***Airbus A380*:**
Solutions to the Aerodynamic Challenges of Designing the World's Largest Passenger Aircraft

Royal Aeronautical Society, Hamburg Branch / DGLR / VDI / HAW

Axel FLAIG, Head of Aerodynamics, Airbus

Presentation overview

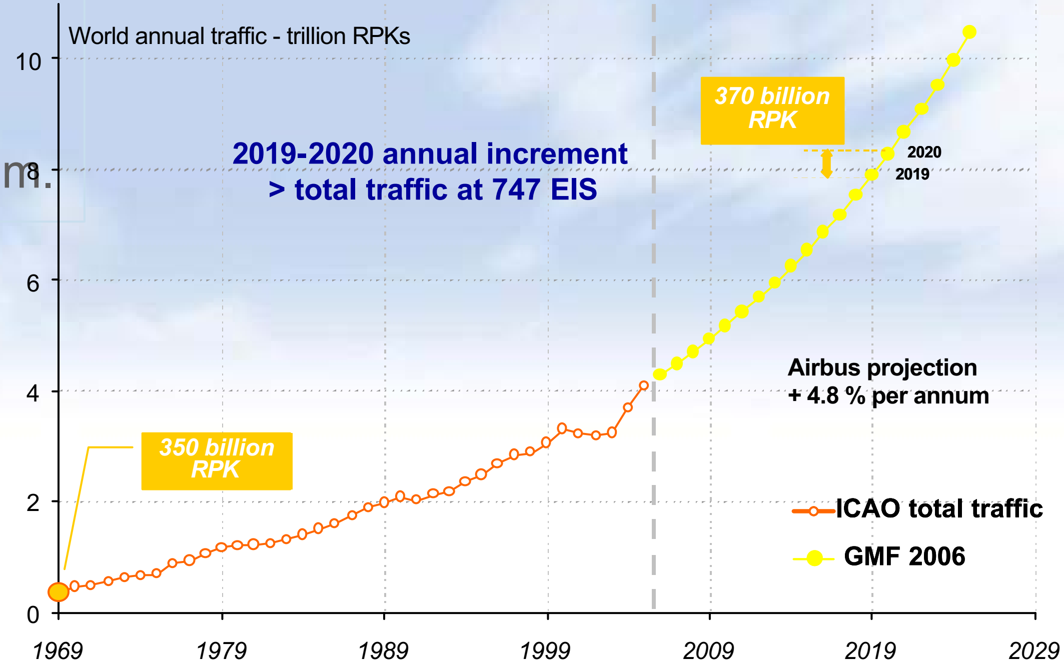
- Introducing the Airbus A380
- Airbus Aerodynamics
- Aerodynamic Design Challenges on A380
- The Aerodynamic Solutions – Some examples
- Flight Test

Introducing…

Introduction:
The Market Drivers for A380

Traffic Growth

- Predicted increase in traffic growth of almost 5% per annum.



Airport Congestion

- Main airport hubs already overcrowded.

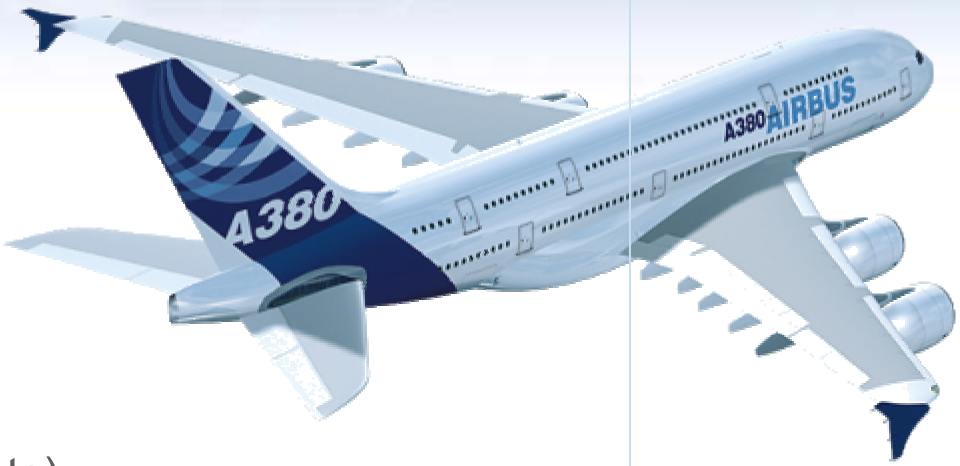
Environmental Impact

- Increased pressure to reduce environmental impact (e.g. ACARE 2020 Vision)
- Significantly reduced emissions
- Significantly reduced noise

Introduction:
The Need for A380

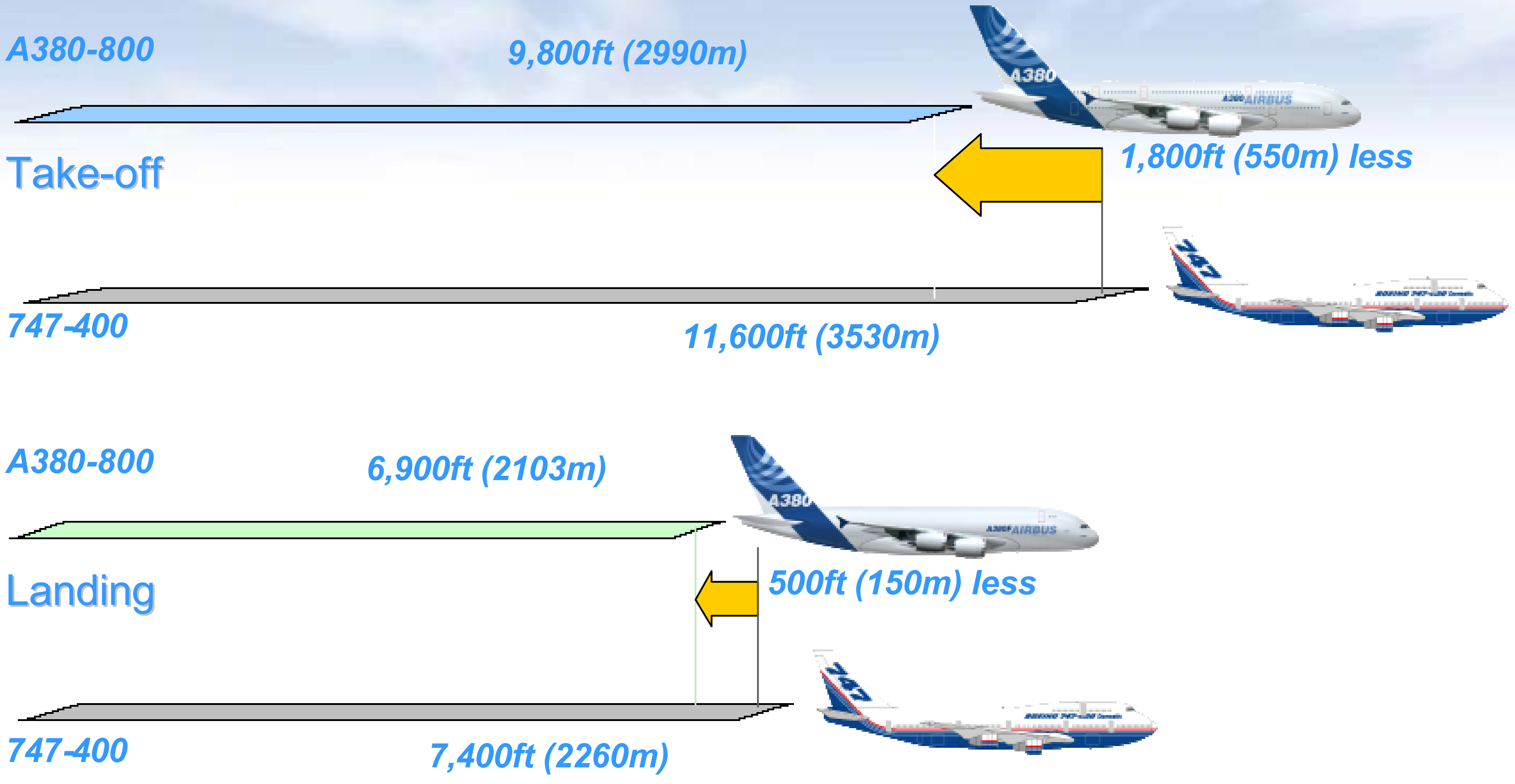
In the early 90s initial market studies identified a need for an aircraft that (in comparison to the Boeing 747 “Jumbo Jet”):

- Has more capacity
  (is significantly larger)
- Has more range
- Has more comfort
- Is significantly more efficient
  (up to 20% lower operating costs)
- Is more environmentally friendly
  (less fuel burn, is significantly quieter)

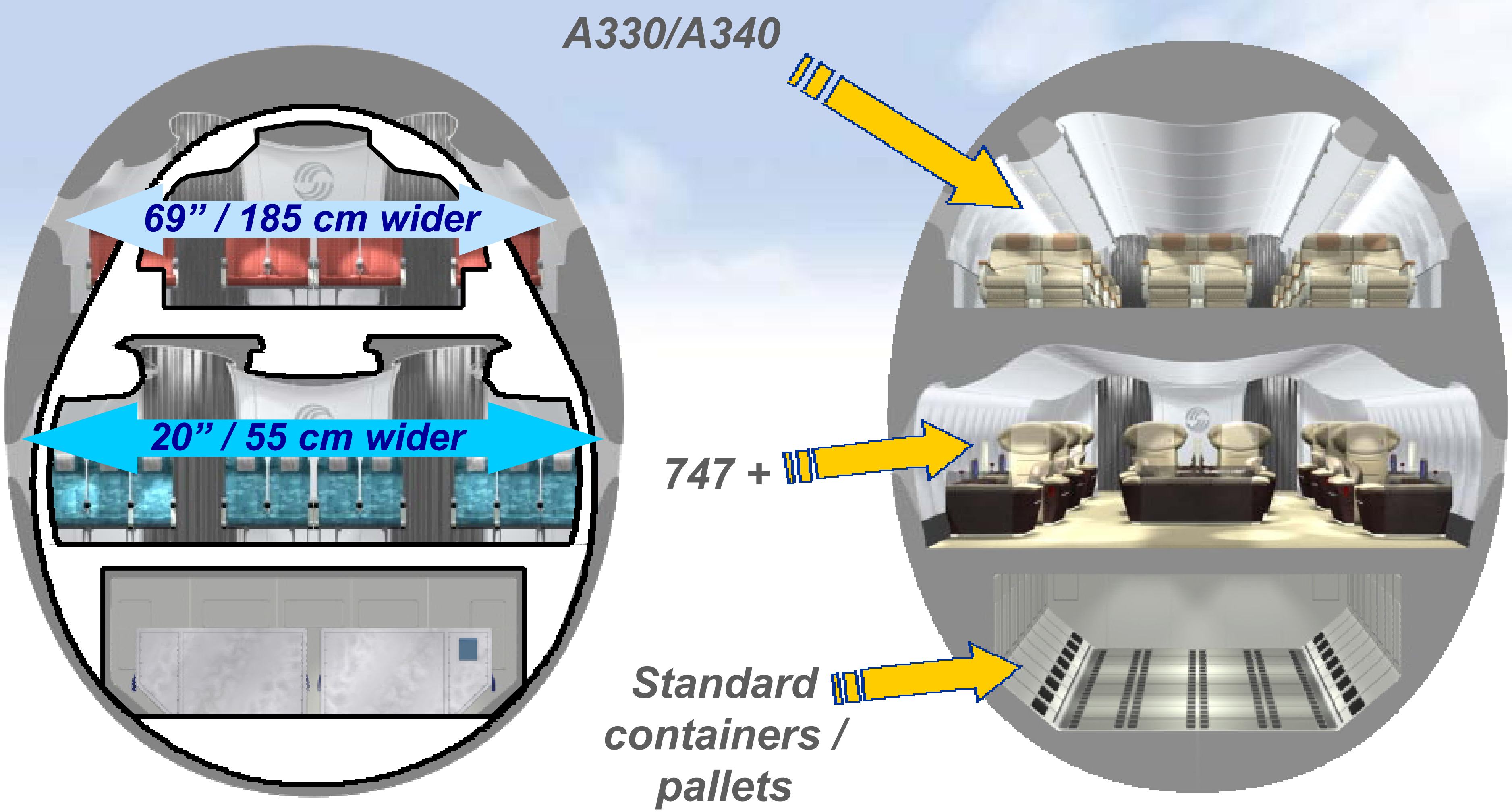


Introduction:
A380 Field Performance

Better field performance



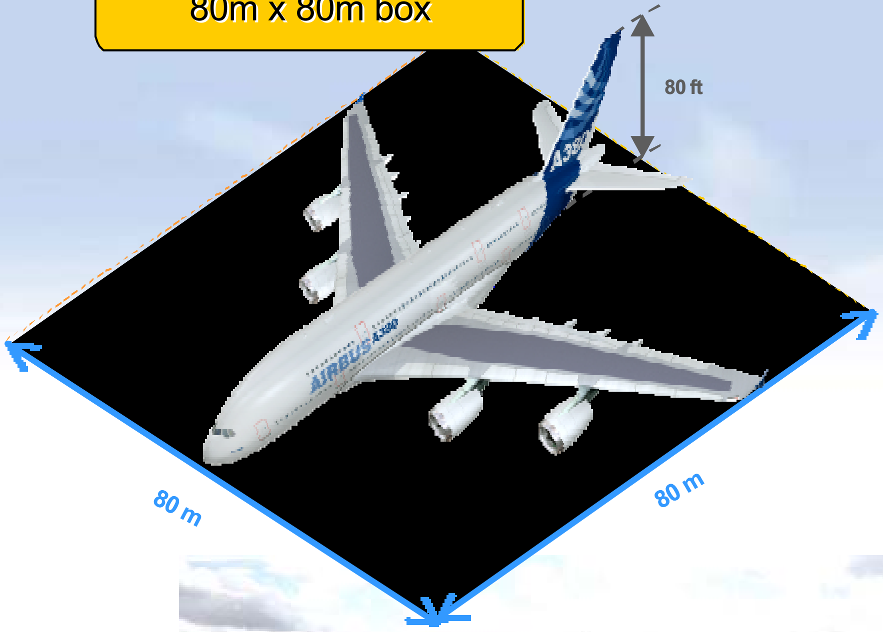
Introduction:
A380 Cabin



A380 has the quietest cabin in sky and provides a very smooth ride!

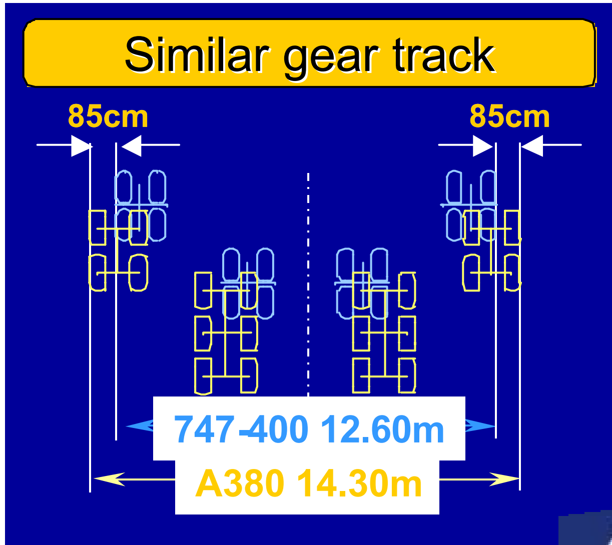
Introduction:
Airport Compatibility

80m x 80m box



AIRBUS S.A.S. 2006 photo by Mike Bromfield

Pavement loading

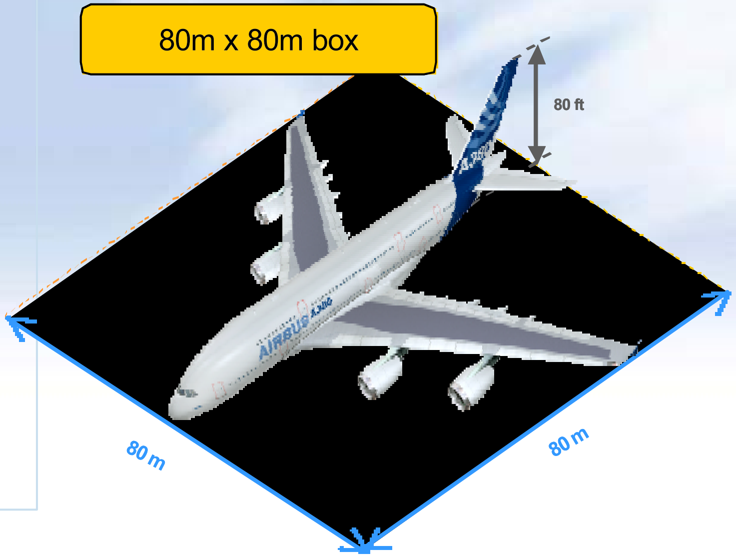


Introduction:
A380 – A Significant Design Challenge

A Significant Design Challenge

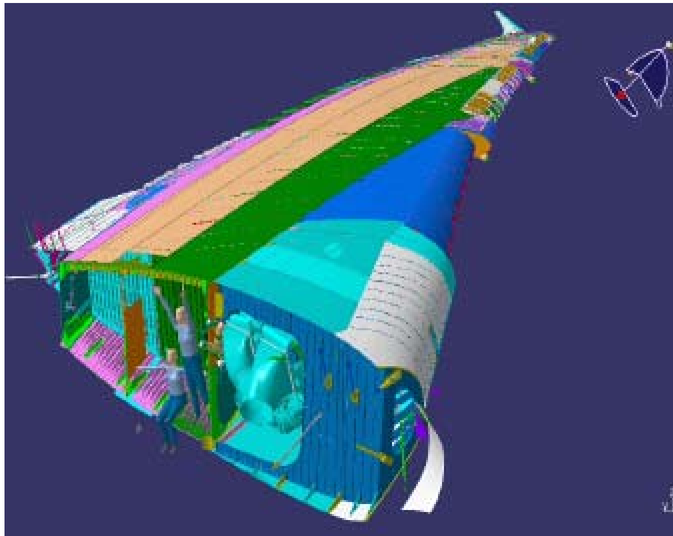
Additional design challenge due to being constrained to operate within the existing airport infrastructure:

- take-off / landing on existing runways
- 80m x 80m x 80ft envelope
- must be able to use existing ground support infrastructure

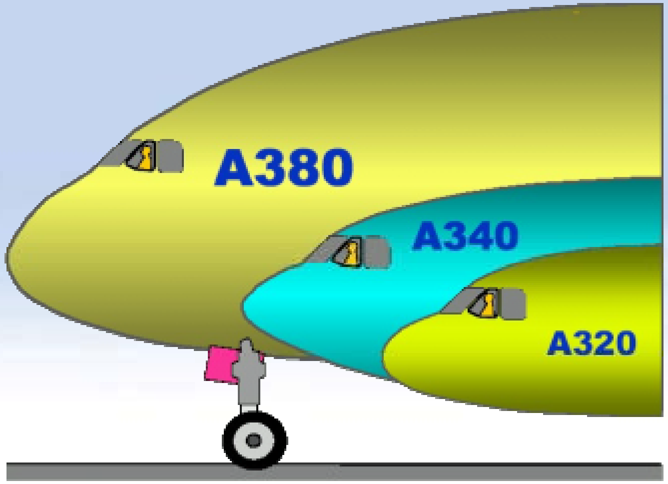


Size

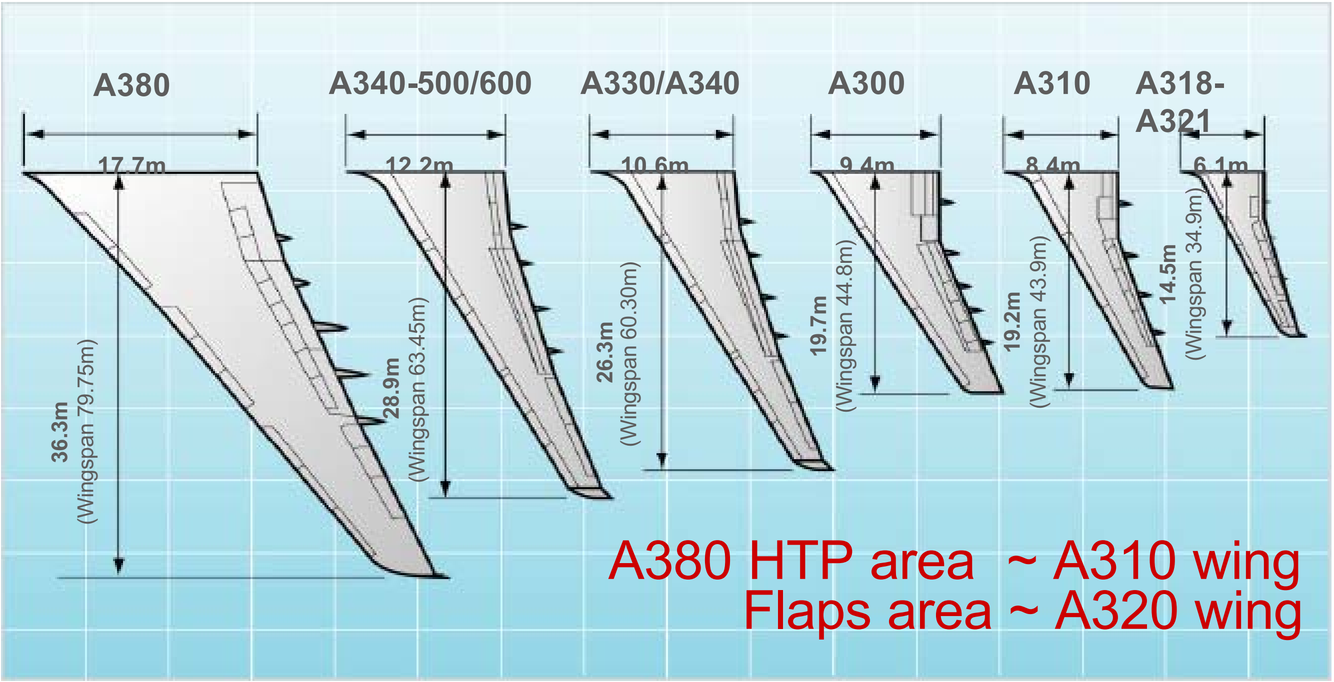
The A380 wing is the largest wing produced for a civil airliner



