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PROPULSION INTEGRATION CHALLENGES- Lecture to DGLR

Hamburg, July 5th 2007

AIRBUS

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PERFORMANCE

1962 : CONVAIR 990 “Coronado” programme endangered

☞ severe cruise performance deficit during flight tests. *Complete reshaping of wing/engine integration* (6 fairings/engine !) to recover guaranteed performance and General Dynamics’ program viability

Source : AIAA paper n° 63-276, summer meeting June 17-20, 1963 (J Kutney, S Piszkin)

SAFETY

1991-1992 : two B747 crashes caused by engine separation

☞ *structural design modification of pylon to wing attachment* requested by FAA (June 1995) . More than 1000 B747 concerned. Retrofit costs 10000 to 15000 man-hour per A/C

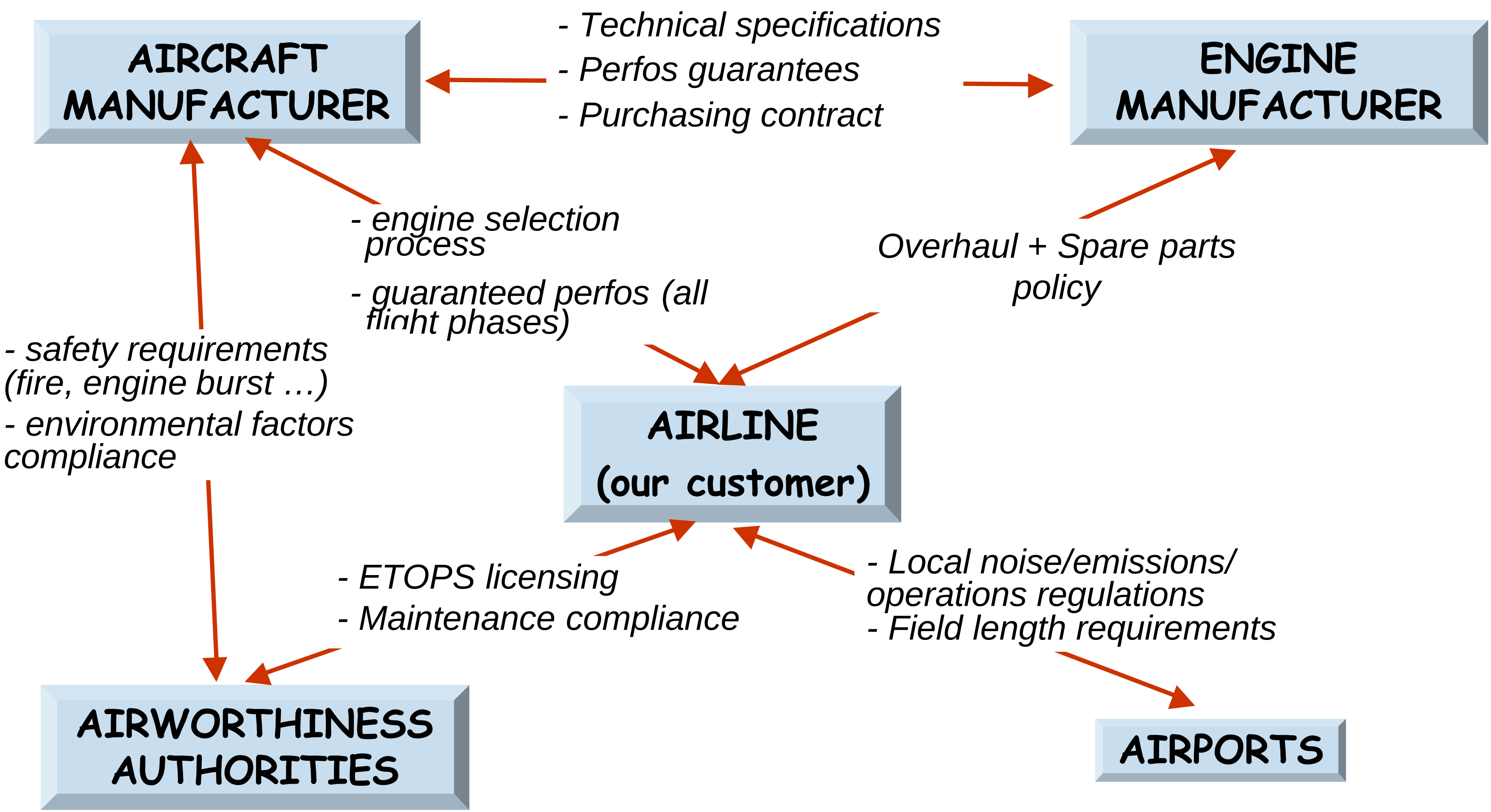
Source : Aircraft Economics n°28, Nov/Dec 1996

ENVIRONMENT

2000 : A380 launch customer demands QC2 noise level compliance

☞ *major engine and A/C configuration adaptations* required to fulfill stringent noise guarantee, quite late in A/C development

STAKEHOLDERS



Design options influenced by complete network

A CHALLENGE FOR FUTURE ADVANCED POWERPLANTS

need for

↗ thrust capabilities
high capacity A/C or
large twin-engined A/C)
↘ fuel burn
↘ noise levels

⇨

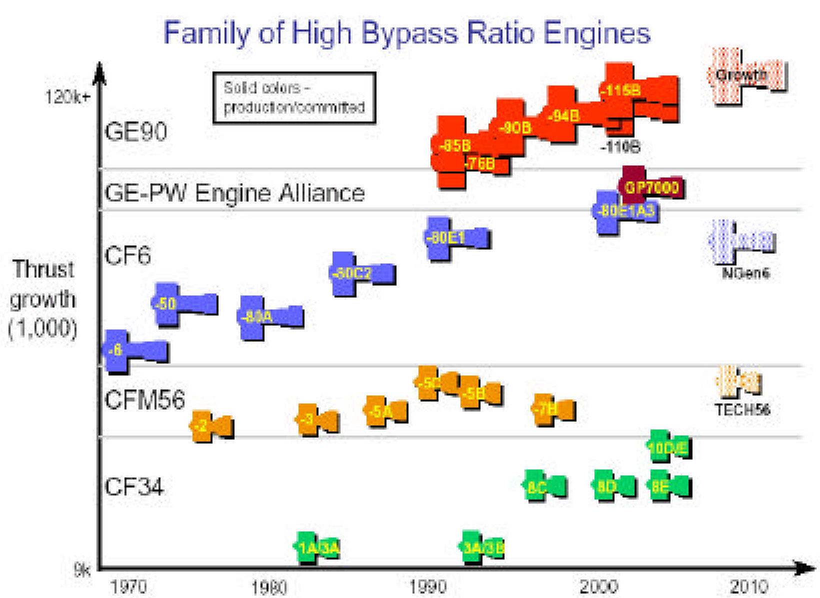
present trend

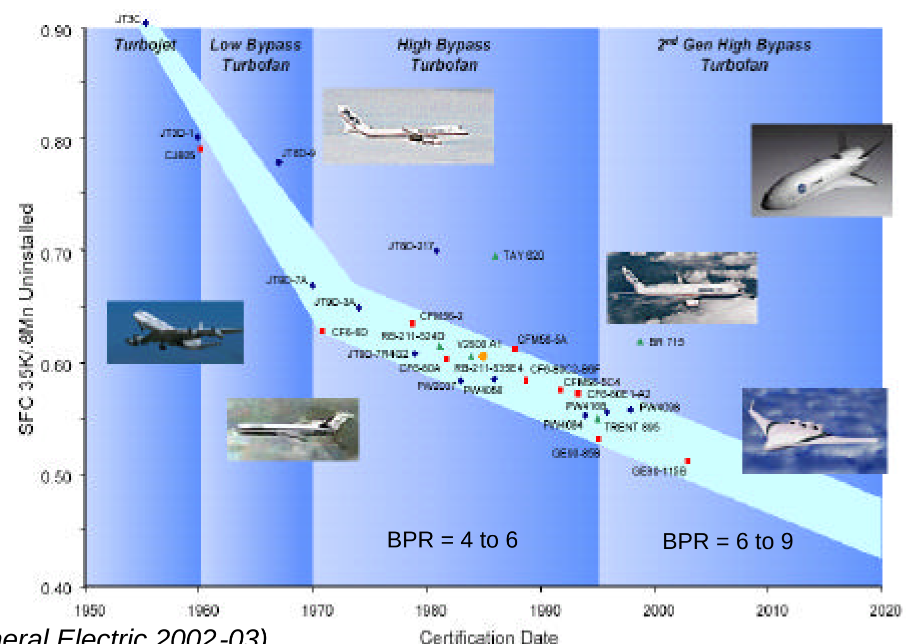
↗ bypass ratios
↗ fan diameters
↗ nacelle length

⇨

Integration challenges

↗ engine/airframe interference
↗ engine weights/loads
↘ ground clearances
↗ environmental compliance issues





(Source: General Electric 2002-03)

Need for new integration concepts (close-coupling, noise-shielding ...)

