FLIGHT TEST OF AN ADVANCED HYBRID-LAMINAR-FLOW-CONTROL (HLFC) SYSTEM ON AN A320 VERTICAL TAIL PLANE

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Presented by

Heiko Frhr. von Geyr*, Gerald Ernst* , Sonja Pawellek **, Alexander Büscher **

on behalf of the AFLoNext team

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AFLoNext
2ND GENERATION ACTIVE WING

AFLoNext project Coordinator: Martin Wahlich **

* German Aerospace Center (DLR)
** Airbus Operations GmbH

Presentation Outline

1. Motivation and Objectives
2. Overview of system architecture
3. Design and leading-edge manufacturing
4. FTI Installation (Working Party)
5. Flight Testing – Exemplary Results
6. Conclusions

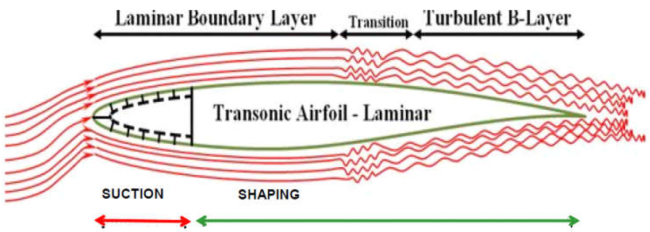
Motivation and Objectives

- The worldwide traffic will significantly grow within the next decade.
- This makes it inevitable to reduce the ecological footprint of passenger aircrafts.
- The European project AFLoNext contributes with dedicated research activities towards more ecological aircrafts targeting at FlightPath 2050:

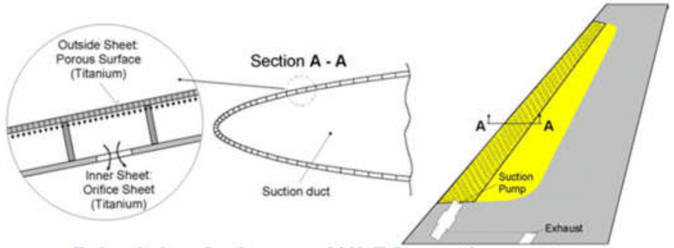
1) **Hybrid Laminar Flow Control** to reduce aircraft drag during cruise flight to reduce fuel burn.
2) Active Flow Control on local applications to increase aerodynamic performance during take-off and landing and to allow installation of more efficient engines.
3) Vibration Mitigation & Control to allow design of optimized airframe components to reduce overall aircraft weight.
4) Passive Noise Control technologies to reduce aircraft noise during approach and landing.

Motivation and Objectives

Flight Test demonstration of advanced HLFC technology on an A320 Vertical Tail Plane.



Hybrid Laminar Flow Control: Adequate suction meets proper shaping



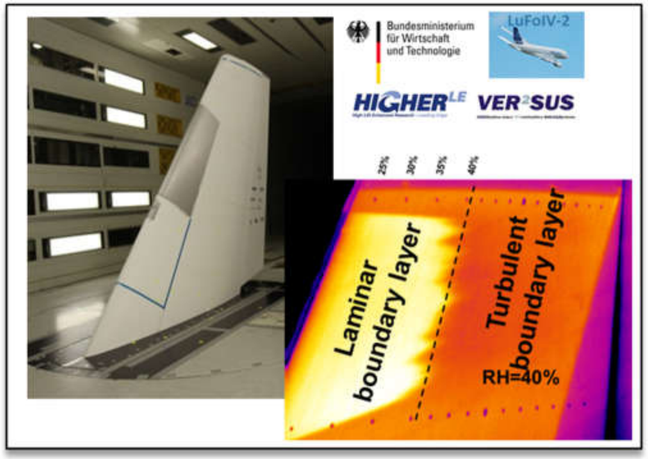
Principle of advanced HLFC-suction system invented in the European project ALTTA, 2004

- First time in Europe the application of an advanced HLFC-system on a VTP was successfully tested in 2014 at Flight-Reynolds-numbers in the DNW-Large Low speed Facility in the framework of a German national funded project HIGHER-LE/VER²SUS.

→ Design and manufacture an advanced suction system for flight testing at realistic flight conditions.

→ Demonstrate functionality of the system in flight

→ Verify passive suction power system



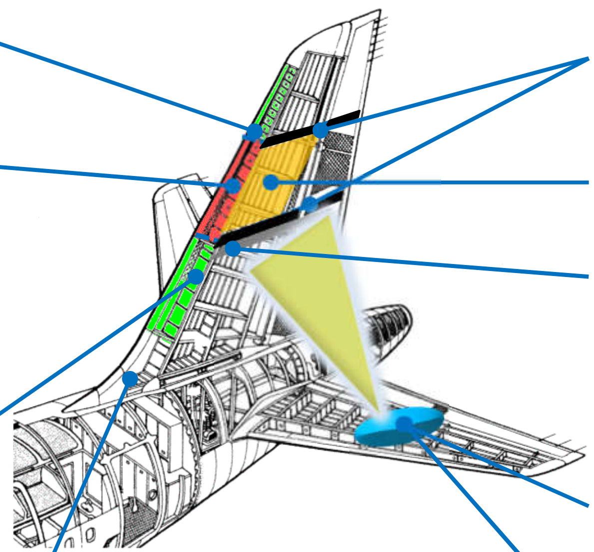
Research base: Results of German national funded project HIGHER-LE/VER²SUS

Airbus Operations, DLR, SONACA, TAI, AcQ Inducom, ONERA, Fraunhofer, CIRA, IBK, FOI, Dassault

Overview of system architecture

HLFC-suction system

- **pressure taps** at leading edge and **hot film sensors**
- **advanced HLFC-suction system** and high level of **instrumentation**
- **active and passive** adjustable **suction power system**
- **ram air flap**
- pressure tabs at leading edge, flush mounted hot film sensors and **anti-contamination-device**
- **suction system exhaust**



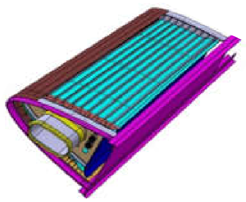
Schematic overview

Vertical Tail Plan

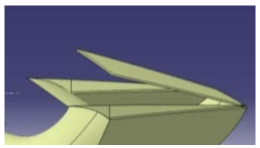
- **Pressure tabs** in two cross sections on center box and rudder
- **Infrared** compatible **foil** for transition detection
- **MEMS pressure** belt on center box

Horizontal Tail Plan

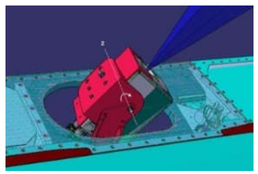
- Integrated adjustable **Infrared-Cameras** on both sides
- **Aerodynamic fairing**



HLFC-leading edge



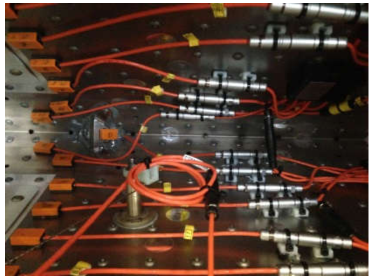
Passive suction flap



Infrared-camera installation into HTP

Overview of system architecture

- **Highly instrumented HLFC-leading edge**
  - Suction chambers:
    - Two MEMS sensors per chamber for pressure, temperature and humidity → 46 sensors
    - One pneum. pressure tab per chamber
    - 11 analog sensors for rel. humidity in 11 selected suction chambers



