NATURAL LAMINAR FLOW AT CRUISE MACH NUMBER 0.78: FIRST RESULTS OF ETW CONCEPT VERIFICATION TESTS

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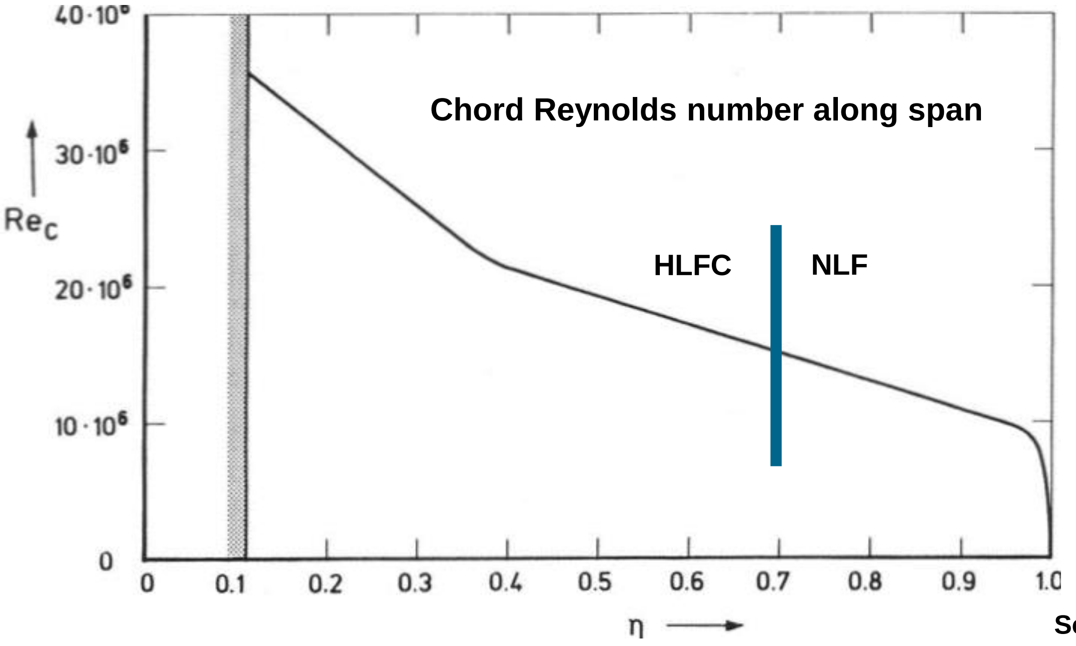
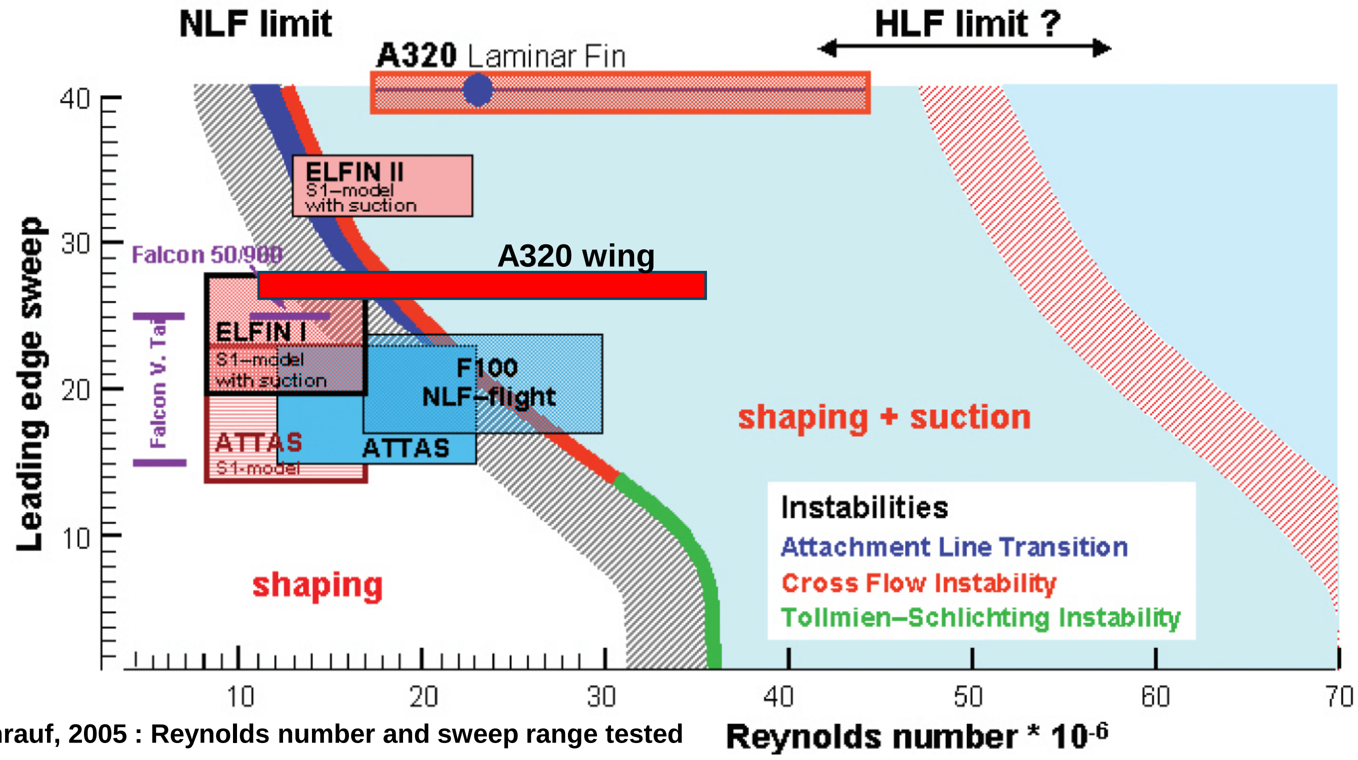
The Concept: Forward Sweep and Natural Laminar Flow

Problem: Design of a new short and medium range aircraft with Natural Laminar Flow (NLF) wing, featuring:

- Top Level Aircraft Requirements (TLARs) equal to A320:
  - Cruise flight at **M = 0.78 (Mach range 0.76 – 0.80, MMO 0.82) in FL= 350**
  - Payload range diagram
  - Take-off (1900m at MTOW) and landing (1470m at MLW) distance
- NLF wing design at M = 0.78 problematic with today's Backward Swept Wing technology due to
  - high leading edge sweep
  - high Reynolds number
- e.g. A320: $\phi_{L.E.} = 27°$, $Re_{AMC} = 24.7$ million





Schrauf, 2005 : Reynolds number and sweep range tested

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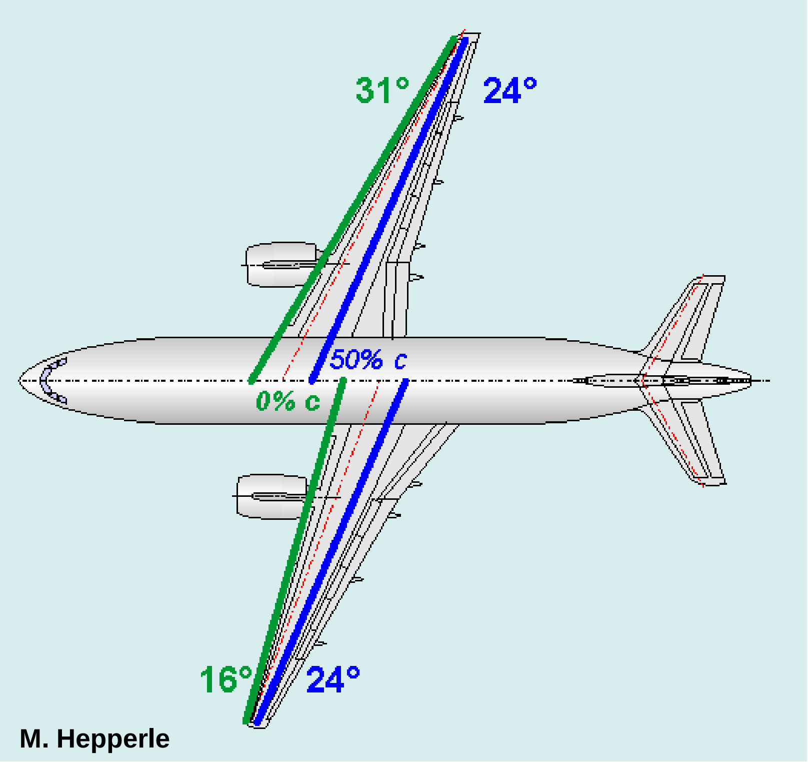
Solution: **Forward swept and tapered wing** allows for reduced leading edge sweep! Why?

Effect of forward sweep in combination with taper:

1. Sweep in recompression zone (50% - 60% chord) will be retained
2. Wave drag will be as low as for a backward swept wing
3. Sweep in the leading edge region is reduced, depending on taper ratio
4. Transition phenomena in leading edge region, i.e.
   – Attachment Line Transition (ALT) and
   – Crossflow Instability (CFI) growth

   can easily be controlled



The Concept: Forward Sweep and Natural Laminar Flow

Preliminary Aircraft Design applying FSW-NLF technology

- Top Level Aircraft Requirements (TLARs) equal to A320-200:
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  - Payload range diagram
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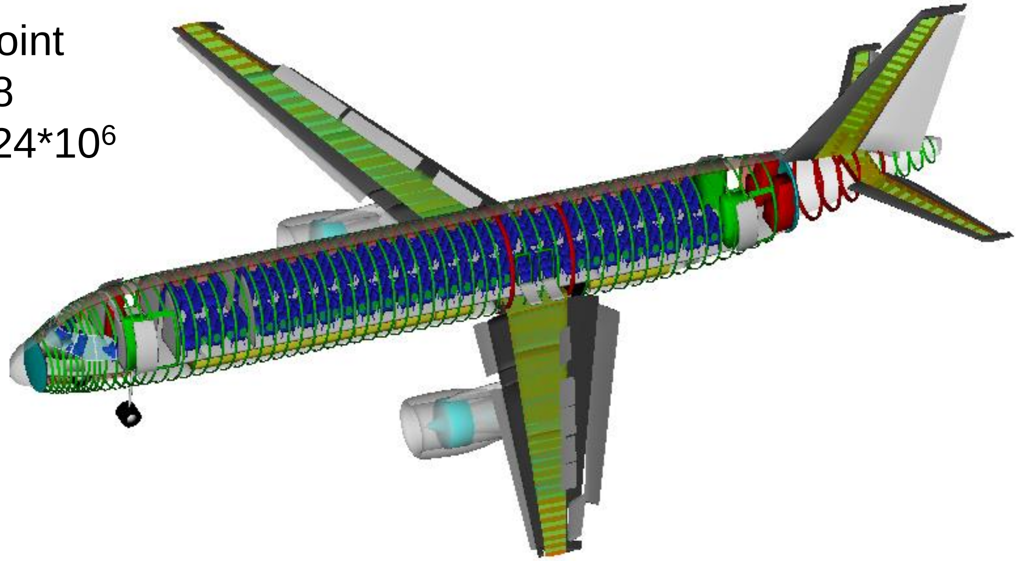
Selected configuration:

- Mono-trapezoidal wing
- High-lift devices: shielding Krüger and fixed vane Fowler
- Laminar flow only on upper surface, lower surface full chord turbulent
- Fuselage and empennage conventional (size and stability margin as A320)
- Engines in underwing arrangement

Design Point
Ma = 0.78
$Re_{AMC} = 24*10^6$
$C_L = 0.52$



Parameter		Value
wing area	S	122.0 m²
wing span	b	34.0 m
aspect ratio	Λ	9.4754
taper ratio	λ	0.3402
Root chord	c_t	5.080 m
mean aerodynamic chord	c_{MAC}	3.896 m
sweep at leading edge	φ_{le}	-17.0°
sweep at trailing edge	φ_{te}	-27.8°
sweep at 60% chord (~shock location)	φ_{60}	-23.6°

