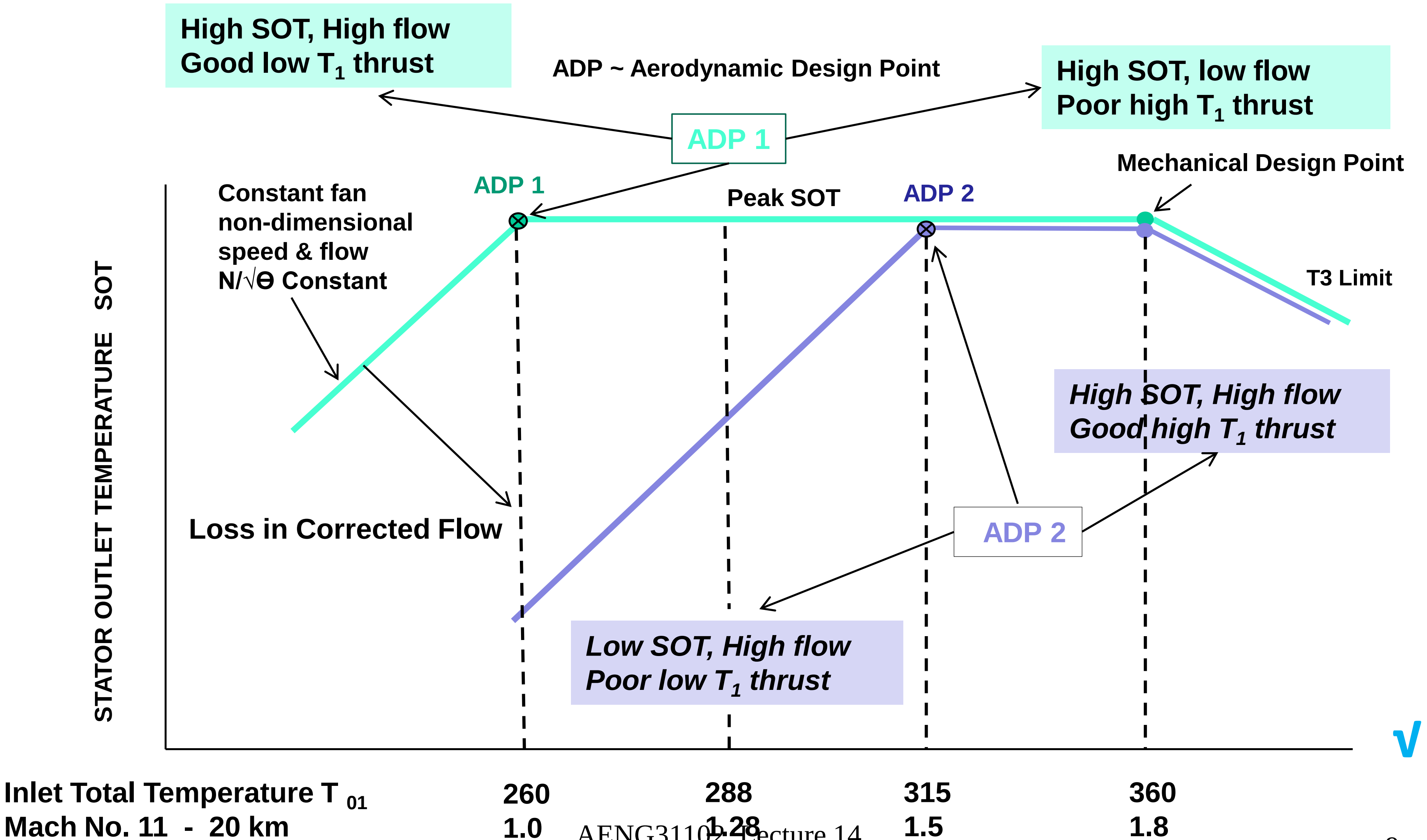
Typical Civil Rating Structure



Typical Military Rating Structure



Examples of Military Rating Structures



Notes

- **ADP 1**
  - **Main emphasis: performance at High Altitude Subsonic Mach Numbers (Low T_1)**

- **ADP 2**
  - **Main emphasis: performance at High Altitude at Supersonic Speeds. (High T_1)**

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Transient Response of Gas Turbines

A rapid & safe response to the Pilot's demands for thrust changes is required for a number of reasons:

- Baulked landings where an overshoot & go around is required

- In flight manoeuvres, to give rapid changes in aircraft conditions i.e. aerobatics, combat etc.

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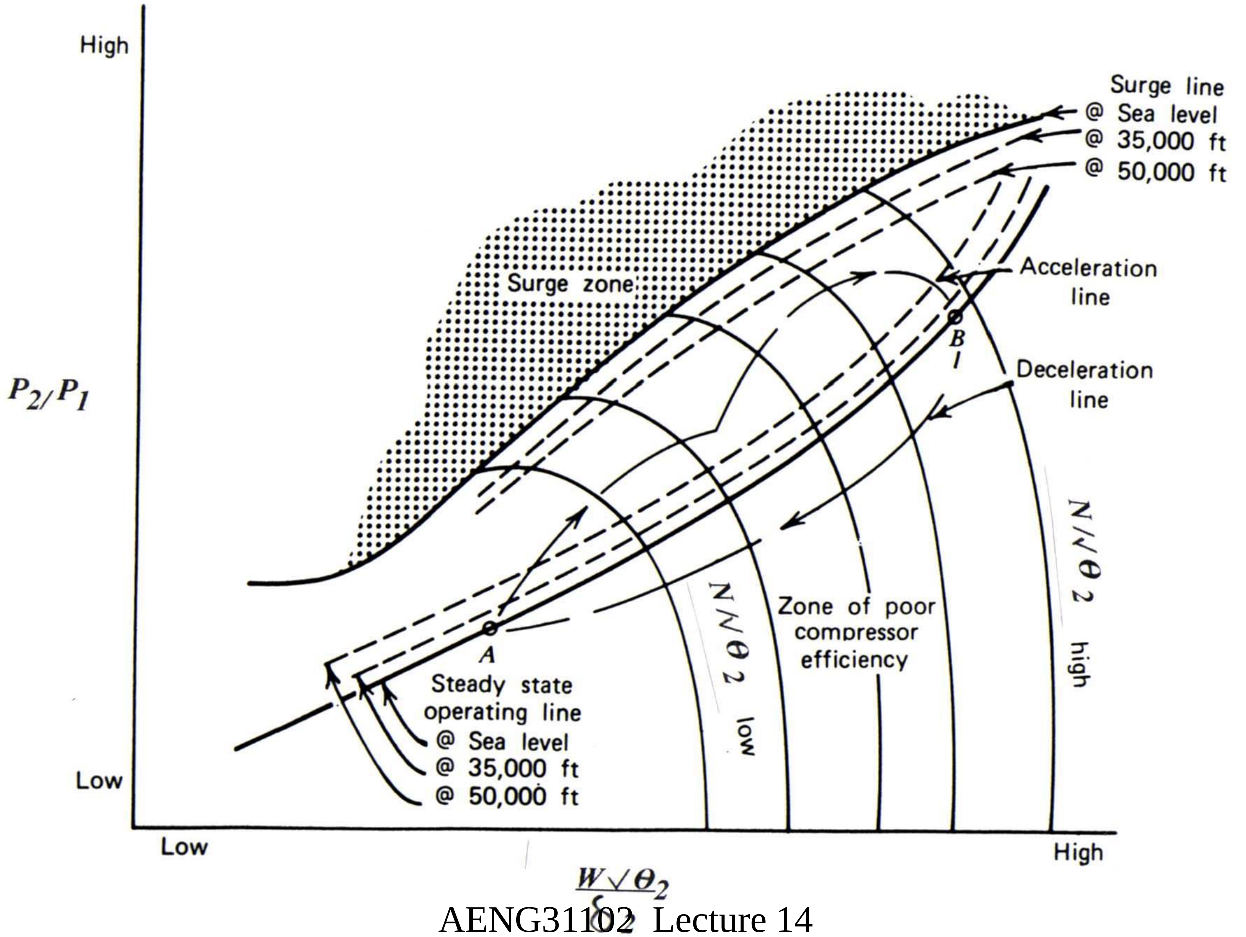
Transient Response of Gas Turbines

- Controlling the aircraft where changes in engine parameters are part of the Aircraft's Primary Flight Control System:

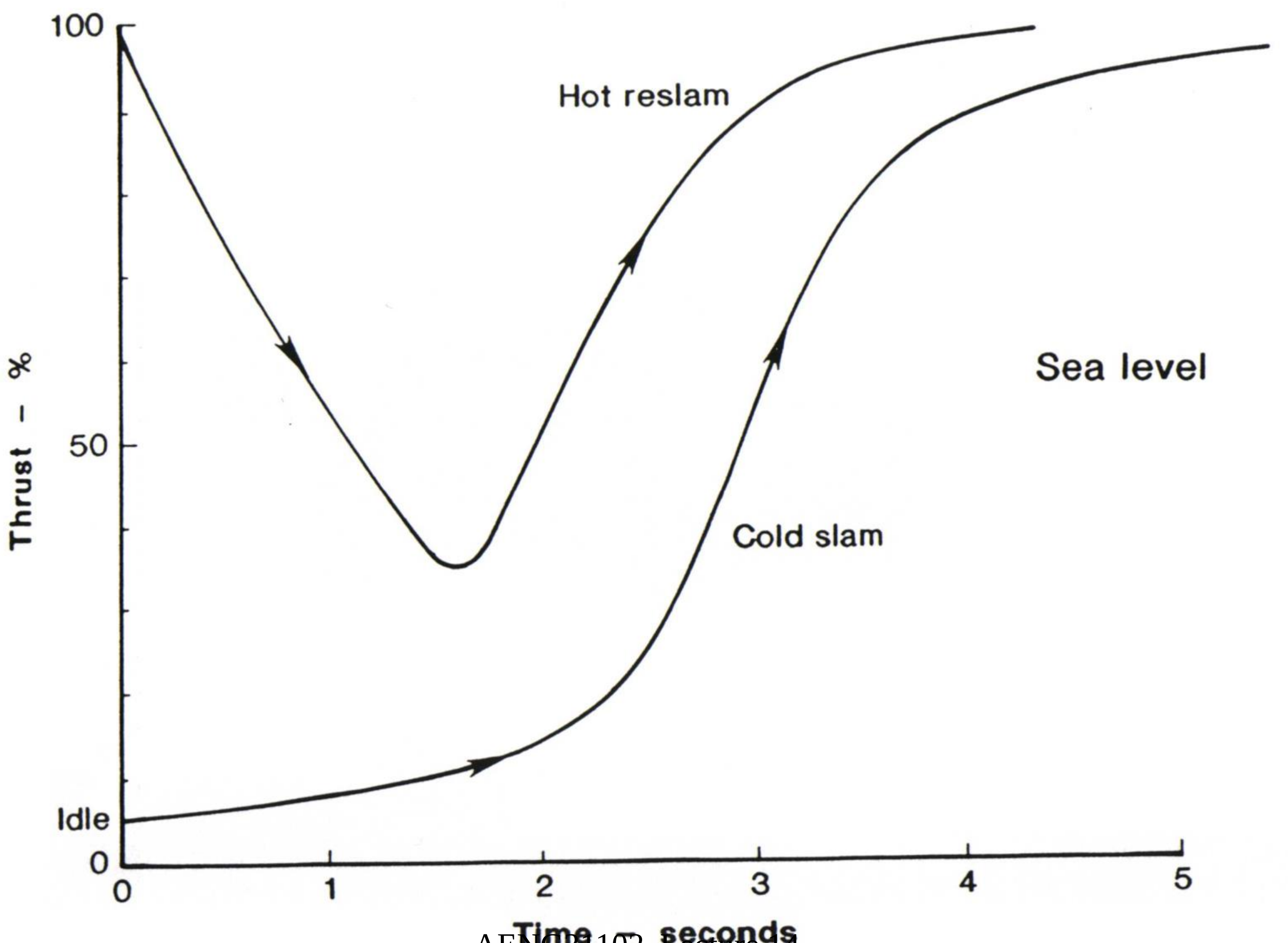
  - Thrust vectoring for enhanced combat capability

  - V/STOL or STOVL Aircraft where the engine is the primary flight control system in non wing-borne flight.

Typical Transient Compressor Working Lines



Typical Gas Turbine Thrust Response

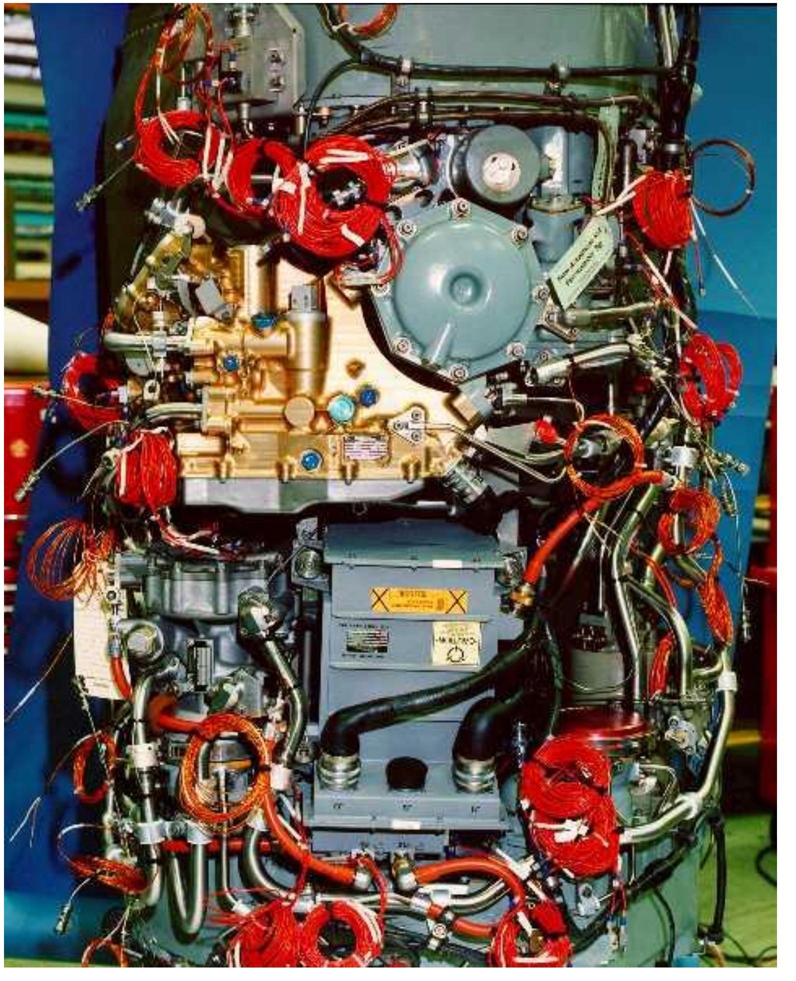


Control facts

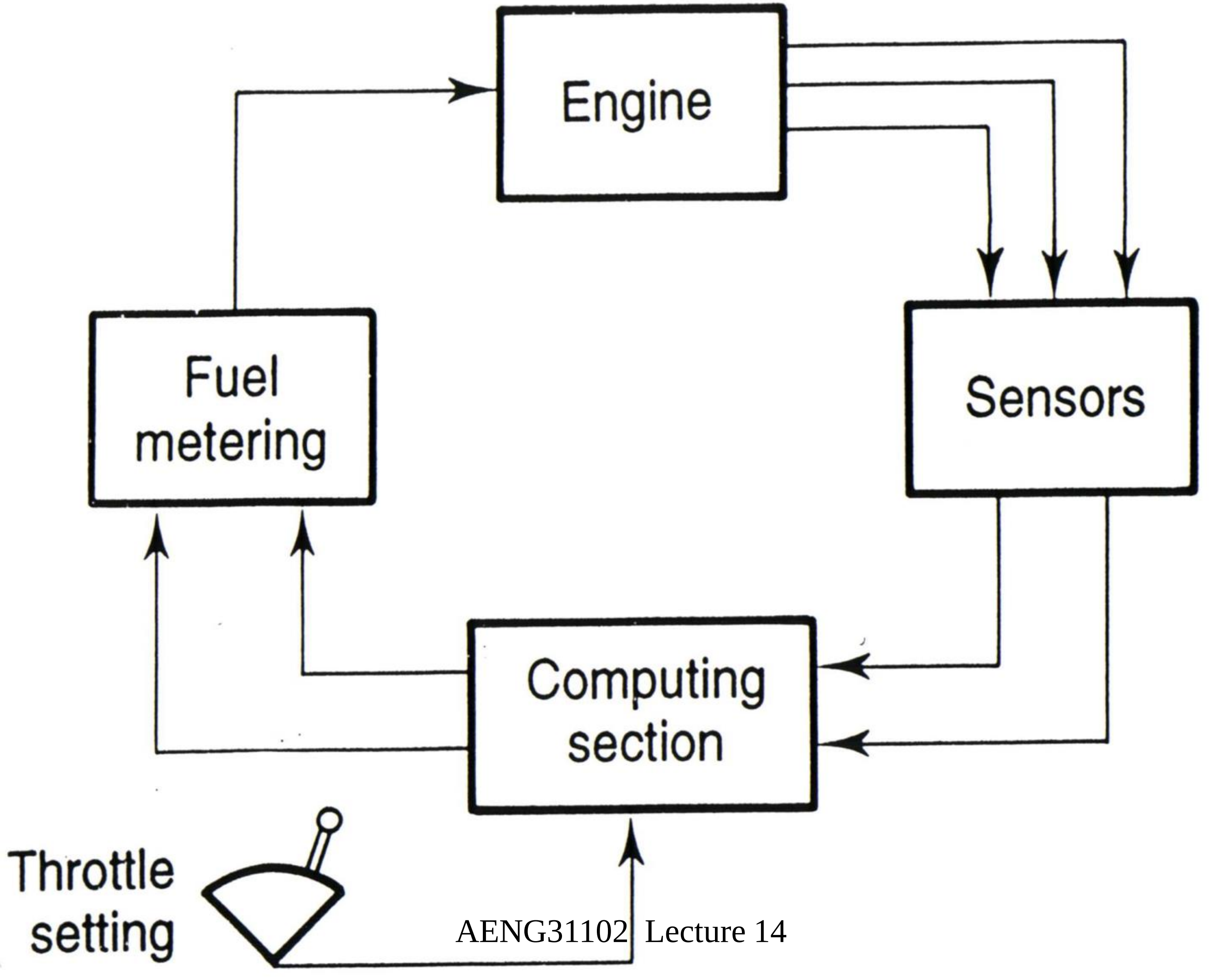
- Cost 5 to 30% of engine cost
- Mass 5 to 30% of engine mass
- Failures leading to loss of control $<1\text{x}10^{-6}$ per engine flying hour
- Operating lives of up to 30,000 hours, over 30+ years
- Operate between –50 and +180 ºC
- High vibration environment and corrosive atmosphere

Description of system components

The engine control system includes a large number of 'subsystems'.