  - Pressure duct
    - Two MEMS sensors for pressure, temperature and humidity
    - Two pneumatic pressure tabs
    - One analog rel. humidity sensor
    - One analog temperature sensor
- **Multiple data acquisition and inflight data processing systems**
  - InfraRed Measurement System
  - Suction Control System
  - MEMS data acquisition system
  - HLFC Verification System
  - Pneum. Pressure Measurement System
  - Data Processing System
  - Hot-Film Measurement System
  - Aircraft Basic FTI System

Design & Leading-edge manufacturing

Multi-Disciplinary design

\ Chambering & suction distribution

\ Laser drilling & testing

\ Loop with structures towards convergence

Manufacturing steps

\ Titanium sheet welding

\ Micro-perforation

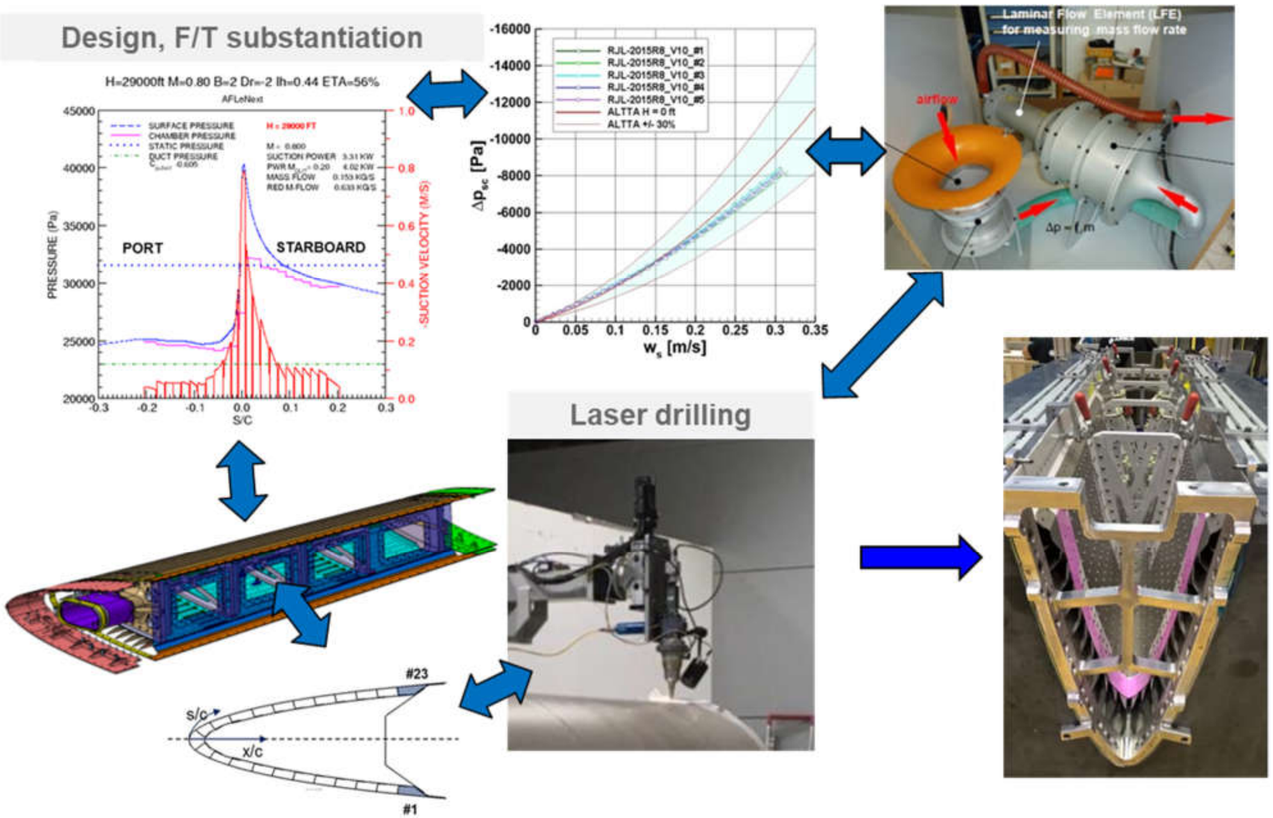
\ Stringer welding

\ Forming

\ Assembly

\ FTI Installation

\ Leading-edge closure



Leading-edge manufacturing – Titanium sheet welding and micro-perforation

Oversize panel manufactured by welding performed by RJ-Lasertechnik

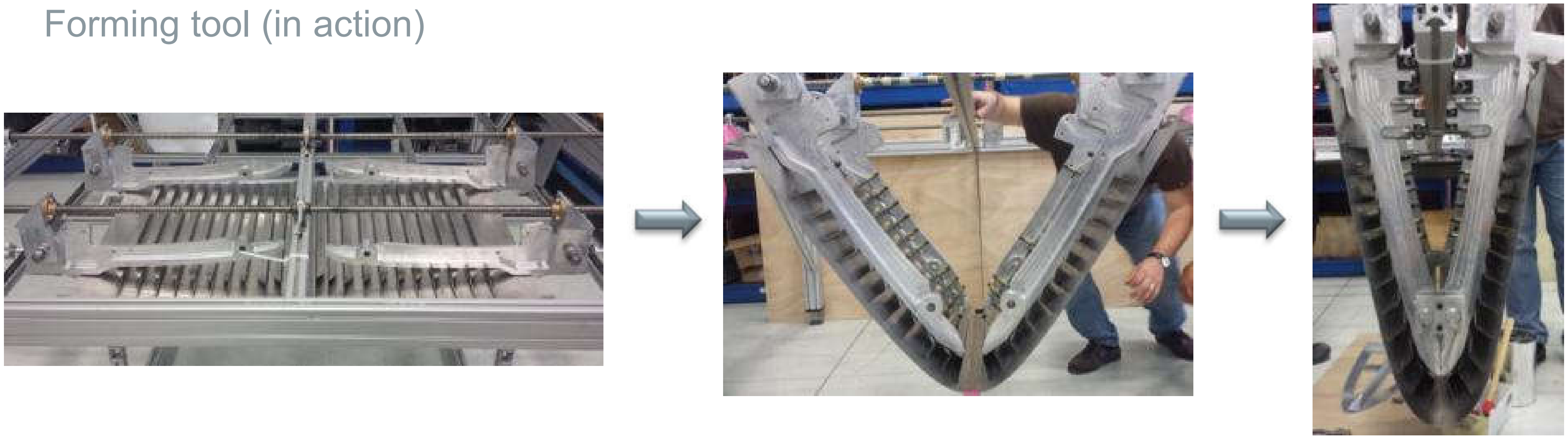
Laser drilling of micro-perforation for oversize sheet „on a barrel“