Introduction:
A380 Size Comparisons



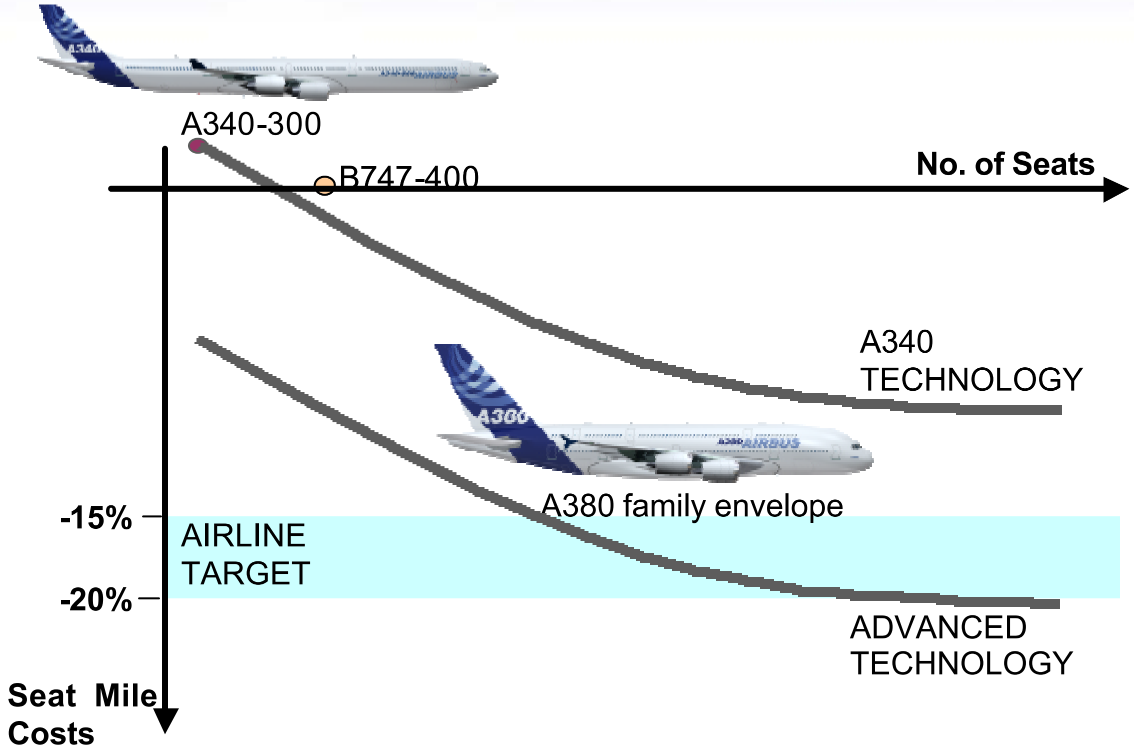
A320 & A380 Section 21 comparison



Introduction:
Advanced Technology

- The key requirement is to offer the capacity / range requirements but with a 15 - 20% seat mile cost advantage over the 747-400

- “Advanced Technology” is required to meet the targets

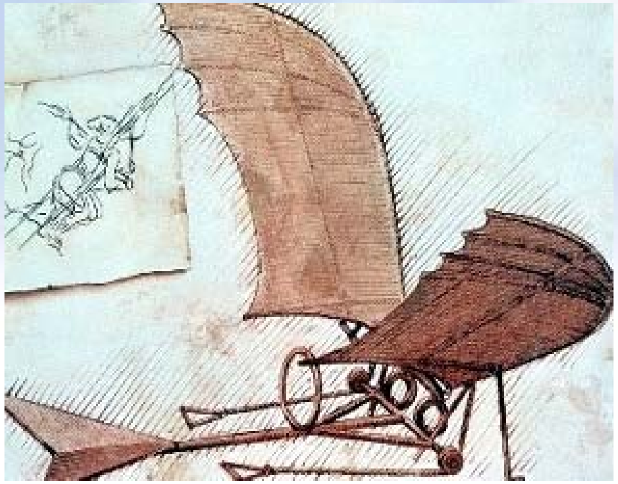


Introduction:
Innovation and Integration

Need for Innovation

Initial studies quickly confirmed that existing technologies would not allow these targets to be met and hence significant innovation would be required in virtually all areas of design:

- Aerodynamics, structures, systems etc
- Design processes
- Manufacturing



Integration

The key to success is not simply single-disciplinary advances but multi-disciplinary advances and integration.

A380 Key Design Features

- Use of advanced materials
  CFRP & GLARE...
- All variants fit in 80m x 80m box
- Complete airport compatibility
- Noise & Emissions improvements
- Fast turn round time

- 15 - 20% lower operating costs
- Cross Crew Qualification
- Engine options
  RR Trent 900
  GP7200
- electro hydrostatic actuators
- 5000 PSI hydraulics

A380 Performance: Superior by Design

Compared with the 747, the A380 :

- requires 10% less runway length to take-off.
- has 4,000 ft higher initial cruise altitude.
- offers the same cruise Mach number.
- has a 20kt lower approach speed.

A380 in the Airbus family

- **8,500** *orders*
- **290** *customers*

- **5000** *delivered to date*
- ***453*** *delivered in 2007*

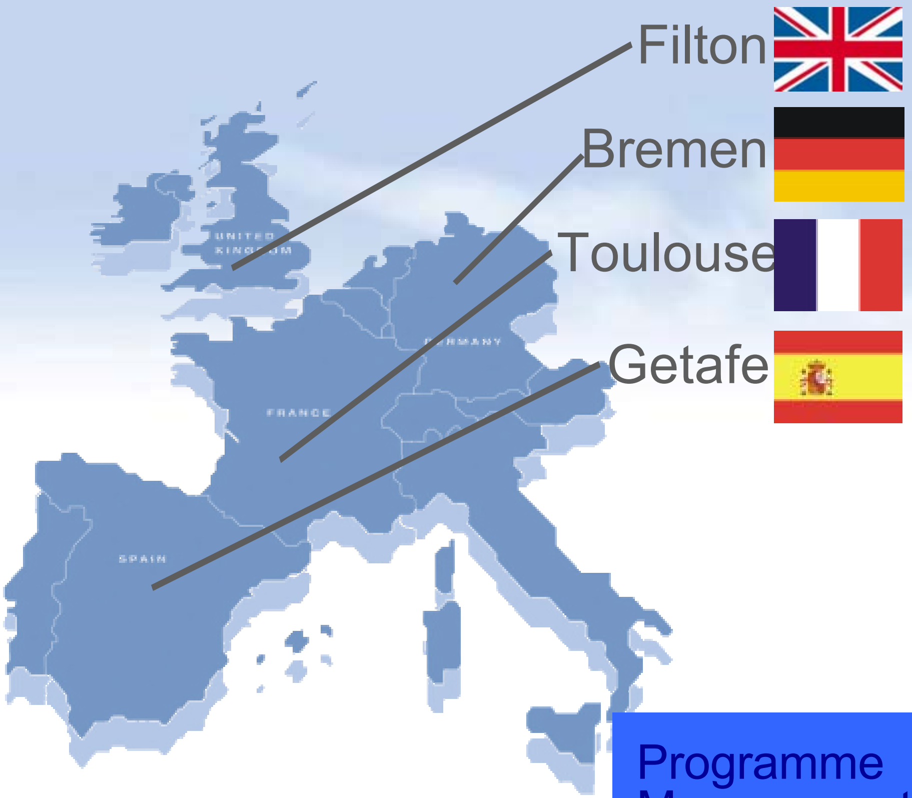
Airbus Aerodynamics

A World-Class, Transnational Team

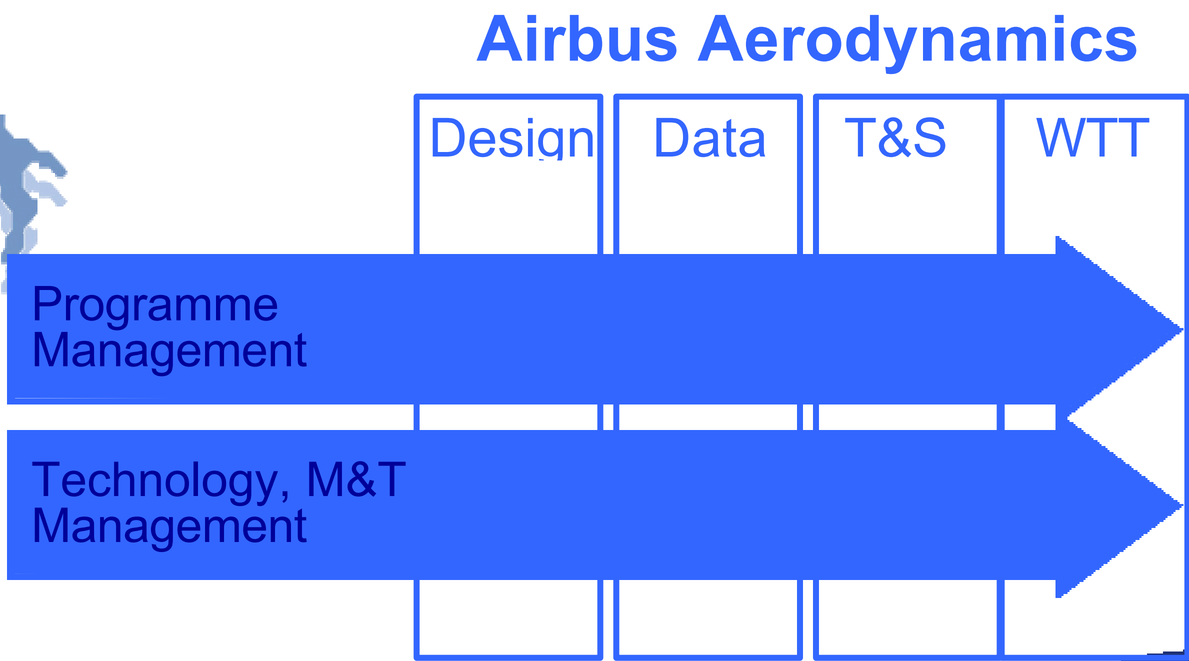
Airbus Aerodynamics

- Aerodynamics - overview
- Aerodynamic design processes
- Aerodynamics evolving strategy

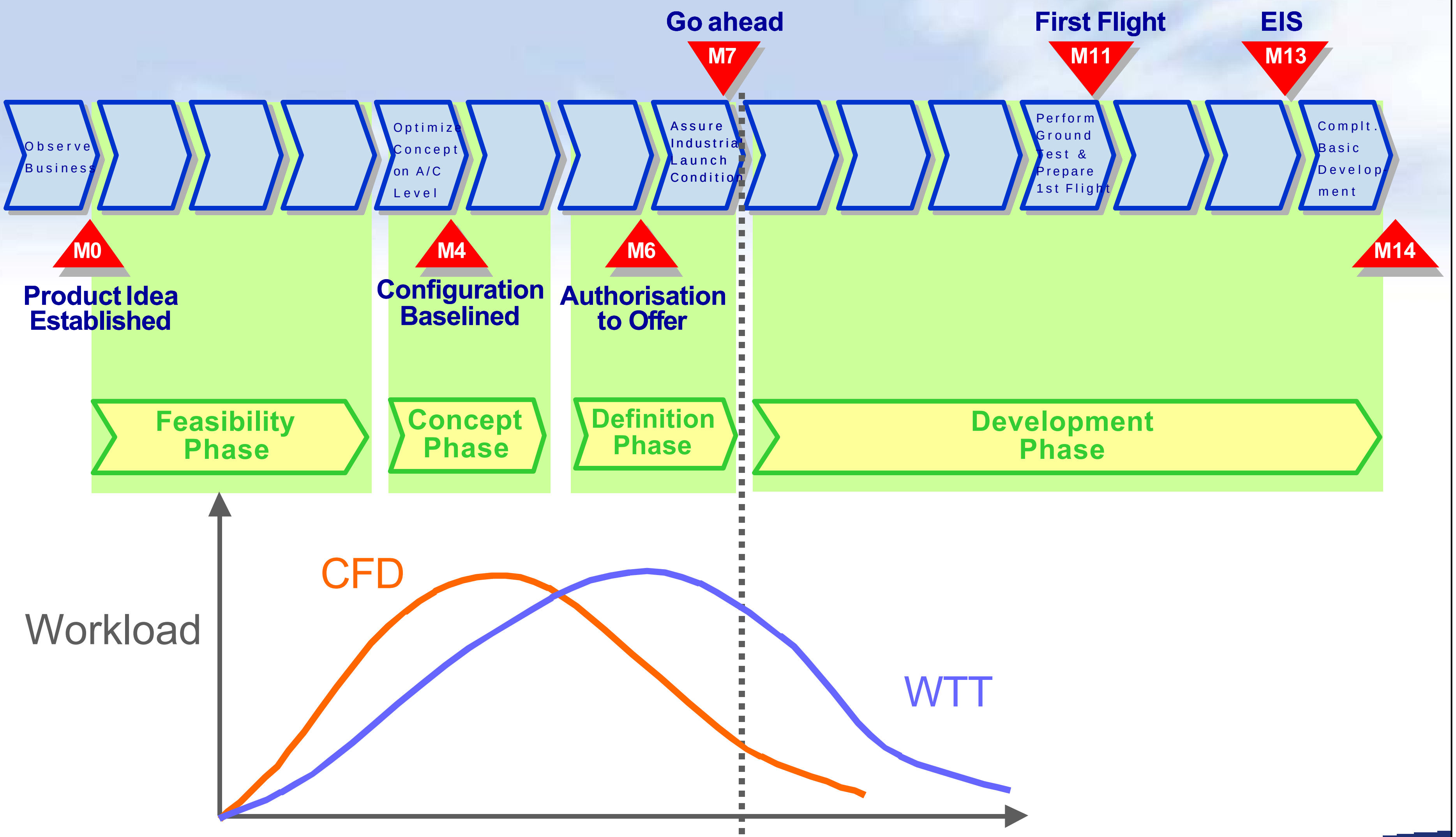
Aerodynamics – A Single Transnational Team



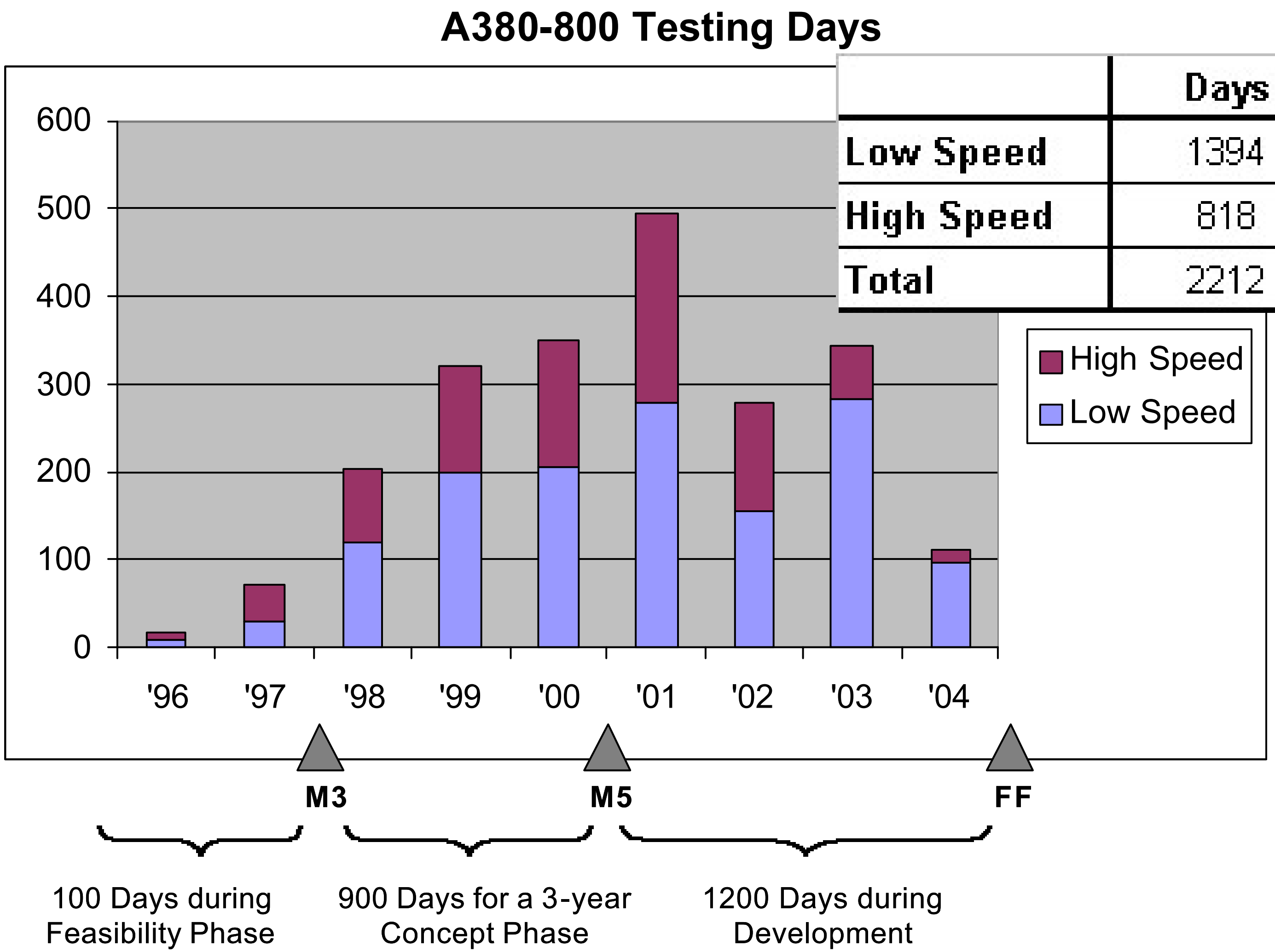
- One Transnational Team
- 4 European sites