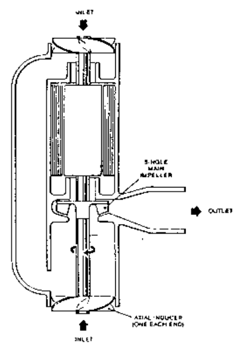
Engine Control System Components



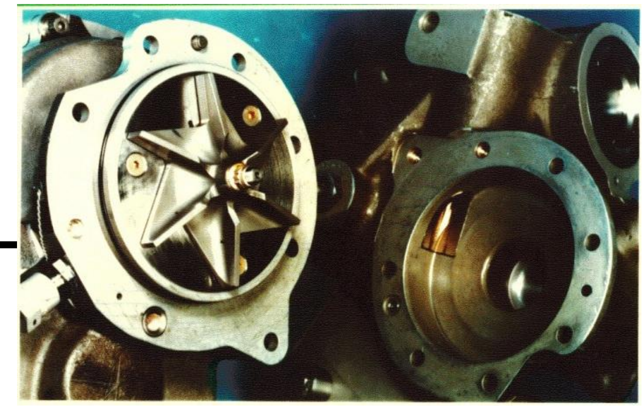
Control System Design Requirements

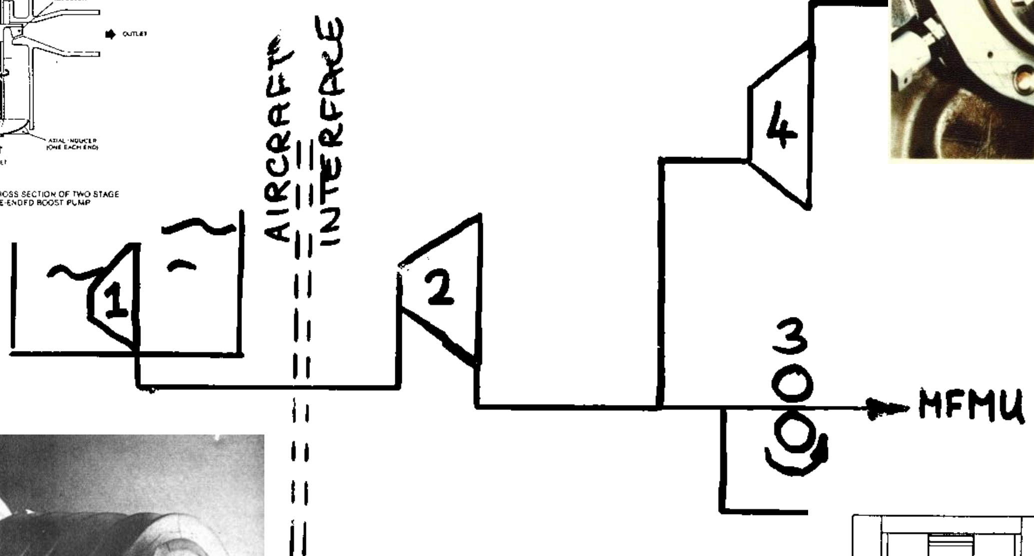
- Safety & Reliability
- Environmental
  - Temperature, Vibration, Atmosphere
  - Salt fog, sand & dust, EMC, nuclear
- Functional
  - Fuel flow & actuator schedules, limits, rates & responses etc
- Interface
  - Inputs (sensors & PLA) outputs (actuator drives, cockpit signals, databuses etc)
- Legislative
  - Certification standards, materials, HS&E