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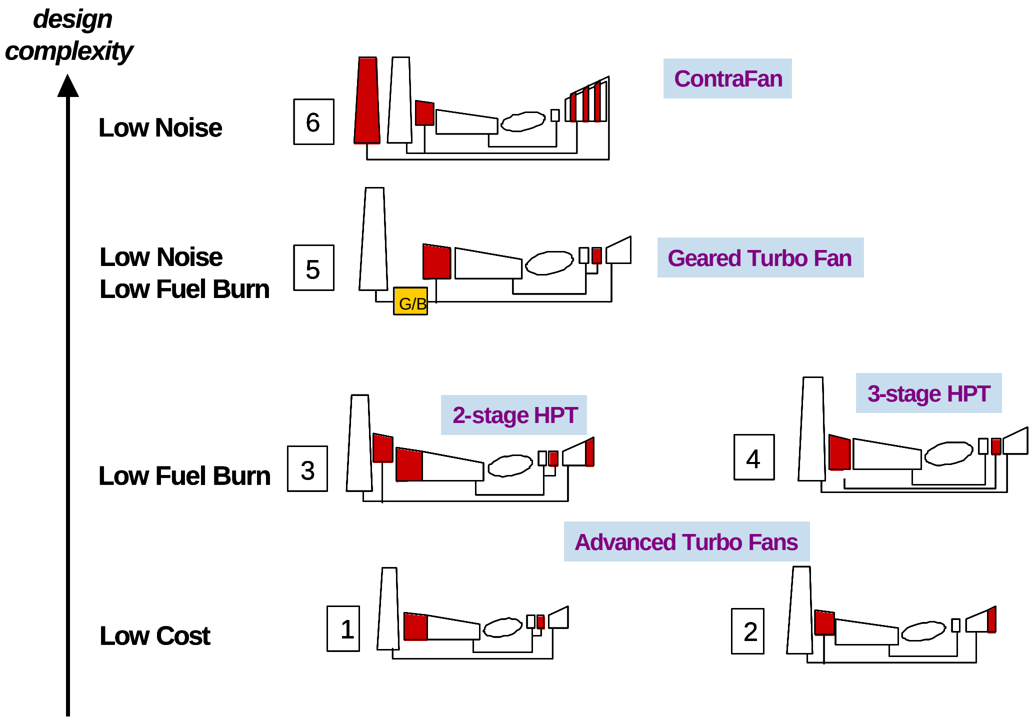
FROM SELECTION OF CANDIDATE TECHNOLOGIES ...



(Exemples of candidate engine architectures)

GUIDELINES :

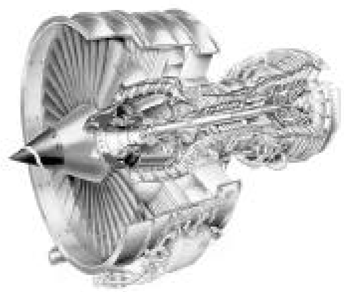
- Thrust, Noise, Operational requirements
- New technologies assessment. Benefits / risks tradeoff
- Suppliers market situation : adapted or new engine
- Airline demands and economics : low design/maintenance cost (regional) vs low fuel consumption (long range)
- Political/strategical considerations (alliances, competitors projects ...)

- Not always a straighforward decision (cf. A400M military cargo)
- Not only technical drivers

... TO COMMITMENTS FOR COOPERATION

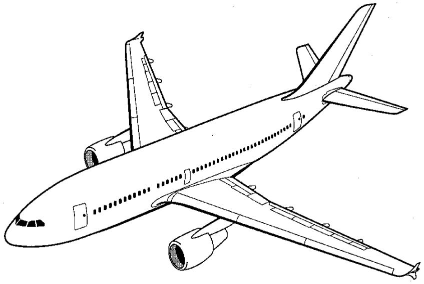
Two industrial partners with respective business standpoints, sharing risks

ENGINE MANUFACTURER : One engine program for several A/C (optimize business case)



Eg : GE CF6-80C2 → DOUGLAS MD11, AIRBUS A310

AIRFRAME MANUFACTURER : Same A/C with different engines (with max. commonality)

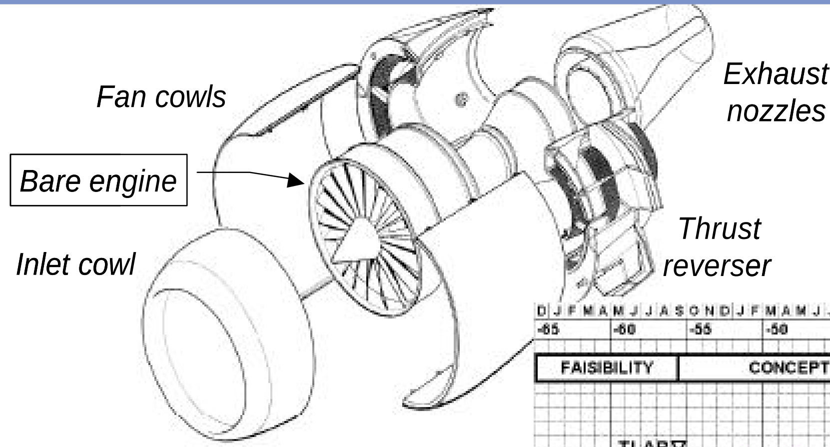


Eg : A320 → CFM 56-5, IAE V2500

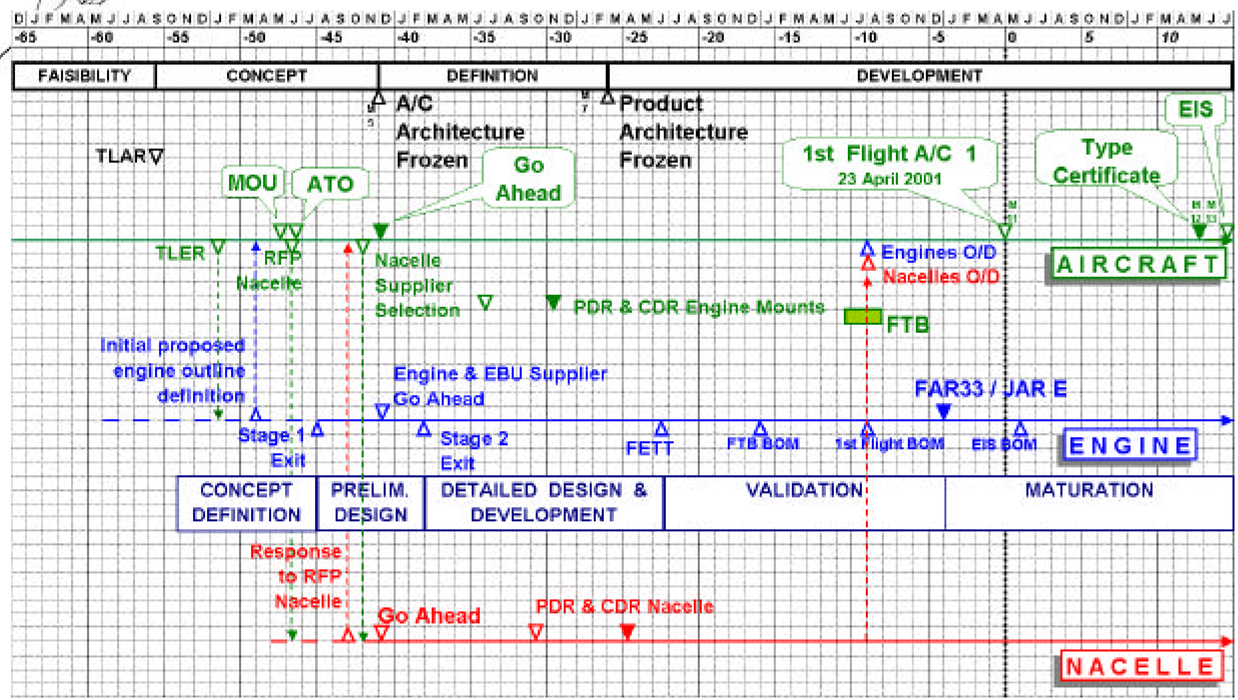
A330 → GE CF6-80 E1, PW 4164/68, RR TRENT772

- **Capability to get commitments for best adapted engines is of prime importance in competitive environment**
- **Engine manufacturers run their own A/C market forecasts !**
- **A/C manufacturers must audit engine manufacturers proposals**

INDUSTRIAL RESPONSABILITIES - INTERFACES



Clear workshare required for specification, design and manufacture of Powerplant interface components



- **Boeing and – more recently – Airbus tend to retain nacelle responsibility.**
- **To save significant leadtime, Airframer must ensure development plans coordination with Engine and Nacelle suppliers.**

