European Research Infrastructure

EUROPEAN TRANSONIC WINDTUNNEL

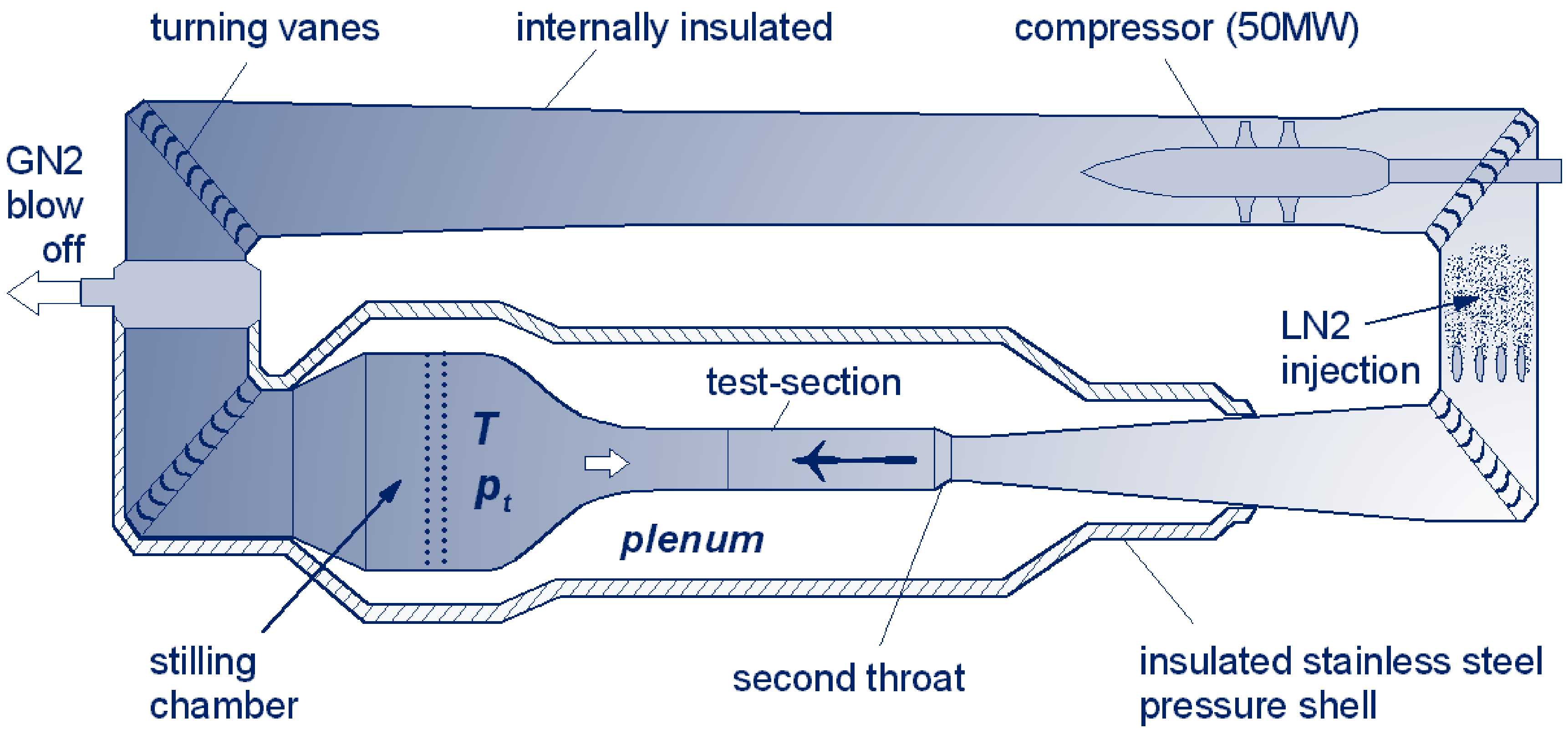
The Engagement of a modern wind tunnel in the design loop of a new aircraft

Jürgen Quest, Chief Aerodynamicist & External Project Manager (retired)

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

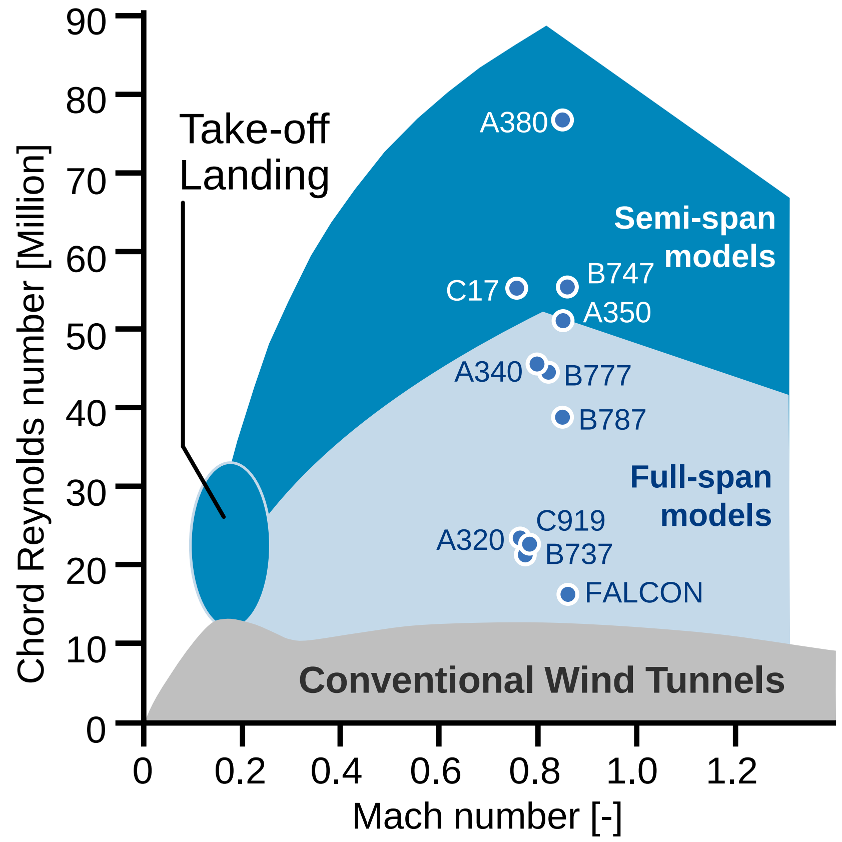
ETW Working Principle



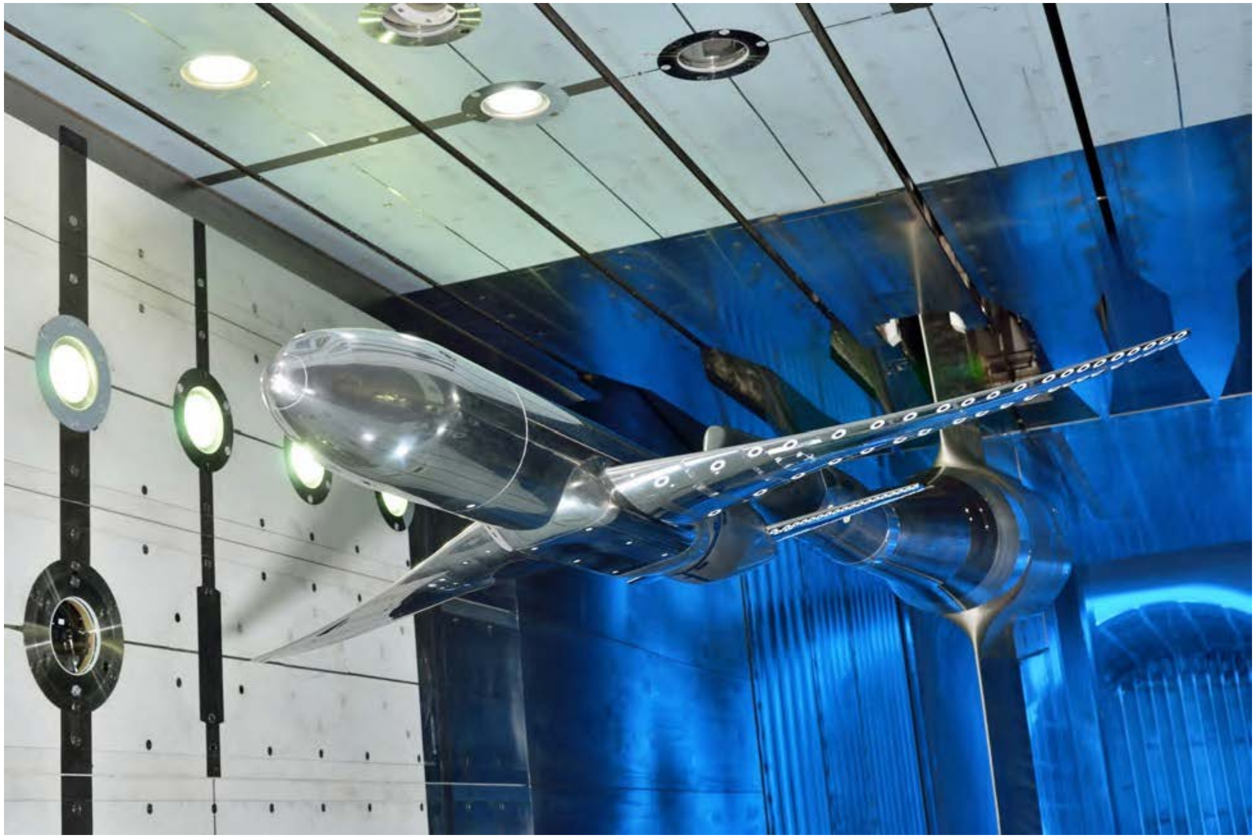
> **Flow temperature & pressure level are controlled by injection of liquid nitrogen and exhaust of gaseous nitrogen**