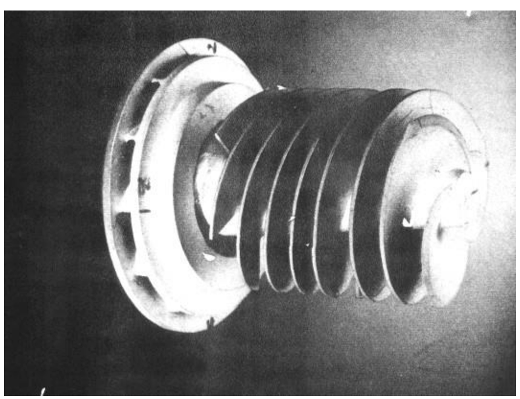
Subsystems – Fuel Pumping

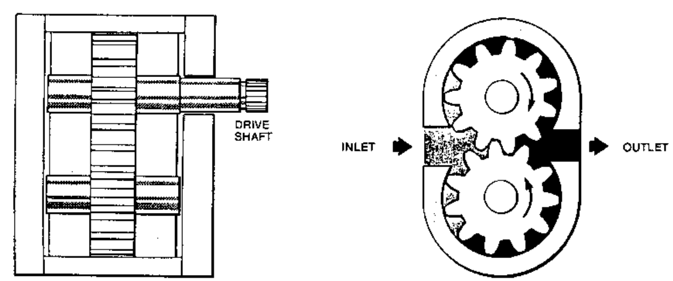


SCHEMATIC CROSS SECTION OF TWO STAGE DOUBLE-ENDED BOOST PUMP



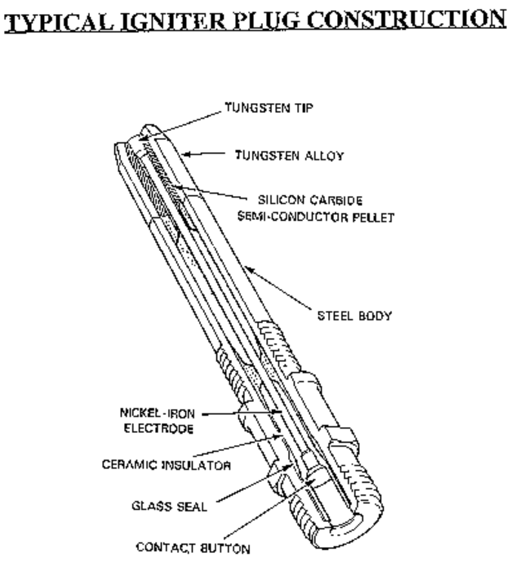


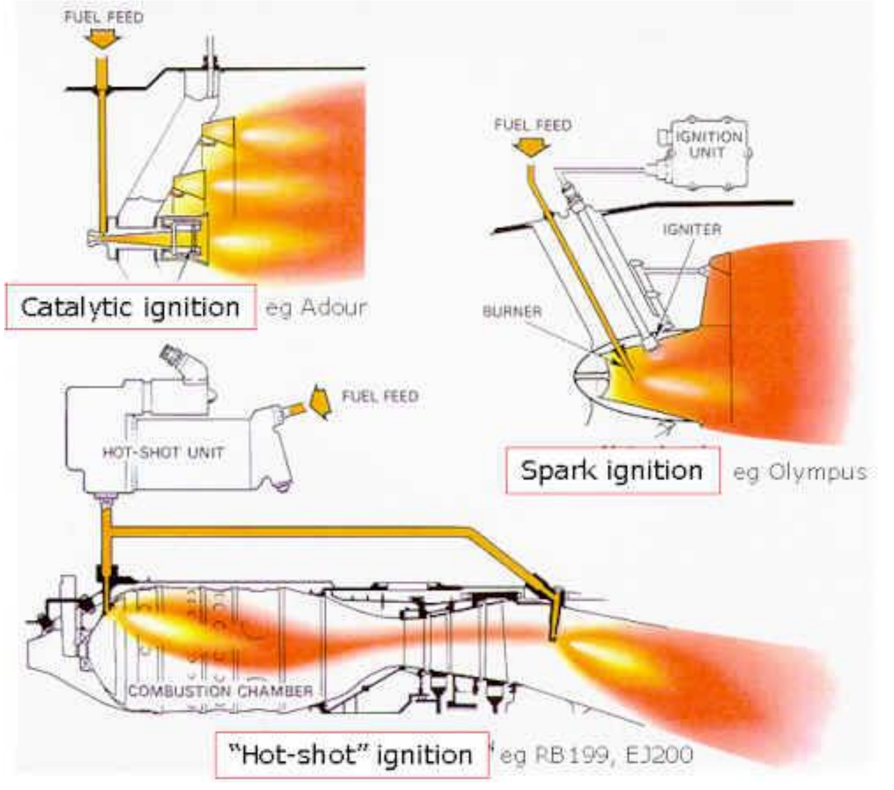




SIMPLE GEAR PUMP CONCEPT

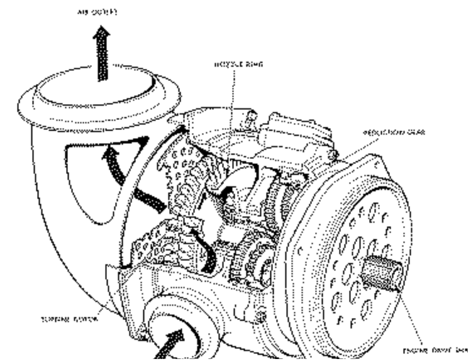
Subsystems - Ignition

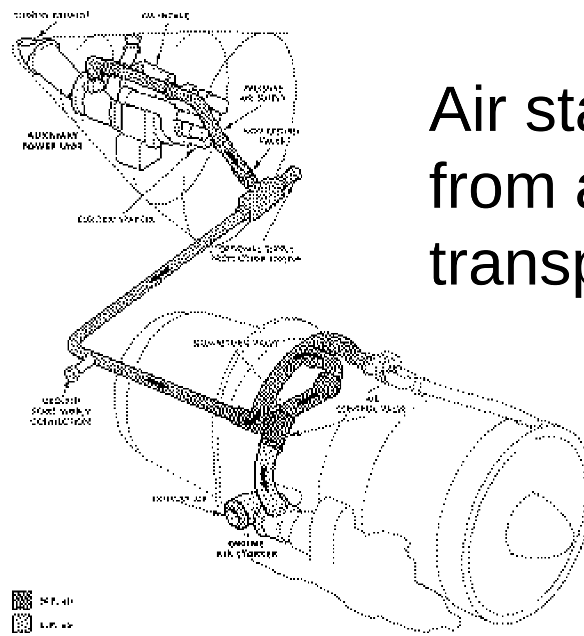




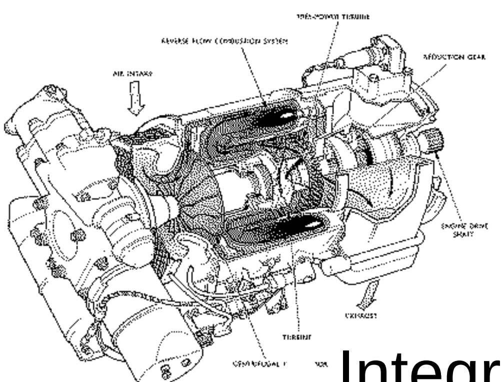
Subsystems – starting systems

Engines are usually started by rotating the engine via an external power source through the gearbox





Air starter from a civil transport



Integrated gas turbine starter

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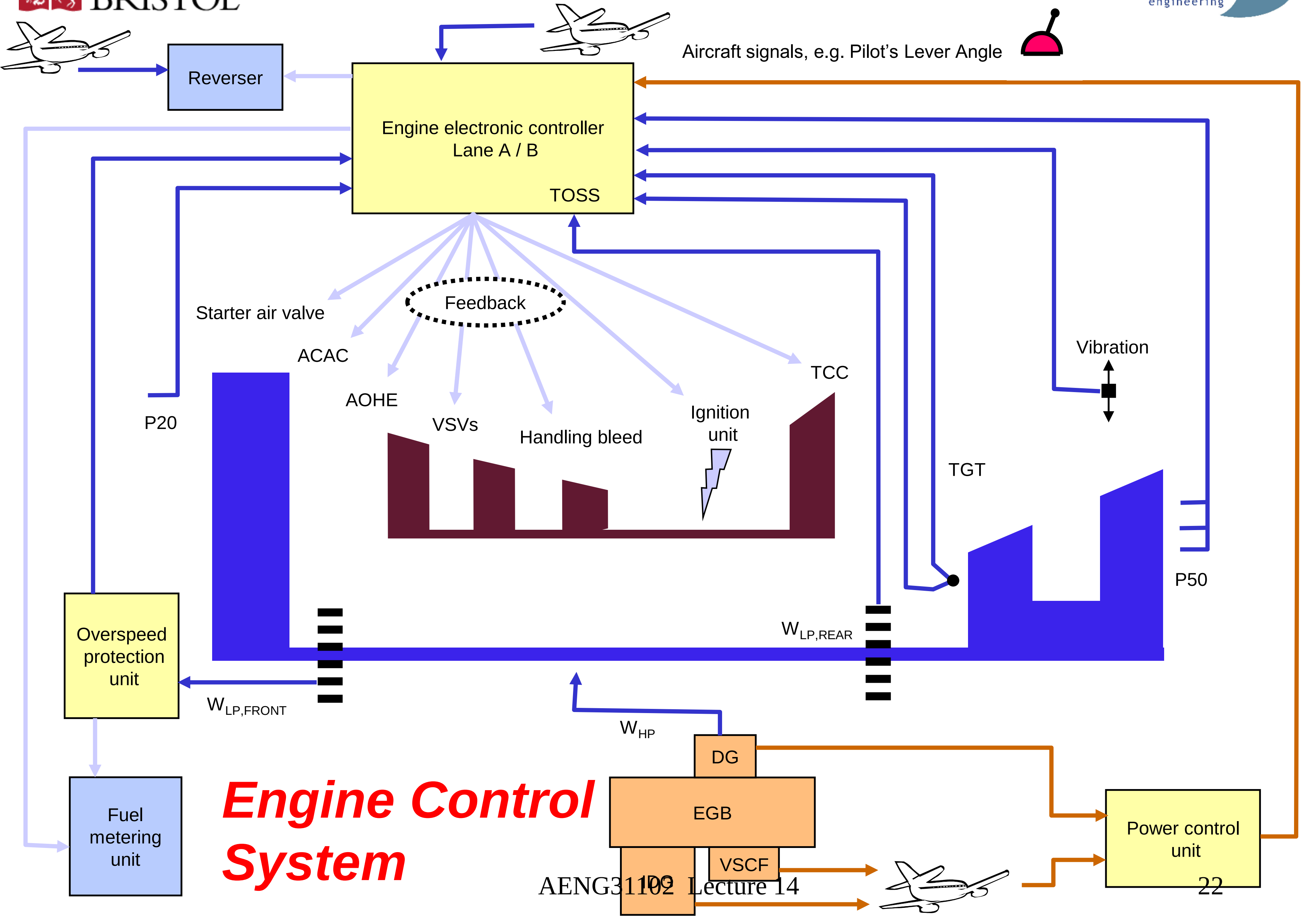
Engine Control System



