HLFC TECHNOLOGY INTEGRATION ON A LONG-RANGE WING

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Thomas Kilian, Geza Schrauf

DLR, Institut für Aerodynamik und Strömungstechnik, Braunschweig

HLFC–WIN

DLR

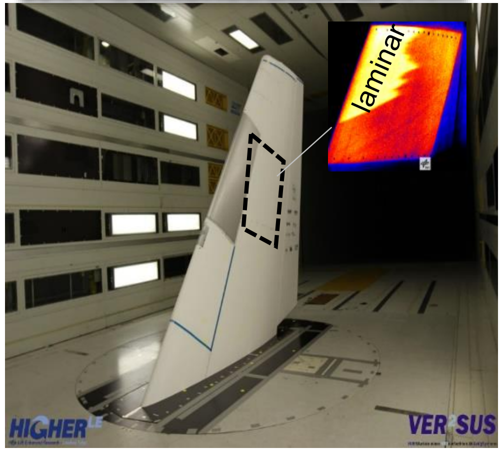
*HLFC: Hybrid Laminar Flow Control

Overview

- Introduction
  - Recent HLFC developments at DLR
  - Overview of the CS-2 Project HLFCWin
- Some specific challenges of an HLFC integration on a long-range wing
  - Interference with de-icing system
  - Large HLFC segments / spanwise pressure loss
- HLFC system design
- Summary and Outlook

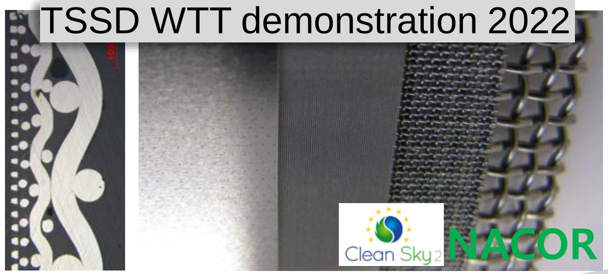
Recent HLFC technology development highlights at DLR

Simplified suction system
WTT demonstration 2014

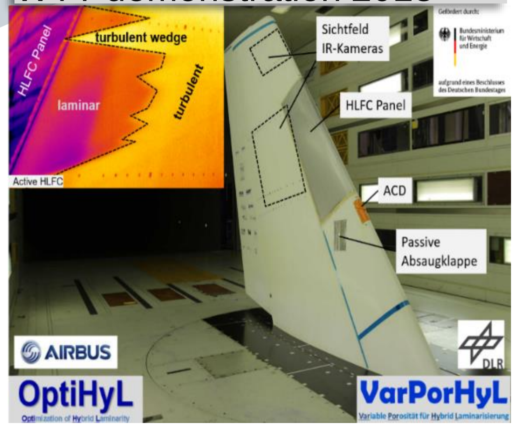


Simplified suction system
FT demonstration 2018

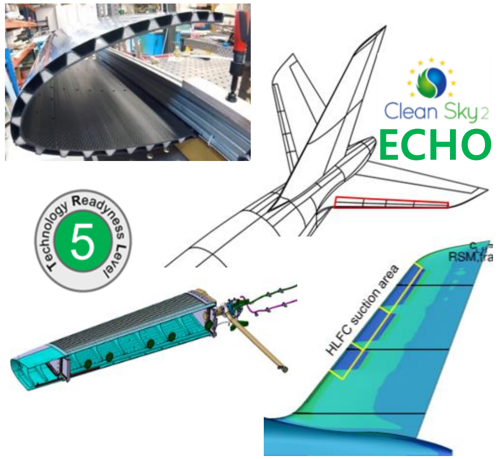
TSSD WTT demonstration 2022



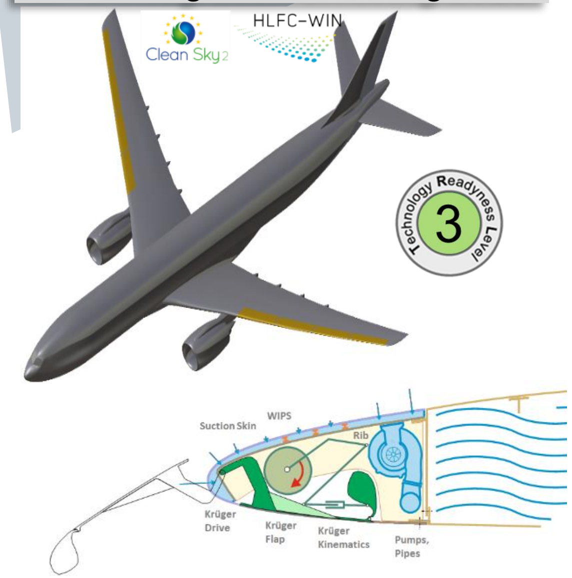
Optimization variable porosity
WTT demonstration 2018



HLFC integration on HTP 2022



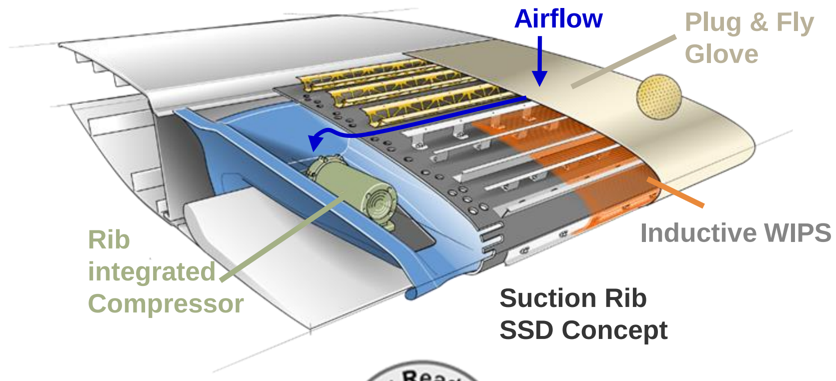
HLFC integration on Wing 2023



Technology integration (CS-2)

Maturation of design, simulation and manufacturing

HLFC technology integration on a long-range wing
Clean Sky 2 - HLFCWin

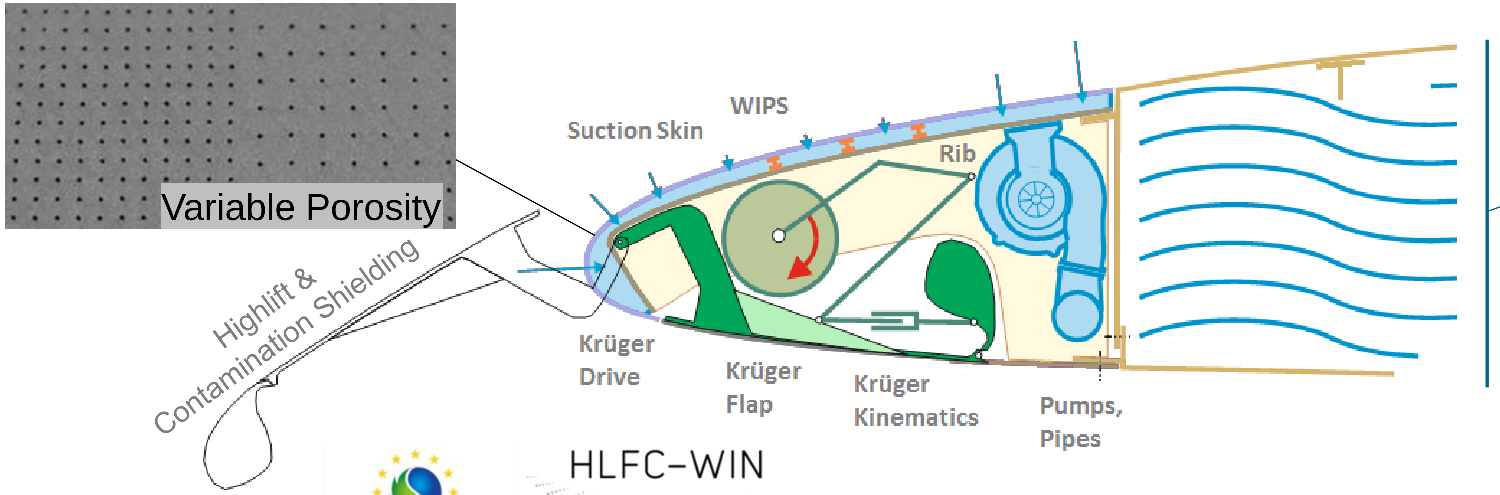


Goal: Multi-disciplinary design of a long-range HLFC wing

- Design of a HLFC leading-edge with variable porosity
- System design for suction, high-lift and de-icing
- Laminar benefit assessment using RANS-CFD