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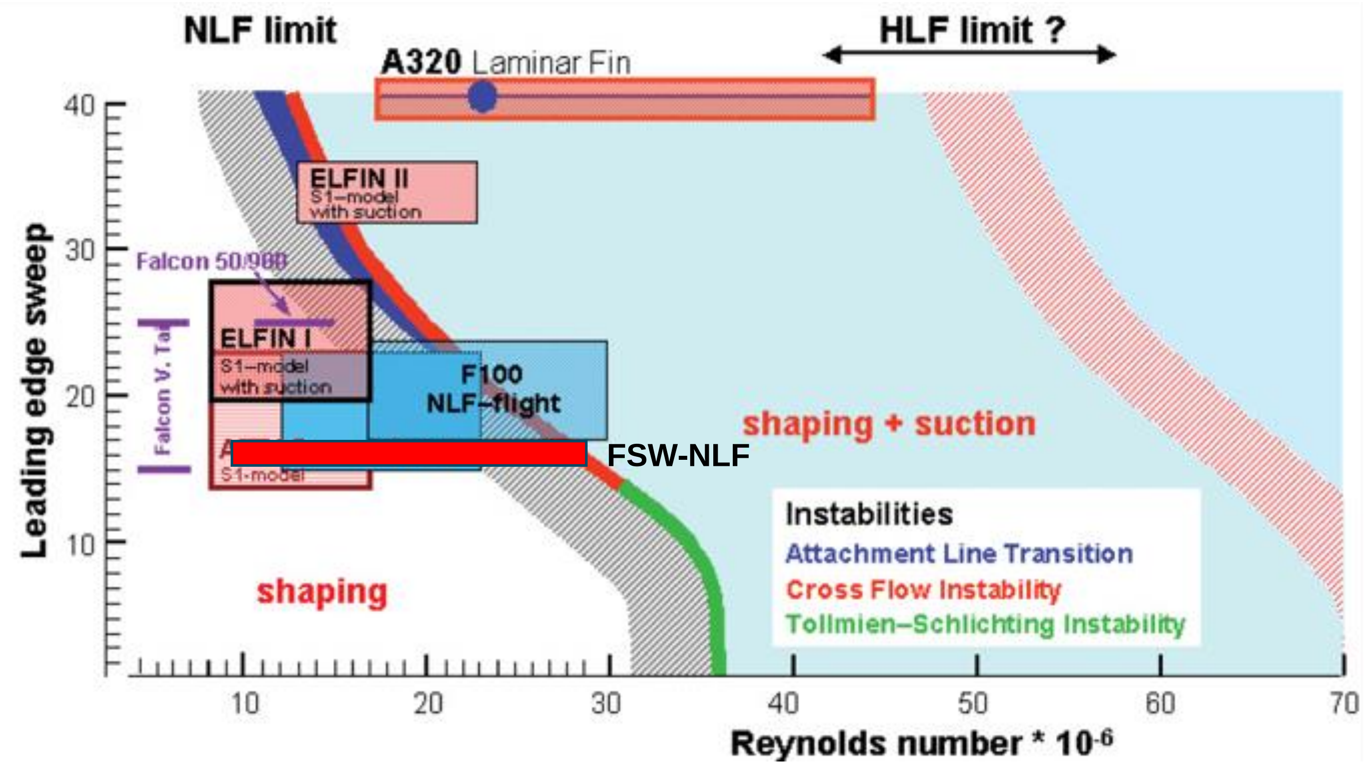

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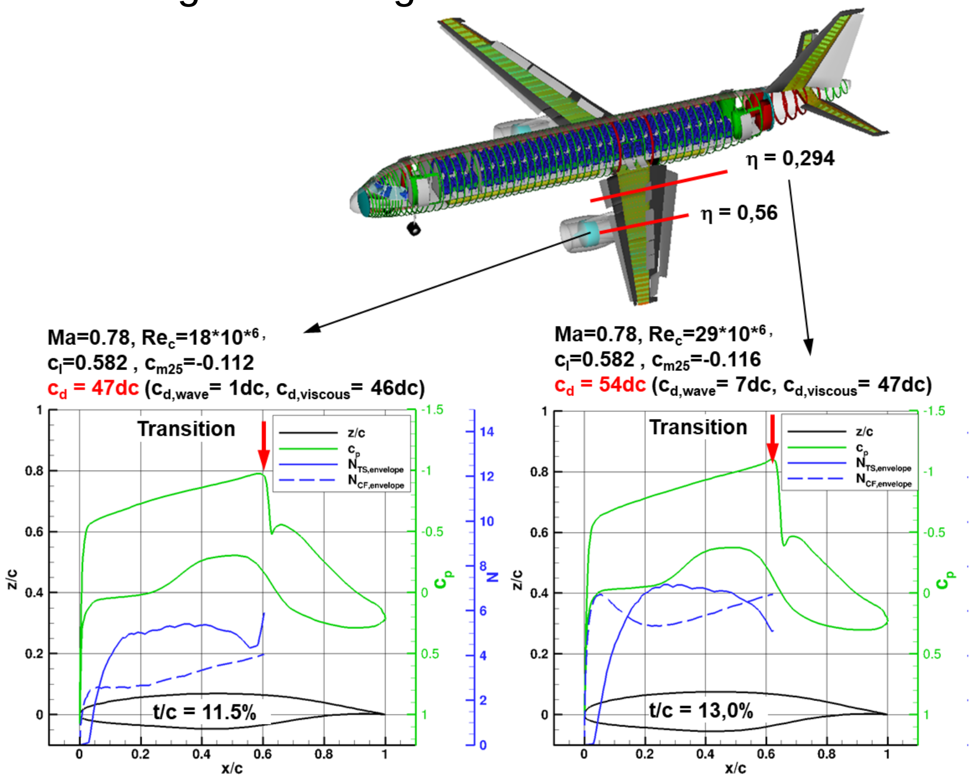
Detailed Aerodynamic Design and Testing of Wing-Body Combination

2014 – 2017		2020 – 2021		2022 – 2025
TuLam	→	ECOWING	→	ULTIMATE

- Overall Aircraft Design
- Definition of spanwise loading
- Definition of target Cp distributions
- Design of initial generator sections



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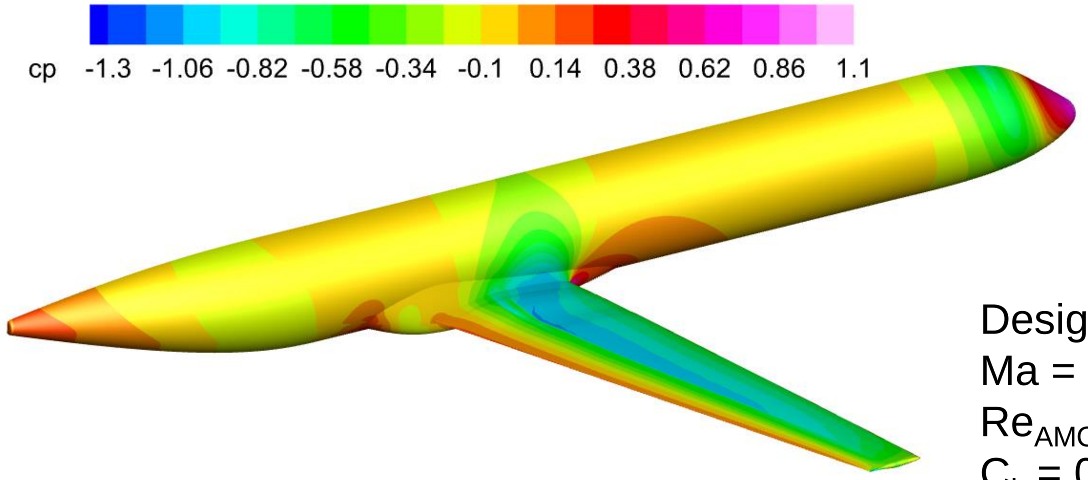
- Analysis with RANS code Tau



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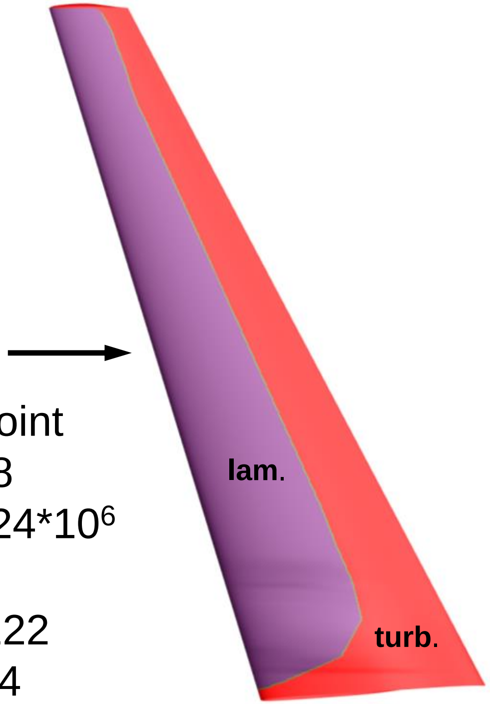
$C_L = 0.52$
$C_D = 0.0222$
L/D = 23.4



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- CAD of wind tunnel halfmodel (Airbus)
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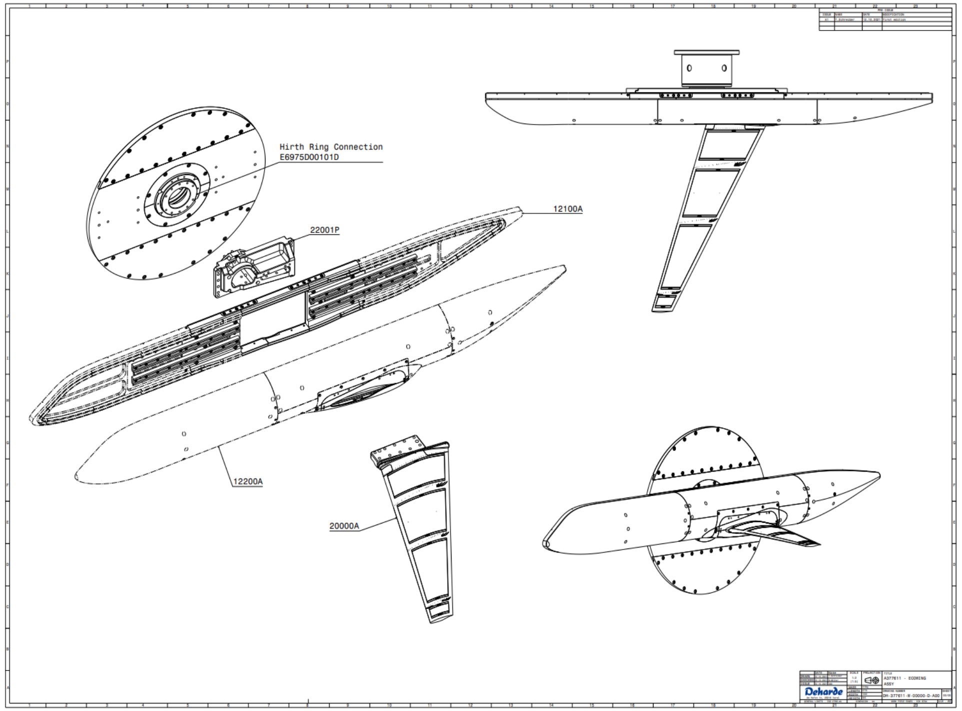
ULTIMATE (2022 – 2025)

- ETW performance test in May 2022
- Force mesurements with balance
- 4 pressure rows
- Transition detection with TSP



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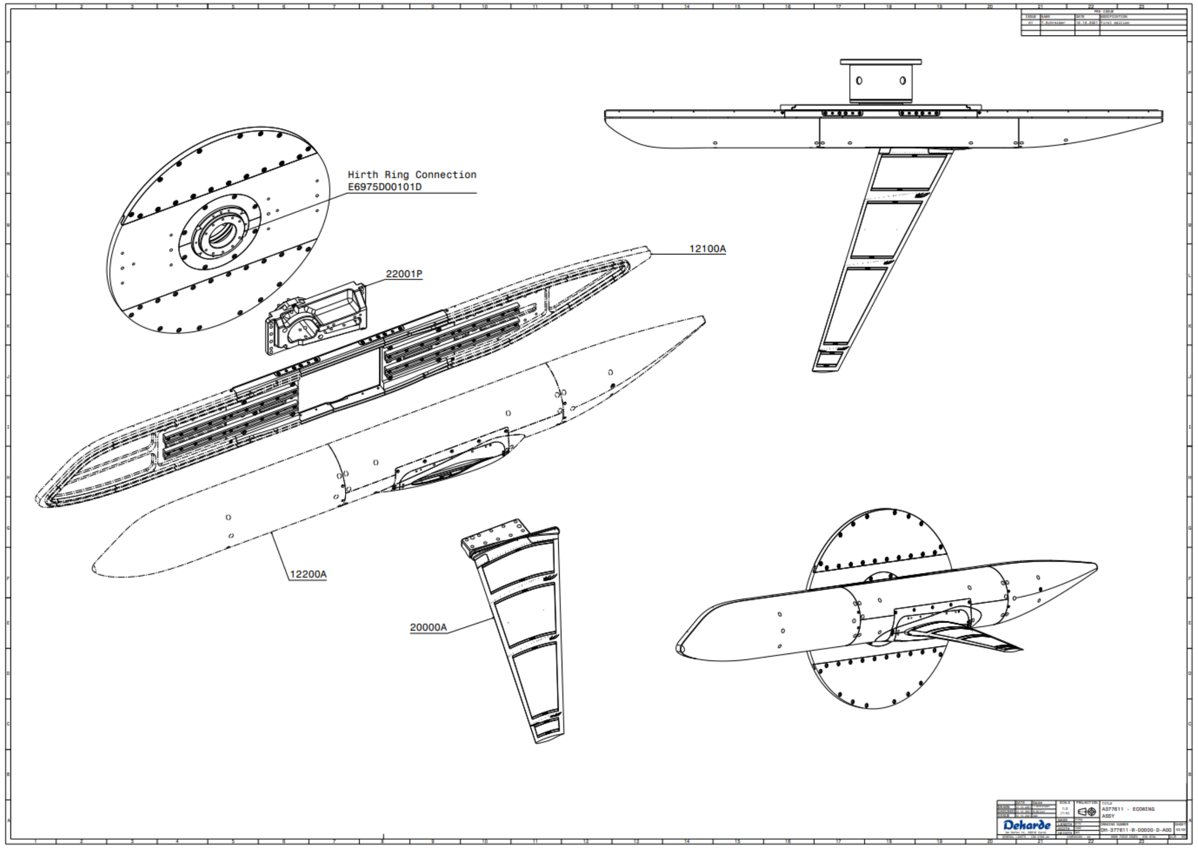
Model Instrumentation and Transition Fixing



