AeroSHARK™

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Aeroshark – Drag Reduction Using Riblet Film on Commercial Aircraft

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Part 1
Introduction

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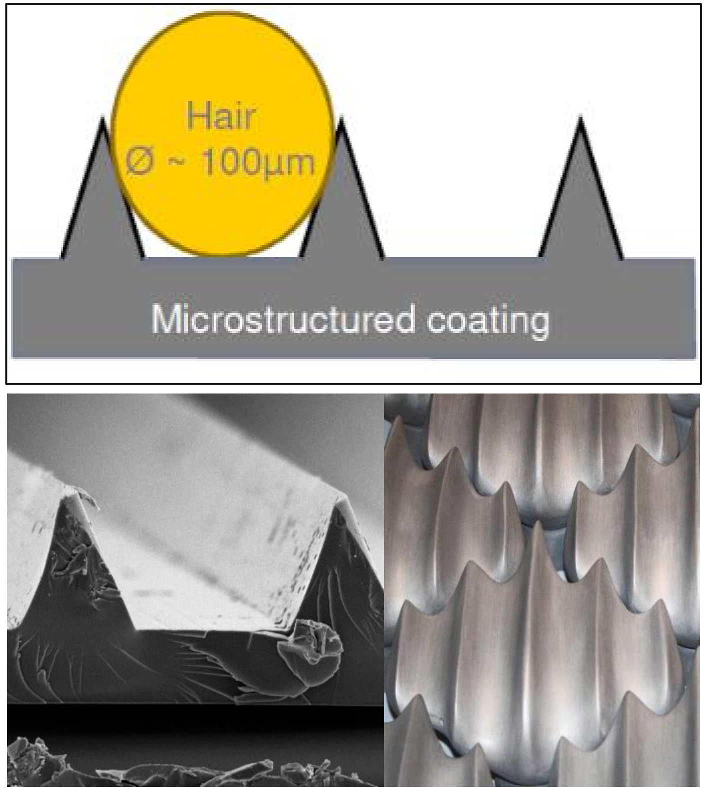
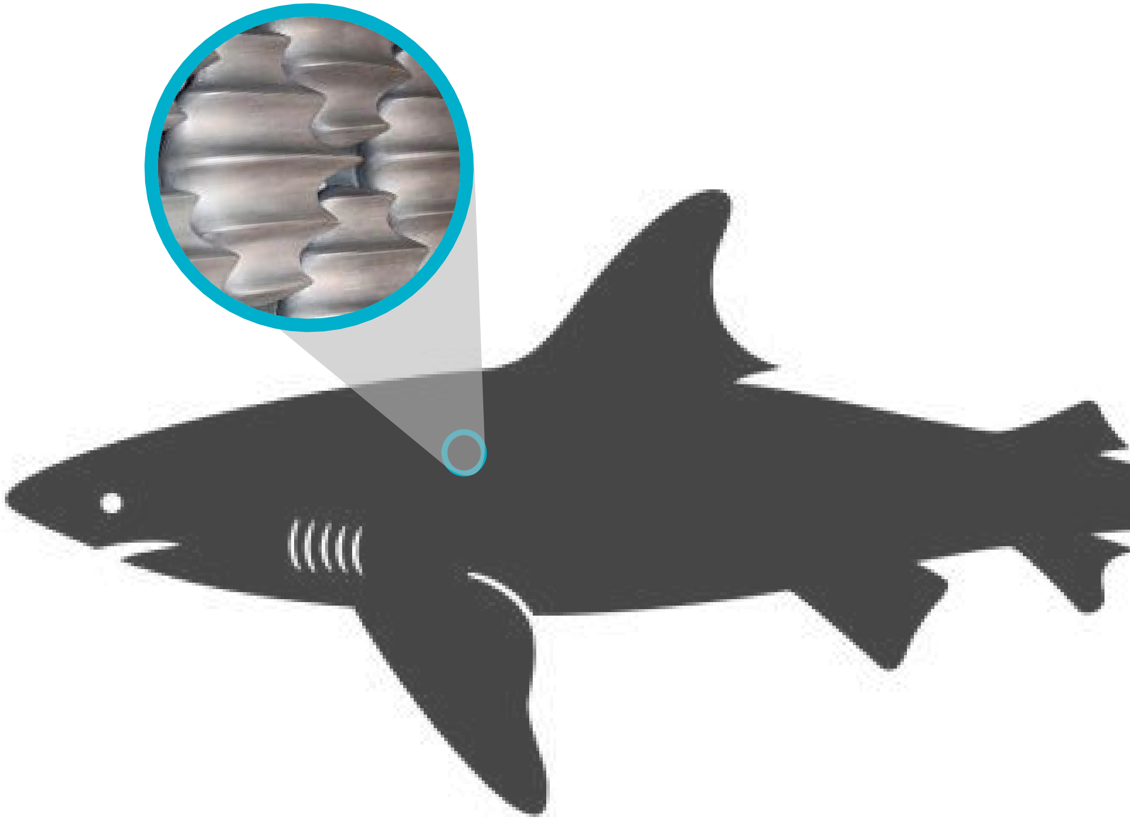
What is AeroSHARK?

AeroSHARK is a film that imitates the shark skin effect.





Primary goal: Reduction in wall shear…

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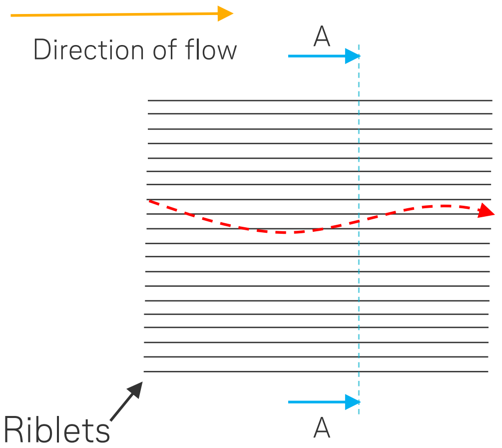
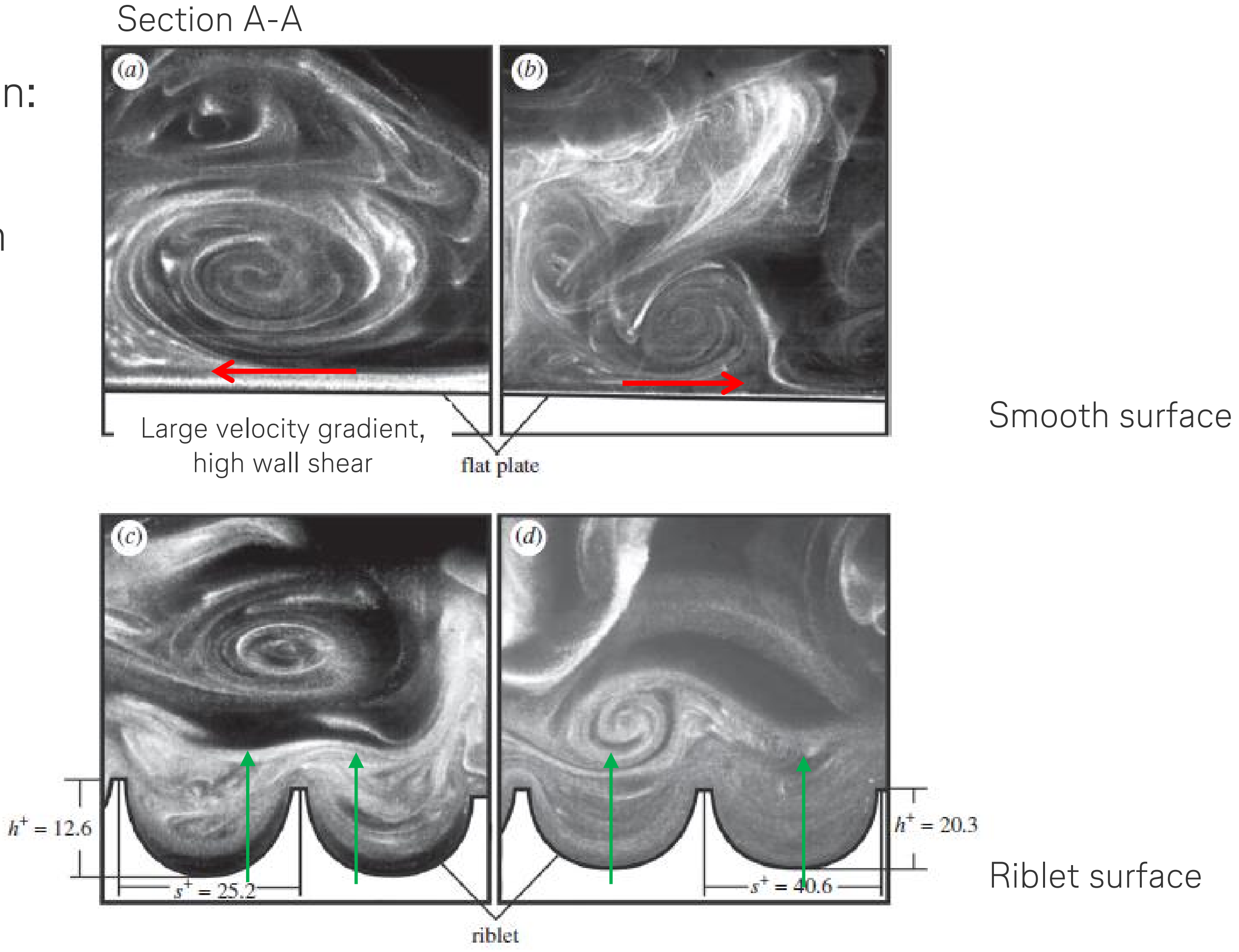
What is AeroSHARK?

....the more professional explanation:

Riblets reduce lateral momentum transfer in fully turbulent flow.





Reference: Dean and Bhushan, 2010

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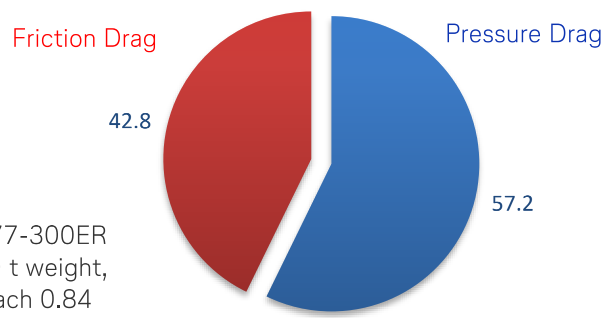
Saving potential – What can we expect?