AIRBUS

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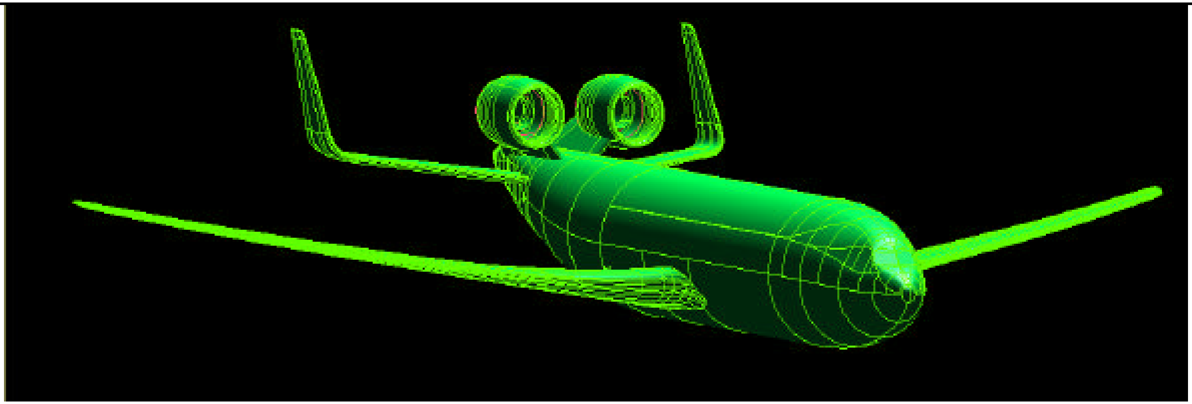
FEASIBILITY PHASE : BASIC OPTIONS

Example : Rear Fuselage mount compared to Wing mount



☺ ***Advantages***

- No adverse interference on the wing (better C_D and C_{lmax})
- Better lateral control in case of one engine failure
- Relaxed nacelle ground clearances
- **Engine noise shielding benefit**

☹ ***Drawbacks***

- Safety compliance in case of engine burst
- More restricted A/C loading /CG travel
- Rear doors arrangement on fuselage
- Weight penalty : fuselage, empennage
- Air inlet behaviour at high angle of attack
- Rear fuselage aerodynamic interference
- Poor engine accessibility/maintainability

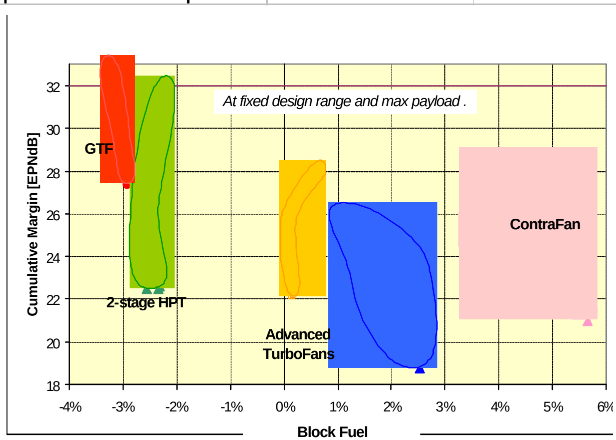
Need to mitigate configuration risk for noise advantage

CONCEPT PHASE : A MULTIDISCIPLINARY BALANCE

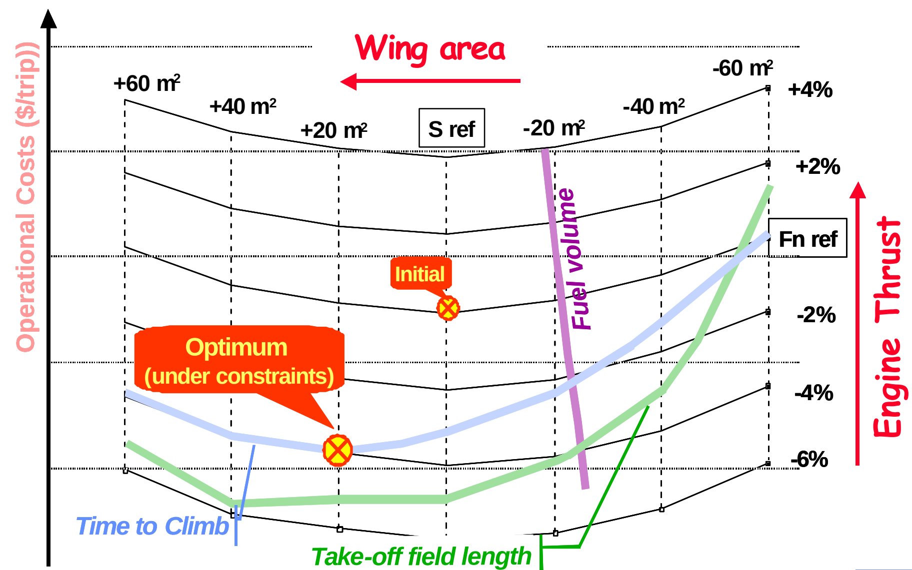
- **Propulsion system installation impacts largely A/C configuration**
- **Basic options must always be balanced on a <u>multidisciplinary</u> basis :**
  - ➢**sensitivity factors for quick comparisons and decisions**
  - ➢**integrated sizing tools for preliminary General Arrangement set-up**

Exemples of sensitivity factors

	Short Range eg A320	Long Range eg A340	Large Aircraft eg A380
dRange/dMWE	-220 nm/t	-90 nm/t	-50 nm/t
dRange/(dCD/CD)	-35 nm/%	- 70 nm/%	- 75 nm/%
dRange/dSFC	-32 nm/%	-77 nm/%	-85 nm/%
MWE : A/C empty weight ; CD: drag coefficient			
SFC : engine specific fuel consumption			



Exemple of Wing area / Engine thrust trade-off



DEFINITION PHASE : THE OPTIMISATION LOGIC

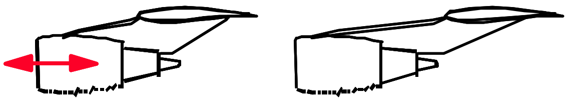
- **Detailed propulsion system integration is a <u>highly iterative process</u>, involving many engineering and non-engineering functions.**

- **We can differentiate :**
  - **The degrees of freedom available**
  - **The target function to be minimised**
  - **The requirements to comply with**

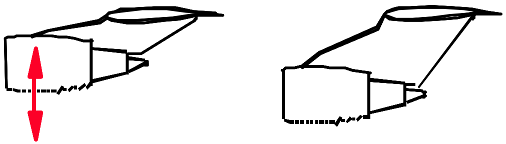
- **Such design process can therefore be considered as**

A CONSTRAINED OPTIMISATION

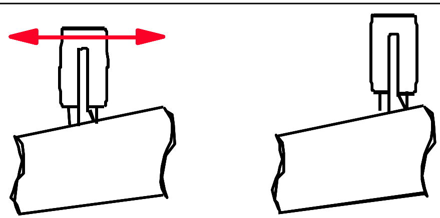
DEGREES OF FREEDOM : POSITIONS and SHAPES



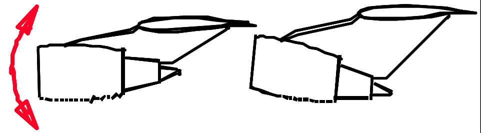
AXIAL (X) POSITION



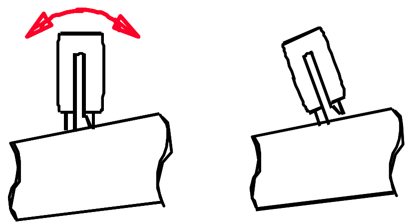
VERTICAL (Z) POSITION



SPANWISE (Y) POSITION

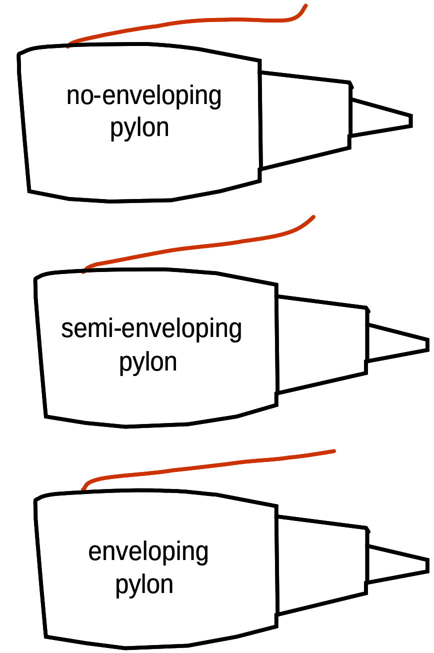


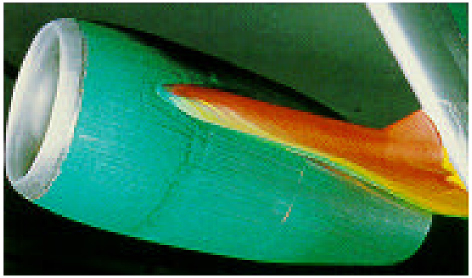
PITCH ANGLE



TOE ANGLE

Engine position on wing





Pylon and nacelle external shapes

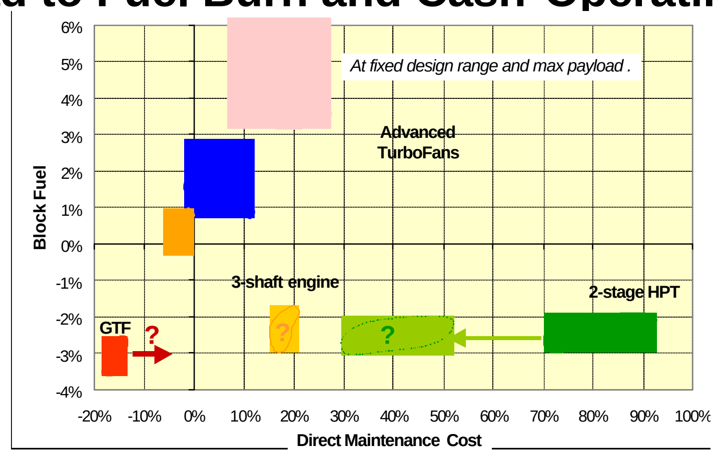
THE TARGET FUNCTION

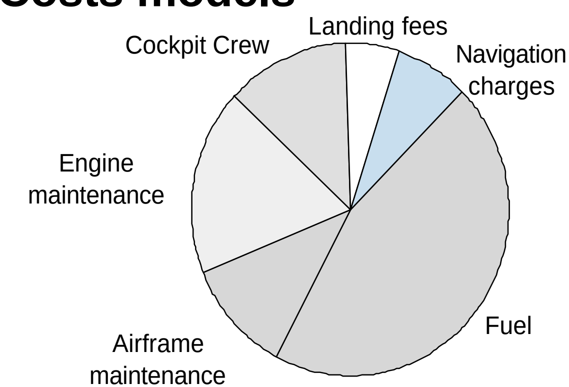
- **The design process aims at minimising a combination of :**