- ETW half model 5-component strain gauge balance
- 4 TSP pockets for T-Step Transition detection
- Section A (root) with 62 pressure tappings on upper and lower side, connected to psi static pressure scanner
- Sections B, C (midboard) and D (tip) with 25, 20 and 16 stagggered Kulite sensors (unsteady), only on upper side
- Stereo Pattern Tracking (SPT) dots on lower side for deformation measurements
- Lower side: Transition fixed at 5% chord
- Upper side:
  config. 1: Transition free
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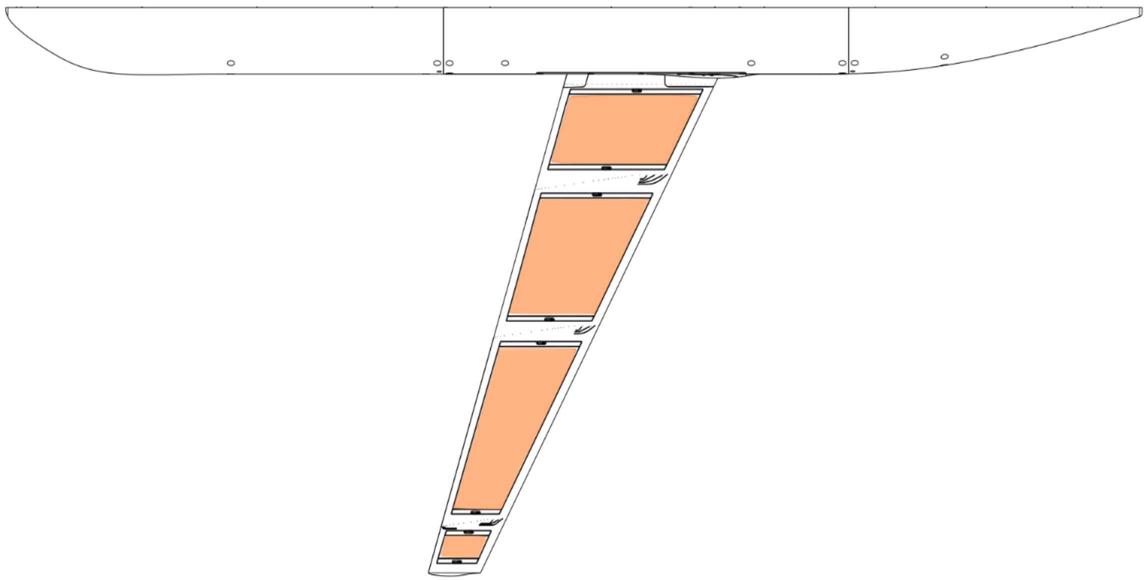

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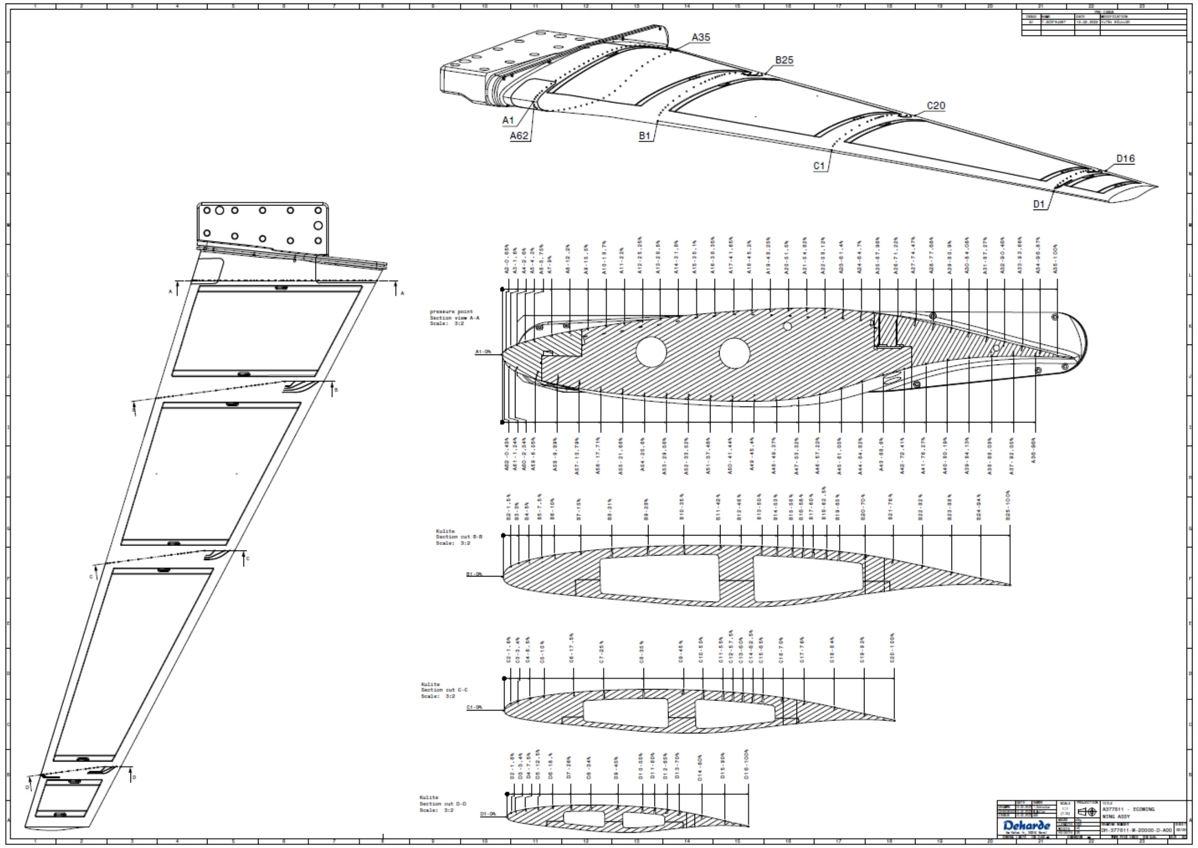

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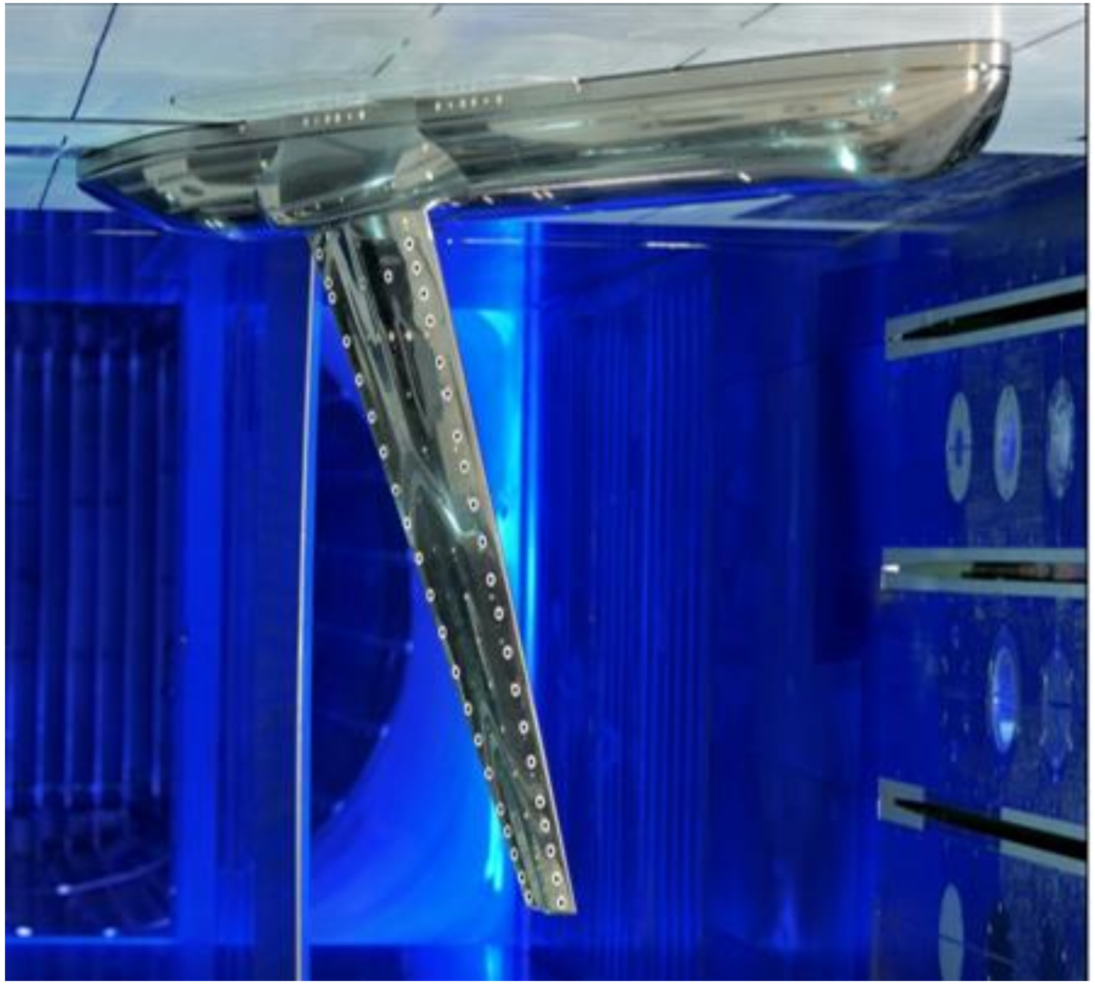