ETW is a Unique, Worldwide Leading Facility

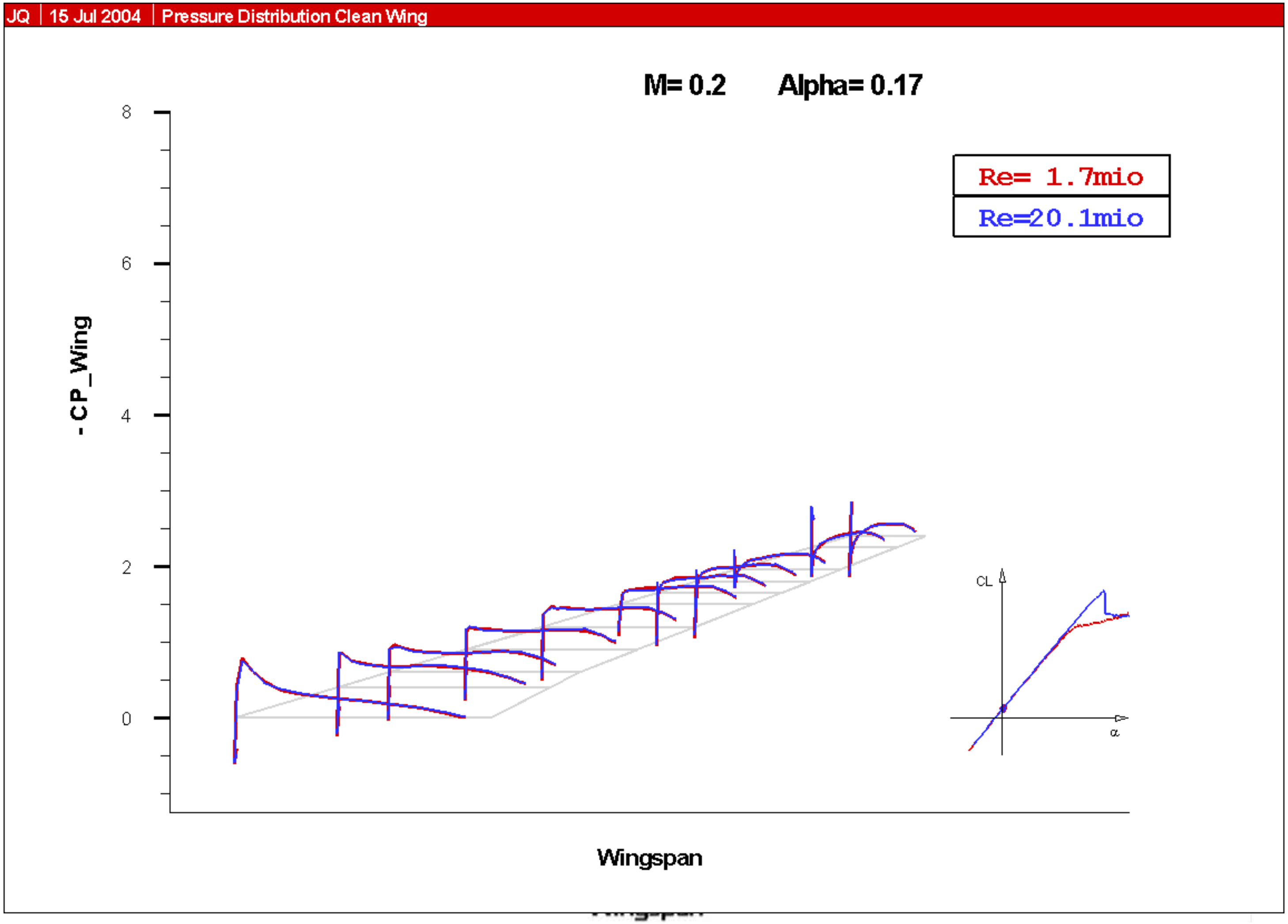
1. **Full-scale Flight Reynolds Number**
2. **Independent Variation of Reynolds Number and Structural Loads**
3. **High Productivity and Costs Efficiency**
4. **Security and Client Confidentiality**



The NASA CRM-model in the slotted wall test-section of ETW (EU-ESWIRP project)



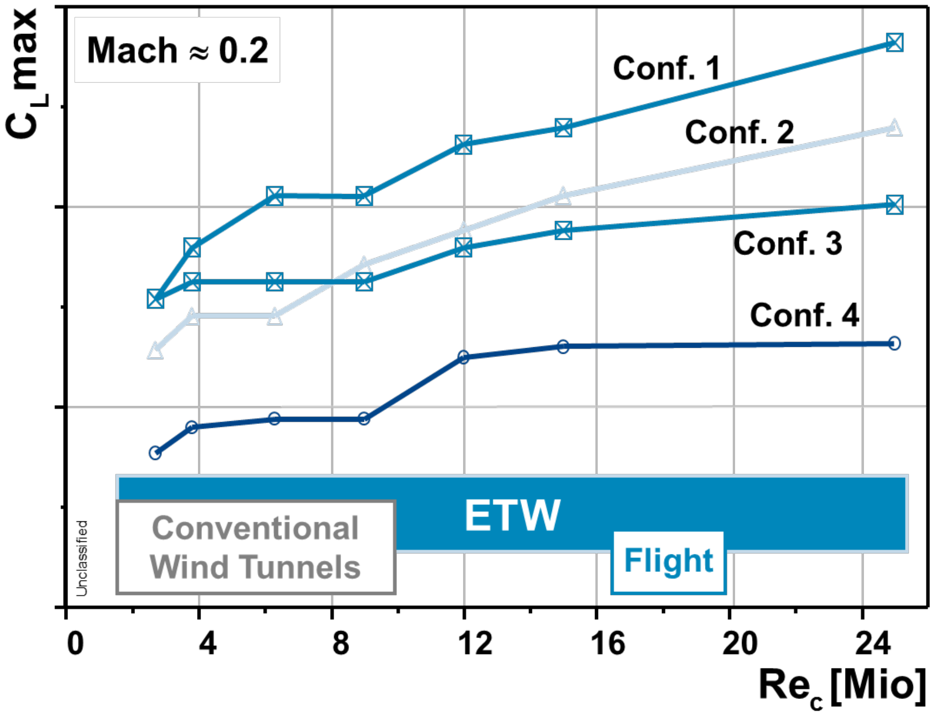
Reynolds-Number Effect on Pressure Distribution

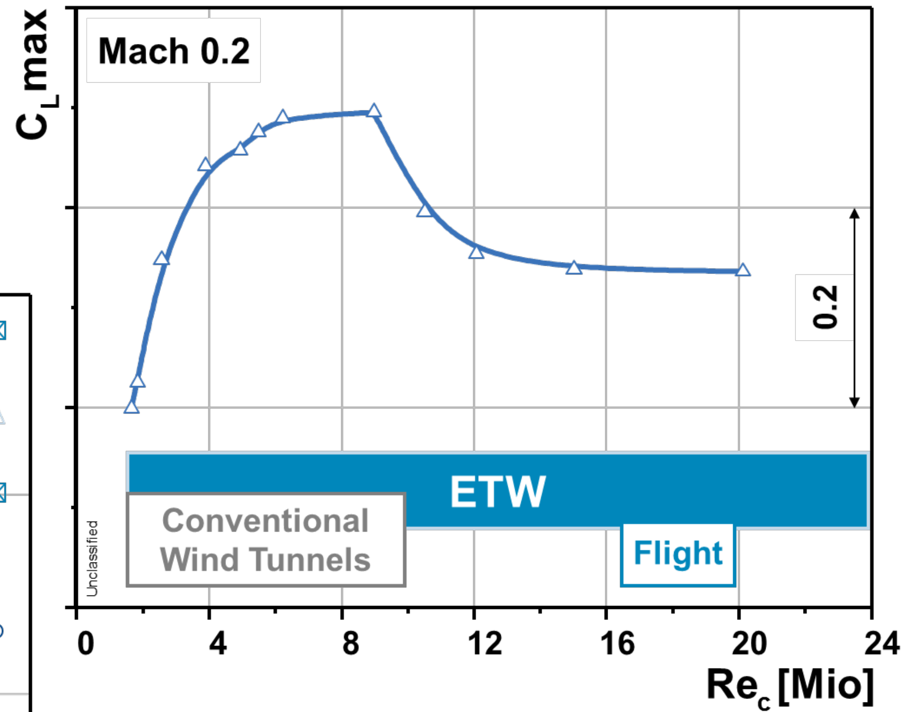


Unclassified

High-Lift Performance

- Measuring settings performance and failures
- Identification of optima

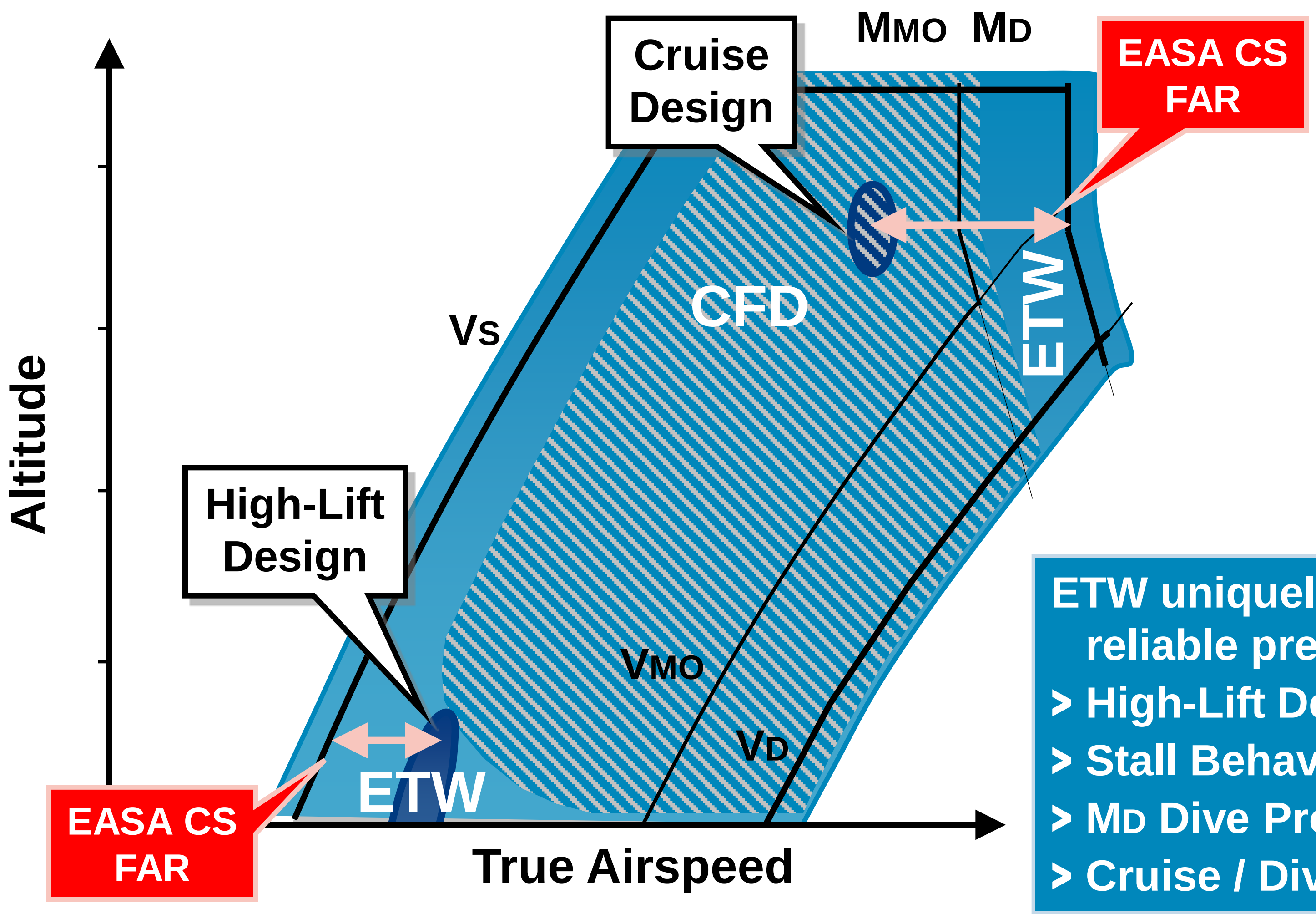




Aircraft Design Challenge: Performance (1/3)

