The influence of high spanwise chamber extent on HLFC performance

DLRK 2021 Bremen / Virtual

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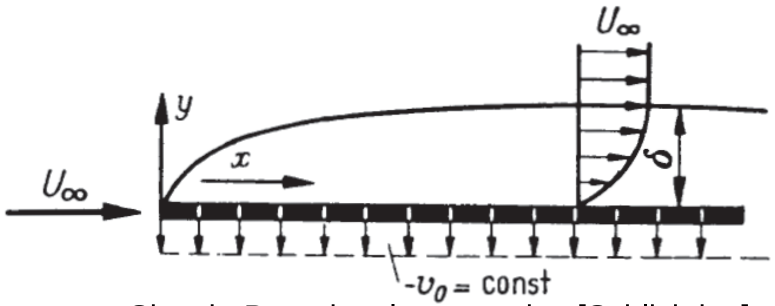
Overview

- Introduction
  - HLFC and recent developments at DLR
  - Overview of the HLFC design of a long-range wing
- Experimental and numerical investigations on spanwise pressure loss along chambers
- Impact on HLFC design and overall laminar benefit
- Summary and Outlook

Introduction – Drag reduction through Hybrid Laminar Flow Control HLFC

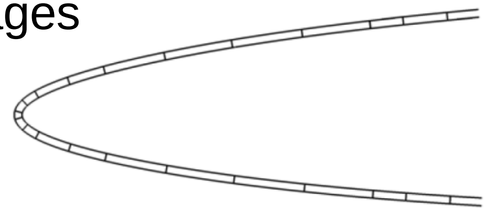
- Boundary layer manipulation through suction known for over 100 years, first experiments by Prandtl in 1904.
- Suction through a porous surface stabilizes the boundary layer in two ways:
  1. Change BL profile curvature → Re_{crit} increased
  2. BL height reduced → less tendency to transition

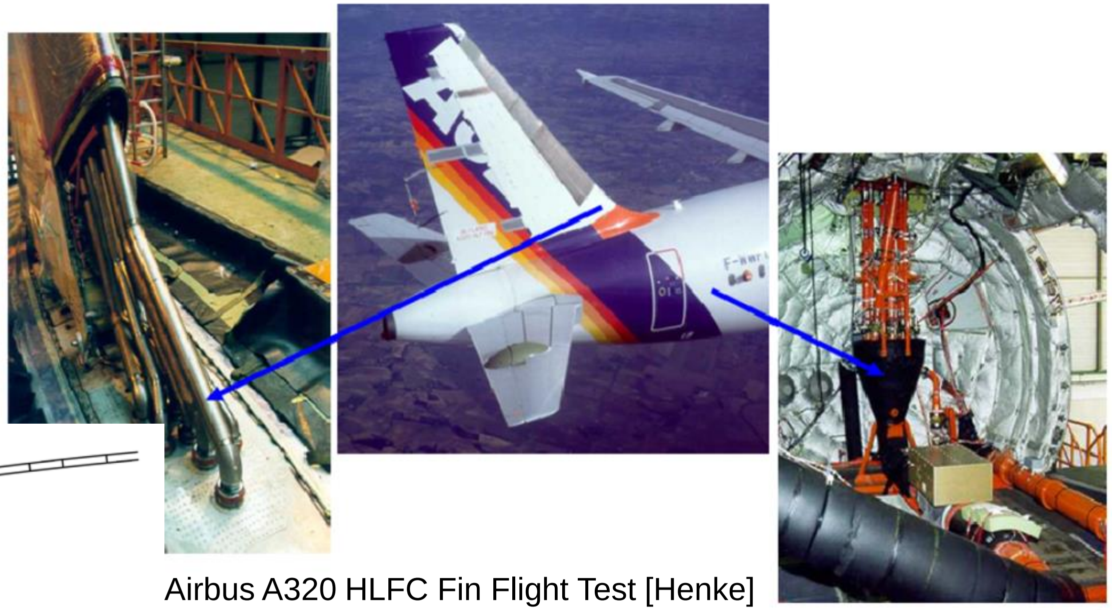


Sketch: Boundary layer suction [Schlichting]

Potential for aircraft drag reduction demonstrated in large-scale in the 1990s on a A320 VTP leading edge.

- 18 chambers individually pressurized through pumps to provide the suction velocity needed
- Transition shift verified through infrared images
- **Yet, high system complexity and costs**





Airbus A320 HLFC Fin Flight Test [Henke]

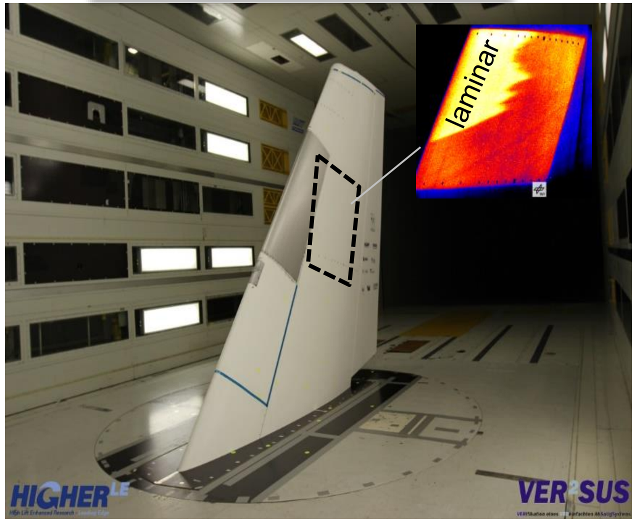
Introduction – Recent HLFC technology development at DLR