Riblets reduce wall shear up to 8 %. What does this mean for the operator?

Assumption: **Film completely applied on Fuselage and Wings!**

Reduction in % Drag

Drag Composition Viscous Drag in [%]



B777-300ER
260 t weight,
Mach 0.84

With less weight, drag saving in % gets higher

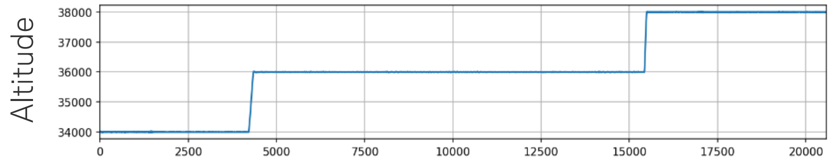
2.2 - 3.6 %
saving potential (delta drag)

Reduction in kg Fuel

Weight	*320 t*	*270 t*	*185 t*
Optimum Cruise altitude	FL310	FL350	FL410
Fuel Consumpt.	8.8 t/h	7.3 t/h	5.4 t/h
Delta Drag %	-2.2	-2.7	-3.6
Delta in kg/h	~190	~200	~180

At high weights, the aircraft operates at lower altitudes
→ Higher fuel flow, higher savings due to Riblets

Reduction in EUR / trip



During a mission, the aircraft operates at different flight levels with changing weight.

Total saving can be determined with synthesis tools

With Jet A1 (03.04.2024)
680 USD/metric ton:
for a 10h flight, savings of up to
1200 EUR/flight can be achieved

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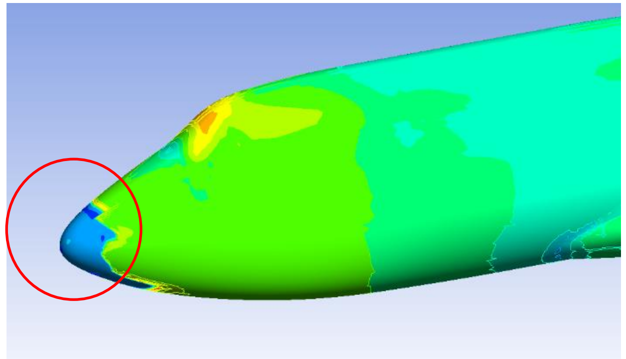
Theory and practice

- Riblets cannot be applied everywhere:



  - Avoid areas with laminar flow and complex curvature

  - Avoid areas with high contamination, e.g. from hydraulic fluid

  - Avoid areas with high wear and tear

  - Be careful with the certification effort!

2.2 - 3.6 %

⇩

1 %

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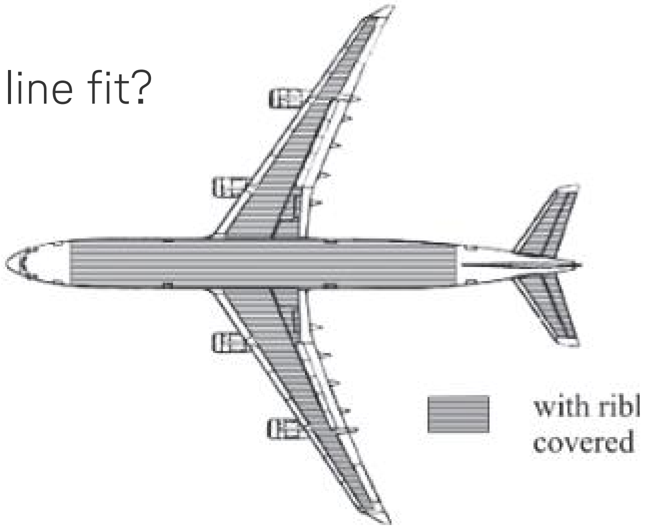
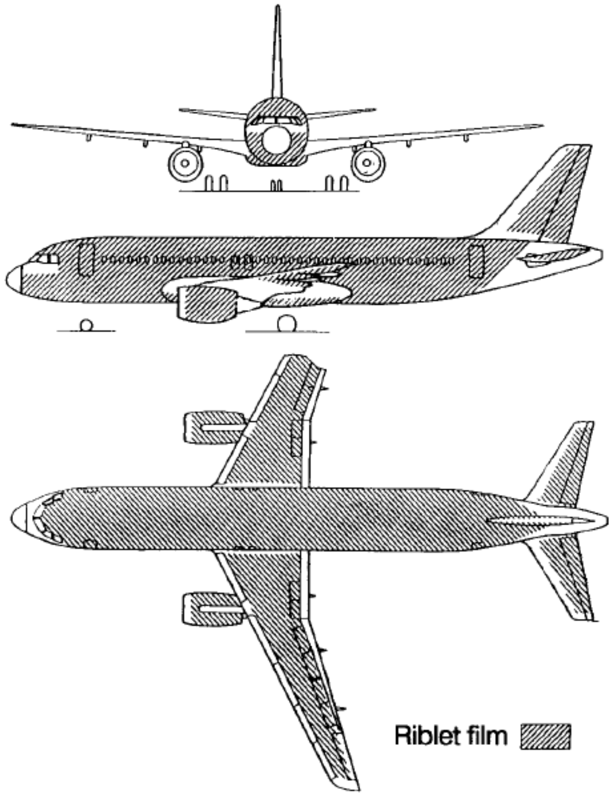
History

- Riblet film has been tested already in the 1990's and the mechanism itself is known since the 1950's
  - Airbus did tests with an A320 with 3M Riblet film, proven saving of 2% acc. to Airbus
  - A340-300 from Cathay Pacific, predicted saving of 2%
- Why did we not see these technologies in line fit?



D.W. Bechert & Hage, DLR, 2006



J. Szodruch, Airbus GmbH, 1991

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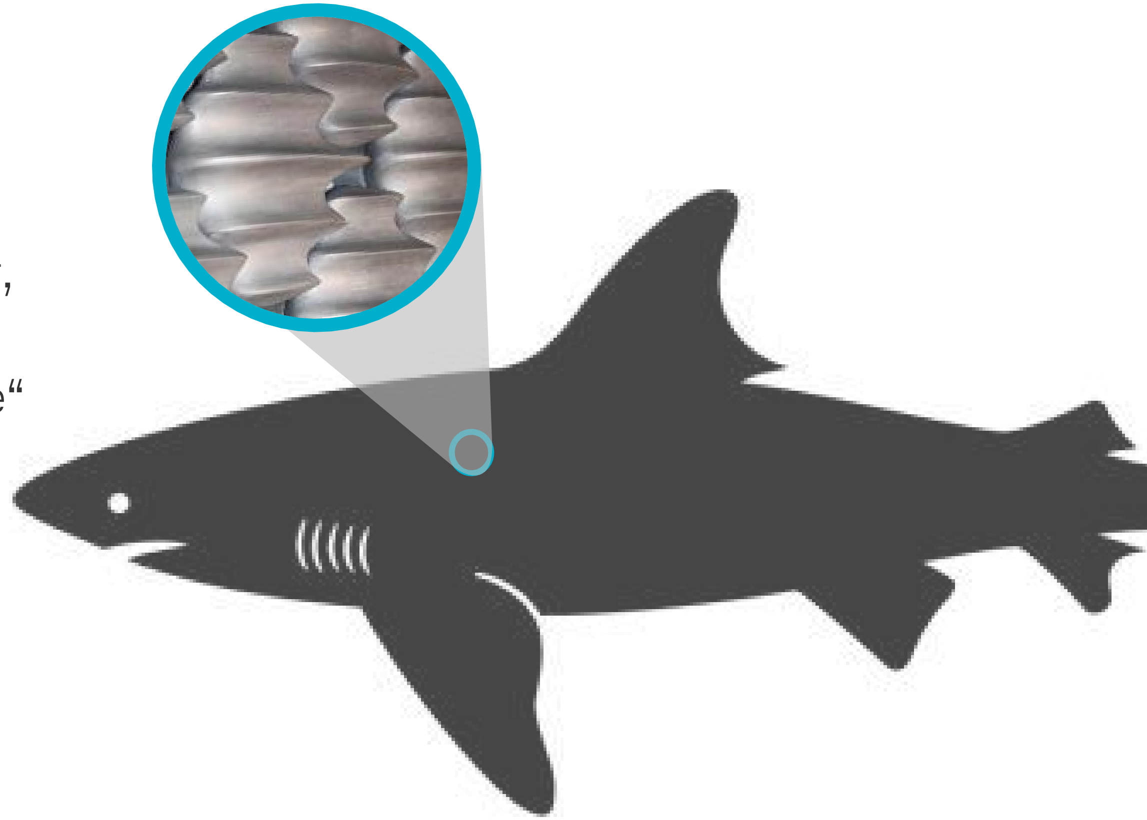
What‘s the problem?

1. Material:

- Hundreds of m2 of film have to be applied on the aircraft at the right place and angle in a very short time window
- Challenging environmental conditions
  - Temperature (+40°C to -60°C)
  - UV-Radiation
  - Aggressive Fluids: Anti ice, kerosine, hydraulic oil, cleaner, …
- Airlines not willing to cover their livery, film must be „invisible“

2. Certification:

- Certification Specifications (aerodynamics, structures, systems, lightning strike protection, etc …)
- Normally just the OEM has the knowledge to provide substantiation for all requirements



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AeroSHARK
What does it look like?

Riblets applied on lower fuselage in 2019 (~500 m²)

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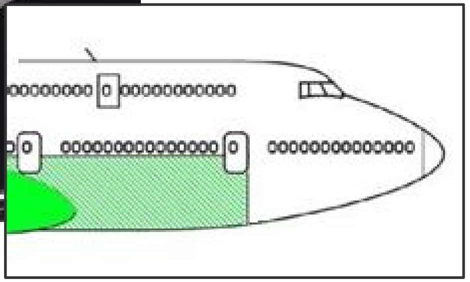
AeroSHARK
What does it look like?



Riblets applied on lower fuselage in 2019 (~500 m²)

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AeroSHARK on Boeing 777

The story was continued in 2021 during the pandemic:

Target: Apply film on fuselage and nacelles. Application on wing shifted due to certification issues.