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Test Matrix

approach

climb

cruise range

MMO

DLR

					Mach Number														
Transition	Re [Mio]	Measurements	Alpha	C_L	0,200	0,450	0,500	0,550	0,600	0,650	0,700	0,730	0,760	0,770	0,780	0,790	0,800	0,810	0,820
free	10	F+P+SPT	-3 > 4.0																
		TSP		0,42/0.52/0.62															
	18	F+P+SPT	-3 > 4.2																
		TSP		0,42/0.52/0.62															
	16	F+P+SPT	-3 > 4.2																
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				0.42/0,52/0.57															
				0,52															
				0,52															
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	14	F+P+SPT	-3 > 18																
	16	F+P+SPT	-3 > 5																
			-3 > 5																
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			-3 > 4.5																
			-3 > 4.3																
			-3 > 4.2																
fixed (config2)			-3 > 5																
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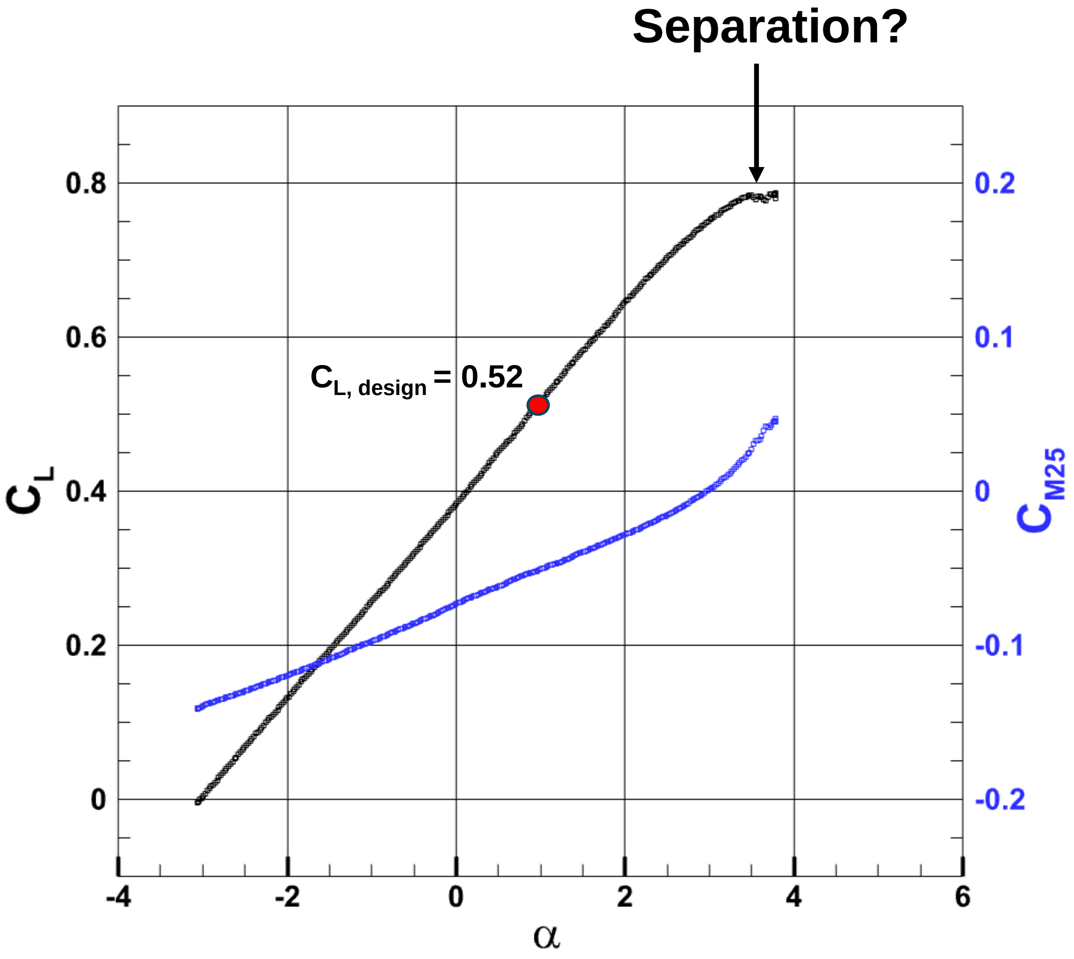
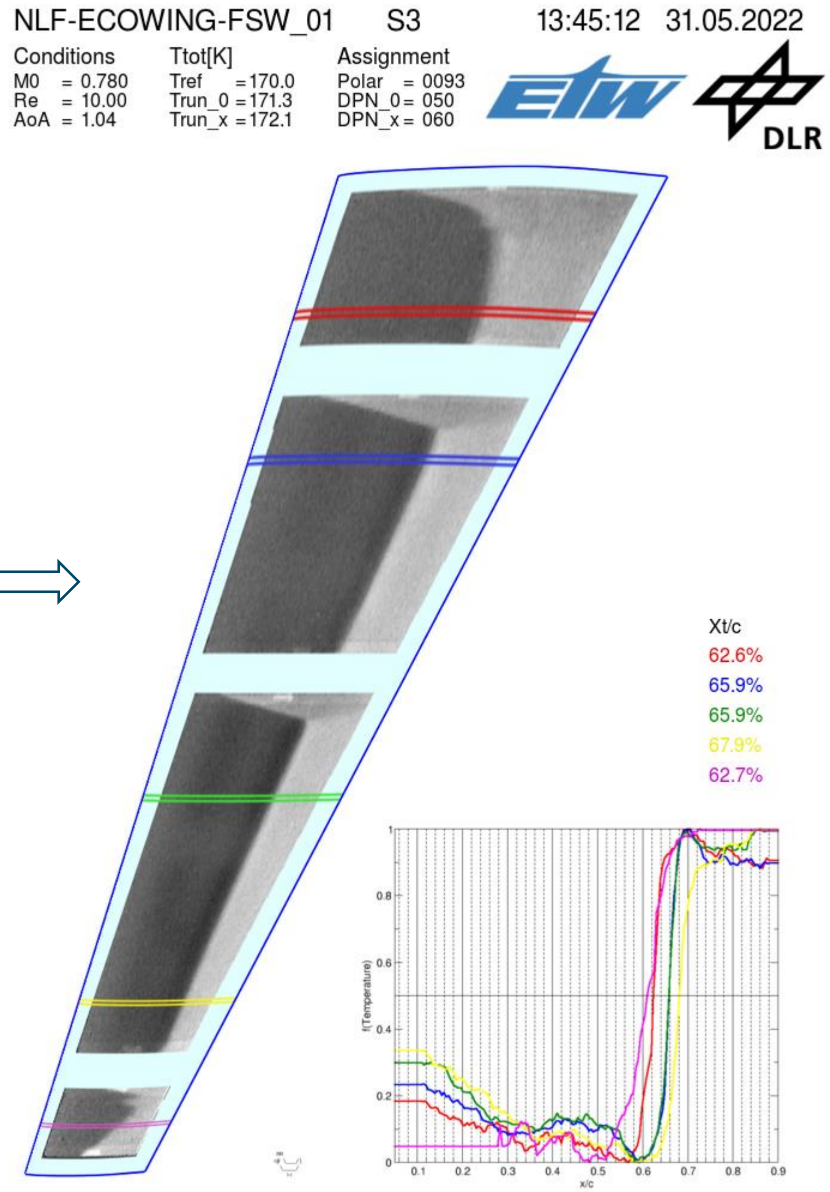
Test Results: Cruise Range

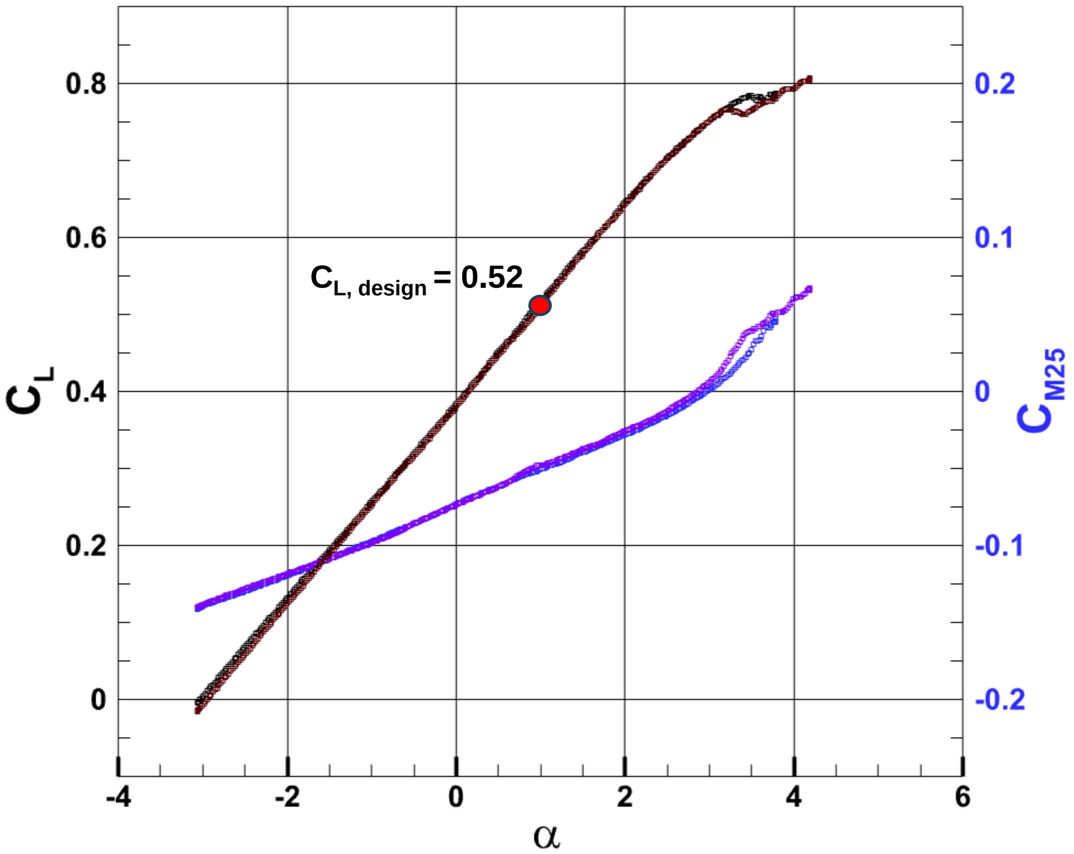
M = 0.78, Re = 10 mil., check run

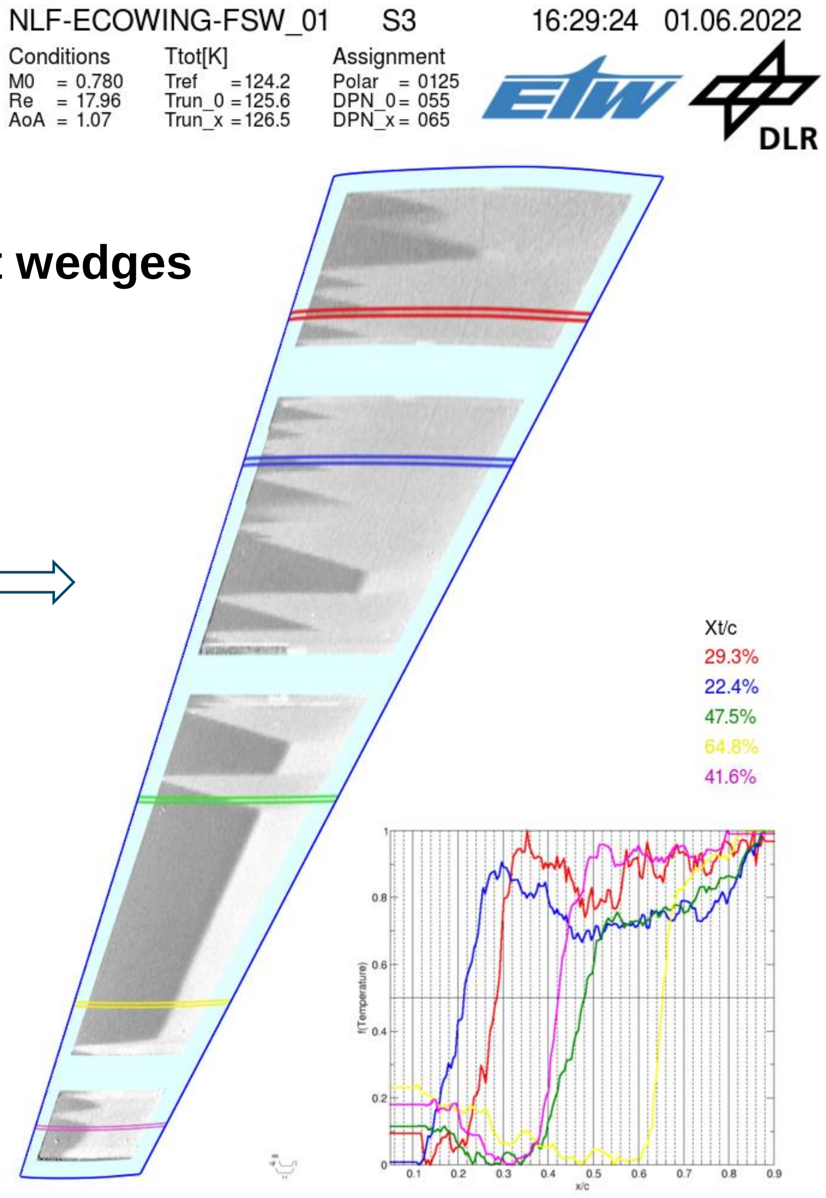




Test Results: Cruise Range

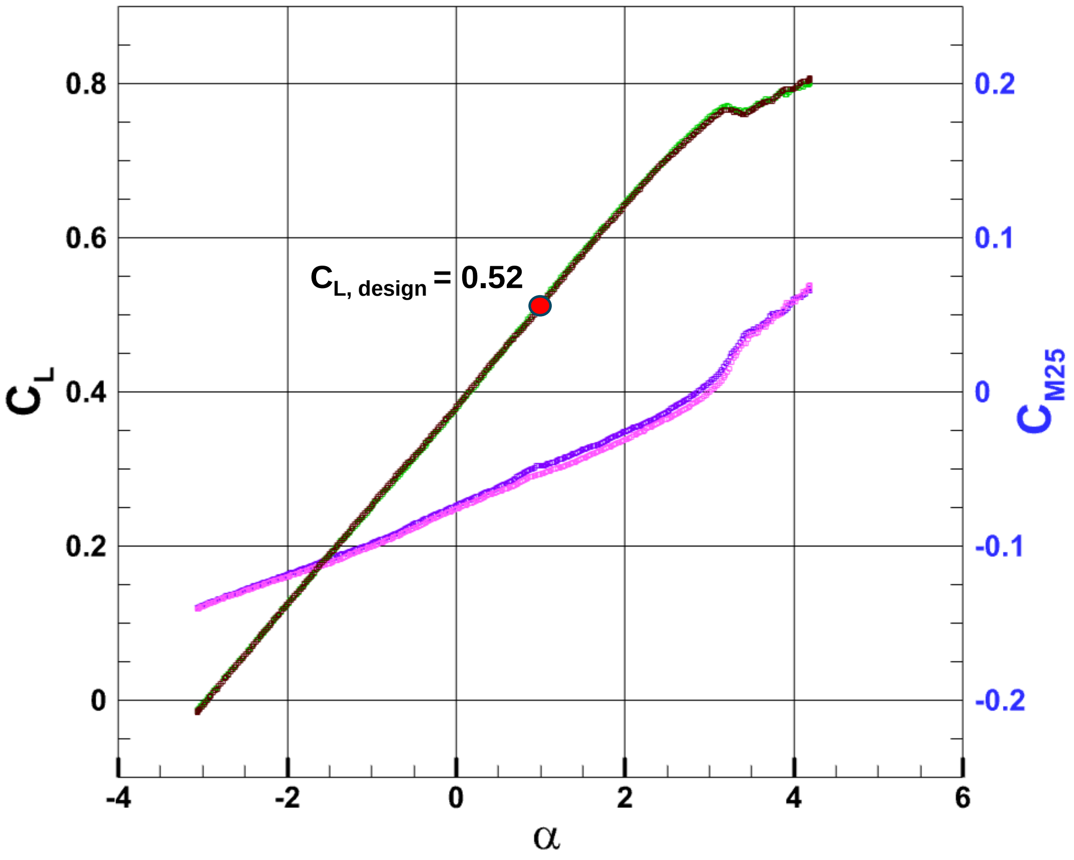
M = 0.78, Re = 18 mil.
Lift still increases (separation limited to root, outboard o.K ?)
TSP partly chipped off during cool down
Tunnel contaminated with small particles
Re had to be reduced in order to mitigate formation of turbulent wedges

