Engine Placement

Objective

- *To examine the issues arising from installing the propulsion system into a vehicle.*

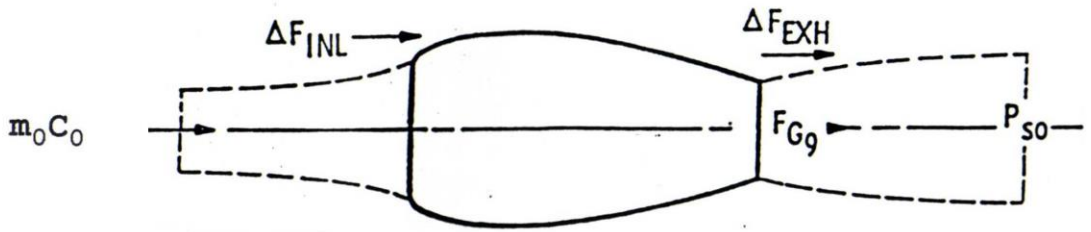
- Types of Nacelle
- Critical Geometry
- Aerodynamic issues
- Thrust Reversers
- Model Testing
- Flight Testing


Wing-mounted pod installation.

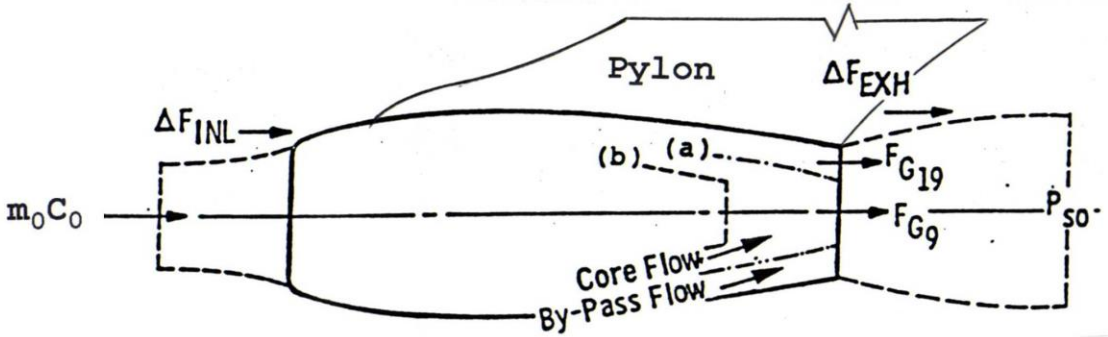

Fuselage — mounted pod installation.


Tail and wing-mounted pod installation.

Types of Nacelle



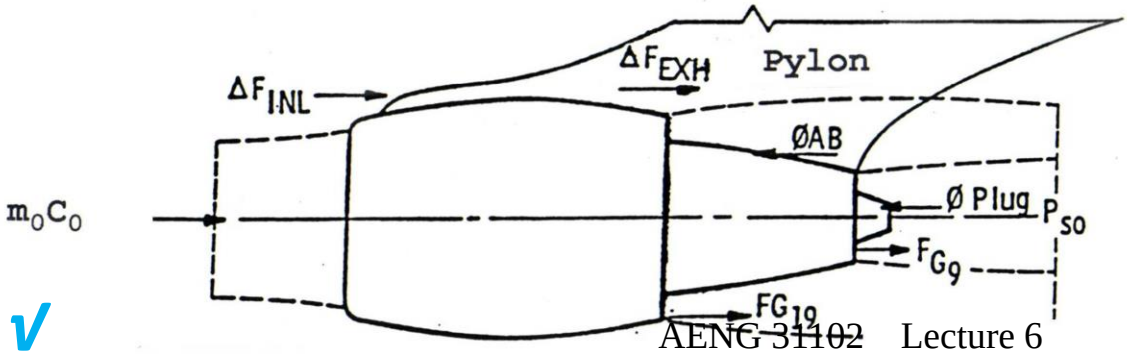
Long-Duct Isolated Nacelle



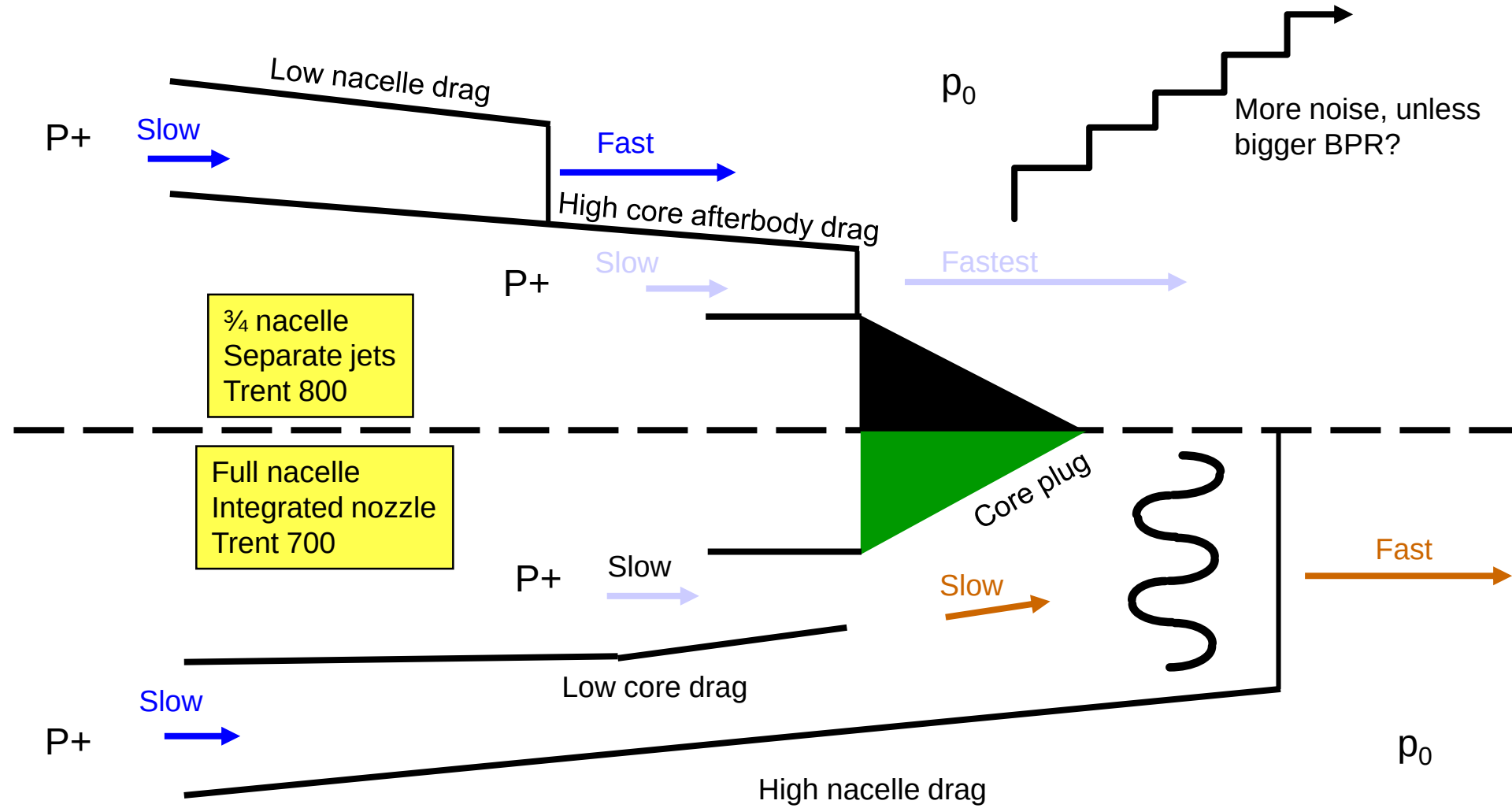
Long-Duct Nacelle

(a) ~ co-planar nozzles

(b) ~ buried nozzle



Intermediate or Short-Duct Nacelle



Unit area of core afterbody is 4x draggier than nacelle

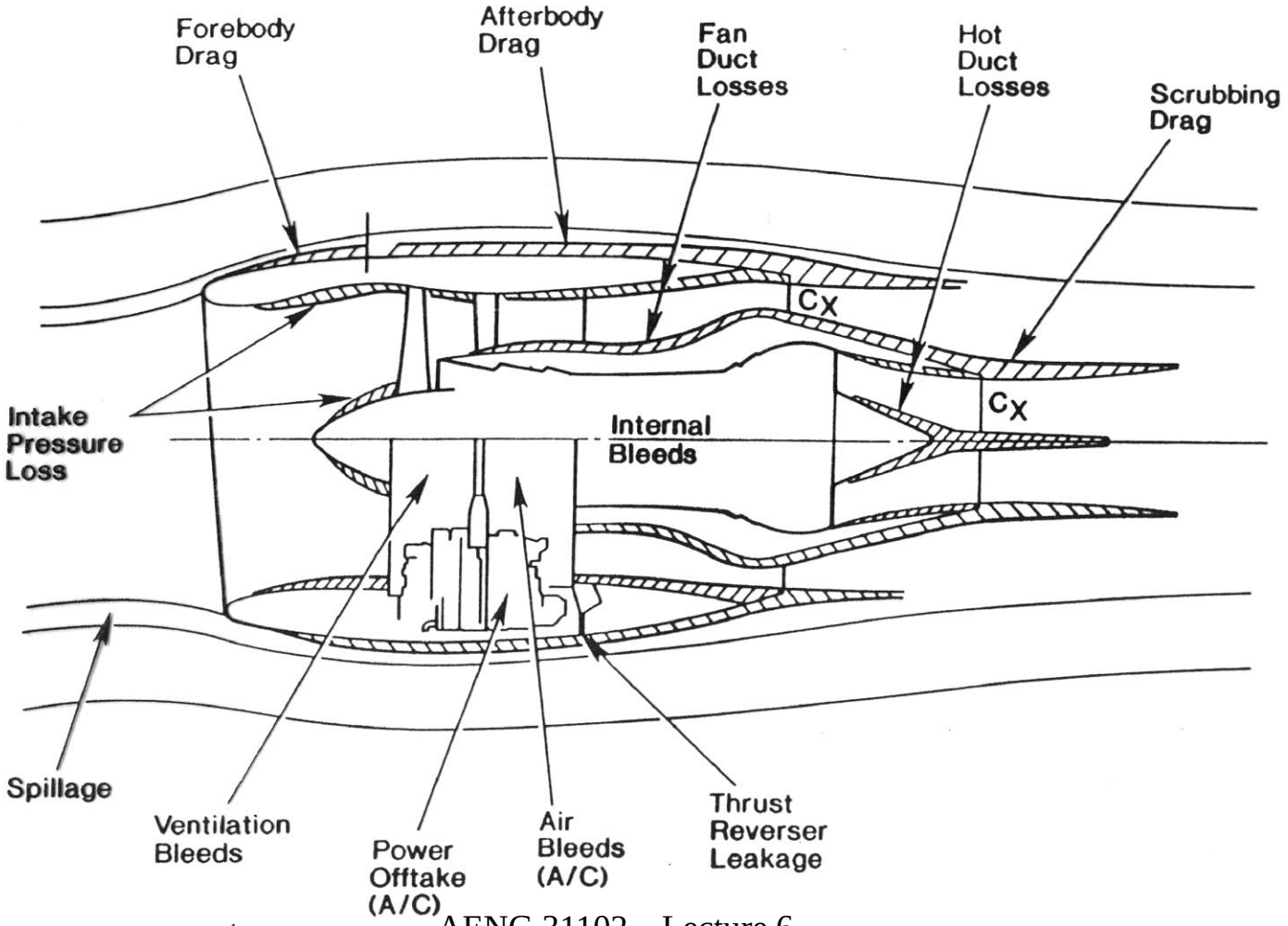
High nacelle drag
Interference with wing
Weight
Cost
Opportunity to have forced mixer

