A320 ATRA Flight Tests with a Hybrid Laminar Flow Control System on the Vertical Tail Plane

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- **Spanwise variation of the transition line and N-factor correlation**
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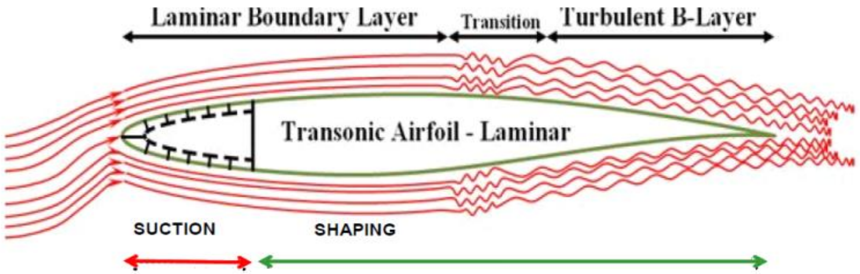
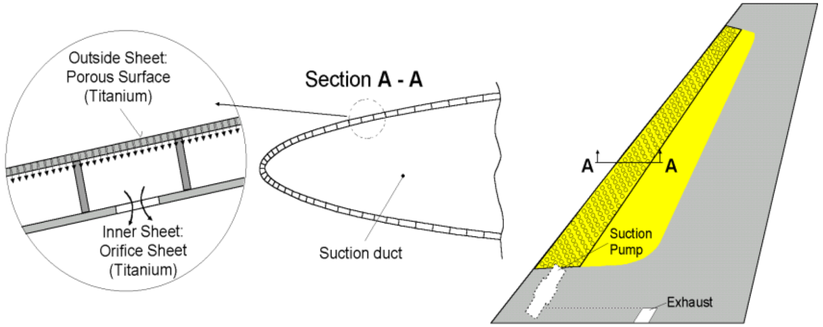
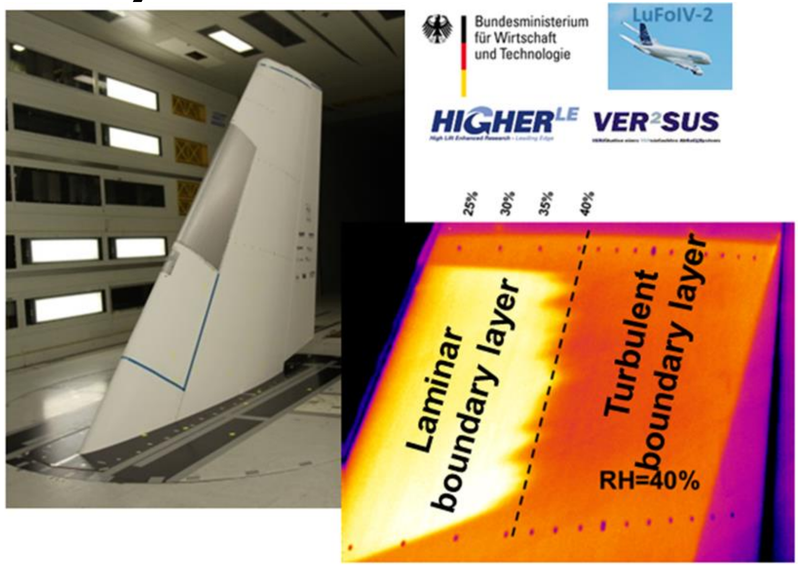
- **Correlated N-factors**

Introduction: Hybrid Laminar Flow Control (HLFC)





Simplified HLFC system
proposed by K. H. Horstmann in 2001



Proof of simplified HLFC in 2014
with A320 VTP in DNW-LLF

Flight test of a simplified HLFC system installed in the VTP of the DLR A320 ATRA aircraft (AFLoNext WP 1.1)

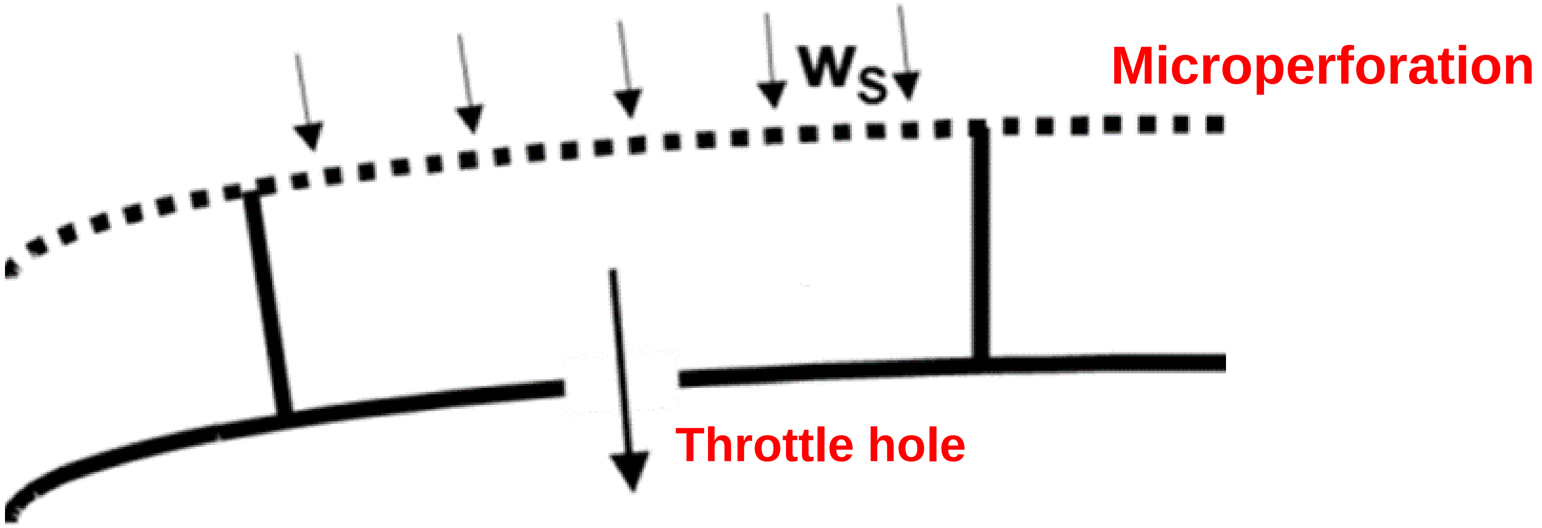
K. H. Horstmann, W. Schröder: "A Simplified Suction System for a HLFC L/E Box of an A320 Fin," ALTTA TR 23, 2001.
G. Schrauf: "The Need of Large-Scale HLFC Testing in Europe," AFLoNext, 2013, http://www.aflonext.eu/files/pdf/schrauf_2013_HLFC_research-needs_v2.pdf

Design requirements

The suction system should provide laminar flow at the following flight conditions:

• **Flight levels:**	**FL 290 …… 310 …... 390**
• **Mach numbers:**	**M = 0.76 ... 0.78 ..… 0.80**
• **Sideslip angles (active):**	**β = -2° …… 0° …… +2°**
• **Ruder deflections (active):**	**δ = -2° …… 0° …… +2°**
• **Sideslip angles (passive):**	**β = -1° …… 0° …… +1°**
• **Ruder deflections (passive):**	**δ = -1° …… 0° …… +1°**

Microperforated suction panel and throttle holes



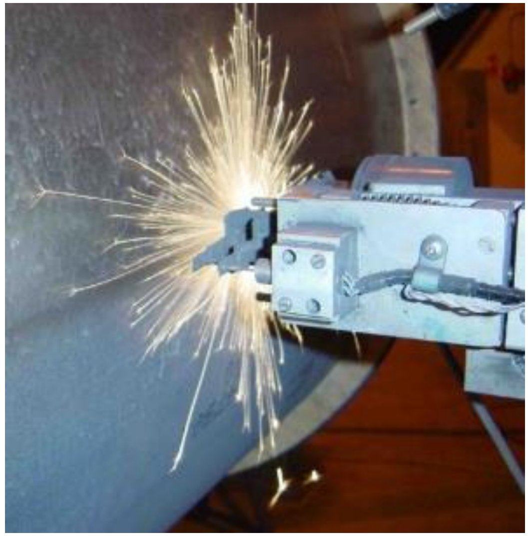
Microperforated suction panel
Decoupling of aerodynamic and system design from manufacturing

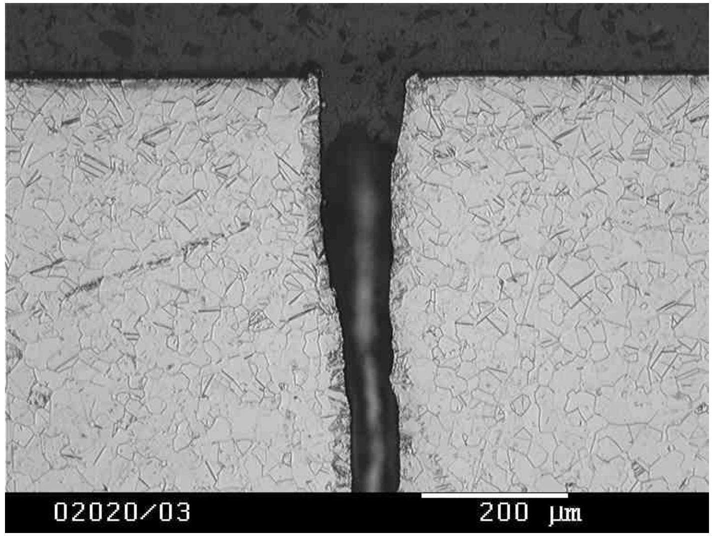
Do not use geometric hole parameters such as diameter, conicity, and pitch