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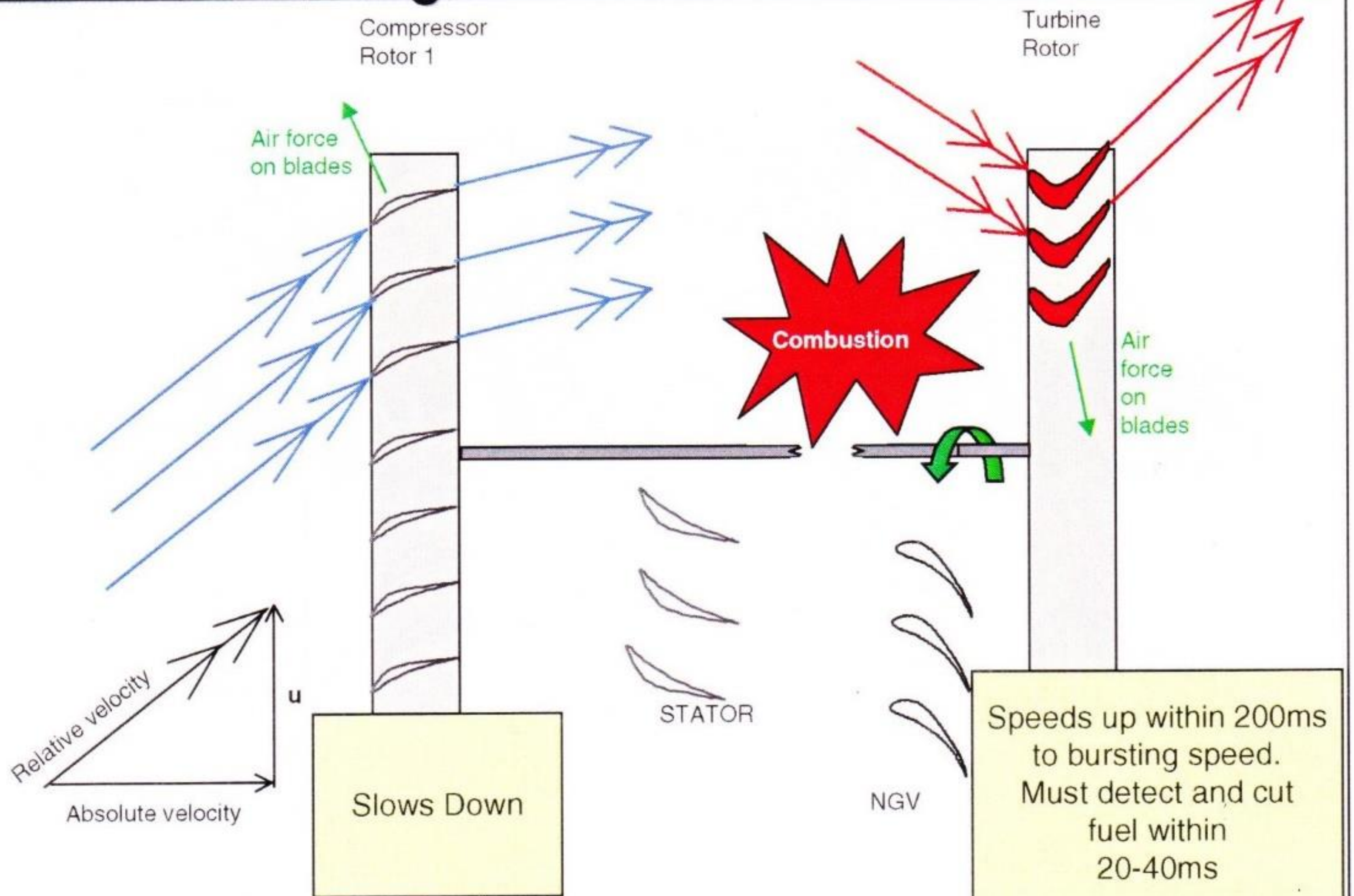
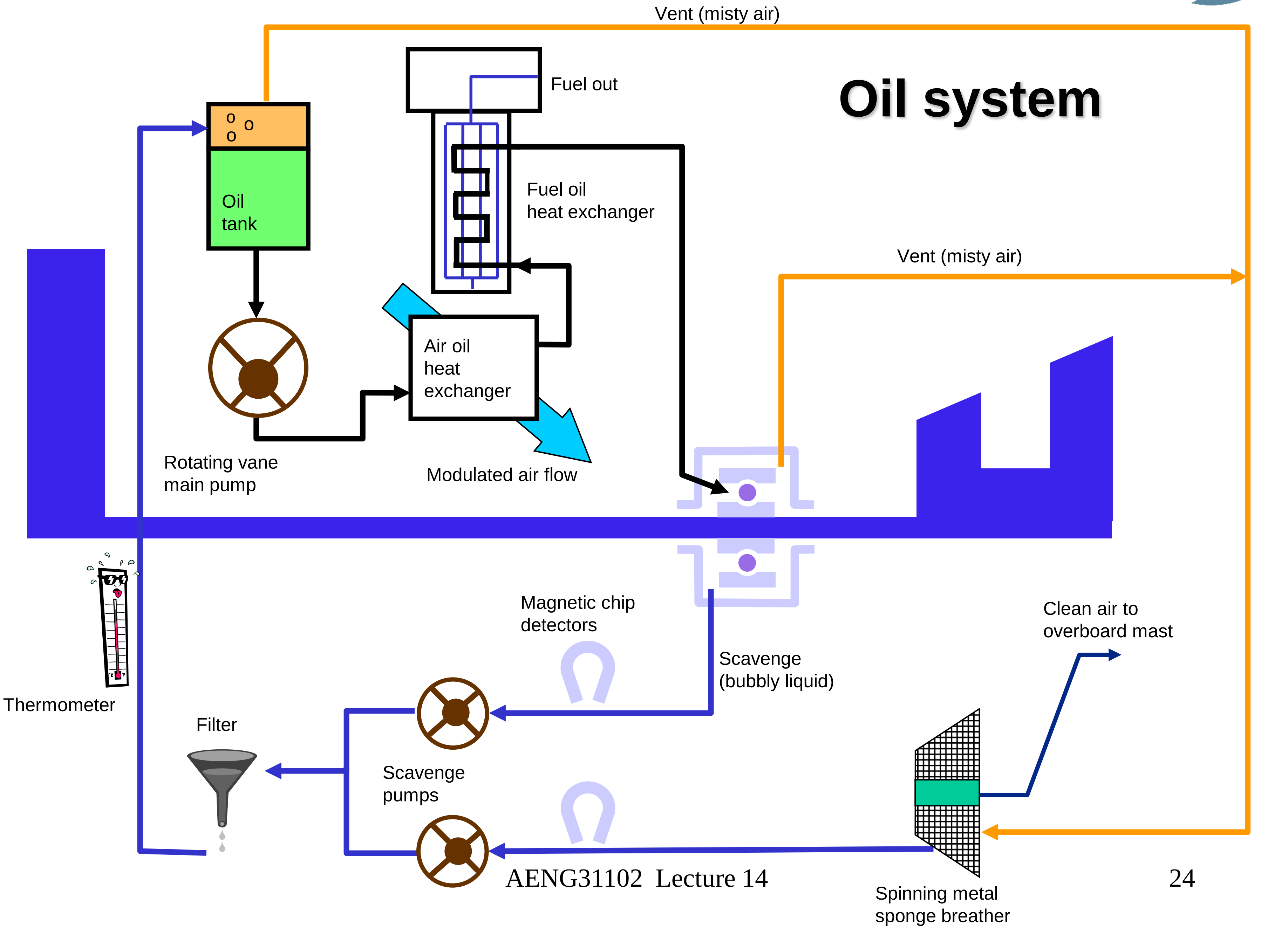
Shaft breakage