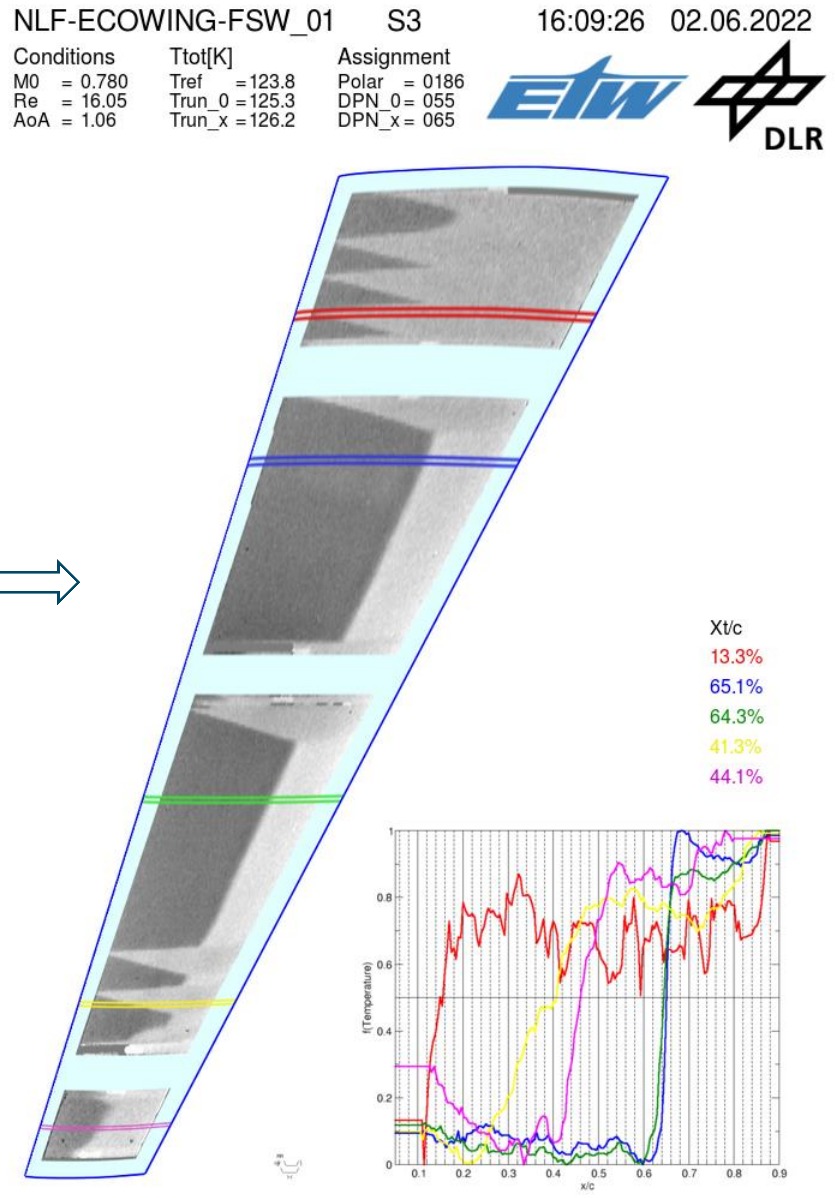




Test Results: Cruise Range

M = 0.78, Re = 16 mil.

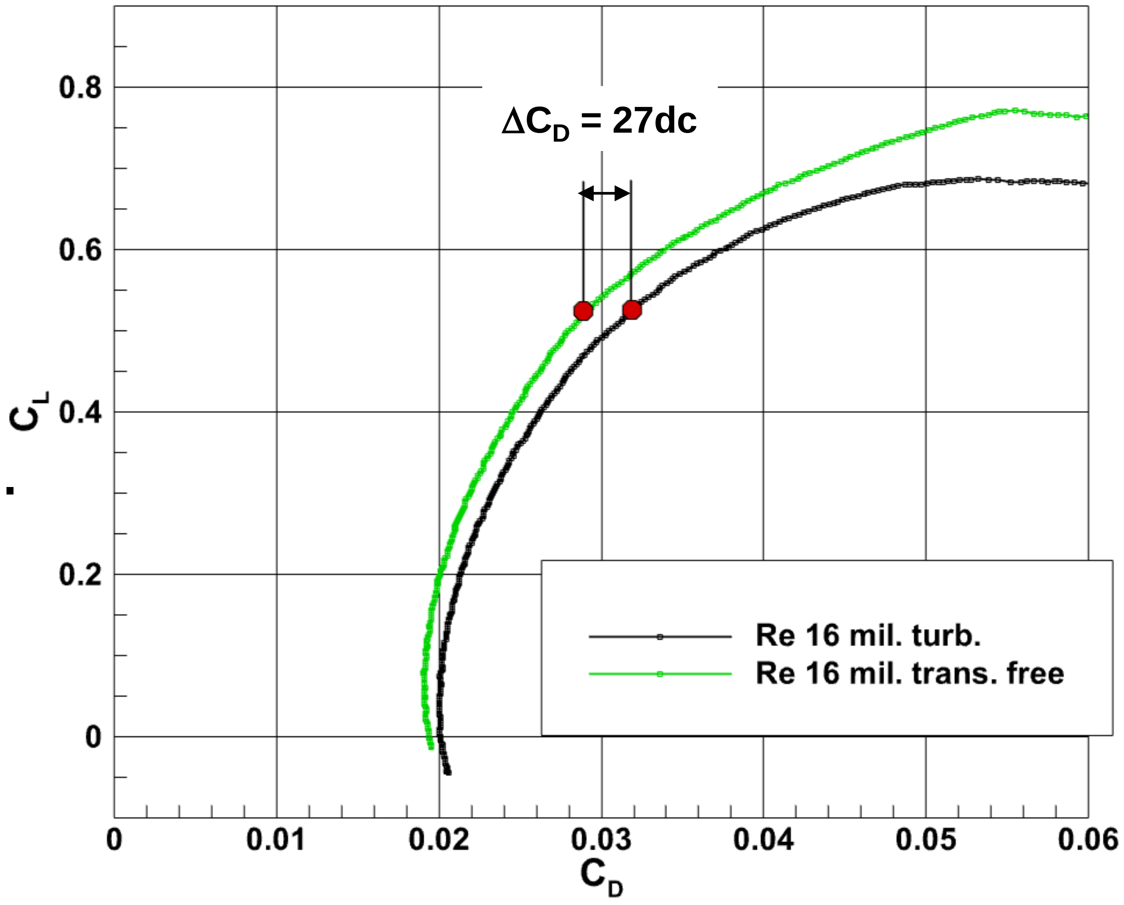




Test Results: Cruise Range

Drag polars at design Mach number M = 0.78, Re = 16 mil.

- **Drag reduction by laminarization at design lift C_L = .52**
  ΔC_D = 27dc ($C_{D,turb}$ = 316dc, $C_{D,lam}$ = 289dc 8.3% gain)
- **But: These are raw data without tunnel corrections**
- **Compared to free flight conditions drag might be higher by up to 22% due to tunnel blockage effects**
  (see: Gross, N., Quest, J.: *THE ETW WALL INTERFERENCE ASSESSMENT FOR FULL AND HALF MODELS., AIAA 2004-0769, 2004)*
- **Reynolds number is Re = 16 mil. instead of Re = 24 mil.**
  Re correction of C_D is also necessary
  Difference shown exemplarily for Re = 10mil and 16mil



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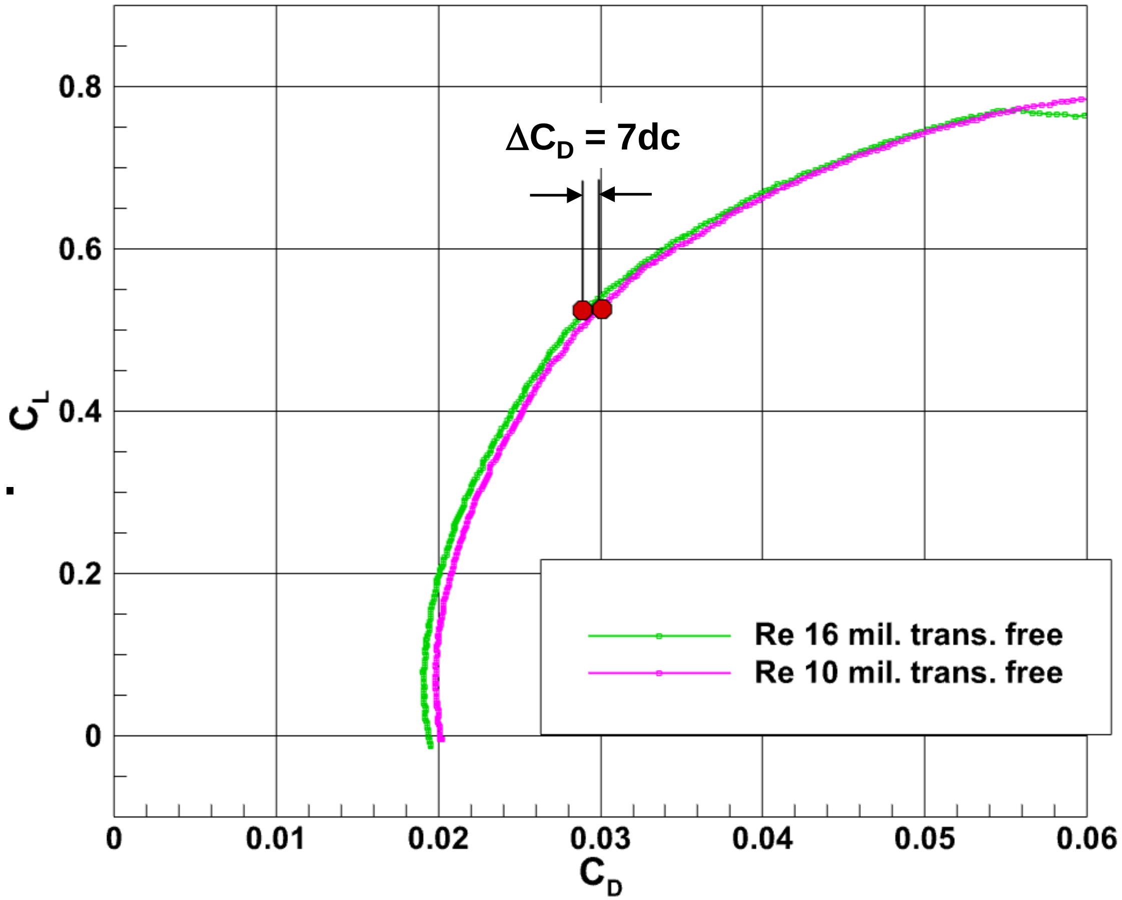

