The Engagement of a modern wind tunnel in the design loop of a new aircraft

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Content

- The European Transonic Windtunnel ETW
- Why flight Reynolds number testing?
- CFD versus wind tunnel testing
- Specific benefits of testing in ETW
- What type of test techniques are available at flight conditions?
- AIRBUS is taking the full ETW capacity in the design process of new aircrafts
ETW Working Principle

Flow temperature & pressure level are controlled by injection of liquid nitrogen and exhaust of gaseous nitrogen.
ETW is a Unique, Worldwide Leading Facility

1. Full-scale Flight Reynolds Number
2. Independent Variation of Reynolds Number and Structural Loads
3. High Productivity and Costs Efficiency
4. Security and Client Confidentiality
The NASA CRM-model in the slotted wall test-section of ETW (EU-ESWIRP project)
Reynolds-Number Effect on Pressure Distribution

M = 0.2  \quad \text{Alpha} = 0.17

\begin{align*}
\text{Re} &= 1.7\text{mio} \\
\text{Re} &= 20.1\text{mio}
\end{align*}
High-Lift Performance

- Measuring settings performance and failures
- Identification of optima

![Graph showing the comparison of conventional wind tunnels, ETW, and flight performance with Mach 0.2 at various Reynolds numbers (Re)]
Aircraft Design Challenge: Performance (1/3)

- Competitive A/C performance is one top level A/C requirement since it is key to marketability and achievable price of the product.
- Early accurate prediction of A/C performance is essential as performance guarantees are part of every A/C sales contract and involve significant financial stakes.
- Performance assessment activities start early in a programme and performance optimisation accompanies the products lifetime.
- Due to safety implications, regulations pose boundaries, and compliance to it has to be demonstrated for certification.
- Associated challenges are:
  - Optimise design performance in compliance with regulations.
  - Provide airlines with the means to exploit this optimum performance.
Flight Envelope – ETW complements CFD

ETW uniquely provides reliable prediction for:
- High-Lift Design
- Stall Behaviour
- \(M_D\) Dive Properties
- Cruise / Dive Separation
Cruise Performance – Comparison with flight-test data

- ETW provides reliably accurate prediction
- For cruise CFD provides accuracy, but reliably?
- ETW verifies CFD
ETW and CFD Complement Each Other

ETW strengths:
> Real flow at flight Re
> Complex configurations
> Separated flow
> Reliable performance-risk identification
> Productivity to acquire vast amounts of data in reasonable time

CFD strength:
> Responsiveness to shape changes

⇒ Best work share: CFD optimizes the design by screening & refining, ETW provides physical data, validates & verifies

Note: Energy and personnel are strong costs drivers for both tools!
ETW Enables First-Time-Right Design for Flight-Re

Aero-model accuracy & confidence
ETW Enables First-Time-Right Design for Flight-Re

Aero-model accuracy & confidence

- Reduced lead time
- Higher accuracy before AtO
- Higher confidence before FT
⇒ Significantly reduced risks
Aircraft Design Challenge: Performance (2/3)

> Essentially, A/C performance is the result of
  – Weight
  – Propulsion
  – Aerodynamics
  – Other parameter

> The other parameter are amongst others dependent
  – on regulation interpretation, and
  – on the quality of the tests performed and used for certification

⇒ Test quality can significantly impact performance

> Regulations affect A/C performance through
  – Airworthiness of the design in relation to CS 25 / FAR 25
  – Technical operating rules in relation to JAR-OPS 1 / FAR 121
Benefits from ETW testing

Range = \( \frac{\text{Velocity}}{\text{Specific Fuel Consumption}} \cdot \frac{\text{Lift}}{\text{Drag}} \cdot \ln \left( 1 + \frac{\text{Fuel Weight}}{\text{Load} + \text{Empty Weight}} \right) \)

**Engines**
- UHBR / OR
- Engine Integration

**Aerodynamics**
- Flight-Re Design
- Lift-induced Drag
- Flow Control, e.g. Laminarity

**Structures**
- Lightweight
- Aeroelastic Tailoring
- New configurations
- Lack of Tool Calibration

Plus understanding/prediction of cruise safety margins

Vital need for ETW Capabilities in Research & Development
High Reynolds number testing at ETW enables the designer to exploit physical limits at high prediction accuracy. Thus, the designer may e.g. increase range performance by:

- **Improving the aerodynamic efficiency** through
  - maximising lift of all lifting components,
  - minimising lift loss of non-lifting components and propulsion integration, and
  - minimising drag for all components
- **Reducing empty weight** for a given volume by allowing higher recompression gradients
  - Relatively thicker and thus lighter wings
  - Reduced length and thus shorter fuselage, and fairings
Aerodynamic Drag Components

- Optimum wing design achieves a **low profile, wave and induced drag** while providing sufficient volume for hosting the load carrying structure, movables, and fuel tanks.
- Apart from these main drag types, **trim drag, interference drag**, and parasitic drag have to be minimised.
- Accurate lift and drag prediction requires proper representation of the boundary layer status (laminar, turbulent, separation).
**W/T Test Objectives & Interfaces**