  ➢**Manufacturers' costs : recurring and non-recurring …**
  ➢**Operators' cost : fuel burn, maintenance, airport fees …**
  ➢**Community "cost": sustainable growth aspects, environmental factors …**

- **This target is not a direct computed function of the degrees of freedom. It must be approached qualitatively, with basic decisions at every step**

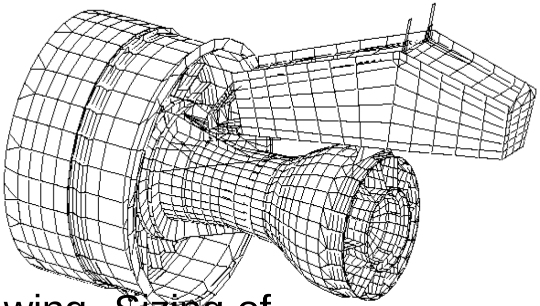
- **Engineering driven cost targets often relate to few basic drivers : <u>weight, drag, engine SFC, noise dBs</u>.**
  They lead to Fuel Burn and Cash-Operating-Costs models



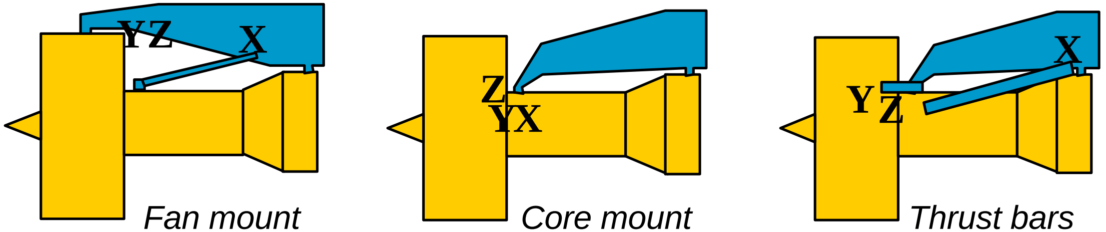


WEIGHT DRIVER : LOADS & DESIGN PRINCIPLES

- Structural sizing of engine/pylon/wing interfaces for certification requirements :
  - reaction to gusts and windshears
  - wheels-up landings (landing gear extension failure)
  - fan blade off (engine failure) and windmilling (cf Cathay Pacific B747 incident, Nov. 1993)



- Most loads cases depend closely on engine location on the wing. Sizing of engine/pylon/wing attachements, with various concepts, may impact space allocation and minimum pylon width.



- Some load cases, like Fan Blade Off, requires complex FEM computational models

• Affects engine position and pylon primary structure sizing
• Sometimes trade-off between contradictory engine/airframe benefits

DRAG DRIVER : INSTALLATION DRAG DEFINITION

Installation drag = interference penalties between propulsive system and airframe

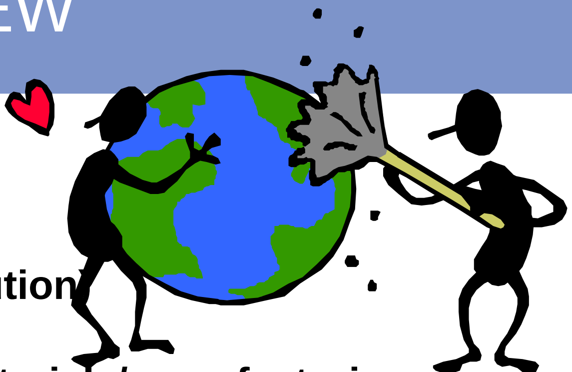
Order of magnitude : 2 to 6% of A/C overall drag

1% drag reduction for long range A340 is :
800 kg of extra payload
100 kEUROS savings for 1 year exploitation

Wing+Pylon+Nacelle (thrust + drag) − Wing alone (drag only) − Isolated nacelle net thrust & nacelle+pylon skin friction

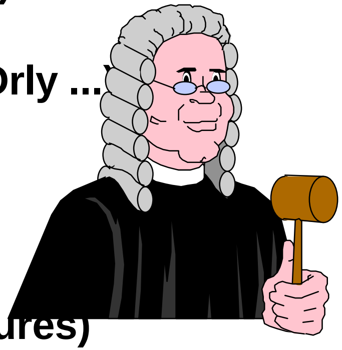
Precise thrust / drag bookkeeping system to be agreed between engine / airframe manufacturers to assess respectives shares in A/C performance

ENVIRONMENTAL DRIVER : OVERVIEW



- **Main factors :**
  - **GAZEOUS EMISSIONS (indirect long term harm, pollution)**
  - **NOISE (immediate harm)**
  - **HAZARDOUS MATERIALS (restrictions on certain materials/manufacturing process)**

- **Regulating process :**
  - **Airworthiness requirements (ICAO - Chicago Agreement / FAR36)**
  - **National laws (eg : French landing tax for noisy A/C)**
  - **Airport local restrictions (eg : Heathrow, Washington National, Orly ...)**
  - **Airline demands ("Green" brand image)**



- **Affects :**
  - **Engine design and integration on the Aircraft**
  - **Operational handling of the Aircraft (take-off and landing procedures)**

Growing consideration for Aerospace Industry due to :
- **increase of Air Traffic**
- **increase of Environmental preoccupation in public opinion**

DESIGN REQUIREMENTS : GENERAL

- **Propulsion system integration must fulfill various design requirements. These an be split in <u>different classes</u> :**

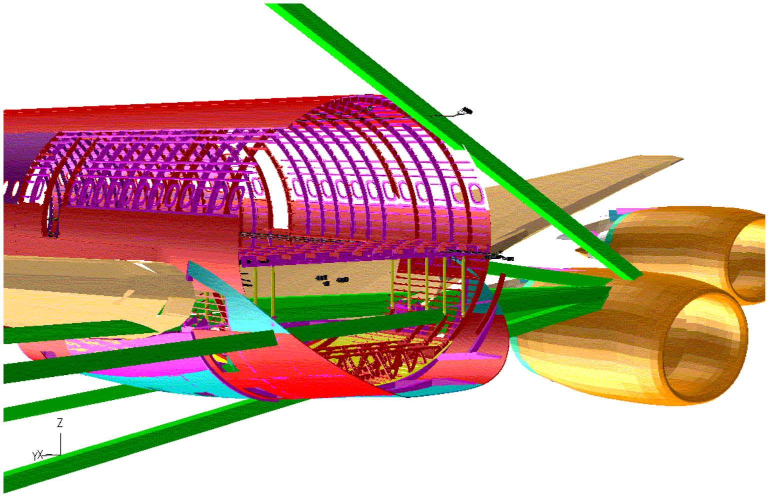
  - ***Safety and Airworthiness*, normal of failure modes**
  - ***Operations*, in-flight, on ground and overhaul procedures**
  - ***Space allocation*, for initial and future growth versions**

- **Compliance to requirements <u>reduces drastically the optimisation window.</u>**
- **Requirements can sometimes be <u>challenged</u> with innovative solutions**

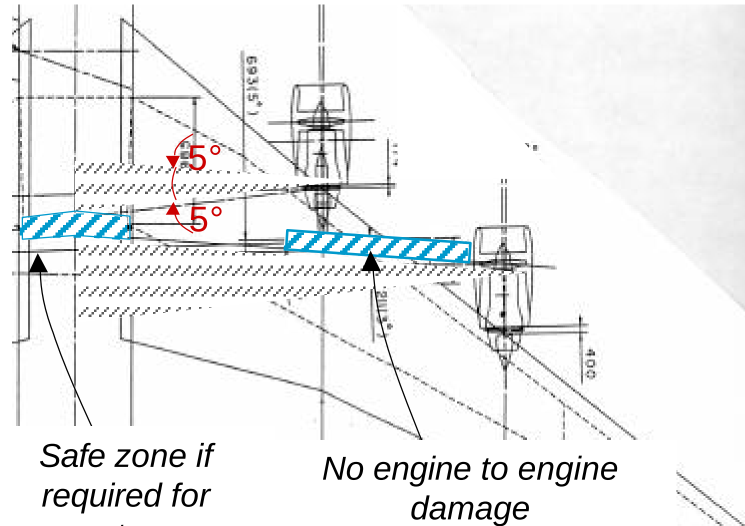
•Bounds the optimisation window
•Must consider and protect full A/C family concept