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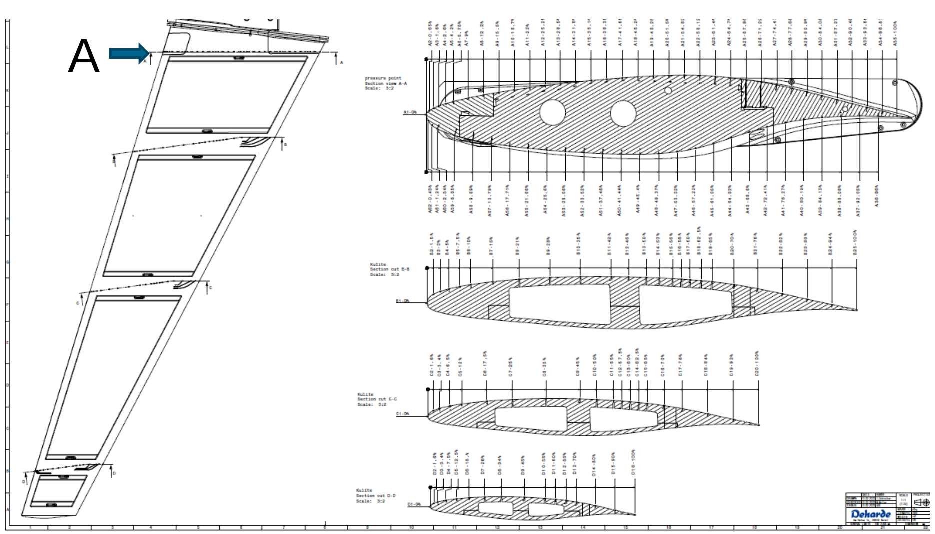
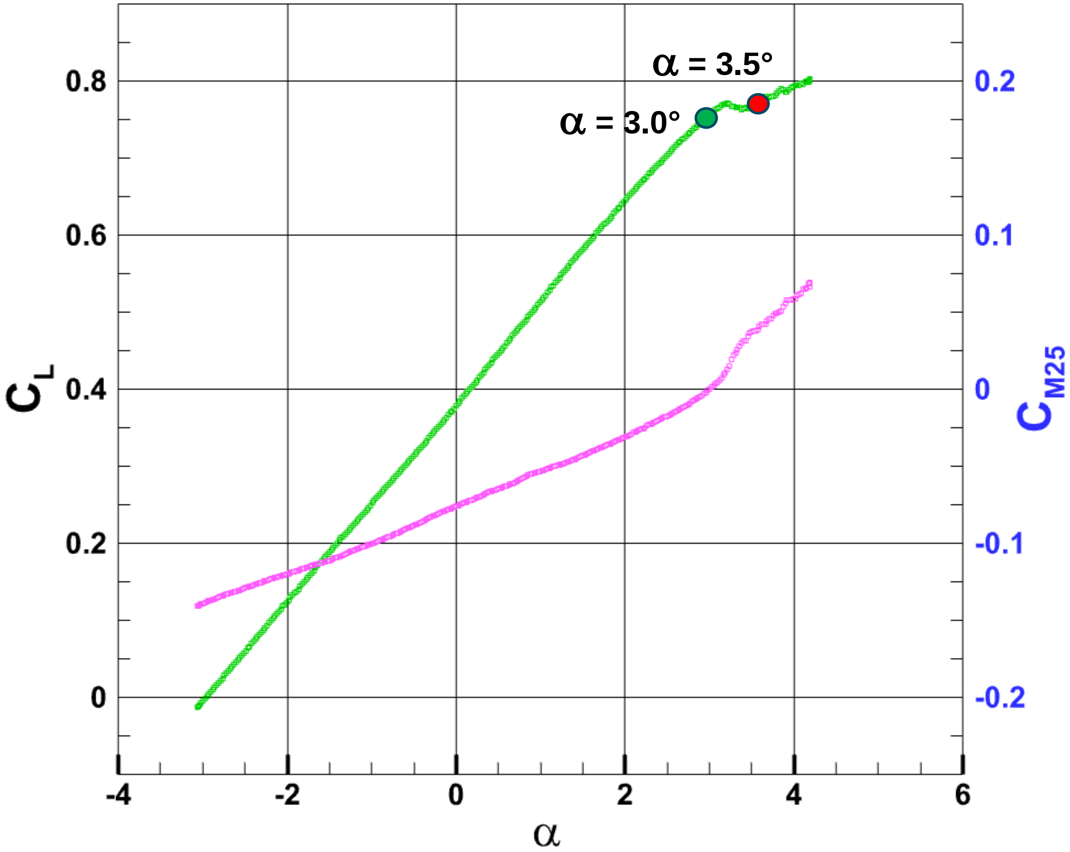
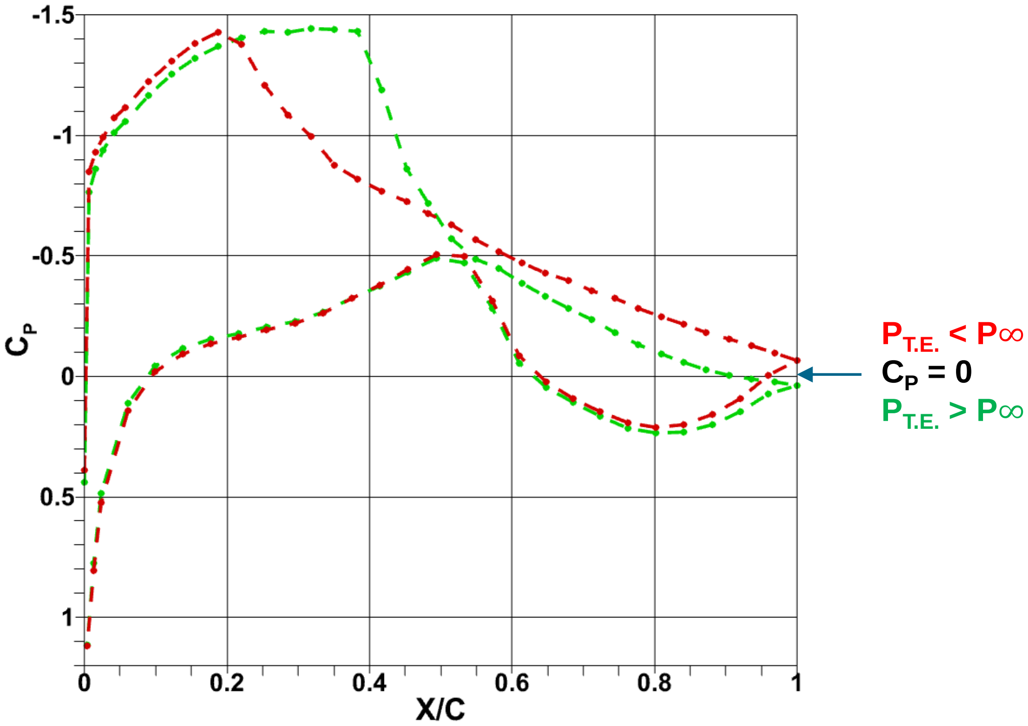


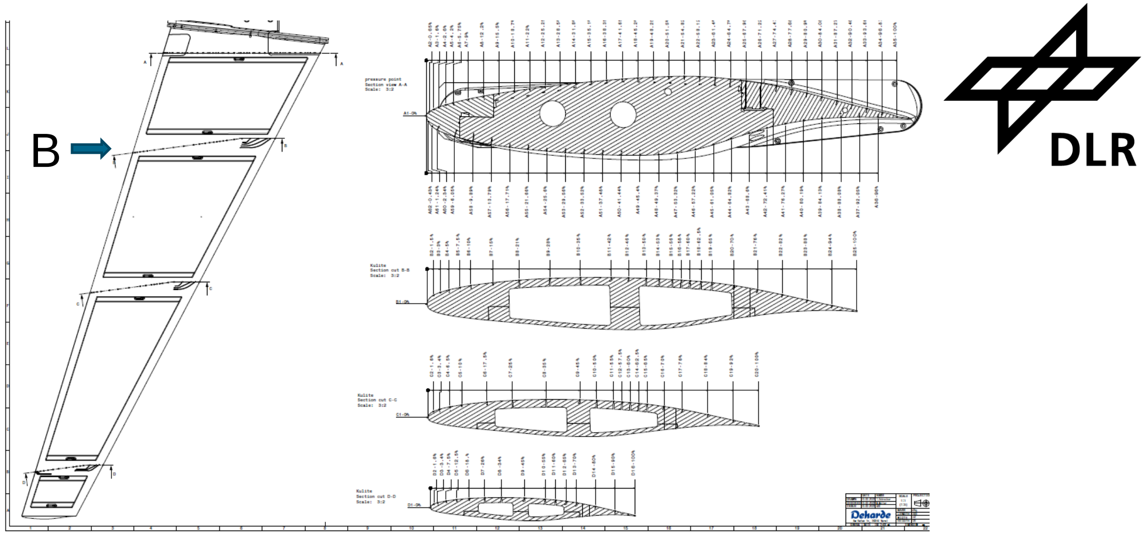
M = 0.78, Re = 16 mil.: Onset of separation
Check of trailing edge pressure in section A

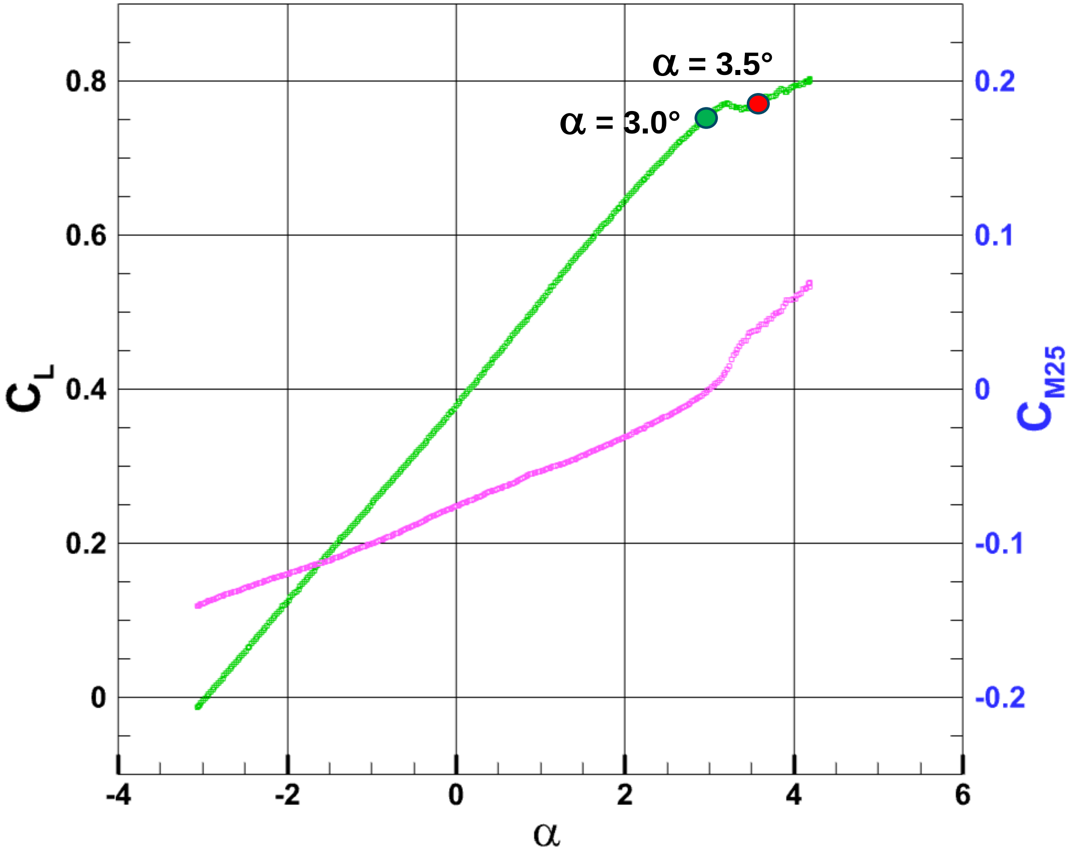


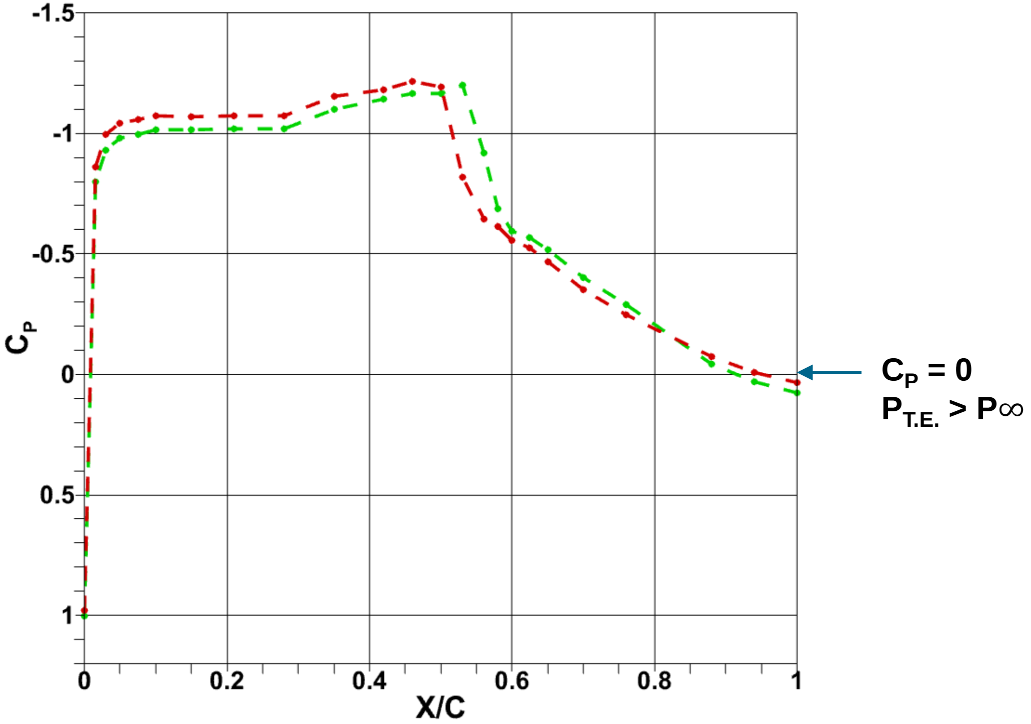


Test Results: Cruise Range

M = 0.78, Re = 16 mil.: Onset of separation
Check of trailing edge pressure in section B