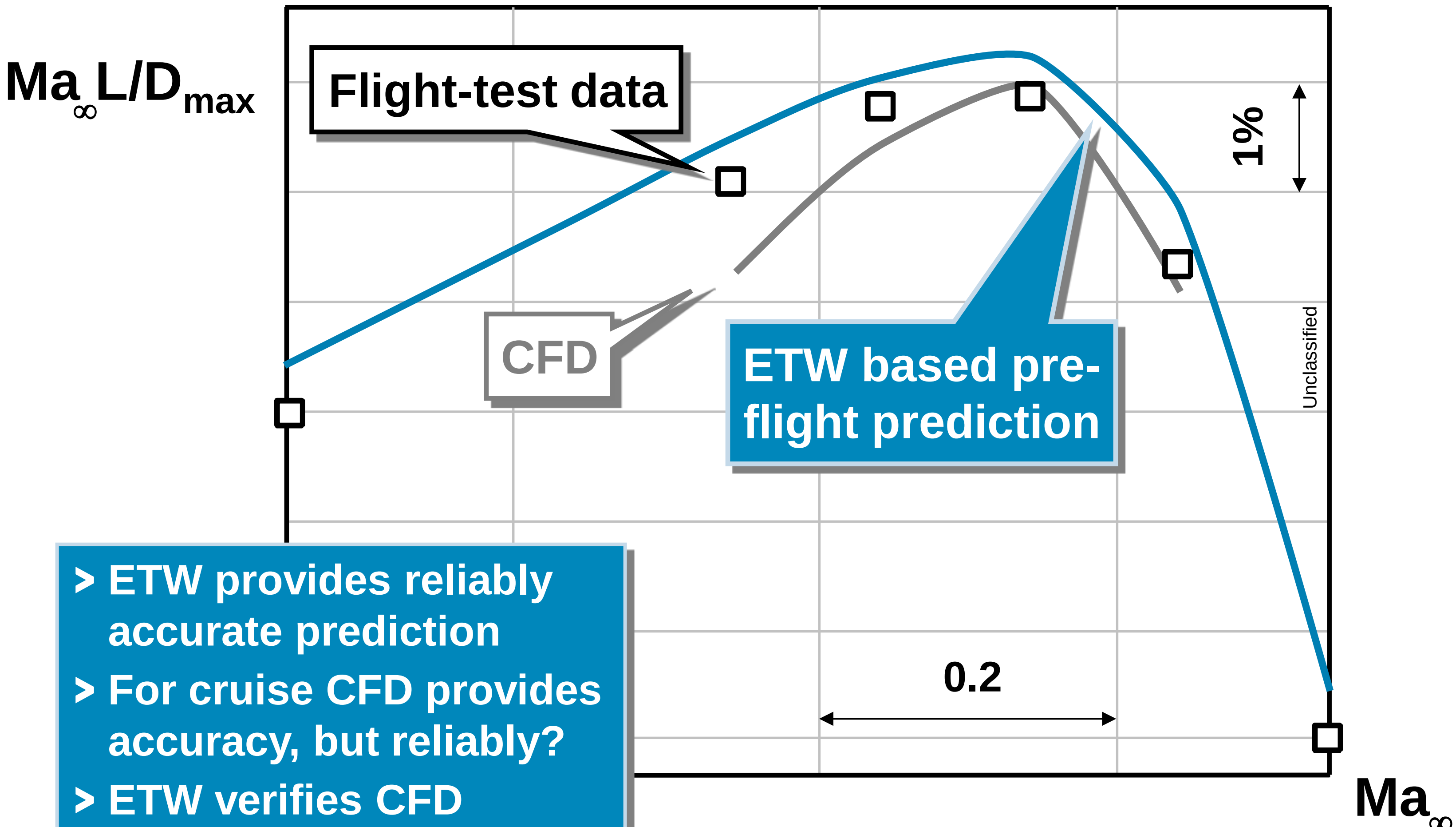
- Competitive **A/C performance is one top level A/C requirement** since it is key to marketability and achievable price of the product
- **Early accurate prediction of A/C performance is essential** as performance guarantees are part of every A/C sales contract and involve significant financial stakes
- **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
- > MD Dive Properties
- > Cruise / Dive Separation

Cruise Performance – Comparison with flight-test data

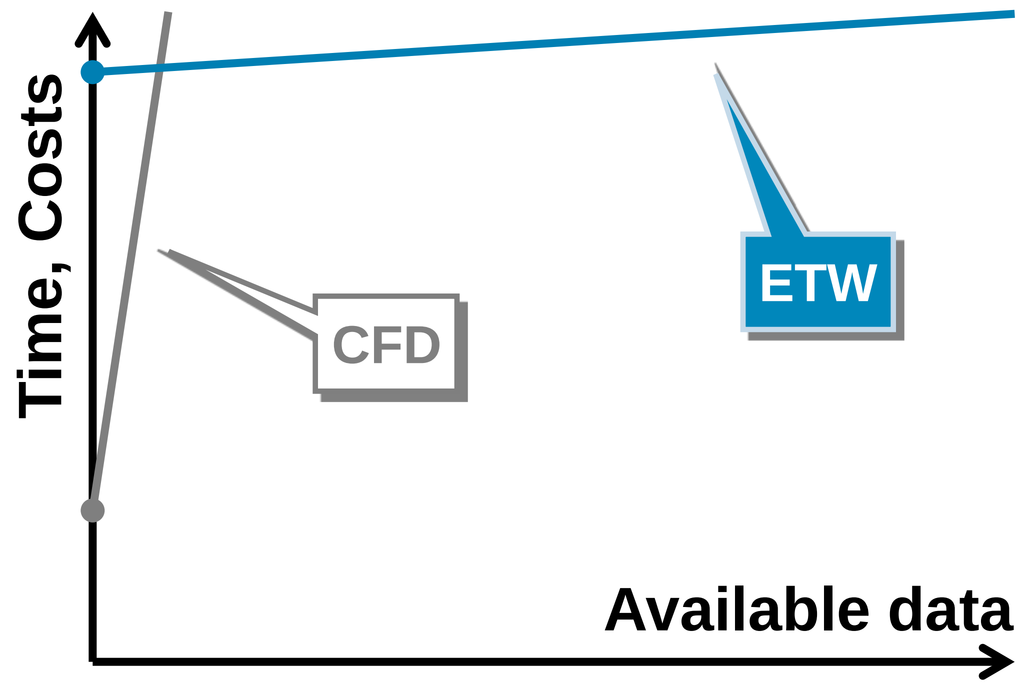


- > ETW provides reliably accurate prediction
- > For cruise CFD provides accuracy, but reliably?
- > ETW verifies CFD

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:

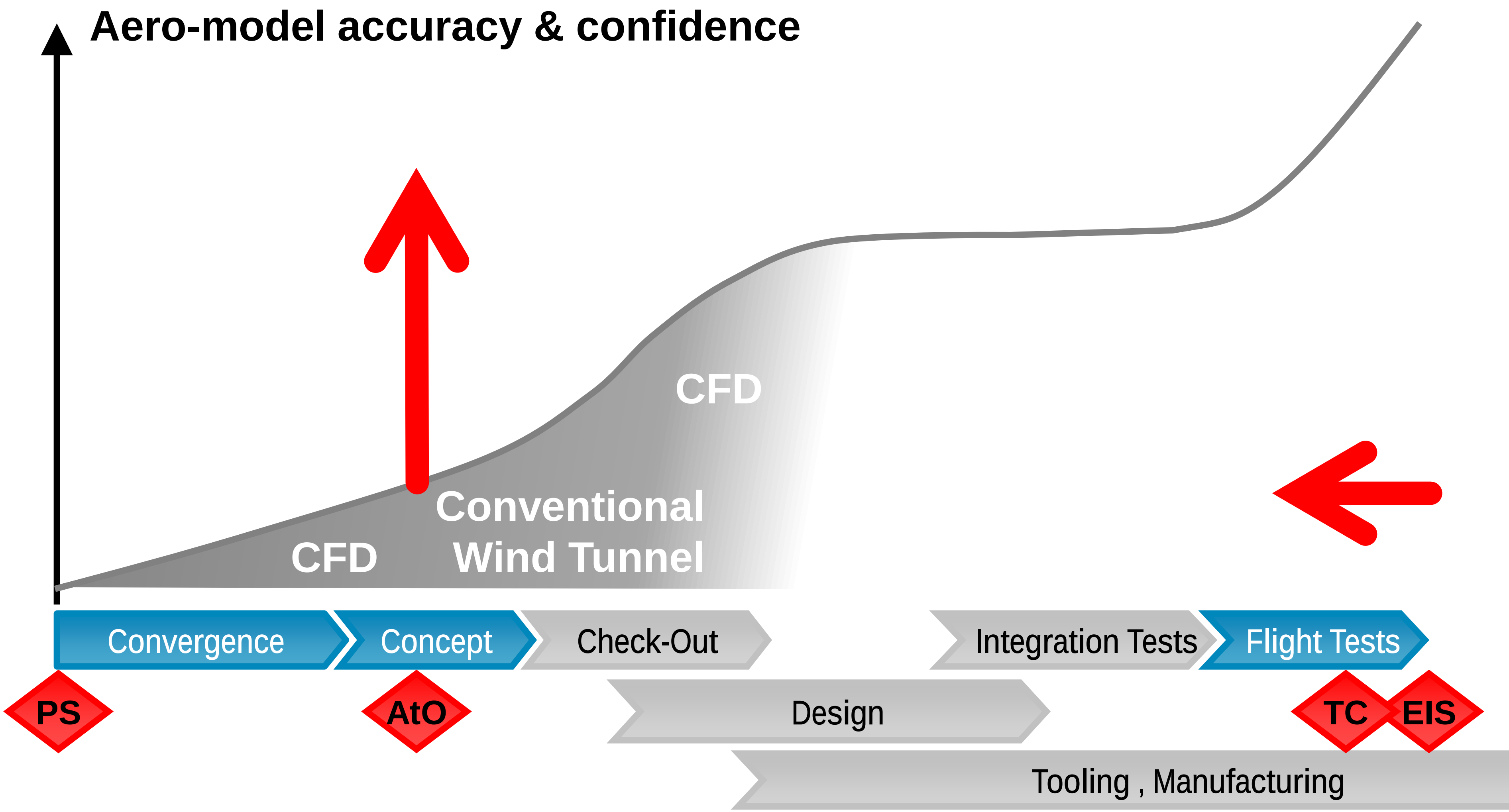
- Responsiveness to shape changes

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

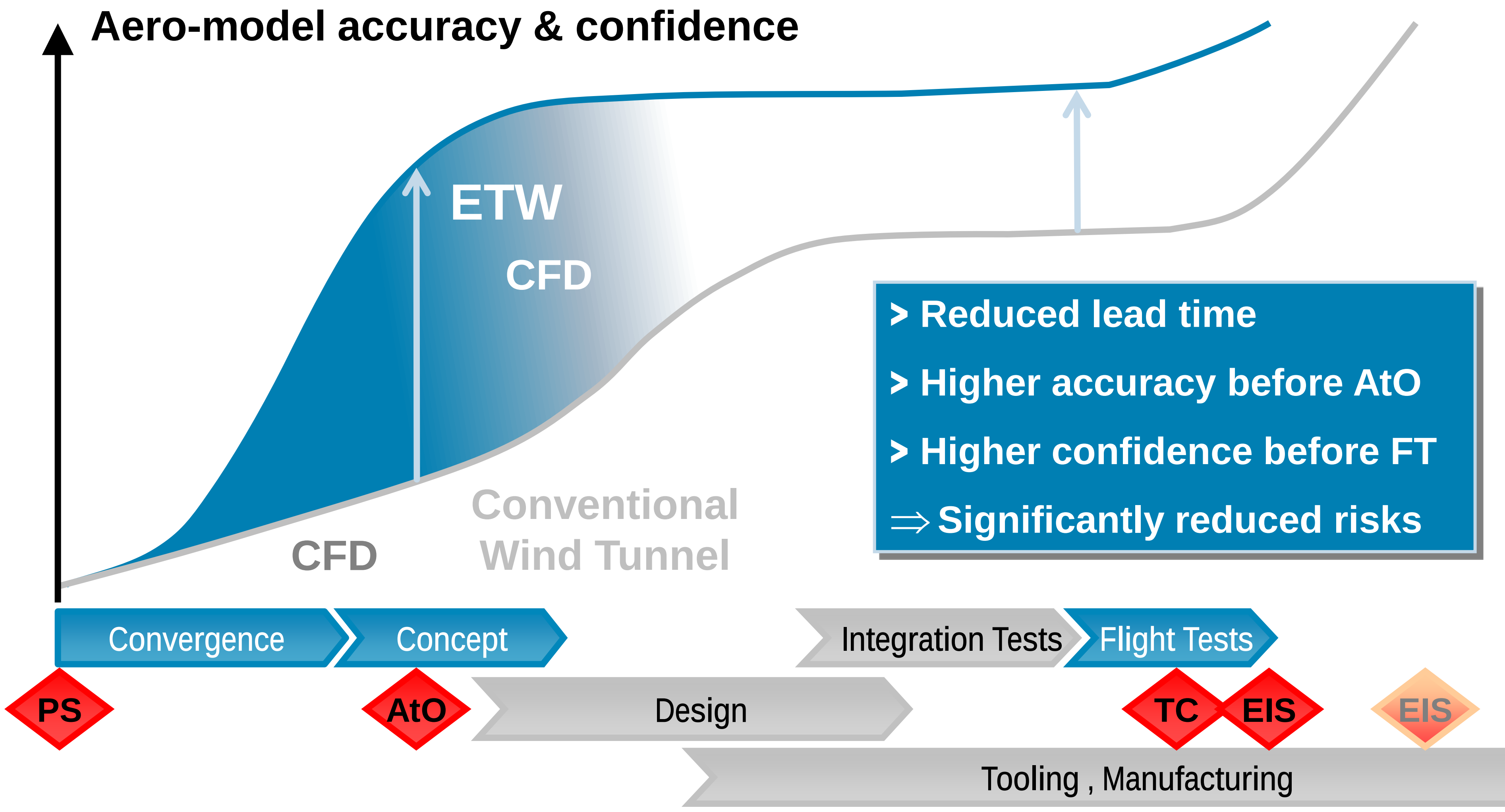
Note: Energy and personnel are strong costs drivers for both tools!

HS WTT provides ~2900 data points, 2012's CFD provides ~1 data point per 8h day

ETW Enables First-Time-Right Design for Flight-Re



ETW Enables First-Time-Right Design for Flight-Re



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

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

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

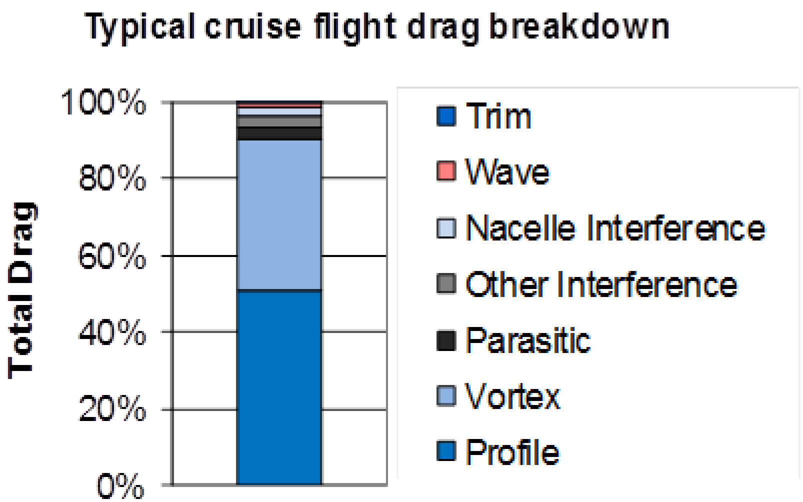
Aircraft Design Challenge: Performance (3/3)

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

Geometries

WT Data

Validation & Verification
- Proof of concepts
- Concept optimisation
- Characteristics
- Verification of CFD/CAE

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

Handling Qualities:
- Flight Controls
- Control Laws / Simulator

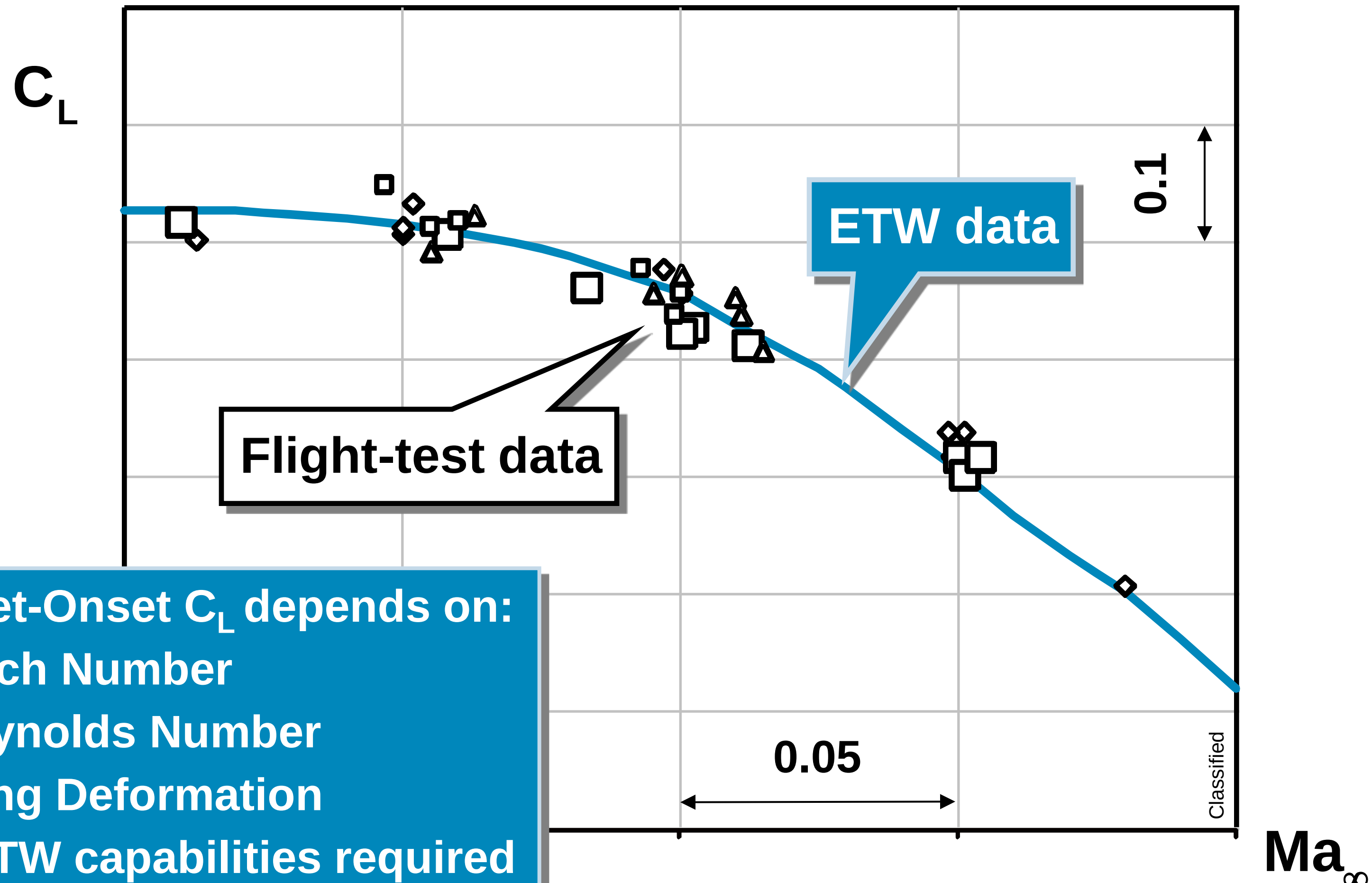
Loads:
- Component Loads for Structural Dimensioning

Measurement Techniques (steady)

measurement	type	technique	type	technique
Force & Moment	integral	balance		
Pressure	local	tap / PSI	area	PSP
Flow vector	local	tufts	area	PIV
Separation	local	tufts	area	liquid crystal
Wing Deformation	local	SPT	area	IPCT
Boundary Layer	local	PSC hot-film	area	TSP

EUROPEAN TRANSONIC WINDTUNNEL

Buffet-Onset Boundary – Comparison with flight-test data



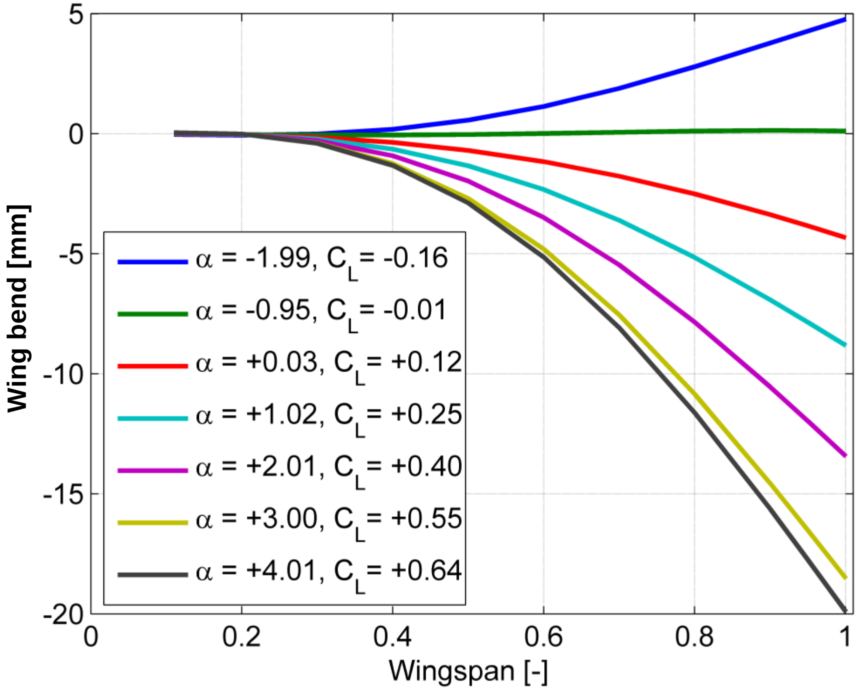
Buffet-Onset C_L depends on:
- Mach Number
- Reynolds Number
- Wing Deformation