Aerodynamics in the Design Process



Aerodynamics in the Design Process

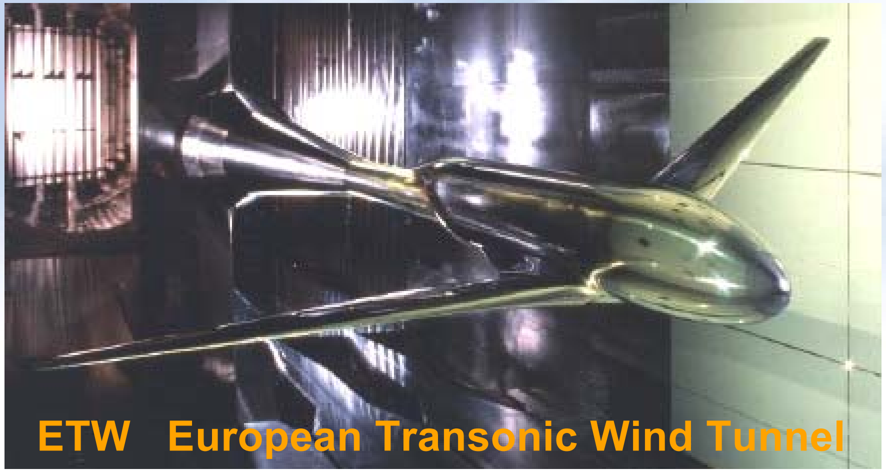


	Days
Low Speed	1394
High Speed	818
Total	2212

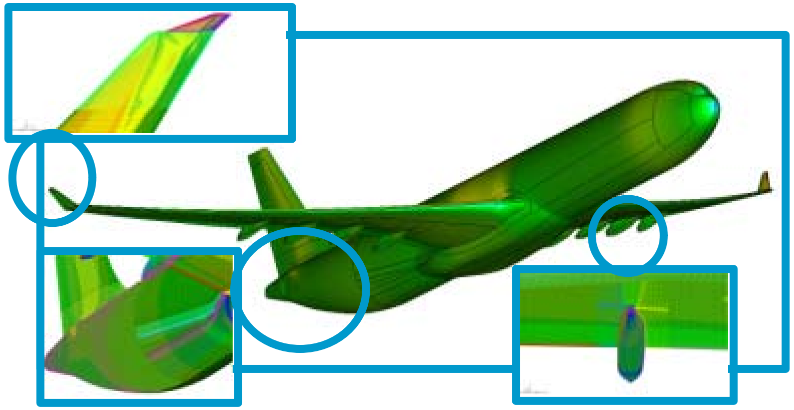
Aerodynamics Evolving Strategy:
Reduce Development Time

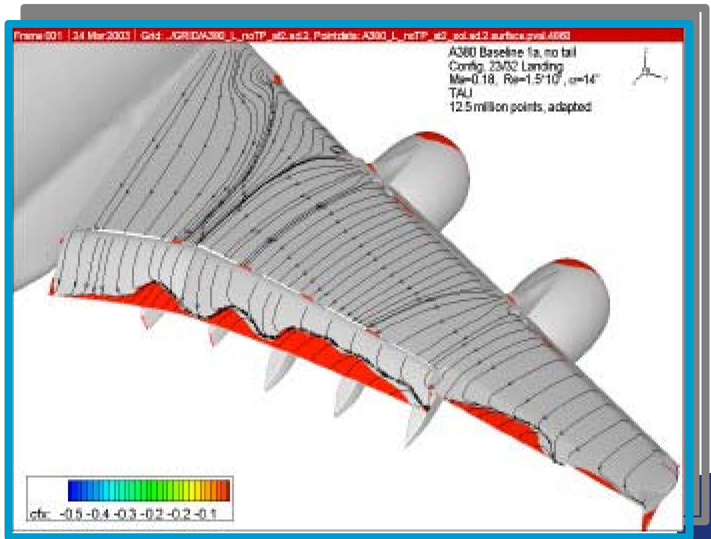
- Faster Development through more efficient processes

- Reduce wind tunnel testing costs
  - Less testing
  - Fewer models
  - Increased use of high Re Testing

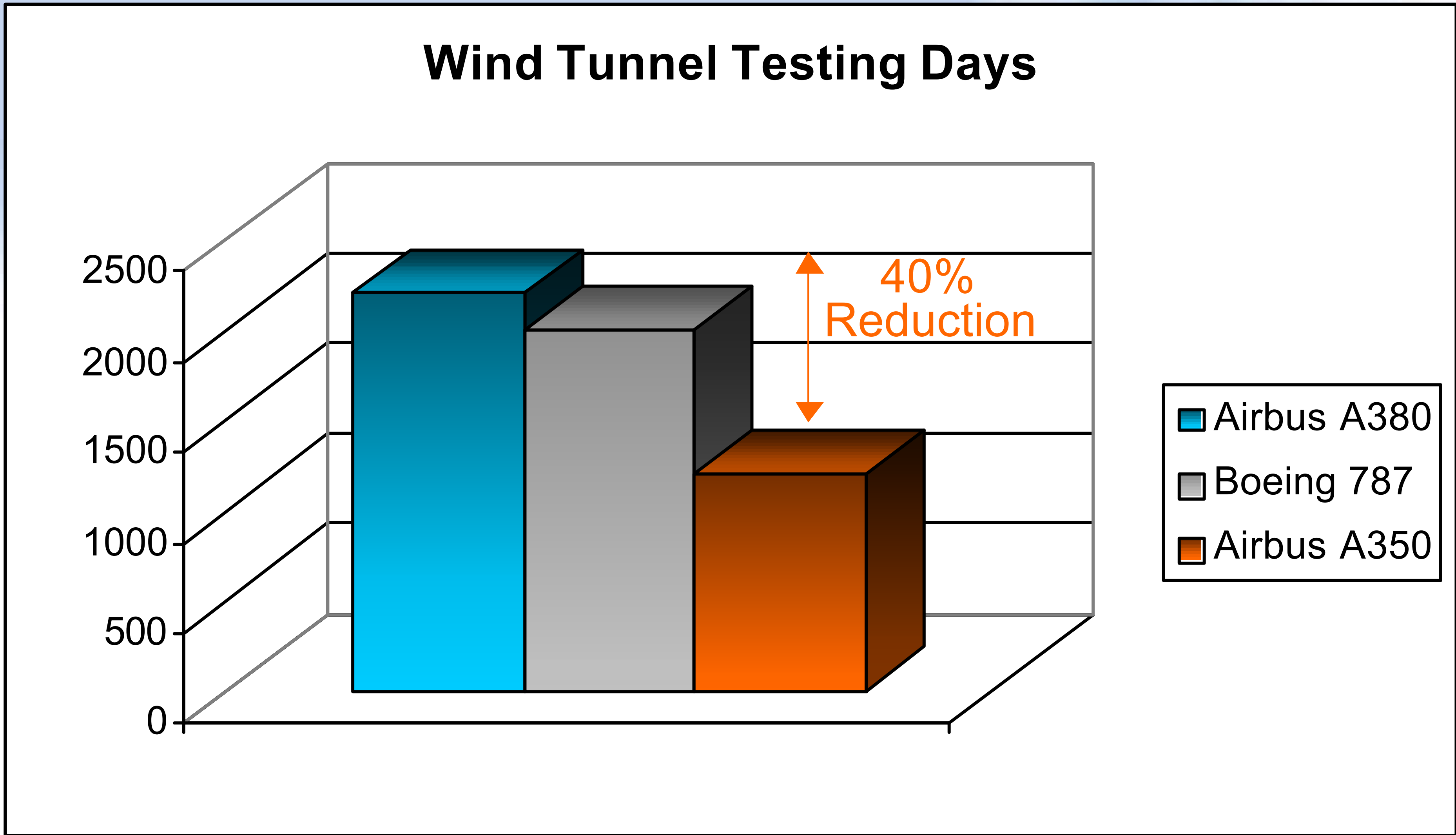


- Complemented by increased use of Advanced CFD



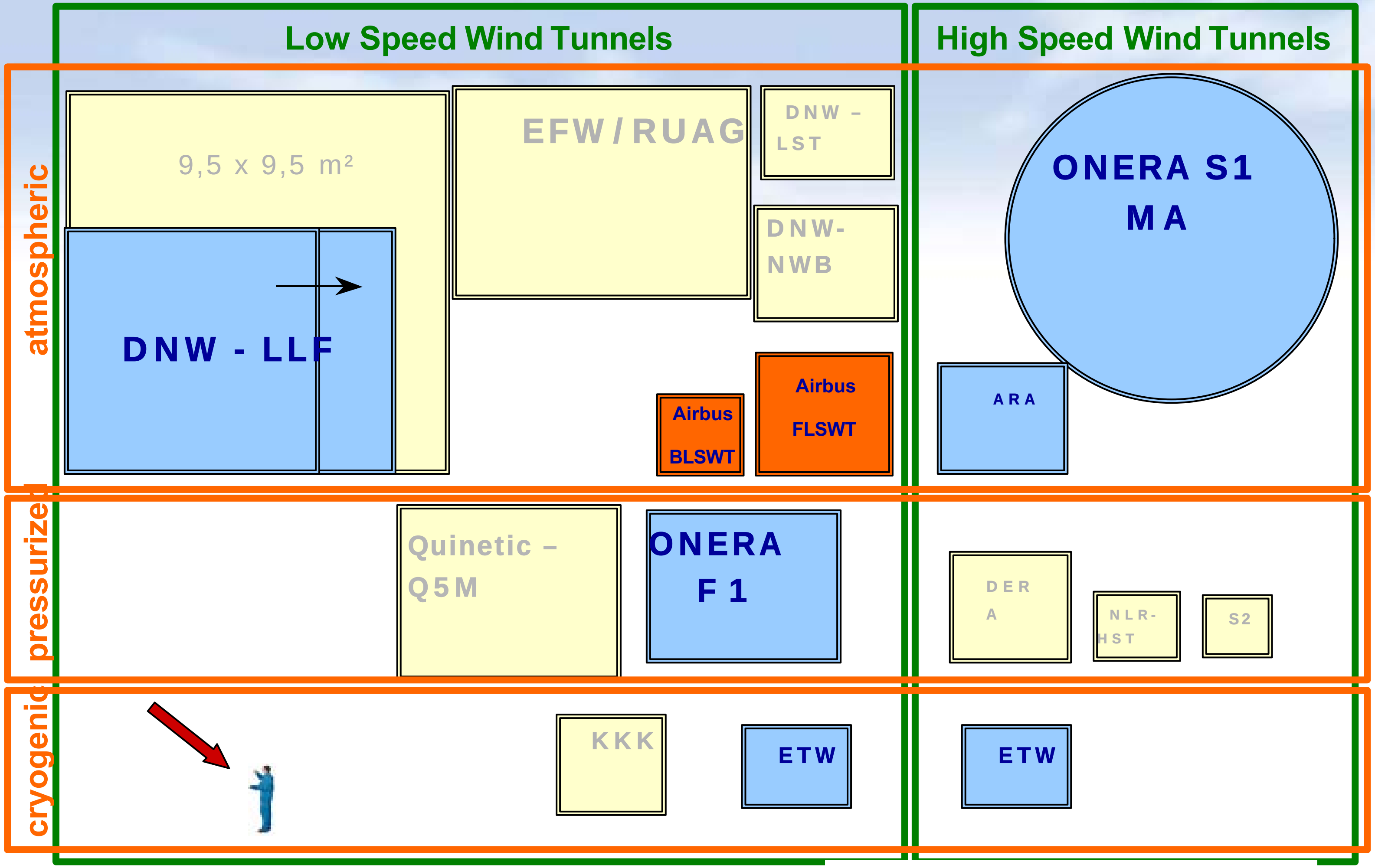


Aerodynamics Evolving Strategy: Reduce Development Time



Aerodynamics Evolving Strategy:
Wind Tunnel Testing: Facilities

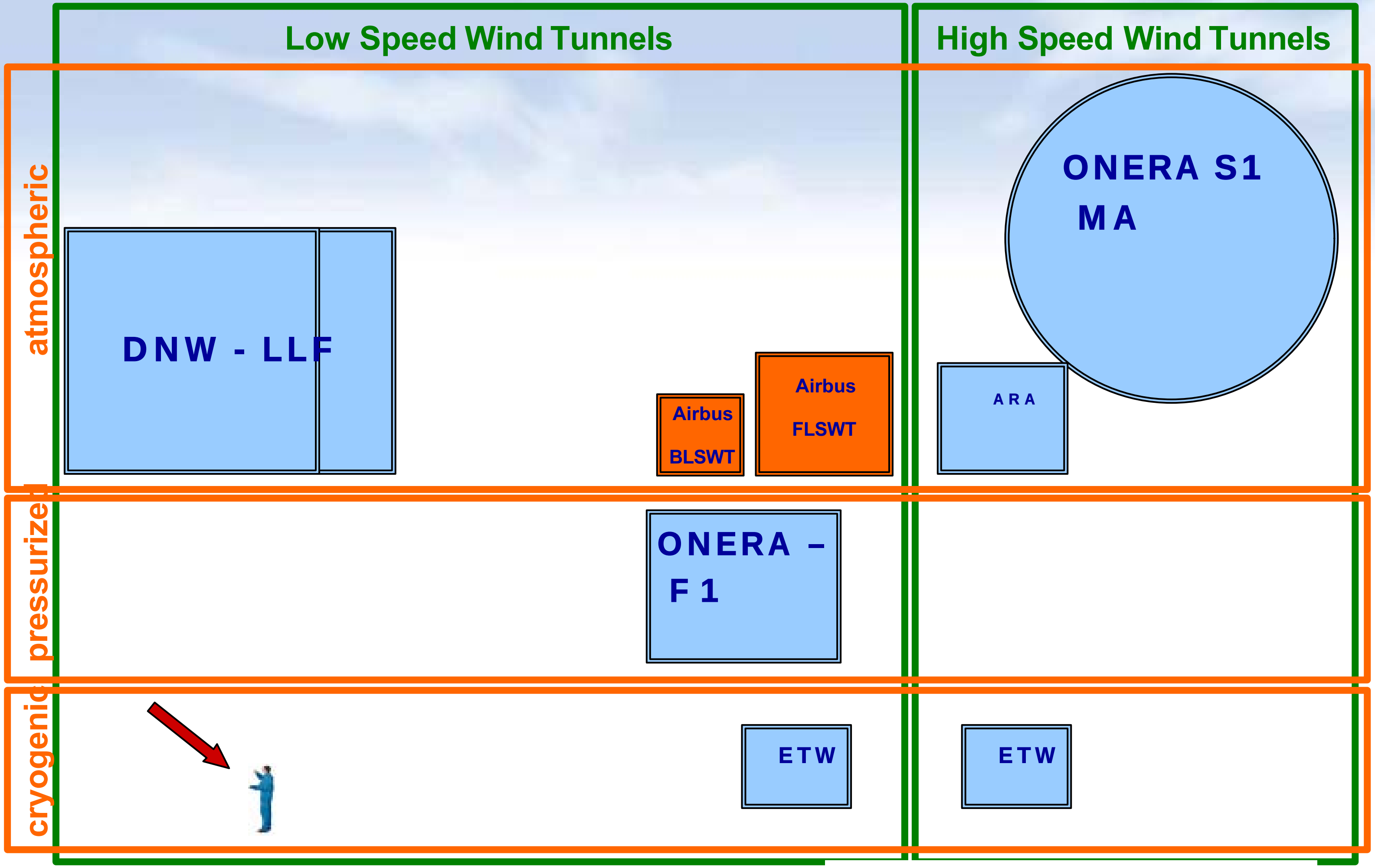
- Today's wind tunnel combine the parameters of enlarged test sections, pressurisation and cryogenic conditions. A variety of options are available:



* Airbus preferred facilities in blue

Aerodynamics Evolving Strategy:
Wind Tunnel Testing: Facilities

- Reduced number of testing facilities to cover all required conditions:



* Airbus preferred facilities in blue

Aerodynamics Evolving Strategy:
Wind Tunnel Testing: Models

- Reduced number of models to be used in different tunnels: **Low Speed**

BLSWT → ONERA F1

BLSWT → ETW

FLSWT → ONERA F1

DNW - LLF

Aerodynamics Evolving Strategy:
Wind Tunnel Testing: Models

- Reduced number of models to be used in different tunnels: **High-Speed**

ARA

ETW

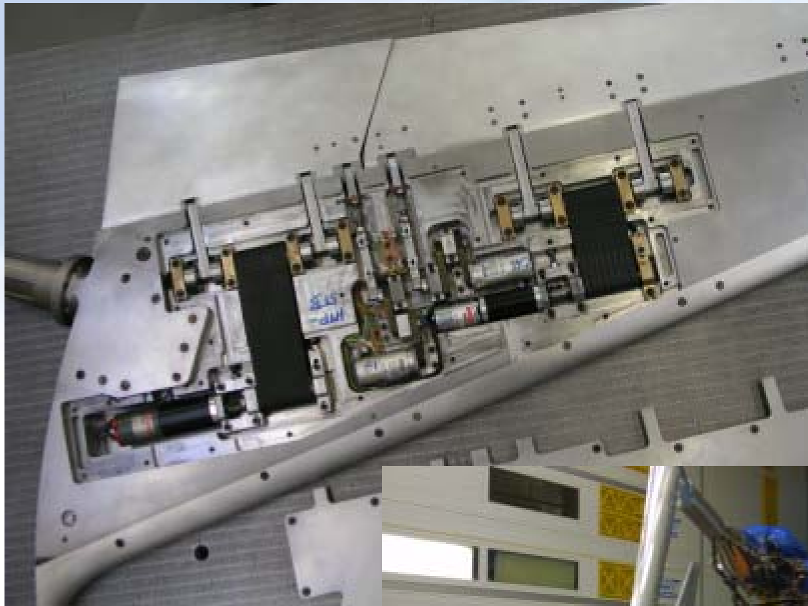
ETW

ONERA S1

Aerodynamics Evolving Strategy:
Wind Tunnel Testing: Technologies

- Advanced Model & Test Technology

Dynamic Testing



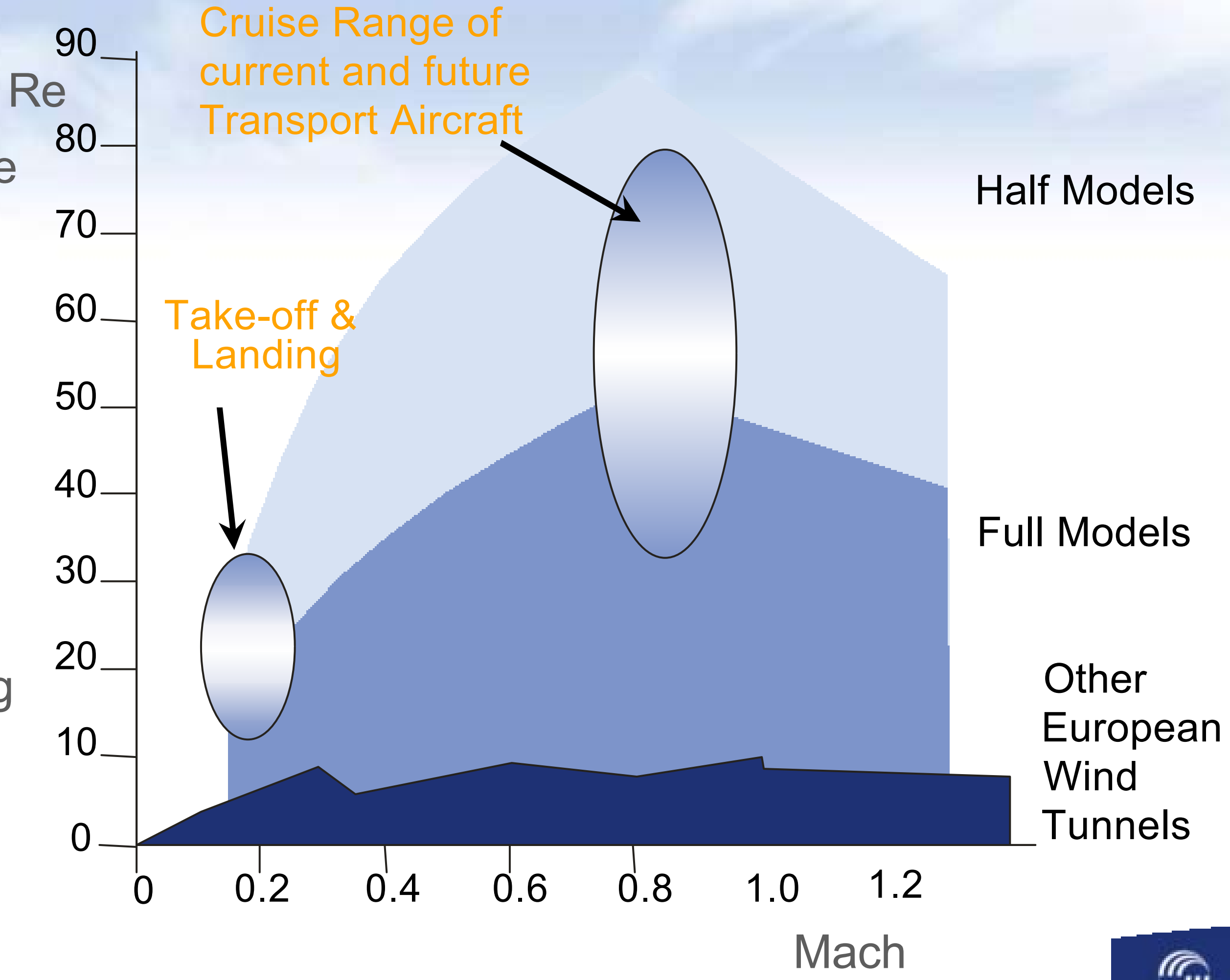
Remote controlled components

Aerodynamics Evolving Strategy:
e.g. High Re Wind Tunnel Testing

European Transonic Wind Tunnel (ETW) offers the capability to obtain test data over a wide Reynolds number range - up to flight