- Continuous HLFC development initiated and lead by DLR for more than 20 years
- Maturation of design, simulation and manufacturing techniques towards industrial application
- European firsts: Technology demonstration of simplified suction system and variable porosity HLFC concept

Currently within Clean Sky 2:

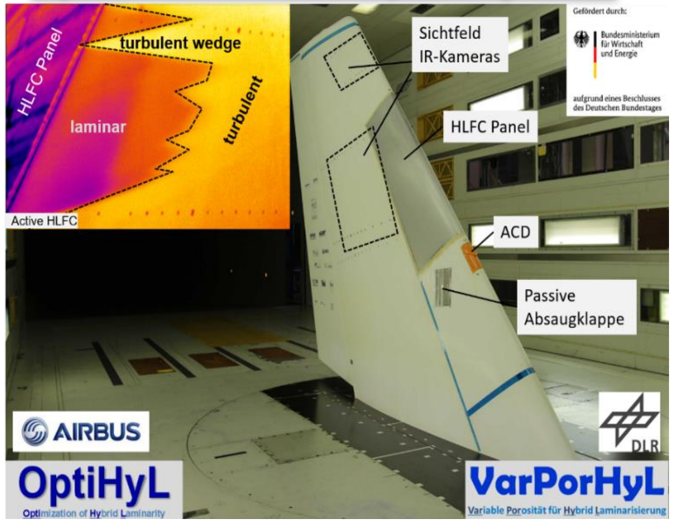
- Integration on horizontal tail-plane with European partners in an industrialized environment
- Technology integration on a long-range wing to maximize laminar benefit

WTT demonstration 2014

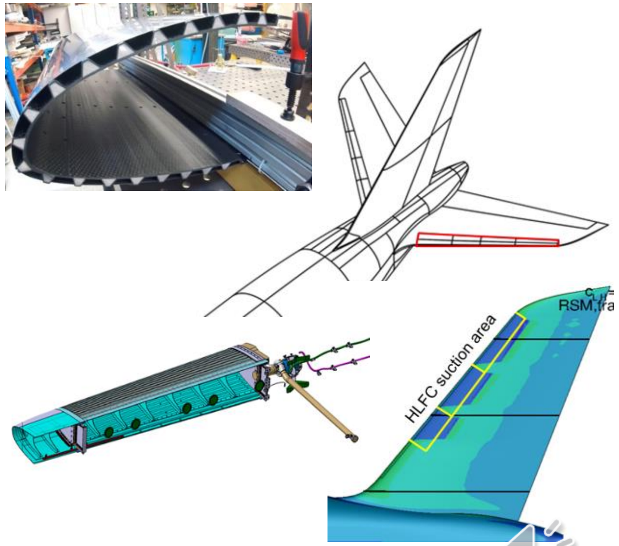


FT demonstration 2018

Optimization variable porosity 2018



HTP technology integration (ongoing)

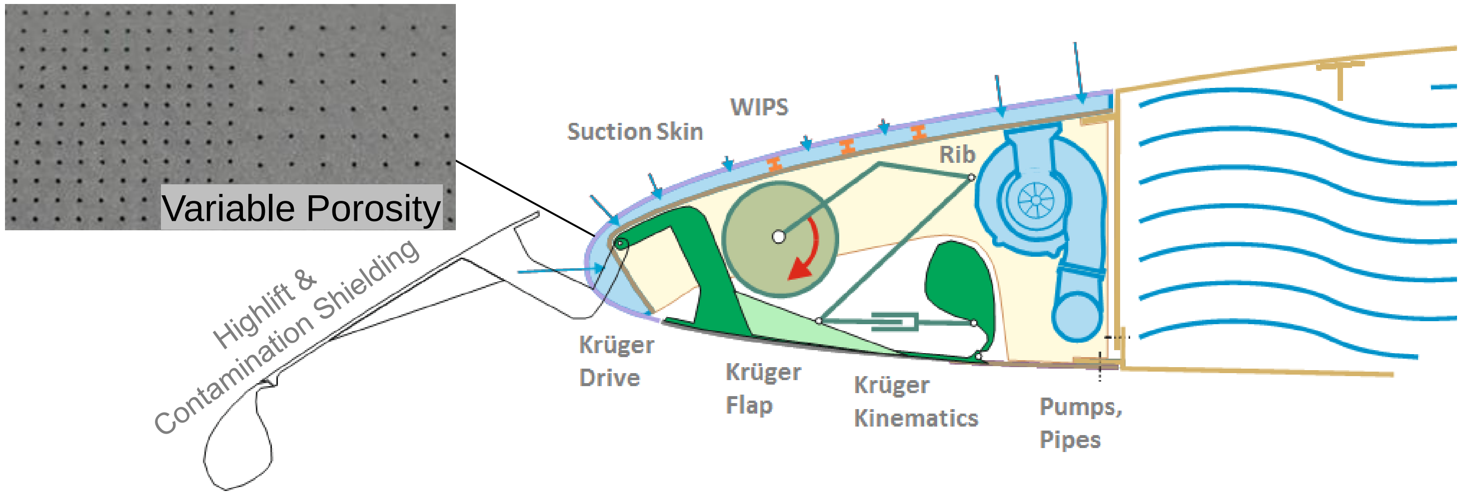


HLFC technology integration on a long-range wing
Clean Sky 2 - HLFCWin

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

- Design of a HLFC leading-edge with variable porosity
- Krüger design for high-lift and shielding
- Laminar benefit assessed using RANS-CFD