Prescribe pressure-loss characteristic

$$\Delta p = A \frac{\mu_s}{\mu_0} w_s + B \frac{\rho_s}{\rho_0} w_s^2$$

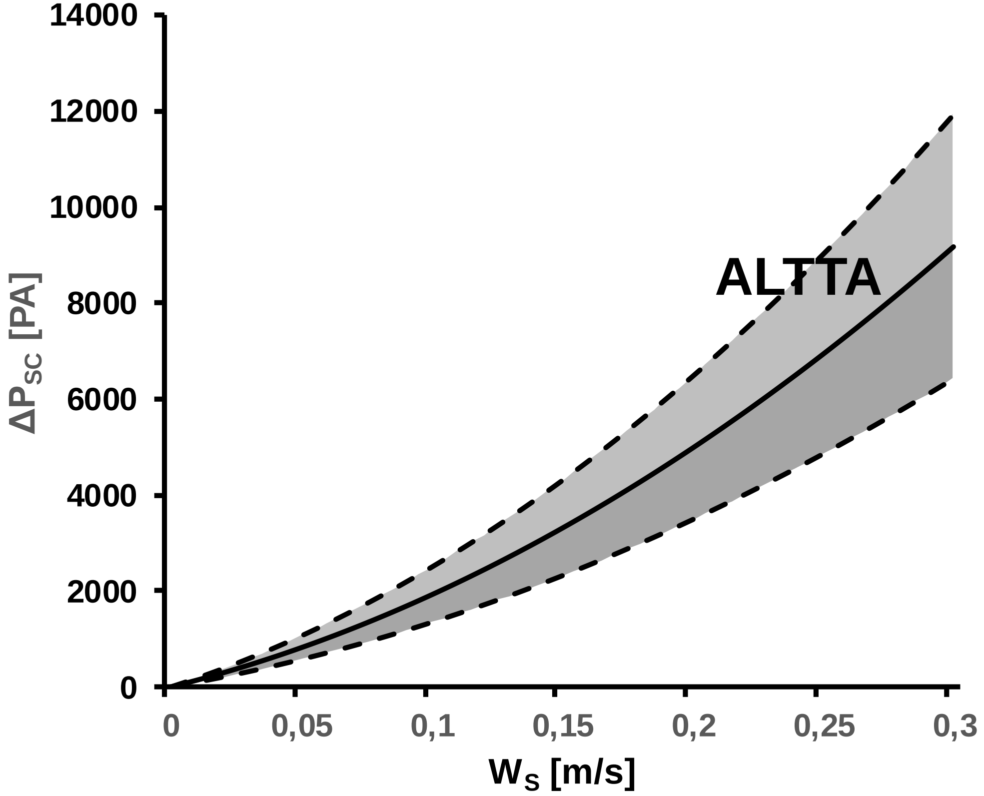
to separate aero & system design from the laser-drilling manufacturing process





Manufacturing deviations are taken into consideration by considering a range of pressure loss characteristics

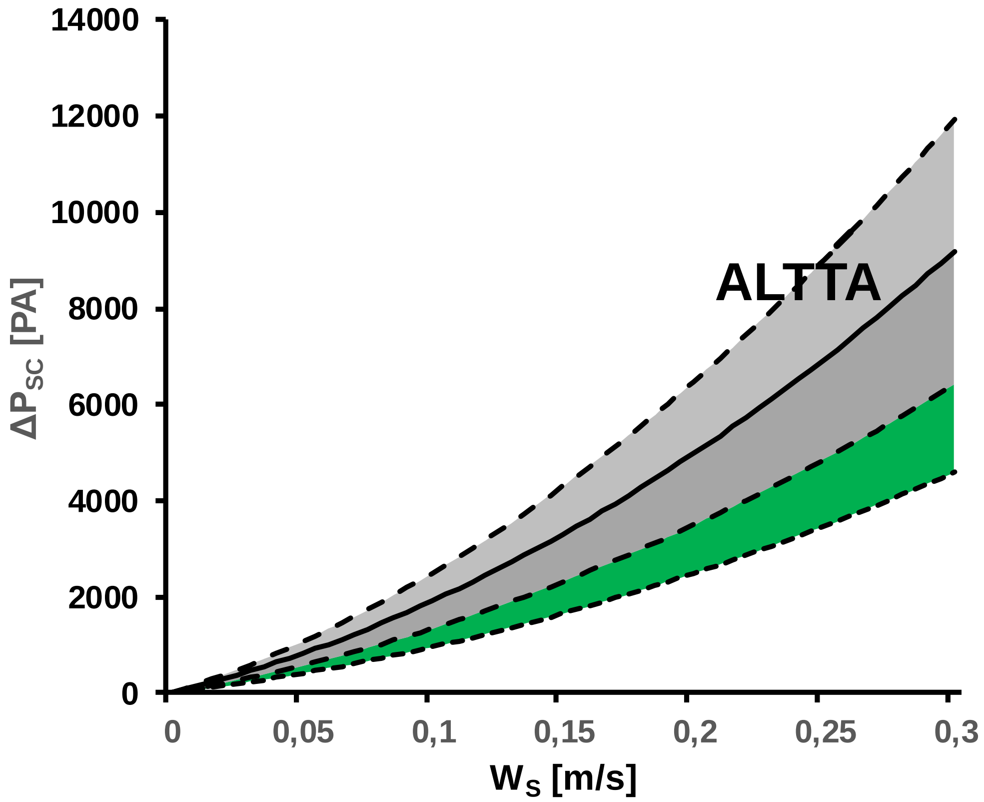
Microperforated suction panel



Initial design range for pressure-loss characteristics

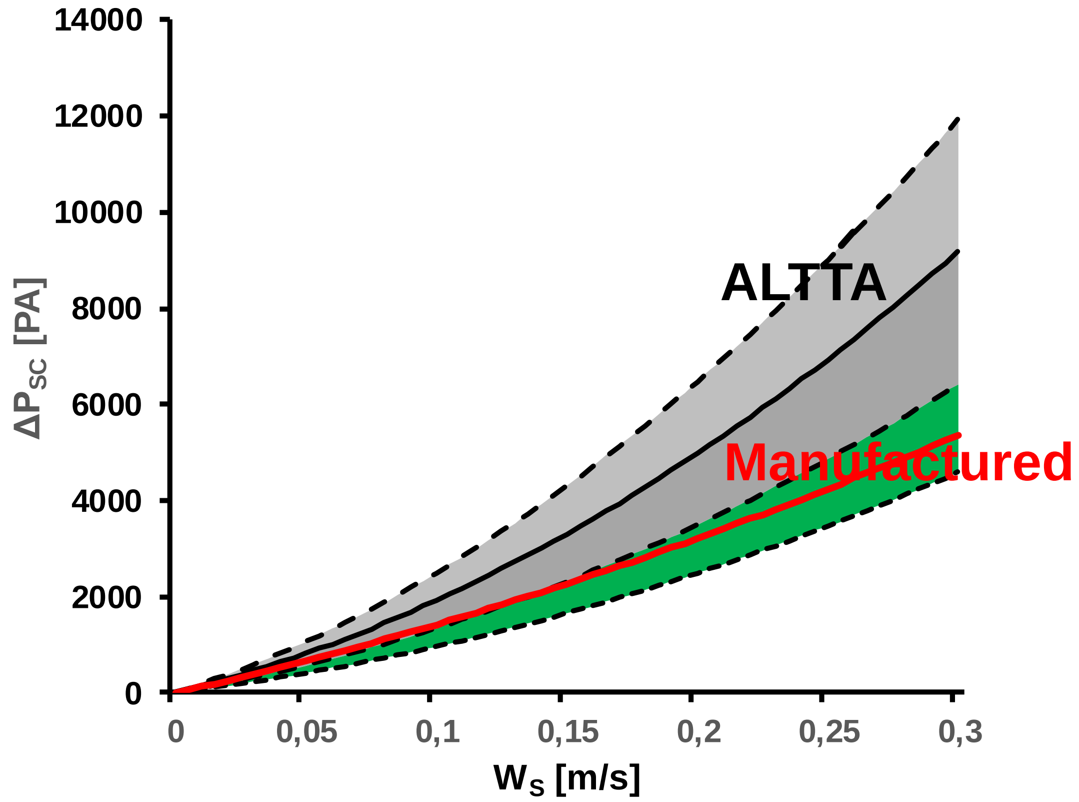
No stable and repeatable manufacturing process achieved

Microperforated suction panel



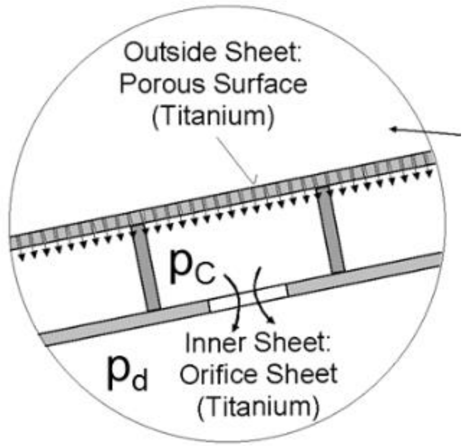
Extended design range for pressure-loss characteristics

Microperforated suction panel



Pressure-loss characteristic of manufactured panel

Throttle holes



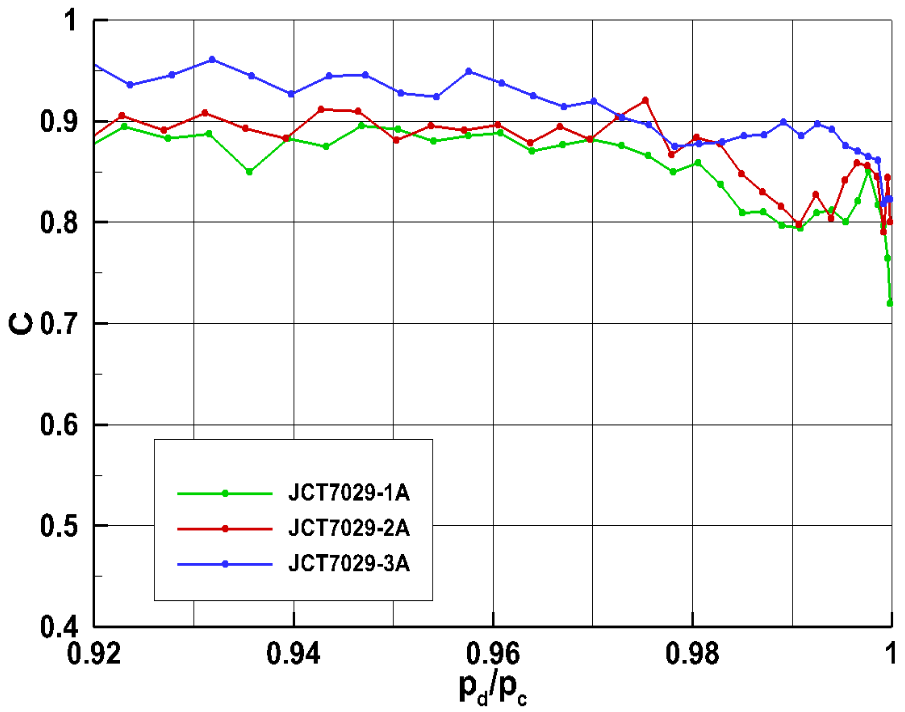
Determine size and number of throttle holes with extension of Bernoulli equation

$$\dot{m} = C \; A \sqrt{p_c \, \rho_c \, \frac{2\gamma}{\gamma - 1} \left\{ \left(\frac{p_d}{p_c}\right)^{2/\gamma} - \left(\frac{p_d}{p_c}\right)^{(\gamma+1)/\gamma} \right\}}$$