Leading-edge manufacturing – Stringer welding and panel forming

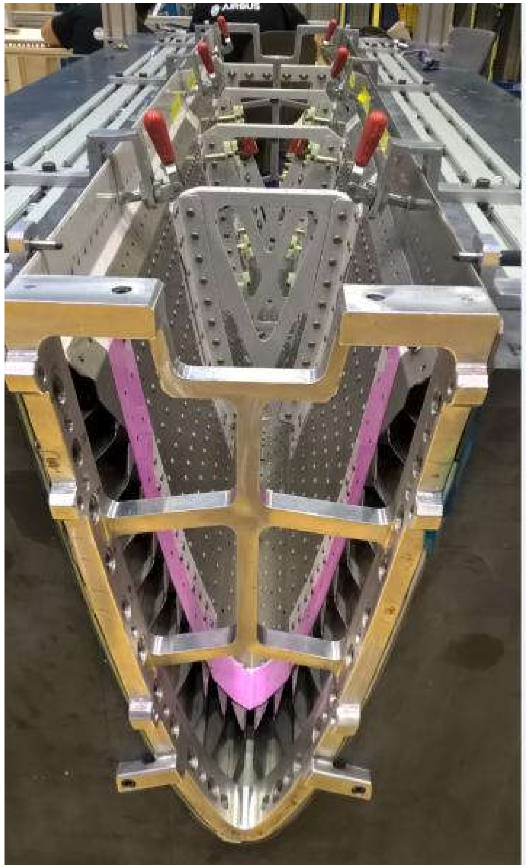
\ Laser Beam welding of T-stiffeners performed by BIAS

\ Preparation of coupons with extra stiffeners for shear tests

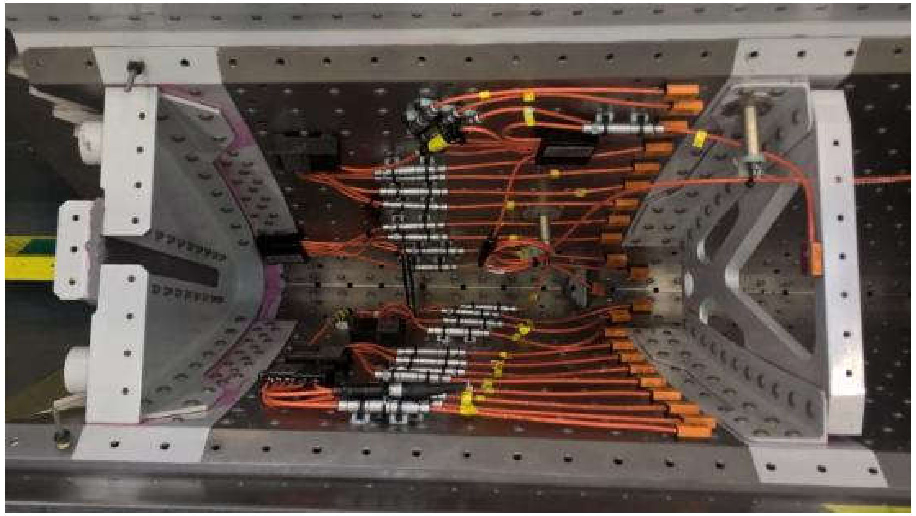
Forming tool (in action)



Leading-edge manufacturing – Assembly, FTI installation and leading-edge closure



Bended Outer Skin in mould and assembly of inner skin using rivets



\ Sensors (p, T, humidity) and routing designed to fulfil extreme conditions; e.g. +50°C / -70°C

\ Flight Test Sensor Installation in chambers and plenum

\ FTI functional test passed

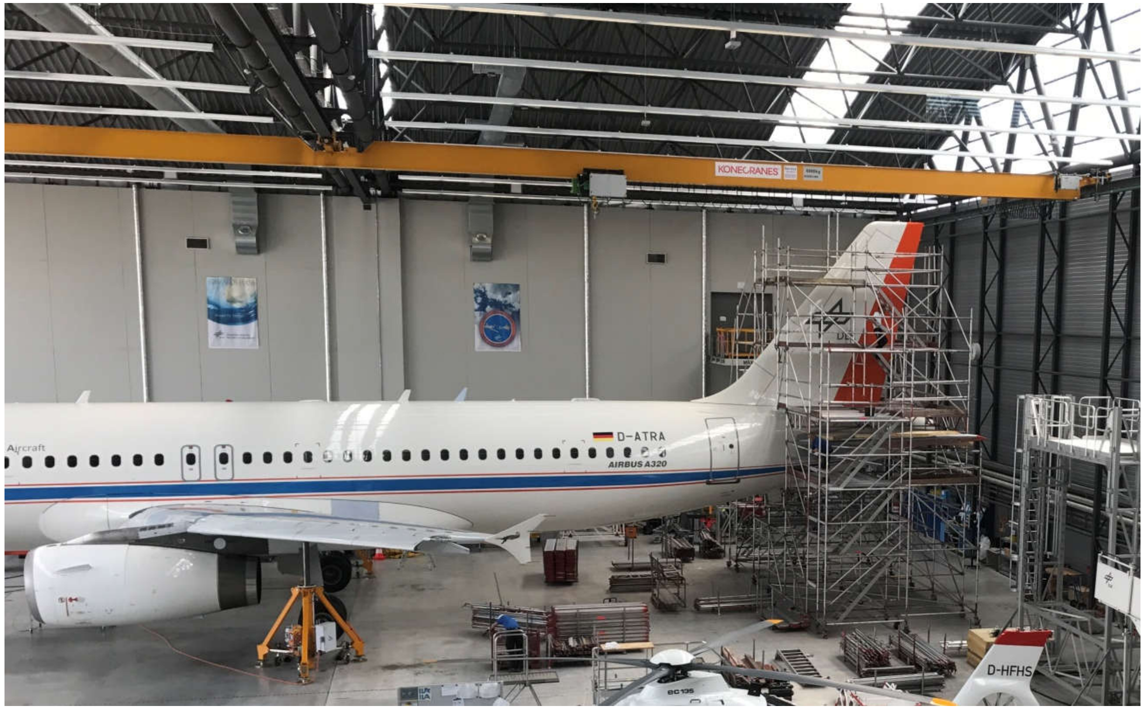
\ Leading-edge closed by membrane

FTI Installation (Working Party)

\ Installation at DLR Brunswick on DLR A320 ATRA

\ Jacking A/C to allow gear swing tests

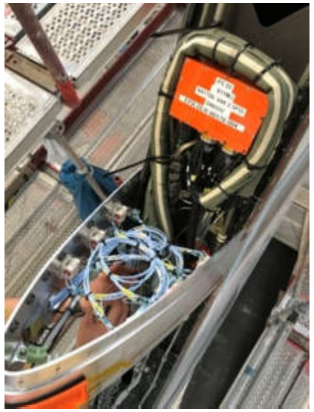
\ Scaffolding tail of jacked A/C on both sides



FTI Installation (Working Party)