SAFETY REQts : ENGINE BURST- (FAR/JAR 25.903)

Systems segregation

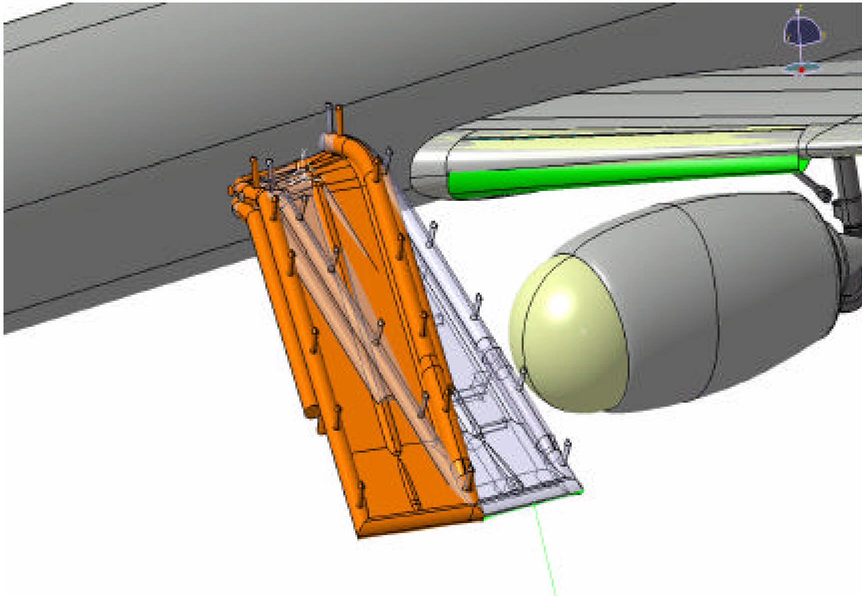


Configuration driver



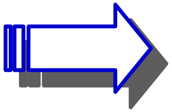
Affects engine position or engine size envelops

SAFETY REQts : EMERGENCY EVACUATION



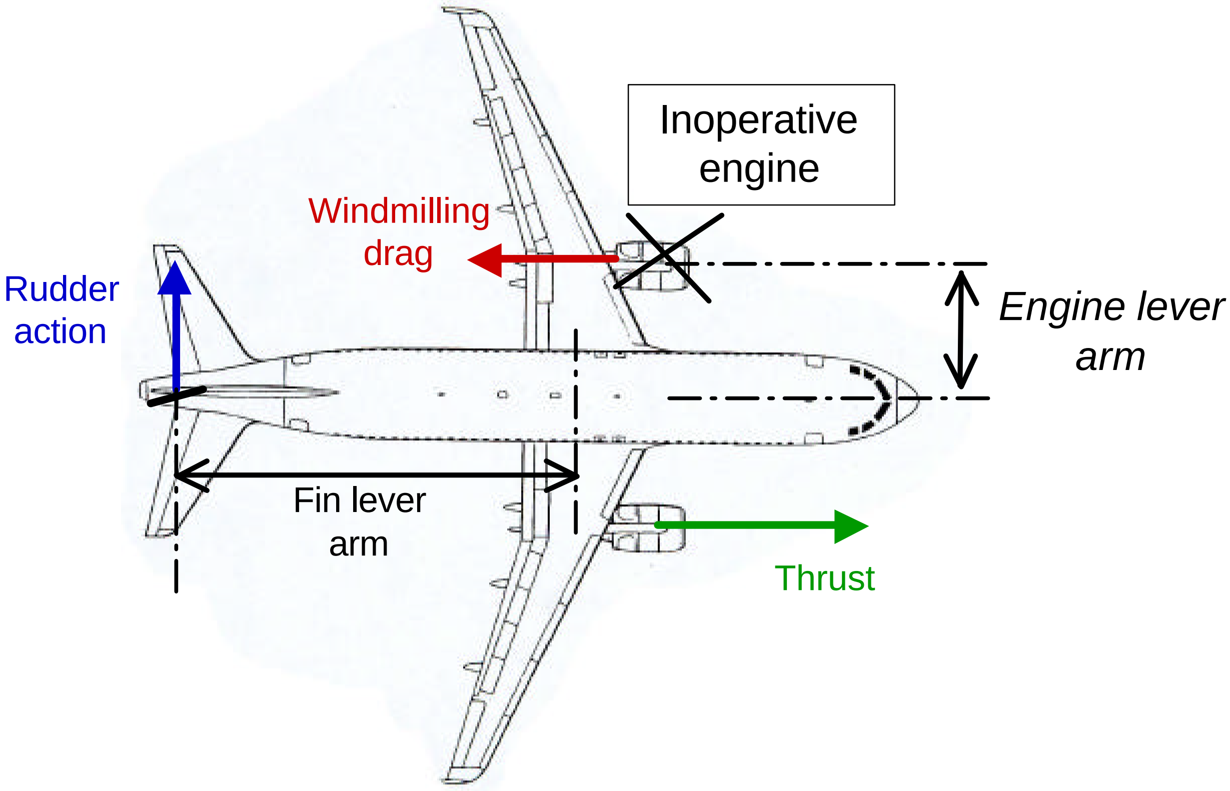
ESCAPE SLIDE & HAZARD ZONE

Slide deployment not always in ideal conditions (A310 -Vienna -10 July 2000)



Affects engine position or engine size envelops, (traded with doors location and slide cant angle)

AIRWORTHINESS REQts : ENGINE FAILURE



LATERAL CONTROL, ONE ENGINE FAILURE CASE

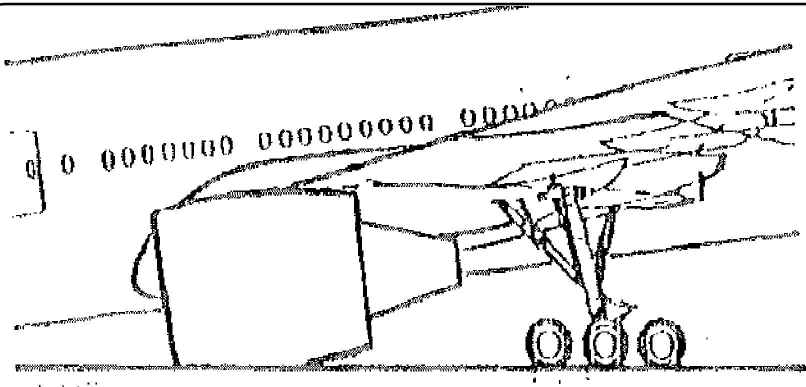
Trade-off fin size & rudder efficiency vs wing bending relief

AIRWORTHINESS REQts : WATER SPRAY

FLOODED RUNWAY SPRAY INGESTION FROM LANDING GEAR

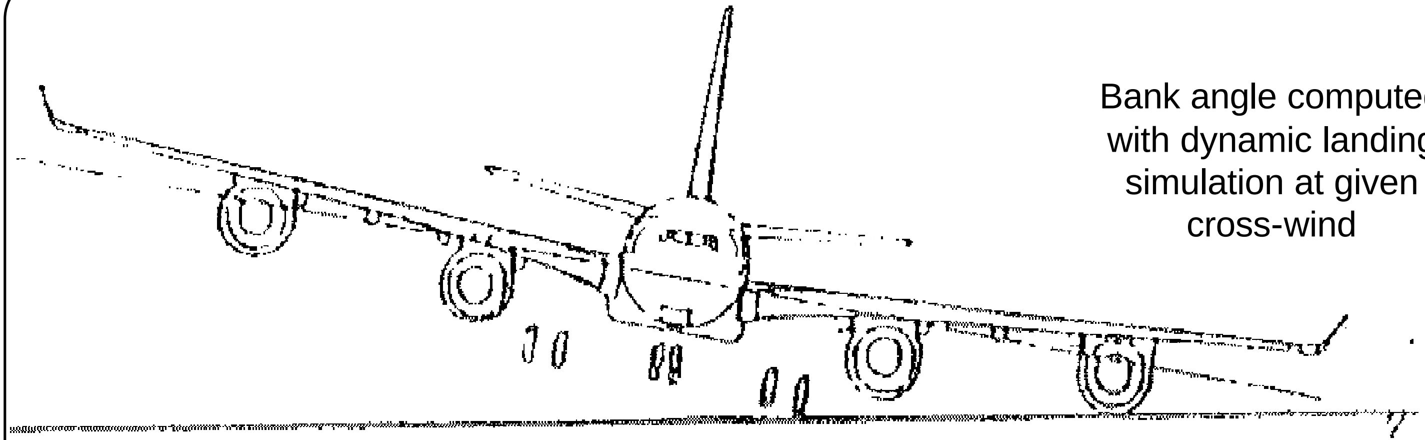
May limit engine location window or require deflector on nose landing gear

OPERATIONAL REQts : GROUND CLEARANCE



Nacelle damage acceptable if engine fan case protected

COLLAPSED NOSE GEAR



Bank angle computed with dynamic landing simulation at given cross-wind

BANK ANGLE (CROSS-WIND LANDINGS)