Challenges: Restricted installation space, high-lift, anti-icing, large segments, power-offtake

Technology Readiness Level 3



Clean Sky 2 HLFC-WIN

ONERA THE FRENCH AEROSPACE LAB DLR AIRBUS sonaca AERnnova

Overview

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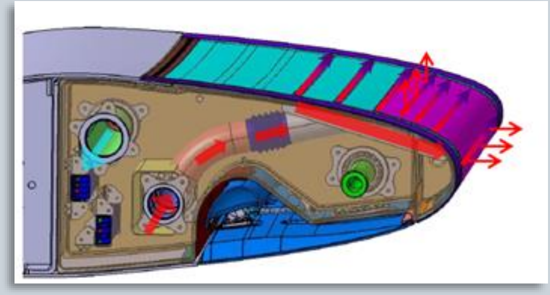
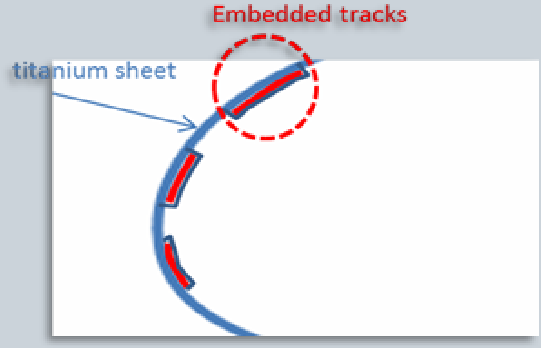
De-Icing of a long-range HLFC wing

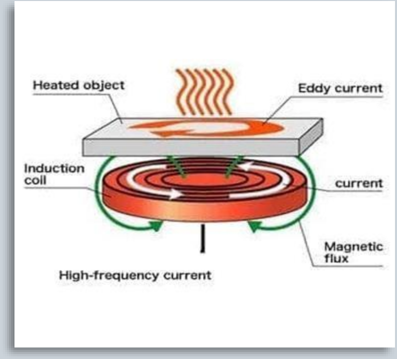
How to de-ice?

Chosen for HLFCWin: Inductive

Hot air / Bleed air	Elektro-thermal	Inductive
• Surface heating by continuous hot air flow • System investigated in AFLoNext	• Heating mats bonded to the outer skin	• Induction coils embedded in inner structure • Low TRL level





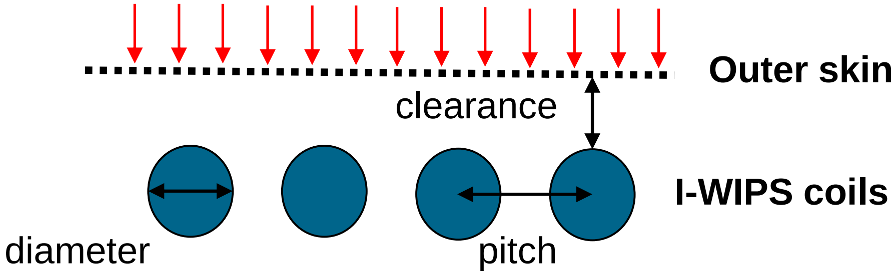


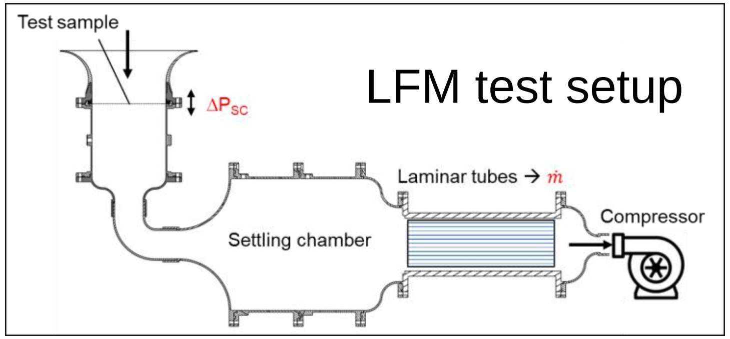
Hot air / Bleed air	Elektro-thermal	Inductive
☺ No blockage of suction surface ☺ High maturity ☹ Temperature compatibility with CFRP structure ☹ Reliant on bleed air	☺ Rel. Low power offtake ☺ MEA compatible ☺ Medium maturity ☹ Partial blockage of suction surface	☺ no blockage of suction surface ☺ MEA compatible ☹ Low maturity

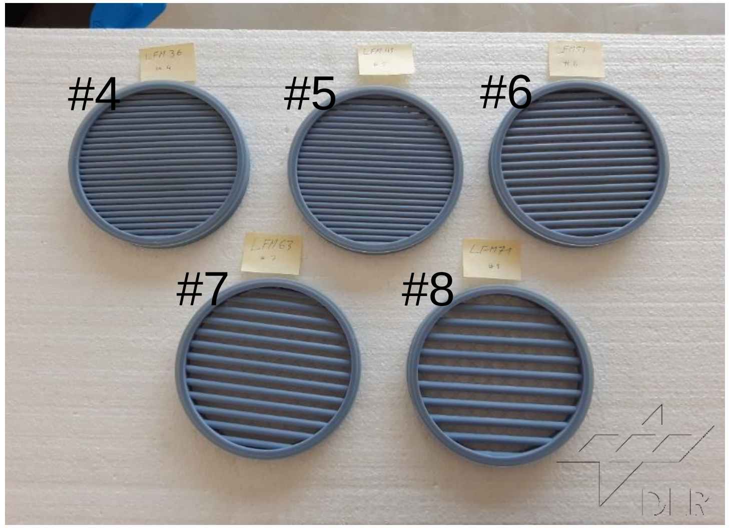
Influence of inductive WIPS coils on suction surface pressure loss

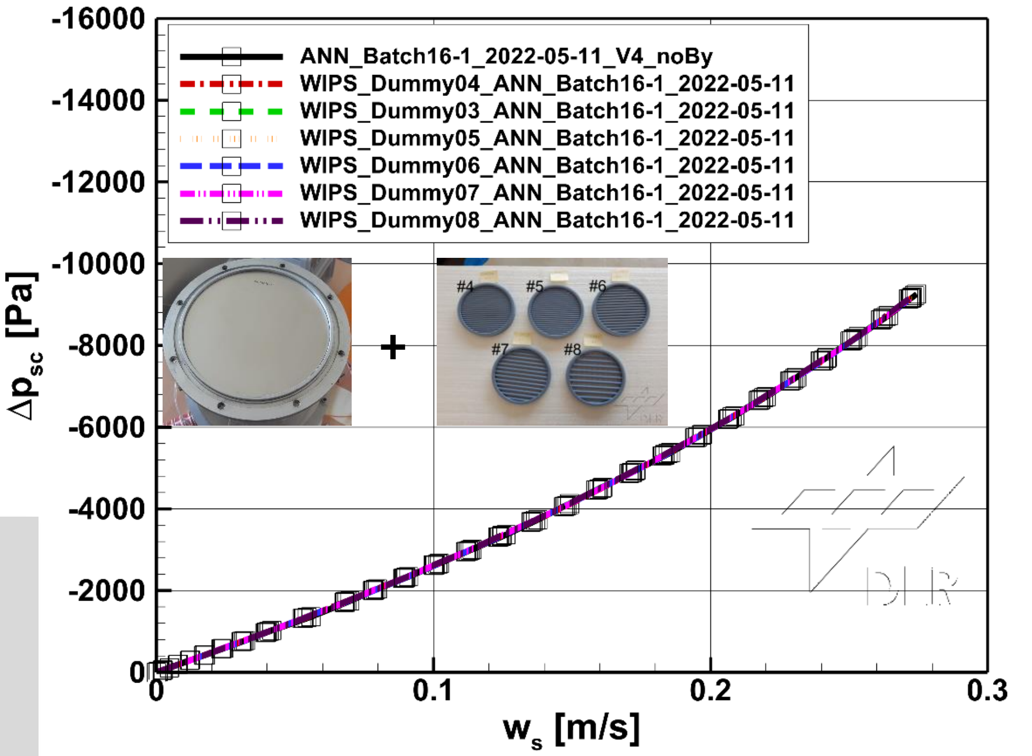
<ins>**Question: Do I-WIPS coils produce additional pressure loss in the system**</ins>

- Assessment by pressure loss measurements using the laminar flow meter (LFM)
- Multiple realistic coil setups tested
  - All with identical and sufficient surface heating properties
- 3D printed IWIPS coupons placed onto micro-perforated Ti coupon









Result: No detrimental interference of I-WIPS coils and suction flow

Outlook: Functionality of I-WIPS setup currently assessed in icing-WTT (by SONACA).