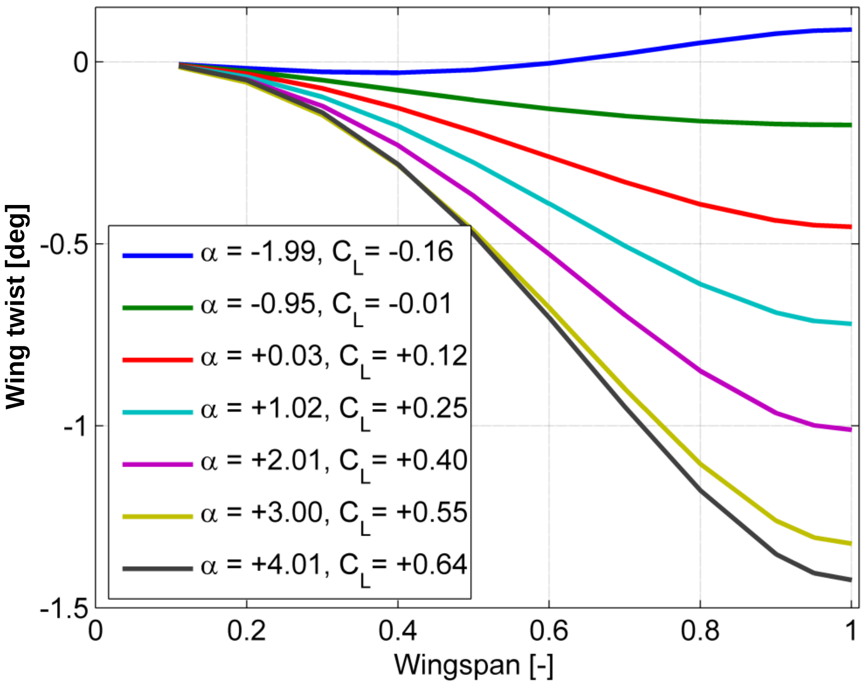
$\Rightarrow$ **ETW capabilities required**

Bend and Twist Evaluation – Wing Example

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

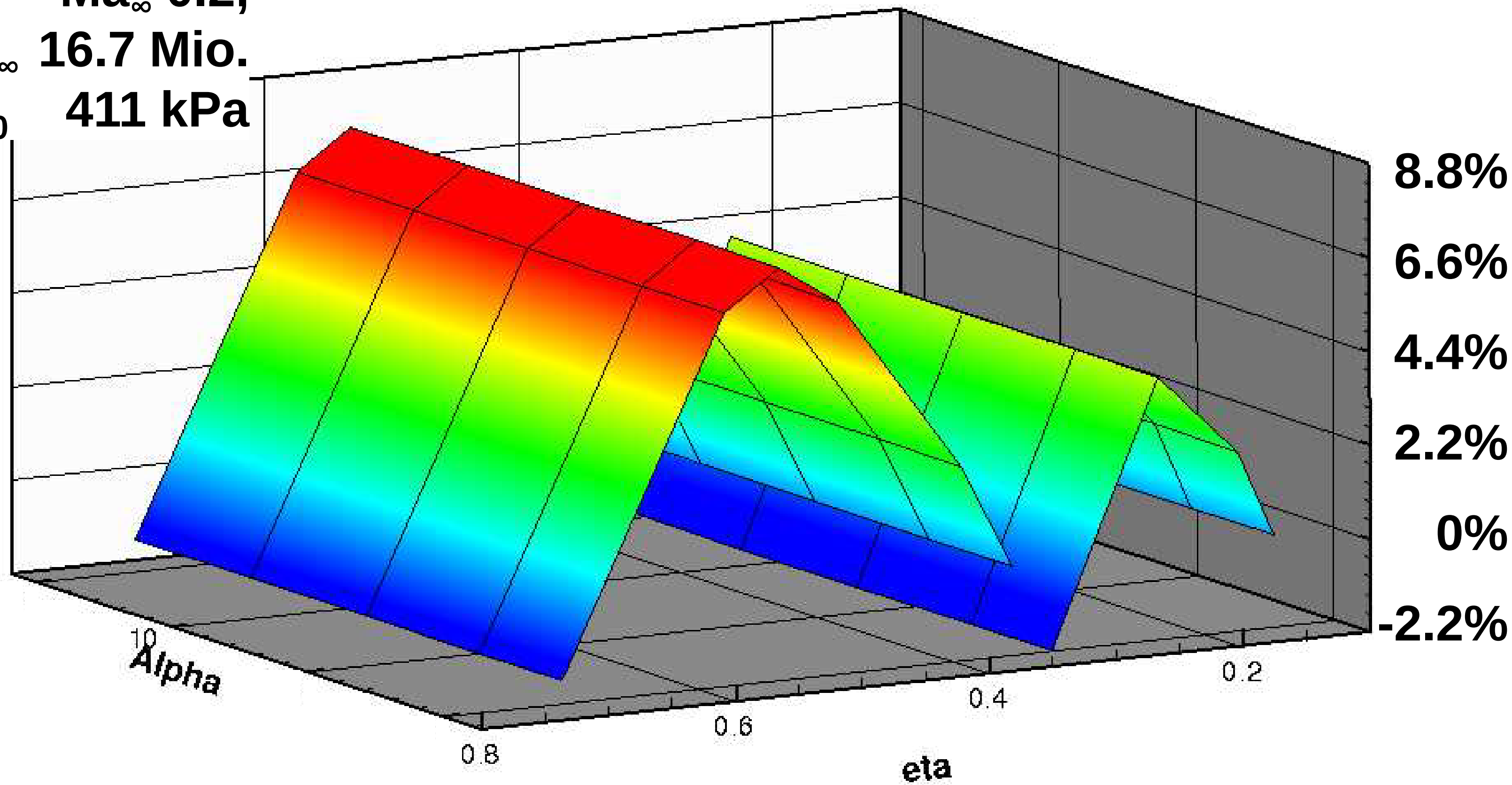
Test conditions: Ma =0.85, Ptot = 200 kPa, Ttot = 117K, Re = $20*10^6$





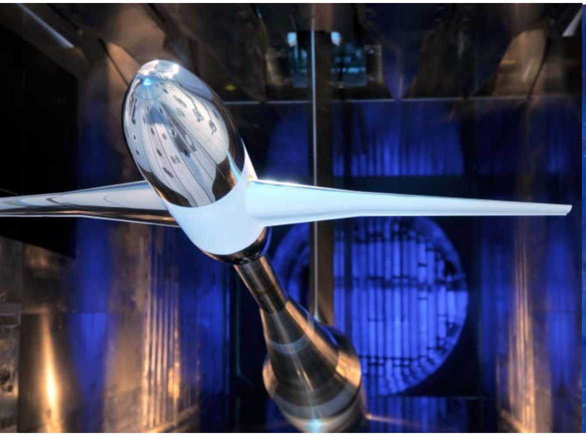
Using SPT for Capturing Flap-Gap Effects

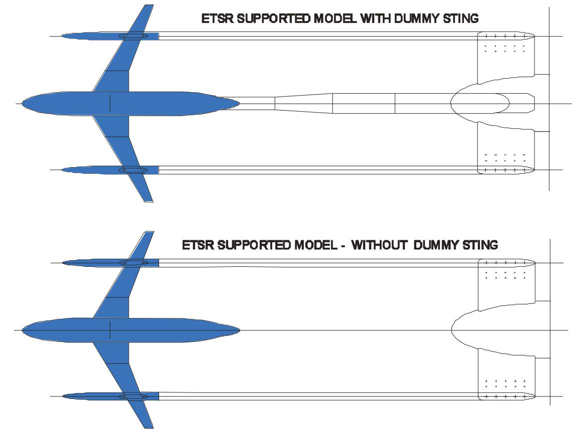
Ma_∞ 0.2,
Re_∞ 16.7 Mio.
p_0 411 kPa



- Flap-gap change versus wingspan and AoA

Full-Span Model Options





Cost Optimized

- 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.

Quality Optimized

- Absolute performance data ba... fully correcte... ...mplete model)

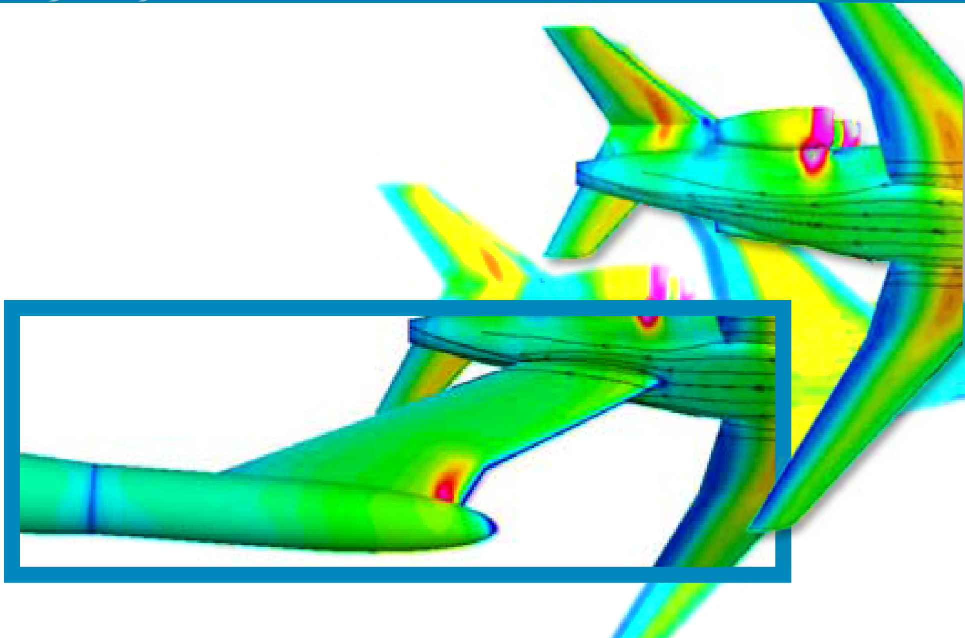
Single-/Twin-Sting Approach:

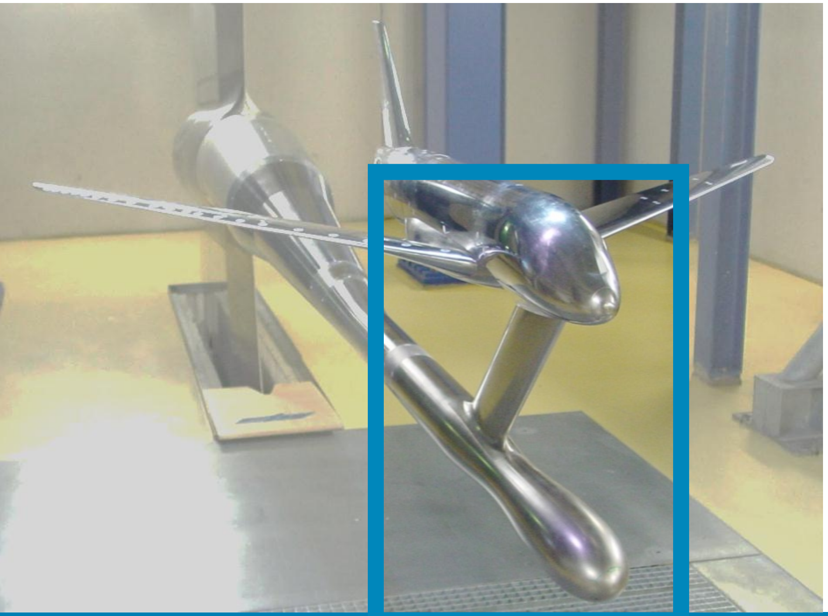
- **Lowest impact of sting correction method on final flight estimate**