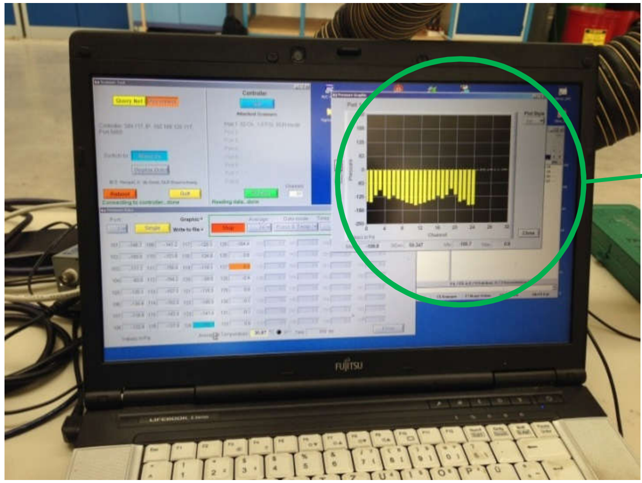
\ Installation of components on VTP

\ Filling and sanding to smoothen VTP-CB @ DLR-logo area

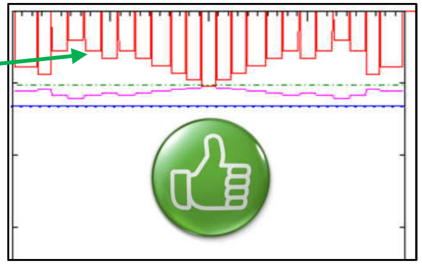


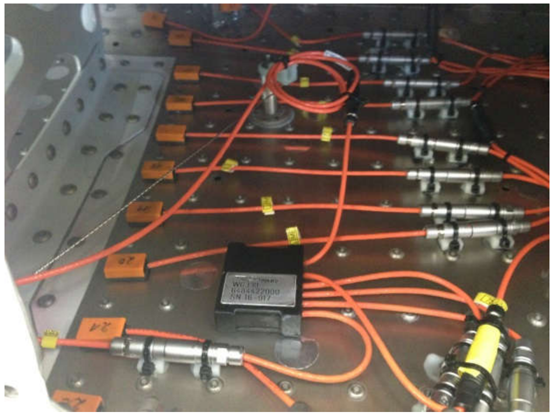
FTI Installation (Working Party)

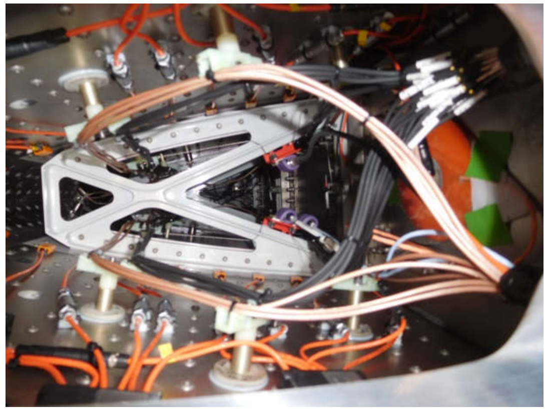
\ Function & airtightness test of HLFC-LE



Num. design

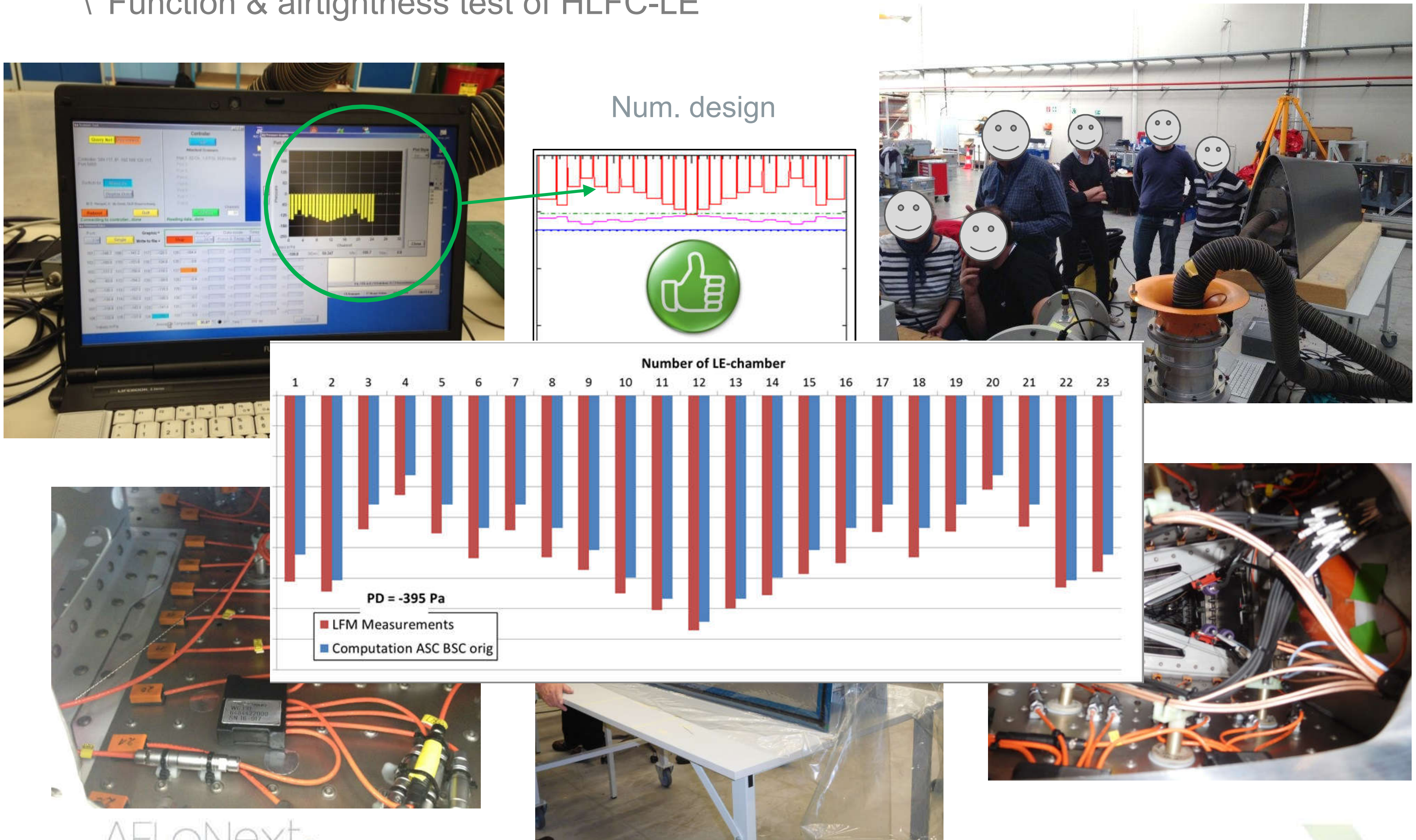






FTI Installation (Working Party)

\ Function & airtightness test of HLFC-LE



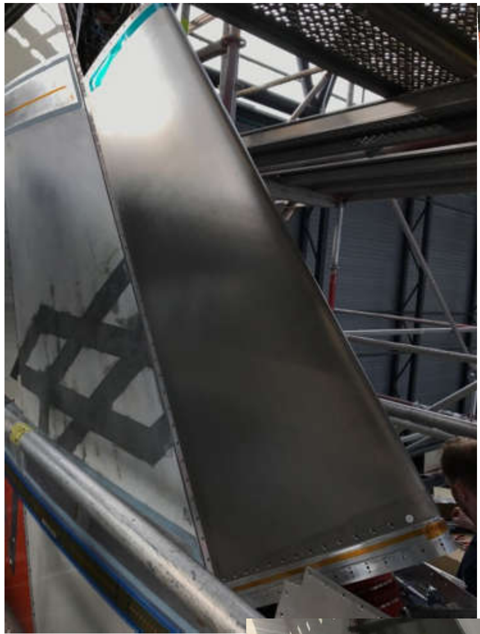
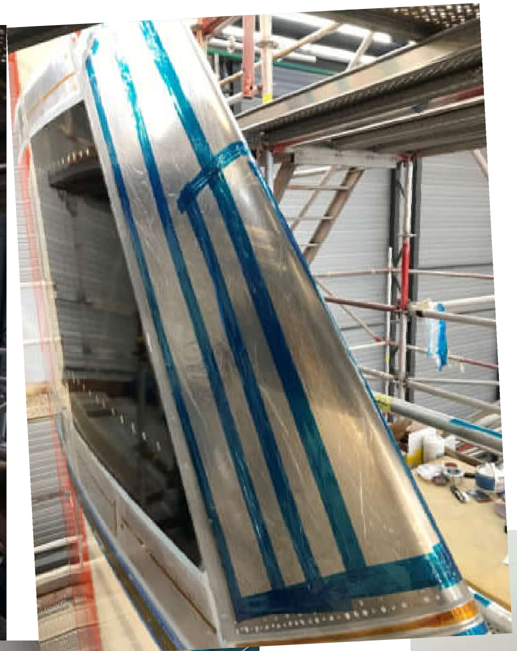
FTI Installation (Working Party)