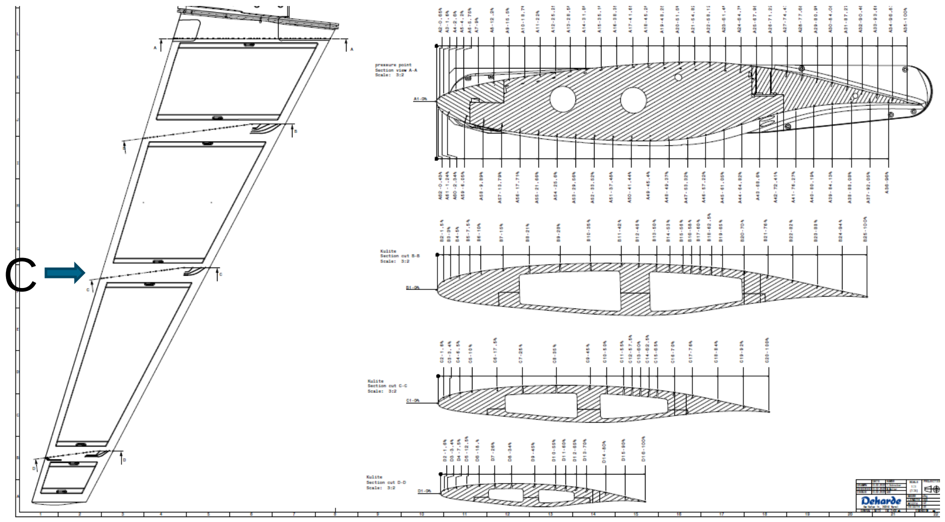


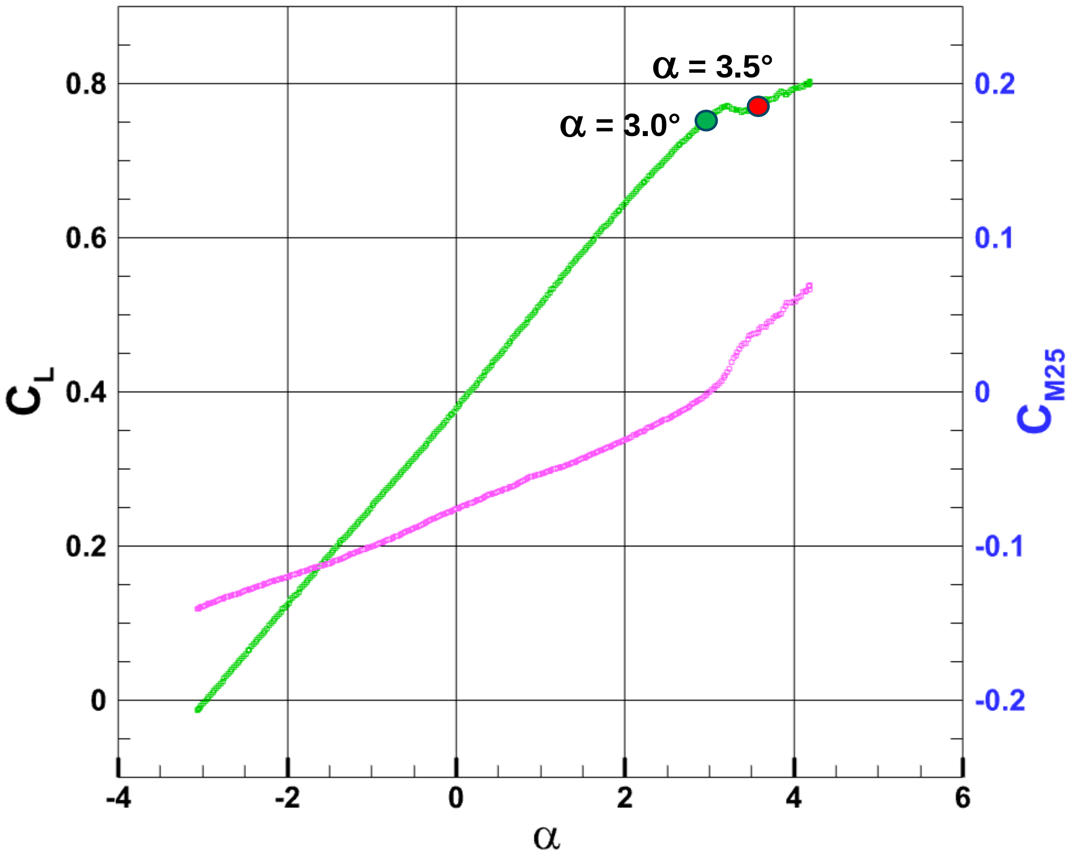


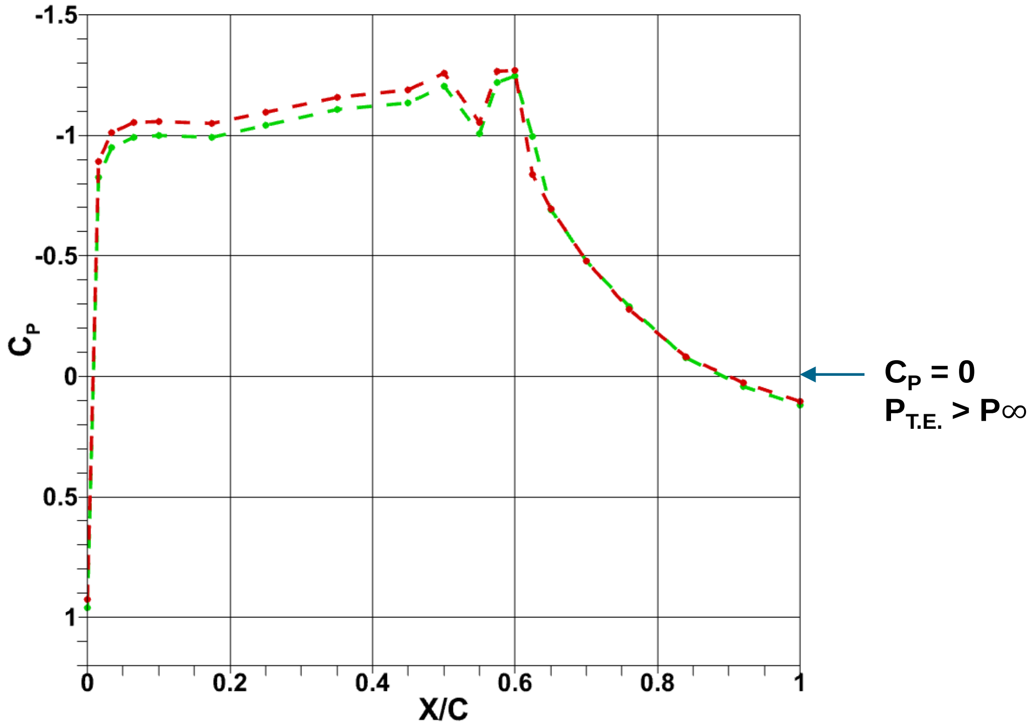


Test Results: Cruise Range

M = 0.78, Re = 16 mil.: Onset of separation
Check of trailing edge pressure in section C







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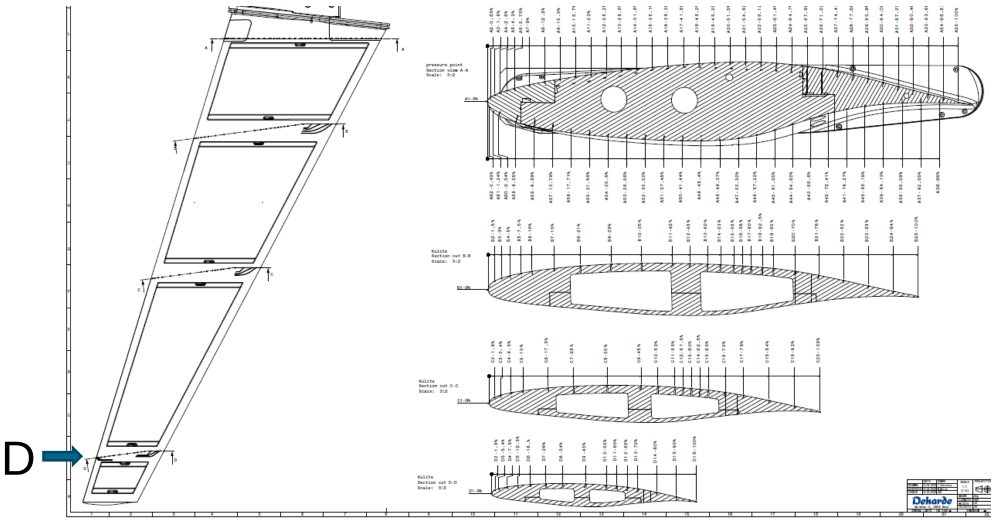
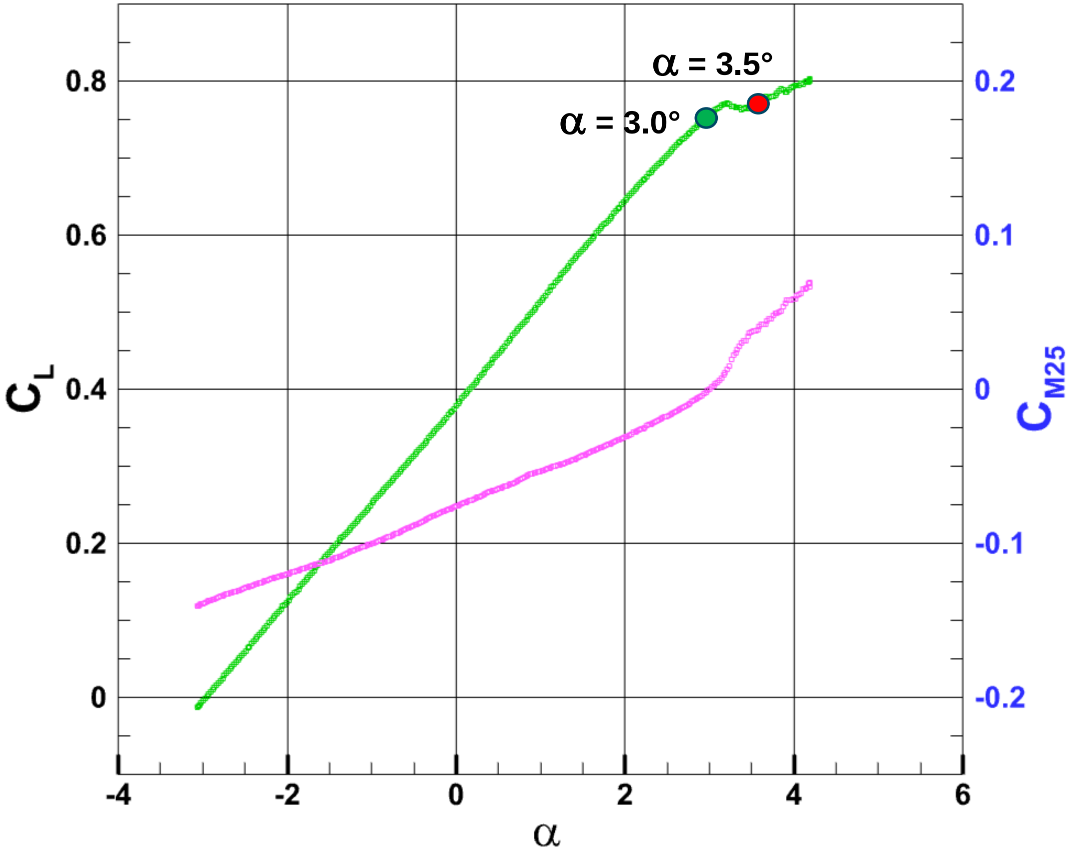
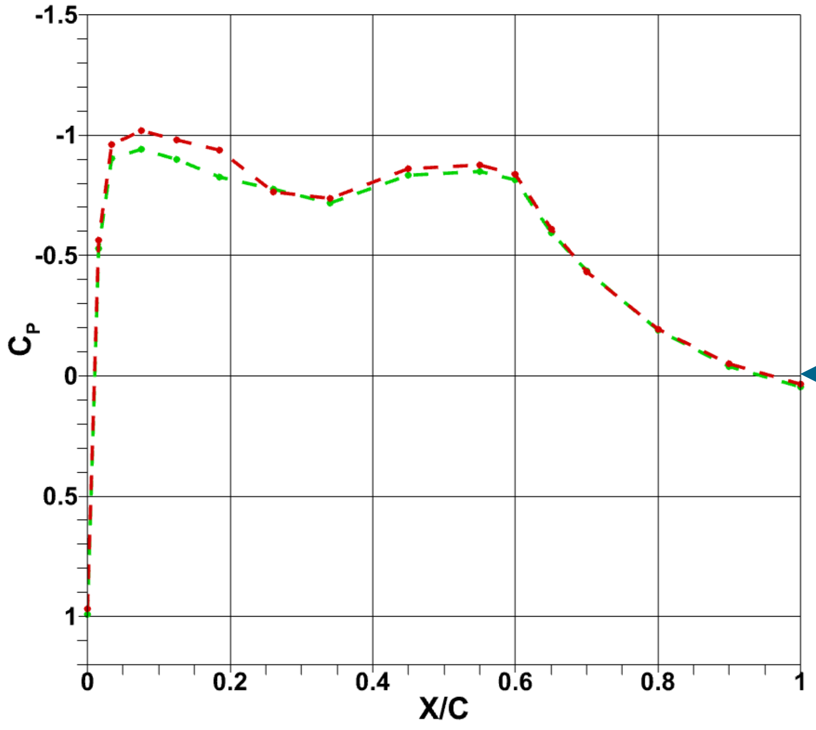