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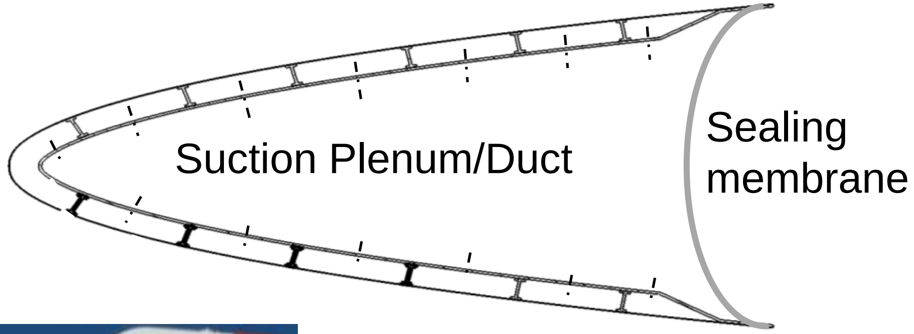
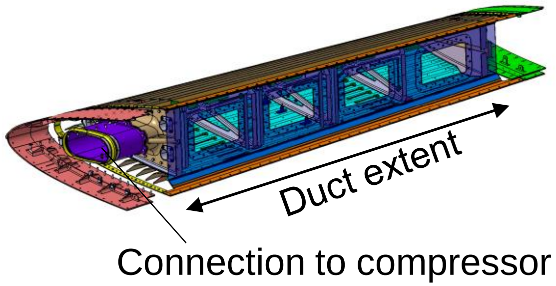
Suction flow distribution along span: VTP/HTP vs. Wing

VTP / HTP

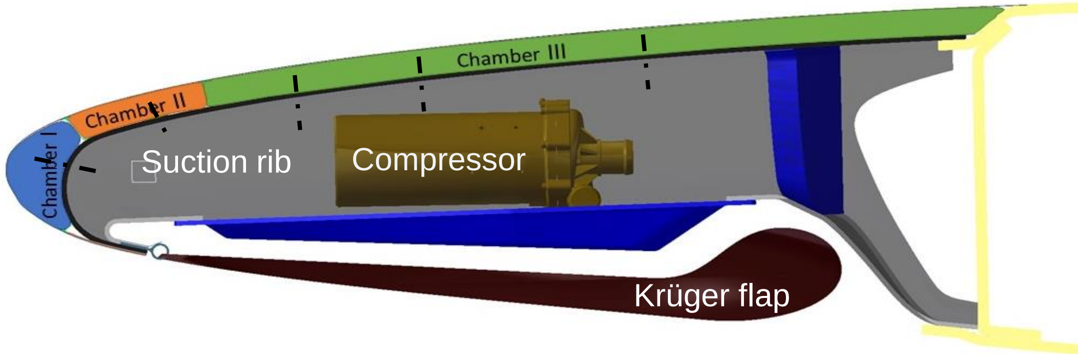
Suction plenum duct extends over complete span

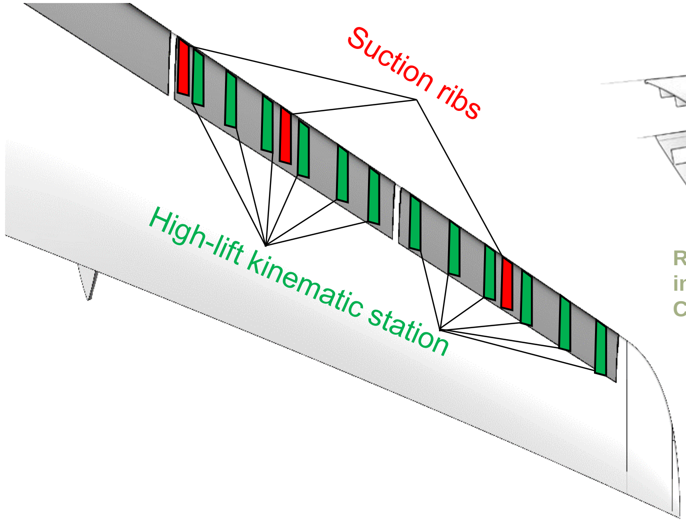


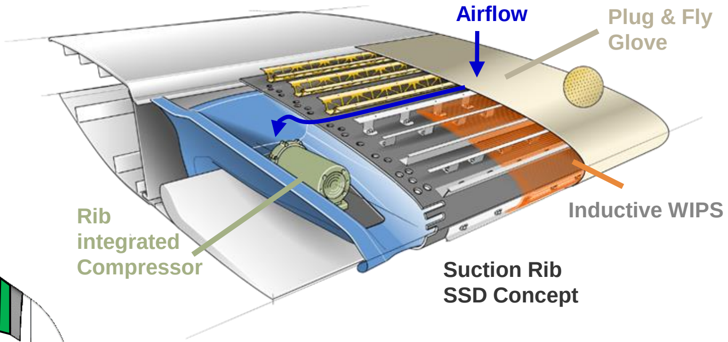


Wing

Compressor within **suction rib** with limited spanwise extent







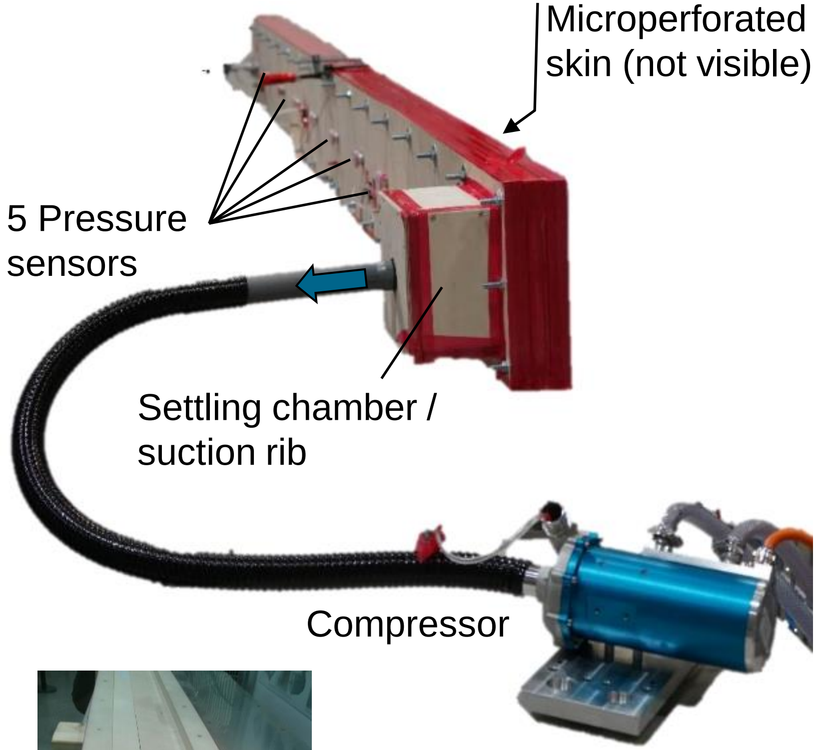
→ Suction mass flow needs to be transported via narrow chambers

Does suction mass flow create additional spanwise losses?