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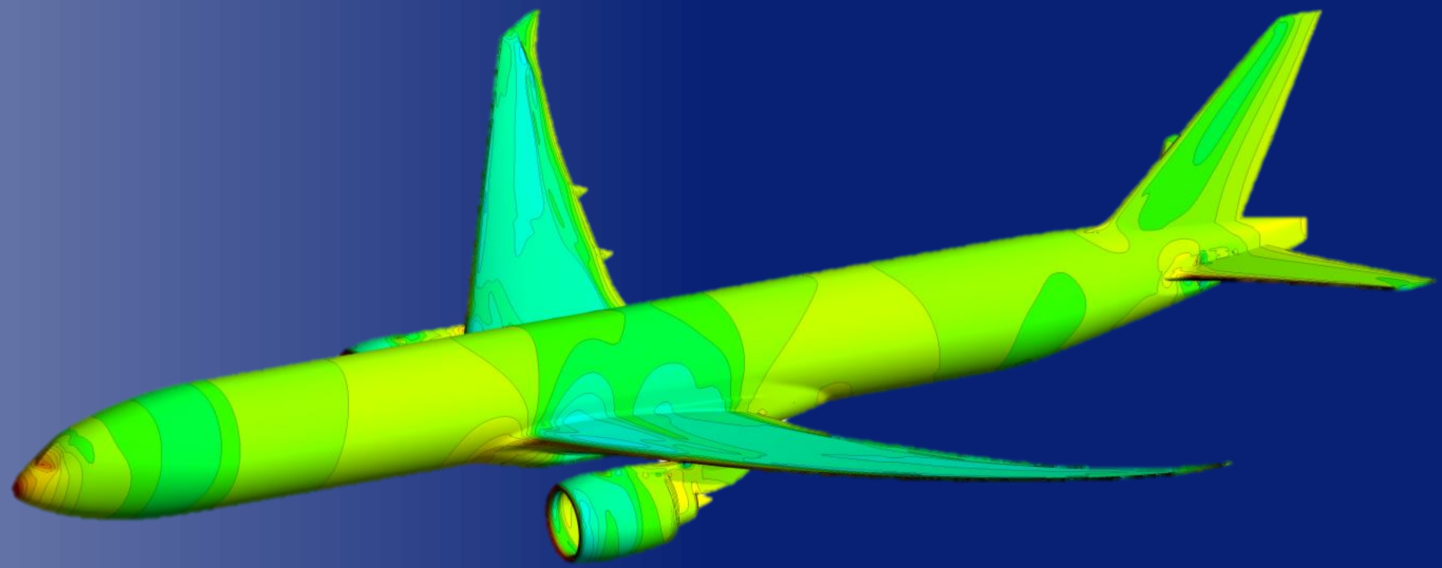
Part 2
Numerical Simulation



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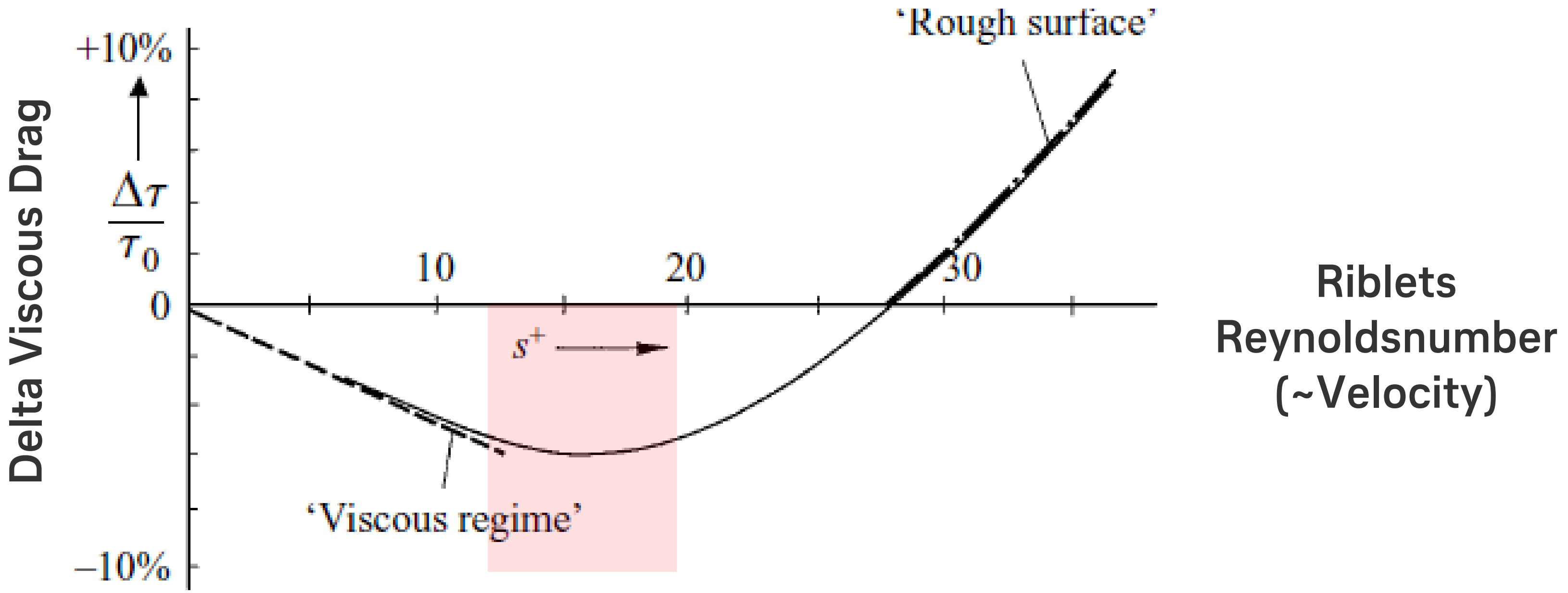
Background – "Riblets"

Drag reduction of **maximum 8%** (viscous drag)

- Sweet spot at Riblet Reynolds Number S+ of ~17
- S+ > ~28 leads to drag increase



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Numerical Approach

Calculate Riblet effect on the aircraft for two reasons

Commercial aspect:

How much fuel do we
safe during operation

Certification aspect:

Whats the effect of the Riblets
on handling, forces & overall safe operation

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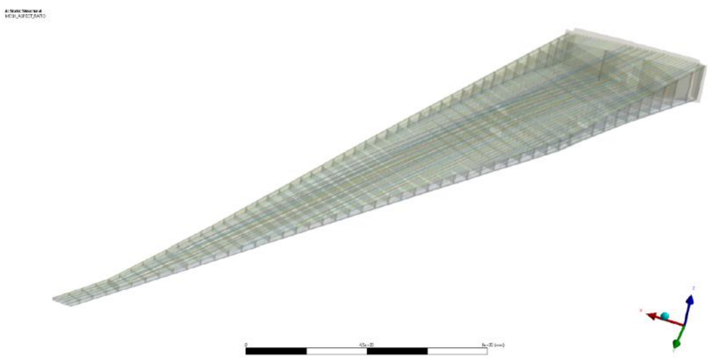
Numerical Approach – CAD Geometry

- CAD geometry by **scanning**

- Deformation of the wing **measured** during commercial flight

- FEM model of the Wing to **calculate** extreme shapes (-1g, 0g, 2.5g ...)



Ground shape ! → **Flight shapes !**

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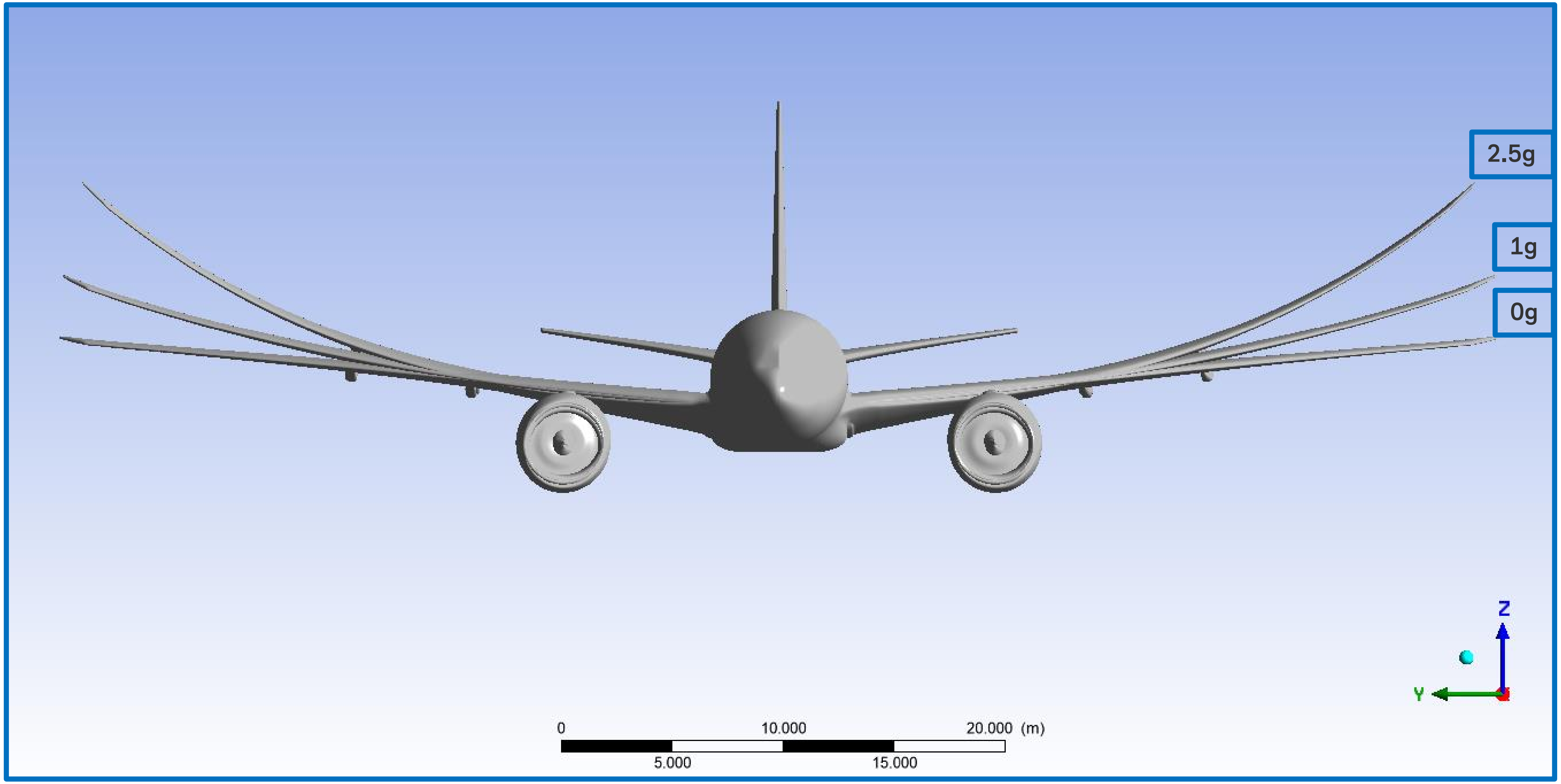
Numerical Approach – Wing Deformation