Integrated nozzle vs separate jets for bypass engines

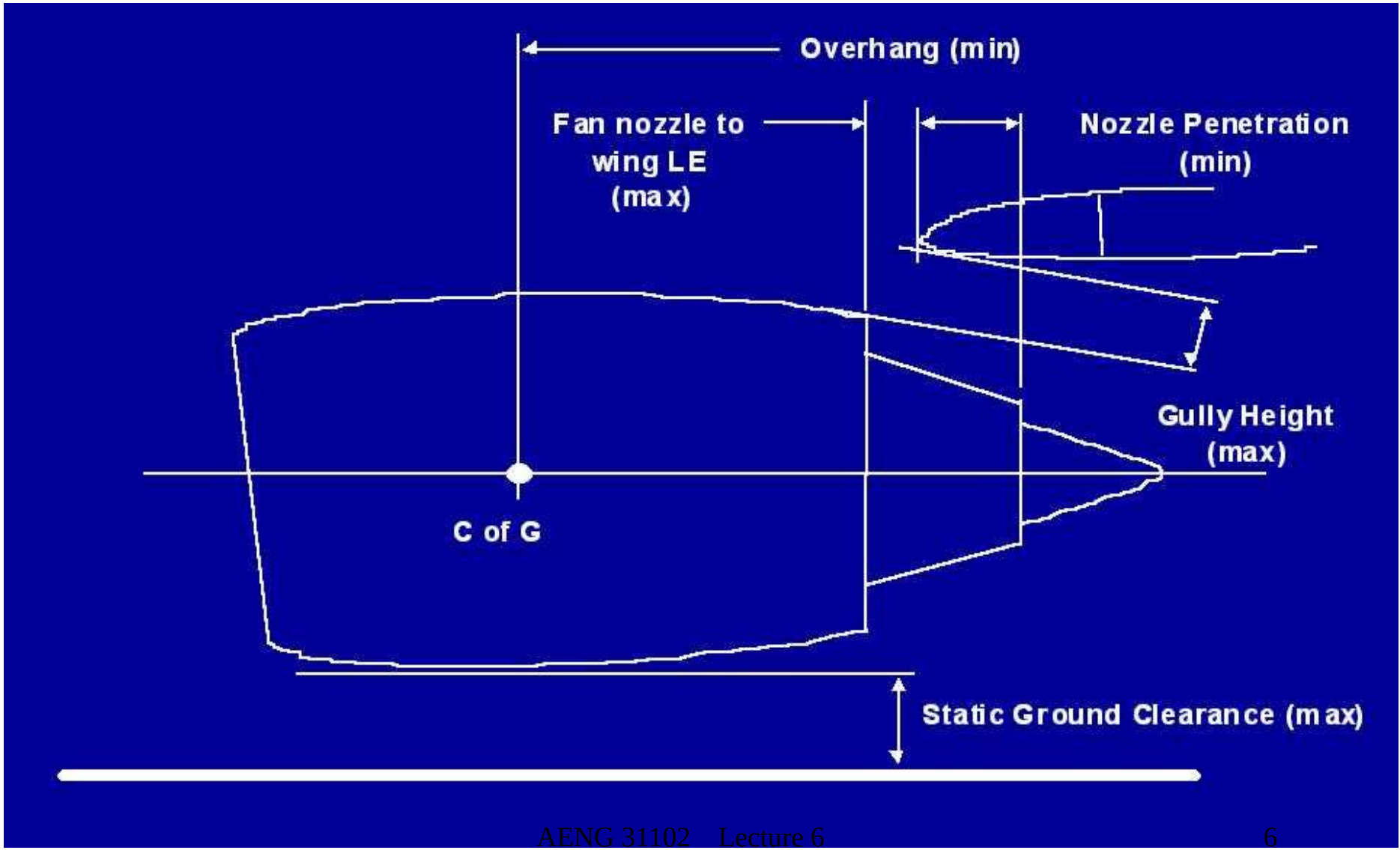
Pros & Cons of Type of Nacelle

- **Drag**
  - Long Cowl has greater wetted area, hence higher skin-friction drag but installation may be superior
- **Mass**
  - Greater surface area of Long Cowl gives rise to higher mass
- **Efficiency**
  - Internal mixing of hot & cold streams in Long Cowl improves SFC
- **Noise**
  - Mixing in Long Cowl reduces jet noise coupled with the opportunity for increased shielding lowers overall noise levels
- **Thrust Reversal**
  - Issues arise with the integration of a thrust reversers for both Long and Intermediate Cowls

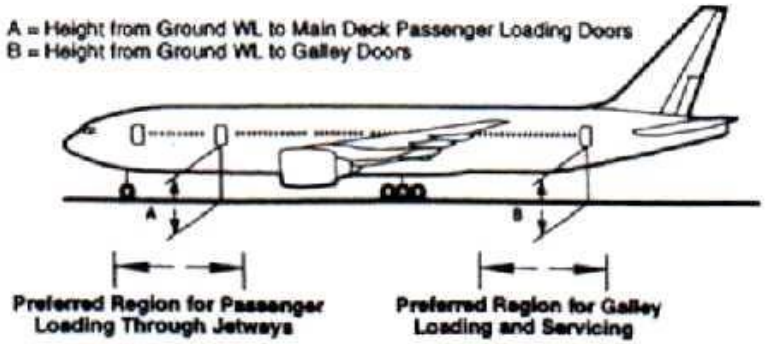
Installed Performance



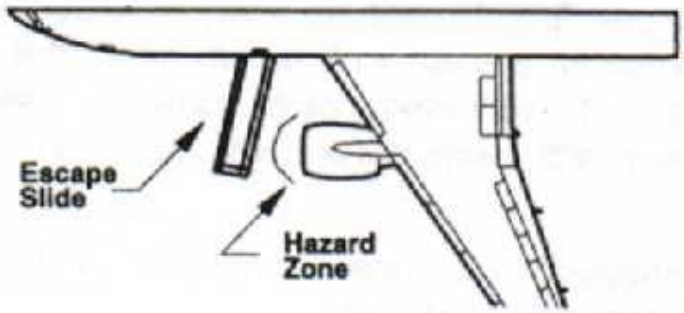
Underwing Installation ~ Critical Geometry



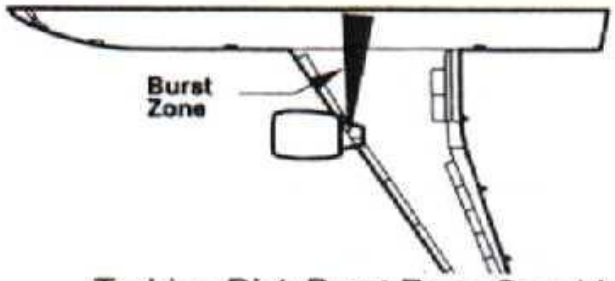
Non-Aerodynamic Design Considerations



Passenger/Loading Door Sill Height Consideration

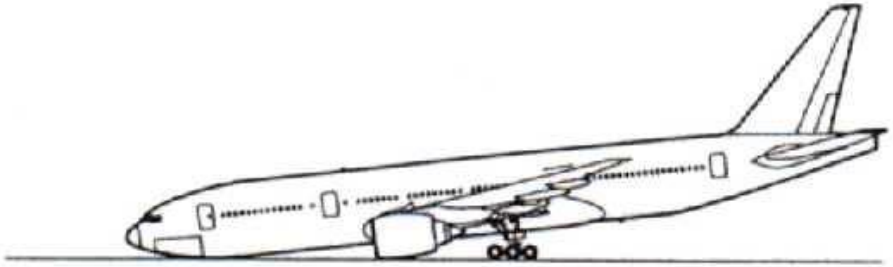


Escape Slide, Loading Ramp & Inlet Hazard Zone Consideration

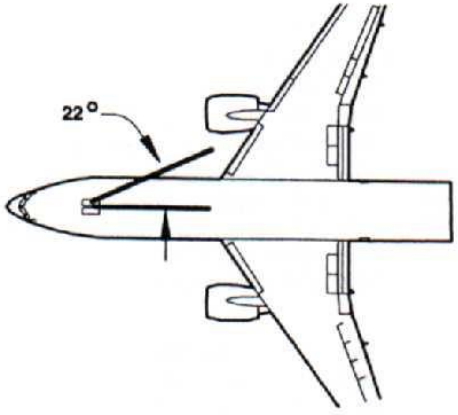


Turbine Disk Burst Zone Consideration

Roll Clearance



Collapsed Nose Gear

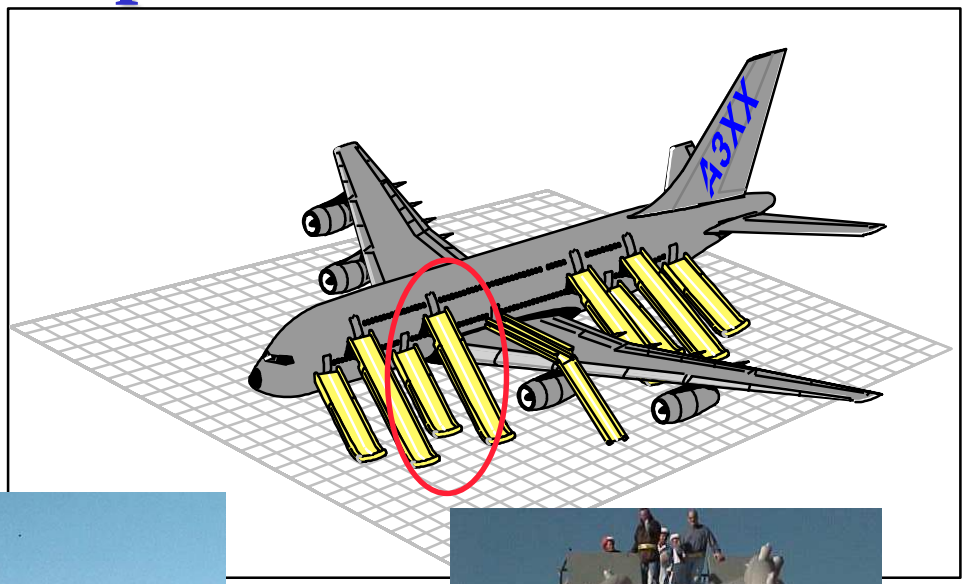


Nose Gear Water Spray Clearance

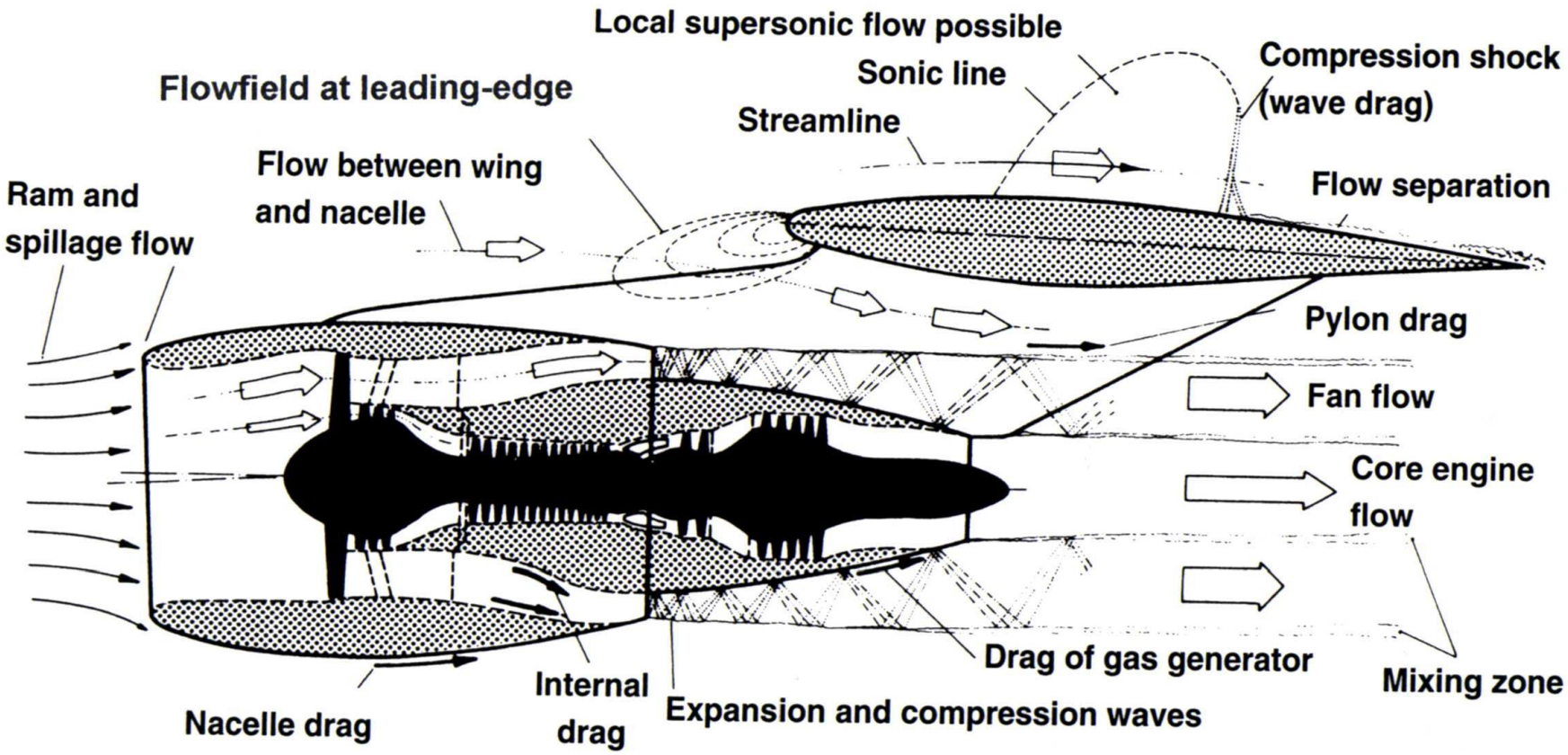
Undercarriage/Powerplant Interaction ~ 1