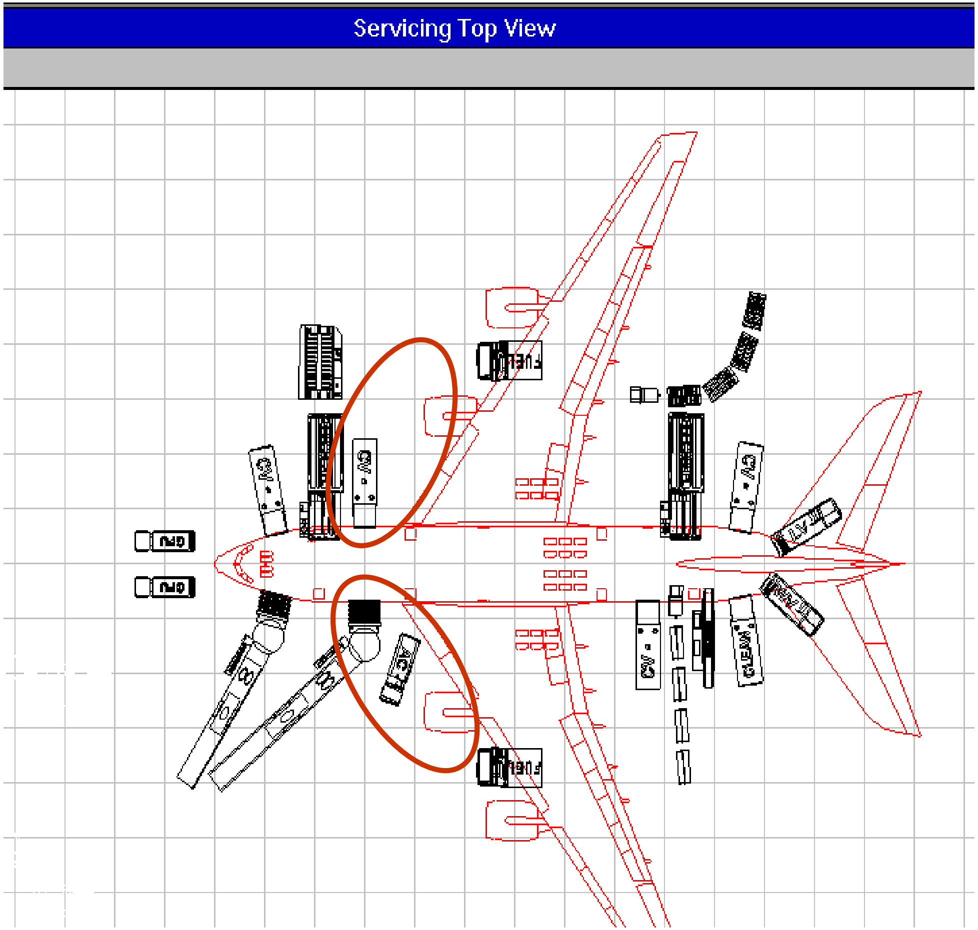
Affects engine position or engine size envelops

OPERATIONAL REQts : GROUND CLEARANCE

Rejected Approach, side wind-TAP_321_VENTOS_FORTES.ASX

Engine STRIKE (CROSS-WIND LANDINGS)

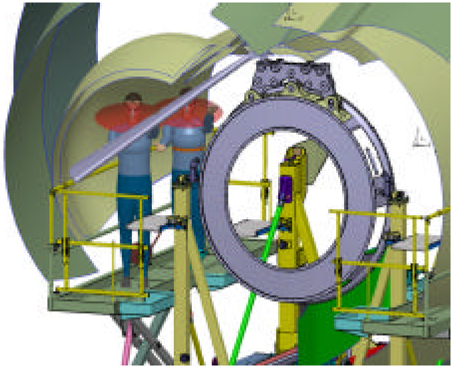
OPERATIONAL REQts : RAMP-HANDLING

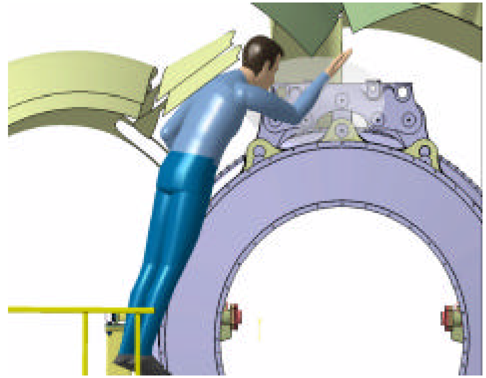


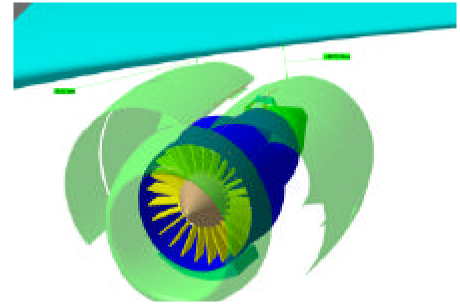
Easy access of Ground Service Equipements, to avoid damage to A/C structure

Affects engine position relative to fuselage doors

OPERATIONAL REQts : MAINTENANCE ASPECTS

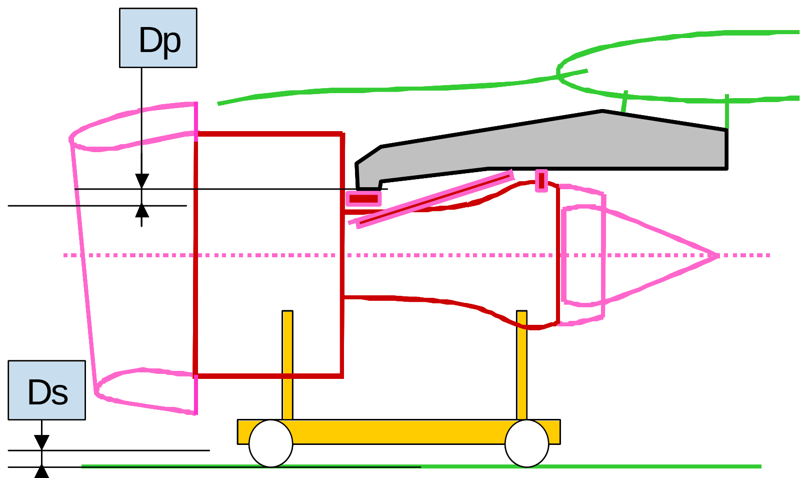






No clash between extended high lift devices and open engine cowls

ENGINE ACCESS – OPEN COWLS



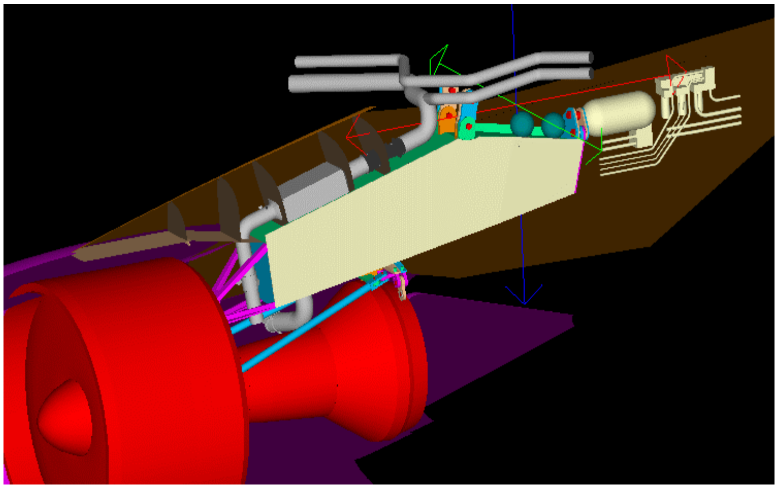
Minimum ground clearance for safe transportation & hoisting of spare engine

ENGINE HOISTING – GROUND CART

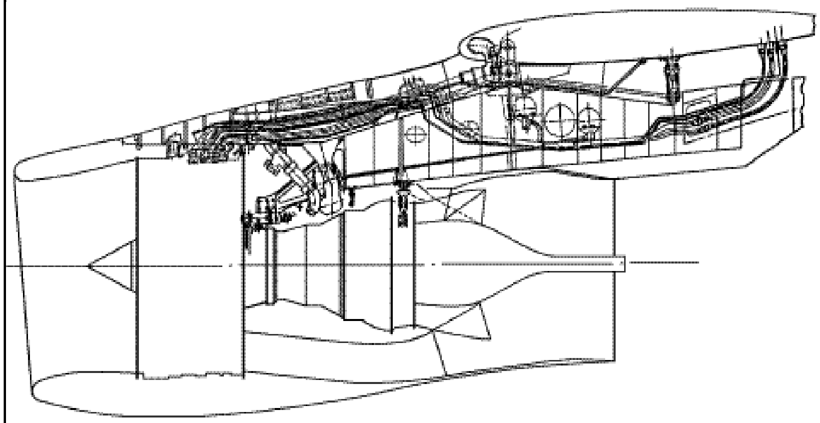
Affects engine position relative to Wing and Ground

SPACE ALLOCATION REQts : SYSTEMS ROUTING

Space allocation for the various systems interfacing the engine and the airframe, with segregation requirements