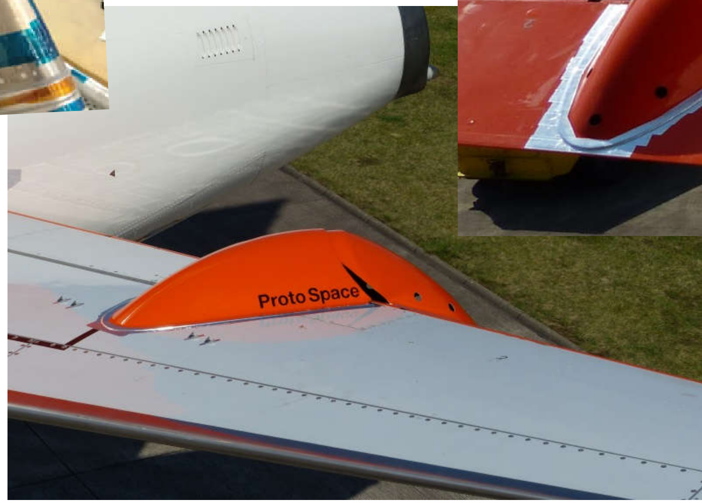
\ Installation of HLFC-LE




FTI Installation (Working Party)

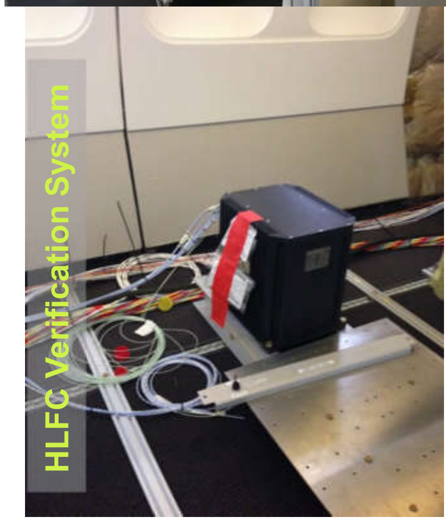
\ Filler application, finishing, HTP modifications

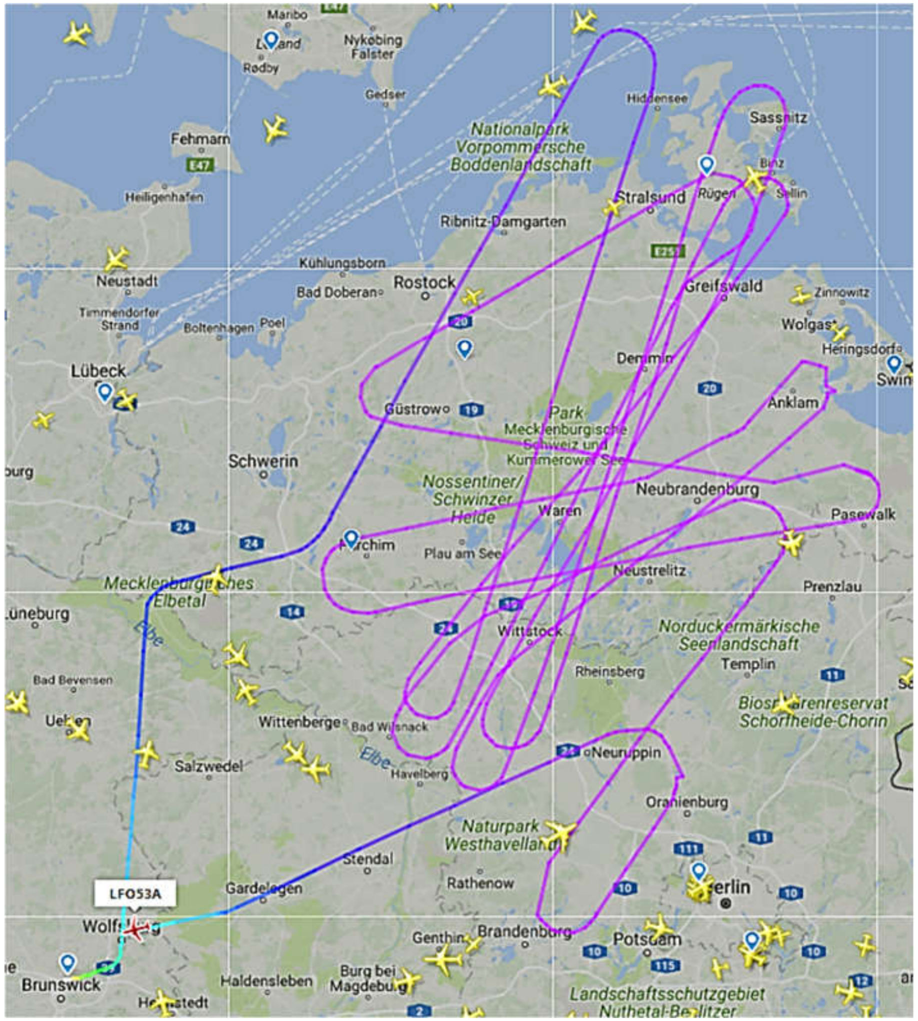
FTI Installation (Working Party)

\ Cabin installation



FTI Installation (Working Party)