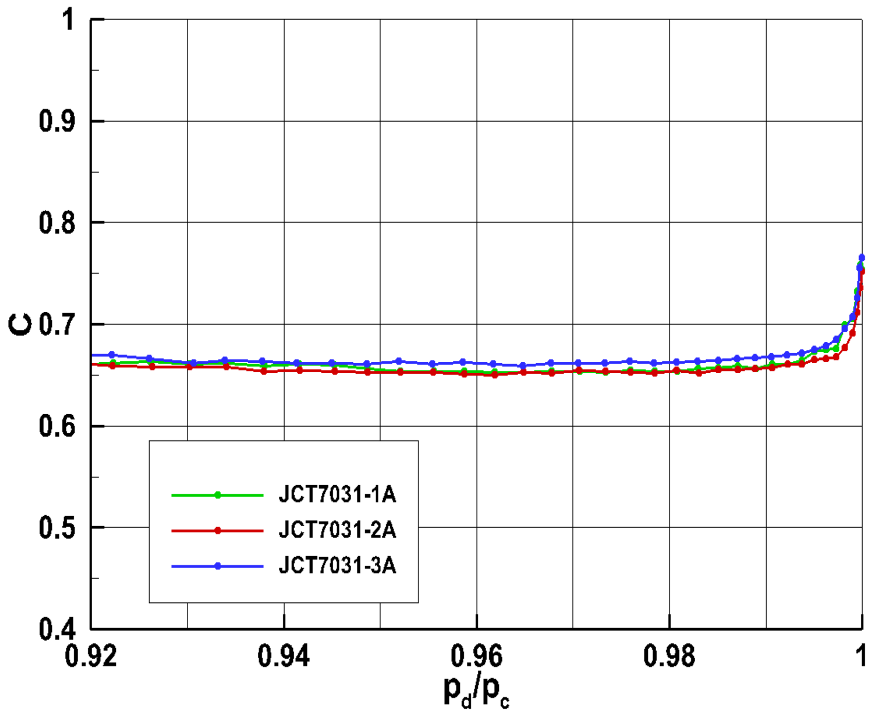
Area of cross section (A)

Discharge coefficient (massflow ratio) (C)

Throttle holes - measured discharge coefficients



Hole diameter 1 mm



Hole diameter 3 mm

Larger holes produce less scatter, because irregularities at edges less important

B. Flache, A. Seitz: "Discharge coefficients of orifice plates." Private communication, 2016.

Principles of aerodynamic chamber design

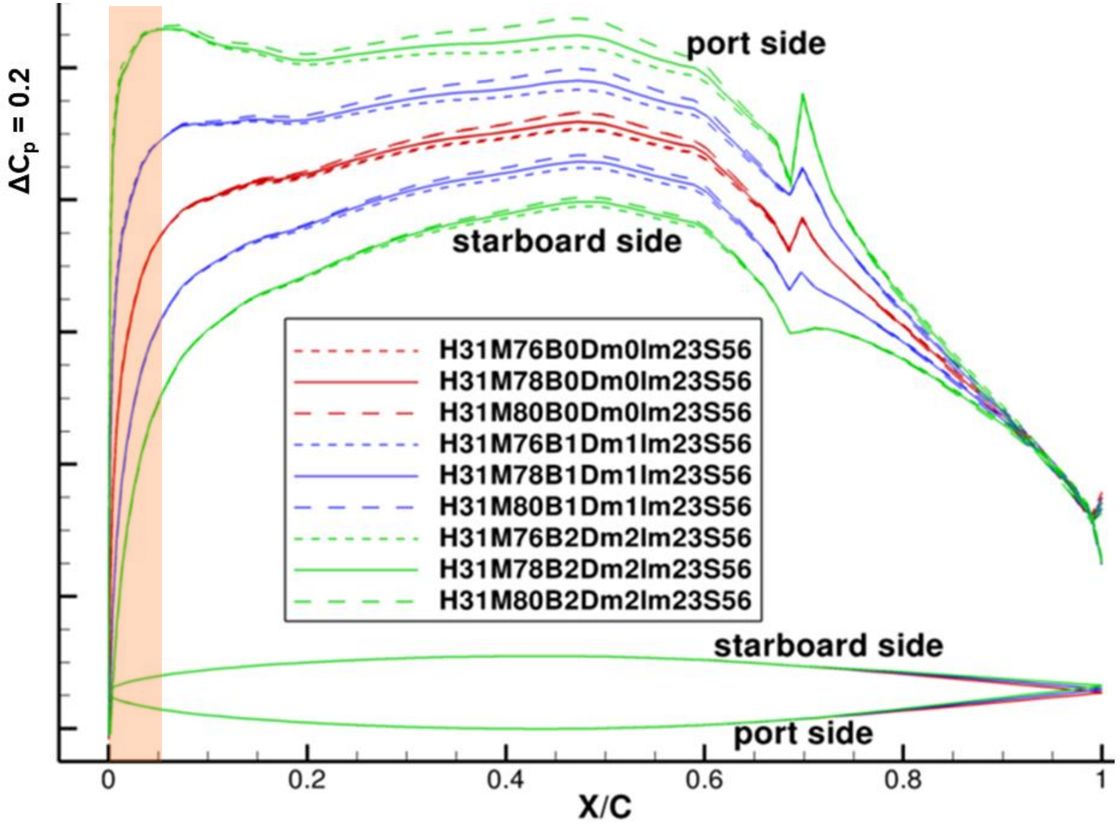
1. Keep attachment line laminar: K-criterion*
2. No stringer at the leading edge: need suction at the attachment line
3. Sufficient suction to delay transition
4. Allow for local blockage of stringer weld lines
5. Avoid outflow when flying with sideslip
6. Avoid transition by equivalent roughness: Re_{rr} < 400 - 450
7. Avoid choking in the suction holes: M_{hole} < 0.3
8. Minimize mass flow and suction power
9. Robust design: allow for a large variation of the microperforation and other manufacturing deviations

* D. Arnal, J. C. Juilien, J. Reneaux, G. Gasparian: "Effect of Wall Suction on Leading-Edge Contamination." Aerospace Science and Technology, No. 8 (1997), pp. 505-571.