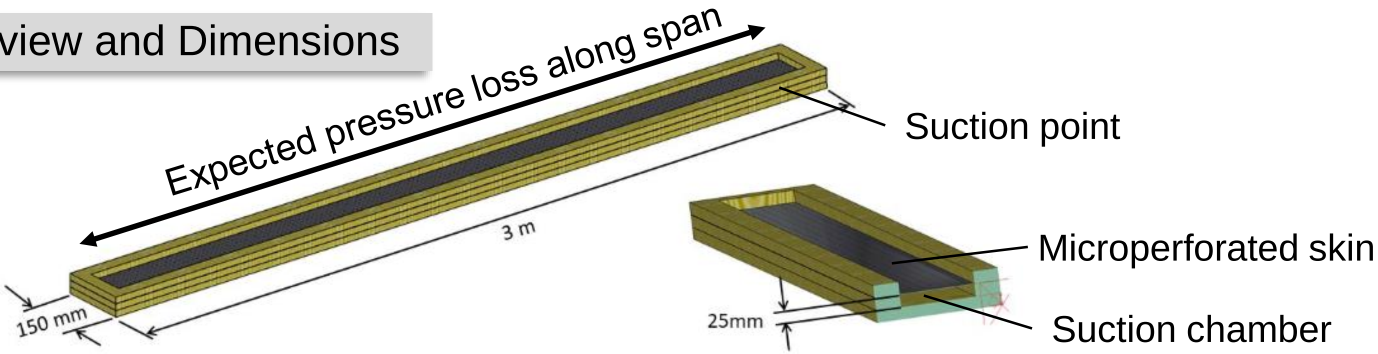
Spanwise suction SSD:

- Micro-perforated titanium skin mounted in sealed wooden box
- Compressor (Fischer EMTC-150k) connected on one end via settling chamber
- Pressure sensors distributed along span

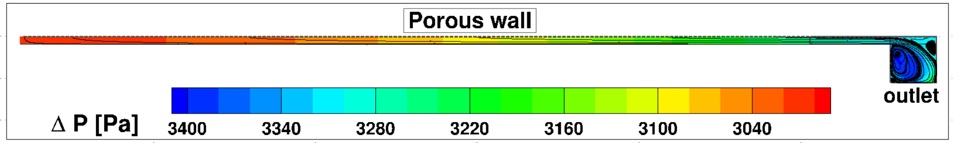
Experimental setup

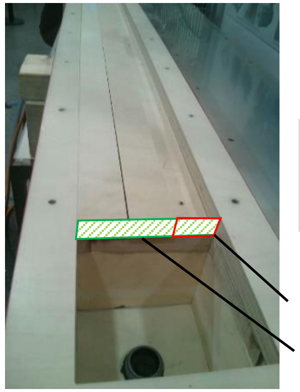


Overview and Dimensions



Simplified 3D CFD representation including porous wall and settling chamber





Chamber cross section variations

Reduced: 50 x 25mm

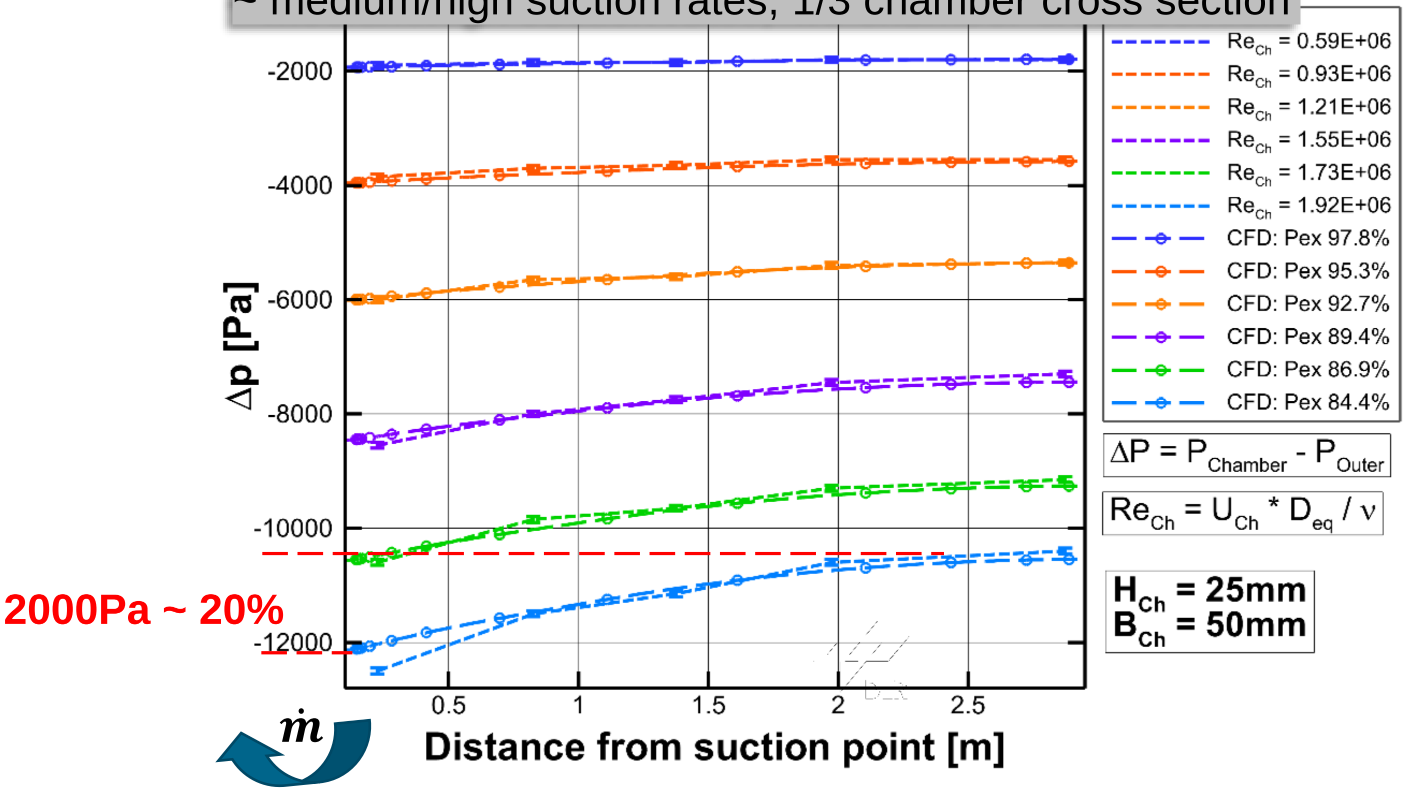
Maximum: 150 x 25mm

Spanwise pressure loss in narrow chambers

- Mass flow range (measured at compressor): 19 g/s to 62 g/s
- Pressure loss along chamber visible and in very good agreement with CFD results.

- **Pressure loss of 20%** at maximum chamber Reynolds number of 1.92 Mio.

~ medium/high suction rates, 1/3 chamber cross section



Spanwise pressure loss needs to be considered during HLFC design.

Highly depends on chamber geometry.

Kilian, T., Bismark, A., Lüdeke, H. und Schröder, A. und van de Kamp, B. "*The influence of high spanwise chamber extent on HLFC performance.*" DLRK 2021, 31. Aug. - 02. Sept. 2021, Bremen.

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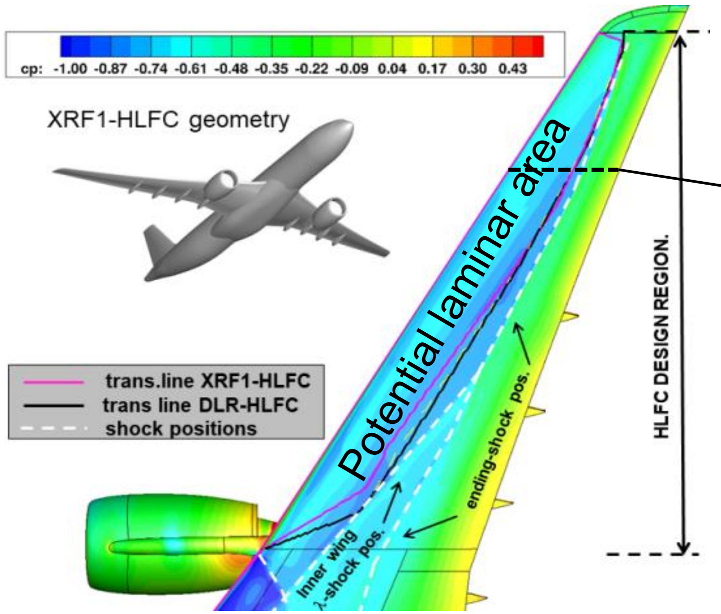
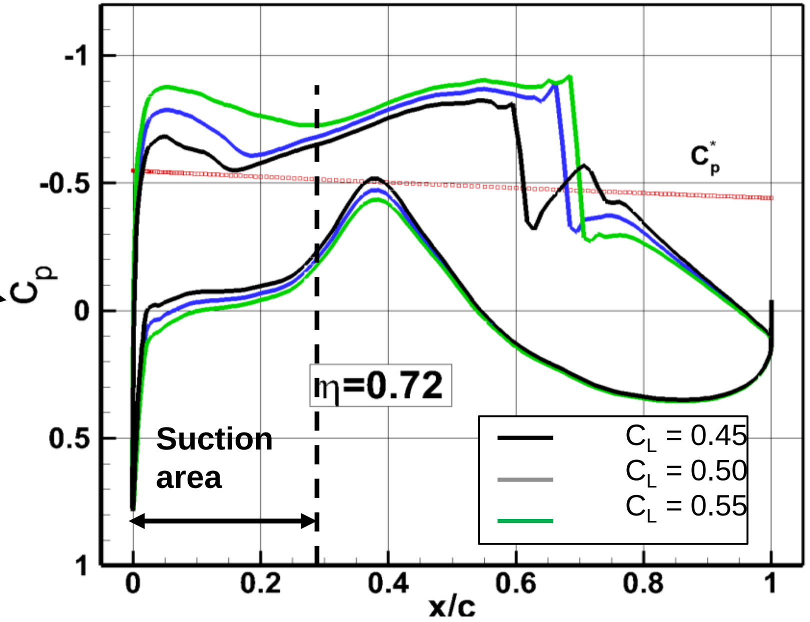
Wing redesign for laminarity