Undercarriage/Powerplant Interaction ~ 2

Escape Slides



Flow-field of an Underwing Installation

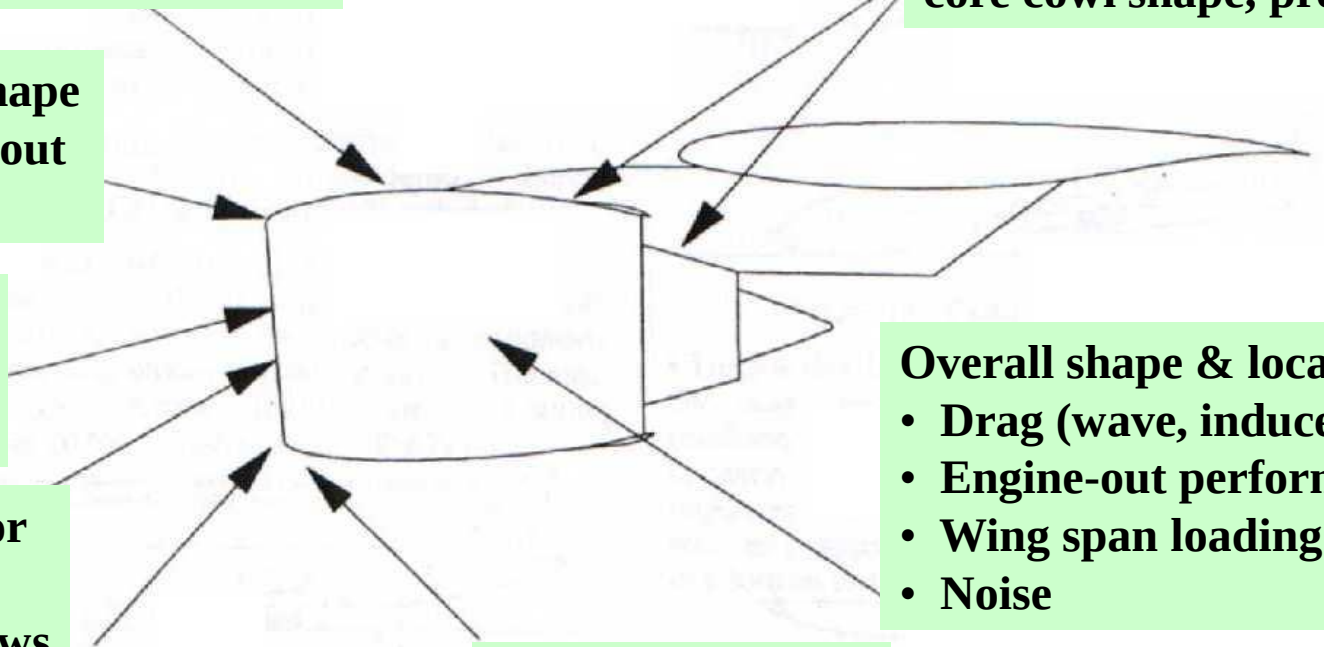


Factors influencing Nacelle Design

Shock strength
Influenced by strut

Boattail/Exhaust System
Interact with wing
Channel height, strut shape, core cowl shape, pressure ratio

External lip shape effects engine-out spillage drag



Inlet droop
Matched to upwash

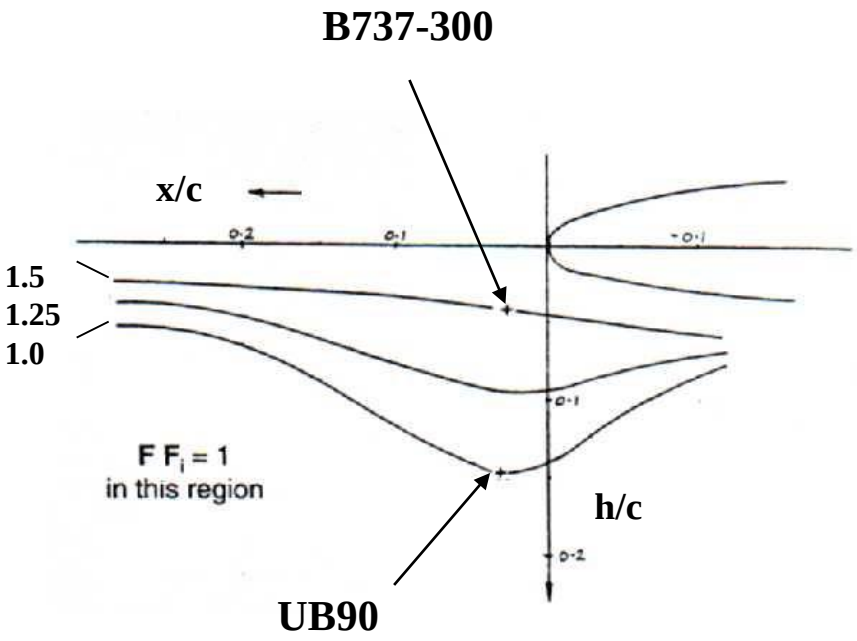
Overall shape & location effects:
- **Drag (wave, induced, wing etc.)**
- **Engine-out performance**
- **Wing span loading**
- **Noise**

Inlet sized for Take-off, Climb airflows

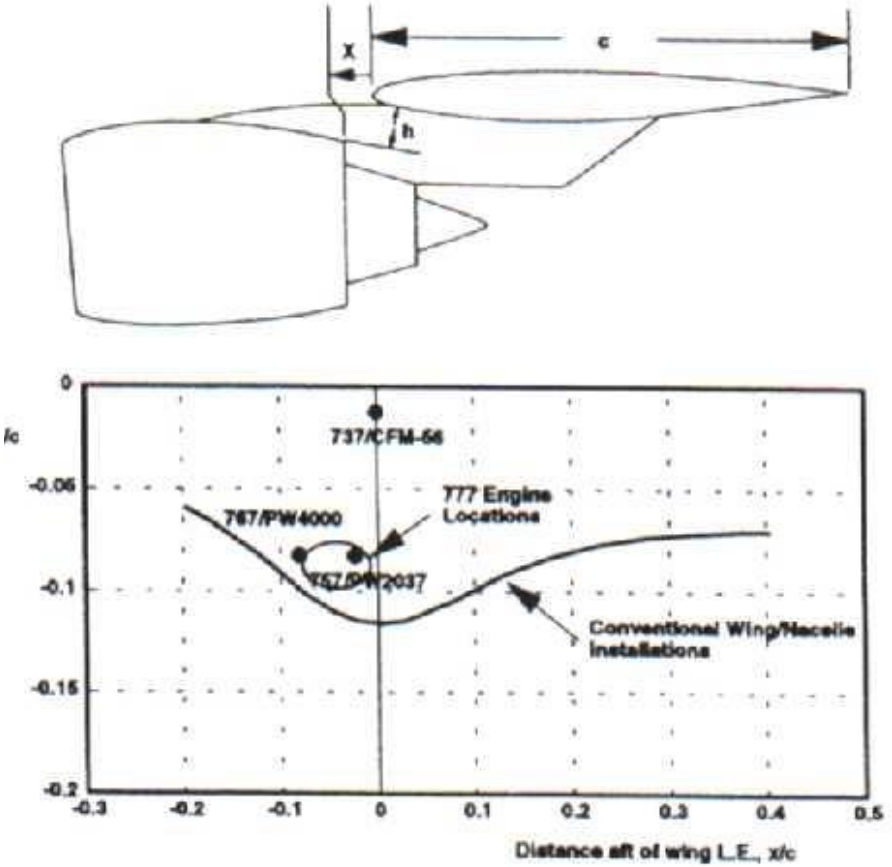
Lower lip shape effects engine/inlet compatibility

External lower lip design effects cowl separation at ETOPS conditions

Drag of Close Coupled Underwing Nacelles



Airbus data from U of B Design Project Manual



Reference: ISABE 97-7043
Engine/Airframe Integration Aerodynamic Design – B777 & Beyond

Boeing 737

Boeing 737-200 powered by low by-pass ratio JT8D

Boeing 737-300 powered by high by-pass ratio CFM 56

How far can Fan Diameter be increased?