Details of design

Details of design

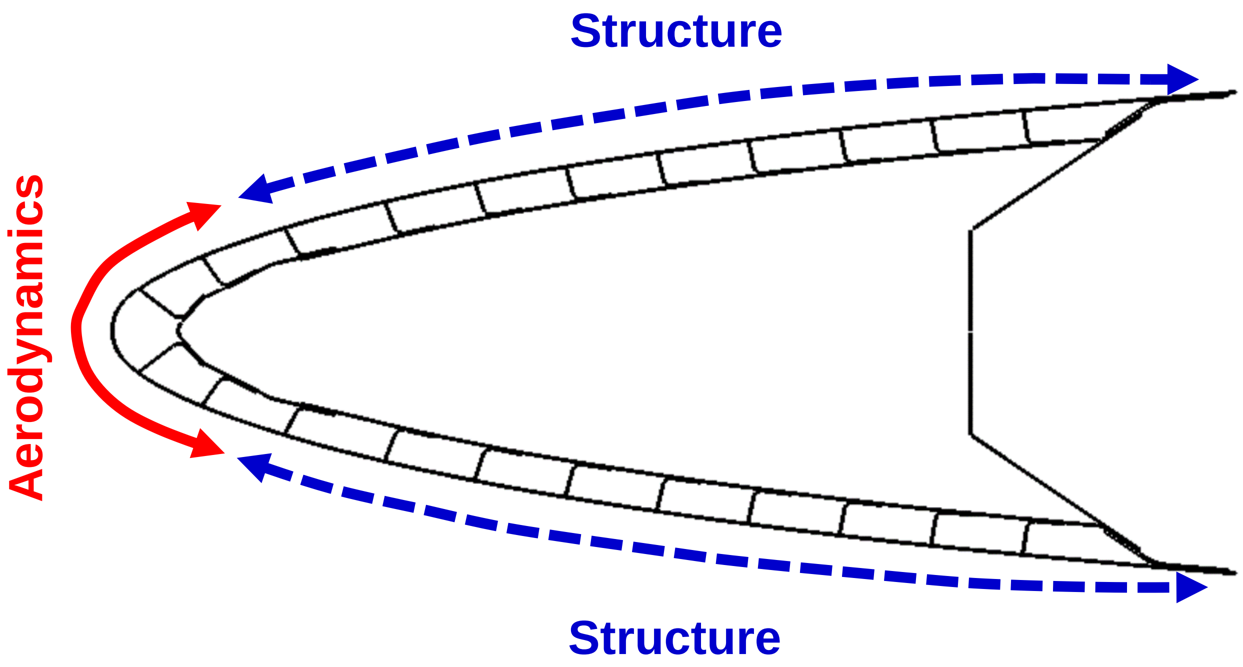
Pressure distributions



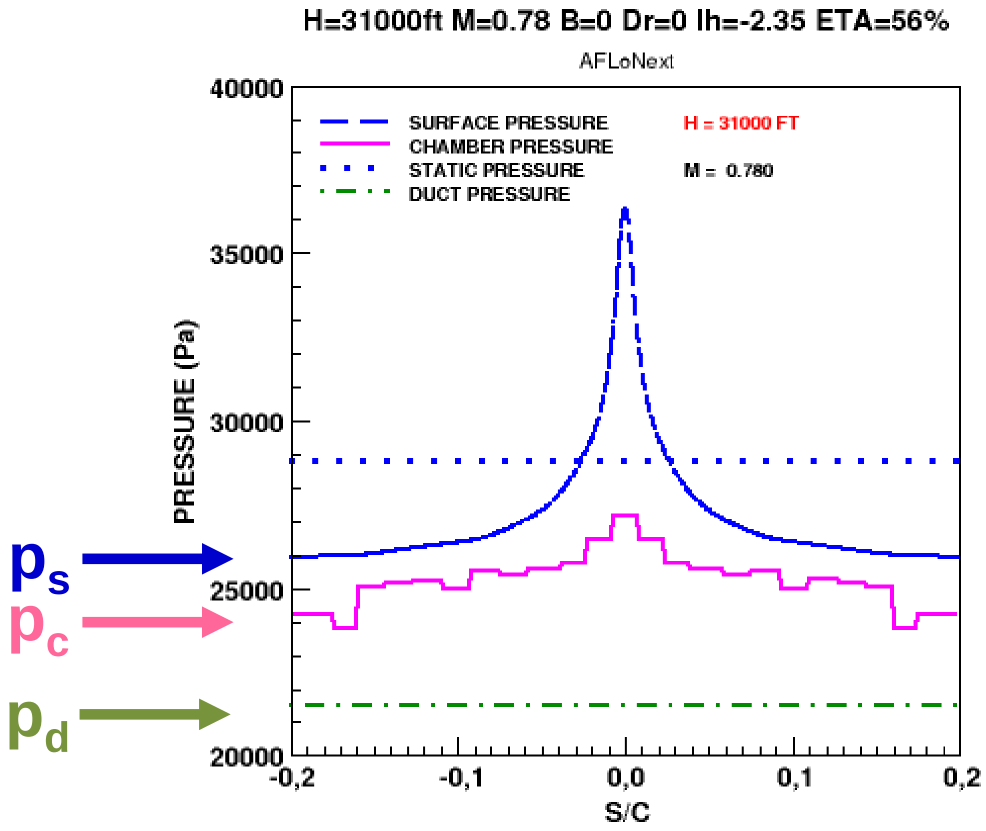
Large gradients for X/C < 0.05 → Chamber size limited by outflow

Smaller gradients for X/C > 0.05 → Large suction chambers possible

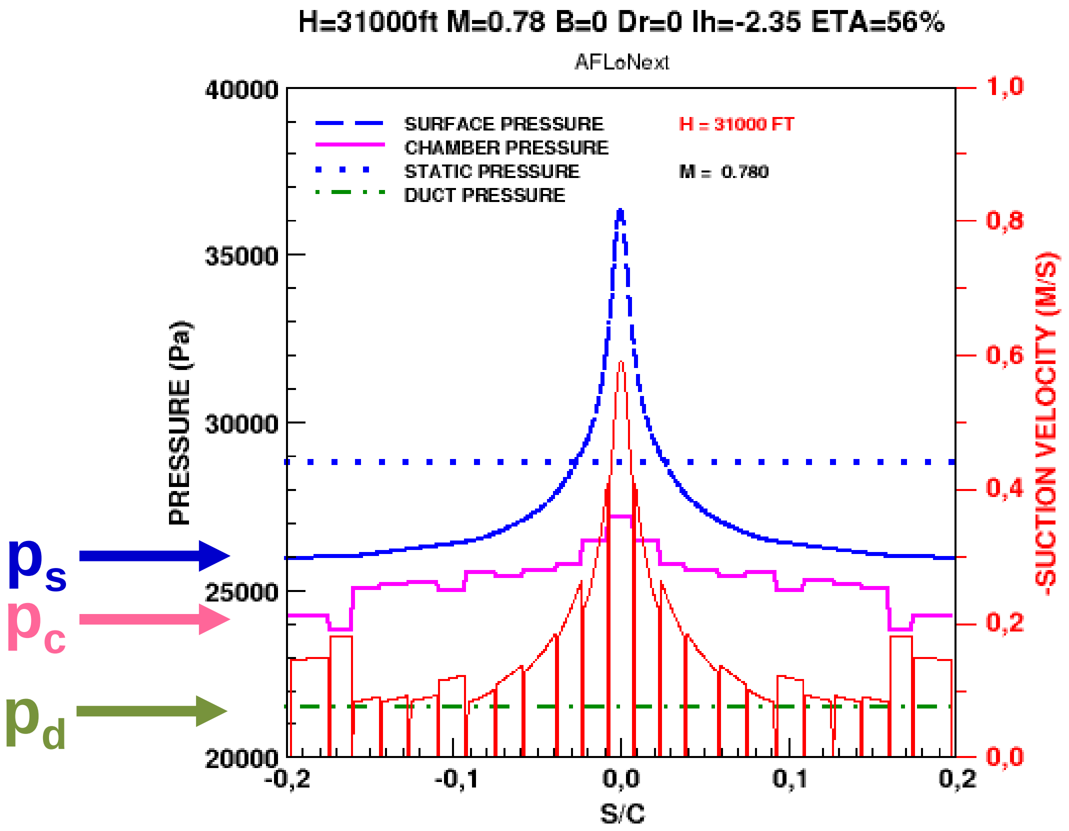
Design drivers and final suction chamber layout



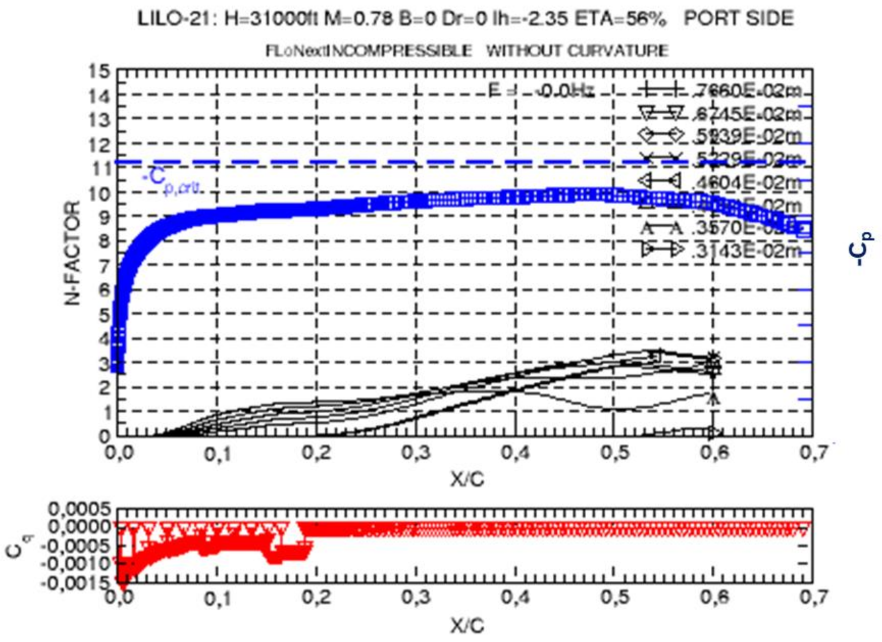
Outer and inner pressures for symmetric case
31000 ft, Mach 0.78, β = 0°, δ = 0°



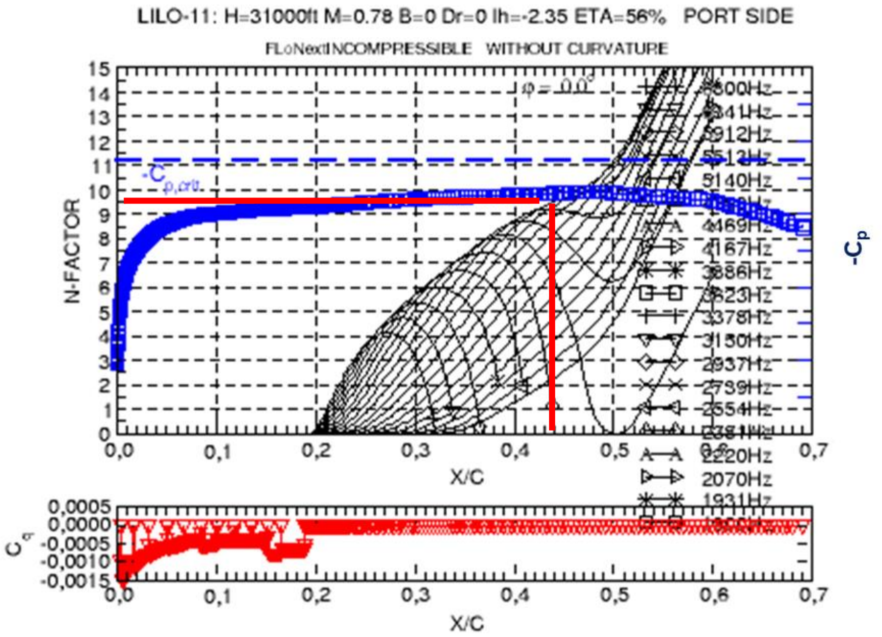
Outer and inner pressures for symmetric case 31000 ft, Mach 0.78, $\beta = 0^o$, $\delta = 0^o$