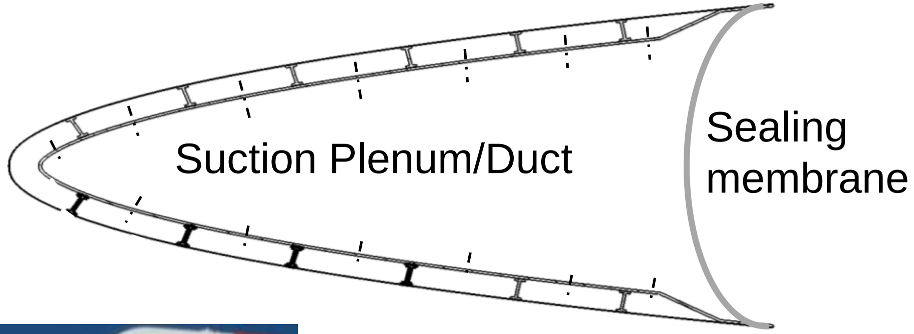
Challenges: Restricted installation space, High-Lift, anti-icing, large segments

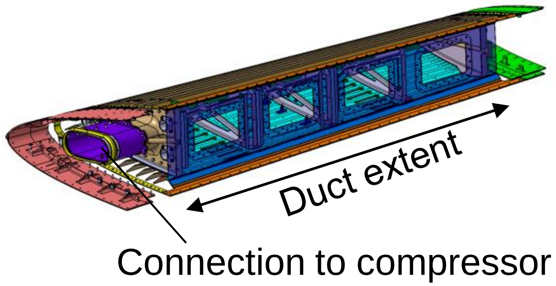


Suction flow distribution along span: VTP/HTP vs. Wing

VTP / HTP

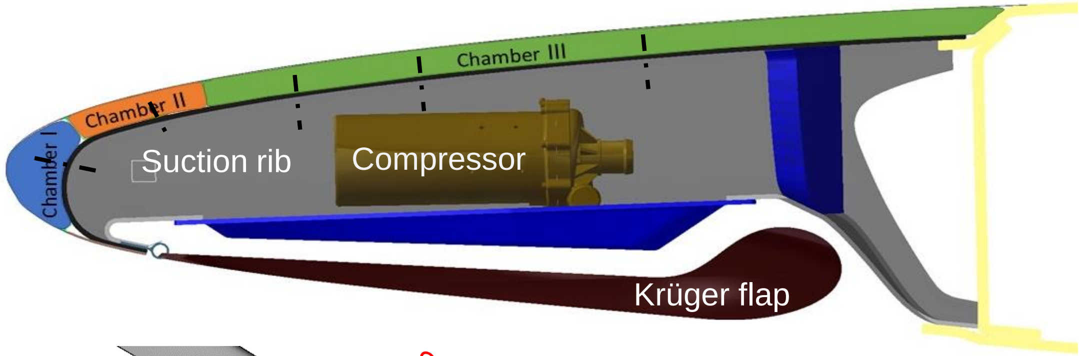
Suction plenum duct extends over complete span