Airbus A350

Boeing 787

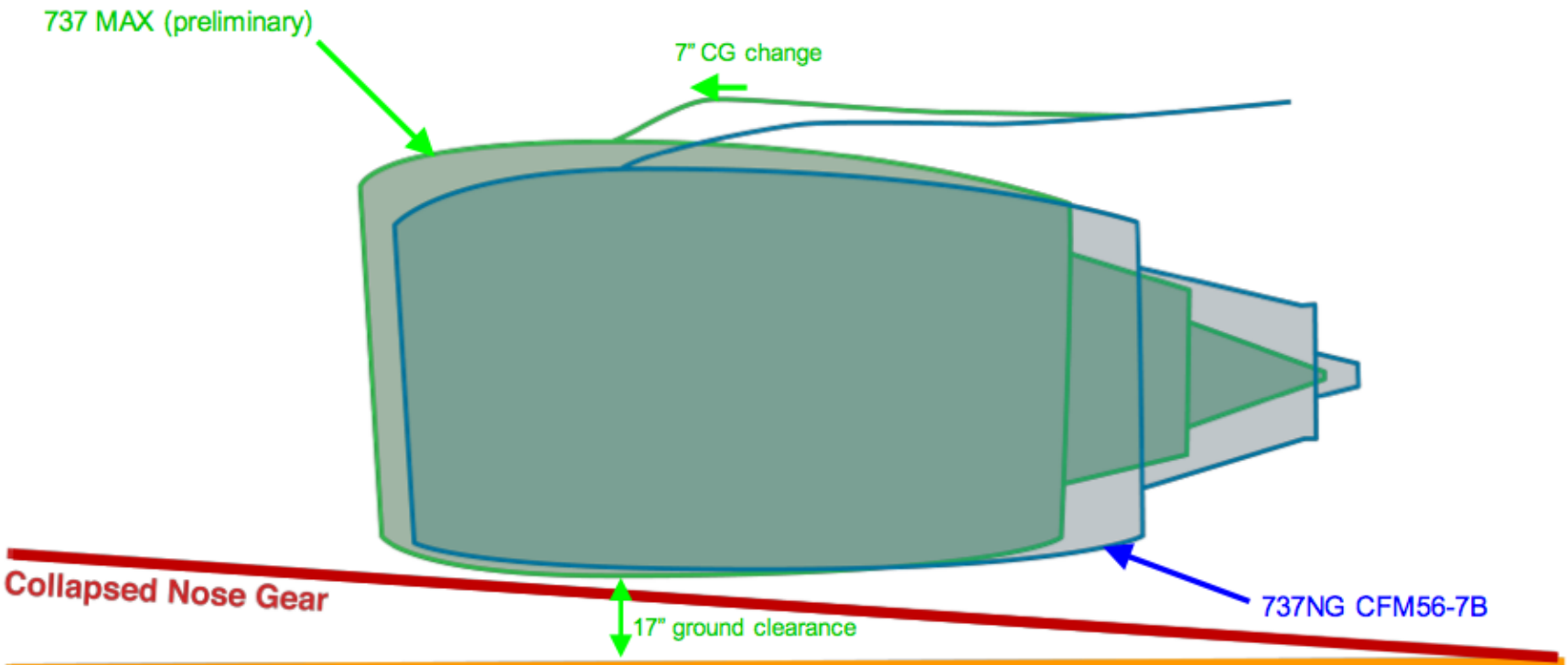
Airbus A320 NEO

Boeing 737 Max

LEAP engine installation meets existing standards

737 MAX relative to 737NG

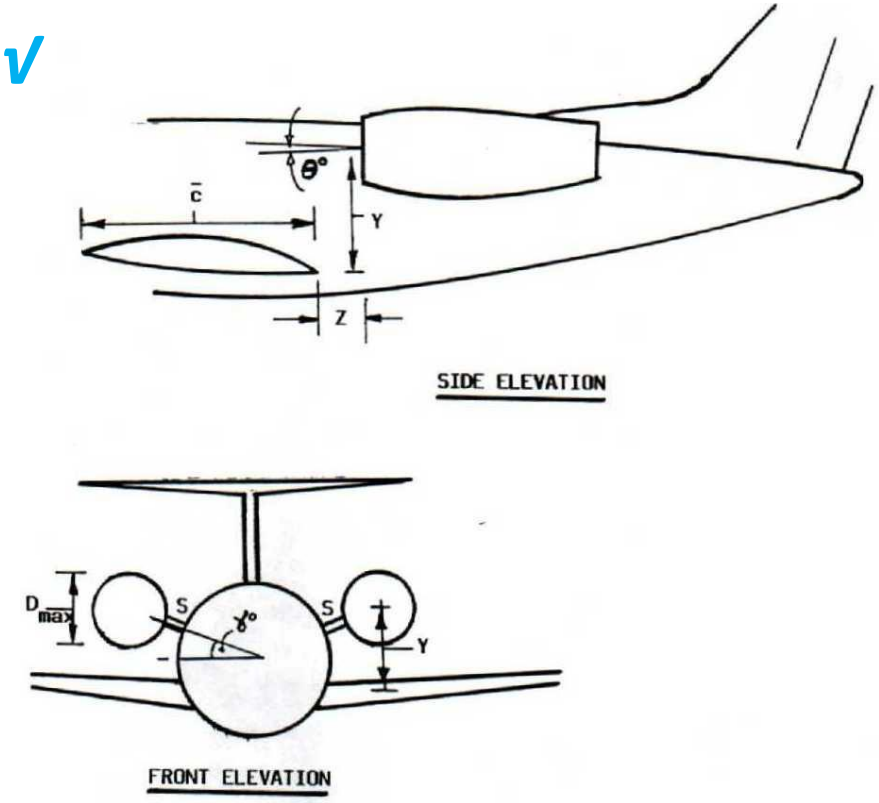
Although the Leap-1B is larger than the CFM-56, its engine installation on the 737 MAX will achieve the same geometric objectives for ground clearance as are achieved on the 737NG

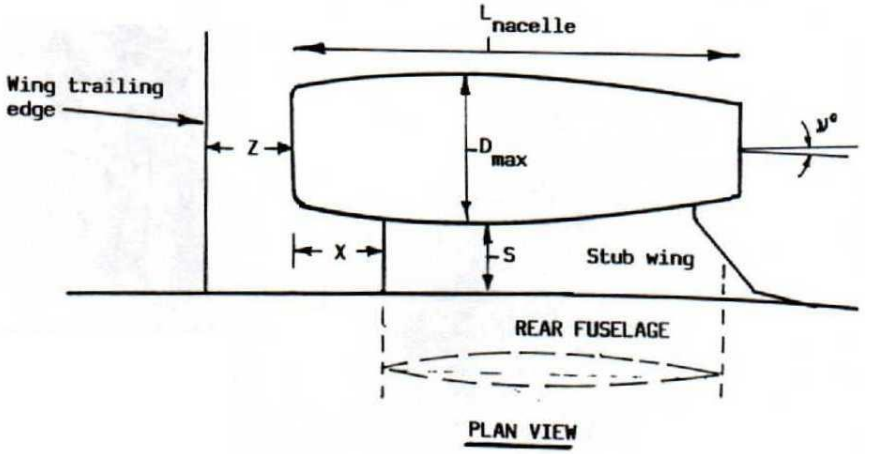



Comparison of the A320neo to the current A320
A320
A320neo
Efficient engines
CFM56-5B, IAE V2500
Wing tip fences
68"
81"
More efficient engines
CFM LEAP-X, PW1100G
Sharklets
ground clearance:46 cm
Only A320neo can accept a 2.65m diameter propulsion system!

A380

Fuselage Mounted Nacelles





$\boldsymbol{\theta}$ = Pod nose angle
$\boldsymbol{\gamma}$ = Pod elevation angle
$\boldsymbol{v}$ = Pod toe angle
$\boldsymbol{c}$ = Wing mean chord
$\boldsymbol{Y}$ = Pod vertical separation
$\boldsymbol{Z}$ = Pod horizontal separation
$\boldsymbol{X}$ = Highlight/Stub wing LE separation
$\boldsymbol{S}$ = Pod/Fuselage separation.

$$0.2 \leq S/D_{max} \leq 0.4$$

$$0.05 \leq X/L_{nac} \leq 0.15$$

$$0.9 \leq Y/D_{max} \leq 1.4$$

$$0 \leq Z/c \leq 0.25$$

Short/Medium Range Rear Engined Configurations

Boeing 727

de Havilland Trident

BAC 1-11

Douglas DC9

Business Jets

Learjet 45

Cessna Citataion X

Falcon 2000

Gulfstream G550

Comparison Underwing v Rear Engines

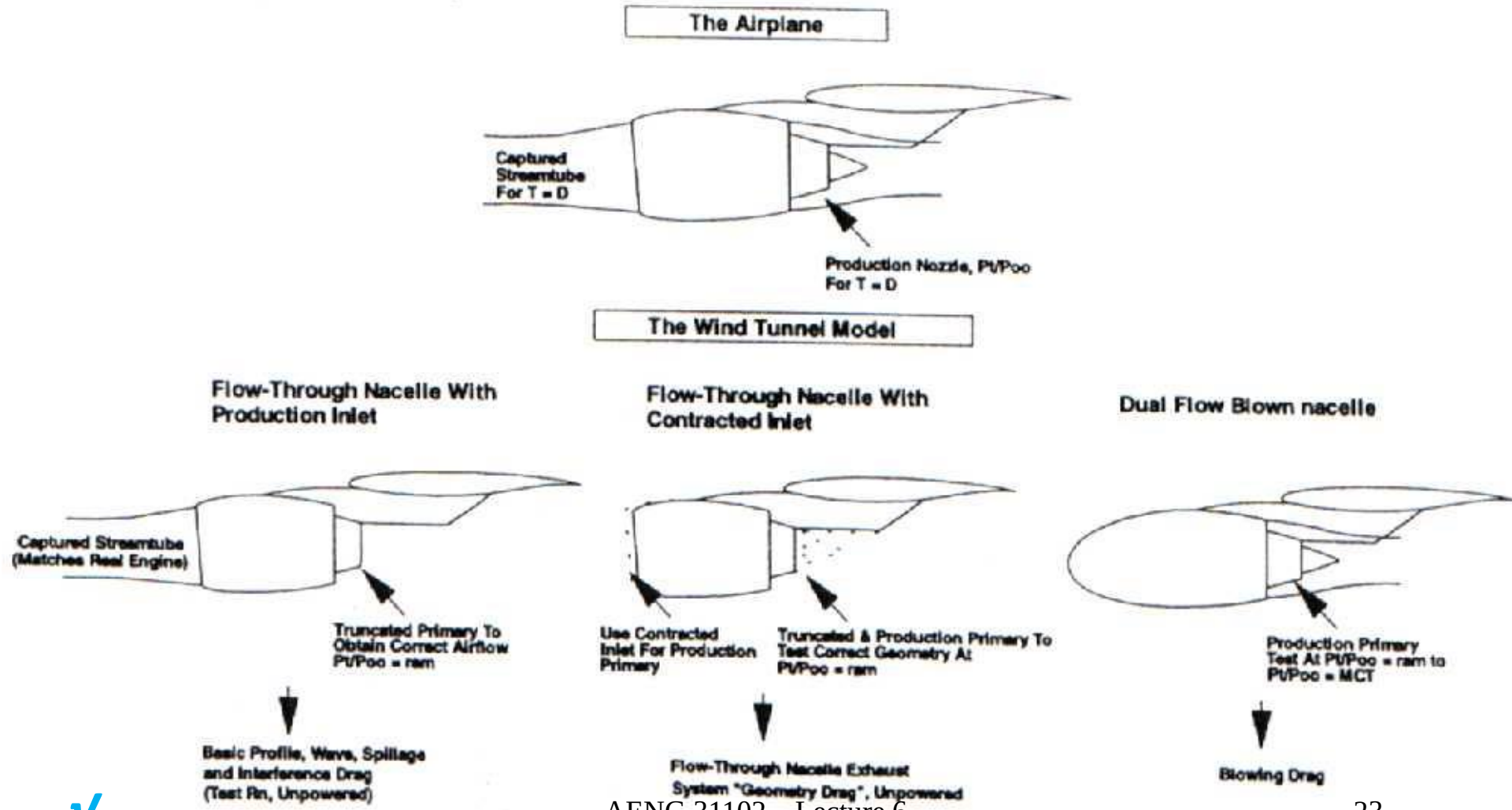
Underwing

- Plusses:
  - Wing bending relief
  - Easier aircraft balance
  - Easier engine maintenance
- Negatives:
  - Bigger fin
  - Not a “clean” wing
  - Flap cut-out for exhaust
  - Ground clearance/Landing gear

Rear Engines

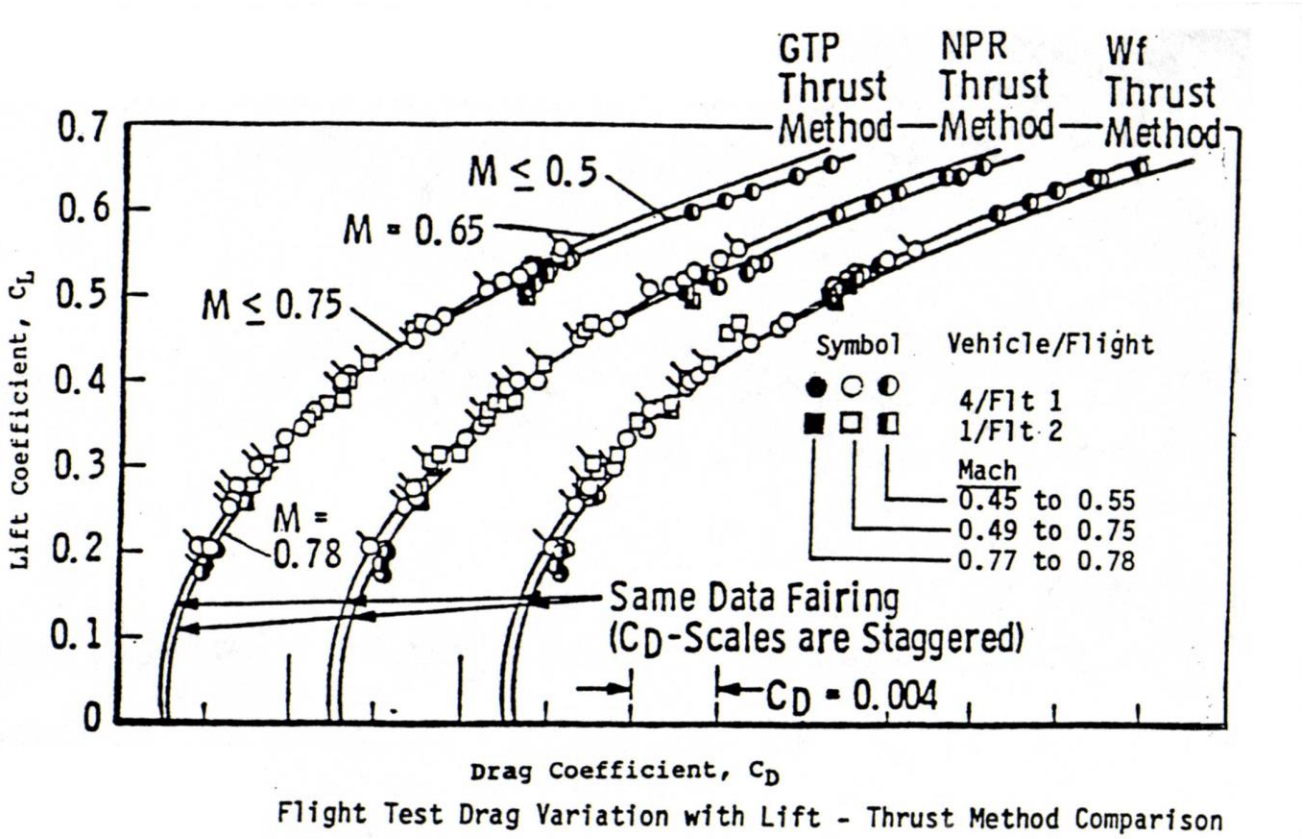
- Plusses:
  - Clean wing
  - Good ground clearance
  - Shorter Landing Gear
- Negatives:
  - Restricted C of G range
  - Engine maintenance
  - Cabin Noise
  - Heavier than underwing for some duties