N_{CF} & N_{TS}-factors for symmetric case 31000 ft, Mach 0.78, β = 0º, δ = 0º



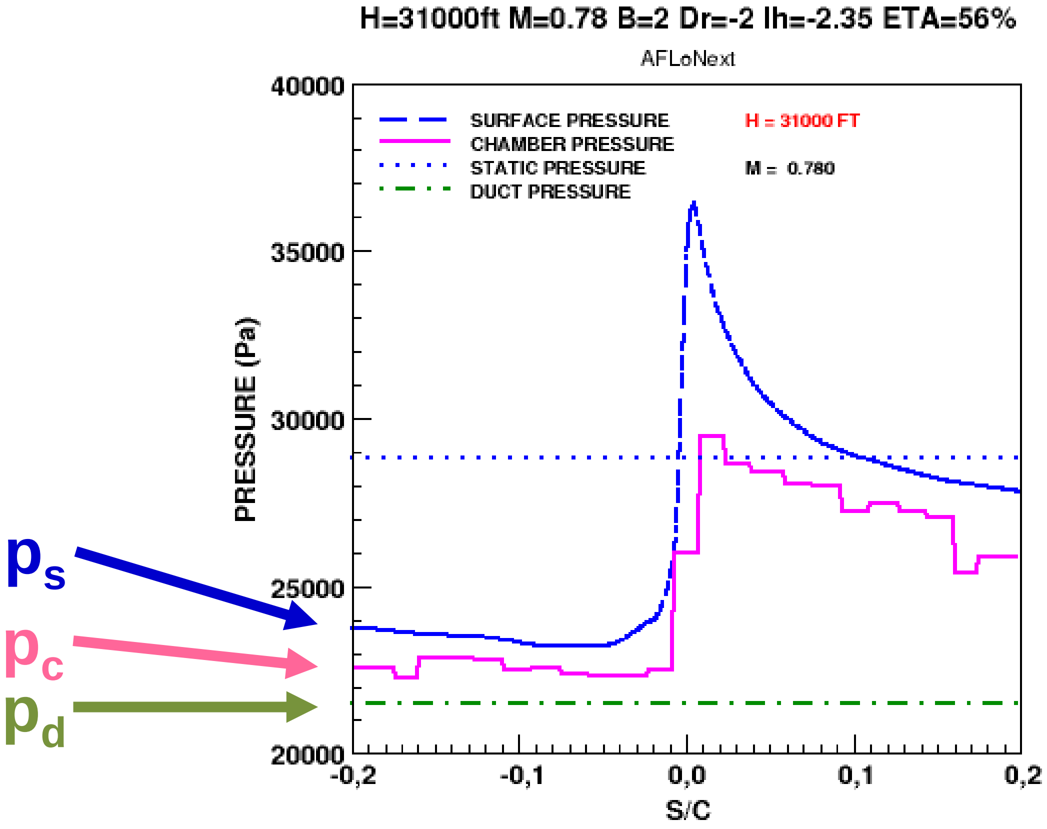
N_{CF}-factors



N_{TS}-factors

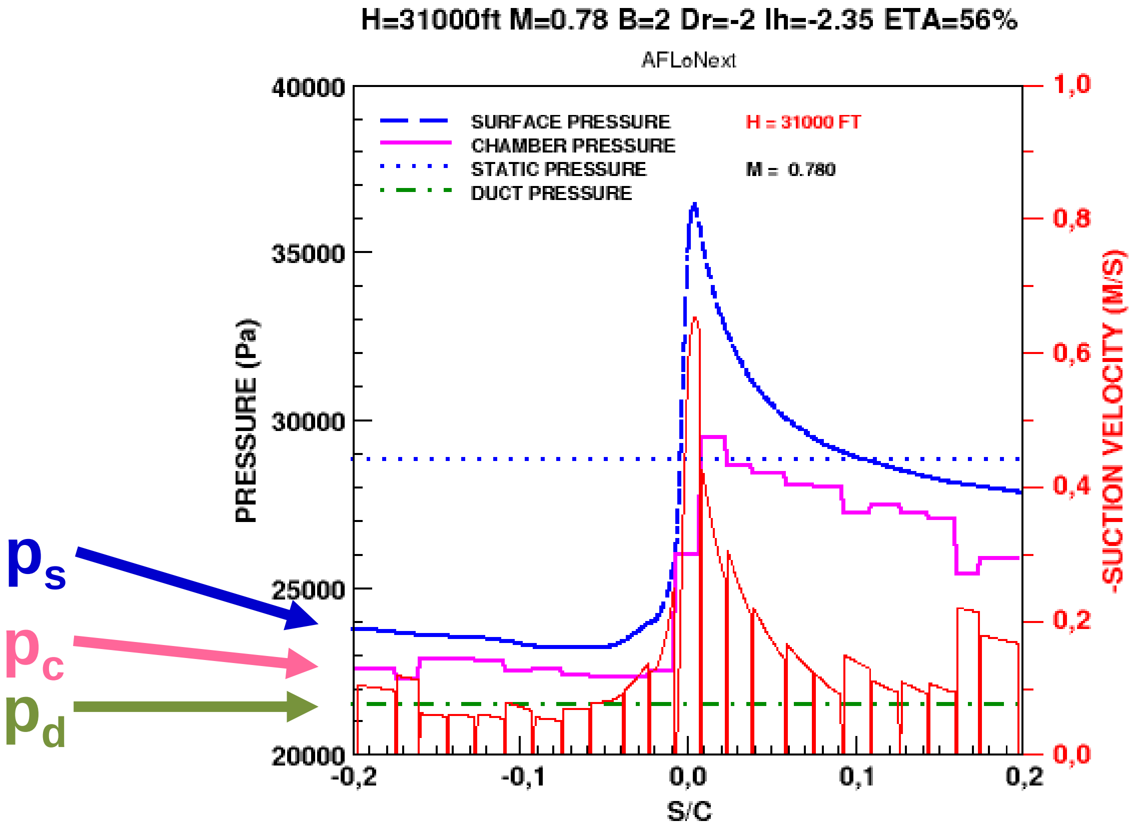
TS-transition predicted at 43%

Outer and inner pressures for asymmetric case
31000 ft, Mach 0.78, β = 2°, δ = -2°



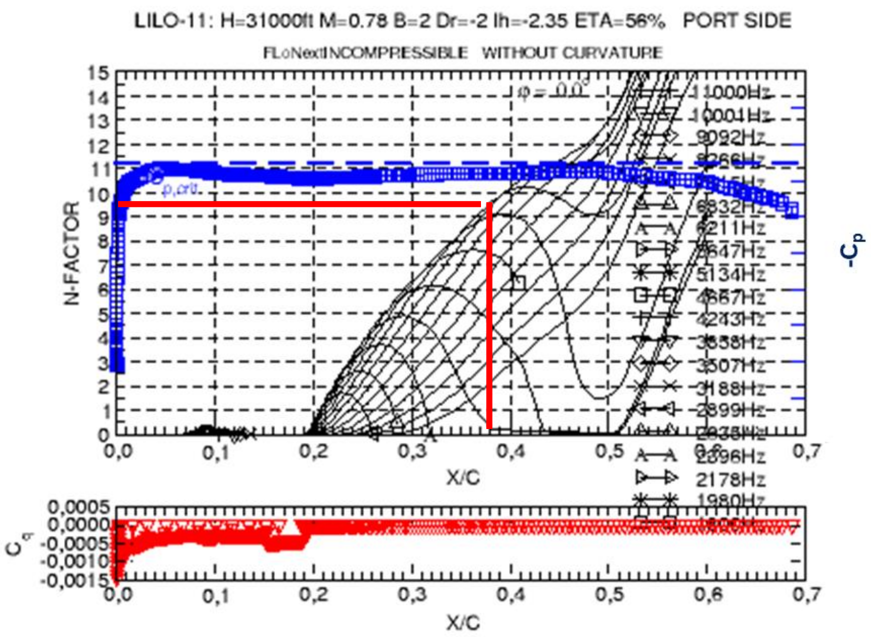
Limitation of chamber size

Outer and inner pressures for asymmetric case 31000 ft, Mach 0.78, β = 2°, δ = -2°