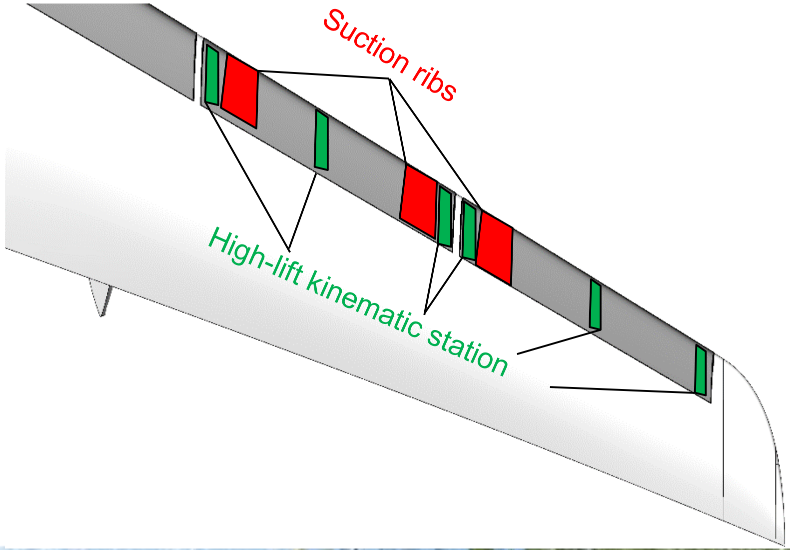




Wing

Compressor within suction rib with limited spanwise extent





→ **Suction mass flow needs to be transported via narrow chambers**

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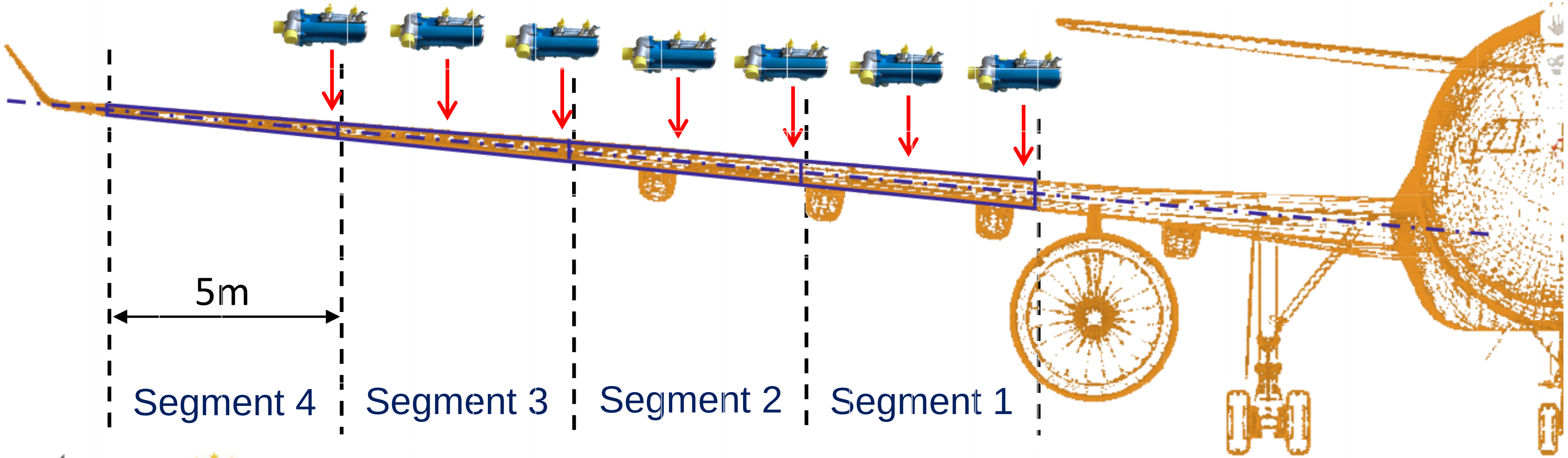
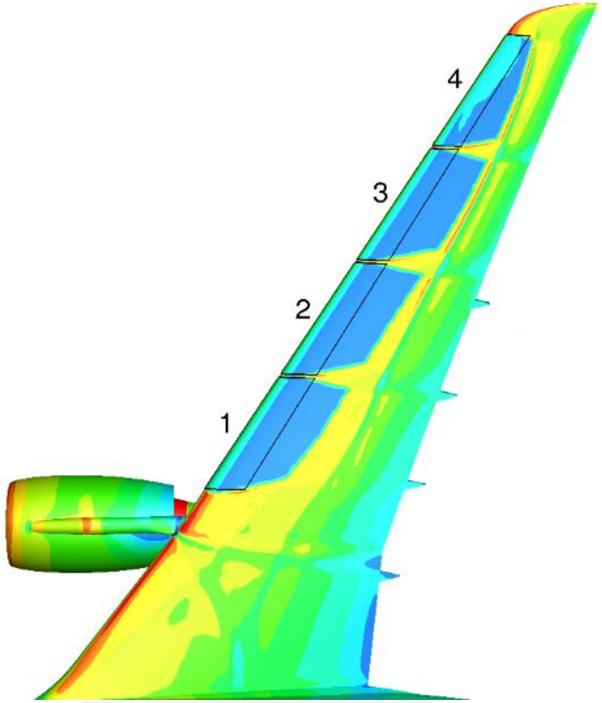
Overview of HLFC segments and compressor location

- Number of HLFC segments minimized to avoid turbulent wedges → 5m
- 2 compressors for segment 1-3: 2.5m span per compressor
- 1 compressor for segment 4: 5m span per compressor → potentially critical

Scientific approach:

- Test spanwise pressure loss with small scale demo (SSD) in conjunction with high-fidelity CFD simulations





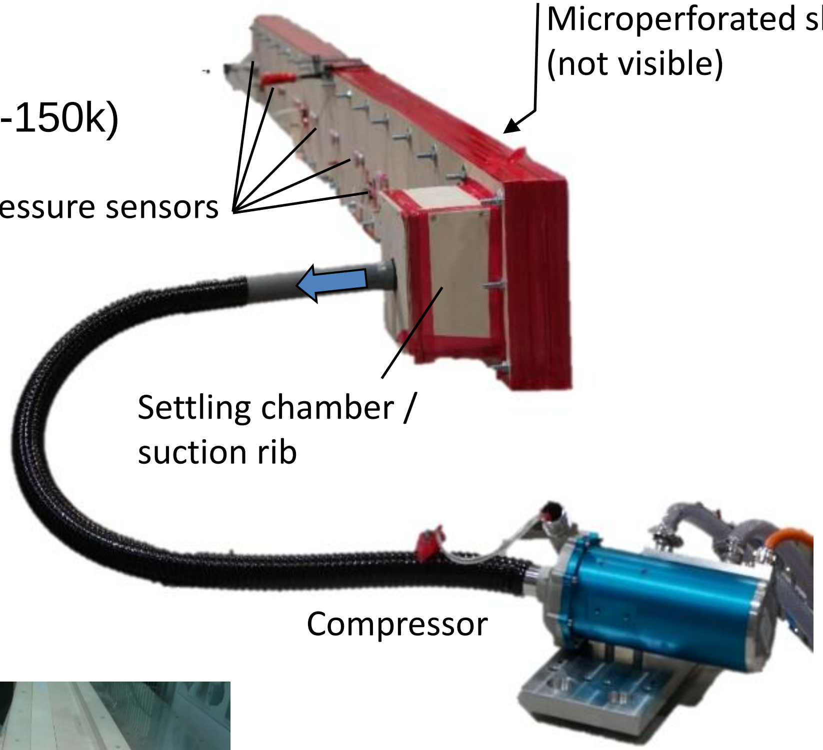
CFD: Surface friction
Laminar areas blue