Model Testing



Typical Aircraft Lift/Drag Polars

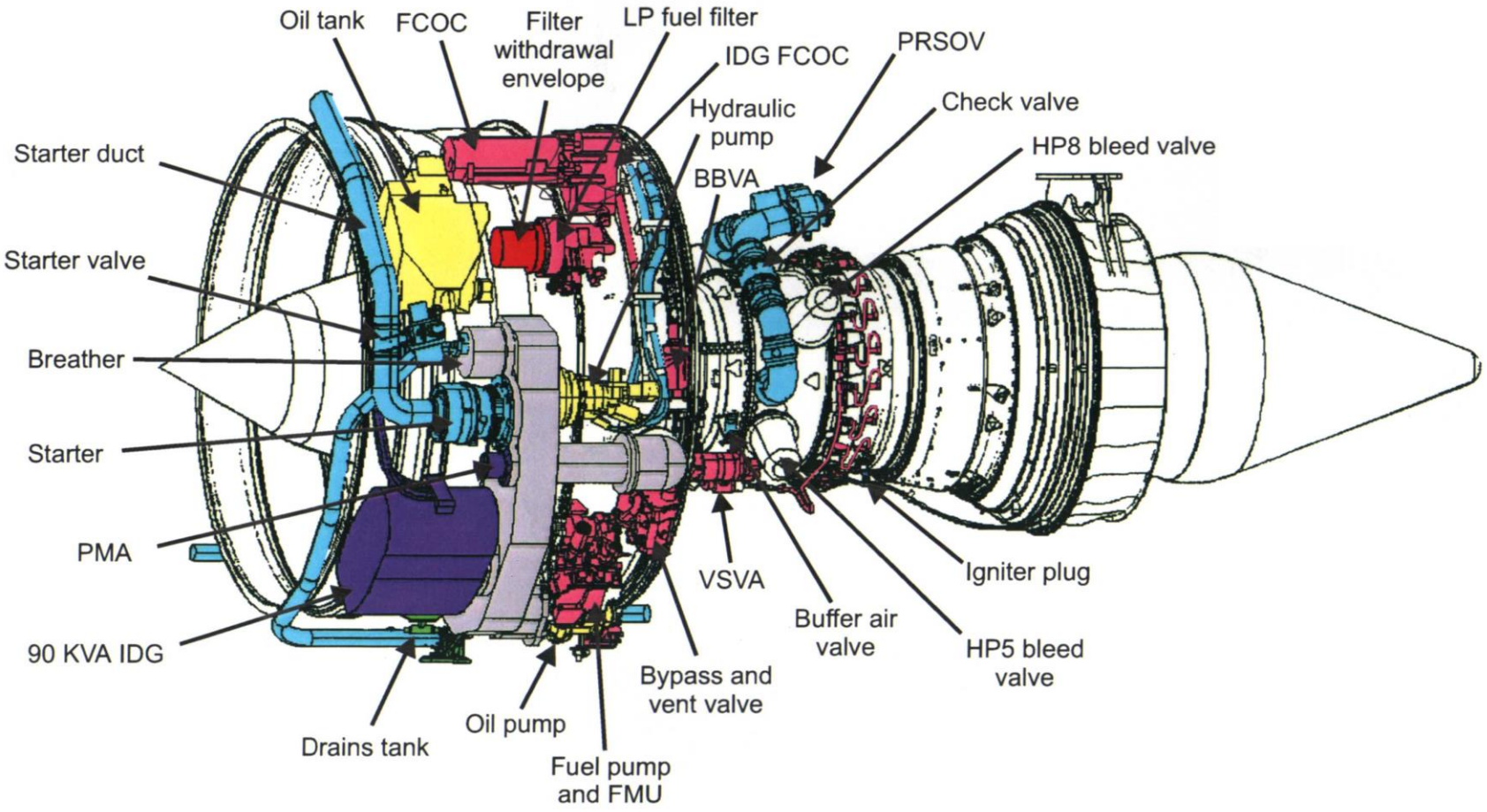
Derived from Flight Test Measurements



Flight Test Drag Variation with Lift - Thrust Method Comparison

GTP – GROSS THRUST PARAMETER
NPR – NOZZLE PRESSURE RATIO
W_f – FUEL FLOW
} — PROPULSION-SYSTEM THRUST METHODS

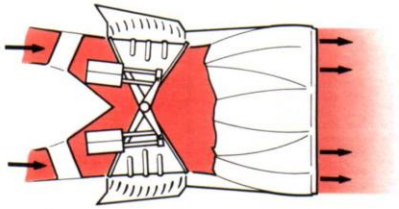
Typical Accessory Layout ~ BR715



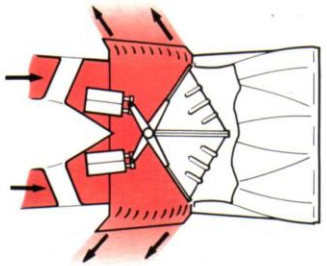
View on port side of engine showing fancase and core mounted accessories