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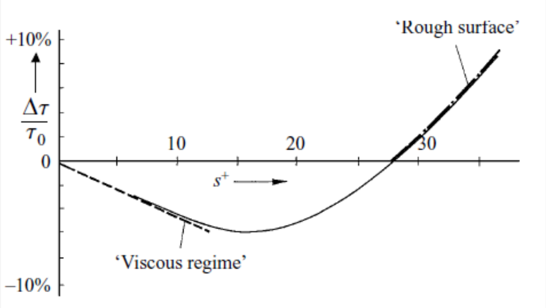
Numerical Approach – Riblet Model

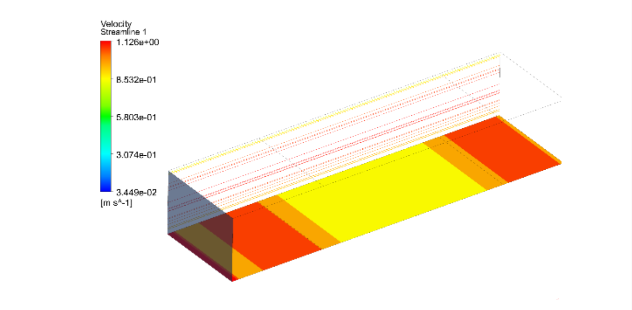
- Riblets are **too small** to resolve them **geometrically**
  - To resolve the effect of Riblets numerically, an **adaption** of the **turbulence model** is required
  - Development of modified and **calibrated CFD Solver** in cooperation with Ansys Germany GmbH
- **Validation** of the modified solver with **wind tunnel tests** in cooperation with DLR Berlin and DNW (German-Dutch Wind Tunnels) in Braunschweig

Measurement of Drag reduction effect



Oil channel DLR Berlin

Calibration of SST Turbulence Model using oil channel model



Ansys Germany GmbH

Validation of load effect with Wind Tunnel Tests

DNW Braunschweig

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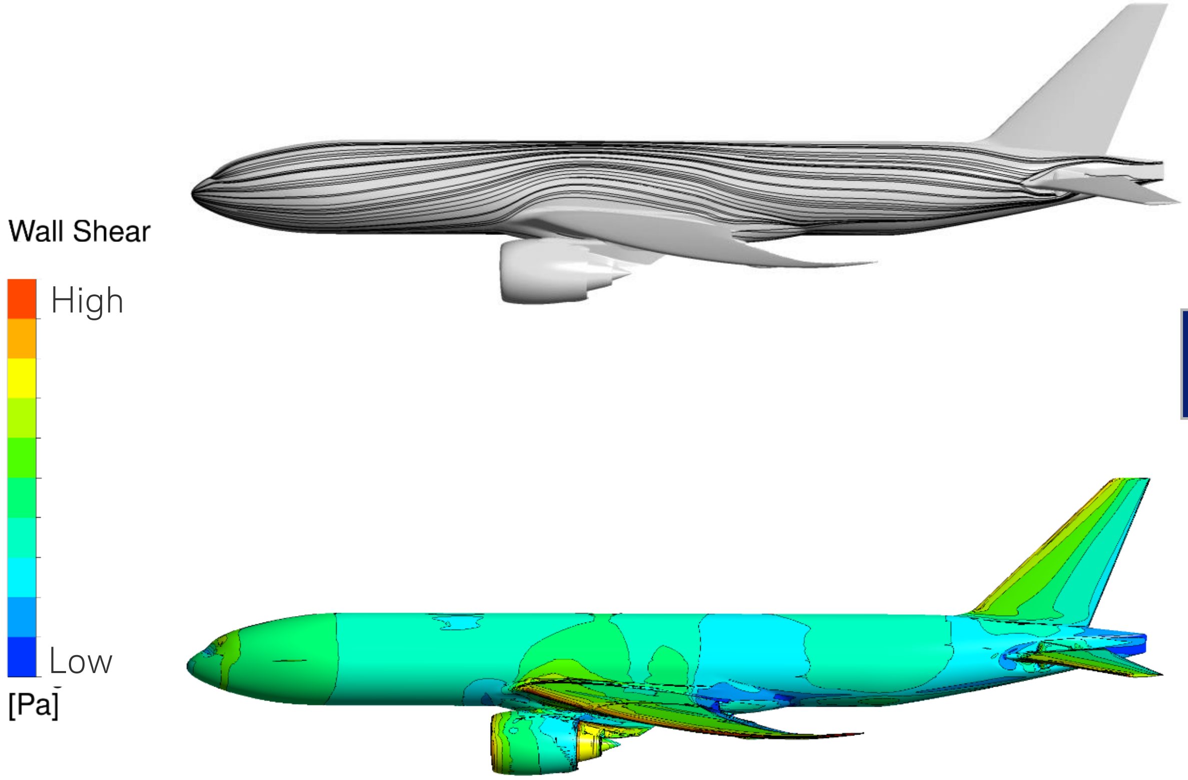
Riblet application design

- **Riblet Layout** is a simplification of the **wall shear distribution**
- Optimized for **cruise conditions** (FL340 / Mach 0.84)

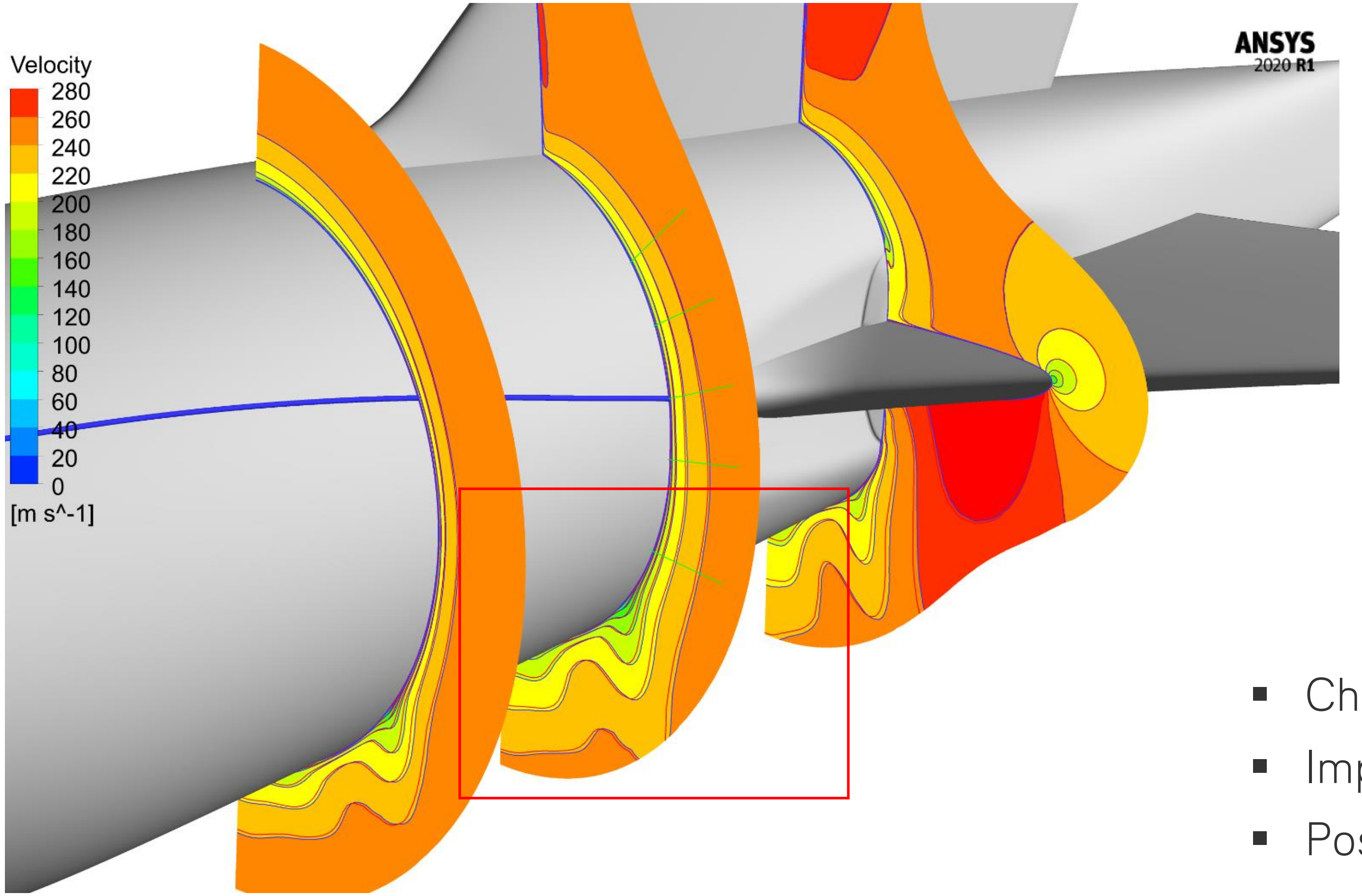


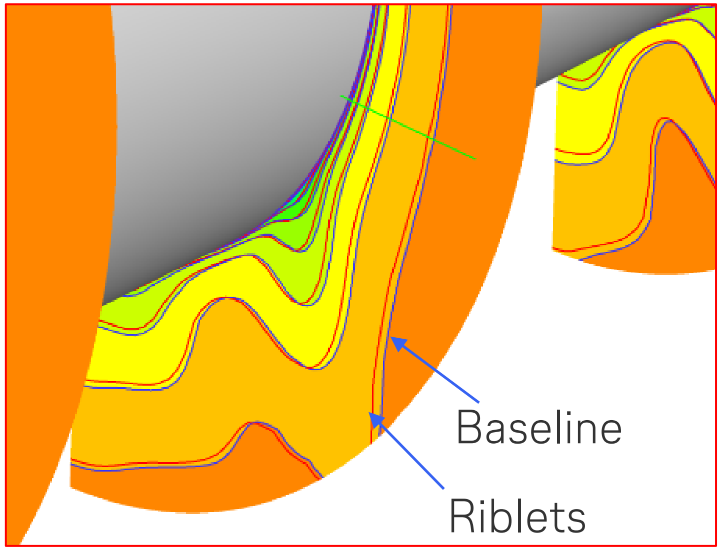
Design

Photo: Vincenzo Pace

Riblet effect on loads

- Riblets create secondary effects due to reduction of boundary layer thickness





- Change of aerodynamic and structural loads
- Impact on handling characteristics
- Possible influence on Autoflight systems