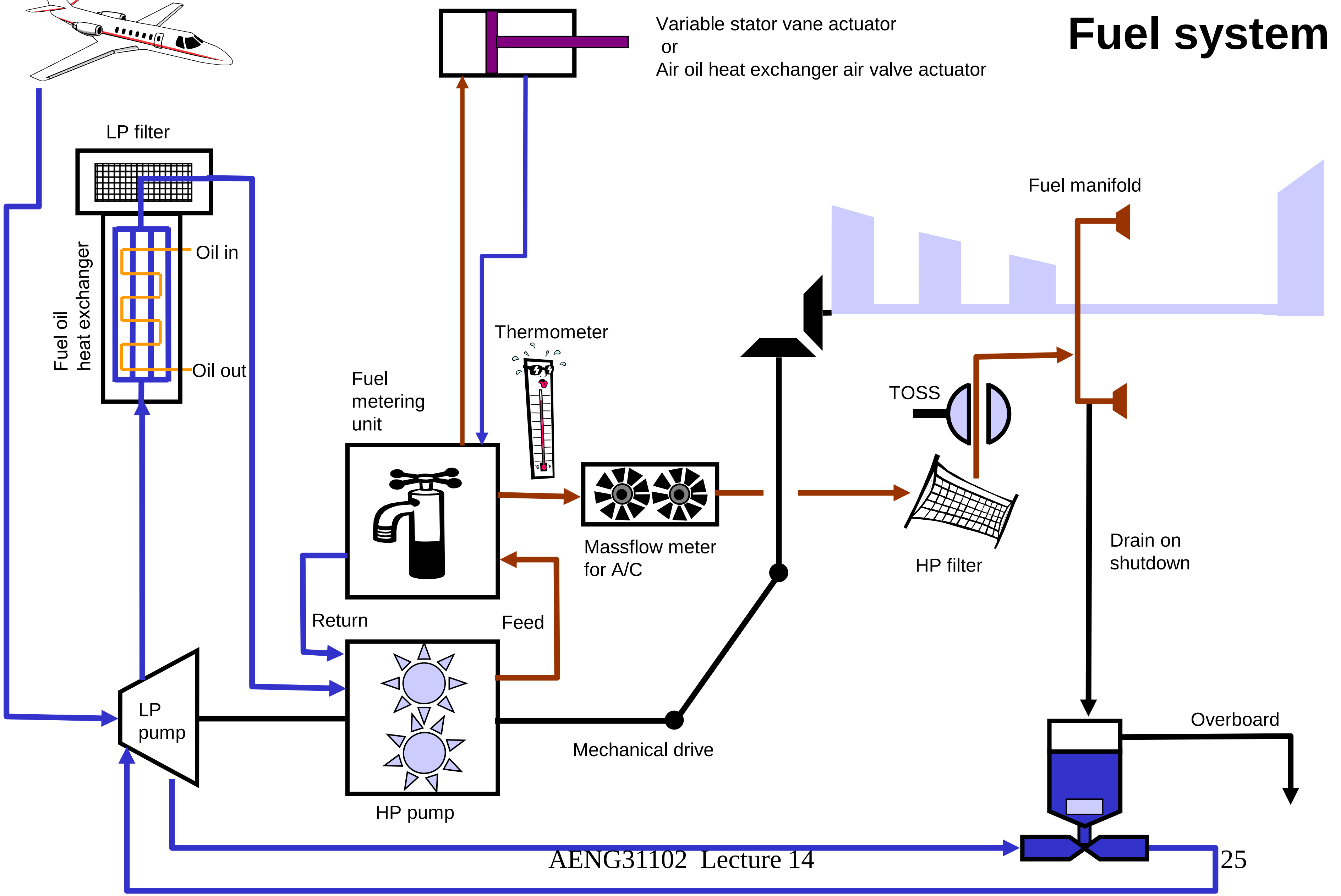


Oil system

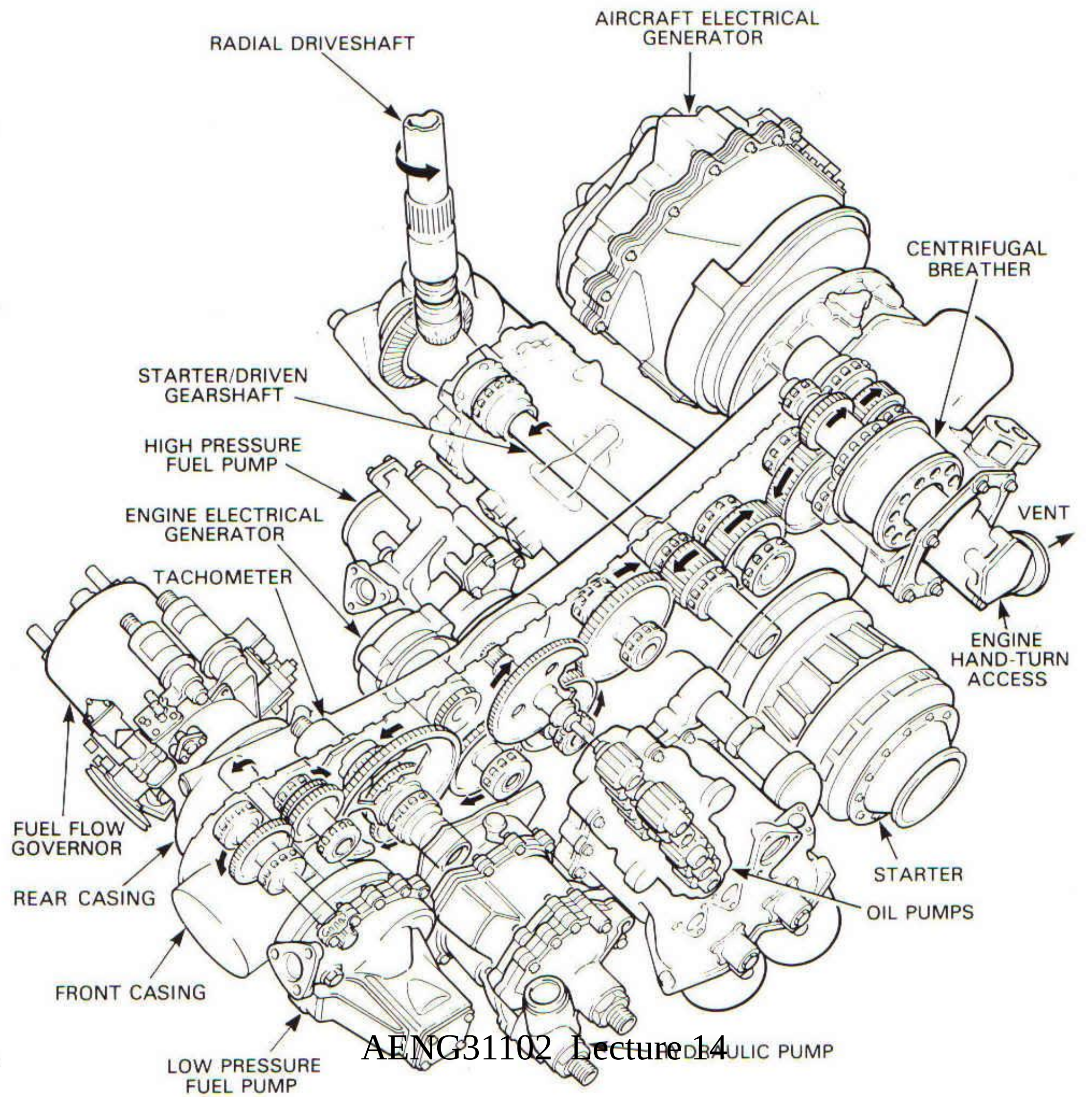


Vent (misty air)
Fuel out
o o
o
Oil
tank
Fuel oil
heat exchanger
Vent (misty air)
Air oil
heat
exchanger
Rotating vane
main pump
Modulated air flow
Thermometer
Magnetic chip
detectors
Scavenge
(bubbly liquid)
Clean air to
overboard mast
Filter
Scavenge
pumps
Spinning metal
sponge breather

Fuel system

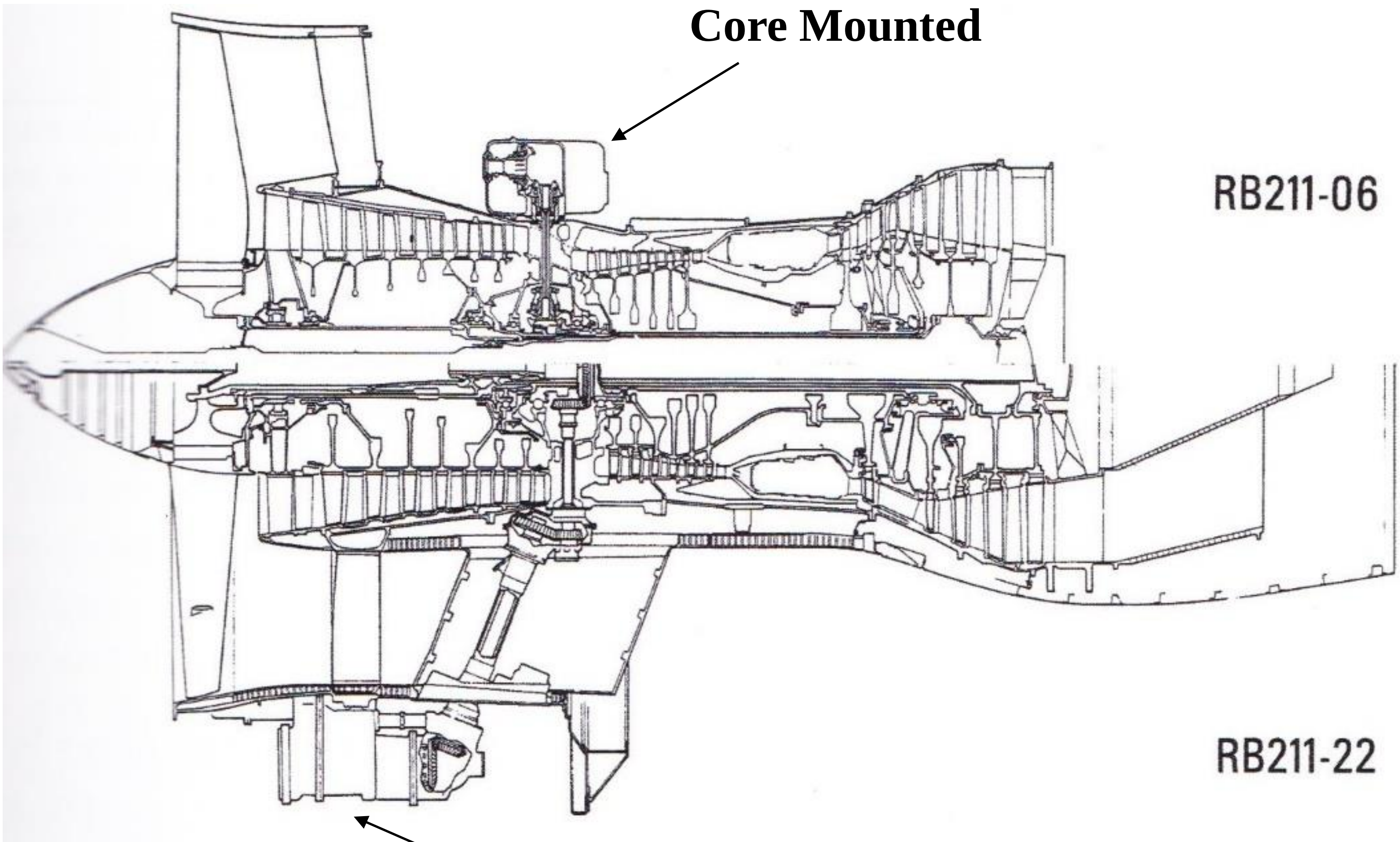

Variable stator vane actuator
or
Air oil heat exchanger air valve actuator
LP filter
Fuel oil heat exchanger
Oil in
Oil out
Thermometer
Fuel metering unit
Fuel manifold
TOSS
Massflow meter for A/C
HP filter
Drain on shutdown
Return
Feed
LP pump
HP pump
Mechanical drive
Overboard