BLEED AIR SYSTEM



ELECTRICS, HYDRAULICS

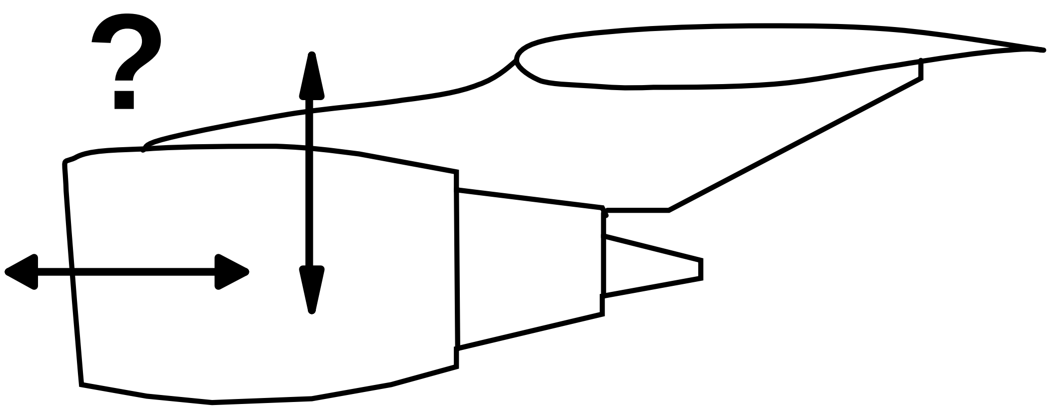
Affects : minimum pylon width and crest line for secondary shapes aerodynamic design

DESIGN DRIVERS : A DIFFICULT LIVING TOGETHER !

To satisfy following criteria

Engine should

To satisfy following criteria	Engine should
Ground clearance …………………………..	Move **upward**
Static and dynamic loads ………………..	Move **backward**
Turbine burst ……………………………….	Move **forward**
Wing bending relief …………………….	Move **outboard**
Lateral control (engine failure) ……….	Move **inboard**
Noise reduction …………………………….	**Long cowl** design
Drag minimization ……………………..	Move **downward** and **forward** ; **Short cowl** design



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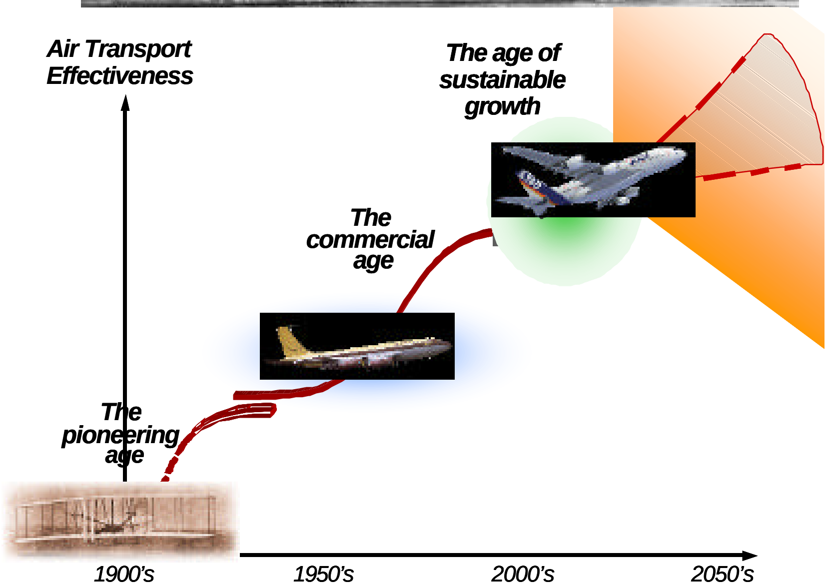
ENVIRONMENTAL ISSUES RECOGNISED

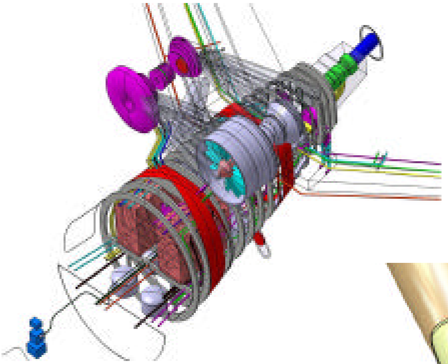


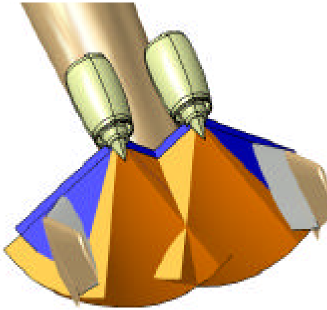
- **Quality and Affordability**
- **Safety**
- **Environment :**
  - *Reduction of CO_2 by 50%*
  - *Reduction of NOx by 80%*
  - *Reduce perceived external noise by 50%*
  - *Substantial progress towards 'Green MMD'*
- **Efficiency**
- **Security**

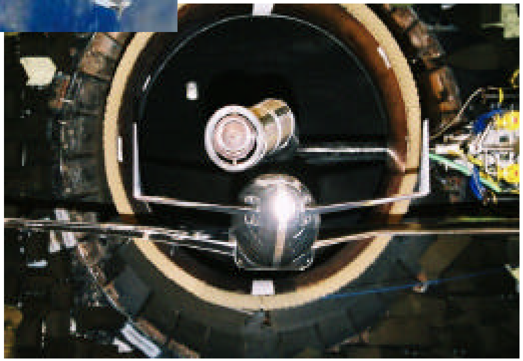
"Vision 2020" – European Aeronautics
January 2001

Evolutionary, or Revolutionary scenarios

GREENER AIRCRAFT CONCEPT







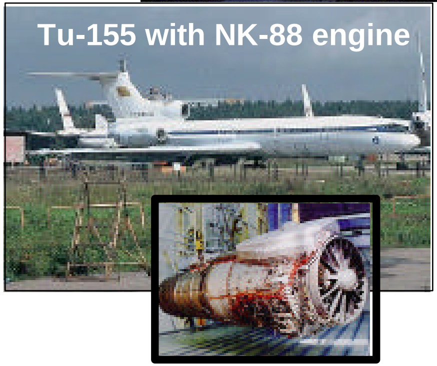
Pros	*Open issues*
• Shielding of engine noise • Lower fuel burn from High aspect ratio wing	• Engine integration (certification, structural concept, aerodynamics interactions) • Accessibility & Maintainability of Engine • trade-off on cruise Mach number

The predictable issue : oil shortage

- **Alternative fuels options :**
  - **Synthetic kerosene**
    - From Coal
    - From Natural Gaz
    - From Methan Hydrates ?
  - **Bio-fuels**
    - Methyl Esthers
  - **Cryogenic fuels**
    - Liquid Natural Gaz (LNG)
    - Liquid Hydrogen (LH2)







➢ A possible scenario :

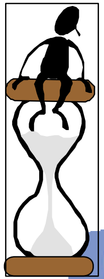
? ***cryogenic Hydrogen***

? ***Synthetic, methan based kerosene***

Synthetic, gaz based kerosene ?

Oil based kerosene (current) + bio-fuel addition ?

2000 — 2010 — 2020 — 2030 — 2040 — 2050



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ILLUSTRATIONS

The Unconventional ones …

ANTONOV 70

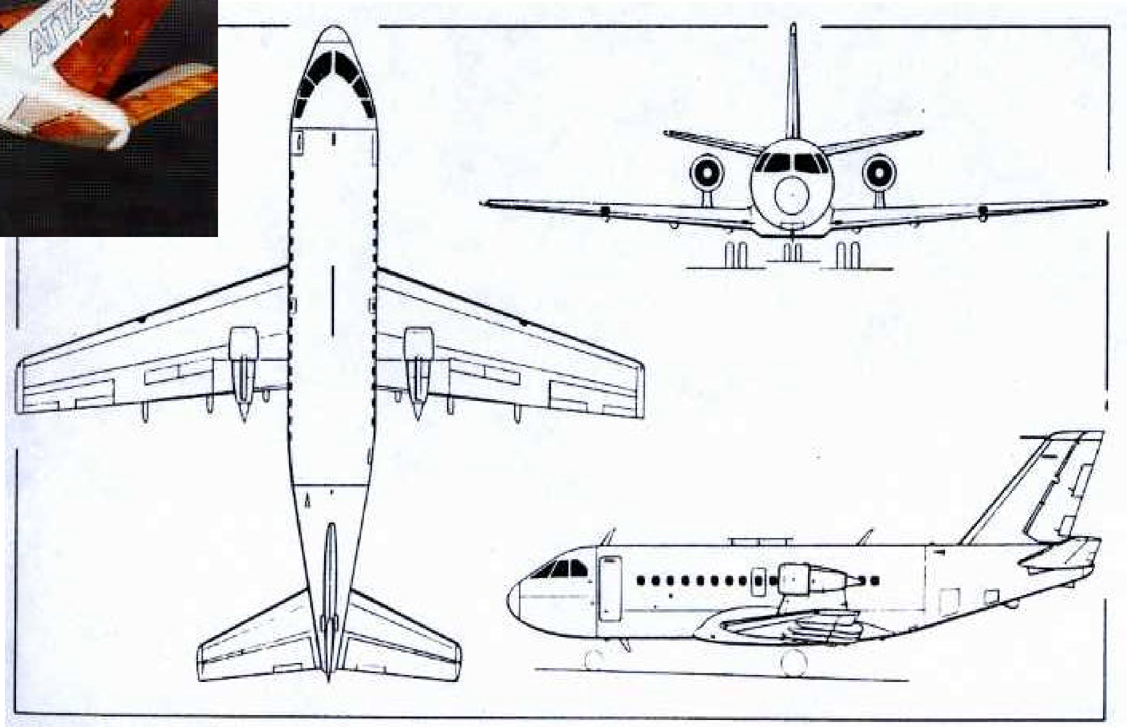
High speed propellers

ANTONOV 225

(wing root insert with additional engines derivated from An 124)