Setup for spanwise pressure loss assessment

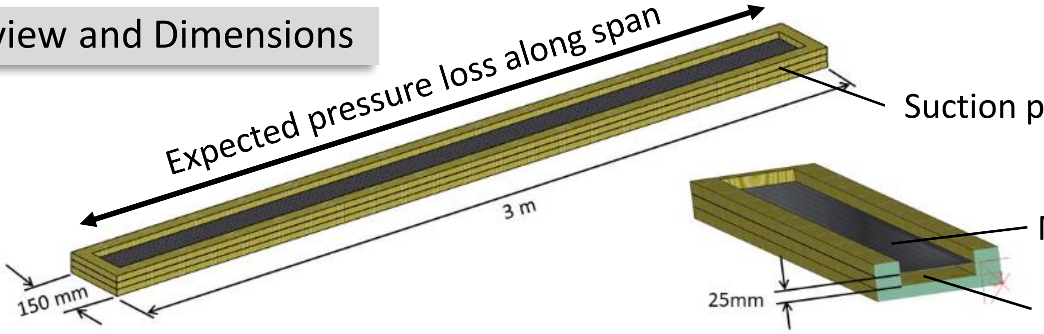
Spanwise suction SSD:

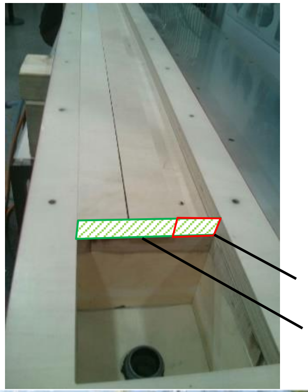
- Micro-perforated titanium skin mounted in sealed wooden box
- Compressor connected via a box on one end via settling chamber (Fischer EMTC-150k)
- Chamber dimensions:
  - 2850 x 25 mm
  - 2 suction area widths for extended cross-flow range:
    - Width 150 / 50mm → medium to very high suction & cross-flow velocity
- Five pressure sensors distributed along span

Experimental setup



Overview and Dimensions



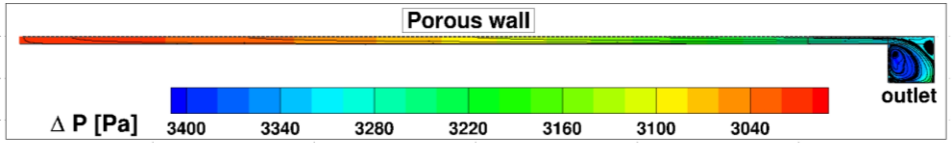


Chamber cross section variations

Reduced: 50 x 25mm

Maximum: 150 x 25mm

Simplified 3D CFD representation including porous wall and settling chamber



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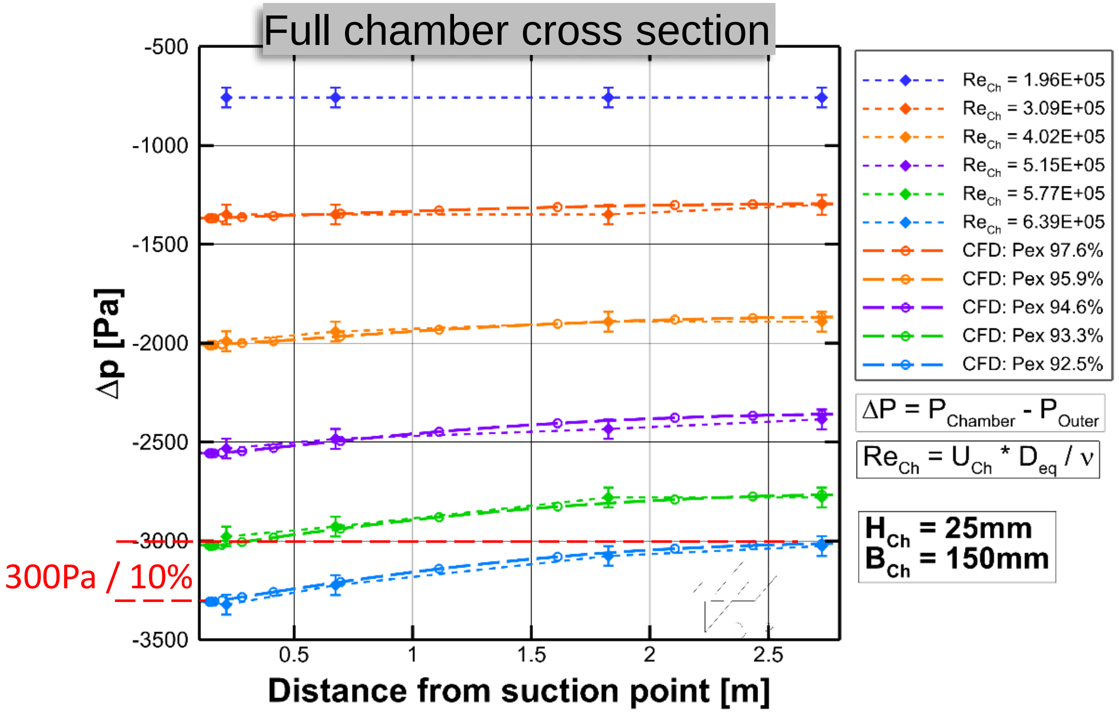
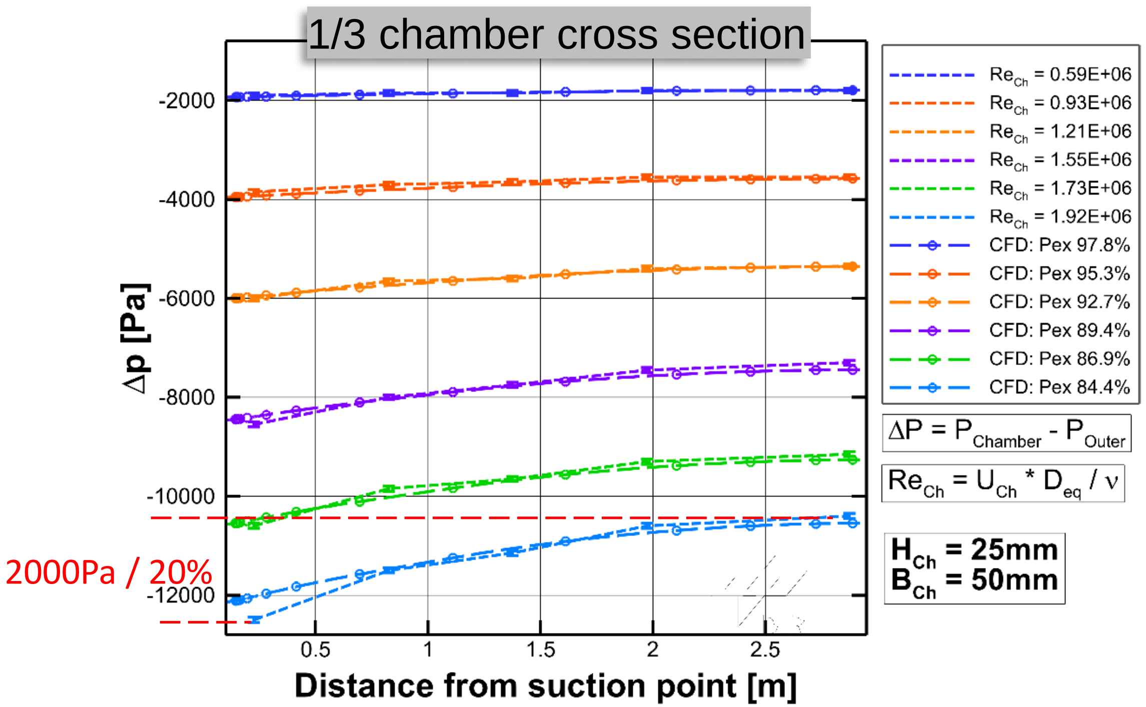
Results for pressure loss along span

