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…

…the Airbus A380
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**

- **Take-off**
  - A380-800: 9,800ft (2990m)
  - 747-400: 11,600ft (3530m)
  - 1,800ft (550m) less

- **Landing**
  - A380-800: 6,900ft (2103m)
  - 747-400: 7,400ft (2260m)
  - 500ft (150m) less

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**
- **Pavement loading**
- **Similar gear track**

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Gear Track</th>
<th>Pavement Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>A380</td>
<td>14.30m</td>
<td>80 m</td>
</tr>
<tr>
<td>747-400</td>
<td>12.60m</td>
<td>80 m</td>
</tr>
<tr>
<td>A380</td>
<td>14.30m</td>
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</tr>
</tbody>
</table>

AIRBUS A380 - RAe Hamburg & VDI January 2008
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

A380 A330/A340 A300 A310 A318-
A321

A340-500/600

A300

A310

A318-
A321

A380 HTP area ~ A310 wing
Flaps area ~ A320 wing
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
- Cross Crew Qualification
- 15 - 20% lower operating costs
- Fast turn round time
- Engine options: RR Trent 900, GP7200
- 5000 PSI hydraulics
- Electro hydrostatic actuators
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**

**A380**
- **5000 delivered to date**
- **453 delivered in 2007**

Number of Seats

Range (nm)
Airbus Aerodynamics
A World-Class, Transnational Team
Airbus Aerodynamics

- Aerodynamics - overview
- Aerodynamic design processes
- Aerodynamics evolving strategy
Aerodynamics – A Single Transnational Team

4 European sites

One Transnational Team

Airbus Aerodynamics

Programme Management

Technology, M&T Management

Design | Data | T&S | WTT
Aerodynamics in the Design Process

A380-800 Testing Days

- **Low Speed**
  - '96: 32 days
  - '97: 39 days
  - '98: 127 days
  - '99: 125 days
  - '00: 210 days
  - '01: 408 days
  - '02: 115 days
  - '03: 100 days
  - '04: 61 days
  - **Total Low Speed**: 818 days

- **High Speed**
  - '96: 7 days
  - '97: 7 days
  - '98: 5 days
  - '99: 7 days
  - '00: 15 days
  - '01: 165 days
  - '02: 45 days
  - '03: 130 days
  - '04: 67 days
  - **Total High Speed**: 400 days

- **Total Testing Days**: 1218 days

**Additional Information**

- **Feasibility Phase**
  - M3: 60 days
  - M5: 90 days
  - **Total Feasibility Phase**: 150 days

- **Concept Phase**
  - 900 days

- **Development**
  - 1200 days
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

Wind Tunnel Testing Days

- **Airbus A380**
- **Boeing 787**
- **Airbus A350**

40% Reduction
Today's wind tunnel combine the parameters of enlarged test sections, pressurisation and cryogenic conditions. A variety of options are available:

- **Low Speed Wind Tunnels**
  - DNW - LLF
  - EFW/ RUAG
  - ONERA S1

- **High Speed Wind Tunnels**
  - ONERA F1
  - Quinetic - Q5M
  - Airbus FLWT
  - Airbus BLWT
  - Airbus

- **Facilities**
  - DNW - LST
  - DNW - NWB
  - ARA
  - DER A
  - NLR - HST
  - S2

*Airbus preferred facilities in blue*
Aerodynamics Evolving Strategy:
Wind Tunnel Testing: Facilities

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

![Diagram of wind tunnel facilities]

* Airbus preferred facilities in blue
Aerodynamics Evolving Strategy:
Wind Tunnel Testing: Models

- Reduced number of models to be used in different tunnels: **Low Speed**
Aerodynamics Evolving Strategy: Wind Tunnel Testing: Models

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

![Diagram showing ARA, ETW, and ONERA S1 models](image.png)
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

Cruise Range of current and future Transport Aircraft

Take-off & Landing

Half Models

Full Models

Other European Wind Tunnels
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

\[ \text{Re} = 8.1 \text{ million} \]
\[ M = 0.85 \]
\[ CL = 0.5 \]
\[ \text{Shape C1} \]
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