Flight Testing – Exemplary Results



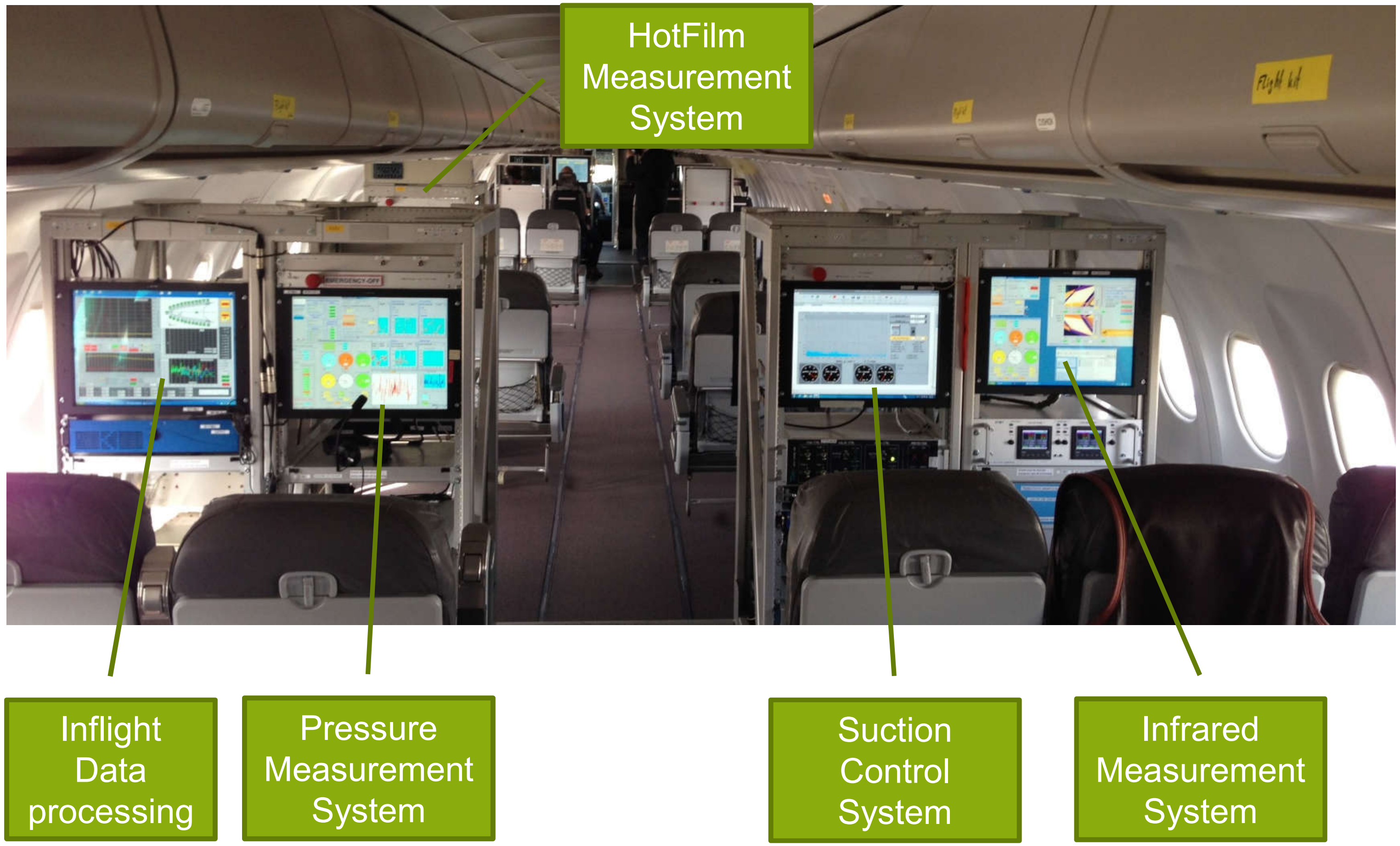
FLIGHT TRACK CYCLING WITH THE SUN:

- Flight test in TRA MVPA with area entry at approx. 11h00 local time
- Sun direction change with 15°/h
- IRT requires flight track adjustment for optimal image quality
- At some conditions it is difficult to get good image quality for both VTP sides at the same time
- Long flight times to get both sides → night flight increases efficiency

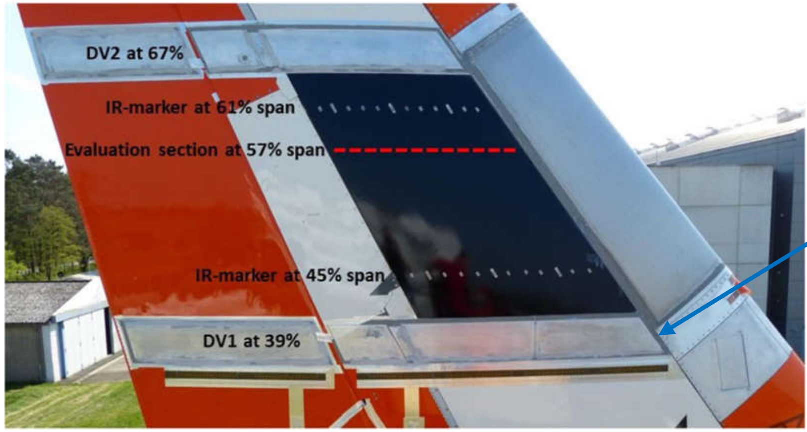
- However, excellent support from ATC and TRA management

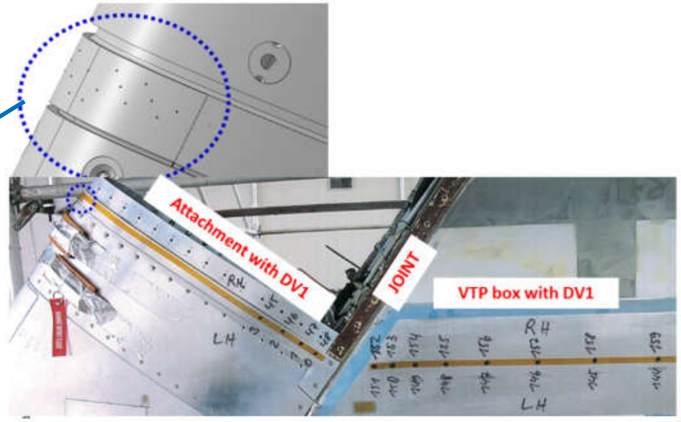
Flight Testing – Exemplary Results

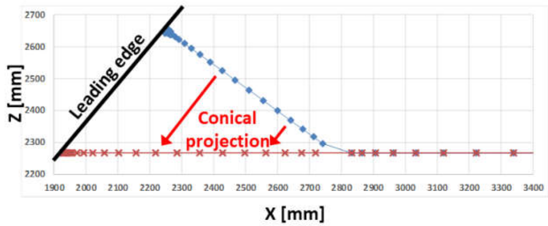
\ Inflight data processing - exemplary



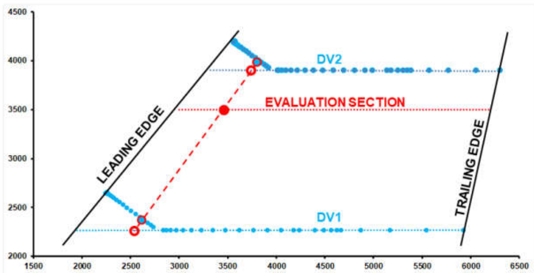
Flight Testing – Evaluating pressure data*







(a) Step 1: Conical projection on DV.



(b) Step 2: Conical interpolation.