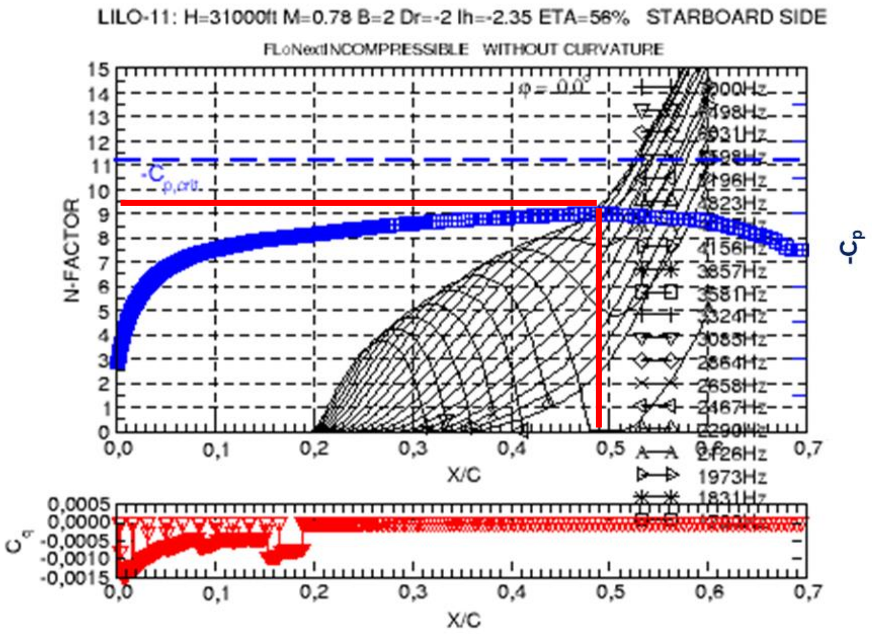


Limitation of chamber size

N_{TS}-factors for asymmetric case
31000 ft, Mach 0.78, β = 2° , δ = -2°

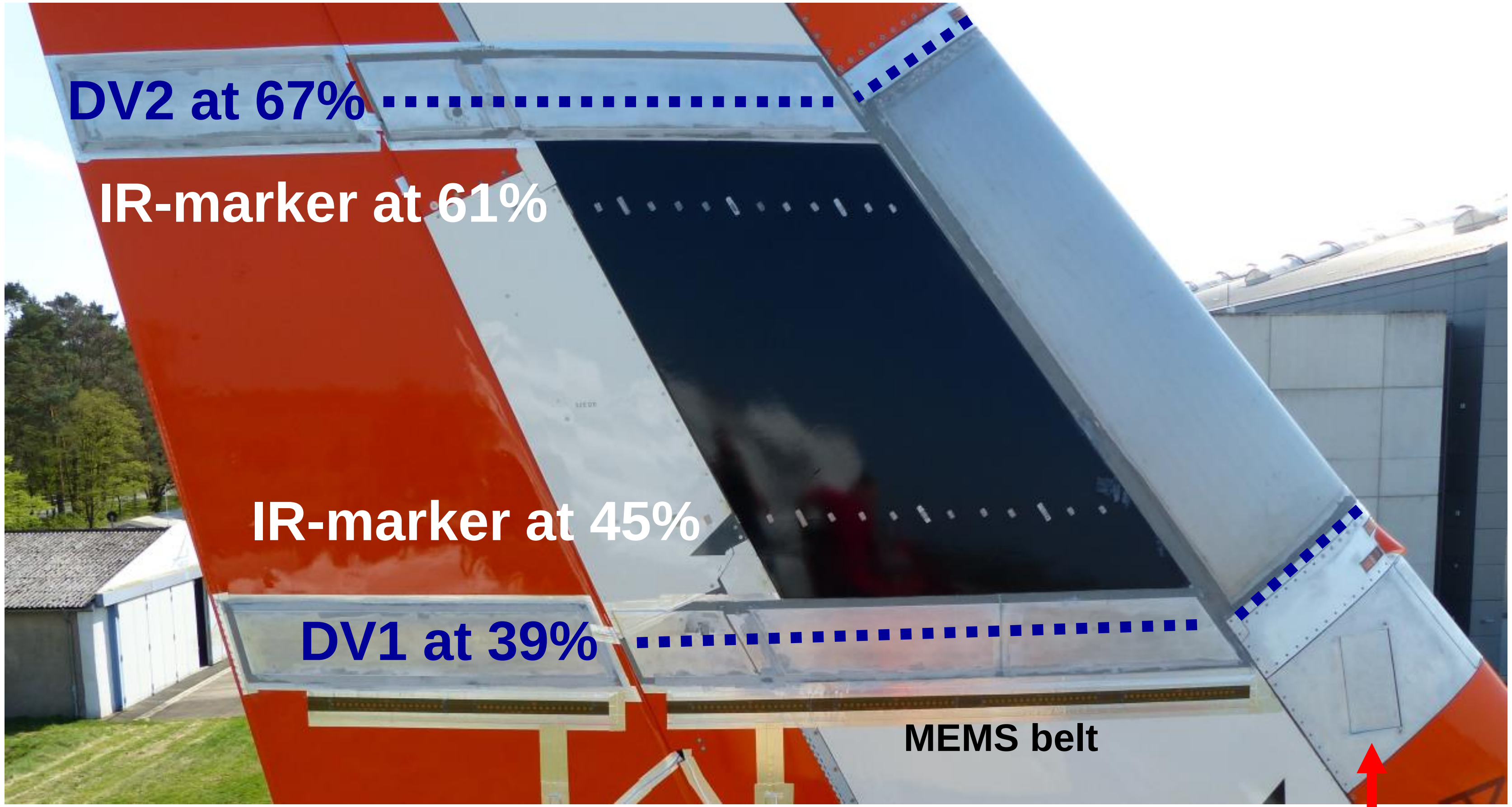


TS-transition predicted at 38%



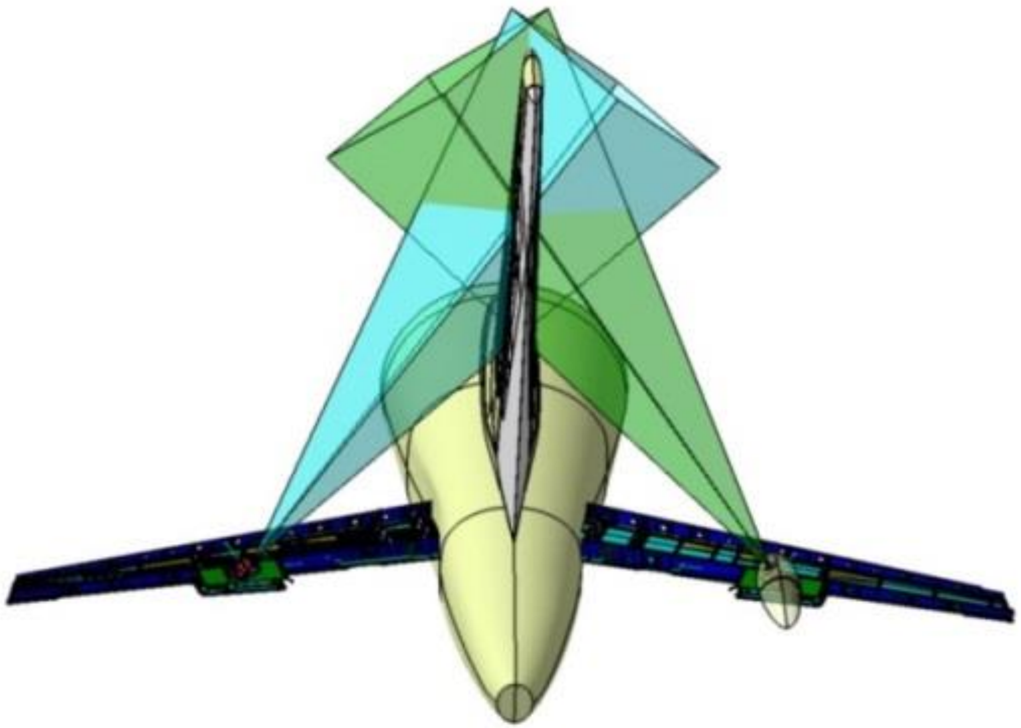
TS-transition predicted at 49%

Instrumentation on starboard (right) side



Suction flap

Flight test instrumentation
Infrared cameras in horizontal tail plane



A320 aircraft with HLFC system installed on tarmac at Brunswick airport

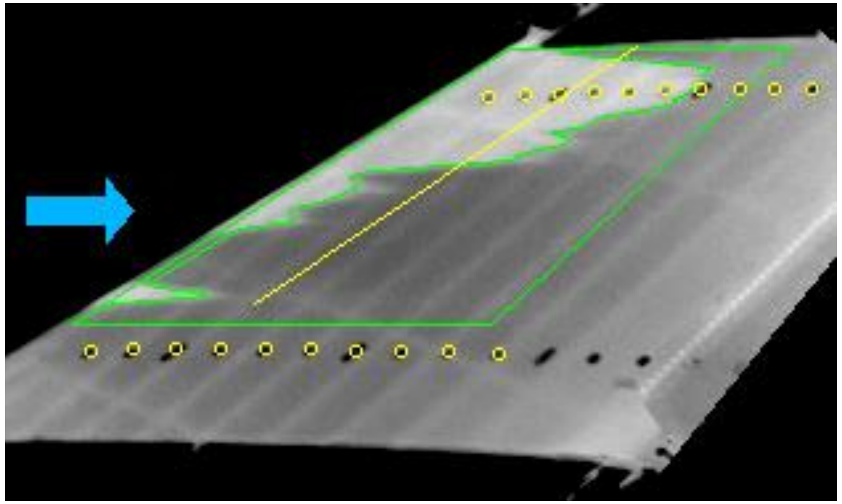
Some flight test results

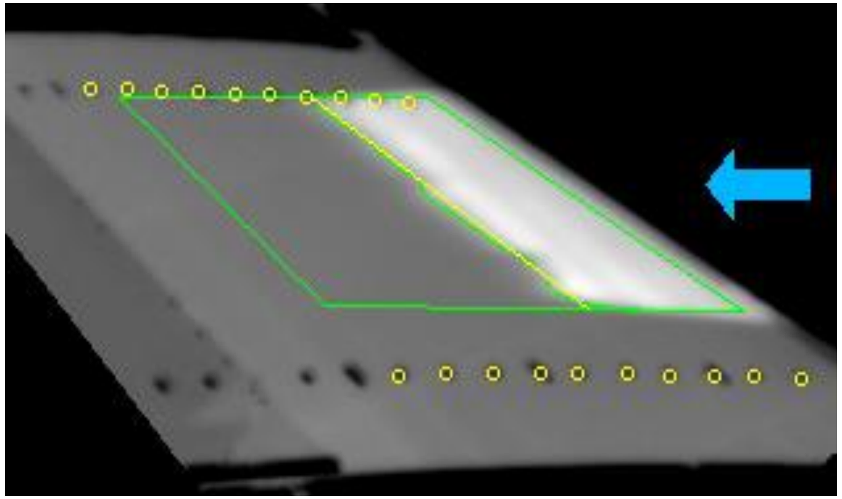
Spanwise variation of the transition line and N-factor correlation

Suction variation

N-factor correlation

31000 ft, M = 0.78, β = 0º, δ = 0º
Active suction





Port

Variation of transition over span from 39% to 20%

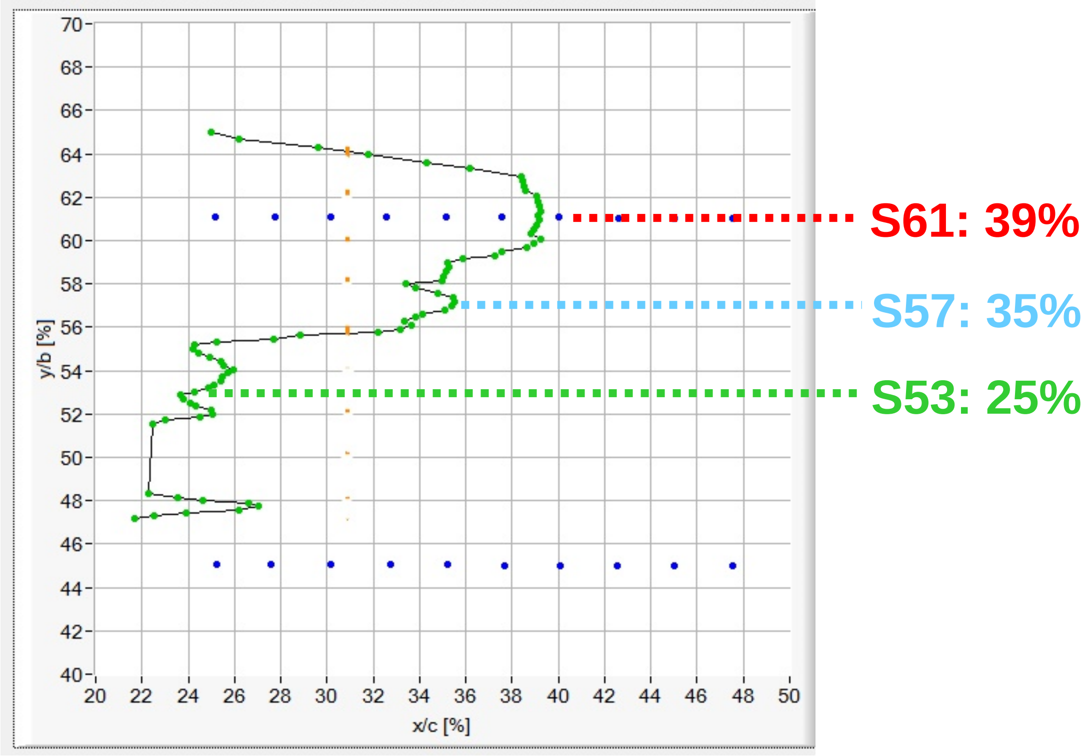
Starboard

Transition at 38% - 40%

Q1: Can we explain the variation of the transition with stability calculations?