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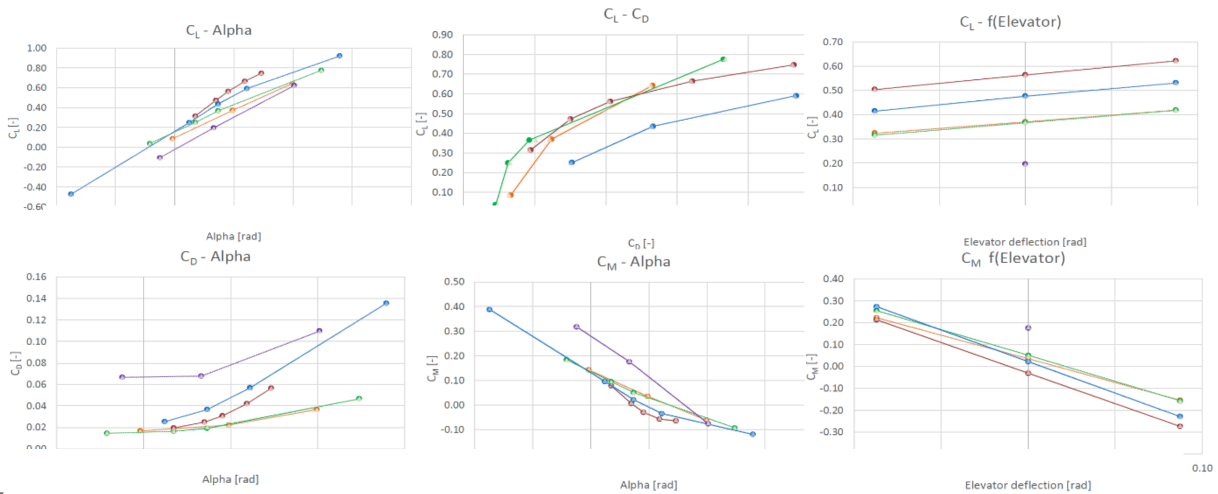
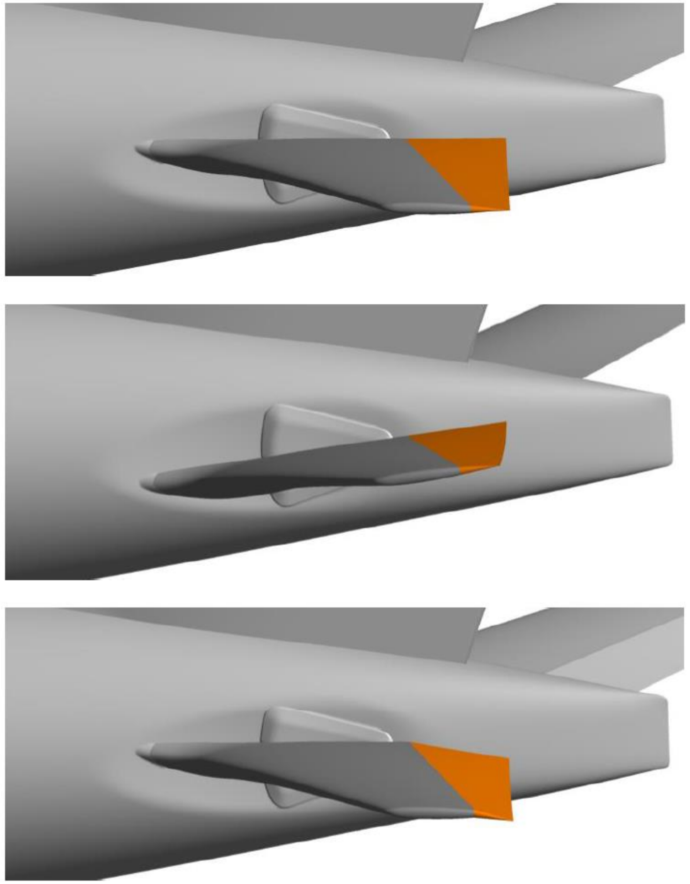
CFD Calculations

- Large number of calculations needed:
  - Variation of geometry (**stabilizer** and **elevator)**
  - **Baseline** and **Riblets**-case
  - Numerous operating points
- More than 100 calculations per aircraft type
  - Temporary use of six High Performance Clusters in parallel
  - Generation of 14 TB Simulation data over 6 months
- Creation of an **aerodynamic database**:





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Part 3
Flight Test

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Purpose of the flight test

Demonstration of safety in addition and beyond the numerical analysis.

Typical questions:

„Will the film remain attached at maximum airspeed?“

„What is the effect at high angles of attack and sideslip?“

„Are the pressure sensors affected?“

„Is there really a performance benefit?“

„What is about effects on the autopilot systems?“

Flight test concept

Certification of Initial TC:

Certification of STC:

Identical Airworthiness Requirements

Test at **extreme condition** and/or:
- All weights,
- All speeds,
- All Flap Settings,
- All CGs

Testing exemplary conditions in **comparison.**
Assuming:
- Same tailsign,
- Similar weight,
- Same speeds,
- Same flap settings,
- Same CG

- Thousands of flight hours
- Dedicated Flight Test Aircraft
- Multi-million EUR flight test campaign...

List of Flight Test Results

Back-to back Comparison of Flight Test Results

Demonstration of Compliance

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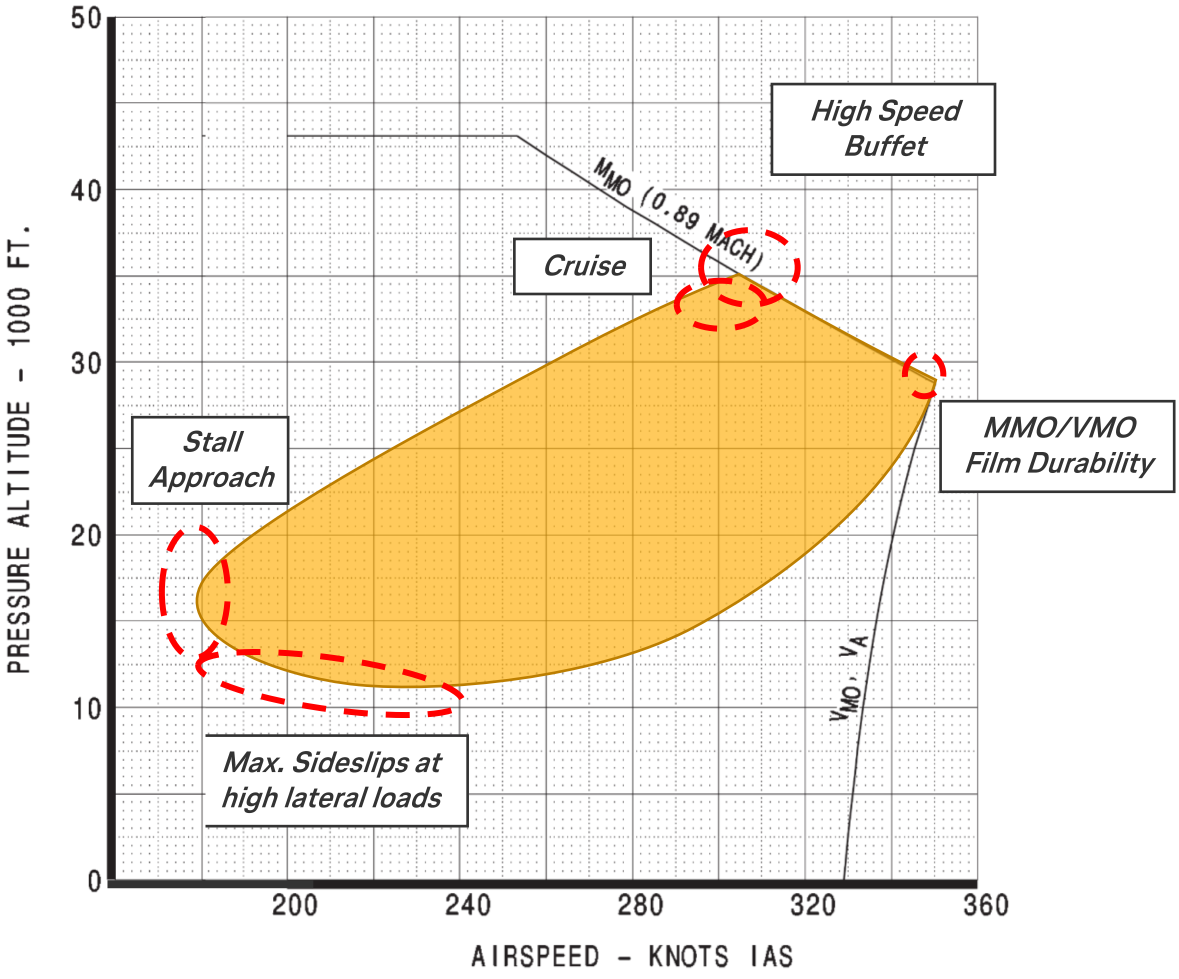
Flight test complexity

What has been tested?