Thrust Reversers

Clamshell

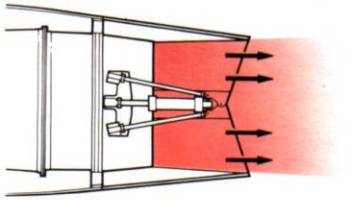


CLAMSHELL DOORS IN FORWARD THRUST POSITION

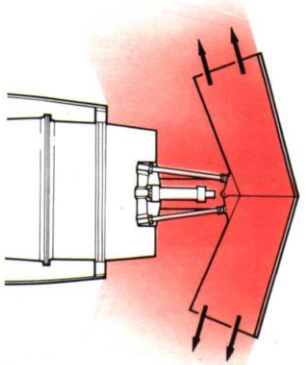


CLAMSHELL DOORS IN REVERSE THRUST POSITION

Bucket

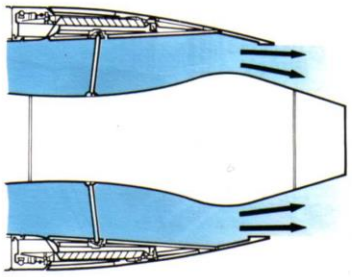


ACTUATOR EXTENDED AND BUCKET DOORS IN FORWARD THRUST POSITION

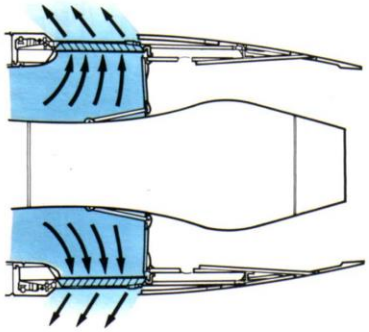


ACTUATOR AND BUCKET DOORS IN REVERSE THRUST POSITION

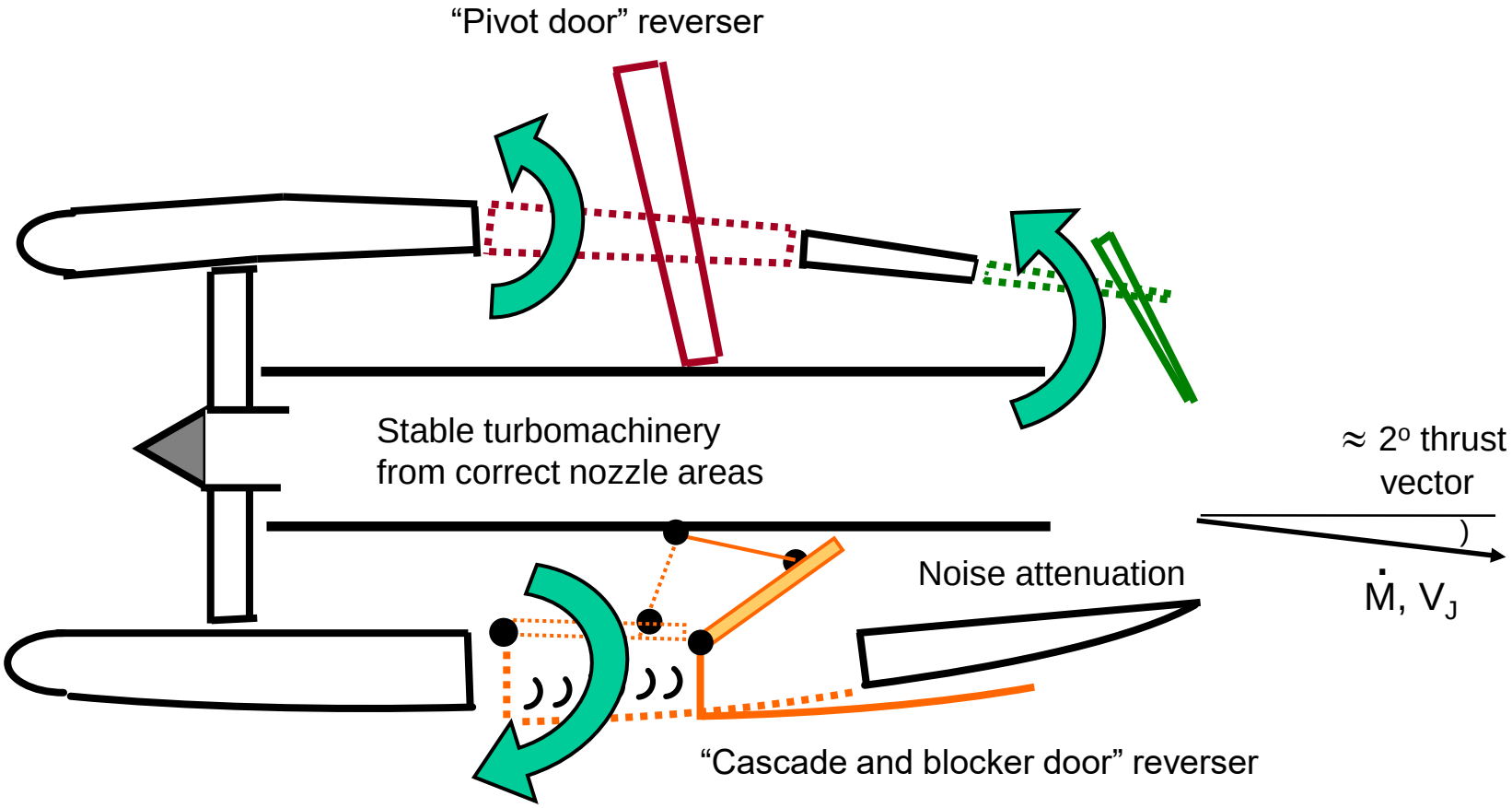
Cold Stream

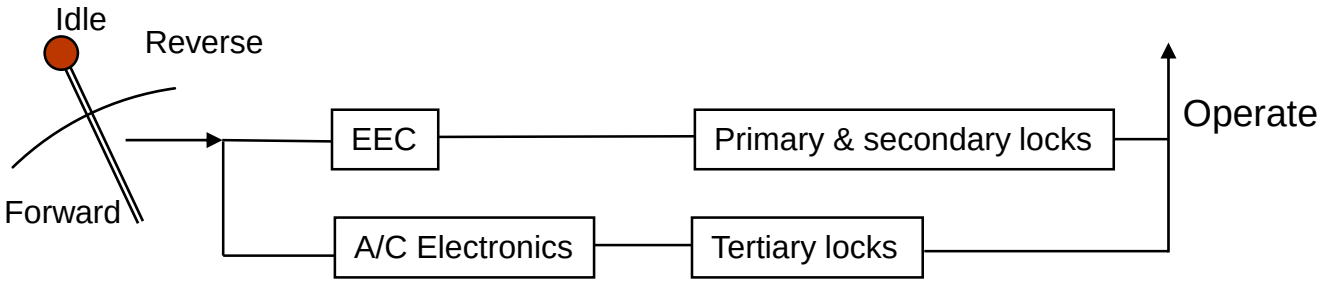


COLD STREAM REVERSER IN FORWARD THRUST POSITION

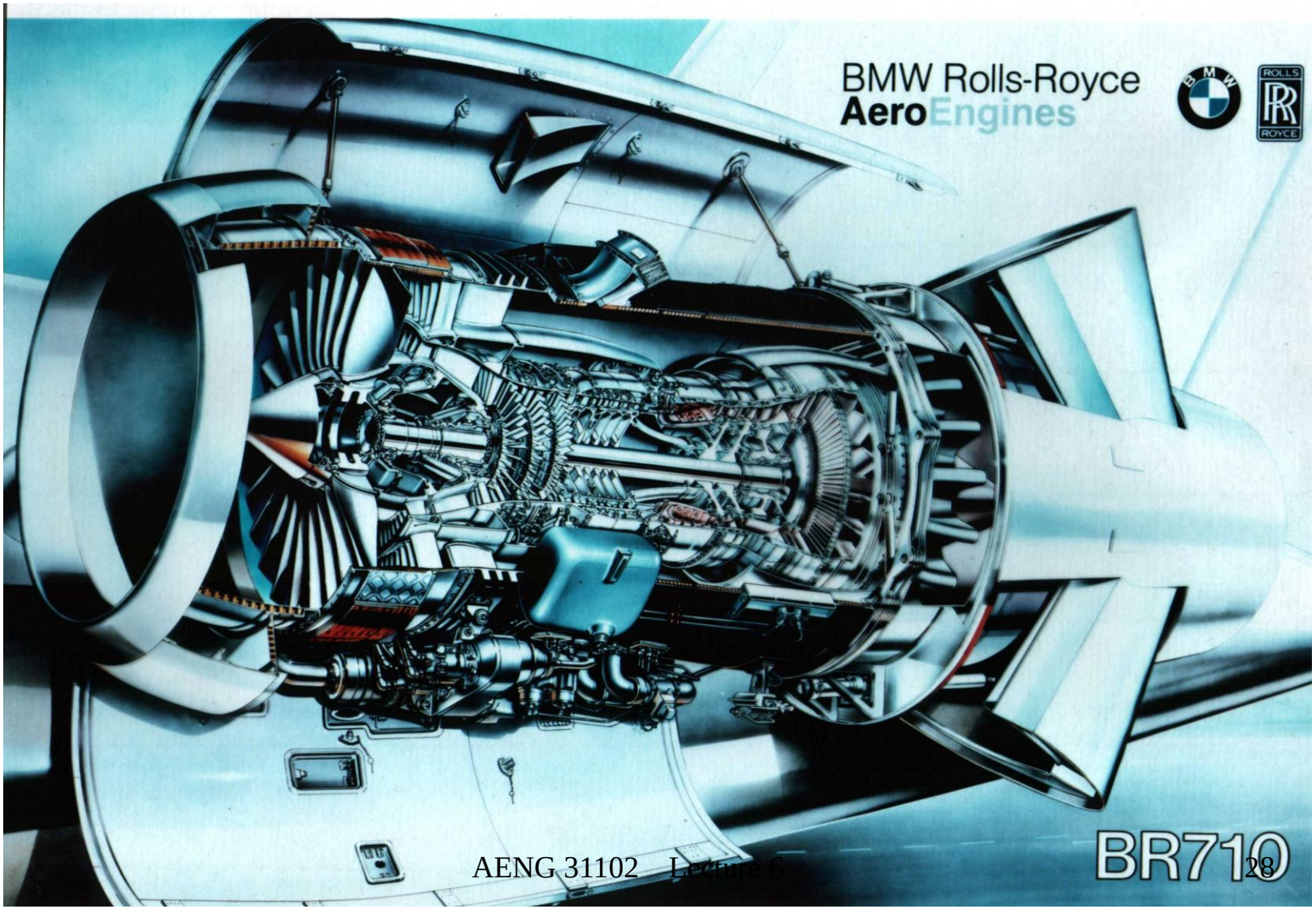


COLD STREAM REVERSER IN REVERSE THRUST POSITION

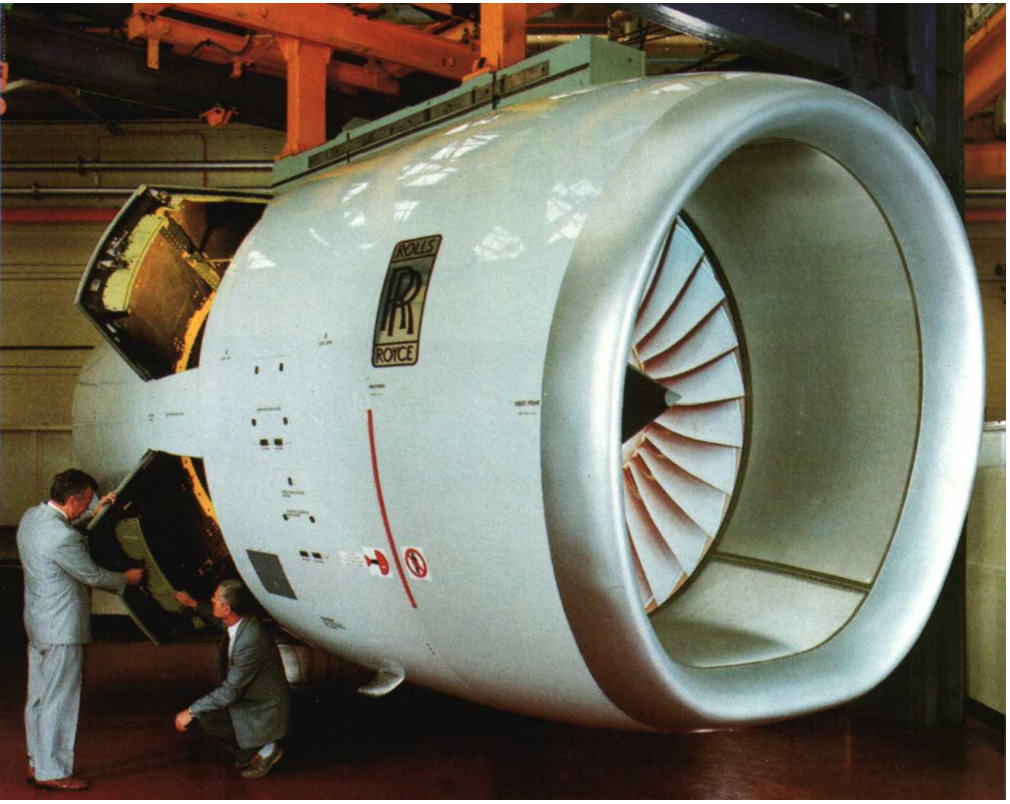

"Pivot door" reverser
Stable turbomachinery
from correct nozzle areas
≈ 2° thrust
vector
Noise attenuation
$\dot{M}$, V_J
"Cascade and blocker door" reverser


Idle
Reverse
Forward
EEC
Primary & secondary locks
Operate
A/C Electronics
Tertiary locks

Typical Podded Installation ~ BR710



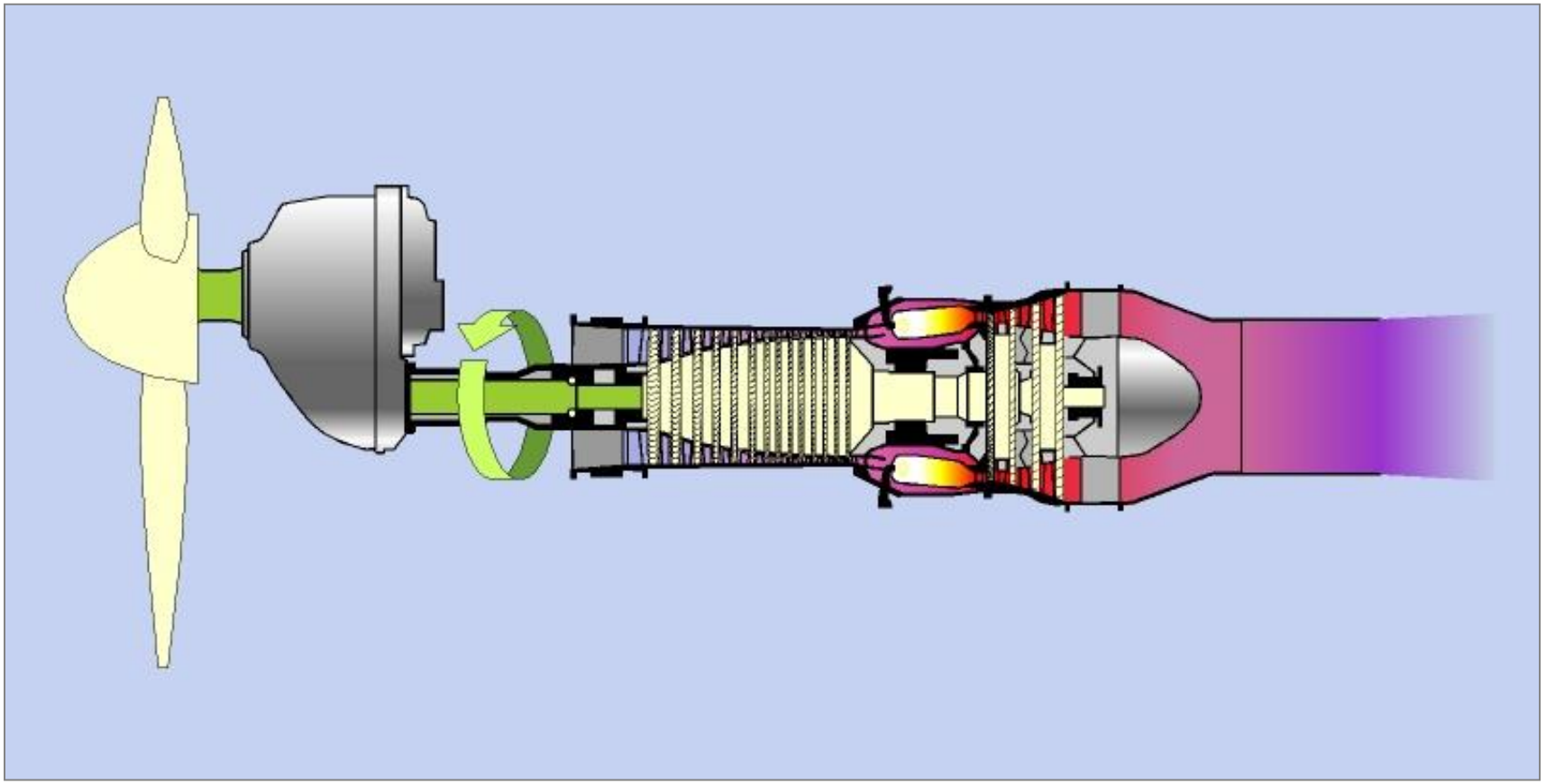
Nacelles for High By-pass Ratio Turbofans