In addition, the tunnel temperature and pressure may be independently varied to investigate:

- Effect of change in Reynolds number with constant wing shape
- Effect of change in wing shape at constant Reynolds number



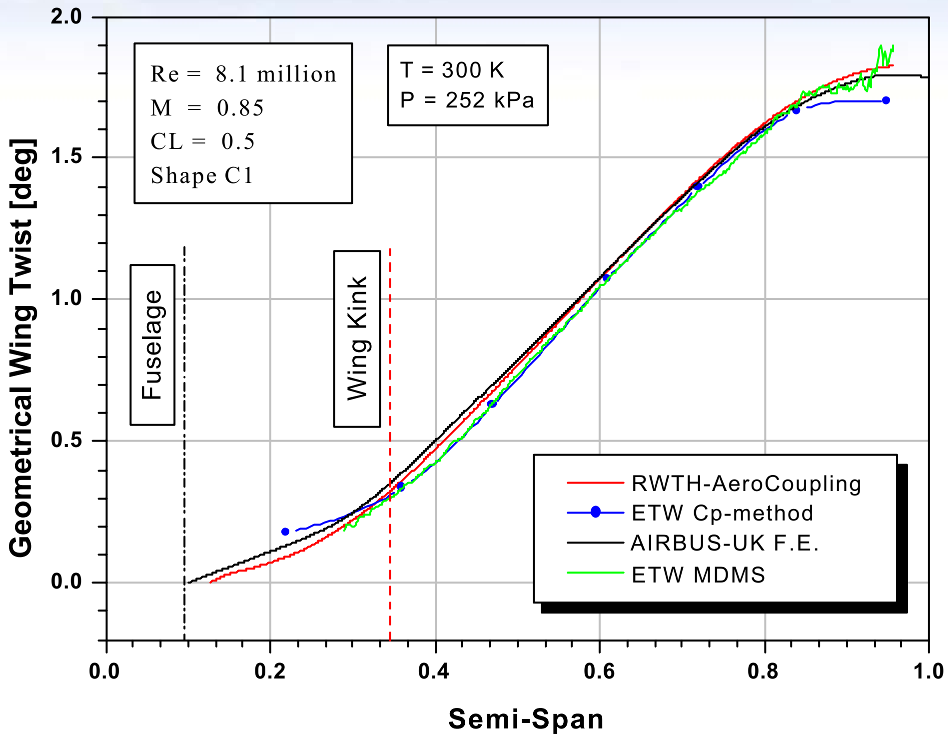
Aerodynamics Evolving Strategy:
e.g. High Re Wind Tunnel Testing

For accurate aircraft performance predictions (for flight conditions) it is vital to have accurate twist information of the tested configuration

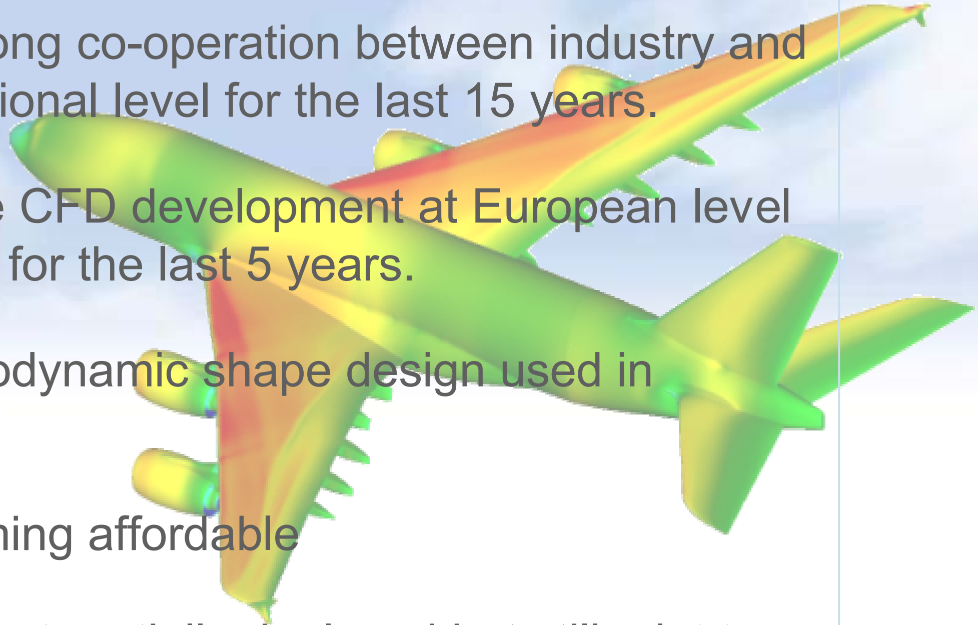
- *Large impact on drag*

- High Reynolds number testing in pressurised facilities such as ETW involves **significantly larger tip twist increments**

- Important to be able to take account of twist effects when comparing CFD with W/T data hence need to evaluate model twist under load



Aerodynamics Evolving Strategy:
CFD (Overview)



- CFD has been developed in strong co-operation between industry and Research Establishments at national level for the last 15 years.
- Airbus endeavours to rationalise CFD development at European level inside and outside the company for the last 5 years.
- CFD is now a major tool for aerodynamic shape design used in conjunction with W/T
- Numerical optimisation is becoming affordable
- CFD-based Aerodynamic Data set partially deployed but still a lot to do for non-linear part of the polars
- Multidisciplinary analysis (MDA) in strong development
- Multidisciplinary Optimisation (MDO) still relies on low fidelity CFD
- High Performance Computing (HPC) capability has increased significantly

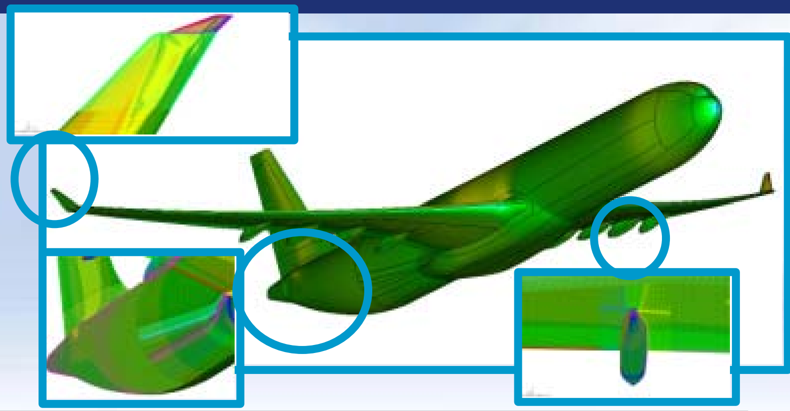
Aerodynamics Evolving Strategy:
CFD (Cruise)

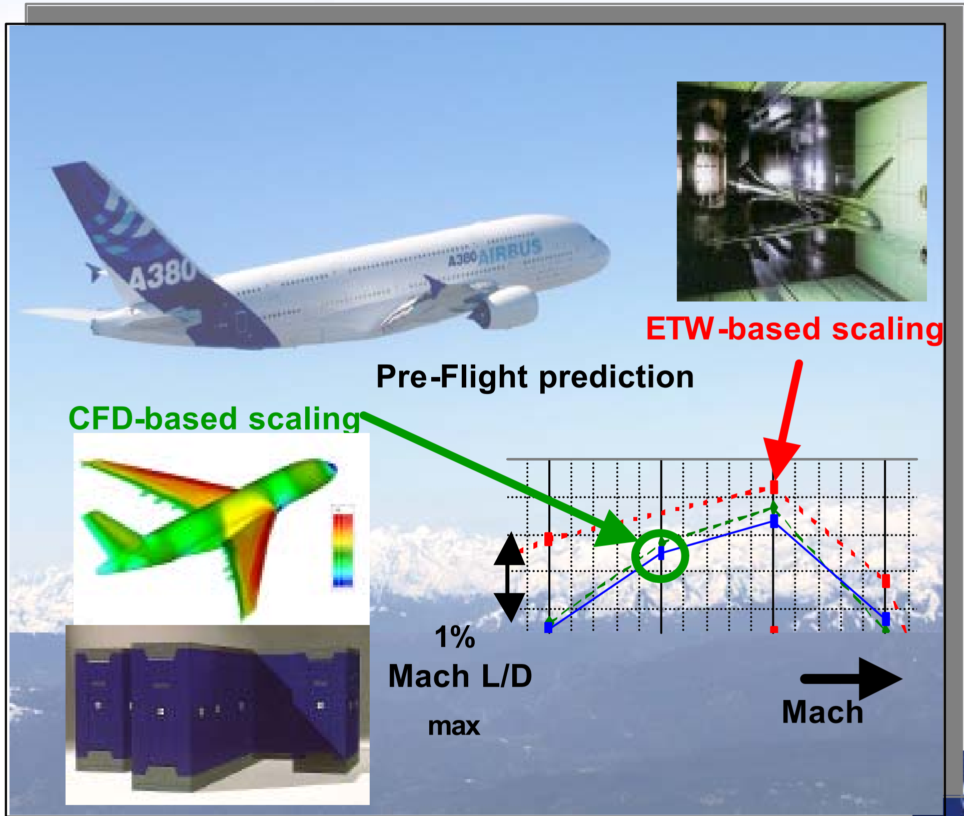
- CFD is about to replace low Re W/T in Design decision making process:
  - 3D Euler up to cruise Mach
  - RANS better suited to assess Mach flexibility

- No absolute value but RANS very accurate for design derivatives

- CFD can now assess the performance in flight with the same level of accuracy as high Re W/T

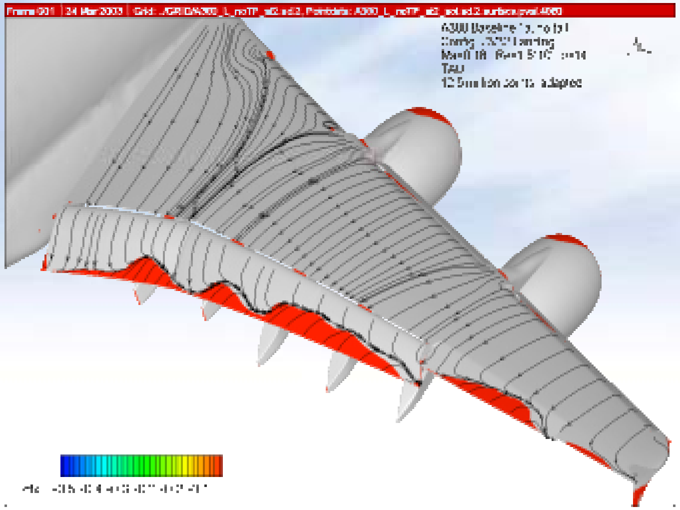
- Buffet onset prediction at high Mach low CL assessed by RANS correlated to unsteady pressure measurement in W/T and F/T.

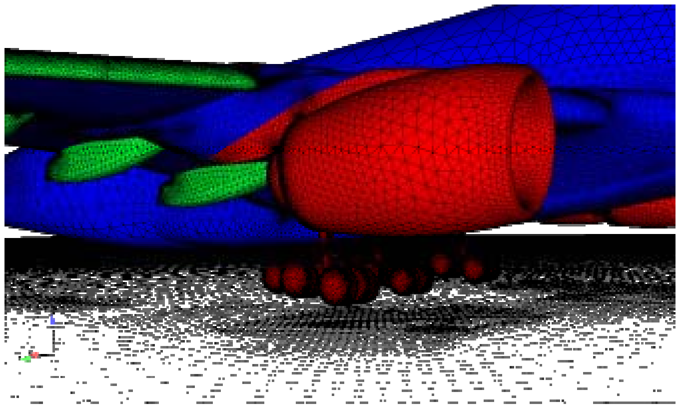


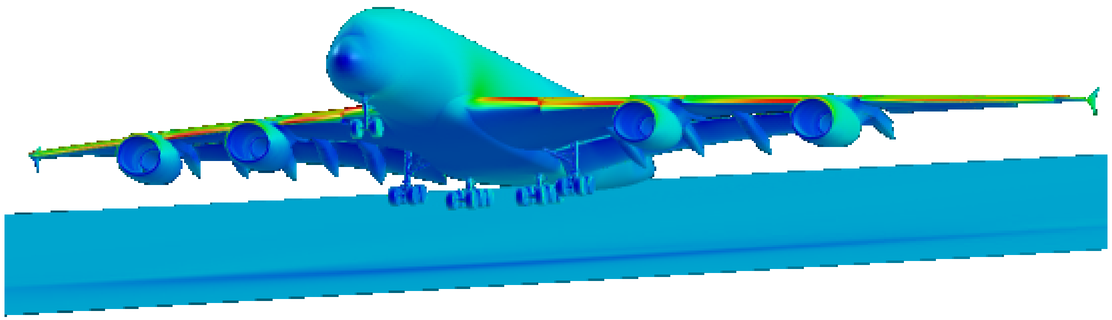


Aerodynamics Evolving Strategy:
CFD (Low Speed Performance)

- Capability exists for computing almost all full complex geometrical configurations
- Still lack of confidence in turbulence models for flow separation prediction in many situations
  - Critical for the A/C performance and safety
  - Massive flow separation
  - Highly sensitive to Reynolds effect and model representation
  - VG's and Strakes widely used to improve CLmax

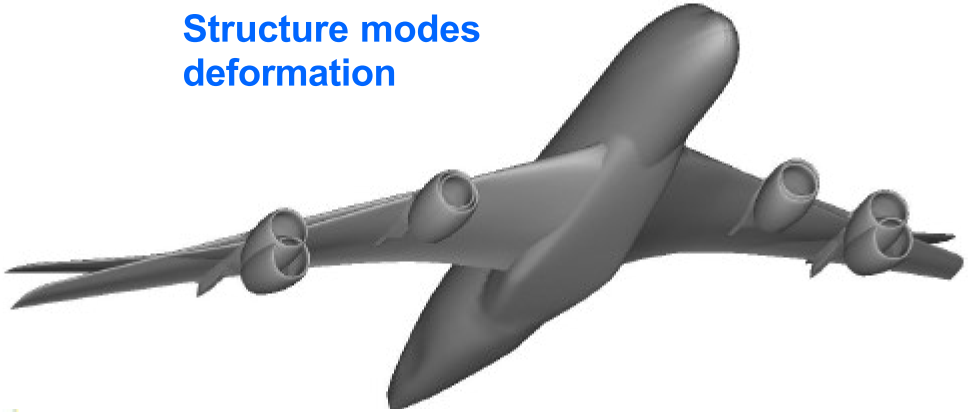


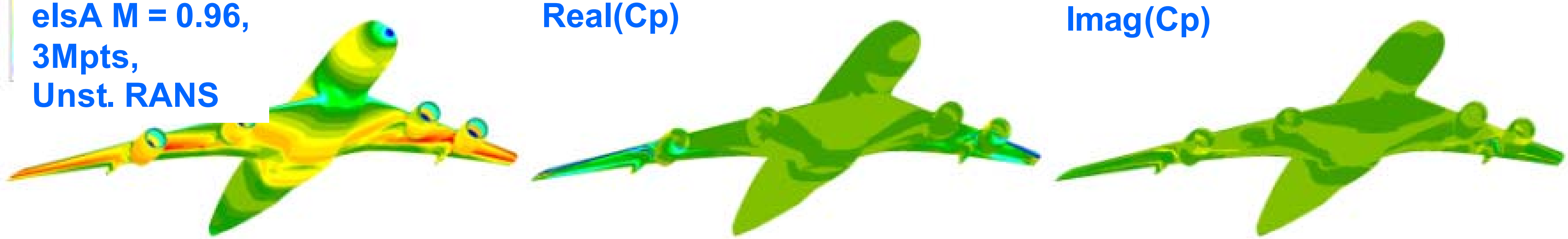




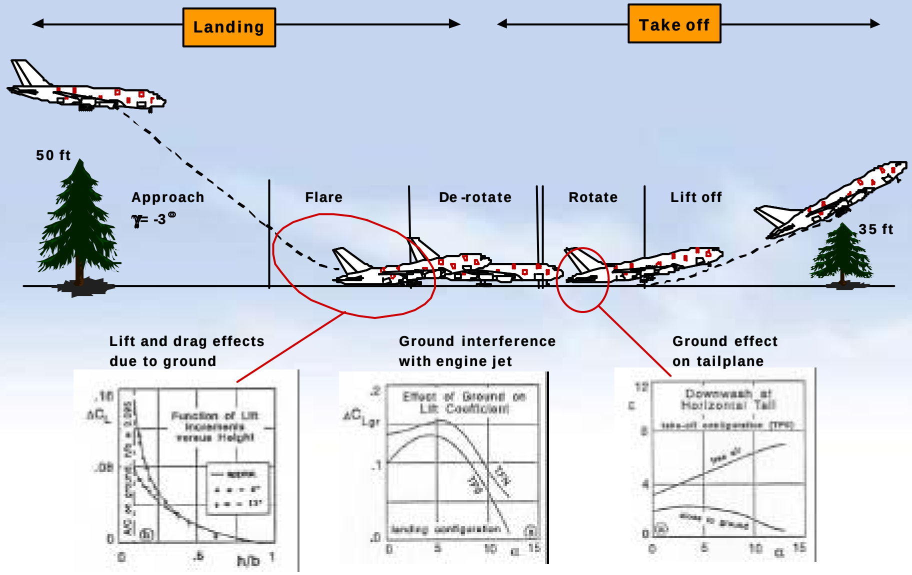
Aerodynamics Evolving Strategy:
e.g. CFD for Flutter Prediction

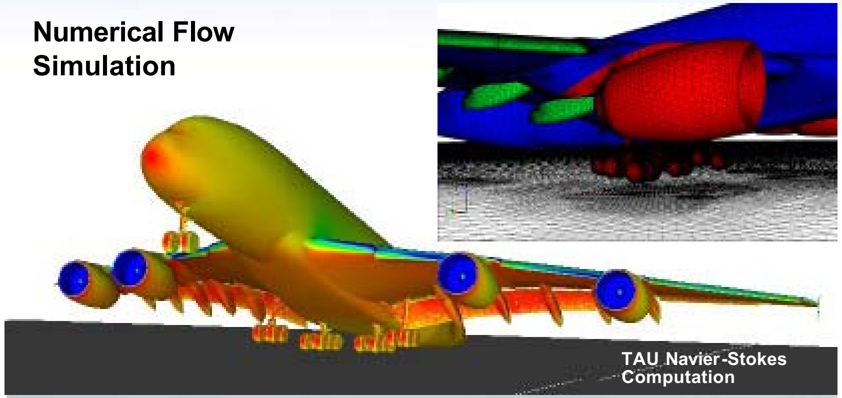
- Steady and unsteady Navier-Stokes capability coupled with structural deformation modes allows flutter prediction
- Flutter prediction for separated flow
- Flutter study traditionally covered by non-viscous unsteady codes





Aerodynamics Evolving Strategy:
e.g. CFD for Modeling Ground Effect





- A380 complex high-lift configuration incl. landing gear

Aerodynamic Design Challenges

Requirements, Targets & Constraints

Aerodynamics: Meeting the A380 requirements

Mission performance

8000nm range with 'max pax'