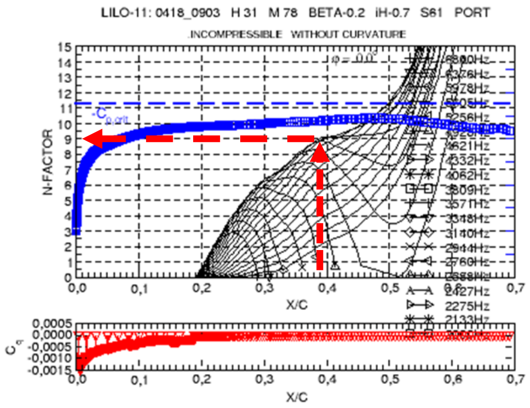
Q2: How do we do the N-factor correlation?

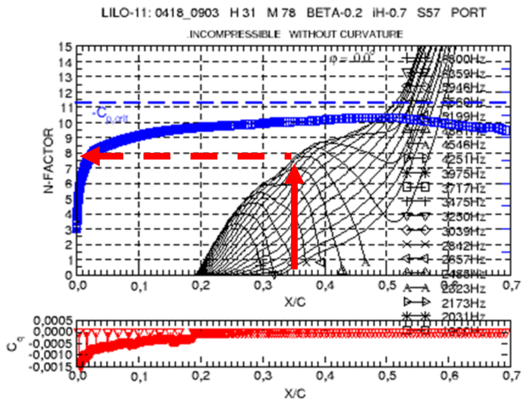
31000 ft, M = 0.78, β = 0º, δ = 0º, port
Projected transition line

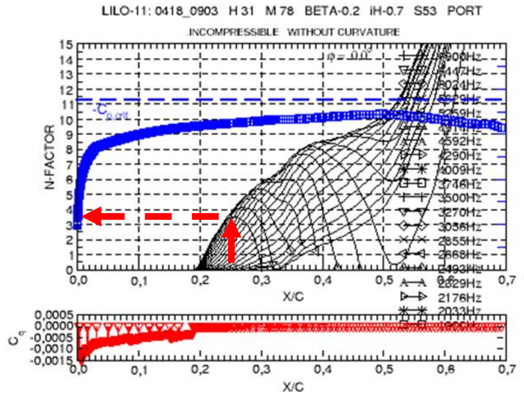


We use these three sections for an N-factor analysis

31000 ft, M = 0.78, β = 0º, δ = 0º, port
N_{TS}-factors for sections S61, S57, S53







Nearly the same N_{TS}-factor results
=> forward movement of transition line not reflected in N-factors

S61: 39% => N_{TS} = 9.0 S57: 35% => N_{TS} = 7.7 S53: 25% => N_{TS} = 3.6

Section S61 shows the laminar potential and should be used for the correlation

For the evaluation of the 1998 HLFC flight tests, we used a fixed “evaluation section” for all N-factor correlations, which might have contributed to the smaller N-factors!

Spanwise variation of the transition line and correlated N-factors

Linear stability theory shows the “laminar potential”

Observed extent of laminar flow might be smaller due to imperfections

For N-factor correlation of this flight test, we use the following procedure:

1. **Use section S61 for boundary layer and stability calculations**
2. **Determine the transition location from a suitable section near S61**

Some flight test results

Spanwise variation of the transition line and N-factor correlation

Suction variation

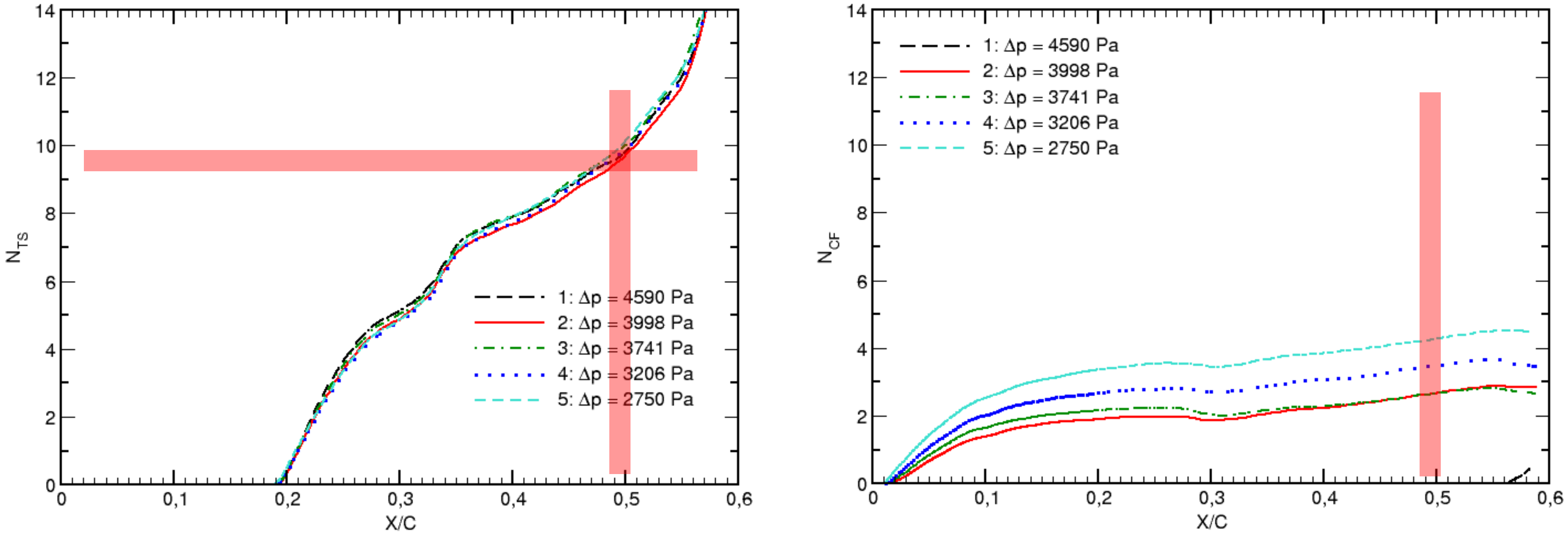
N-factor correlation

Suction variation

39000 ft, M = 0.78, $\beta = 0^o$, $\delta = 0^o$, stabilized flight

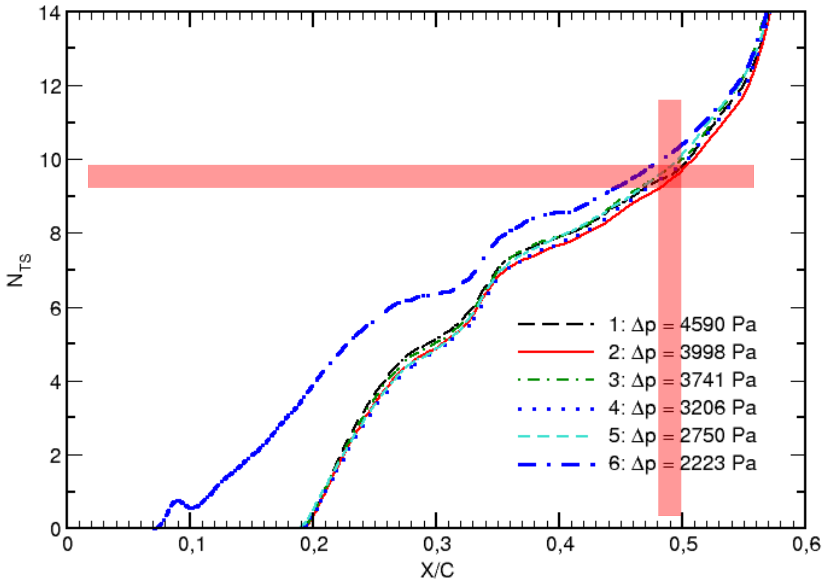
Open suction flap to maximal angle and close it step by step until loss of laminarity is observed

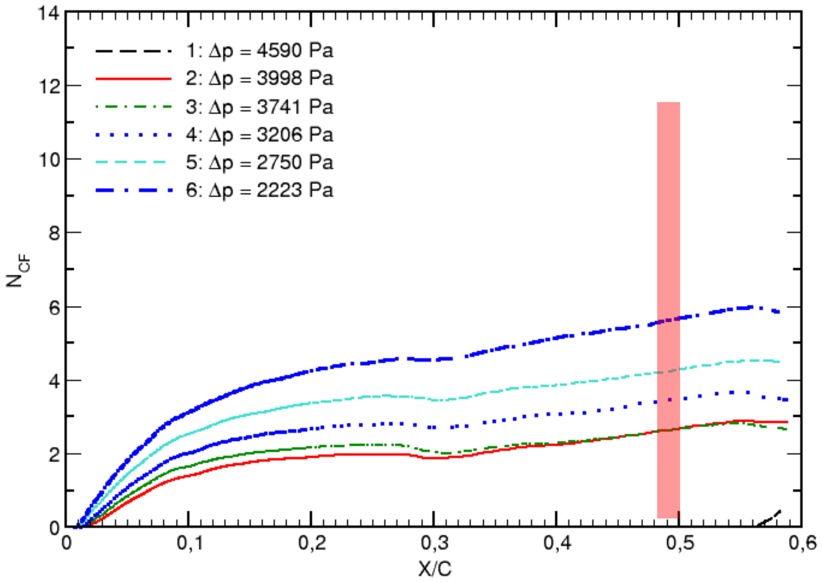
Suction variation



Cases 1-5: Same TS-transition location, same N_{TS}-factors, increasing N_{CF}-factors