- Mass flow range (measured at compressor): 19 g/s to 62 g/s
- Full and 1/3 chamber cross section tested.
- Pressure loss along chamber visible and in very good agreement with CFD results.

- Max losses of 2000 Pa / 20% at maximum suction rate and 1/3 chamber cross section

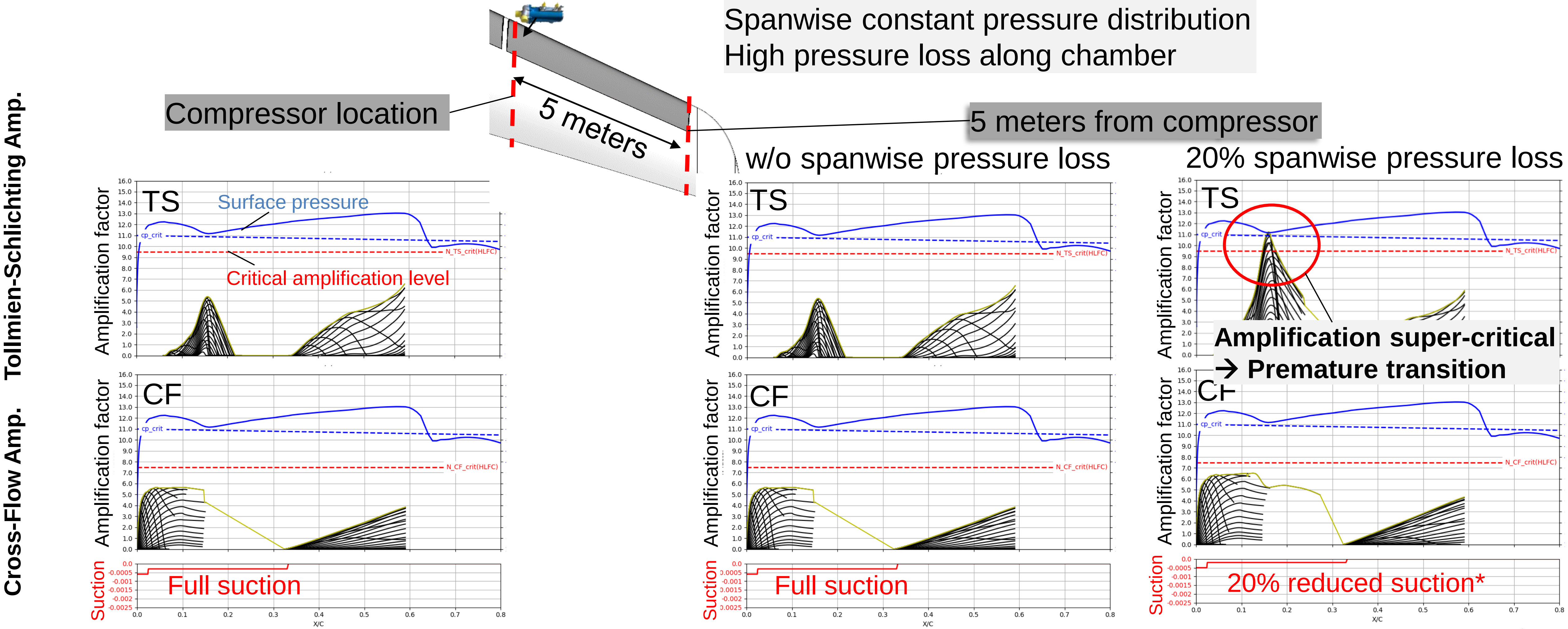




HLFC-WIN