Mach 0.85 cruise speed

Field performance

Take-off Requirements

Landing Speed

Noise & emissions

Noise & Emissions improvements

Engine options
RR Trent 900
GP7200

Take-off L/D

Operating costs

15 - 20% lower operating costs

Using less fuel

Use of advanced materials

Operations

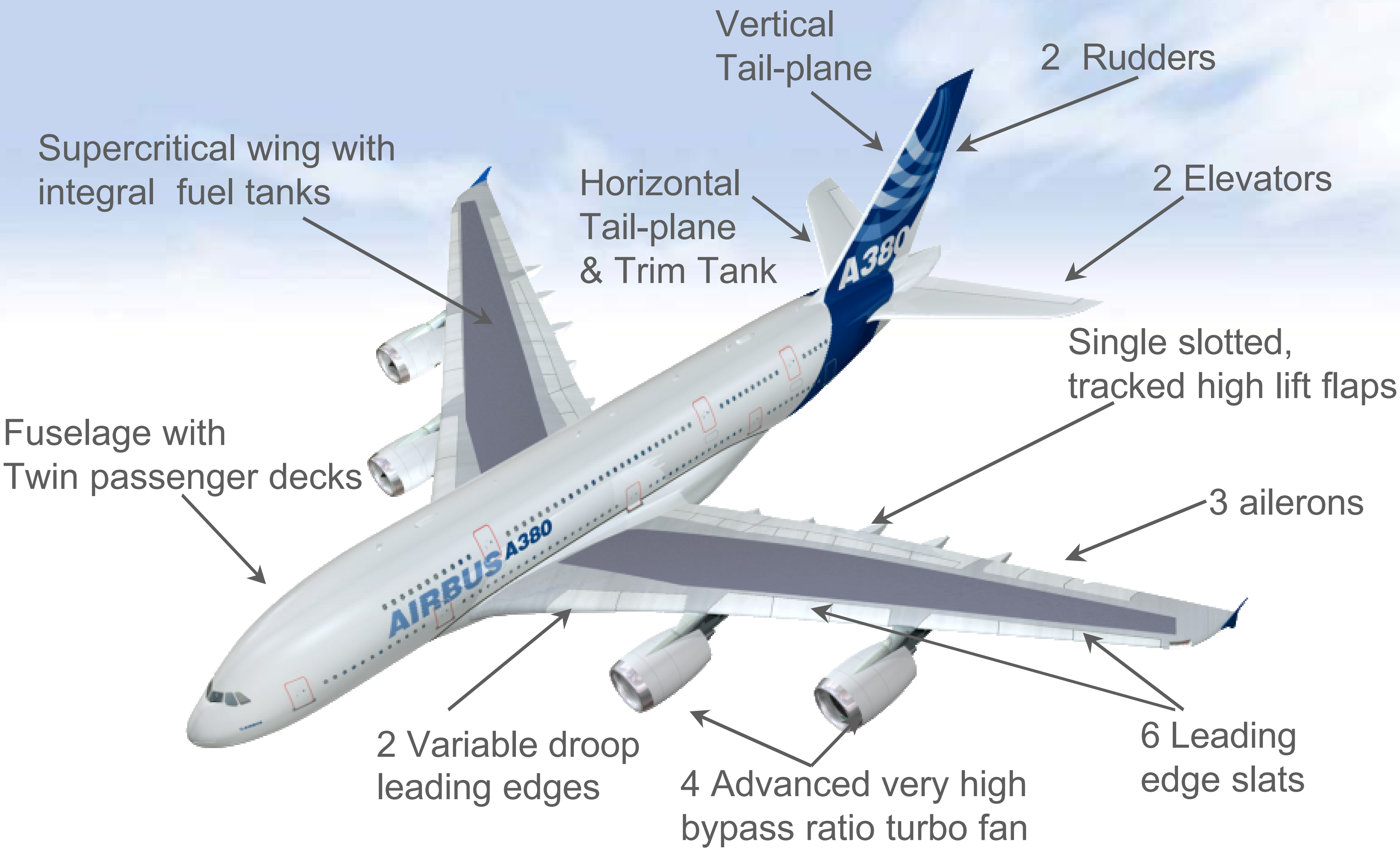
All variants fit in 80m x 80m box

Wake Vortex

Fast turn round time

Cross Crew Qualification

A380-800: Salient Features 1



A380-800: Salient Features 2

845 m2, 33.5 deg sweep wing
Optimized for M=0.85 cruise
Inboard loading distribution

122 m2 VTP
sized by stability and
failure cases

205 m2 HTP sized by stability
at high speed and controllability
at low speed

New generation
engines with reduced
fuel burn and noise

Wing root chord
limited to 60 ft, (18.3m),
for safety regulations

Aerodynamic optimised belly fairing
(18.3 m long)

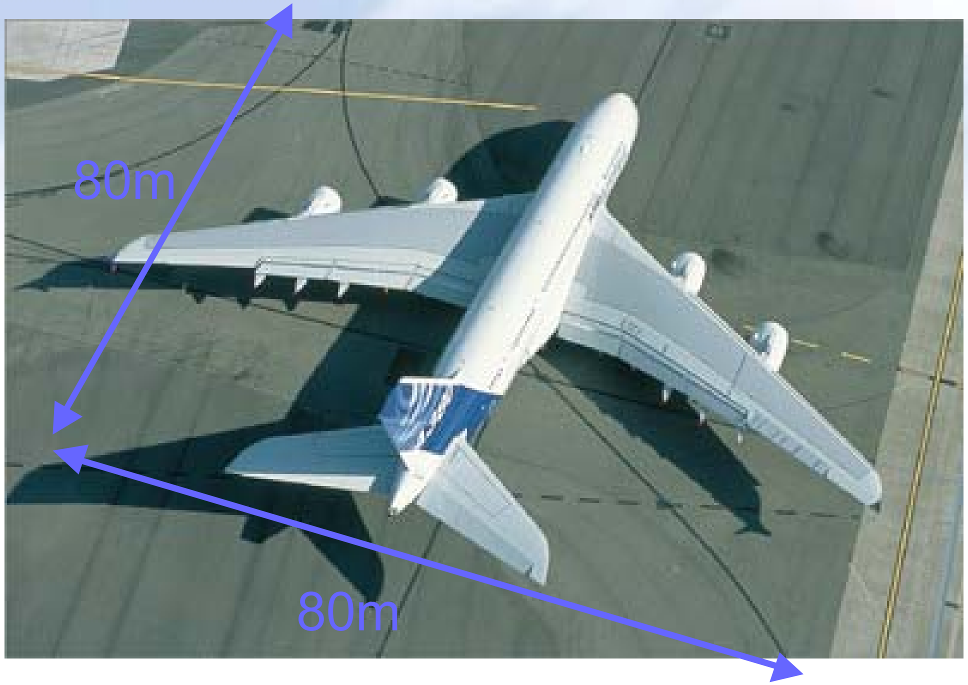
A320-like wing tip
fence to reduce drag
at high & low speed

Nose shape: Best compromise between
visibility, drag and cabin noise

A380 Wing Design Constraints

Wing Planform

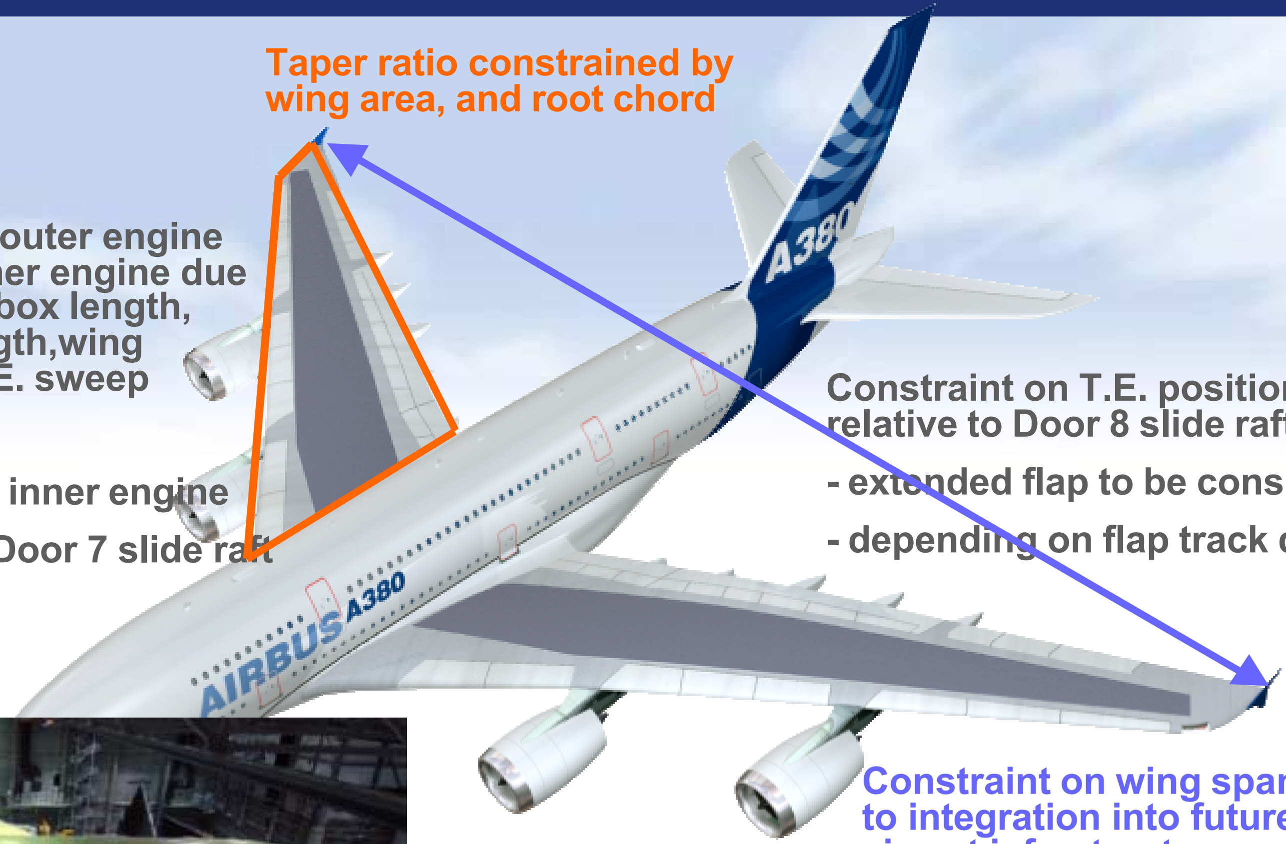
- Infrastructure requirements from Airlines/Airports: Aircraft must fit in the 80 Metre box.
- Passenger Evacuation.
- Best overall aircraft solution
  - overall aircraft Drag, Weight, Cost and Systems Installation.



Wing Area

- Simple, light, robust, High Lift System
  - compatible with a low approach speed, 140kts at MLW.
- No initial cruise altitude limitations due to buffet onset, 560 tonnes to over 35,000 feet.
- Fuel volume requirements. No centre wing box fuel for initial aircraft.

Wing Design Constraints



Taper ratio constrained by wing area, and root chord

Indirect constraint on outer engine position relative to inner engine due to combination pylon box length, disc burst, engine length,wing engine overlap and L.E. sweep

Direct constraint on inner engine position relative to Door 7 slide raft

Constraint on T.E. position relative to Door 8 slide raft

- extended flap to be considered

- depending on flap track design

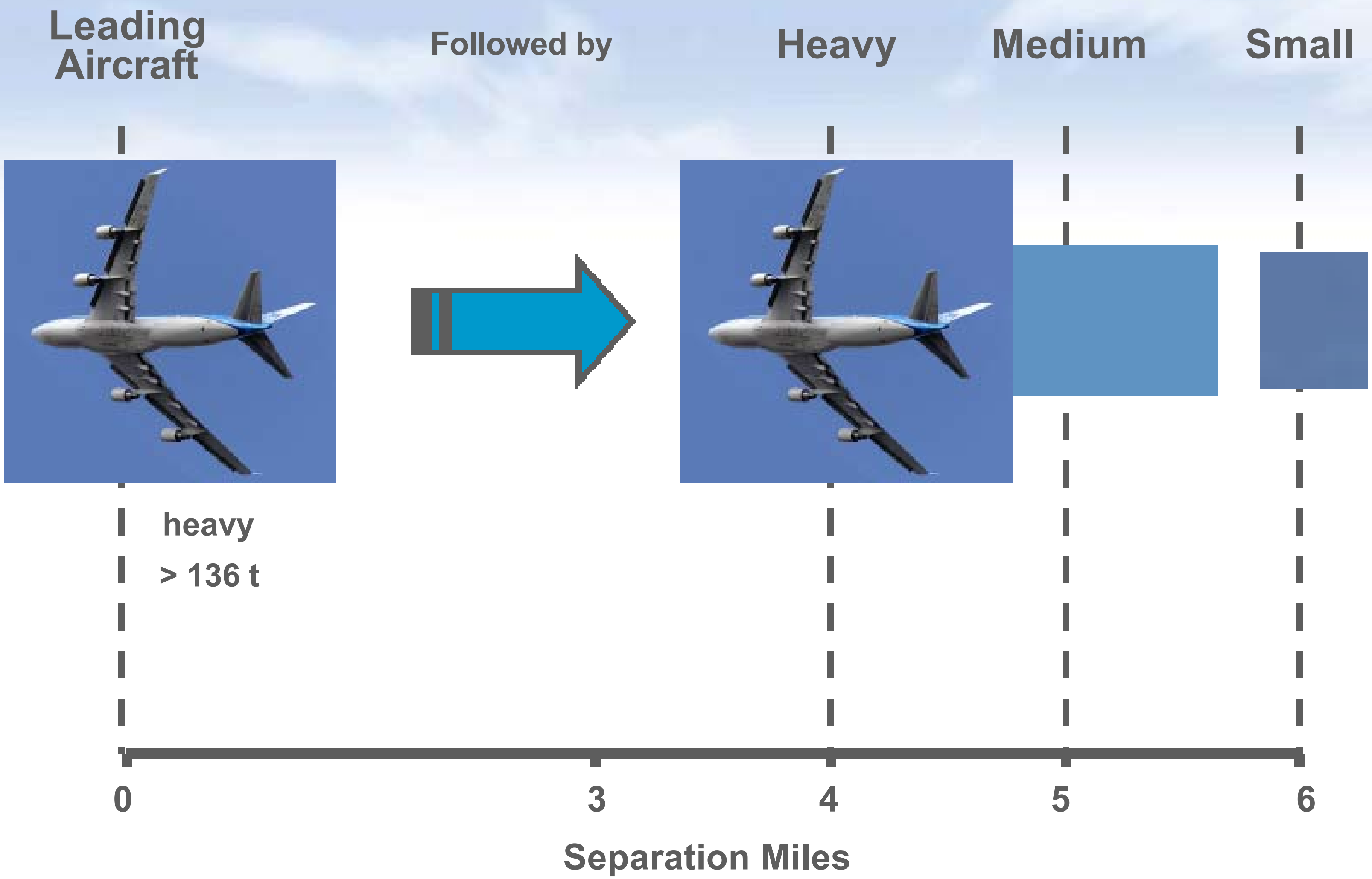
Constraint on wing span due to integration into future airport infrastructure

Constraint on L.E. position relative to Door 7 slide raft

- depending on L.E. shape

Wake Vortex: ICAO Wake Turbulence Separation

Separation Standards in Approach / Landing

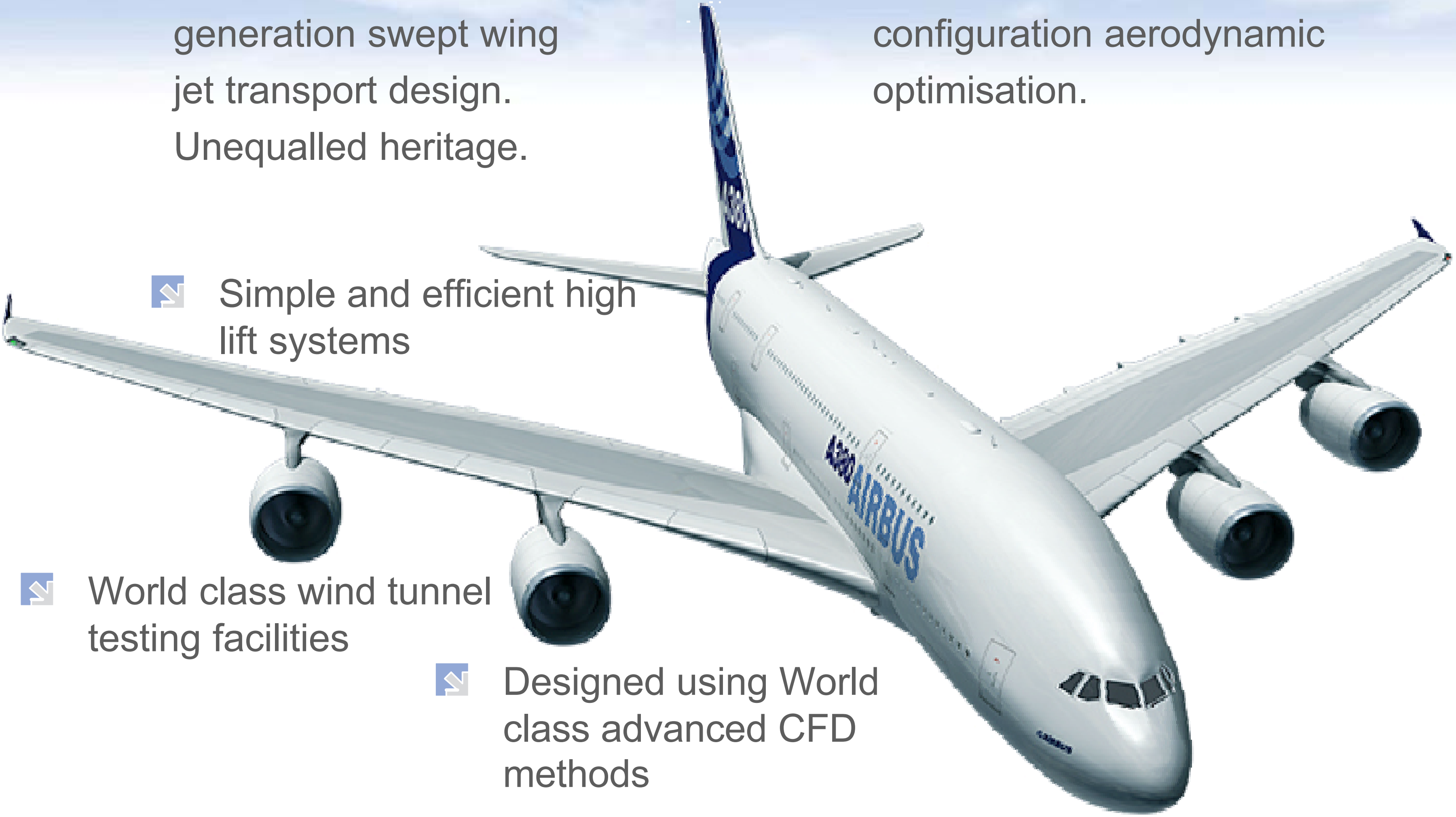


The Aerodynamic Solutions

An Innovative Approach to Aerodynamic Development

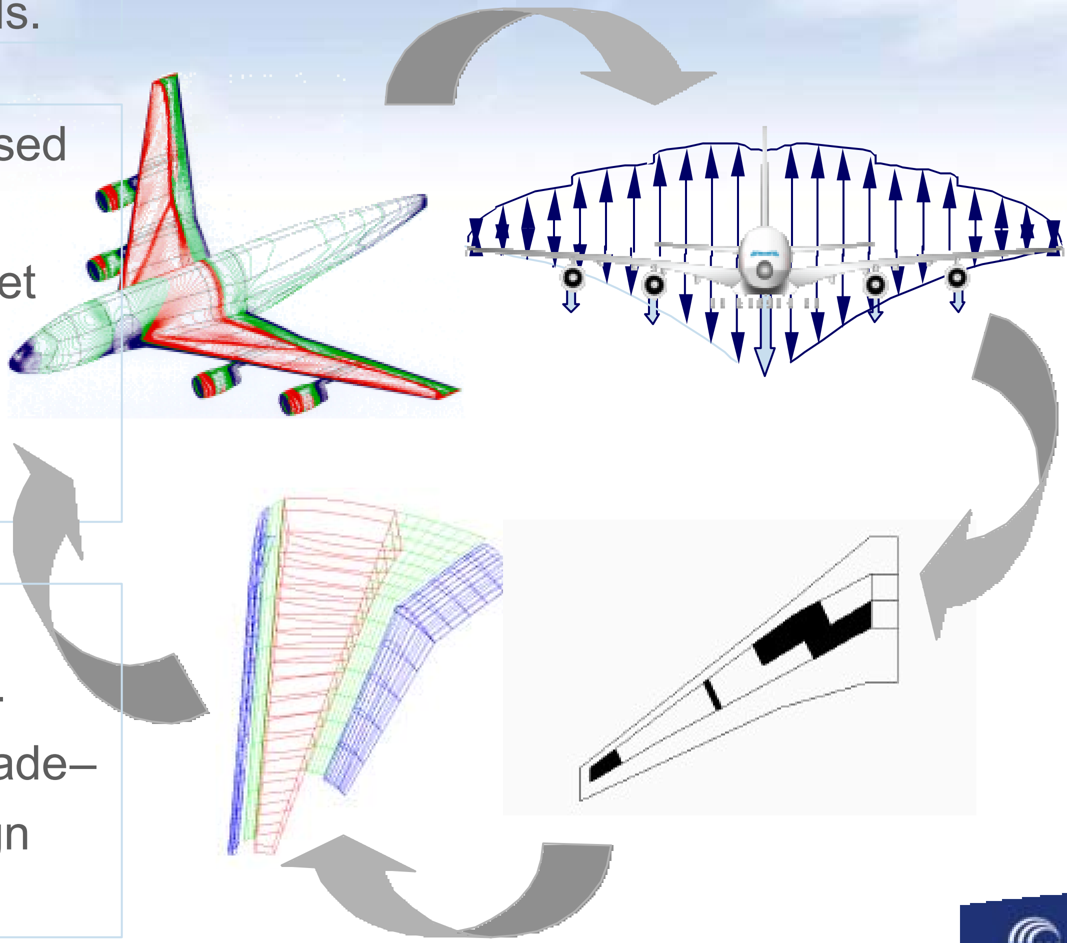
Advanced Aerodynamics on A380

- The A380 wing is a 7th generation swept wing jet transport design. Unequalled heritage.
- Integrated design, and complete configuration aerodynamic optimisation.
- Simple and efficient high lift systems
- World class wind tunnel testing facilities
- Designed using World class advanced CFD methods



Wing Design: A Multidisciplinary Approach

- Simple, rapid, but accurate CFD calculation, giving drag, combined with a mini Loads loop process to get aerodynamic and inertial loads.
- These loads used with a KBE based generic wing structural modular based Finite element model, to get representative sizing of structural components, and thence weight estimates.
- This methodology enabled parametric variation of wing plan-form, and enabled drag weight trade–offs to be made early in the design process.