Accessory Gearbox



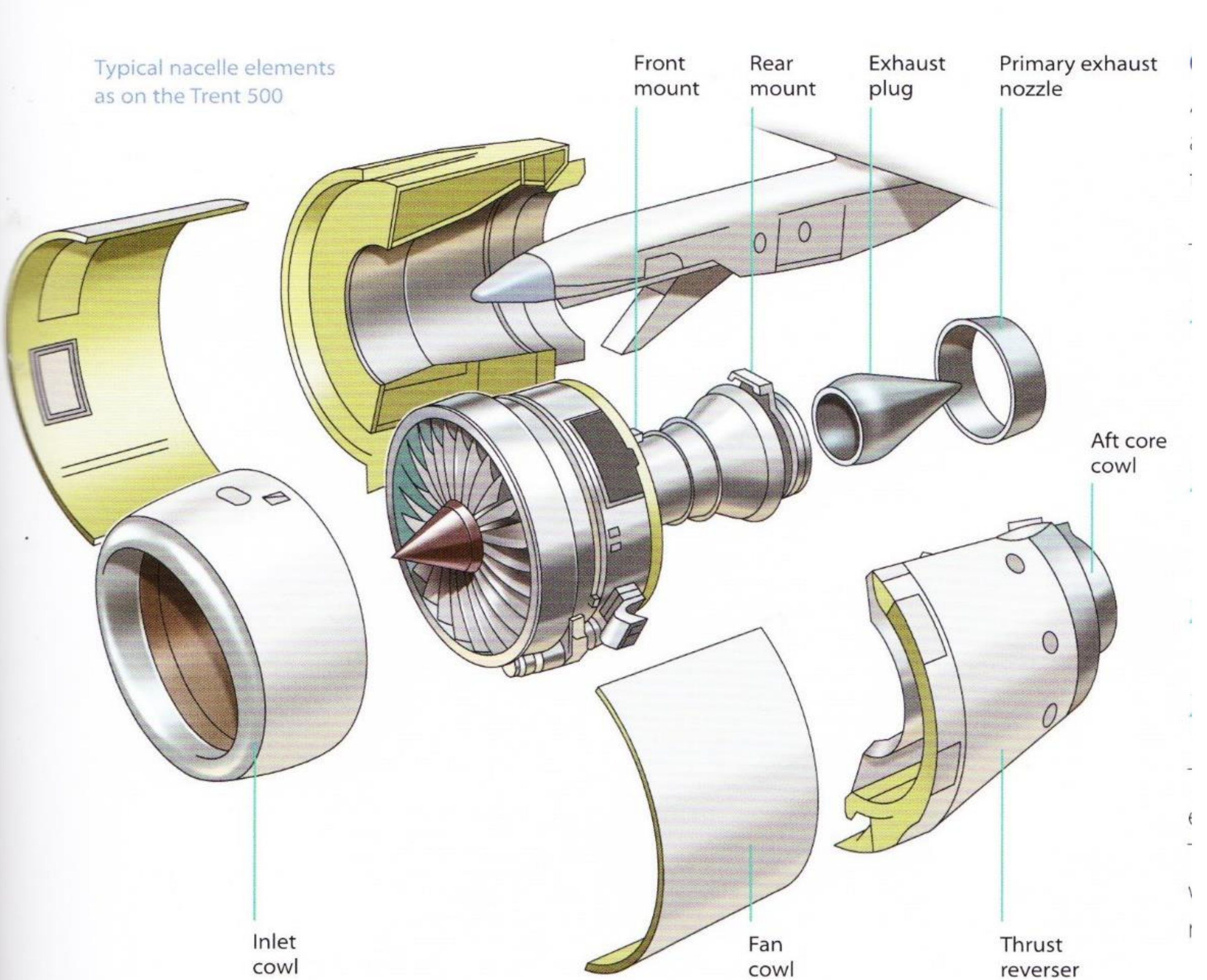
Accessory Gear Box

Core Mounted

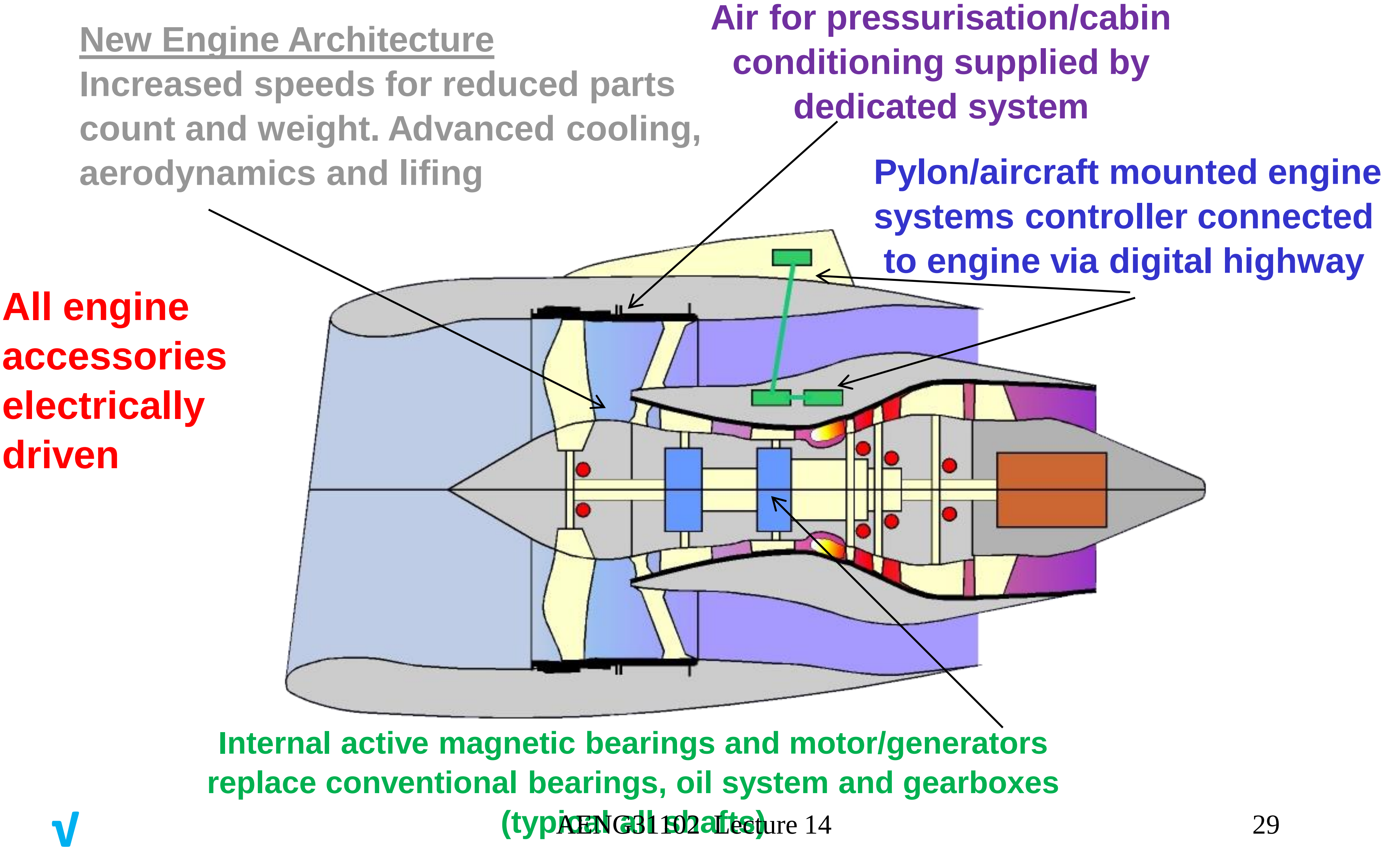


Fan Case Mounted

Typical Nacelle ~ Exploded View



More Electric Engine Concepts



Sensors

The supply of high quality data from engine sensors has always been of paramount importance for a satisfactory Engine Control System. This has been accentuated by the move to FADEC (Full Authority Digital Engine Control) Systems.

Many parameters have to be measured accurately e.g.

- Fuel flow
- Rotational speeds
- Geometric properties i.e. IGV positions, nozzle positions, carcase deflections etc.
- Temperatures & pressures within the engine. Temperatures can be measured by thermocouples (low temperatures) & optical pyrometers (HP Turbines)
- Vibration levels

Additional data e.g. Outside Air Temperature, Mach Number, Aircraft Speed... usually comes from the sensors providing data for the Aircraft Control System.

Validation and Test

Before an engine enters service it must be qualified by an appropriate Body e.g. CAA or FAA. This means it must have gained a Type Certificate to ensure that it is fit for operation.

A Certificate is issued once the following have been completed:

- A Type Test (usually of 150 hours operation at a variety of throttle settings
- An Accelerated Mission Test. The engine is taken through a simulated mission but with reduced time at low (non life consuming) ratings to validate life predictions.
- Various specific tests e.g. Disc Burst, Blade off etc. to ensure that in the event of a failure the engine continues to operate or runs down safely
- Design schemes & analyses validating critical areas.