<u>2 step approach:</u>

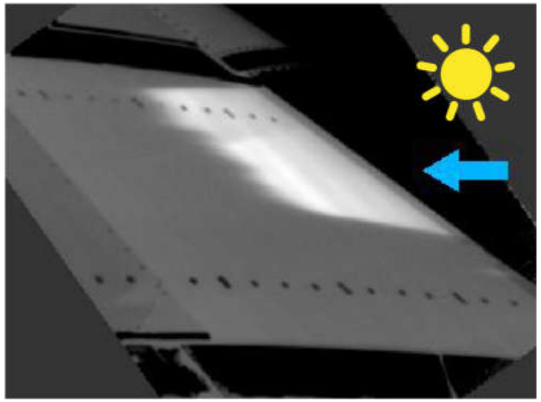
1. Conical projection onto line of flight cross section

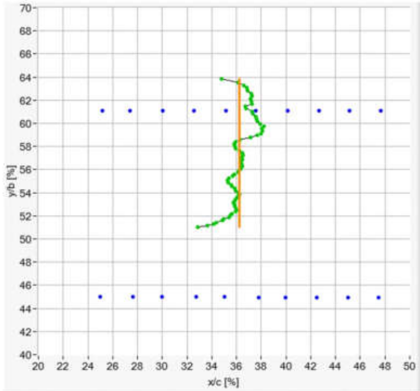
2. Conical interpolation from DV1 and DV2 onto evaluation section

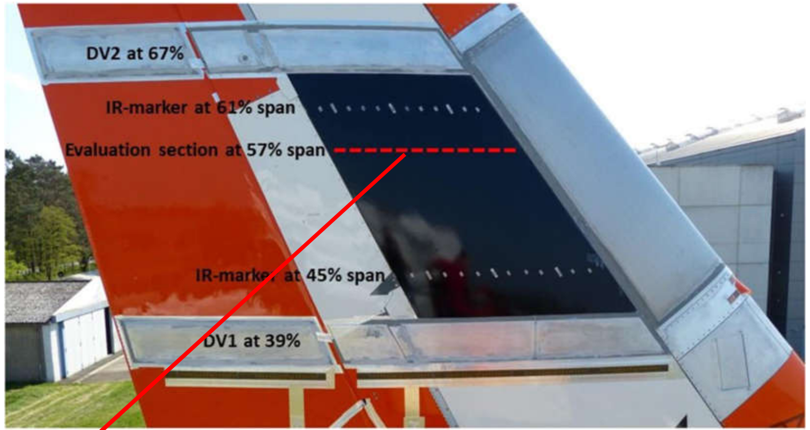
- AIAA SCITECH 2021: https://doi.org/10.2514/6.2021-1305

Flight Testing – Exemplary Results*

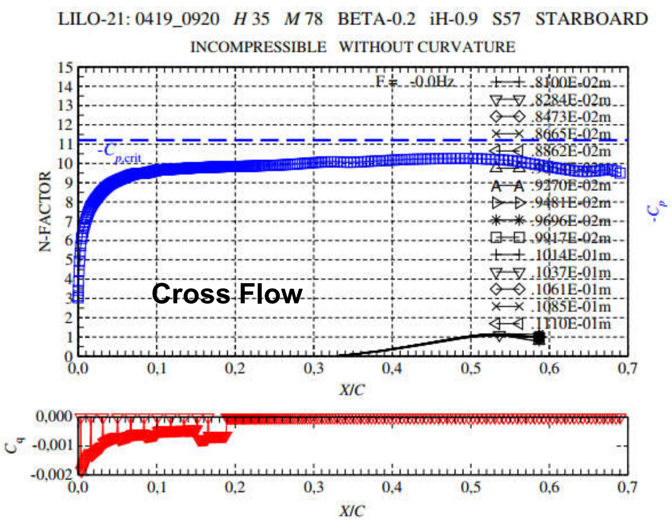
H=35000ft, M=0.78, beta= 0°, rudder=-0.7°

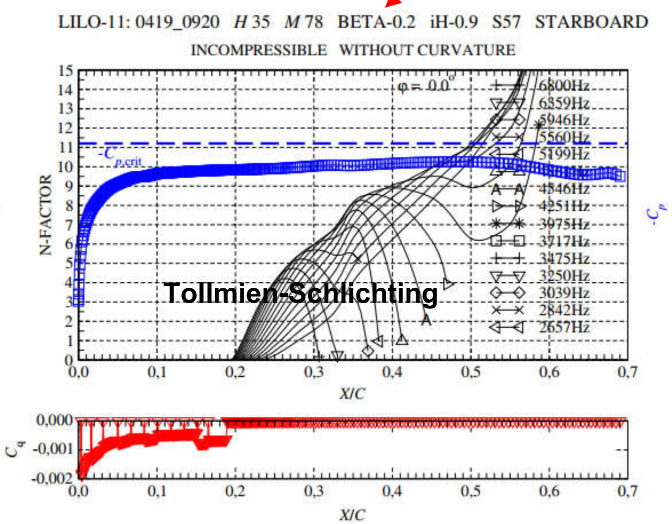






Starboard side: left – infrared; right – transition line



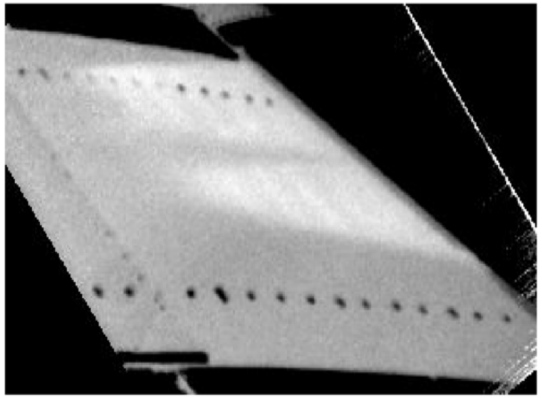


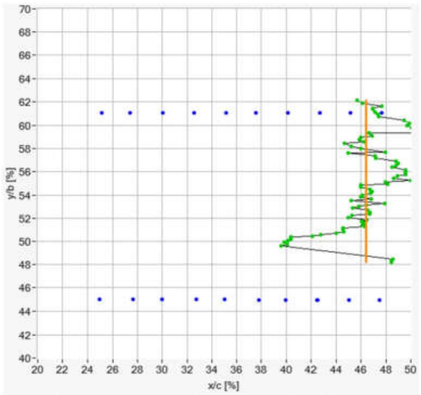
- Strong suction of Δp~6766 Pa
- N_{TS} transition
- N_{TScrit} = 8.5 - 8.8
- Slightly lower, that used for design (minor sun heating effect)

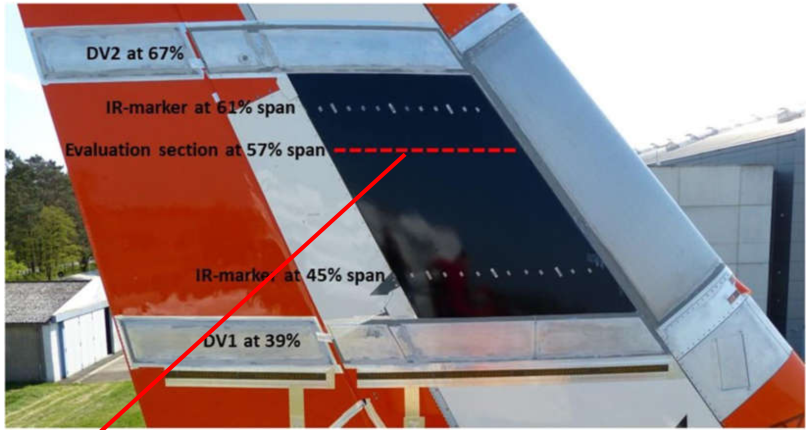
* Journal of Aircraft: https://doi.org/10.2514/1.C036179