The Aerodynamic Solutions: Some Examples

- Cruise Wing Design
- Integrated Wing Design
- Fuselage Design
- High Lift Design
- Noise
- Wake Vortex

Cruise Wing Design:
An Overview

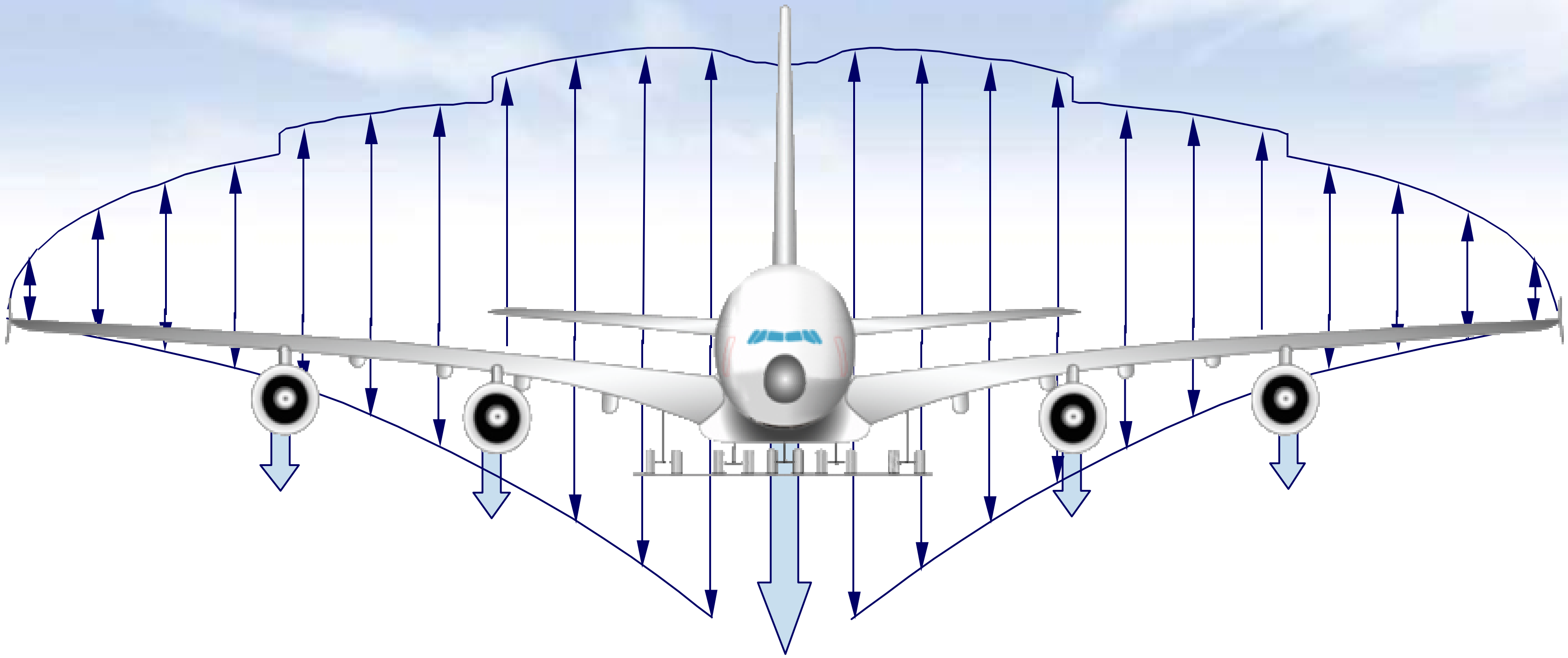
- High Speed development has taken place over a period of 7 years. During that time 11 high speed wing designs have been tested, in 15 wind tunnel campaigns.

- Sectional Design is drawn from features of both the Twin Aisle, and Single Aisle Airbus families. Both high and low speed considerations have been taken into account in the design of the sections.

- Over that period of time, a significant improvement in both cruise Lift / Drag ratio and Mach flexibility was achieved

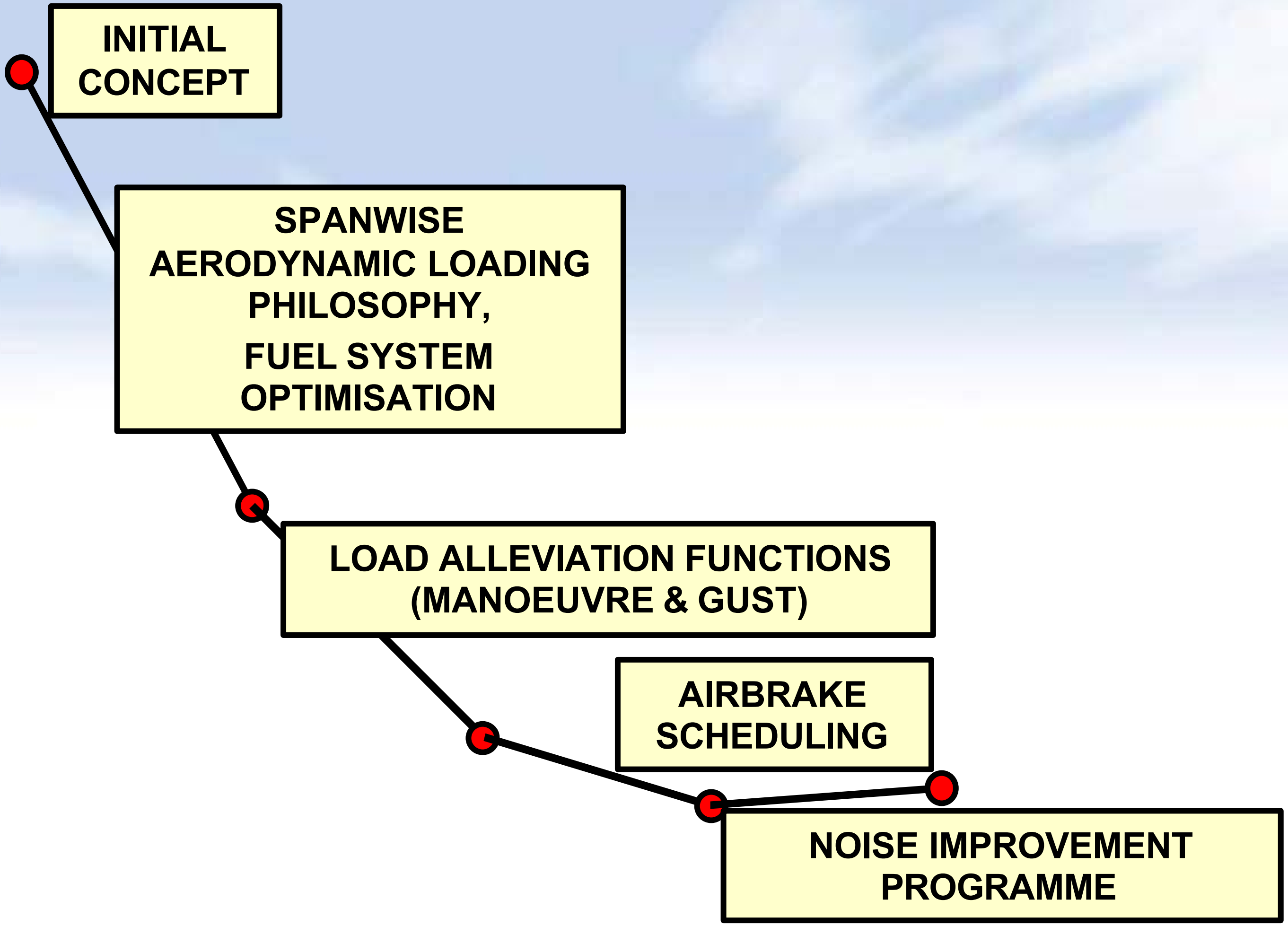
Cruise Wing Design:
Evolution of Aero Efficiency

Cruise Wing Design:
Wing Loading - a Multi Disciplinary Design



Achieved through multi-disciplinary working in Aerodynamics, Loads, Structures & Systems

Cruise Wing Design:
Wing Loading - a Multi Disciplinary Design



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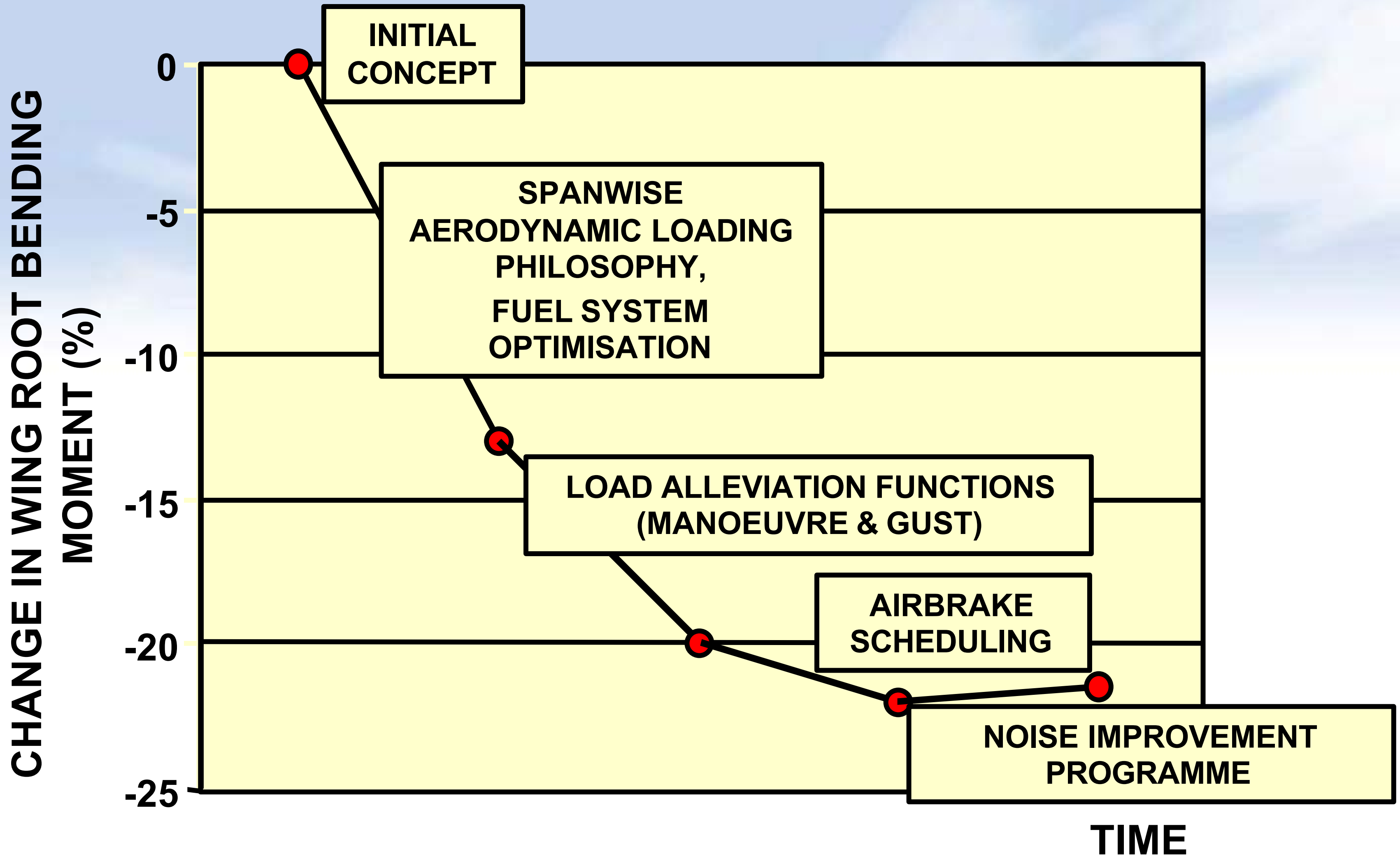
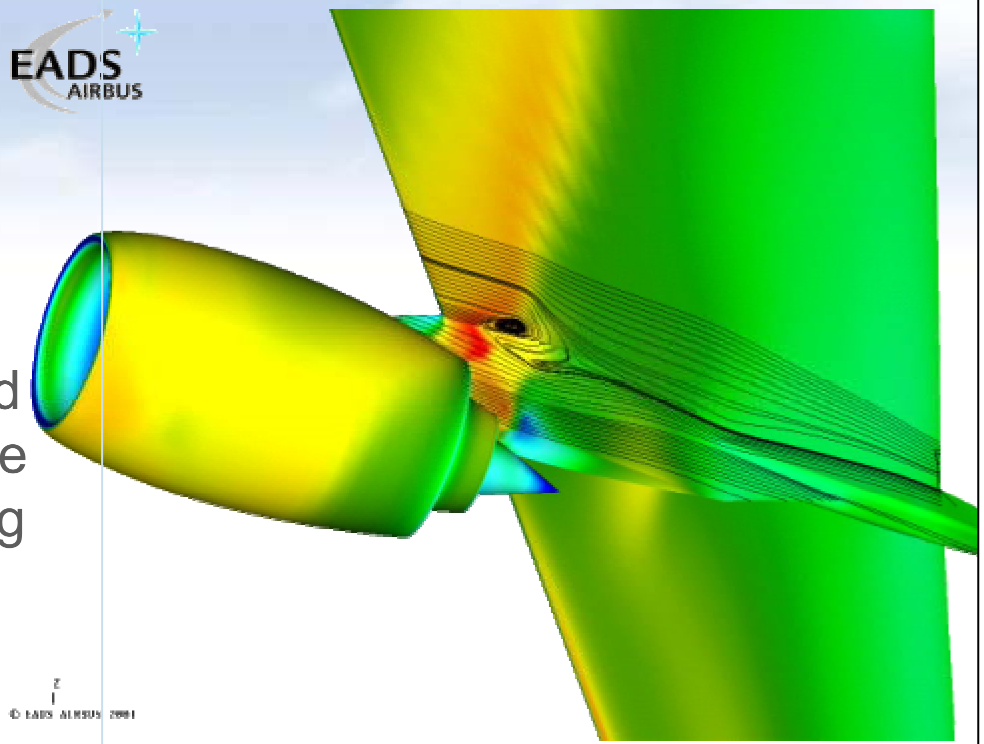
Cruise Wing Design:
Wing Loading - a Multi Disciplinary Design



Achieved through multi-disciplinary working in Aerodynamics, Loads, Structures & Systems

Integrated Wing Design:
Wing-Pylon-Nacelle Integration

- One of the main constrains of the outer pylon design is the aero robustness
  - Limitation of flow separation at High Mach Low CL in order to avoid buffeting



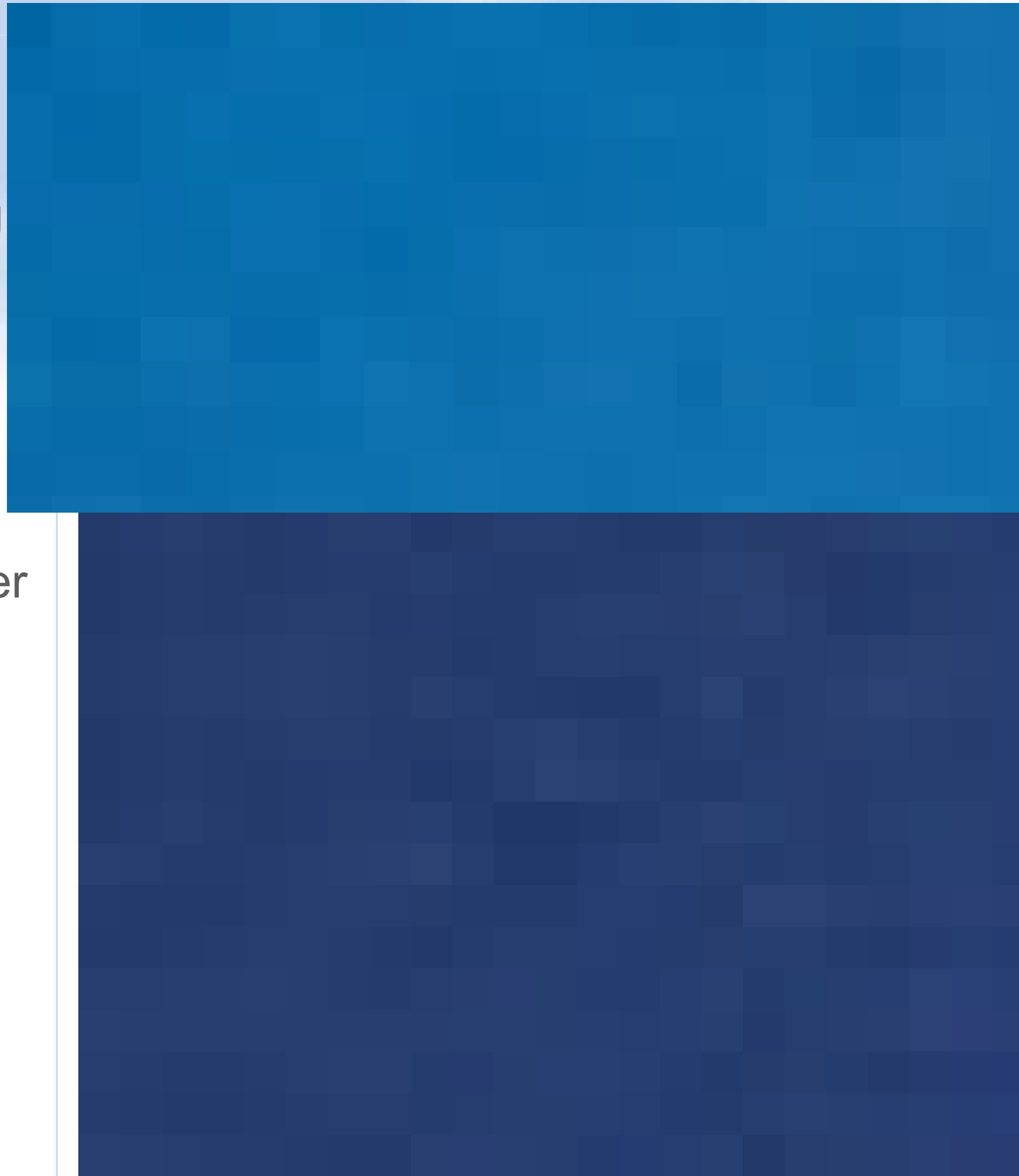
- A methodology has been developed and applied during the design phase to assess and manage the buffeting risk

- The flight tests have confirmed the reliability of the prediction and the flight domain have been opened successfully up to MMO

Integrated Wing Design:
Wing-Belly Fairing Integration

Wing-belly fairing integration

- The over-wing fairings influence upper surface inner and mid-wing pressure distribution.
- The lower belly fairing shape and wing lower surface shape were optimised together to reduce lower surface flow velocities and avoid normal shock waves at low CL conditions, taking account of strong effect of inner engine.
- Belly fairing volume constraints were challenging due to the large landing gear volumes required.