- Stall Approaches
- Buffet Margin at High Speeds
- Directional Control, Maximum Sideslips
- Cruise Performance
- Static Pressure Measurement Accuracy
- Autoflight Systems and Autoland

Due to risk and complexity
→ CAT 2 test flight category



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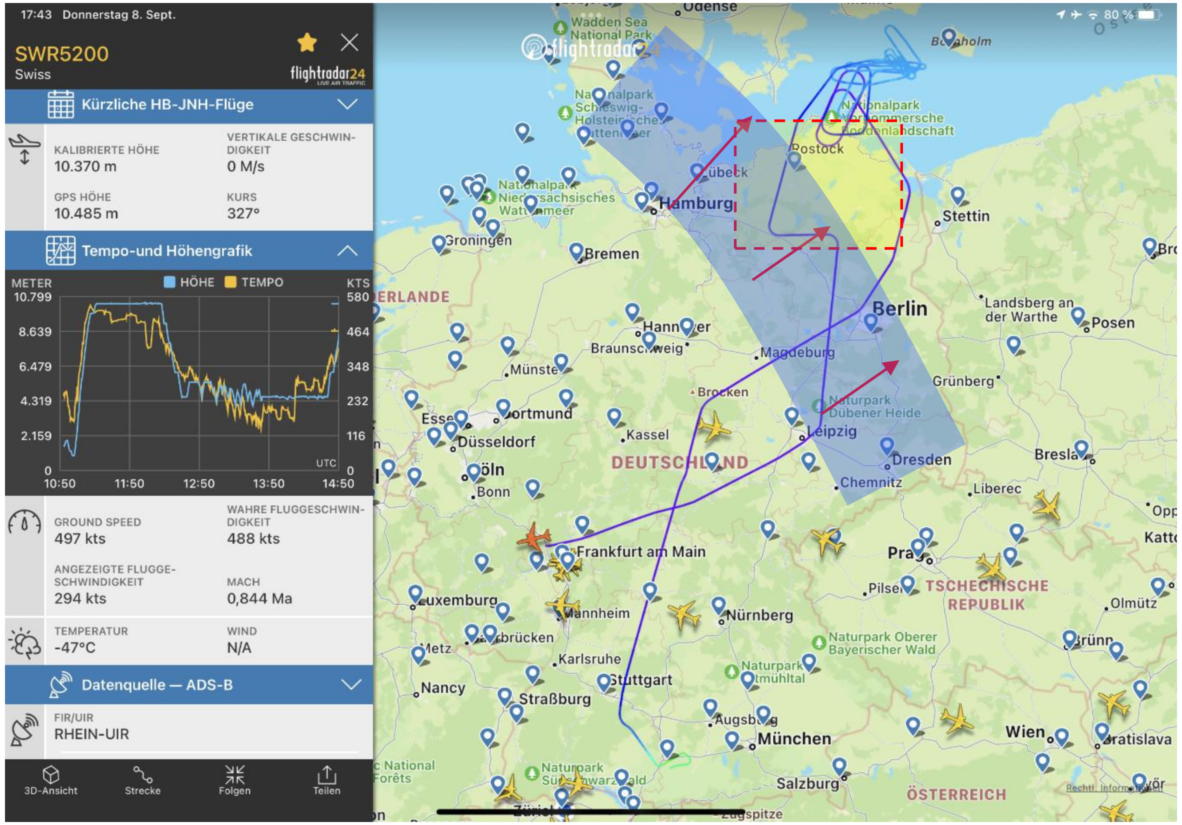
Flight Test Impressions

Flight Profile, Airspace and Weather Restrictions



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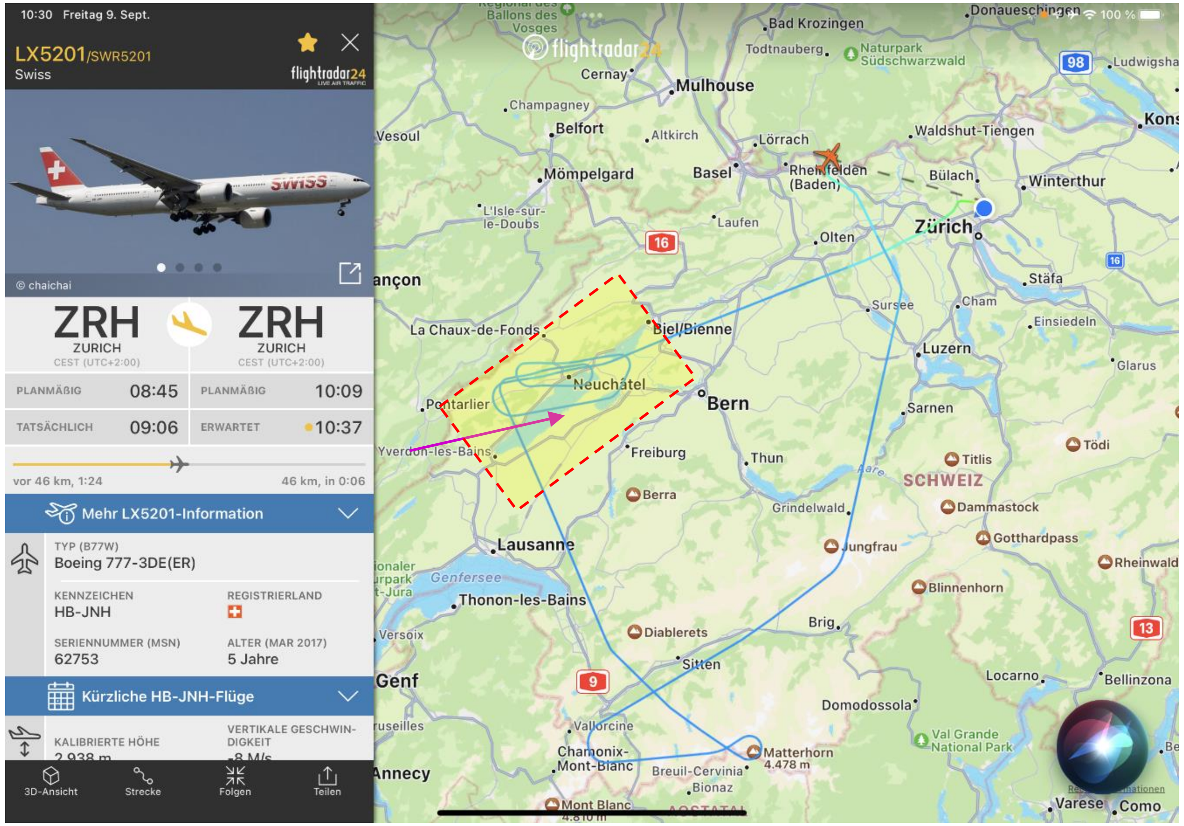

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Part 4
Savings

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How is the performance determined?

- Drag is extremely depending on flight conditions. Without correction for weight, temperature, trim, CG, etc no data comparison possible - because of high scatter
- Approach: For every data point in cruise delta drag is calculated

$$\Delta drag = drag\ of\ actual\ aircraft - drag\ of\ book\ value\ aircraft$$

derived from thrust

derived from official aircraft data

- Input data is obtained from two sources:
  - Standard approach with ACARS snapshots (up to three averaged snapshots (30s) per flight, classic APM)
  - Enhanced approach with full flight data (>30.000 data points per flight)

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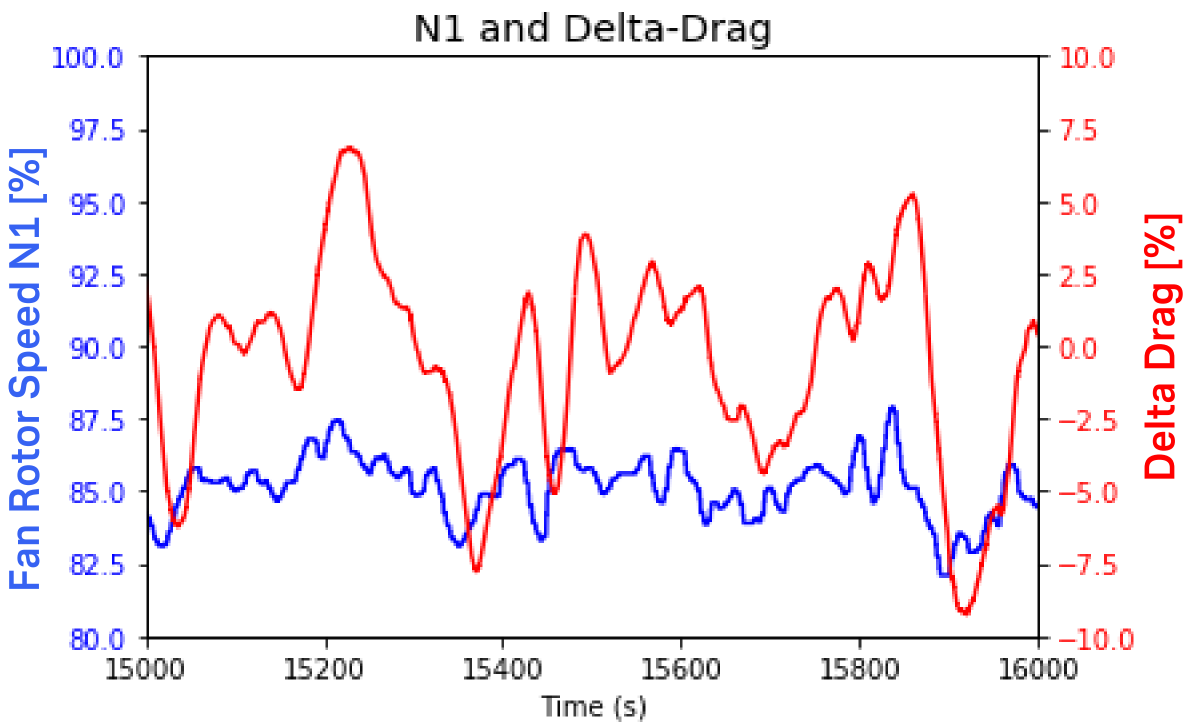
Justification for Full Flight Data (1)

- “Stable” Cruise Segment…
- There is always control activity in the autothrust system due to perturbations in the atmosphere
- Non equilibrium conditions Thrust ≠ Drag cause high variation of delta drag
- With full flight data, the averaging can be performed over much longer period and is less sensitive of when the snapshot has been taken



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Justification for Full Flight Data (2)

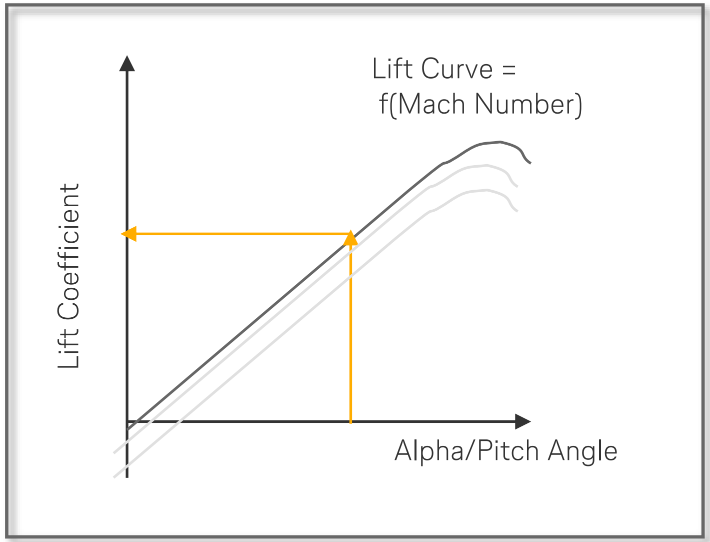
- Weight is not measured directly
  → Determined from load sheet using assumptions
- With full flight data, weight can be determined from aircraft attitude sensors and lift curves
- Inflight weight determination reduces errors in delta drag:
  - Impact of route profile (heavy or lightweight PAX),
  - Weight uncertainty in carry-on baggage
  - Weight from trapped humidity
- Process need many datapoints due to fluctuations in atmosphere: → Full flight data needed