ETW Wind Tunnel Testing

- **Performance:**
  - Field Performance
  - Range / Mission Profiles
  - Noise

- **Handling Qualities:**
  - Flight Controls
  - Control Laws / Simulator

- **Loads:**
  - Component Loads for Structural Dimensioning

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**Validation & Verification**
- Proof of concepts
- Concept optimisation
- Characteristics
- Verification of CFD/CAE
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Buffet-Onset Boundary – Comparison with flight-test data

Buffet-Onset $C_L$ depends on:
- Mach Number
- Reynolds Number
- Wing Deformation

$\Rightarrow$ ETW capabilities required
Bend and Twist Evaluation – Wing Example

Wing deformation of the NASA Common Research Model during the ESWIRP test campaign in 2014

Test conditions: $Ma = 0.85$, $P_{tot} = 200$ kPa, $T_{tot} = 117K$, $Re = 20 \times 10^6$
Using SPT for Capturing Flap-Gap Effects

$Ma_{\infty} = 0.2,$

$Re_{\infty} = 16.7 \text{ Mio.}$

$p_0 = 411 \text{ kPa}$

> Flap-gap change versus wingspan and AoA
Full-Span Model Options

- Performance data based on corrected low & high Reynolds data
- Single-sting data complete model / body alone plus deformation data
- Assessment of sting interference using CFD for the body alone config.
- Wind-tunnel calibration data & robust wall interference correction methodology

Cost Optimized

Quality Optimized

- Absolute performance data based on fully corrected high-Reynolds data
- Single-sting data with high-precision sting corrections from twin-sting tests (live rear fuselage / complete model)

Single-/Twin-Sting Approach:

- Lowest impact of sting correction method on final flight estimate
Alternative Supports for Rear End Measurement

- Z-Sting
- Fin Sting
- Front Blade Sting
TSP Capability to identify Flow Separation

TSP-Image

Balance data
Natural Laminar Flow Half Model

Pressure taps

\[ M \approx 0.78 \]
\[ Re \approx 17 \times 10^6 \]
Measured Velocity distributions

Configuration 2
M = 0.186

Re_C = 13.3 Mio.
\( \alpha = 16.5^\circ \)

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Measured Velocity distributions

Configuration 2
M = 0.186

Re_C = 13.3 Mio.
α = 16.5°
ETW Aeroacoustic Measurements

2. 

Engine idle (30%), landing config, gear in

Flight

High Re 20M

\( S_l^{1/3\text{Oct}} = 120 \) (18.06 kHz)

\( S_l^{1/3\text{Oct}} = 185 \) (27.84 kHz)

Unclassified
Independent Variation of Re-Number & Structural Loads
Lift, drag, pitching-moment characteristics Falcon 7X (1:10)

Reynolds Variation at const. Airloads
- Flight Re \(\approx 16\) Mio.
- Re \(\approx 8\) Mio.
- Re \(\approx 8\) Mio. with transition-tripping

Airloads Variation at const. Reynolds
- Flight Re \(\approx 16\) Mio.
- \(c_d(c_l)\)
- \(c_l(\alpha)\)
- \(c_m(c_l)\)

- Reynolds Number strongly affects aircraft performance
- Aeroelastic distortion strongly affects aircraft stability
Important: ETW Model Jig Shape TBD

Goal: At the ETW model design point (MDP) test condition, the model wing bending and twist resembles wing’s flight shape of full-scale A/C 1g cruise design point

- Calculate the wing shape for the full-scale aircraft at 1 g cruise design point (design Mach number and design CL, i.e. the “flight shape”)
- Estimate the change in wing shape between the ETW MDP and the corresponding wind-off test conditions, by e.g.
  a) Static aeroelastic analysis, or
  b) Scaling of existing deformation data from previous test entries (more simple but potentially less accurate)

Apply resulting difference (twist & bending) to the flight shape for defining the model-manufacturing wing shape, i.e. “ETW model jig shape”. **NB: The resulting model-manufacturing wing shape may not be the same as the full-scale “jig shape”!**
Smart Model Design Improves Test Productivity

Close collaboration of ETW experts and clients required in order to achieve a model design that

- Can be manufactured quickly at appropriate quality
- Enables fast and reproducible model rigging and changes
- Works reliably at ETW
ETW vs. Conventional Wind-Tunnel and Flight Testing

Benefits from data accuracy:
- **ETW Testing**
- **Flight Testing**
- **Conventional WTT**

Costs per Day:

> ETW comes close to Flight-Test accuracy at much lower costs
⇒ Significant cost-quality benefit
Airbus Approach to Aircraft Aerodynamic Development

Integrated design process “5As” advances maximum synergy between wind-tunnel testing & numerical simulation:

> “More simulation, less testing” - specific physical testing
> “First time right” - early reliable verification & validation
ETW Testing Enables Designers to Exploit Physical Limits “Design for Flight Reynolds Numbers”

in order to support aircraft innovation & competitiveness:

- Lighter aircraft, more space & load capacity
- Better take-off & landing performance
- Low-penalty propulsion integration
- Highly competitive / low-emission aircraft design
  - Avoiding late defect discovery
  - Financial and technical risk mitigation