Fuselage Design:
Key Design Challenges

- Fuselage Nose design is driven by Drag, pilots visibility, Fuselage Width and Cabin Acoustic consideration. (Flow is wholly subsonic over nose at M = 0.85, and free of shock waves up to M=0.88.)

- Rear fuselage design is driven by considerations of cabin volume and the minimum interference integration of Fin and Tailplane.

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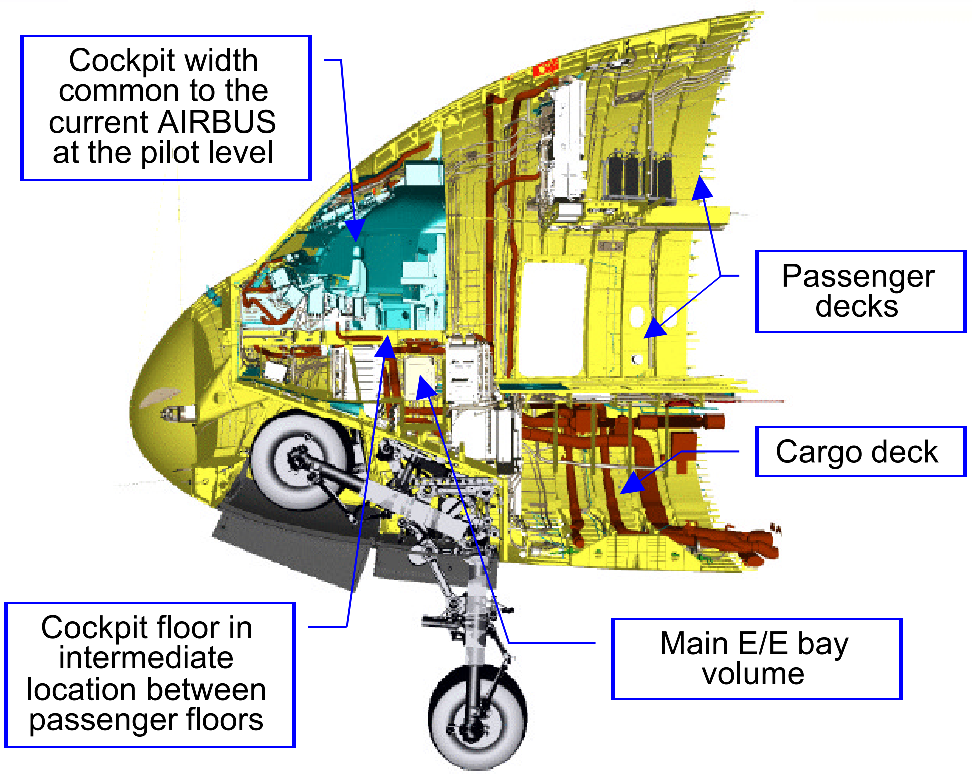
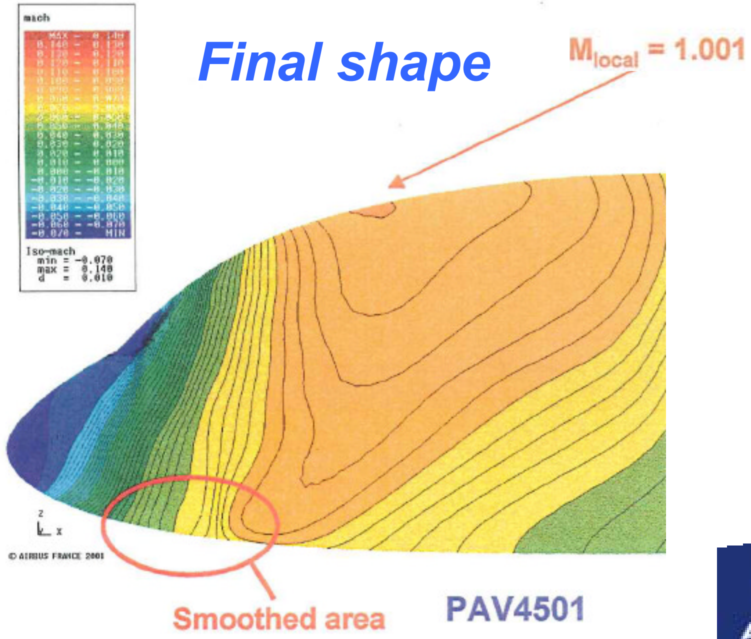
Fuselage Design:
Nose

Constraints

- Windshield definition for Pilot visibility
- Volume required for fitting Systems
- Minimization of drag





Fuselage Design:
Rear Fuselage and Tail

Rear fuselage

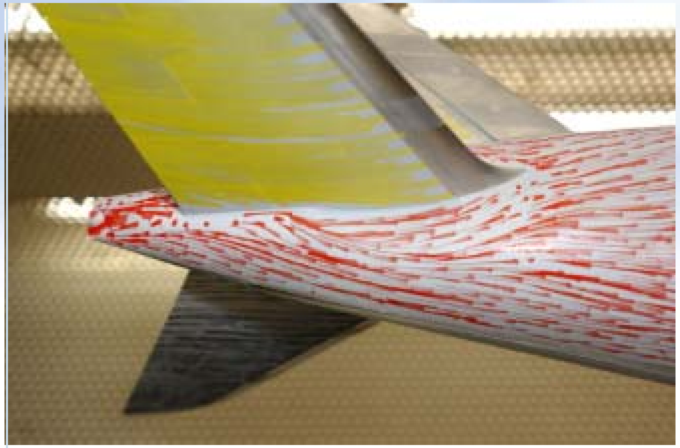
- Reduced length against A340 with only minor drag penalty
- Tailoring to control rear-fuselage/HTP/VTP interaction

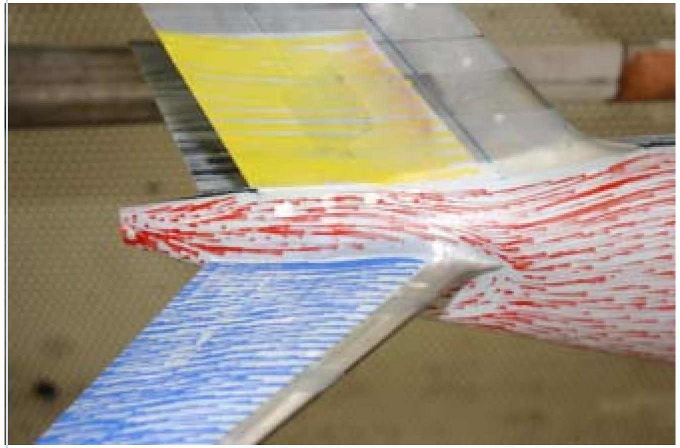
HTP

- Size reduction from 220 to 205 m^2
- Increased root thickness for weight saving without drag penalty
- Improved tail stall capability

VTP

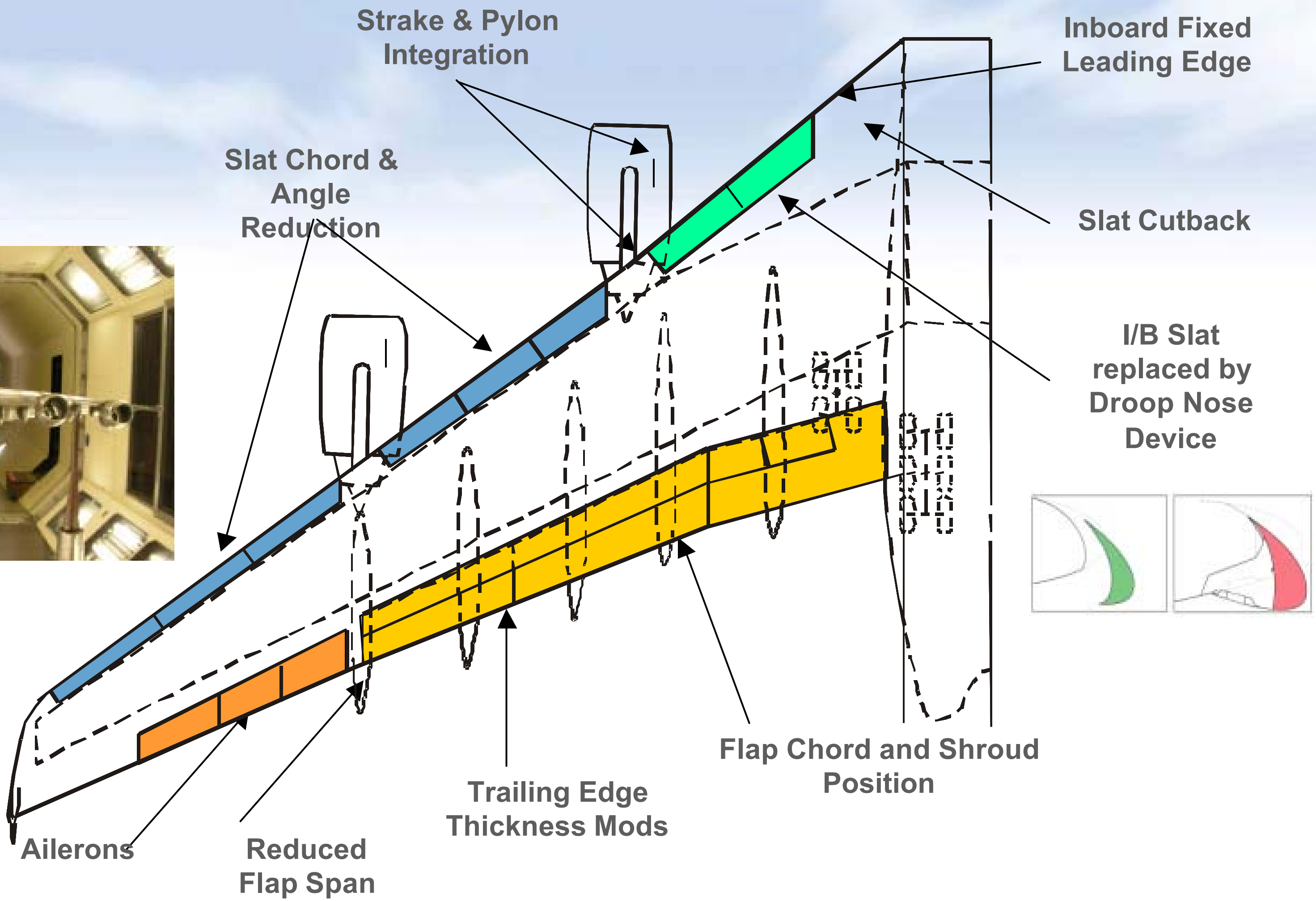
- Size reduction from 140 to 122 m^2
- Increased root thickness for weight saving without drag penalty



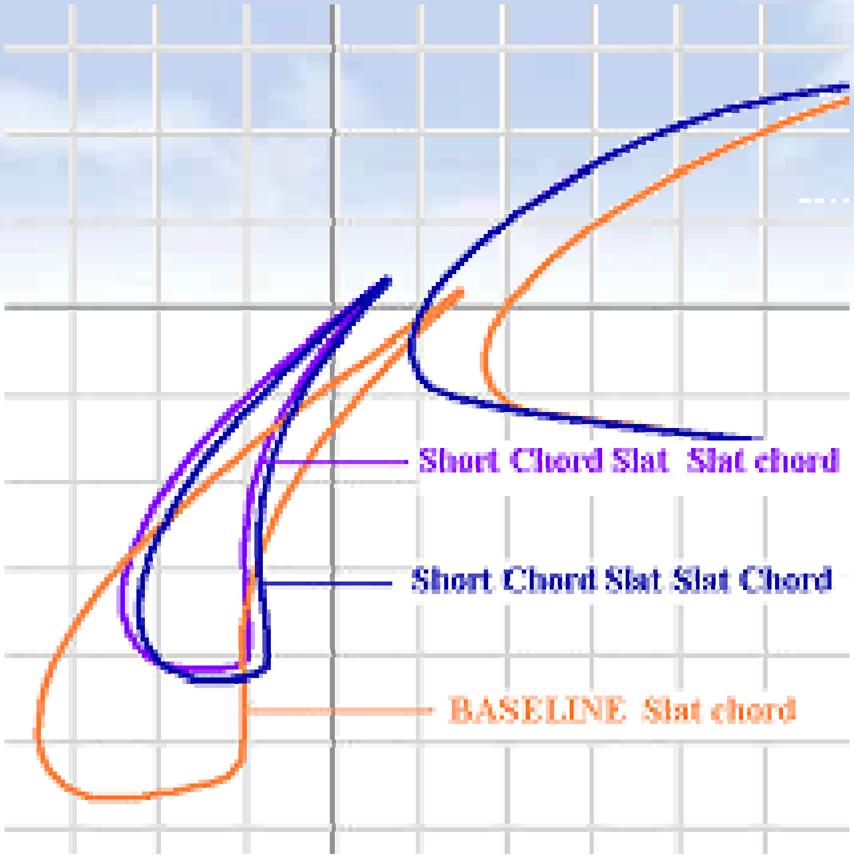


High Lift:
An Overview

Multidisciplinary Integrated Design in the Development of the High Lift System

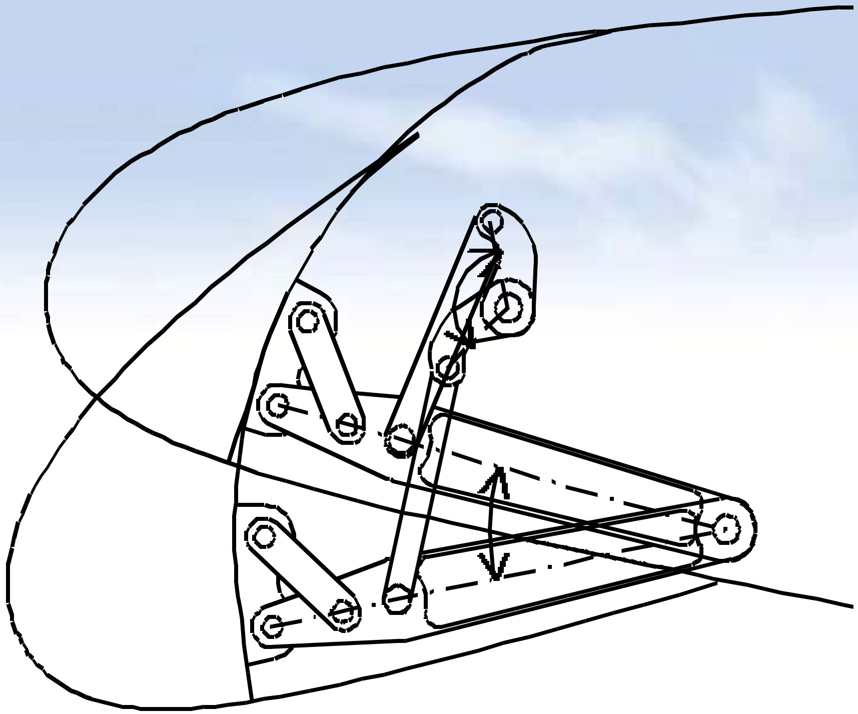


High Lift:
Slat with Reduced Chord and Angle1

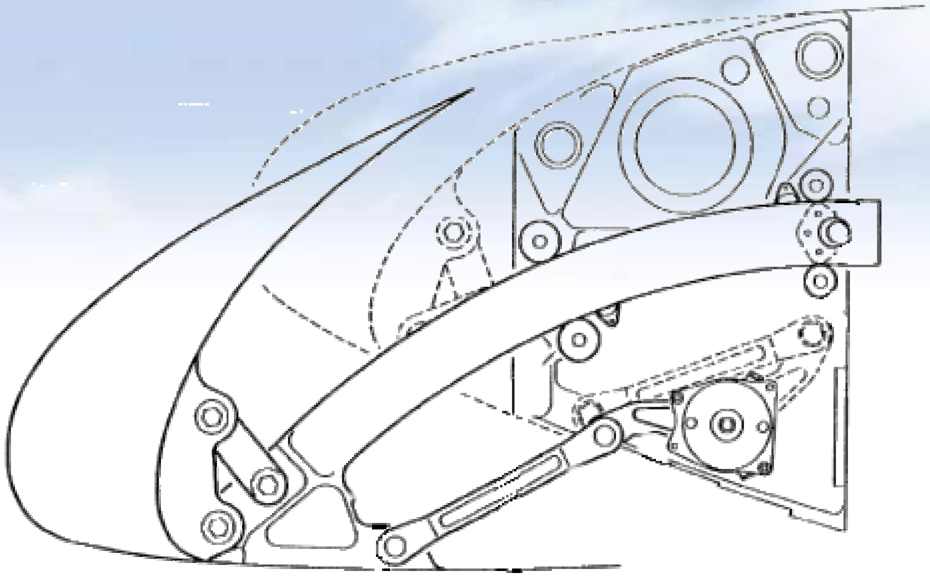


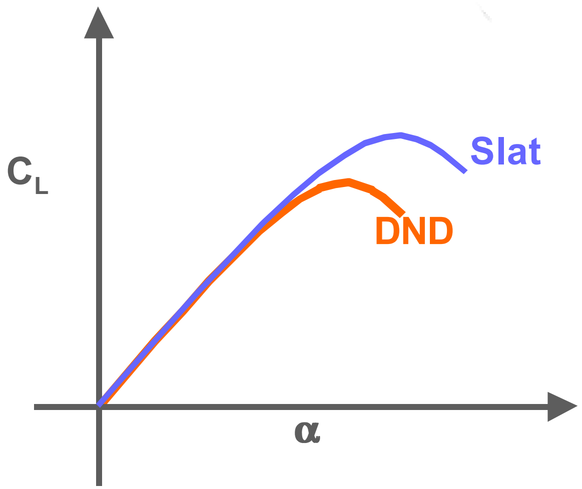
High Lift:
DND Design (for higher t-o L/D and low noise)

Droop Nose Device



Slat





Less drag
- Higher Take-off L/D

Lower CLmax
- but A380 CLmax/αmax limited by tail clearance

Noise Impact (1)

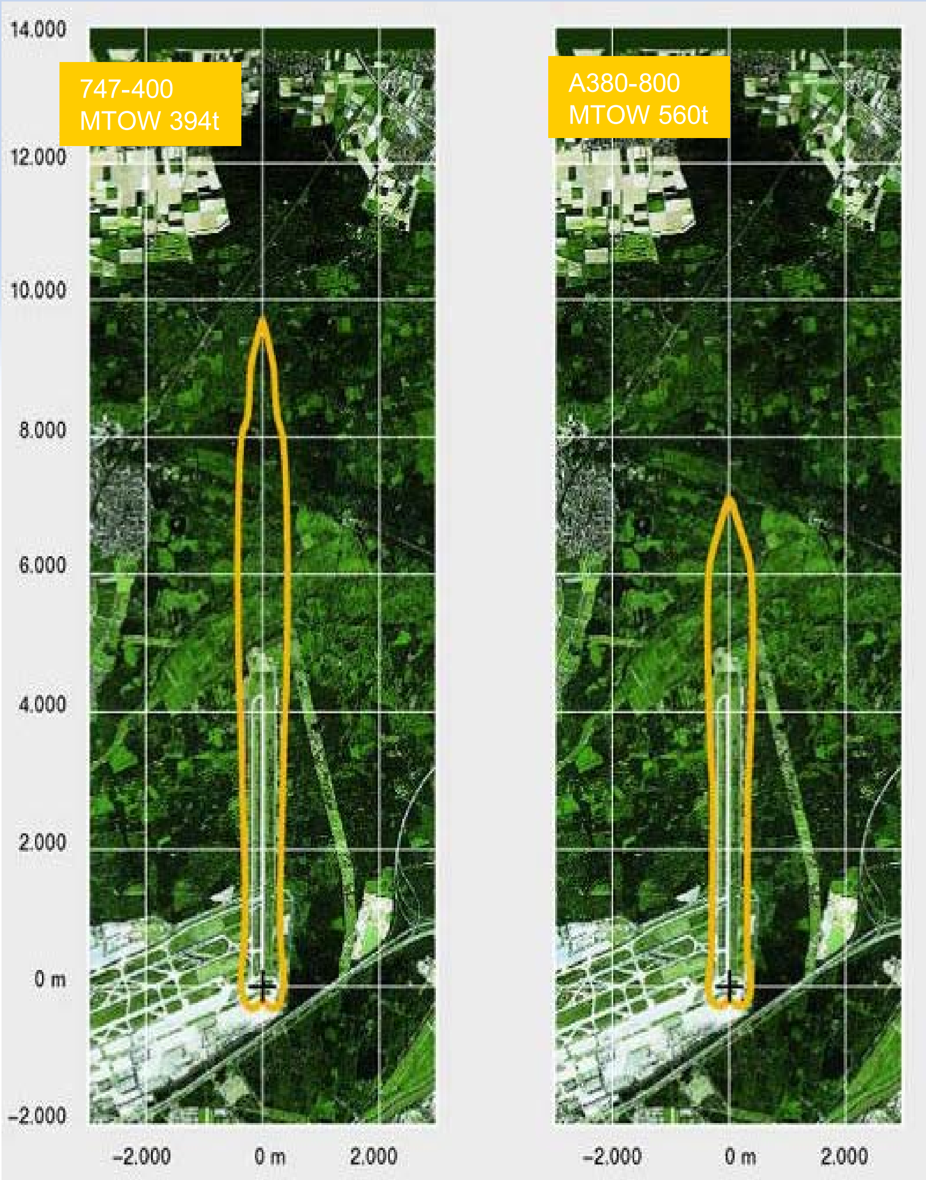
New generation, high bypass ratio engines

- **High-lift system enhancements include aileron droop for take-off & reduced slat setting.**
- **Better take-off performance (L/D) & lower approach speed (Clmax) reduce departure & arrival noise**

Acoustic treatments including nacelle lengthening, improved linings & inlet.