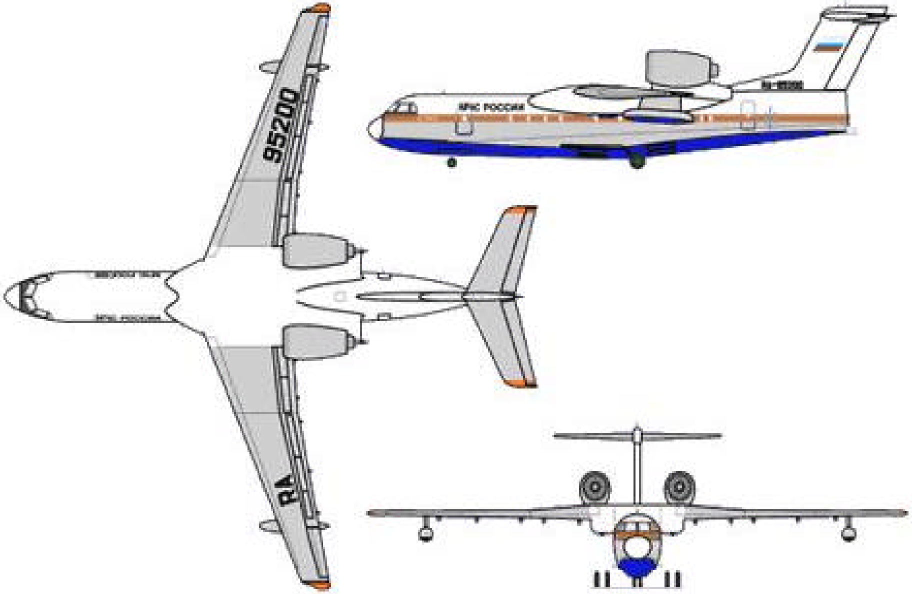
VFW 614 (mid-70s)

research platform
ATTAS in flight



Overwing engine configuration

BERIEV 200



PW 6000 Flight test bed on B720

TR 900 Flight test bed on A340-300

A380 - RR Trent 900 engines -

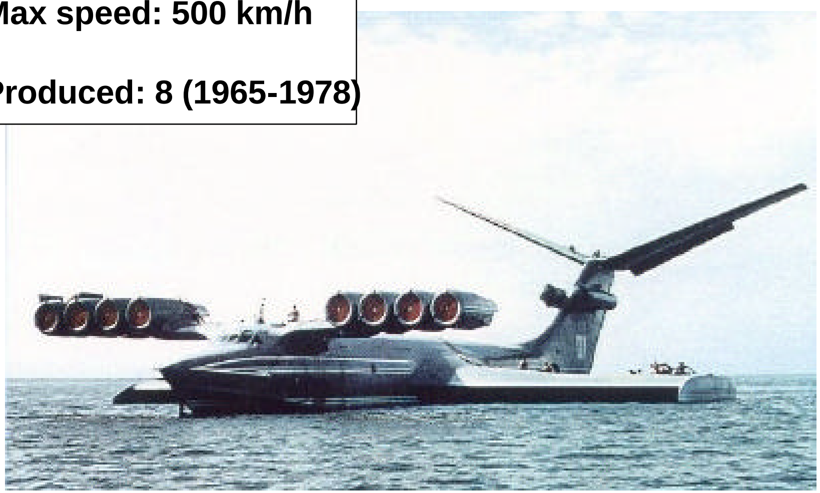
Guess what !

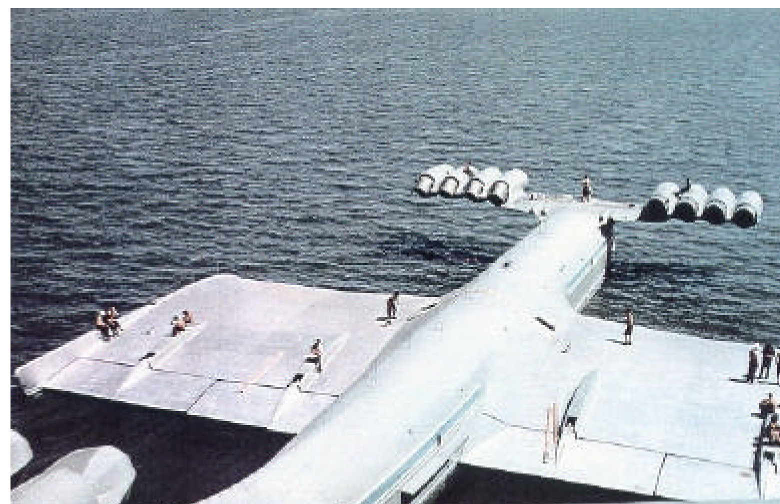
Spare engine ferried to Heathrow, mounted on B747 wing (without reconfiguration)

KM« Caspian Sea Monster », experimental transport

Wingspan: 40 m
Length: 106 m
Height: 22 m
MTOW: 550 t
Max speed: 500 km/h

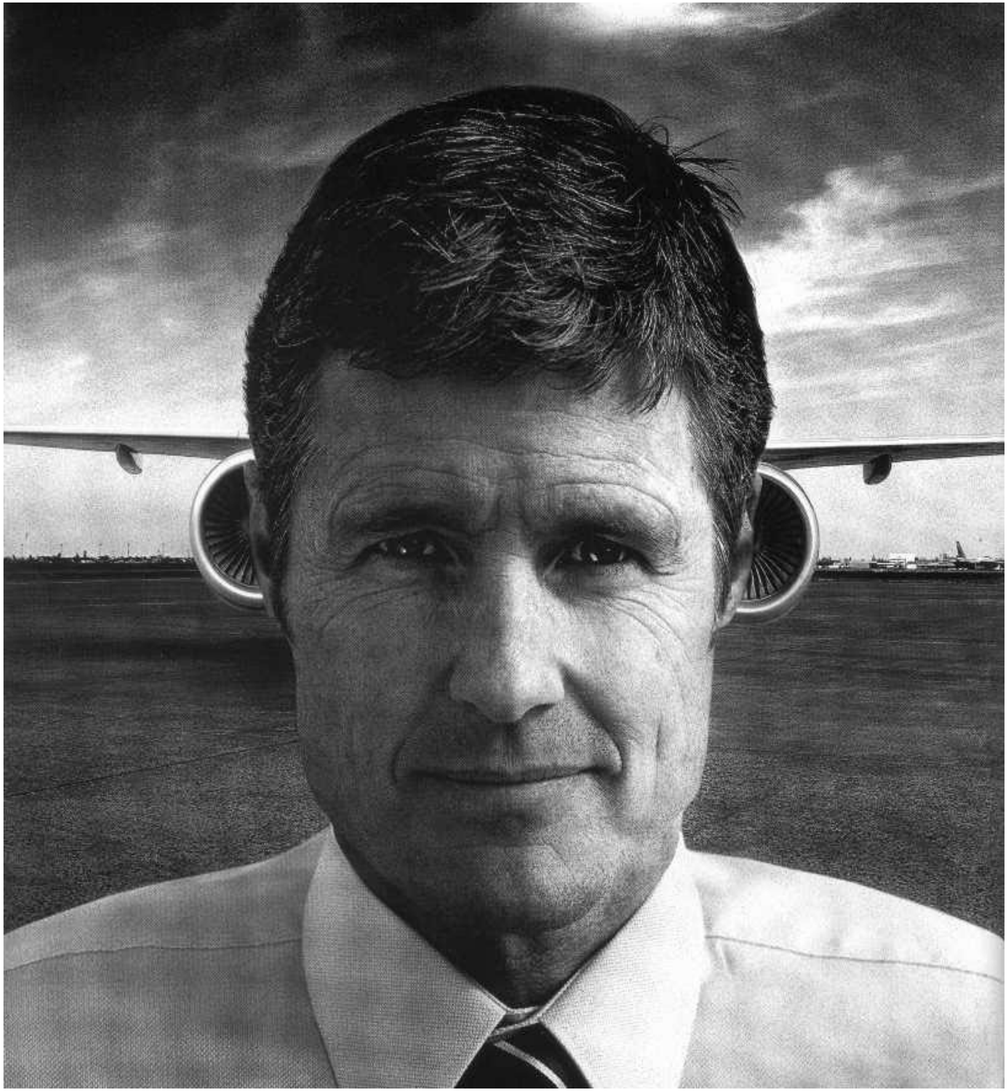
Produced: 8 (1965-1978)





New challenges ?

Thank you for your attention !



AIRBUS

AN EADS COMPANY