Flight Testing – Exemplary Results*

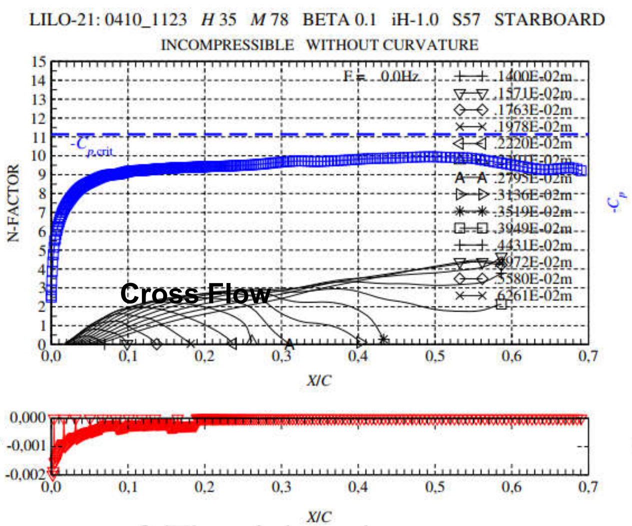
H=35000ft, M=0.78, beta= 0°, rudder=-0.4°

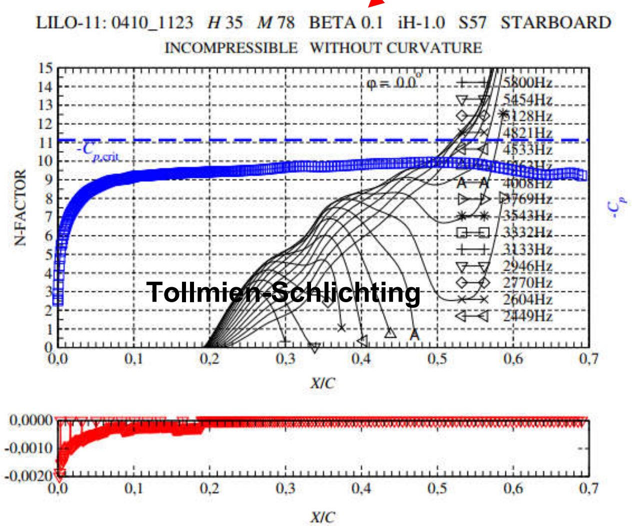






Starboard side: left – infrared; right – transition line





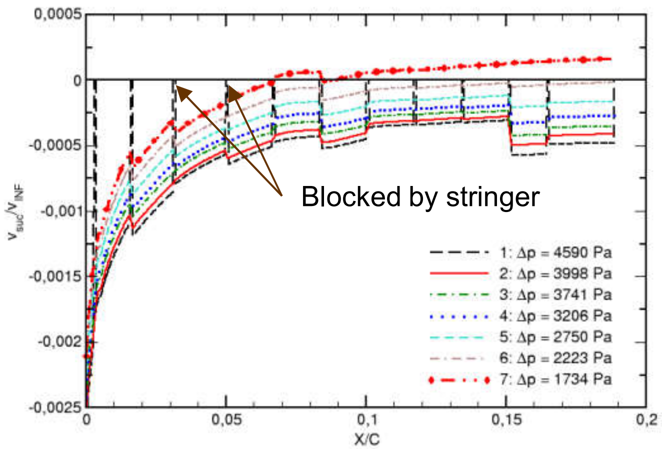
- Reduced suction of Δp~3613 Pa
- Still N_{TS} triggered
- N_{TScrit} = 10 – 10.5
- Slightly larger than for previous case.
- No sun heating

* Journal of Aircraft: https://doi.org/10.2514/1.C036179

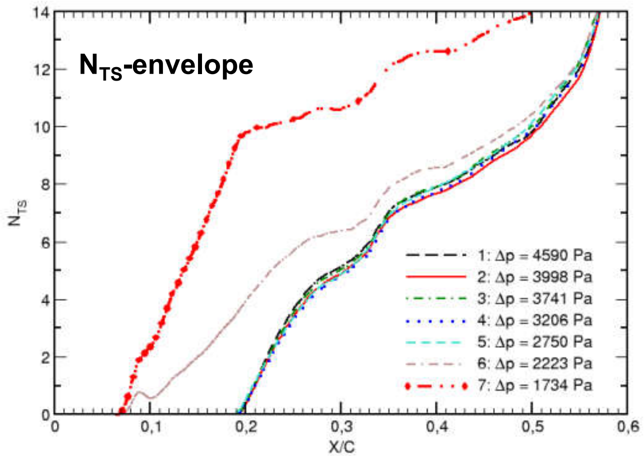
Flight Testing – Exemplary Results**

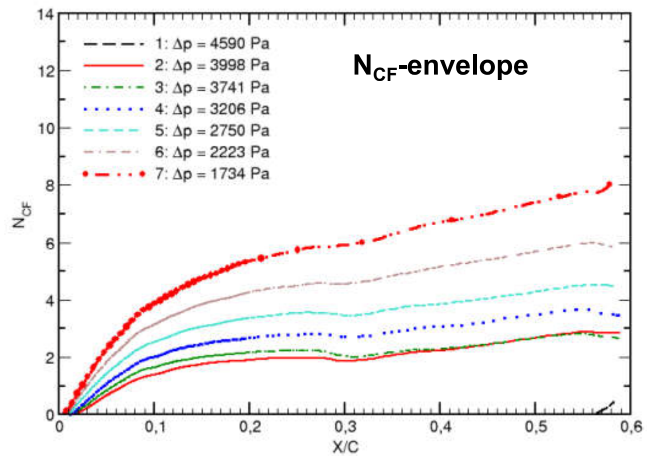
H=39000ft, M=0.78, beta=0°, rudder=0° - passive suction – 2500 Pa < Δp < 5800 Pa

No.	Time	δ [deg]	Δp [Pa]	$X_{tr,1}$	$X_{tr,2}$	$X_{tr,mean}$	$N_{TS,1}$	$N_{TS,2}$	$N_{TS,mean}$
1	120513	15.5	4590	48%	48%	48%	9.4	9.5	9.45
2	120621	13.2	3958	47%	49%	48%	9.0	9.7	9.35
3	120700	12.2	3741	47%	50%	48.5%	9.3	10.0	9.65
4	120730	10.3	3206	50%	51%	50.5%	9.9	10.6	10.25
5	120803	8.1	2750	49%	50%	49.5%	9.8	10.4	10.10
6	120833	6.2	2223	49%	51%	50%	10.1	10.8	10.45
7	120925	5.5	1734						



- Transition at weak suction still around 50%
→ CF (N_{CF}~5) still does not affect transition process yet
→ Linear stability theory still valid
- If suction is further reduced outflow causes transition on the suction panel
(N_{TS}=10 @ end of panel)





** AIAA SCITECH 2021: https://doi.org/10.2514/6.2021-1305

Conclusions

- All chambers of HLFC-LE were airtight, manufacturing process successful.
- The simplified HLFC system (multiple suction chambers) operated as expected.
- All FTI systems (HVS, PMS, HFMS, IRMS, SCS) operated without failures.
- New inflight data evaluation was very valuable as it allows corrective test point adjustments during flight testing and hence enables very efficient testing
- The ACD-device operated as predicted (Gaster bump)
- The filler joint between the HLFC nose and the VTP box worked properly; no early transition, no cracks even with small movements of the parts
- Passive suction first time in Europe successfully demonstrated in flight (2018)
- Exemplary result concludes:
  - Passive suction flap operated as expected and according to design *
  - It has been found that the correlated N_{TS} factors, obtained with incompressible stability theory, are in the expected range**
  - Design methodology verified
- Today's technology successfully focus on variable porosity omitting multiple suction chambers (beyond AFLoNext)

* AIAA SCITEC 2021 https://doi.org/10.2514/6.2021-1305 ** Journal of Aircraft: https://doi.org/10.2514/1.C036179

Conclusions

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