Trent Nacelle

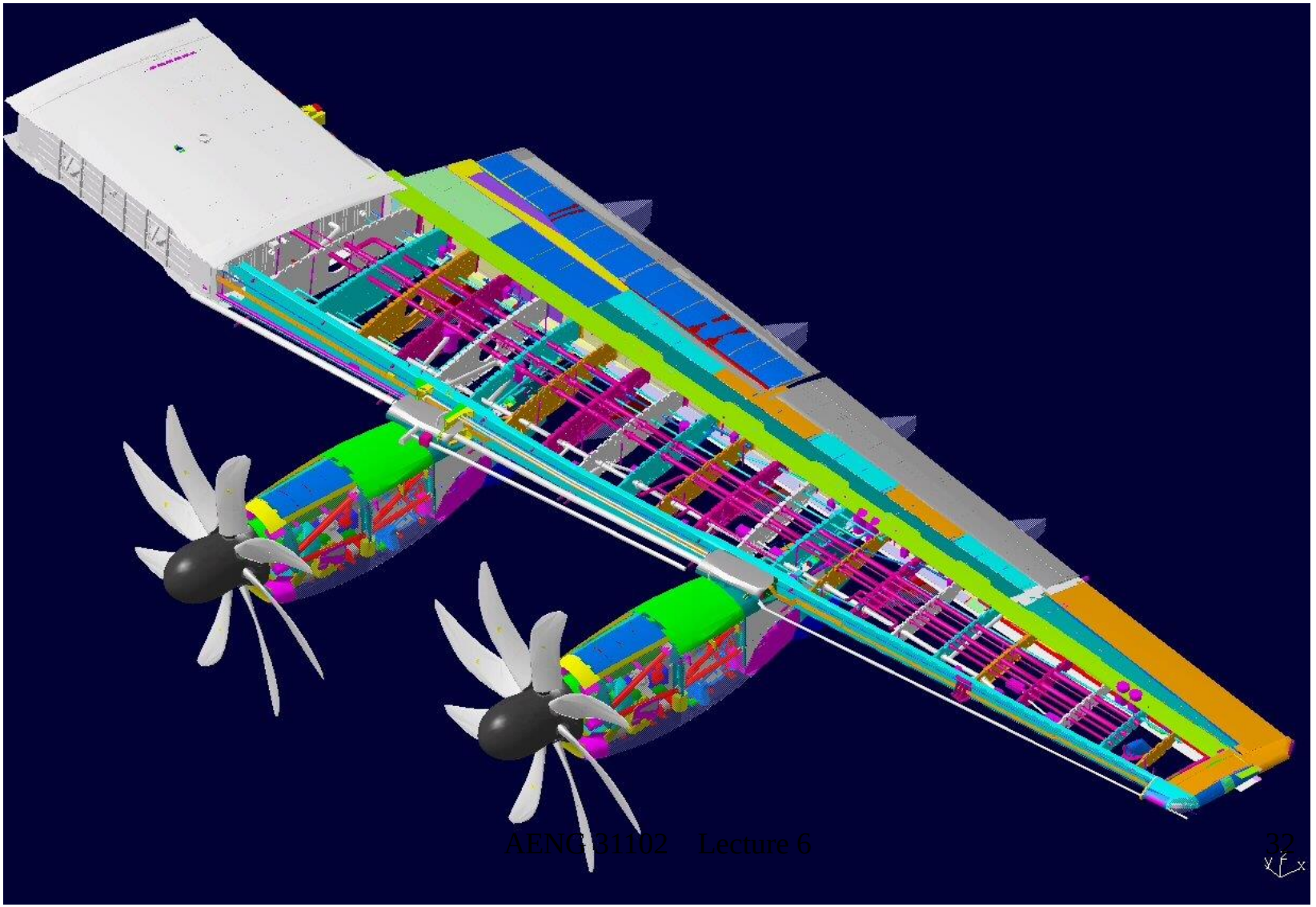
RB 211 – 524 on a Boeing 747

Turboprop - AE 2100

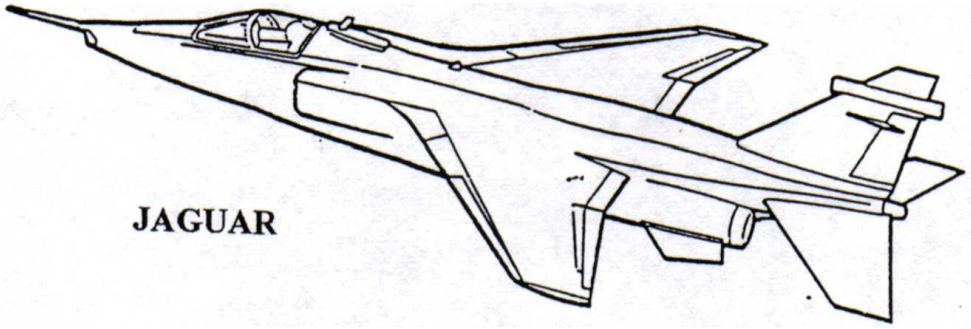


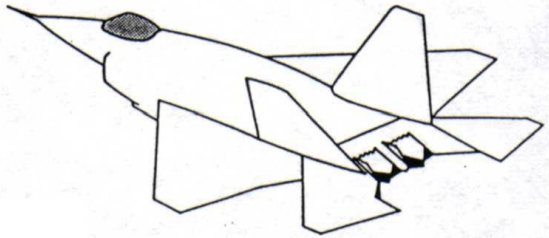
Turboprop & Propfan Layouts

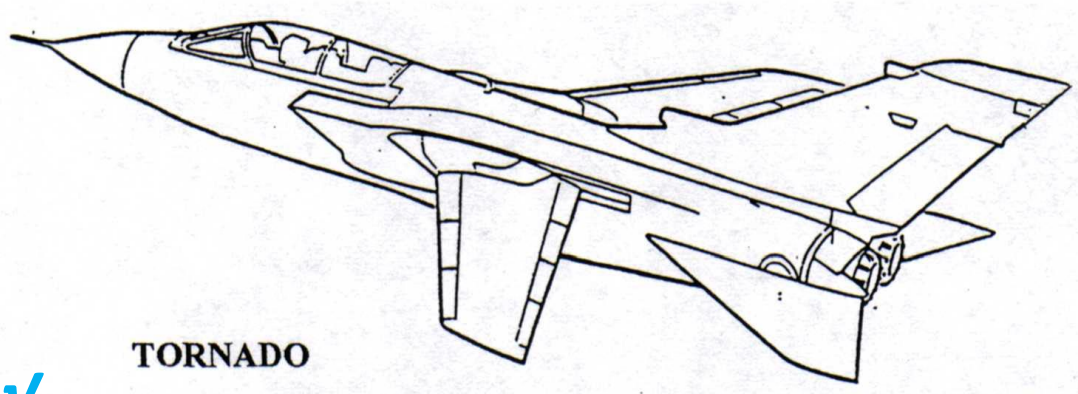
A400M Wing/Powerplant Layout

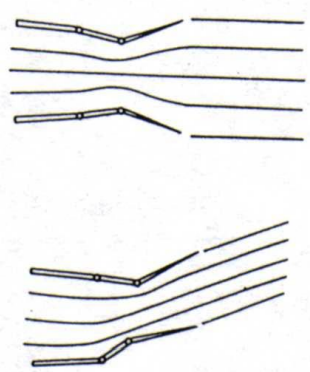


Typical Military CTOL Installations



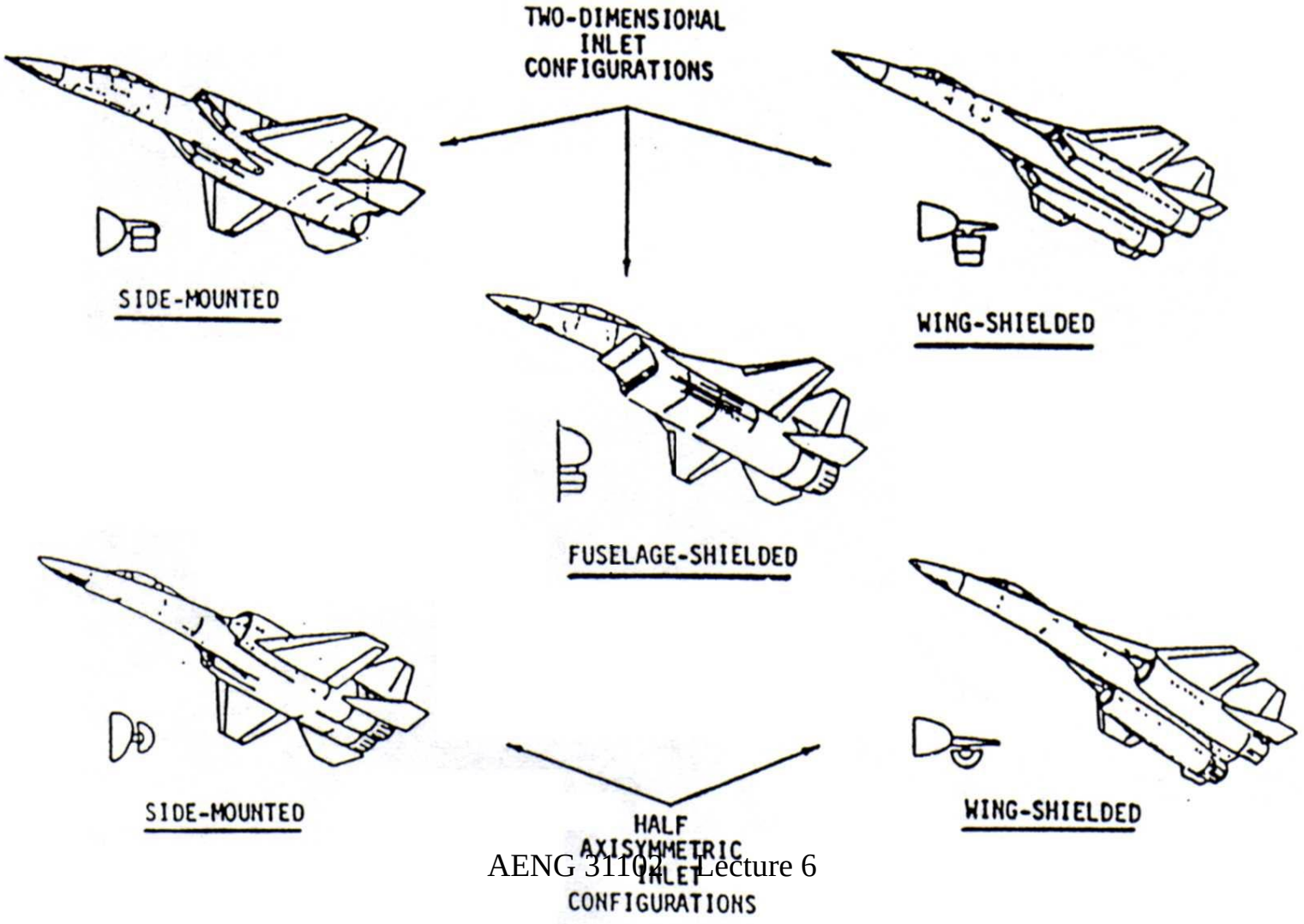






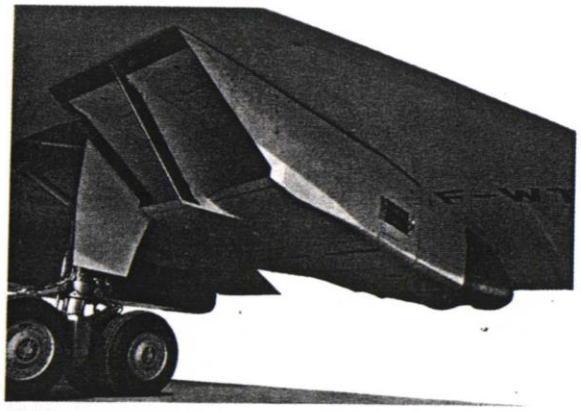
F22 with pitch vectoring.