- Airfoil redesign based on turbulent XRF1 to maximize laminar benefit.
- Optimization of (target) surface suction distribution.
- Laminar area extends mostly up to the shock.
- Large variation in suction peak throughout HLFC envelope.



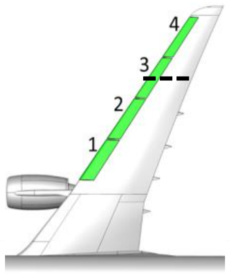
Laminar extents of Airbus and DLR wing design



Surface pressure distributions across HLFC operating envelope

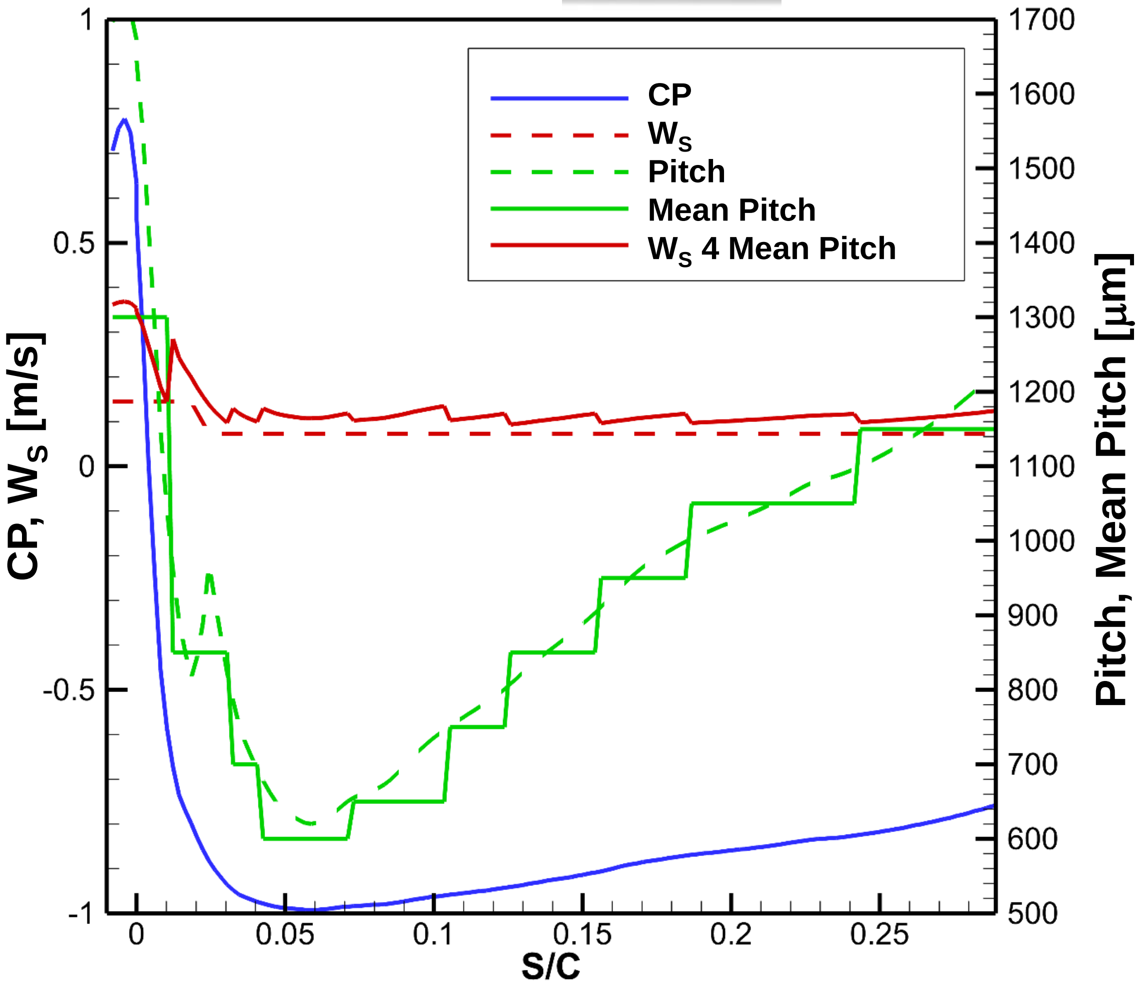
T. Streit, M. Kruse, T. Kilian, J. v. Geyr, I. Petroupoulus: „Aerodynamical design and analysis of HLFC wings within the European project HLFC-Win.“ ICAS 2022

Segment 3: Surface porosity design



FL = 330
Ma = 0.81
CL = 0.55
Segment: 3

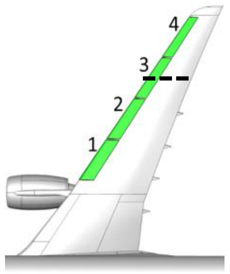
- Target suction distribution and pressure levels used to calculate pressure loss coefficients for variable porosity design
- Micro-perforation porosity constant in spanwise and variable in chordwise direction
- Hole pitch variation in steps of 50µm to ease manufacturing



<u>Results:</u>

- **Inputs for chambering design and manufacturing** generated:
  - Pressure loss coefficients A&B
  - Porosity distribution (e.g. pitch)
  - Duct Pressure P_{duct}
- **Single Chamber design** fount to be sufficient to achieve desired suction rates and cover pressure fluctuations throughout envelope.

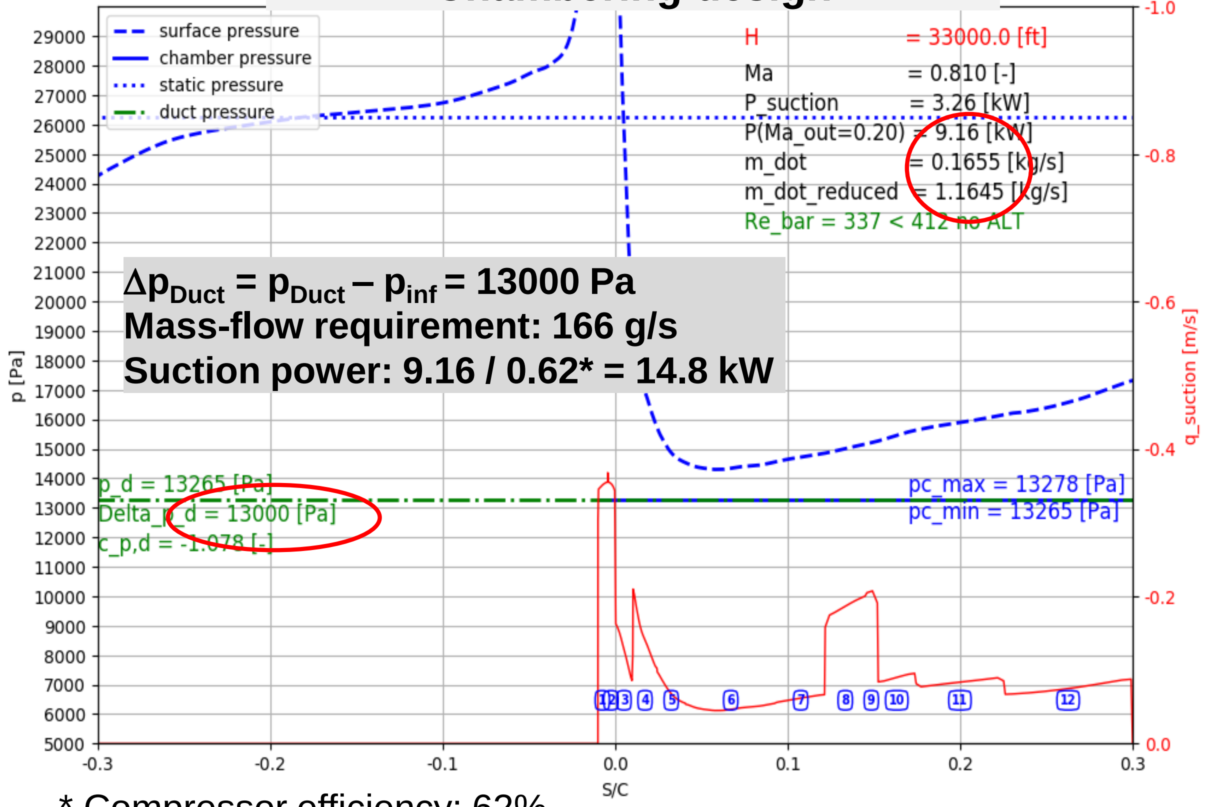
Segment 3: Chamber design and stability analysis