- Wind-tunnel calibration data & robust wa... interference correction methodology

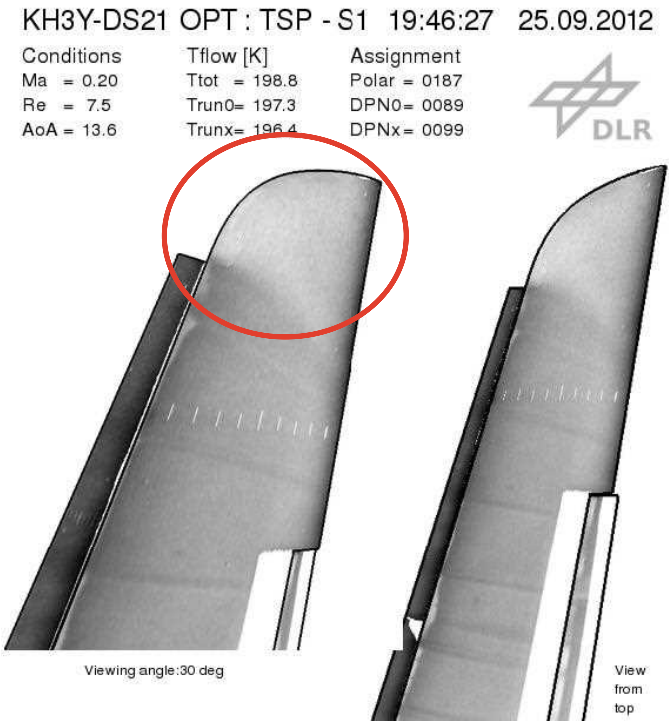
Alternative Supports for Rear End Measurement

- Z-Sting
- Fin Sting
- Front Blade Sting

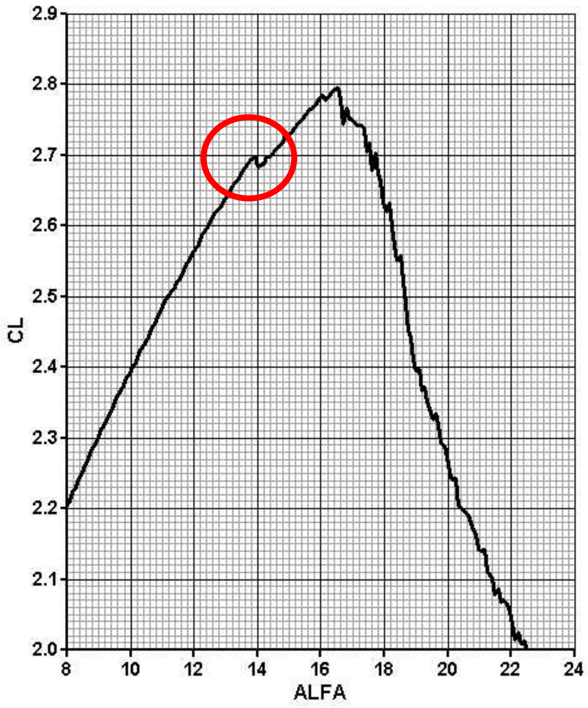




TSP Capability to identify Flow Separation

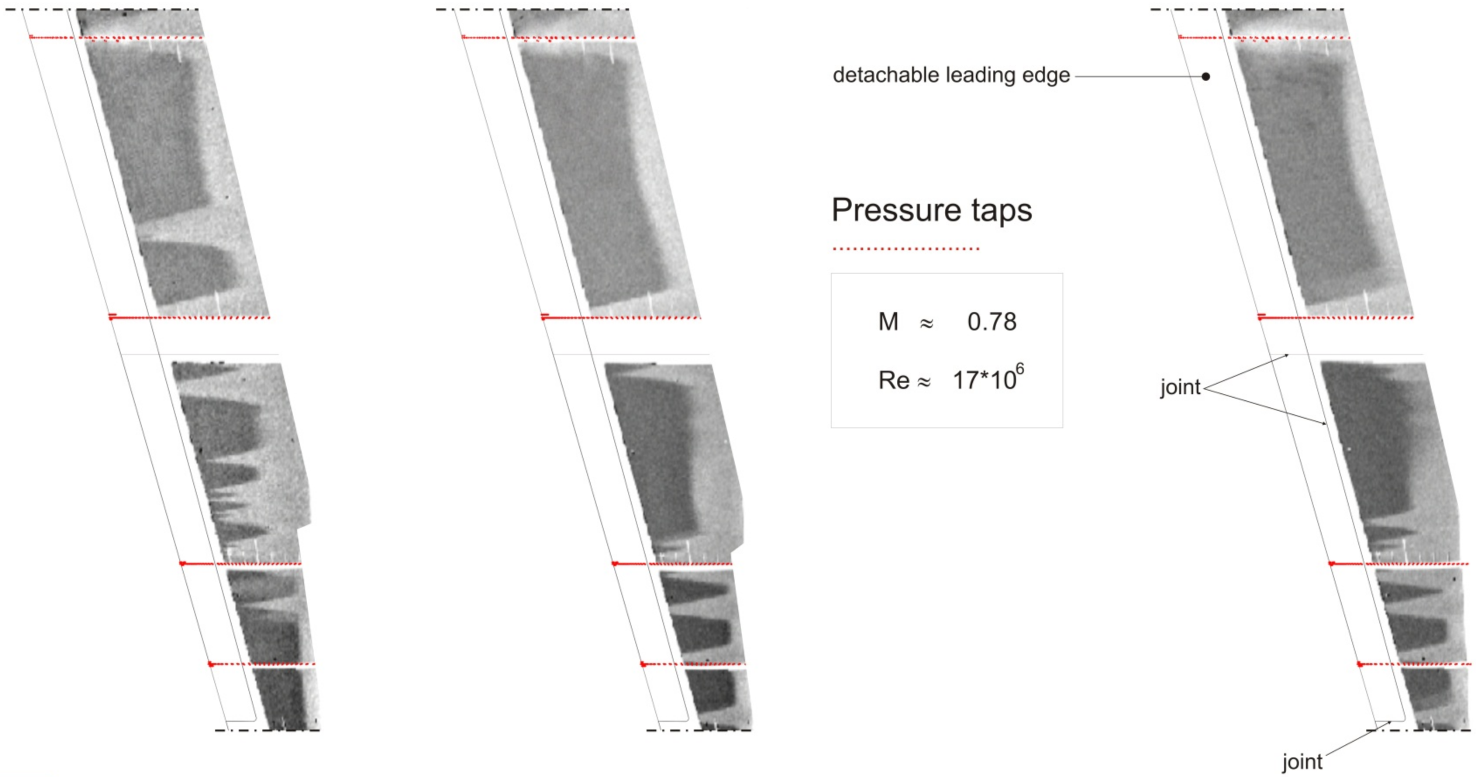


TSP-Image



Balance data

Natural Laminar Flow Half Model

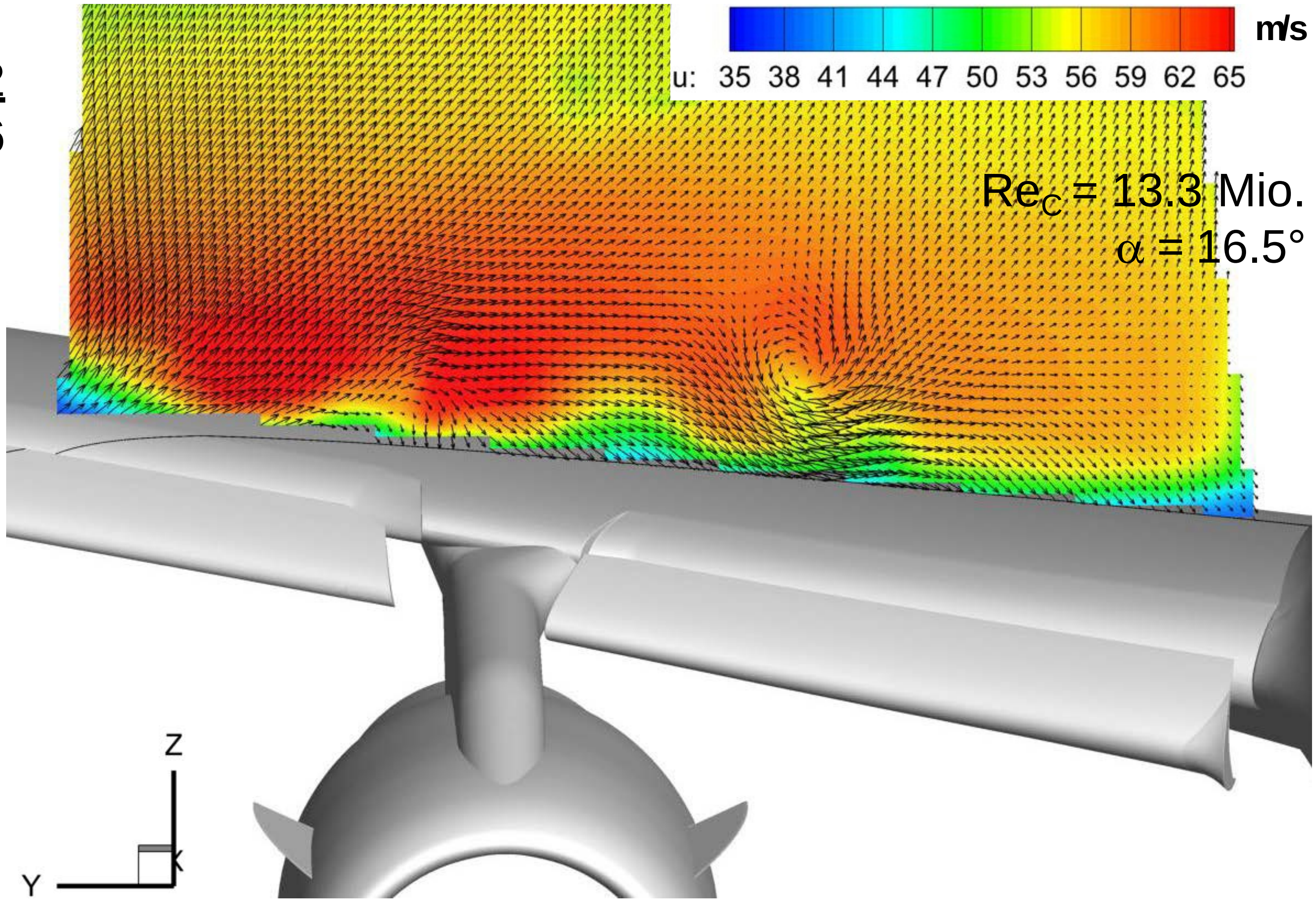


1st Image → model cleaning → 3.5 hours continuous testing →

This work receives funding from the European Union FP7/2007-2013 under grant agreement no 323452. ETW GmbH/CleanSky has sole copyright of all the contents of this document which must therefore not be copied or reproduced in any way without the prior written permission of ETW GmbH.