Operating costs
- 15 - 20% lower operating costs
- Using less fuel
- Use of advanced materials

Field performance
- Take-off Requirements
- Landing Speed

Noise & emissions
- Noise & Emissions improvements
- Engine options
  - RR Trent 900
  - GP7200
- Take-off L/D

Operations
- All variants fit in 80m x 80m box
- Wake Vortex
- Fast turn round time
- Cross Crew
- Qualification
A380-800: Salient Features

- Supercritical wing with integral fuel tanks
- Fuselage with Twin passenger decks
- 2 Variable droop leading edges
- 4 Advanced very high bypass ratio turbo fan
- 6 Leading edge slats
- 2 Rudders
- 2 Elevators
- Single sloped, tracked high lift flaps
- 2 Horizontal Tail-plane & Trim Tank
- 3 ailerons
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

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.

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.

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

Constraint on L.E. position relative to Door 7 slide raft:
- depending on L.E. shape

Taper ratio constrained by wing area, and root chord.
Wake Vortex: ICAO Wake Turbulence Separation

Separation Standards in Approach / Landing

Leading Aircraft

Followed by

Heavy

Medium

Small

Heavy

> 136 t

Separation Miles

0

3

4

5

6
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
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 planform, 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

M*L/Dopt


A300-B4 A300-600 A320 A330
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

Achieved through multi-disciplinary working in Aerospace, Loads, Structures & Systems
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 constraints 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.
Fuselage Design: Nose

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

Cockpit width common to the current AIRBUS at the pilot level

- Passenger decks
- Cargo deck
- Cockpit floor in intermediate location between passenger floors
- Main E/E bay volume

Final shape

\[ M_{local} = 1.001 \]
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 m²
  - Increased root thickness for weight saving without drag penalty
  - Improved tail stall capability

- **VTP**
  - Size reduction from 140 to 122 m²
  - Increased root thickness for weight saving without drag penalty
High Lift: An Overview

Multidisciplinary Integrated Design in the Development of the High Lift System

- Slat Chord & Angle Reduction
- Strake & Pylon Integration
- Inboard Fixed Leading Edge
- Slat Cutback
- I/B Slat replaced by Droop Nose Device
- Ailerons
- Reduced Flap Span
- Trailing Edge Thickness Mods
- Flap Chord and Shroud Position
High Lift:
Slat with Reduced Chord and Angle
High Lift:
DND Design (for higher t-o L/D and low noise)

Droop Nose Device
DNT

Slat

Less drag
• Higher Take-off L/D

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

DND

CL

Slat

DND

α

Airbus A380 - RAe Hamburg & VDI January 2008
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)

Noise levels relative to the London “Quota Count” system

Noise levels relative to the London “Quota Count” system

QC 8
QC 4
QC 2
QC 1
QC 0.5

EPNdB

A380-800 A340-600 777-300 747-400 747-8I

No take off during night period for QC4 and above

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)
Wake Vortex:
A long-term Airbus engagement

1994-2005: A380 Pre-flight activities -
Development/Validation/Application of wake characteristics prediction methods
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

Oberpfaffenhofen & Tarbes...2006 / 2007
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

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Seats</th>
<th>Fuel Burn Reduction</th>
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</thead>
<tbody>
<tr>
<td>777-300ER</td>
<td>(310)</td>
<td>11%</td>
</tr>
<tr>
<td>747-400</td>
<td>(370)</td>
<td>21%</td>
</tr>
<tr>
<td>747-8I</td>
<td>(405)</td>
<td>6%</td>
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<tr>
<td>A380-800</td>
<td>(525)</td>
<td>DATUM</td>
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</tbody>
</table>
Flight Test
Delivering Aerodynamic Performance
First Flight 27th April 2005, Toulouse
– watched by 40,000 people
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
(first 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.”

“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 is very stable but also very responsive; more like flying an A320 than an A340.”

“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.”

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

“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

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!