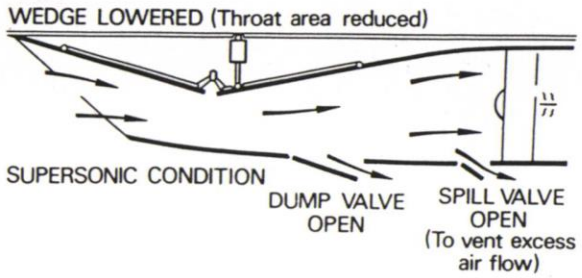
Supersonic Combat Aircraft Configurations

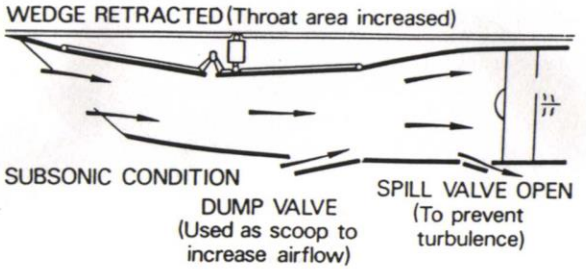


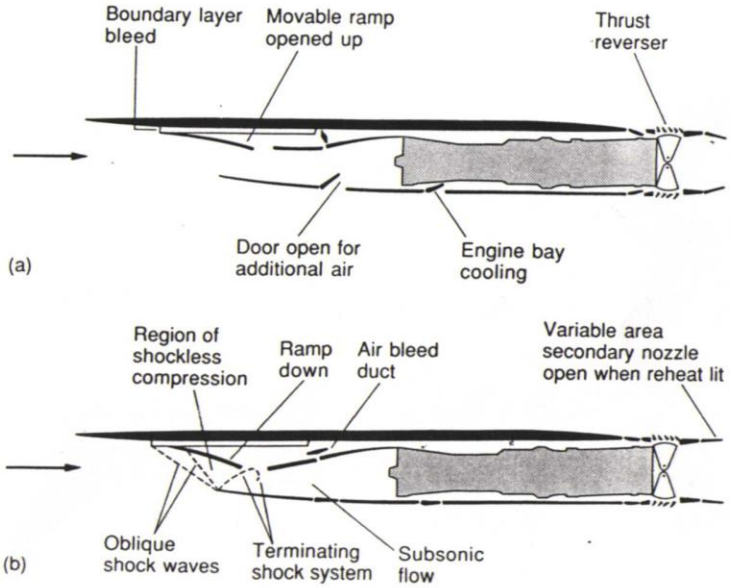
Typical Supersonic Airliner Installation

Concorde

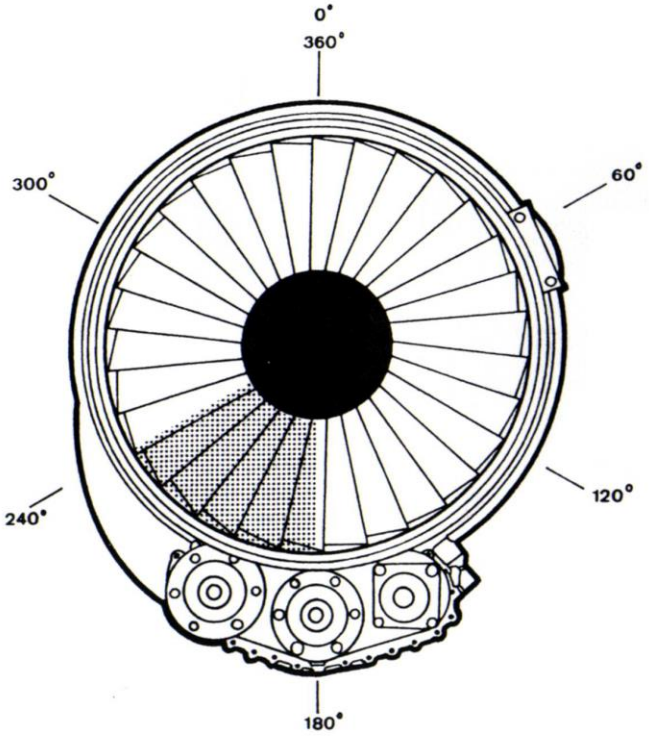


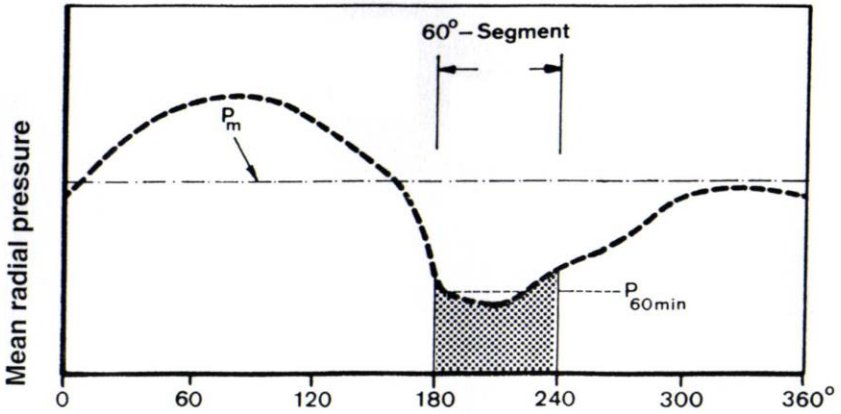






Inlet Distortion





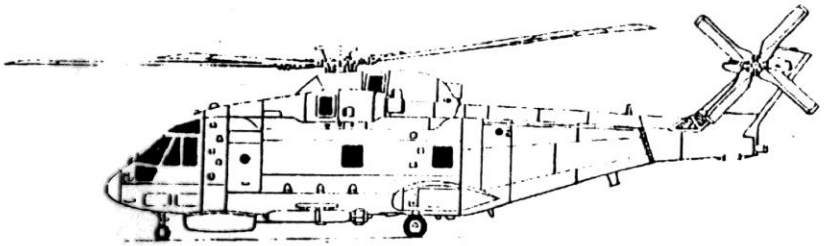
$$\text{Distortion parameter DC60} = \frac{P_m - P_{60min}}{q}$$

Helicopter - Installation Issues

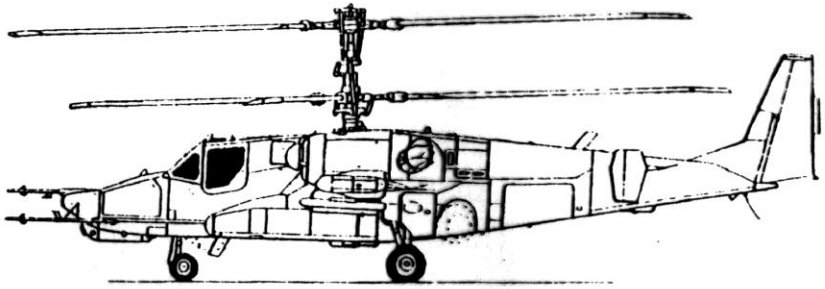
- **Installed performance**
  - Intake Pressure recovery & distortion
  - External Drag
  - Exhaust System performance
  - Rotor interactions
- **Infra-red suppression**
- **Ingestion**
  - Sand
  - Rain/hail/spray
  - Foreign objects
- **Icing**

Helicopters

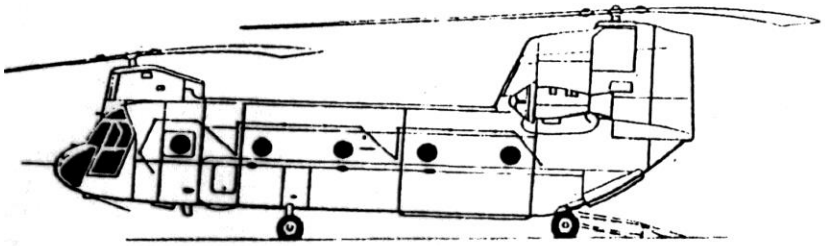
Major Configurations



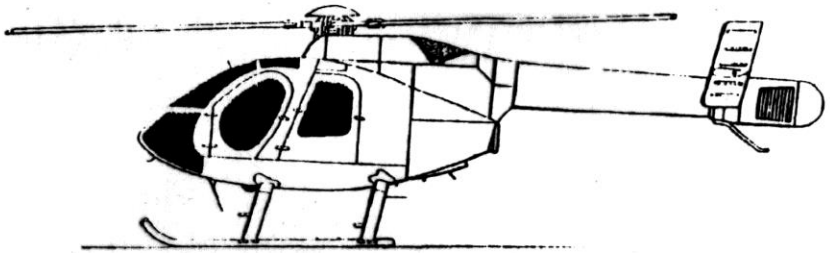
Conventional Main Rotor - Tail Rotor
Naval EH101



Co - axial Main Rotor
Kamov Ka - 50 'Hokum'

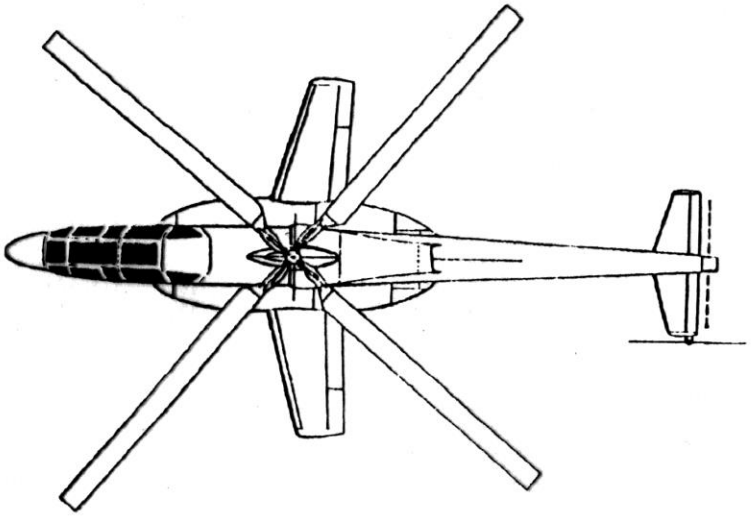


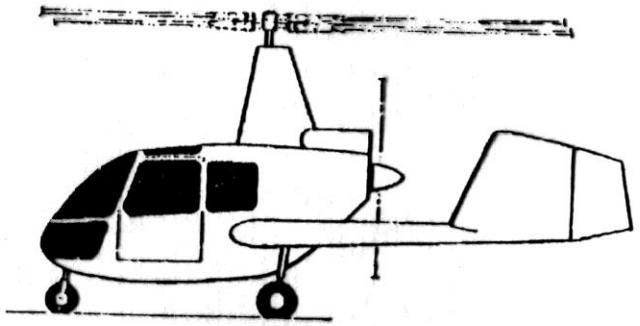
Tandem Main Rotor
Boeing CH - 47D Chinook



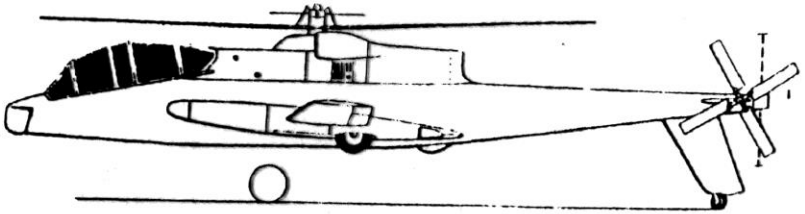
NOTAR - NO TAil Rotor
Mc Donnell Douglas MD 520N

Rotary Wing & other Aircraft Configurations

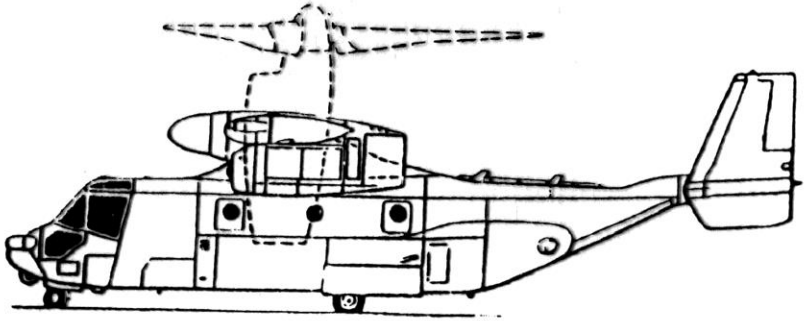




Autogyro
AISA Autogyro GN



Compound Helicopter
Lockheed AH-56A Cheyenne



Tilt - Rotor
Bell / Boeing V-22 Osprey

Engine Integration Issues

- **Aerodynamics & Control**
  - Interference drags
  - Engine thrust line
  - Ground clearance &debris ingestion
  - Control aspects
- **Structure & Configuration**
  - Attachment to pylon & aircraft
  - Loads & vibration into the aircraft structure
  - Effect of weight & balance
  - Emergency evacuation
  - Disc burst
- **Systems**
  - Integration of propulsion & aircraft systems
- **Maintenance of Engine & Airframe**
  - Reliability
  - Scheduled & unscheduled maintenance
  - Accessibility

Key Lessons from Lecture 6

- ***The engine provides:***
  - Thrust for flight
  - Reverse thrust for landing
  - Electrical generation
  - Hydraulic power
  - Air bleed for:
    - The environmental control system
    - Cooling
    - Hot air for anti-icing

- **But:**
  - It burns fuel
  - Is a major source of noise
  - Is the source of all of the emissions

Engine Cycles for Subsonic Transport Aircraft

Objective ~ Lecture 7

To outline the reasons for the choice of engine cycle.