Max. Delta for B777-300: 7.8 t

In reality people are mixed nationalities

Region	Adult population (millions)	Average weight
Africa	535	60.7 kg (133.8 lb)
Asia	2,815	57.7 kg (127.2 lb)
Europe	606	70.8 kg (156.1 lb)
Latin America and the Caribbean	386	67.9 kg (149.7 lb)
North America	263	80.7 kg (177.9 lb)
Oceania	24	74.1 kg (163.4 lb)
World	4,630	62.0 kg (136.7 lb)

From Wikipedia



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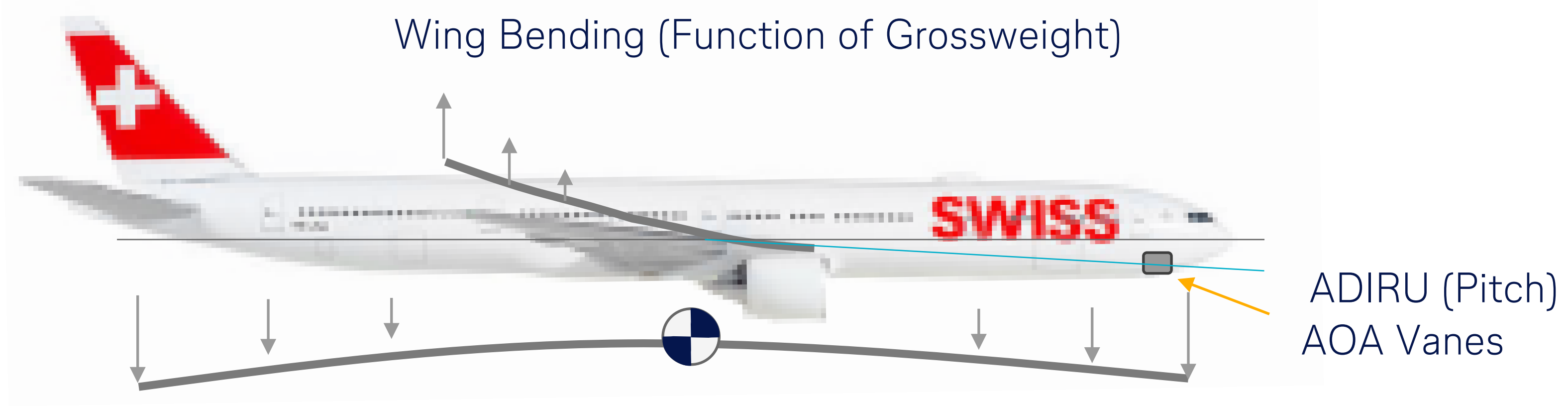
Independent weight determination

- Inflight weight determination requires complex corrections
  - Aeroelastic effects (wing and fuselage)



  - Corrections for Reynolds Number and Temperature: Influences lift production of wing
  - Corrections for CG: Stabilizer generates downforce, which must be subtracted from total lift

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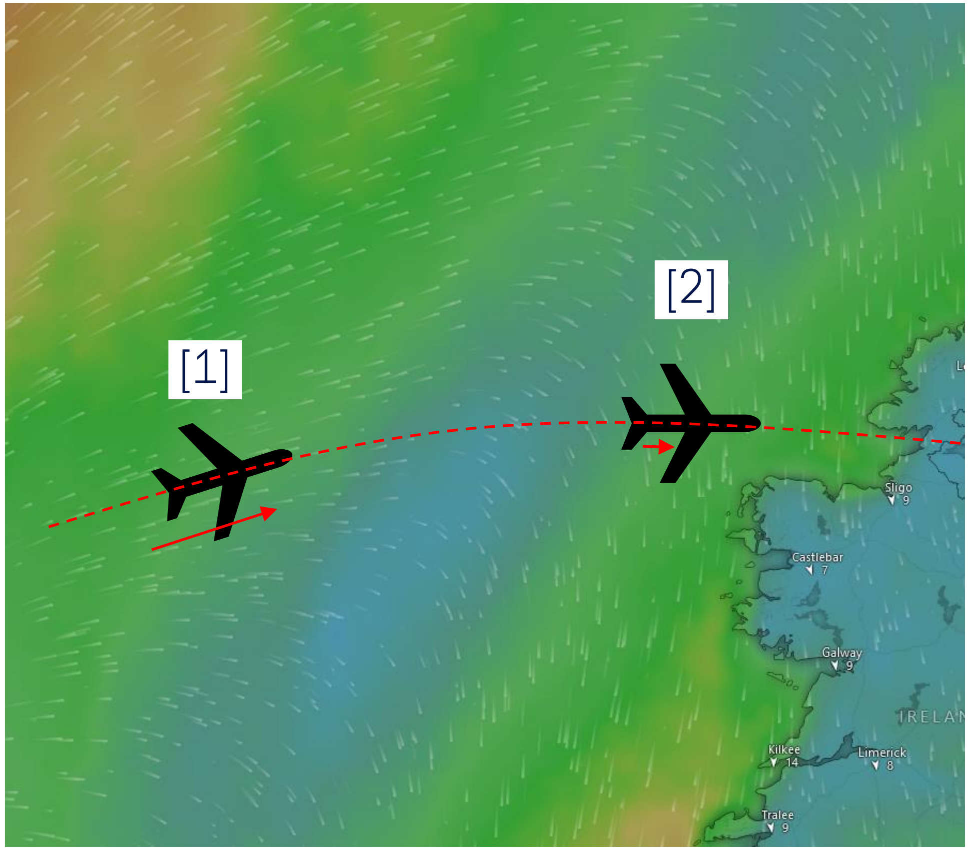
Further corrections

- "True" Kinetic Energy of aircraft depends on Groundspeed
- If wind pattern changes suddenly like in example, excess of kinetic energy hurts force equilibrium where: thrust = drag
  - [1] Groundspeed high due to tailwind: Kinetic energy high
  - [2] Groundspeed low, no tailwind: Release of kinetic energy from [1] → [2] reduces required thrust
- Further effects cause deviations in delta drag as well:
  - Non-constant earth's gravitation for flights over equator
  - Coriolis effects
  - Large temperature deviation: Reynolds Effects
  - Any kind of weight and fuel asymmetry
- LHT developed corrections to compensate these effects



Source: Windy.com

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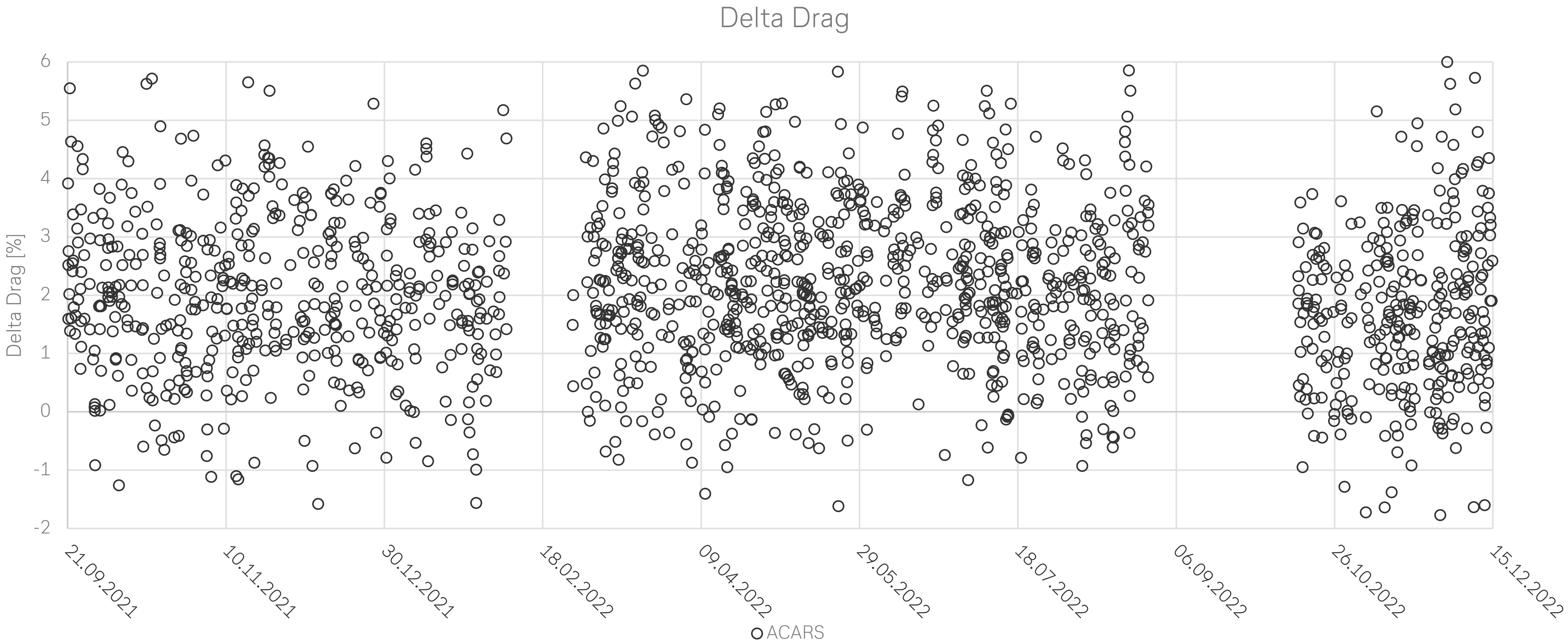
Delta Drag Standard APM

- Delta Drag Snapshot Data (ACARS)