Impact on HLFC wing design with highly streched suction chambers
Generic example

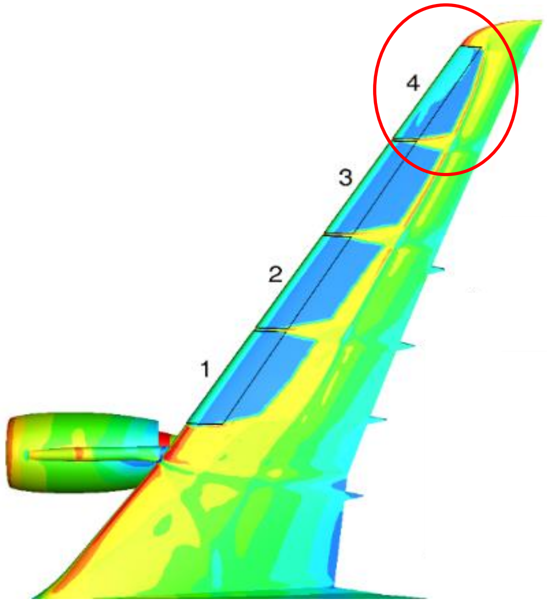
Assumptions:
Spanwise constant pressure distribution
High pressure loss along chamber

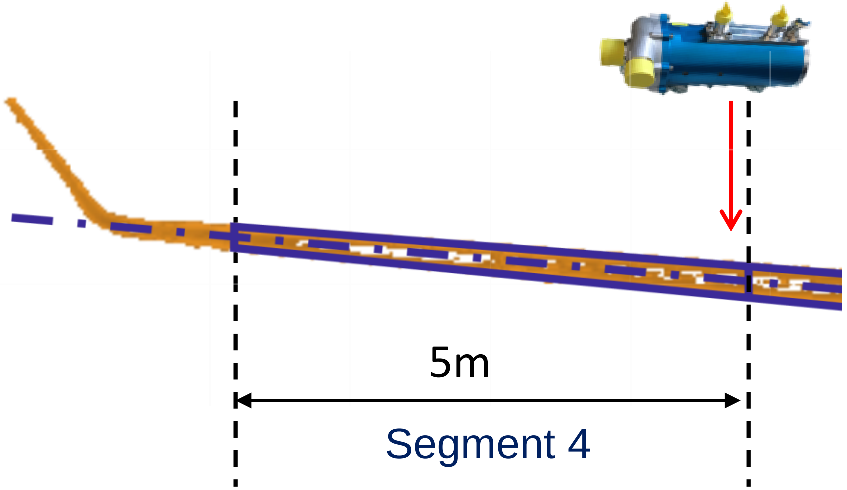


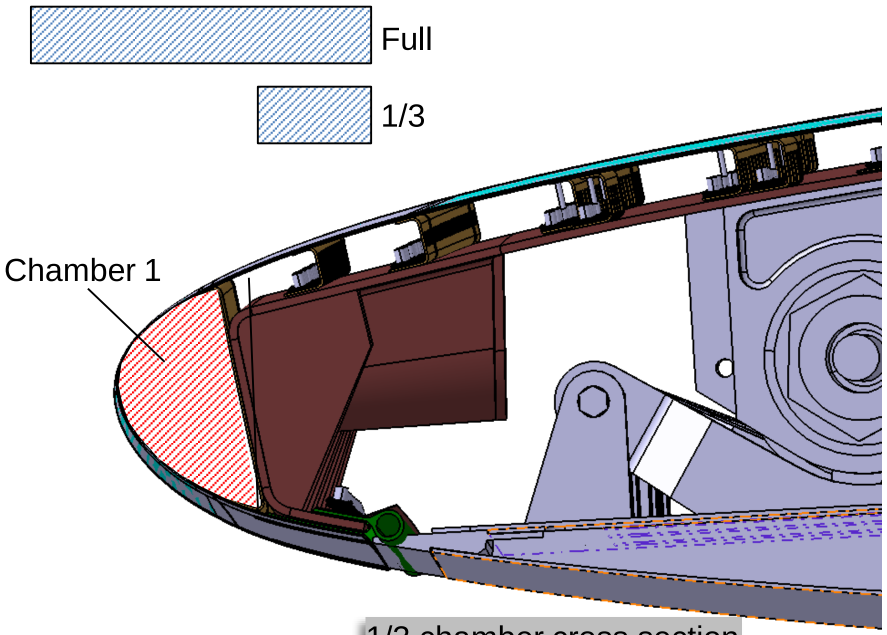
*Ratio of suction pressure to suction velocity linearized