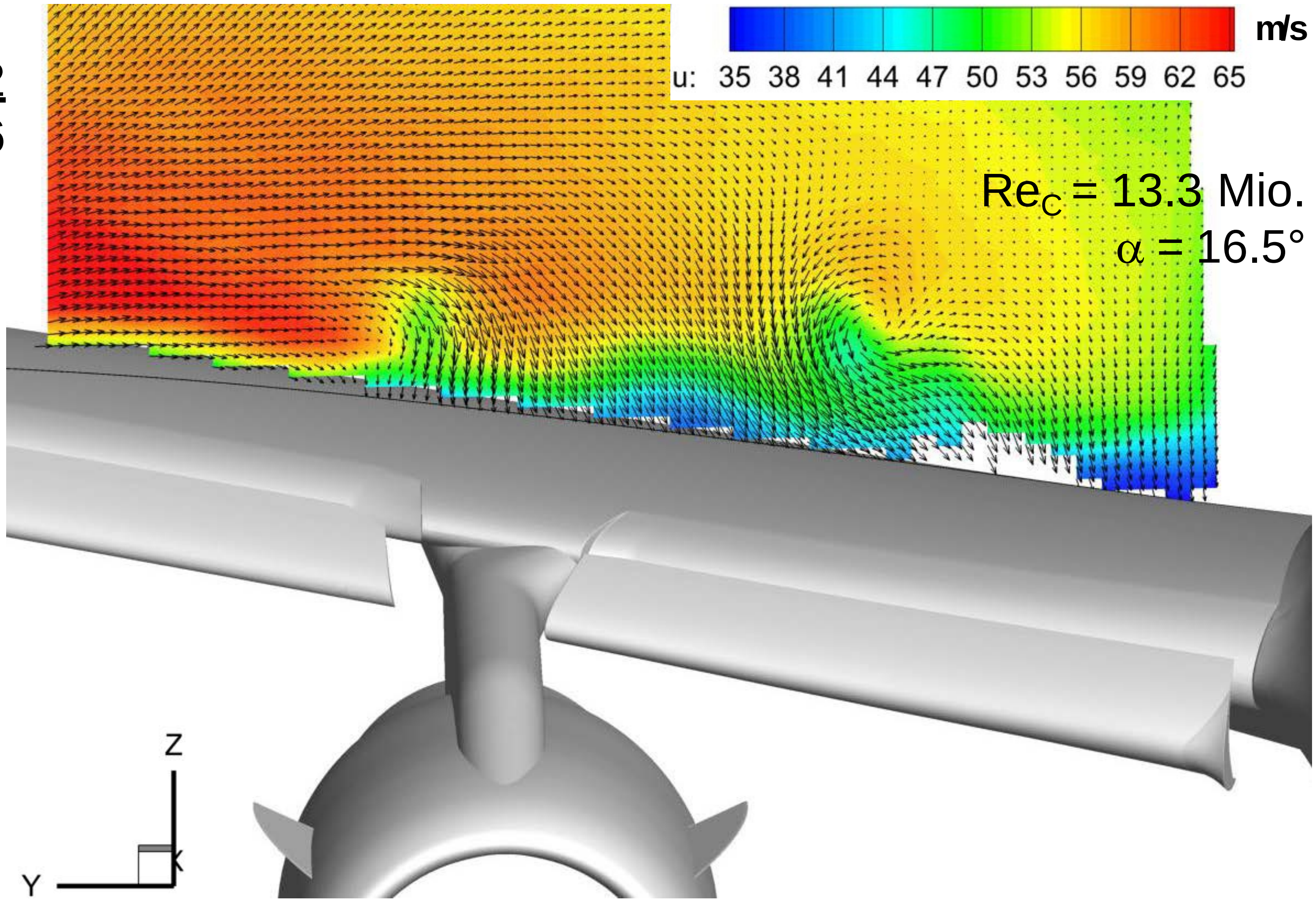
Measured Velocity distributions

Configuration 2
M = 0.186

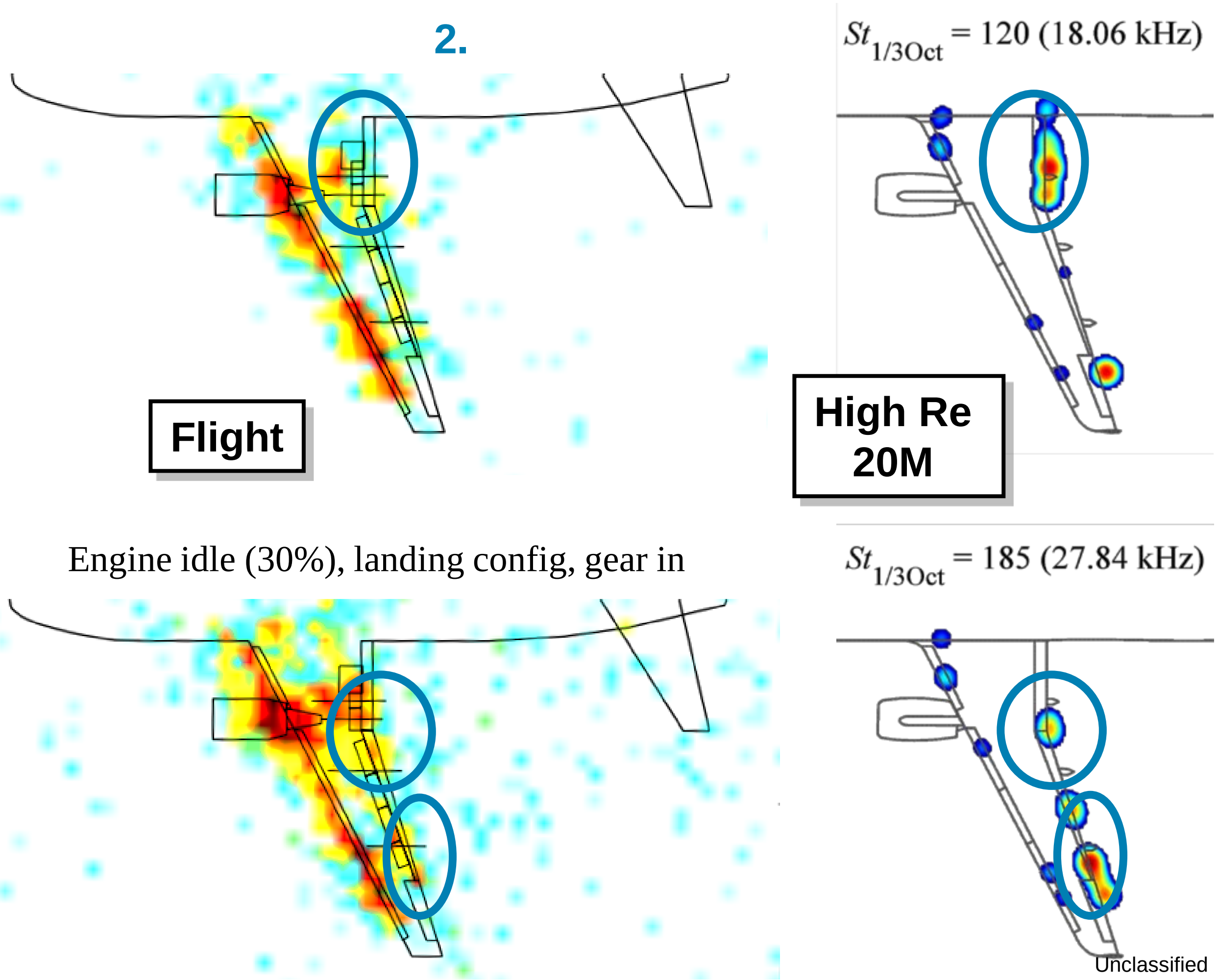


Measured Velocity distributions

Configuration 2
M = 0.186



ETW Aeroacoustic Measurements

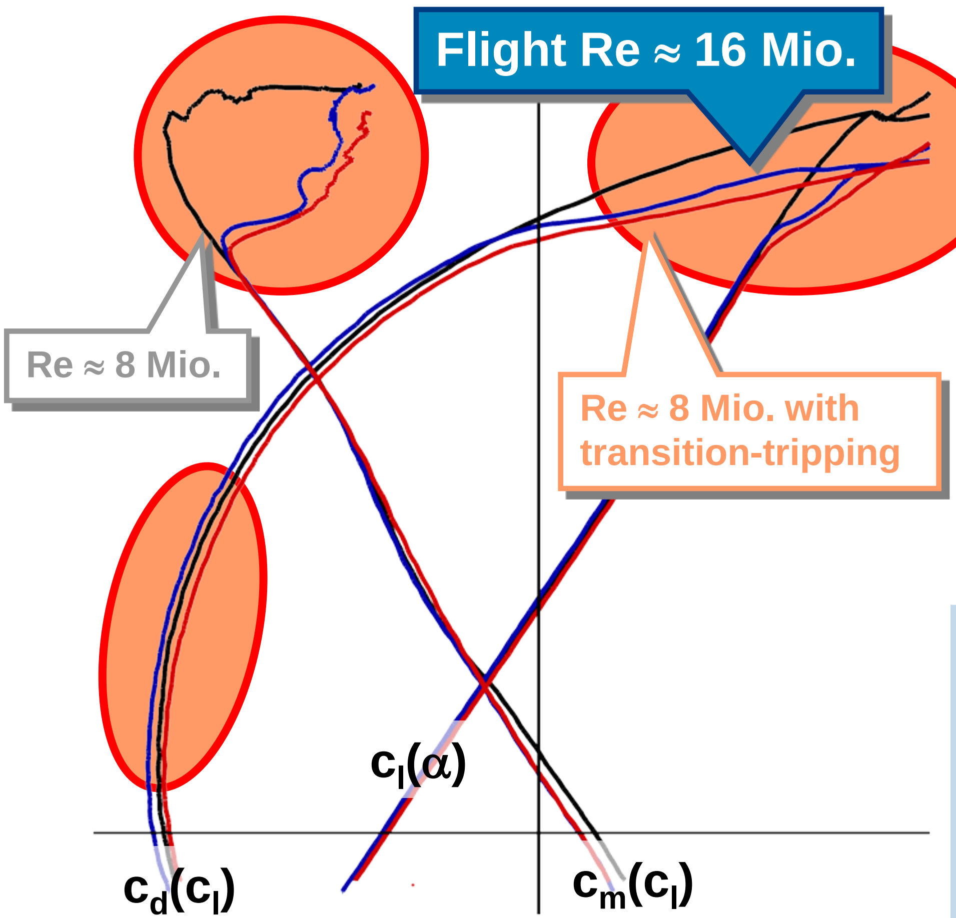


Unclassified

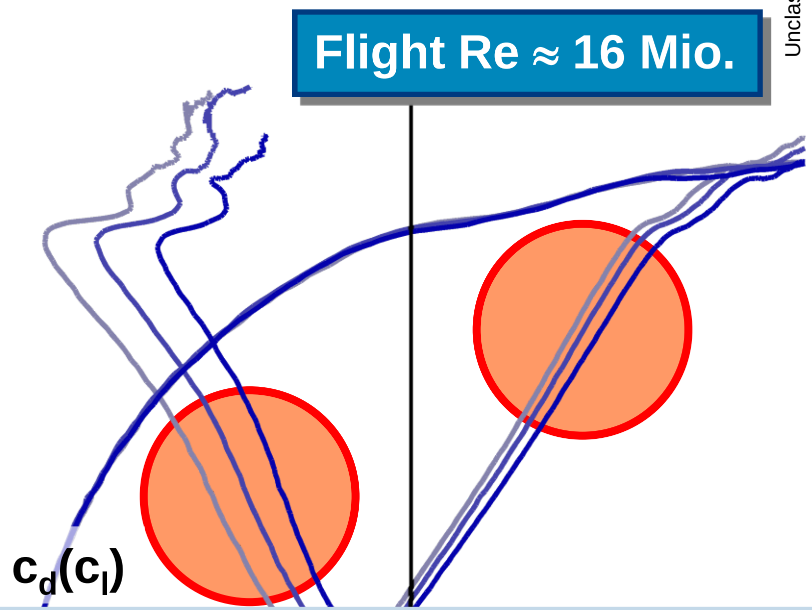
Independent Variation of Re-Number & Structural Loads