Suction variation

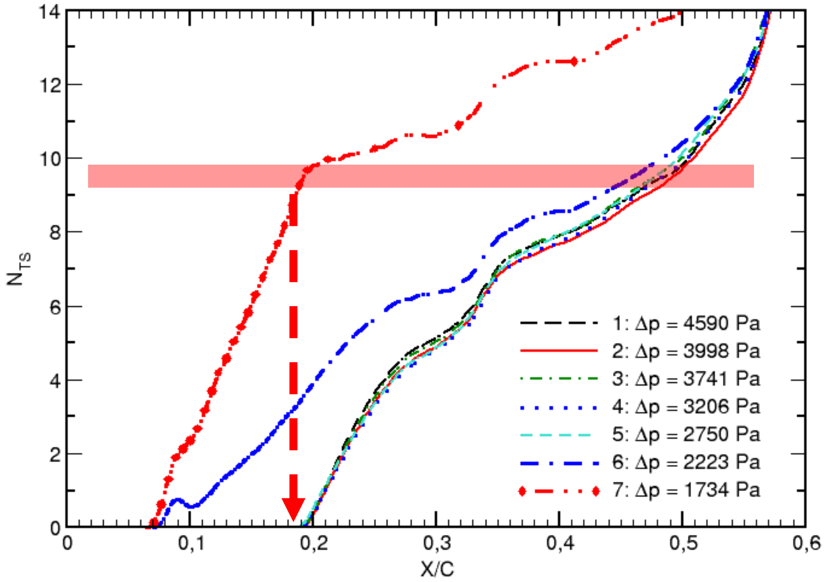


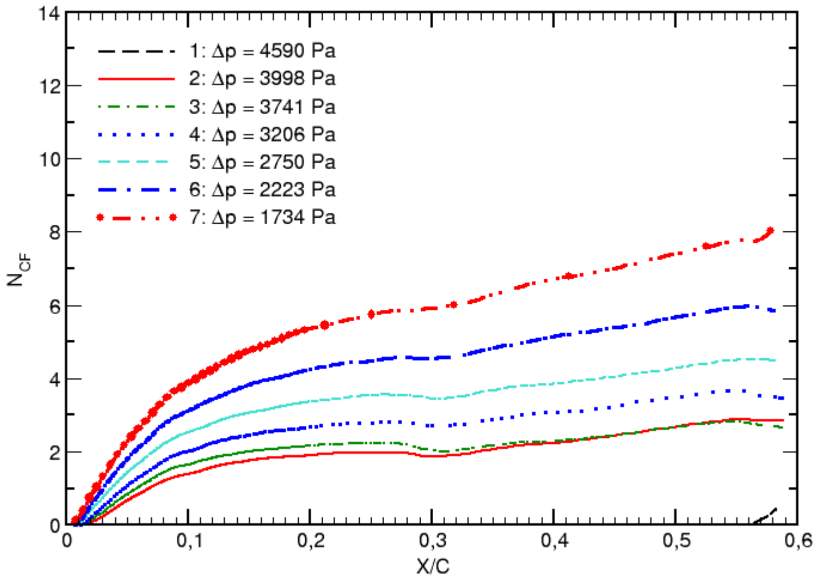


Cases 1-5: Same TS-transition location, same N_{TS}-factors, increasing N_{CF}-factors

Case 6 Very weak suction:
TS-transition at same location
N_{TS}-factor growth already on suction panel
$N_{CF} \approx 5$ has no influence in TS-transition

Suction variation





Cases 1-5: Same TS-transition location, same N_{TS}-factors, increasing N_{CF}-factors

Case 6 — **Very weak suction:**
TS-transition at same location
N_{TS}-factor growth already on suction panel
N_{CF} = 5 has no influence in TS-transition

Case 7: — **Outflow starting at 7%**
Strong N_{TS}-factor growth on suction panel
Forward shift of TS-transition which is consistent with N_{TS}≈9-10

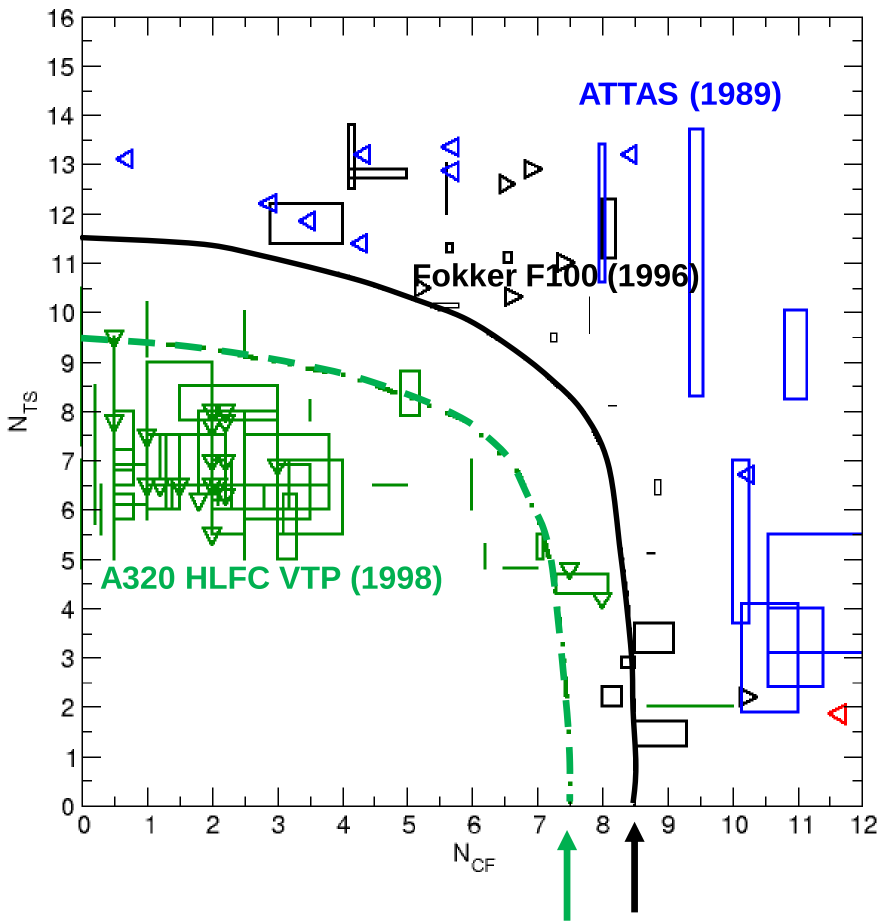
Some flight test results

Spanwise variation of the transition line and N-factor correlation

Suction variation

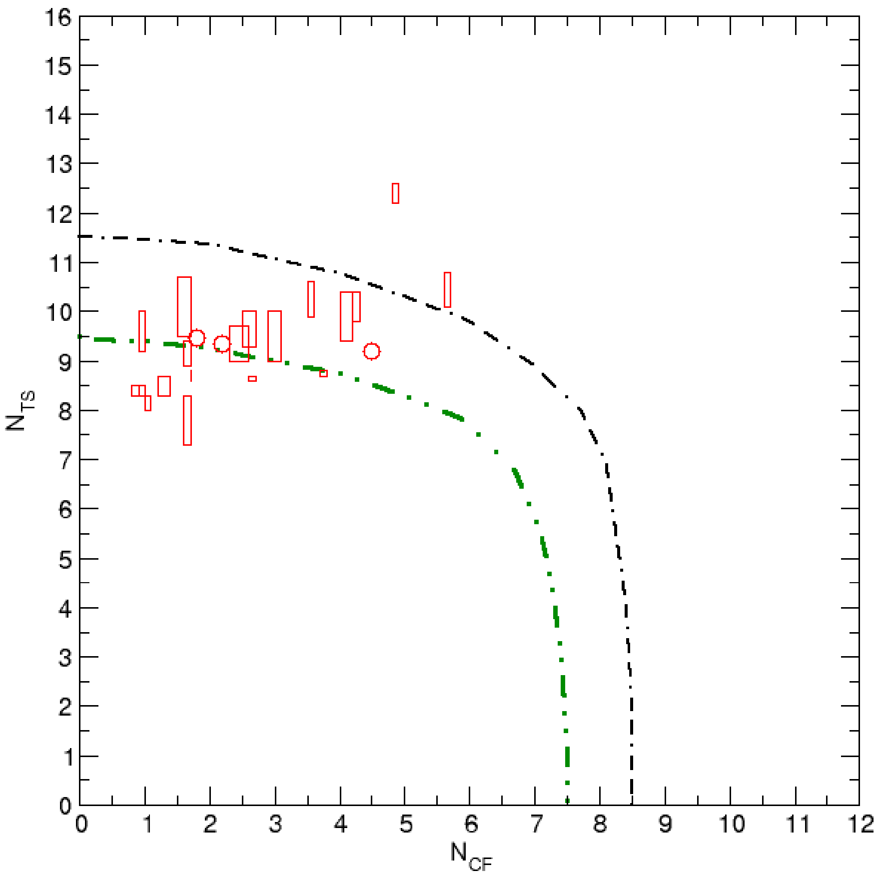
N-factor correlation and comparison with 1998 flight tests

N-factor correlation



Proposed correlation for HLFC design

Conservative NLF correlation



New results

Conclusions

Aerodynamic and system design, especially microperforation and throttle holes

Incompressible stability theory

Procedure for N-factor correlation (“laminar potential”)

Suction variation causing a shift of TS-transition consistent with $N_{TS} \approx 9 - 10$

Proposed N-factor correlation curve for HLFC design is shown to be correct

Incompressible stability theory: $N_{TS} \approx 9 - 10$

Compressible stability theory: $N_{TS} \approx 5 - 6$ (M = 0.78)

Further information

G. Schrauf: "Status and Perspectives of Laminar Flow." The Aeronautical Journal, Vol. 109, pp. 639-644, 2005.
https://doi.org/10.1017/s000192400000097x

G. Schrauf, H. von Geyr: "Simplified Hybrid Laminar Flow Control for Transport Aircraft."
6th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2012), September 10-14, 2012, Vienna, Austria.
https://www.eccomas.org/wp-content/uploads/sites/15/2019/10/ECCOMAS-CONGRESS-PROCEEDINGS-2012.pdf

G. Schrauf, H. von Geyr: "Simplified Hybrid Laminar Flow Control for the A320 Fin – Aerodynamic and System Design, First Results."
SciTech Forum, 6-10 January 2020, Orlando, Florida, USA. AIAA Paper AIAA-2020-1536. Jan 2020.
https://doi.org/10.2514/6.2020-1536

G. Schrauf, H. von Geyr: "Simplified Hybrid Laminar Flow Control for the A320 Fin - Part 2: Evaluation with the eN-method."
AIAA SciTech Forum, 11-15 & 19-21 January 2021, Virtual Event. AIAA Paper AIAA-2021-1305.
https://arc.aiaa.org/doi/10.2514/6.2021-1305

G. Schrauf, H. von Geyr: "Hybrid Laminar Flow Control on A320 Fin: Retrofit Design and Sample Results."
To appear in AIAA Journal of Aircraft, 2021.
https://arc.aiaa.org/doi/10.2514/1.C036179

G. Schrauf, "Large-Scale Laminar-Flow Tests Evaluated with Linear Stability Theory."
AIAA Journal of Aircraft, Vol. 41, No. 2, March-April 2004, pp. 224 - 230.
https://arc.aiaa.org/doi/10.2514/1.9280

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