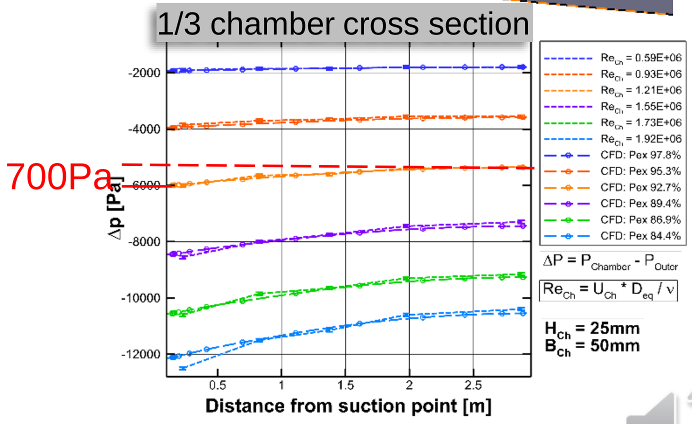
Example: Impact on HLFC design of XRF1 wing, HLFC Segment 4

Estimation of spanwise pressure loss









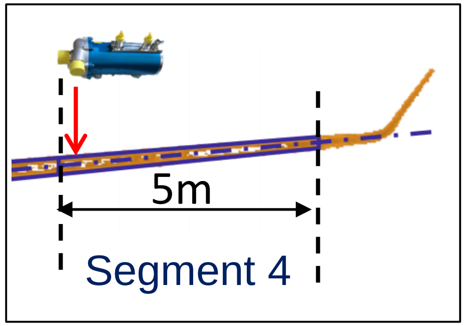
- Maximum spanwise distance to compressor: ~5m
- Critical LE chamber Reynolds number within tested range
- Corresponding SSD test setup: 1/3 chamber cross-section, $\dot{m} = 39\ g/s$

→**Relative spanwise pressure loss extrapolated to 13%**

- Conservative assumption: Same pressure loss for all chambers

Example: Impact on HLFC design of XRF1 wing

Outboard HLFC segment 4

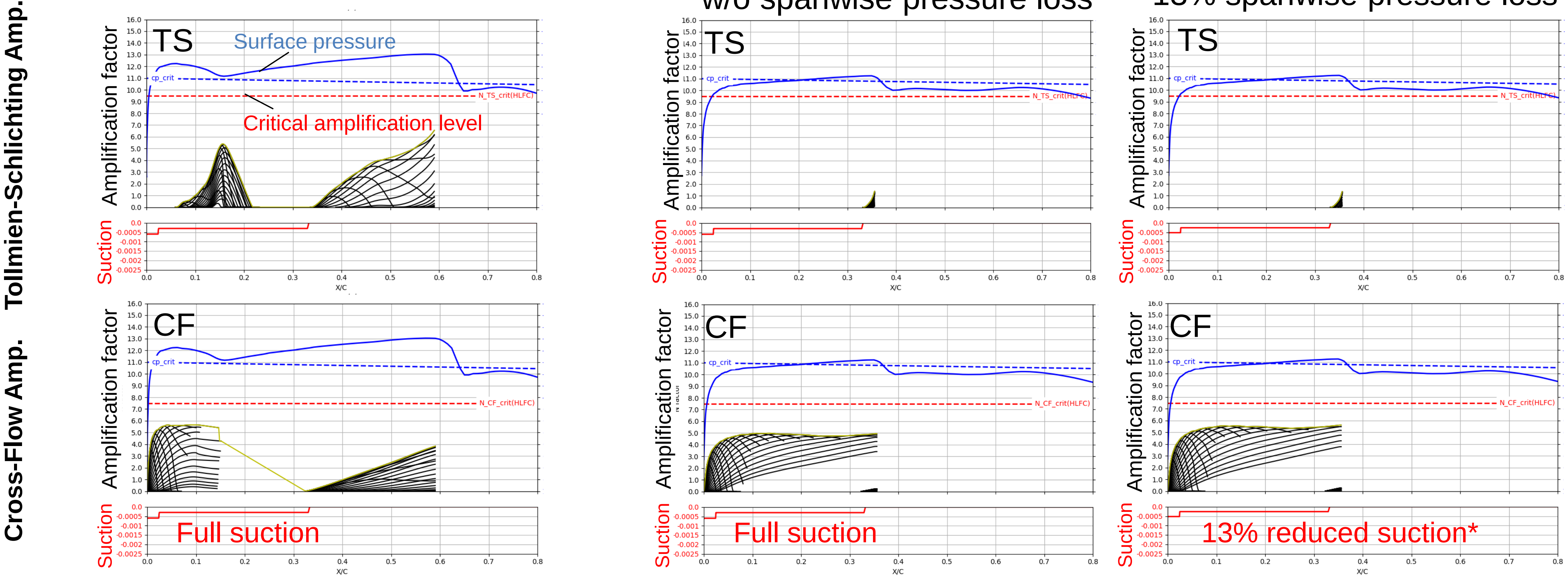


Inboard (Compressor)

Outboard

w/o spanwise pressure loss

13% spanwise pressure loss



→ No influence on transition location due to NLF-like pressure distribution outboard

*Ratio of suction pressure to suction velocity linearized

Summary and Outlook

- Spanwise pressure loss along long chambers needs to be accounted for HLFC wing design using suction ribs instead of plenum ducts.
- Pressure loss was quantified using a dedicated demonstrator setup.
- High-fi CFD results are in very good agreement with the experiments.

- Detrimental impact on HLFC wing design possible. Needs to be assessed case by case w.r.t. suction rates, chamber geometry and surface pressure distribution.

Outlook:

- Quantify additional potential pressure losses induced by internal structures (stiffeners, WIPS)
- Investigate mitigation options for critical cases:
  - Increased baseline suction rate
  - Spanwise variable porosity of outer skin
  - Adaptation of chamber geometry
  - Additional bypass duct

Acknowledgements

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