Flight Management System optimises take-off performance & noise abatement procedure.

Noise Impact (2)

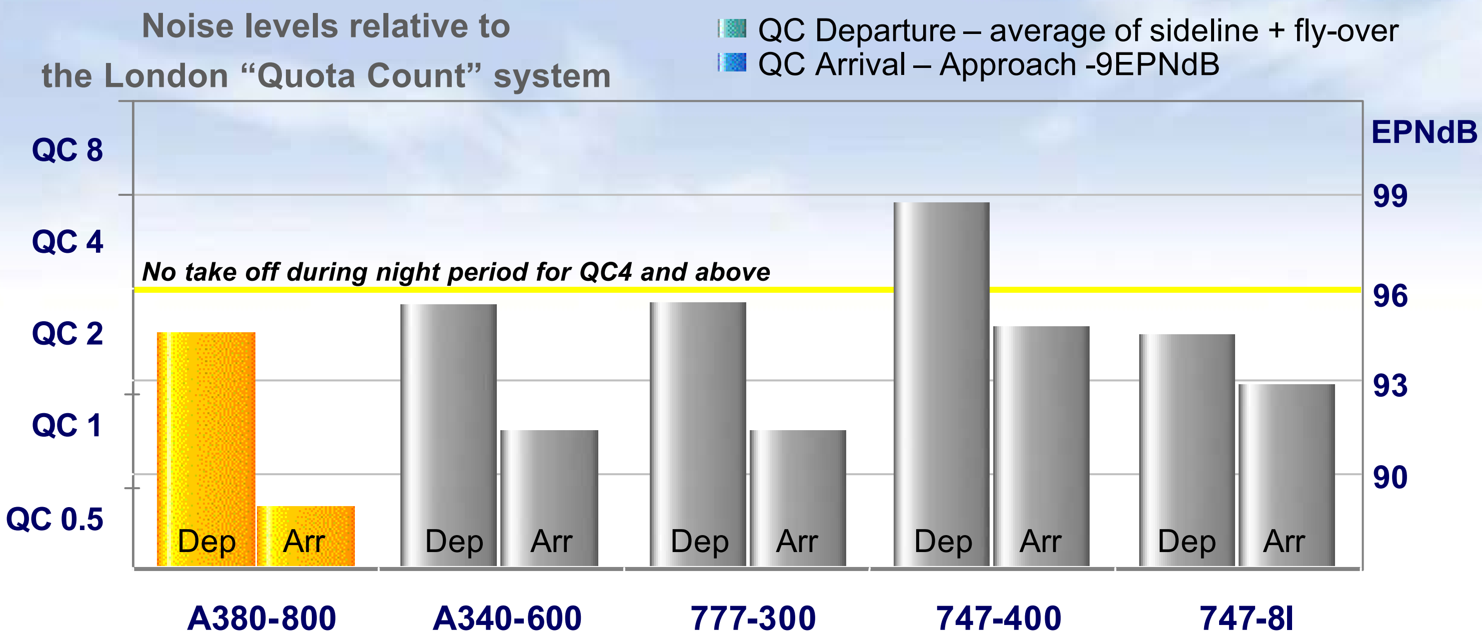


85dB(A) Noise Contour for take-off at FRA as calculated by Lufthansa with input of Boeing and Airbus nominal noise data for same t/o conditions

The A380 noise benefit

- engines
- nacelles
- T/O procedures
- L/D optimized High-Lift system
  - droop nose devices
  - opt. single slotted flap

Noise Impact (3)



A380 Noise levels certificated better than commitments:

- London QC2 Departure with margin, allowing night time departure
- London QC0.5 Arrival (same category as 787 / A350XWB)

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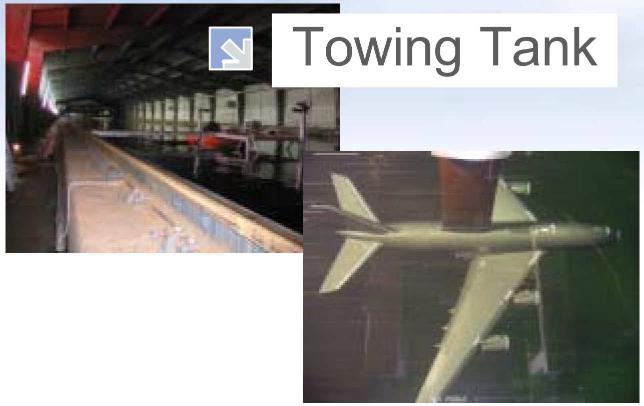
Wake Vortex:
A long-term Airbus engagement

1994-2005: A380 Pre-flight activities -

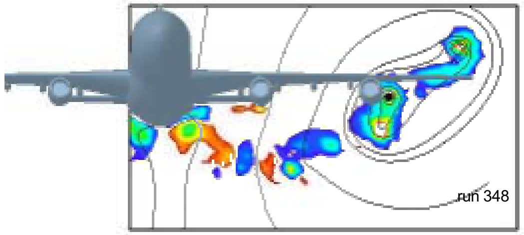
Development/Validation/Application of wake characteristics prediction methods

Wind-tunnel

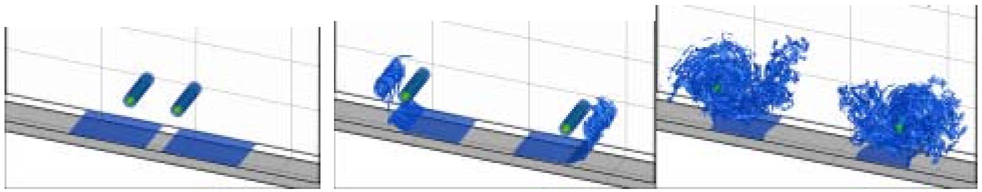
Catapult



Towing Tank

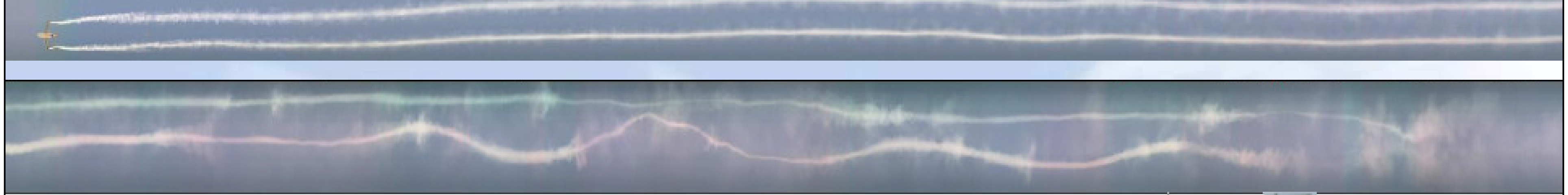


Advanced CFD



Wake Vortex:
A long-term Airbus engagement

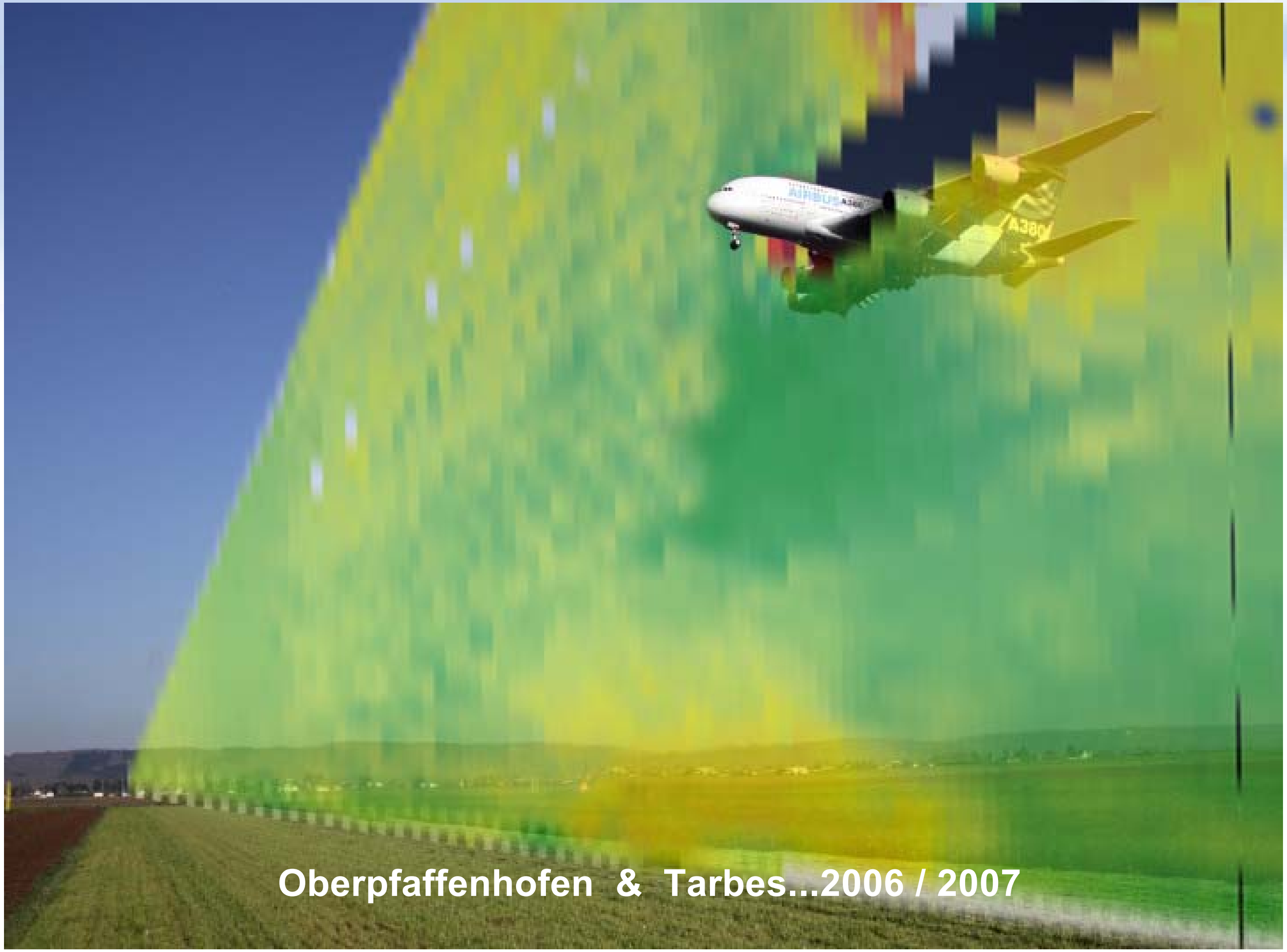
Flight Tests and operational data collection (A340 / B747 / A380



LIDAR measurements:

R&T projects, Frankfurt 2004

Wake Vortex:
A long-term Airbus engagement



Wake Vortex:
Results

- 2005-2006: Very intensive Airbus flight test activity
  - Back-to-back flight tests A380 vs. other Heavies
  - All phases of flight addressed
  - About 250 flight hours altogether

  A strong Airbus multidisciplinary involvement

- First set of Steering Group recommendations issued Oct. 06

  A "first ever" accomplishment in many respects. Exceptional example of an international team effort to support safety goals

  - **Cruise / Holding / TMA: No changes required by introduction of A380 operations**
  - **Take-Off / Landing: Larger separations in trail of A380**
    Reduced separations in front of A380

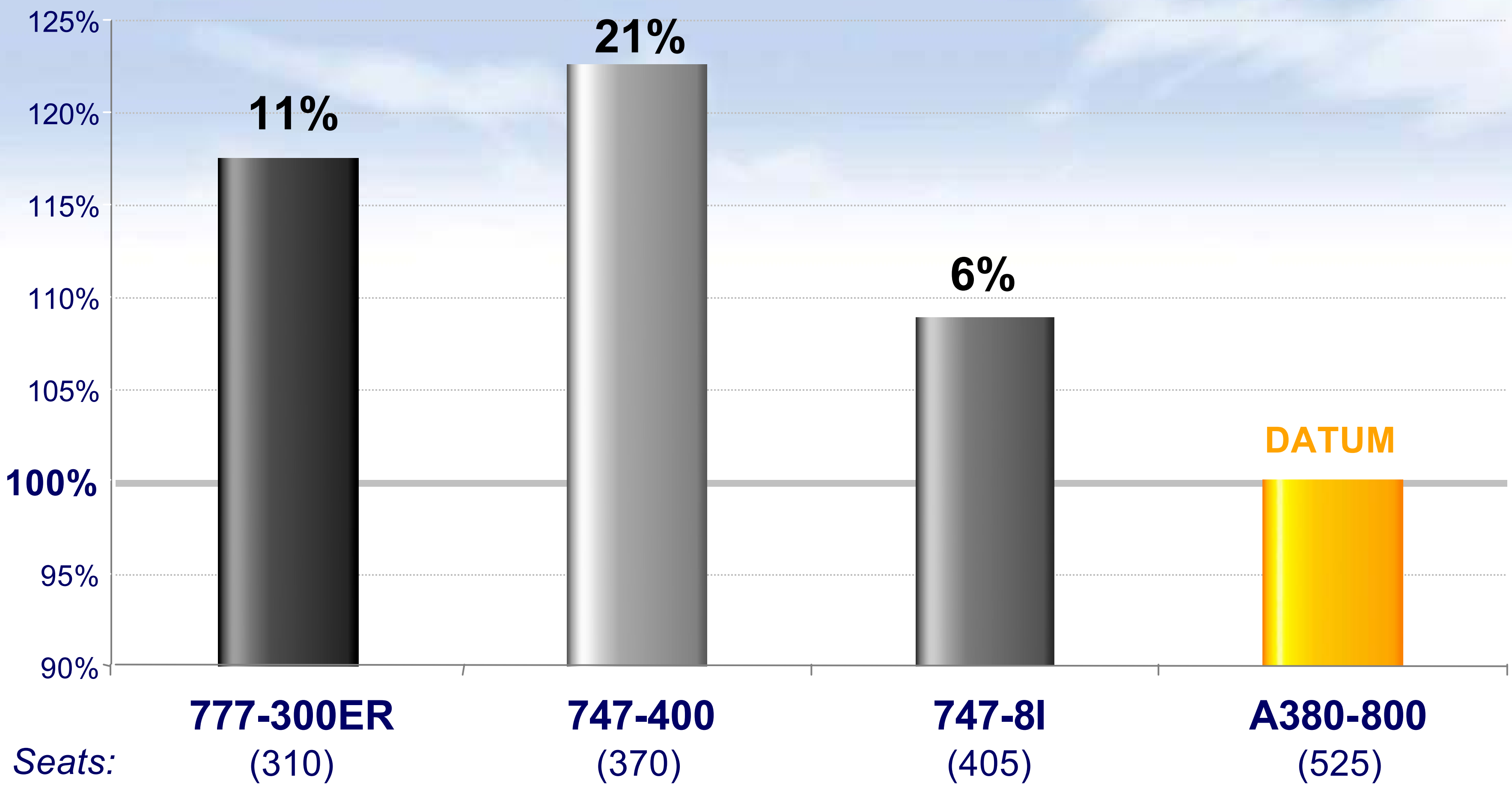
  8.5 to 9NM total separation for A380 landing in sequence between 2 Heavies (8NM for B747 today)

- Airbus and Steering Group activities to continue
  - Further reduction of separations where possible
  - Monitoring of EIS

A380 Fuel Burn Reductions

The first long-haul aircraft with less than 3 litres per pax/100km fuel consumption

A380 Fuel Burn Reductions



A380-800: the most fuel efficient large aircraft

Flight Test

Delivering Aerodynamic Performance

First flight

Flight testing hours

MSN 001
first flight: 27 April 05
hours flown: 1230
take-offs: 1050

MSN 004
first flight: 18 Oct 05
hours flown: 846
take-offs: 645

MSN 002
first flight: 03 Nov 05
hours flown: 402
take-offs: 92

MSN 009
first flight: 24 Aug 06
hours flown: 181
take-offs: 64

MSN 007
(In Hamburg)
first flight: 19th Feb 06
hours flown: 7
take-offs: 3

5 flight test aircraft, 2666 hours, 1846 take-offs

As at 8th December 2006

Aerodynamics involvement in flight tests

Aero Model Validation
- Low speed performance
- High speed performance
- Handling Qualities
- Twist measurements

Certification
- Support to Loads
- Anemometry
- Icing
- Ventilation / drainage
- …

Operations
- Support to a/c maturity development
- Wake Vortex

Flight testing: Aerodynamic Results

- Cruise, Take-off and Landing performances as predicted
- Stall characteristics as predicted, CLmax even better than expected
- Very positive comments from Pilots on handling
- No need for Configuration changes

Flight testing:
e.g. Low Speed Stall Tests

Flight testing:
Comments from Pilots

"Compared to the A320, you do not feel the difference in flight. Although much bigger than the A320, the A380 is easy to taxi."

"The aircraft is very stable but also very responsive; more like flying an A320 than an A340."

"Please do not change the handling qualities of this a/c!"

"I have been flying all the fly-by-wire types of Airbus. It's the same situation here with the A380: it's very easy to fly these aircraft because handling characteristics are extremely similar and it's a real family."

"The aircraft is much more responsive than anticipated, it does not feel like a big aircraft. Cockpit innovation and new technologies are combined well with Airbus cockpit philosophy. Coming from the A330, you feel at home and the transition is very easy."

"The aircraft, for its size, is extremely manoeuvrable: very responsive, easy to fly, very stable. Actually, I would like to take this plane home and start flying with it immediately."

"The cockpit and flying characteristics are similar, so it is easy for somebody who has flown an Airbus before to fly this airplane. I thought that because the A380 is bigger there would be a lot more lag in the controls, but to my pleasant surprise it is very lively and very stable - it's a lovely plane."

Certification Achieved
12th December 2006

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1st A/C achieving simultaneously FAA and EASA certification

The A380 is finally in service

- The 1st A380 delivered to SIA.

- Good reviews from the customer.
  - 2nd aircraft delivered to SIA.

- The aircraft has totalled 100 commercial flights with 100% in service reliability.

Concluding Remarks

- The A380 represents the continuation of a long line of technologically advanced Airbus aircraft and introduces a step change in performance, comfort standards, environmental friendliness and efficiency.
- Innovations in aerodynamics, structures, systems, integration and manufacturing have contributed to the success of the aircraft.
- Excellent aero performance is achieved despite many constraints on wing planform due to size of the A/C.
- An integrated approach to improving aerodynamic efficiency has exploited advances in high Reynolds number test facilities and modern numerical simulation tools.
- This approach will be developed further on future Airbus aircraft.

Many thanks for your attention!

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