FL = 330
Ma = 0.81
CL = 0.55
Segment: 3

- 1-Chamber design leads to negligible spanwise losses → no extra pressure margin needed
- Successfully damps amplifications by TS and CF and attachment line transition (ALT)
- Large laminar regions up to shock match initial design

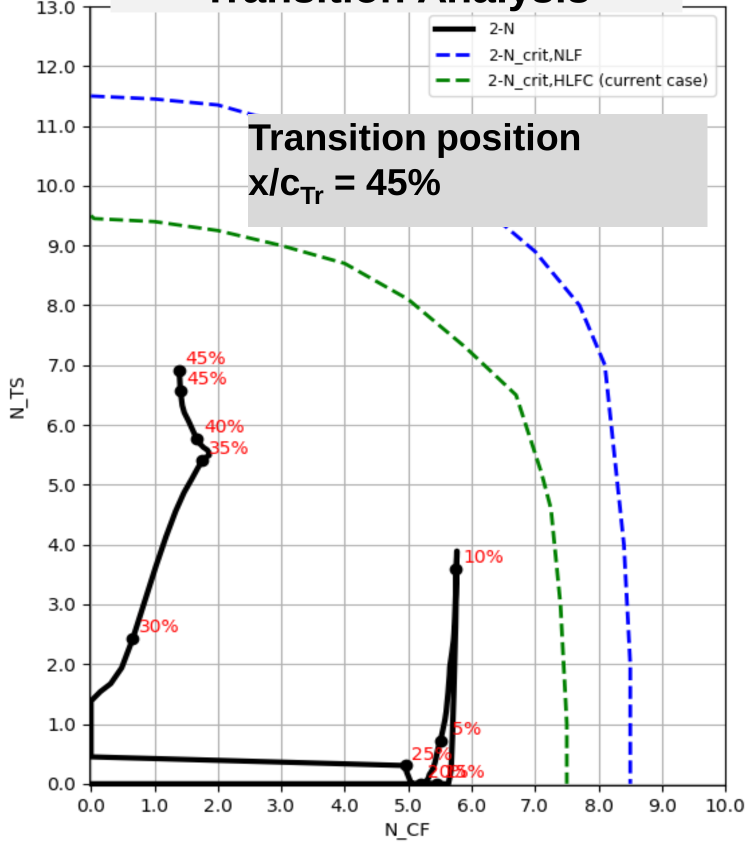
Chambering design



$\Delta p_{Duct} = p_{Duct} - p_{inf} = 13000$ Pa
Mass-flow requirement: 166 g/s
Suction power: 9.16 / 0.62* = 14.8 kW

* Compressor efficiency: 62%

Transition Analysis



Transition position
x/c_{Tr} = 45%

Summary of HLFC chambering and system design

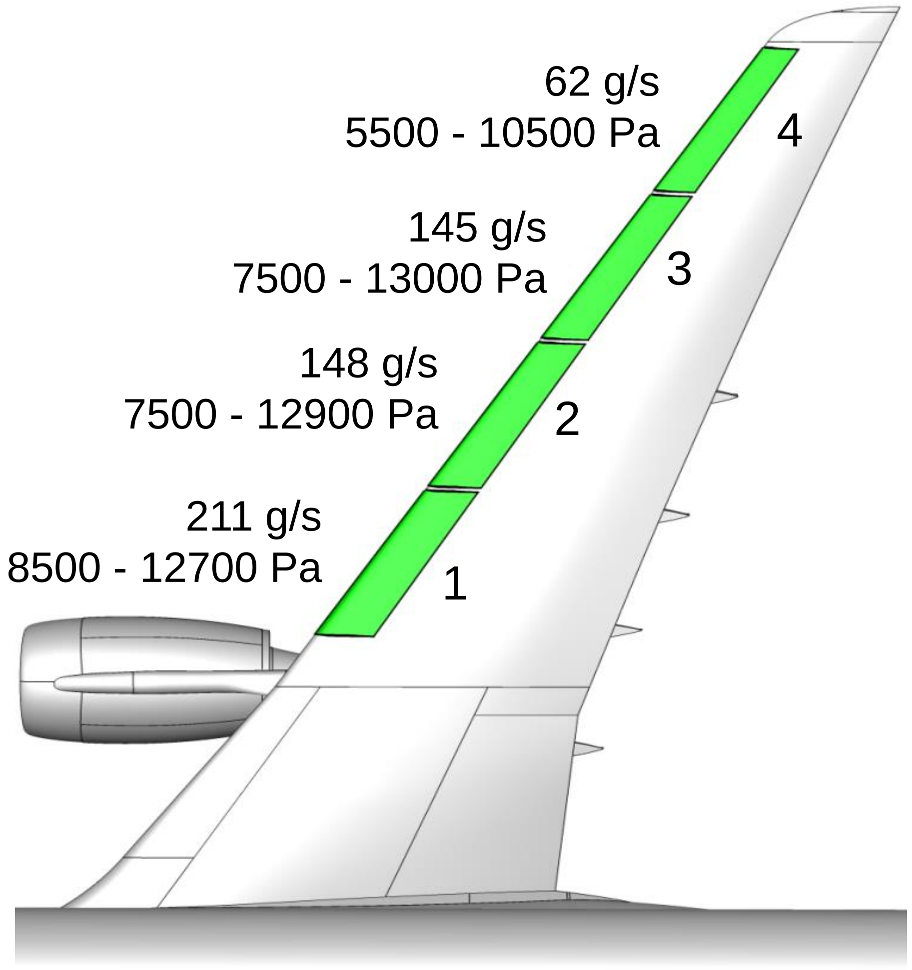
Chambering design sucessfull throughout HLFC envelope:

→Chambering / porosity design successfully delays transition mostly close to shock location

→All design points within compressor limits (mass-flow, compression)

HLFC mass-flow requirement range for 1 complete wing with 4 segments:

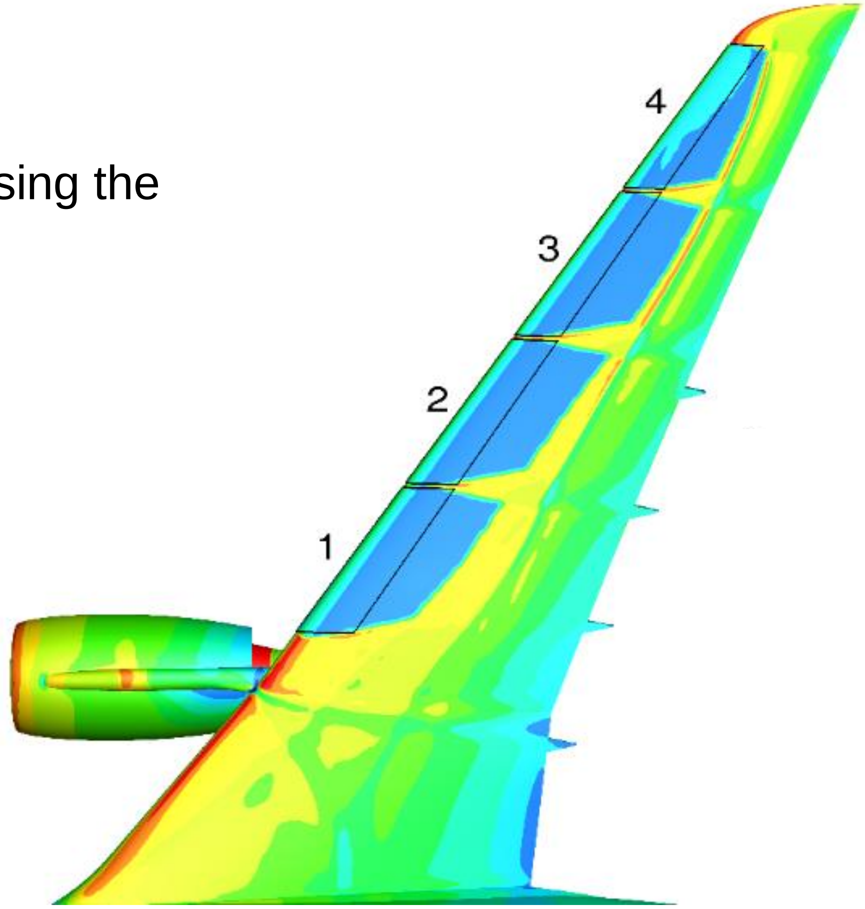
	Massflow [g/s]	$P_{Suction}$ [kW]
min	438	21,44
max	696	34,05
mean	567	27,15



Laminar benefit assessment

Drag assessment based on RANS CFD calculations using the DLR Tau Code including in-the-loop transition analysis

- **Drag reduction: 4% A/C**
  - based on Onera FFD72 results
  - w.r.t. turbulent XRF1
  - only outer wing, upper surface laminarized



Surface friction, wing upper surface
Blue areas laminar
Turbulent wedges at panel boundaries

I. Petropoulos, T. Streit, T. Kilian, M. Kruse: "Numerical aerodynamic performance assessment of HLFC wing configurations using far-field drag analysis." In: 56th 3AF International Conference on Applied Aerodynamics. 28.-30. Mär. 2022, Toulouse, Frankreich.

Summary and Outlook

- Wing HLFC system designed within the Clean Sky project HLFCWin
- Specific challenges identified for HLFC technology integration on a wing:
  - Interference with WIPS system: Feasible solutions for I-WIPS found.
  - High-lift kinematics interferes with suction plenum → spanwise flow distribution through narrow chambers
  - Suction requirements vs. power offtake / compressor limits
- Drag reduction potential of 4% A/C limited due to design restictions within HLFCWin:
  - Retrofit: No planform adaption, constrains for airfoil redesign
  - Inner wing laminarization not within HLFC-Win due to high Reynolds numbers and complex flow topology (costly 3D-redesign!)
- **Maximum laminar benefit to be assessed in current DLR project LamTA (2023-26)**

Acknowledgements

This work has received funding from the **Clean Sky 2** Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No CS2-LPA-GAM-2020-2021.

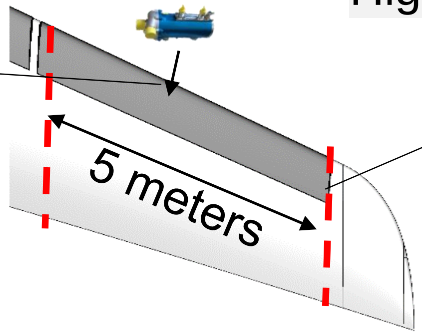
Backup

Impact on HLFC wing design with highly streched suction chambers

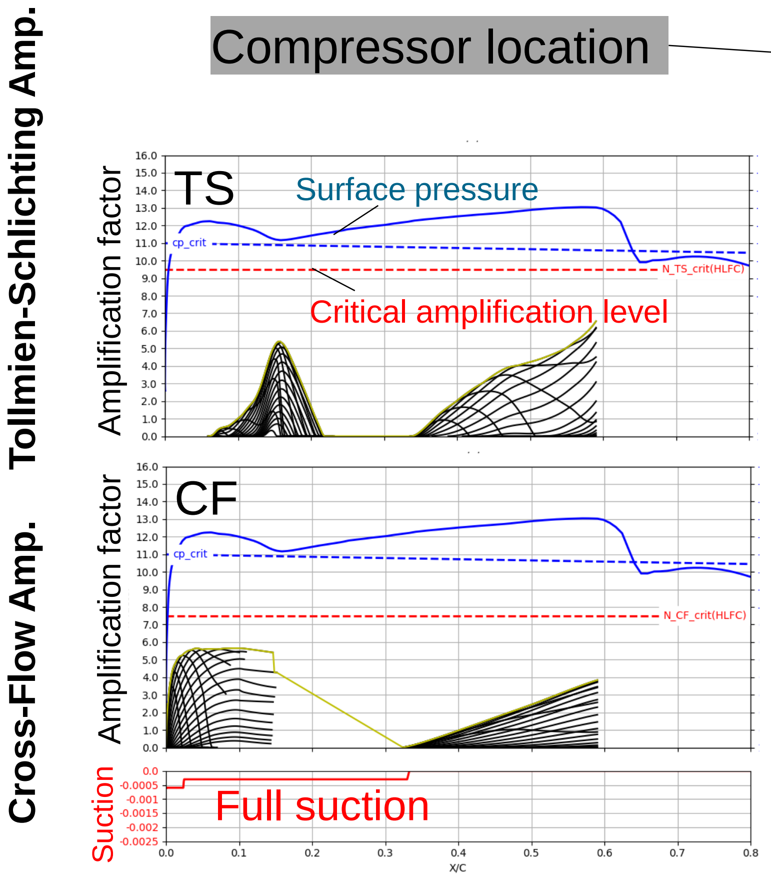
Generic example

<u>Assumptions:</u>
Spanwise constant pressure distribution
Multiple small suction chambers
High pressure loss along chamber

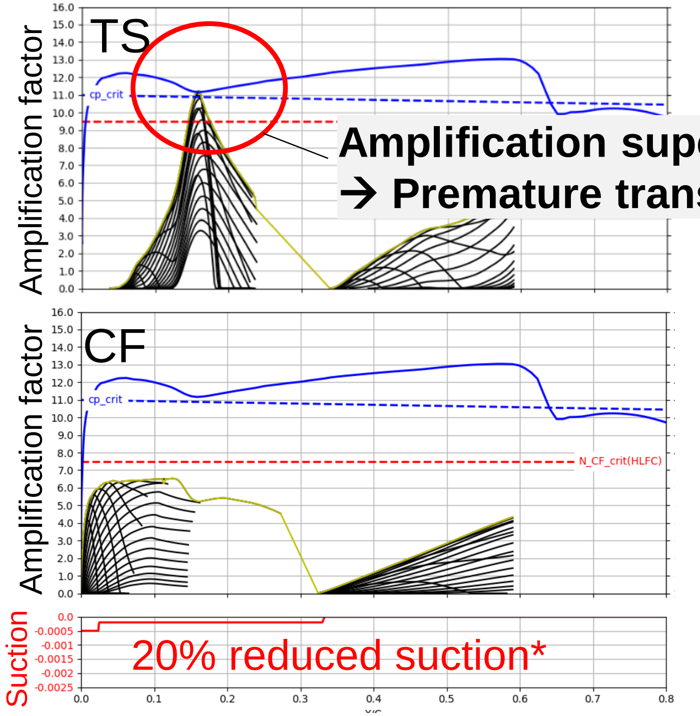
Compressor location



2.5 meters from compressor



20% spanwise pressure loss

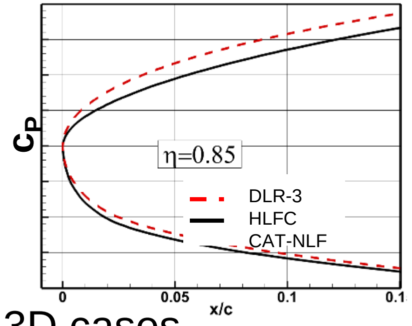


Amplification super-critical
→ Premature transition

Spanwise pressure loss needs to be considered during HLFC design.