Lift, drag, pitching-moment characteristics Falcon 7X (1:10)

Reynolds Variation at const. Airloads



Airloads Variation at const. Reynolds



Unclassified

- Reynolds Number strongly affects aircraft performance
- Aeroelastic distortion strongly affects aircraft stability

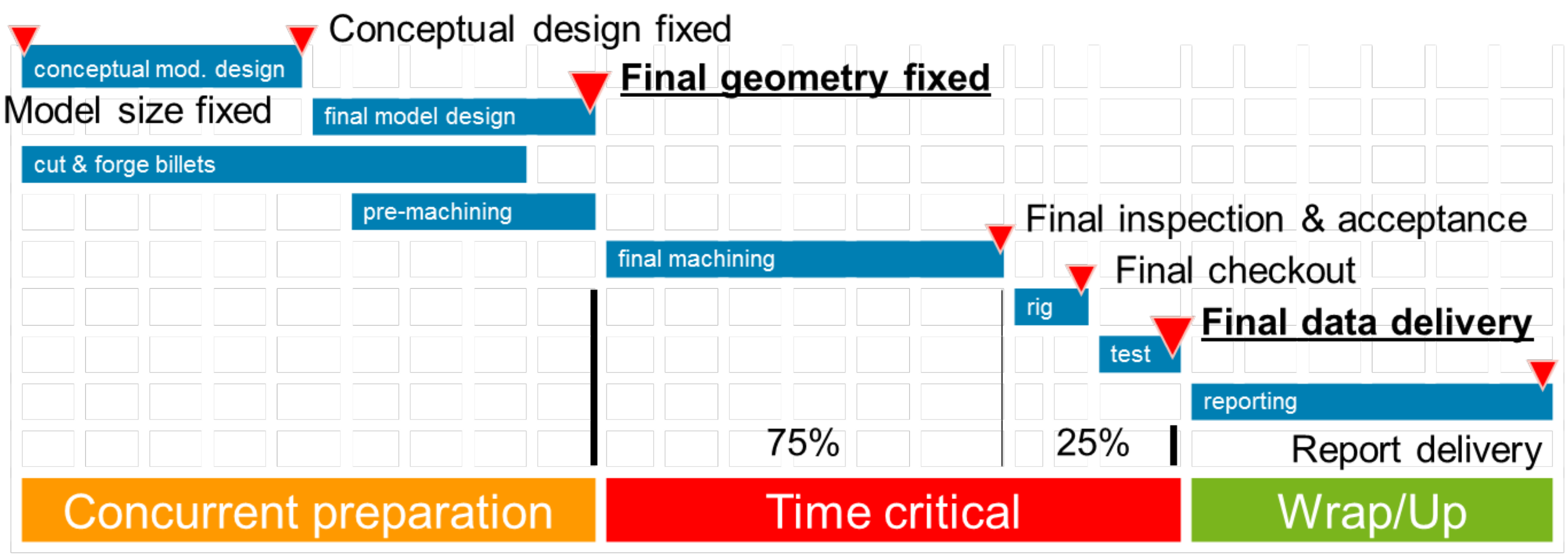
Important: ETW Model Jig Shape TBD

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

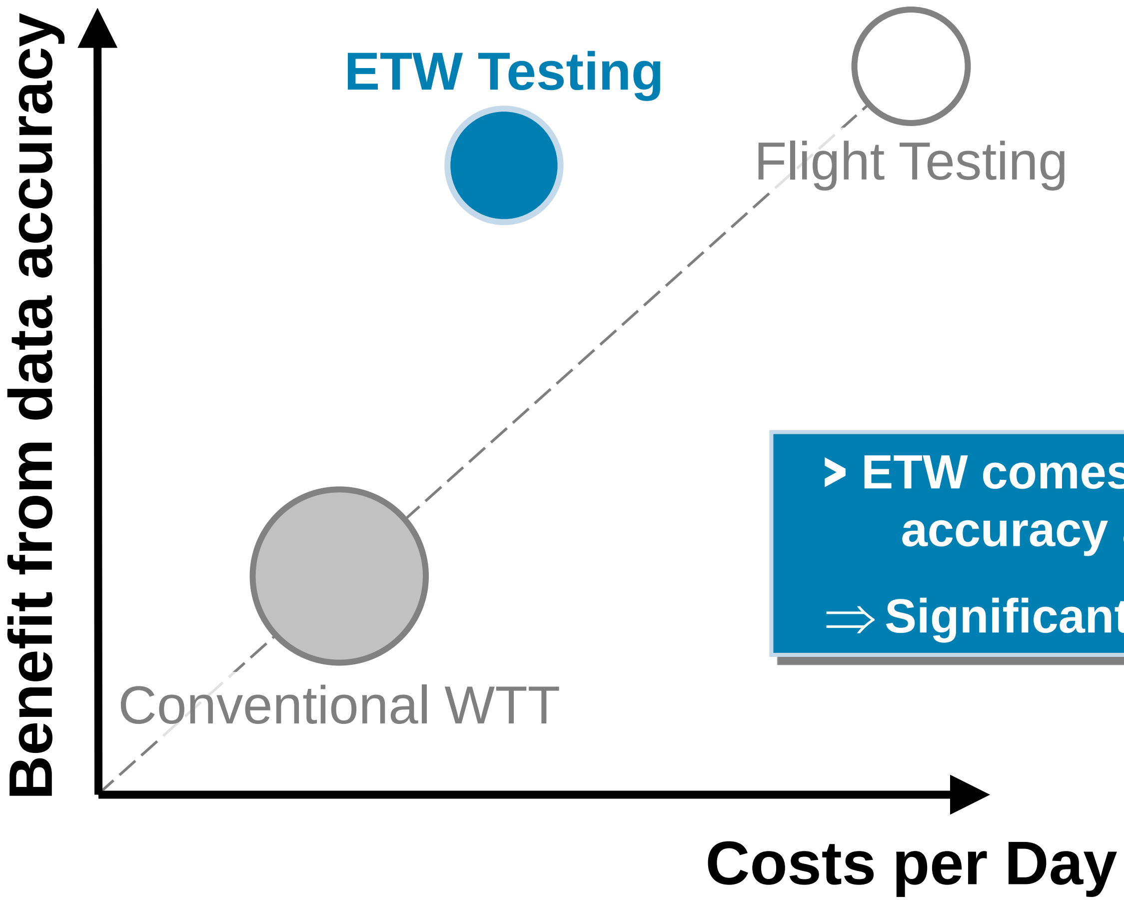


Close collaboration of ETW experts and clients required
in order to achieve a model design that

- Can be **manufactured quickly at appropriate quality**
- Enables **fast and reproducible model rigging and changes**
- **Works reliably at ETW**

Unclassified

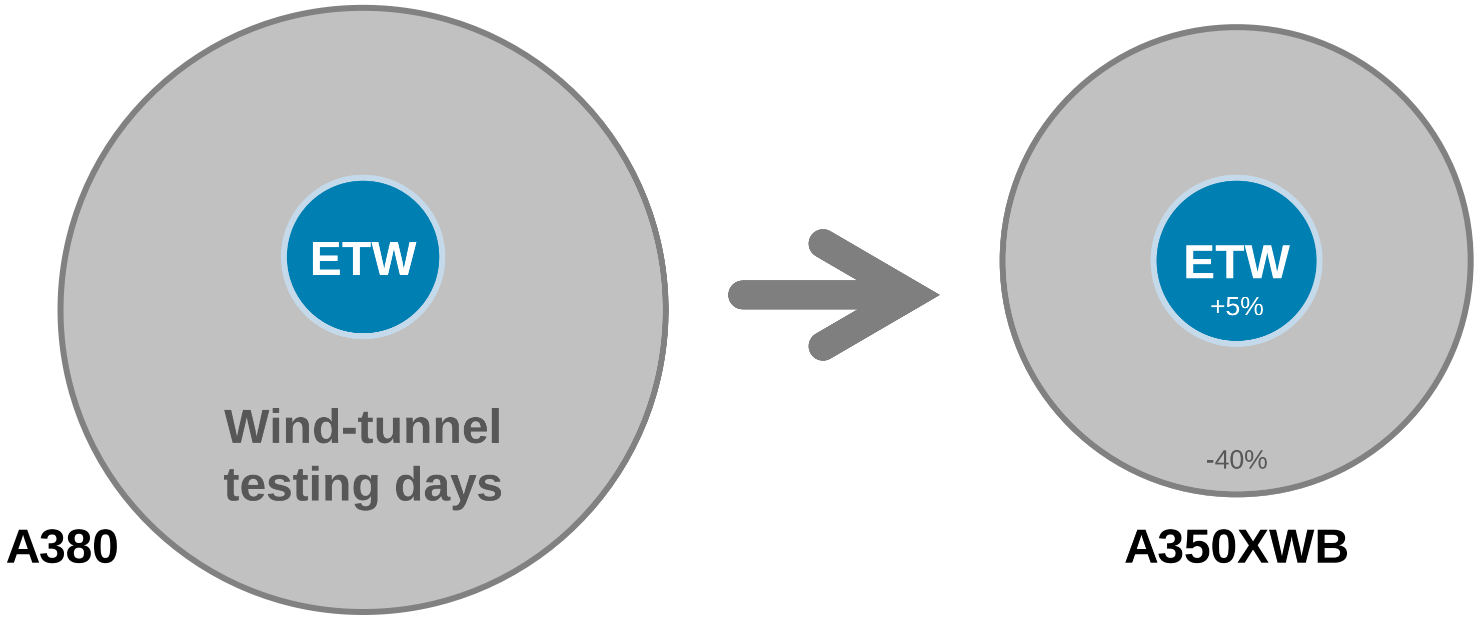
ETW vs. Conventional Wind-Tunnel and Flight Testing



> 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