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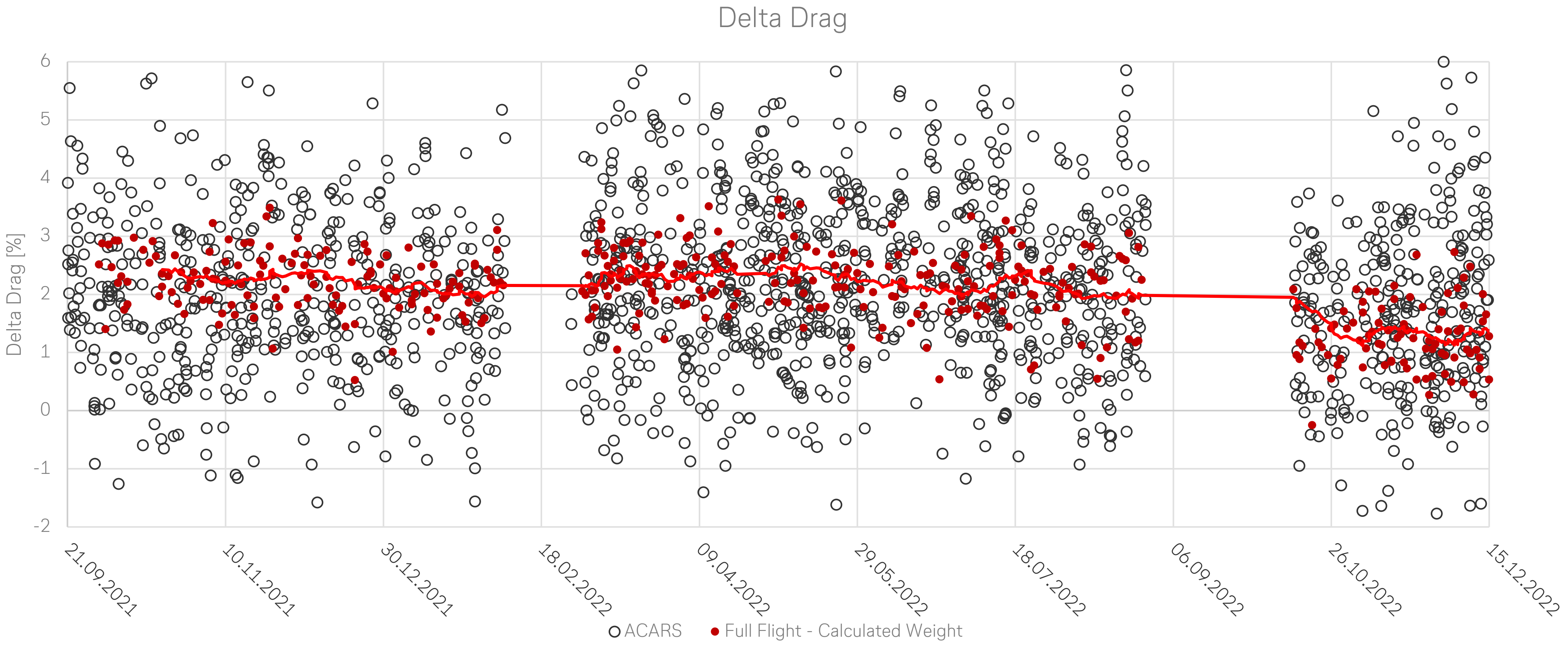
Delta Drag Enhanced APM

- Use of Full Flight Data yields much smoother trend and significantly reduced scatter



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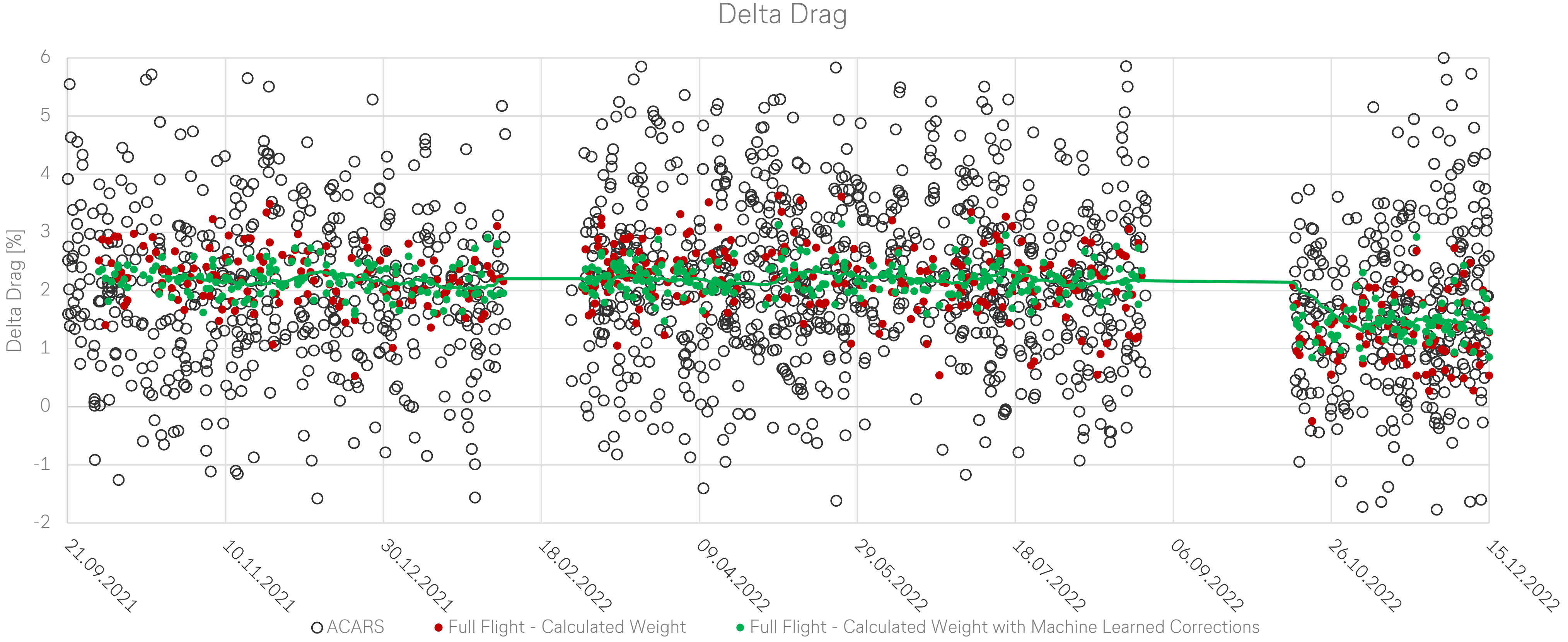
Delta Drag with Machine Learning Improvement

- Result using full flight data based on Pythons Catboost Machine Learning Algorithm: Reduce scatter by use of reasonable physical input parameters (e.g. Roll deviation, fuel imbalance, F/CTL Deflections, ….)



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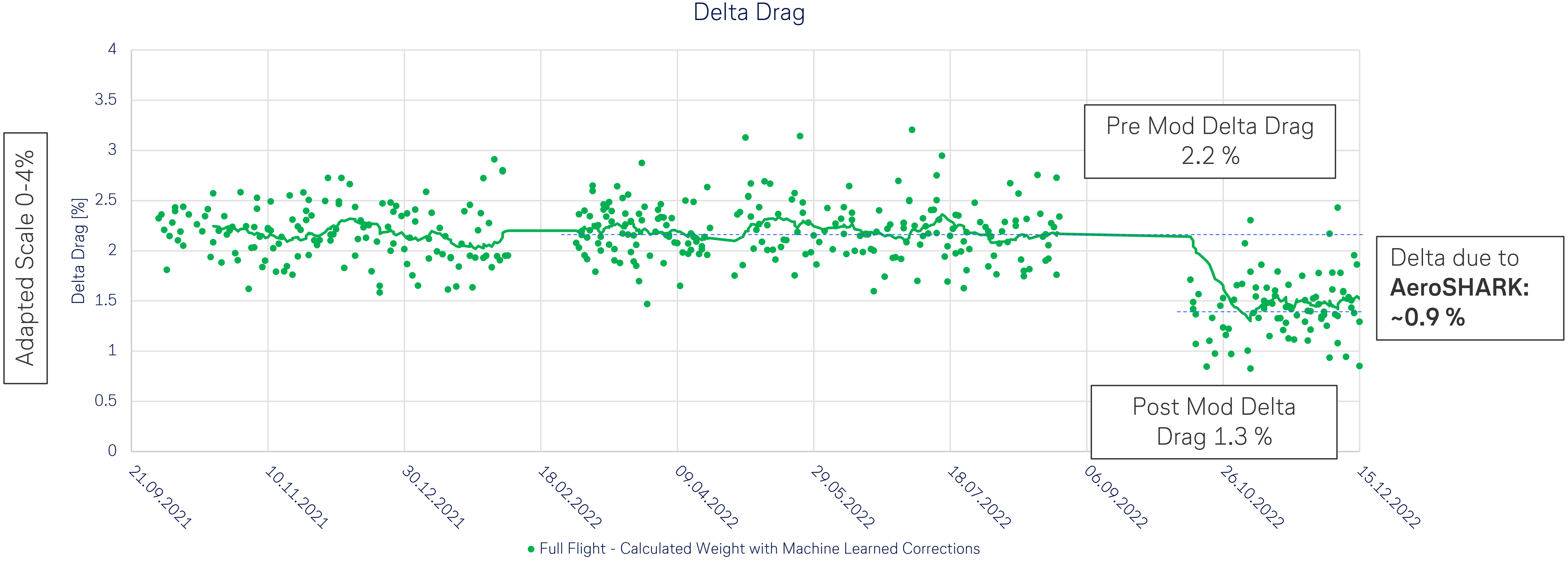
Delta Drag due to AeroSHARK for 1st aircraft

- Sudden offset in Delta Drag due to AeroSHARK
- It is ensured that no other maintenance has been performed during layover



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Cost-of-weight effect

Performance evaluation results in an effect of 0.9 % drag reduction during cruise without taking into account the effect of the weight reduction.

- For a flight ZRH-SFO with 93 t of fuel → 670 – 750 kg fuel savings (0.7 – 0.8 % fuel reduction)
- Reducing the initial fuel by these savings would lead to a total fuel reduction of **1.0 – 1.1 %**
- Airlines perform APM to track tailsign-specific performance factors
- Factor is transferred to dispatch for trip fuel calculation

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Summary

- ✓ Modern analysis tools allowed reverse engineering of aircraft characteristics
- ✓ Tailored Riblet film design to avoid certification issues due to undesired load increments
- ✓ Back-to-Back testing allowed reduction of flight test program
- ✓ Saving targets accomplished, roll-out of product in progress

Questions?