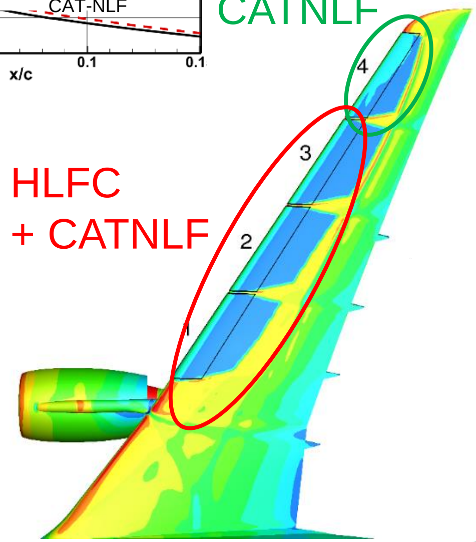
*Ratio of suction pressure to suction velocity linearized

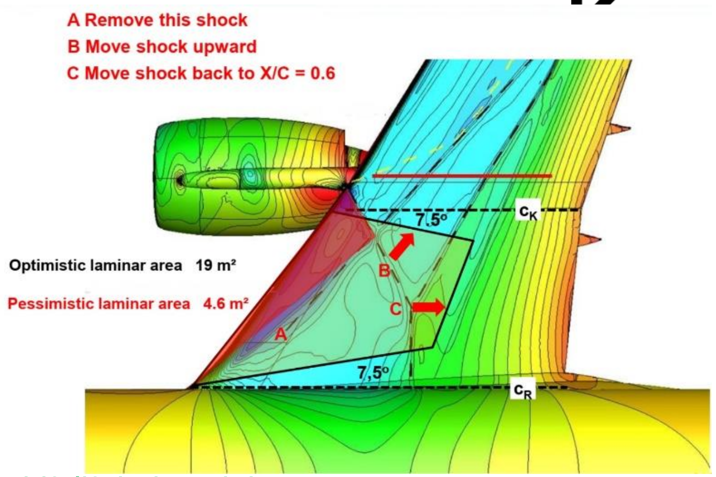
Further options to increase laminar benefit on XRF1 wing



1. Laminarization of inner wing:
   - Elimination of lamda shock system
   - LFC design to lower wave drag impact
   - Data based on 2,75D design and simplified 3D cases

est. 2% BFR

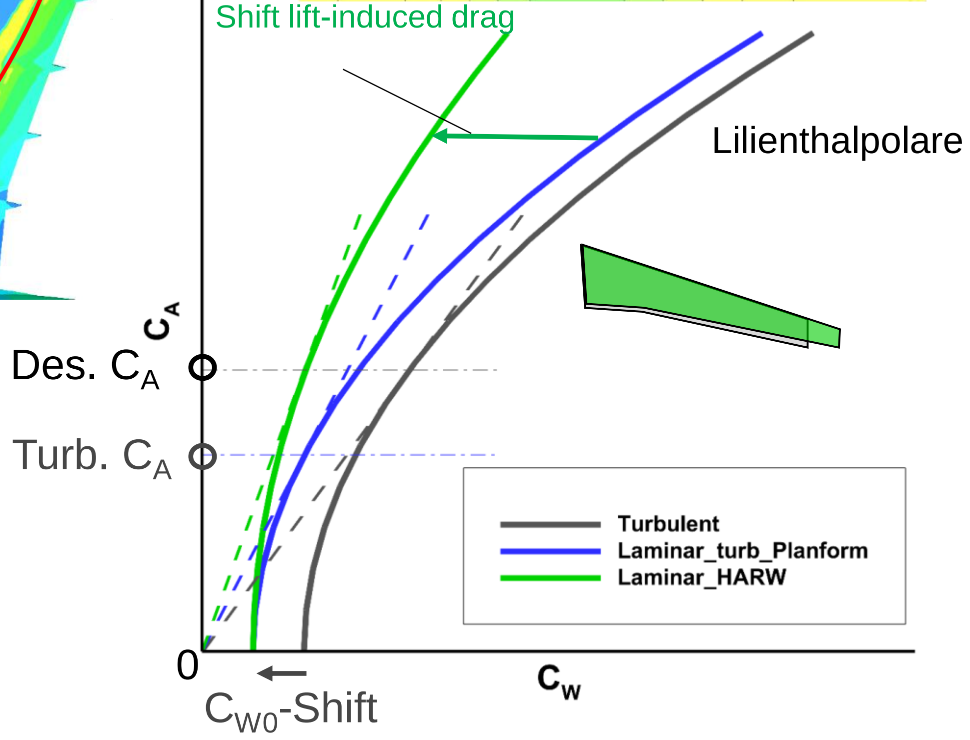




2. CAT-NLF airfoil design for complete outer wing:
   - NLF on segment 4 possible
   - Reduction of suction requirement für HLFC on segment 1-3

est. 0,2% BFR

3. Wing planform adaptation
   - Increase of aspect ratio to maintain design C_L
   - No detailed benefit estimation performed



Projekt LamTA – Laminar Tailored Aircraft

Motivation

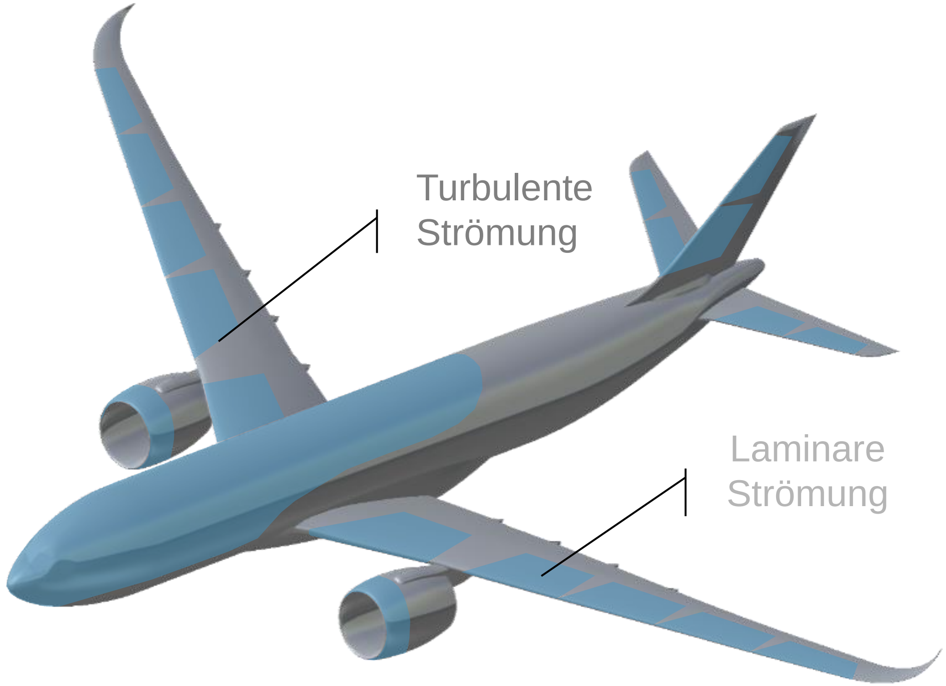
Weiterentwicklung der Laminartechnologie hinsichtlich einer Integration in das Gesamtflugzeugsystem und deren Bewertung im Hinblick auf das Energieeinsparpotential liefern wichtige Entscheidungsgrundlagen für Industrie und Politik und tragen zur Erreichung der Ziele der DLR Luftfahrtstrategie bei.

Themen

- Laminarer Langstreckenflugzeug-Entwurf und Bewertung auf Gesamtflugzeugebene
- Messtechnik- und CFD Methodenentwicklung für die Laminarhaltung
- Fertigungstechniken für die Integration von Laminartechnologie

Ziele

- Entwurf und Bewertung einer auf Laminarhaltung zugeschnittenen Langstrecken-Konfiguration → BFR von 20% angestrebt
- Entwicklung experimenteller und numerischer Methoden für zukünftige Laminarentwürfe
- Verfeinerung der Grenzwerte für Fertigungs- und Oberflächentoleranzen laminarer Bauteile



*Bereiche laminarer Strömung mit aktuellem Technologiepotential abgeschätzt

Laufzeit:	2023 – 2026
Vollkosten:	16.6 M€
Institute:	AS, AE, SY, FT, SL, SR
Externe Partner:	-