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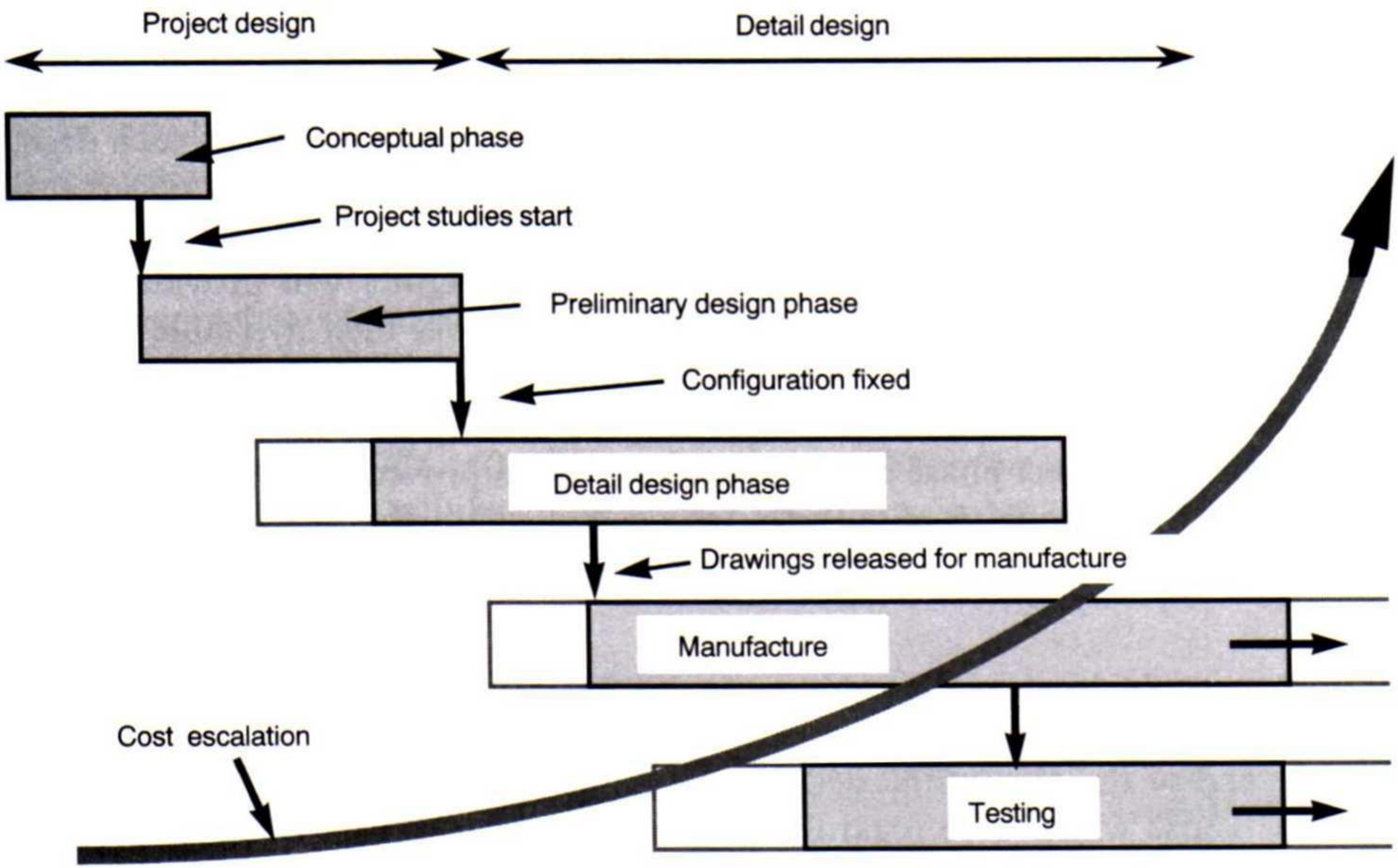
Design & Manufacturing Cycle



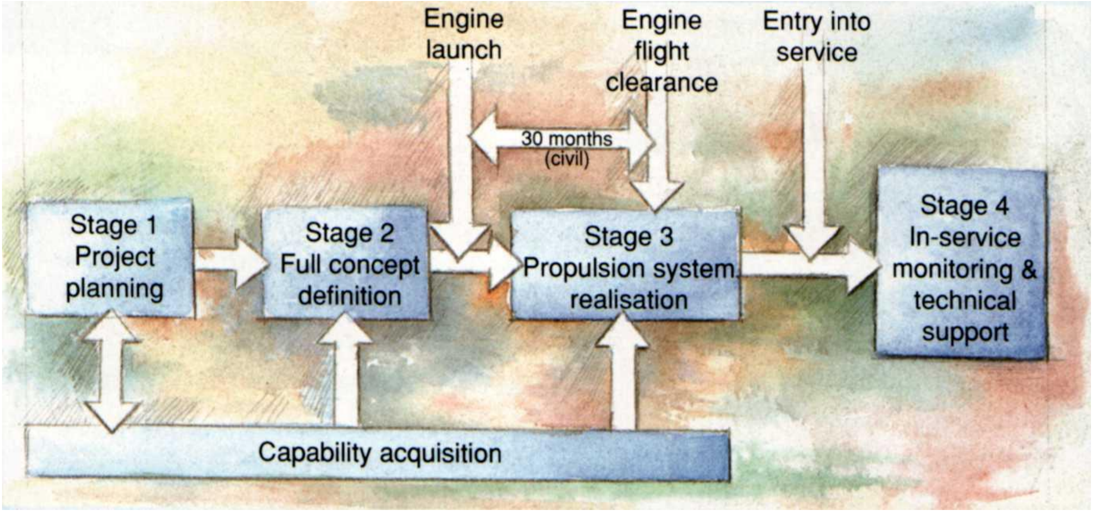
Phases in an Engine Development Programme 1

Stage 1 Project Planning (Conceptual Design):

- Work with customer to produce specification
- Freeze engine architecture
- Identify & launch R & D activities

Stage 2 Concept Definition:

- Finalise specification
- Freeze major components
- Select partners



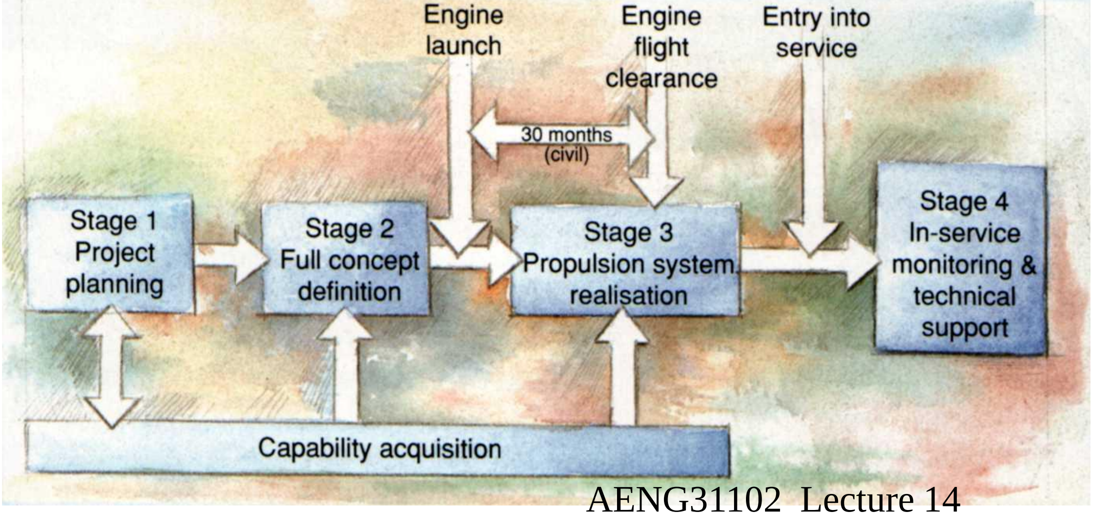
Rolls -Royce

Phases in an Engine Development Programme 2

<u>Stage 3 Programme launch:</u> ~ increase in spend

<u>Detail Design:</u>

- Individual components optimised
- Risk Analysis
- Freeze engine components for manufacture of test engines



Rolls -Royce

Phases in an Engine Development Programme 3

Development Phase:

- Manufacture test engines (6 –9 each with several builds)
- Carry our component rig tests
- Identify real problems identified in representative testing

Certification Testing:

- Performance: thrust, sfc, component behaviour
- Cycles: typical mission repeated thousands of times
- Endurance: 150hour accelerated mission test for certification
- Integrity: fan blade off, bird strike, water/hail ingestion

Phases in an Engine Development Programme 4

Manufacture of Production Units:

- Set up manufacturing & production processes
- Produce components and build complete units
- Deliver certified engines

Stage 4 In service monitoring & technical support

Key Lessons from Lecture 14

- Brief overview of the propulsion system control
- Outline of the major units in a control system
- Some appreciation of system design and the nature of the problems that are experienced
- An outline of the development process for the whole propulsion unit