M = 0.78, Re = 16 mil.: Onset of separation
Check of trailing edge pressure in section D

Conclusions:

- **Separation starts at root**
- **Flow about midboard and outboard sections still attached**
- **More detailed investigation with CFD necessary**

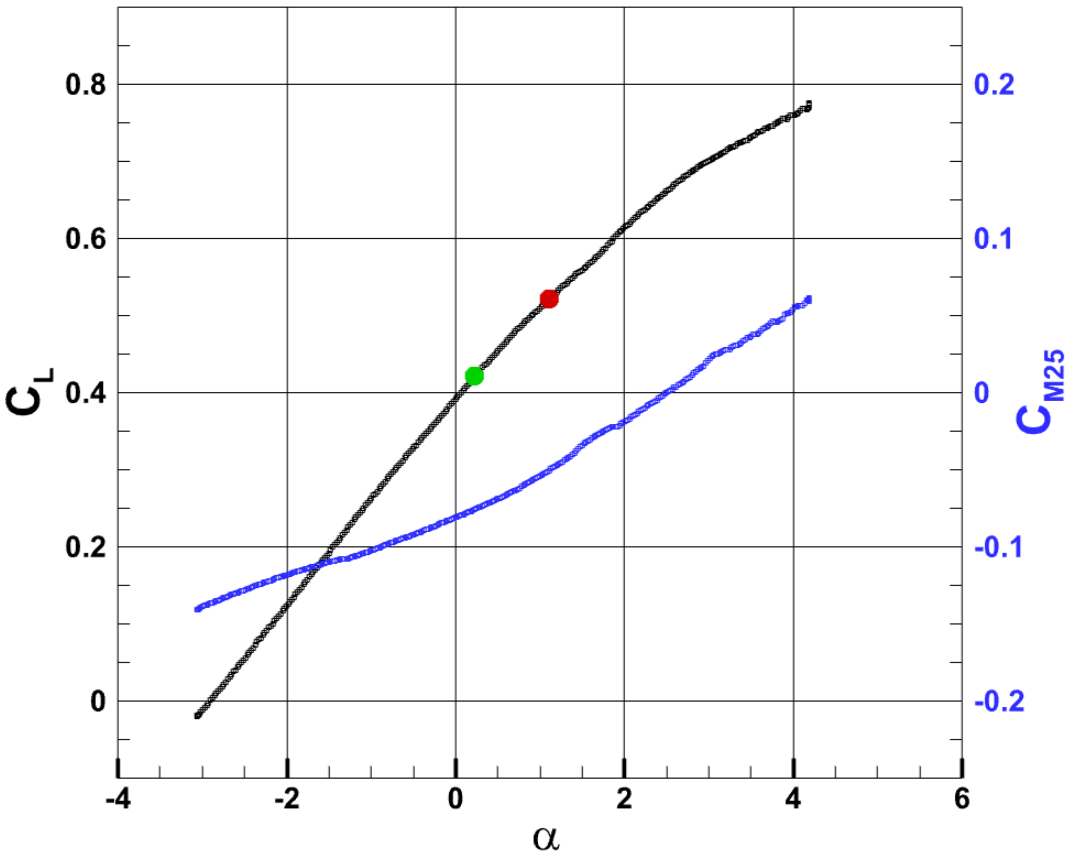


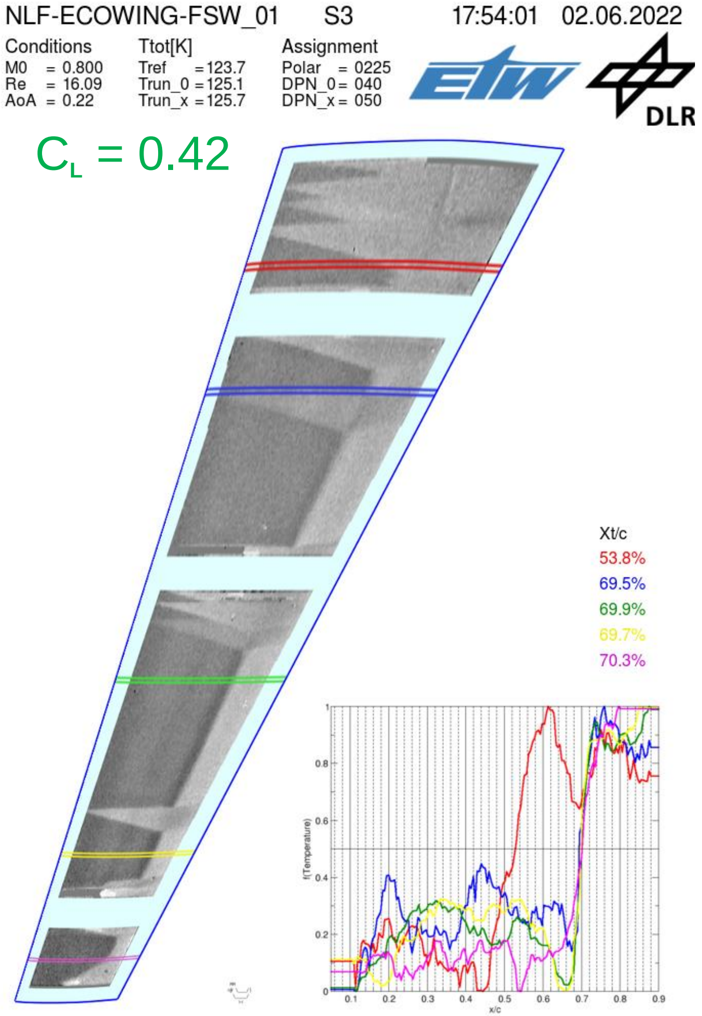


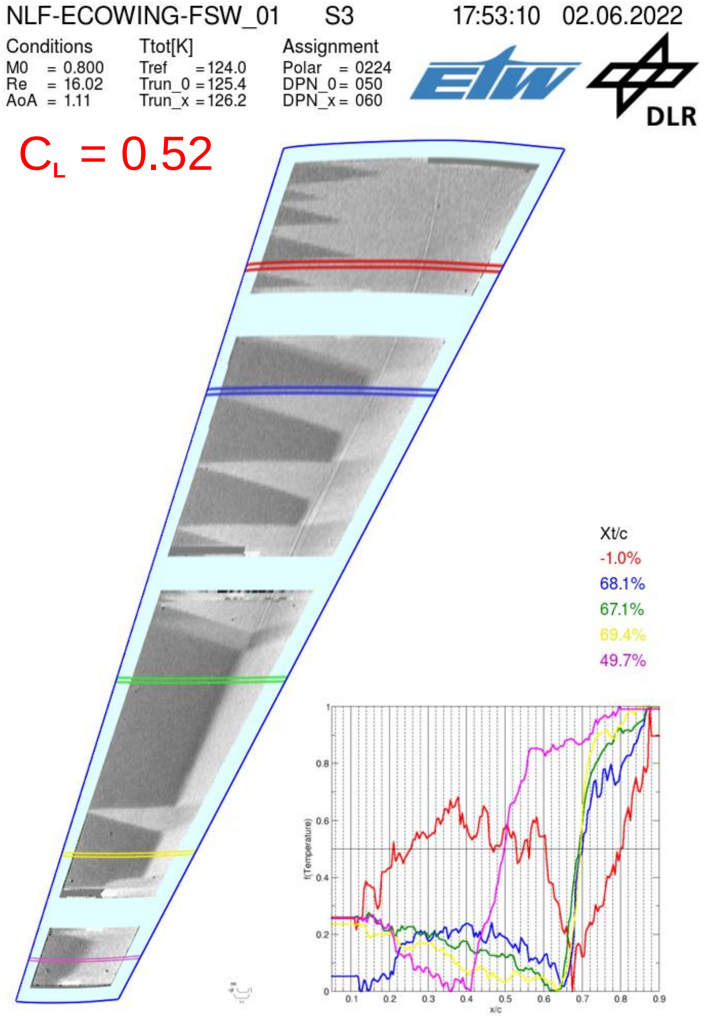
$C_P = 0$
$P_{T.E.} > P_\infty$

Test Results: Cruise Range Upper Branch

M = 0.80, Re = 16 mil.



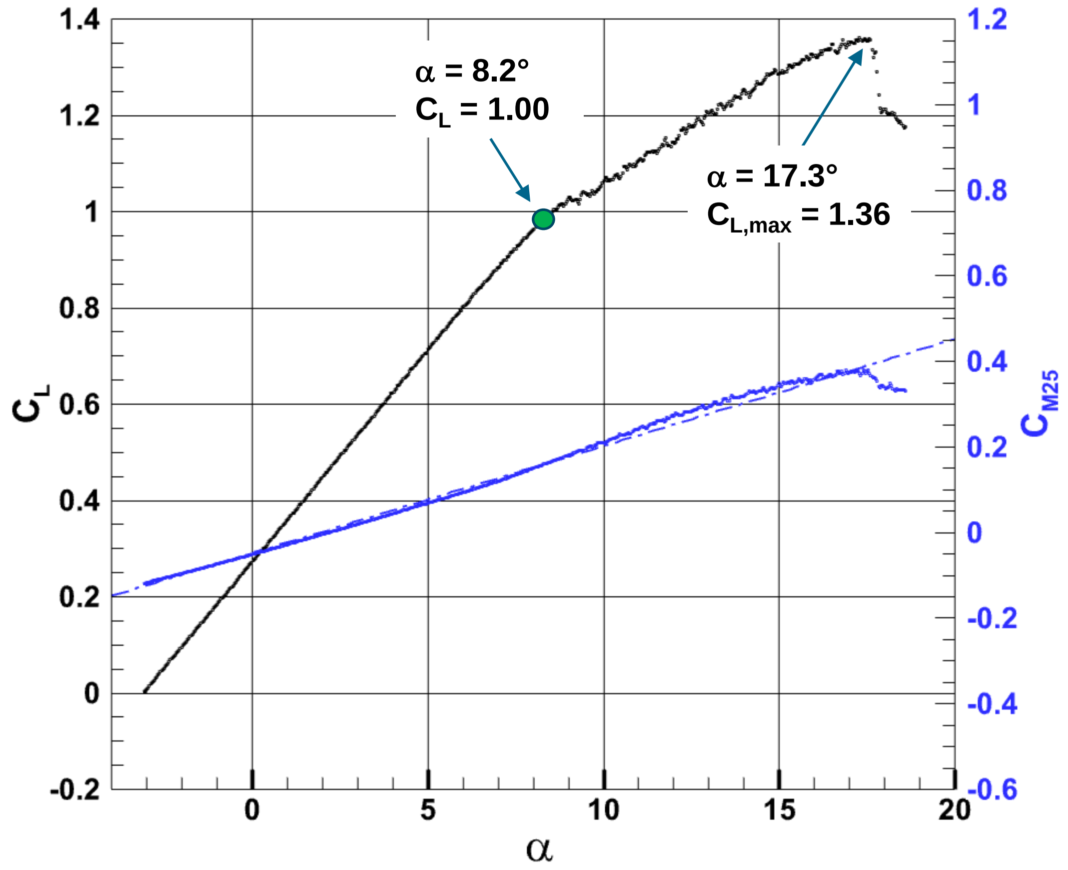


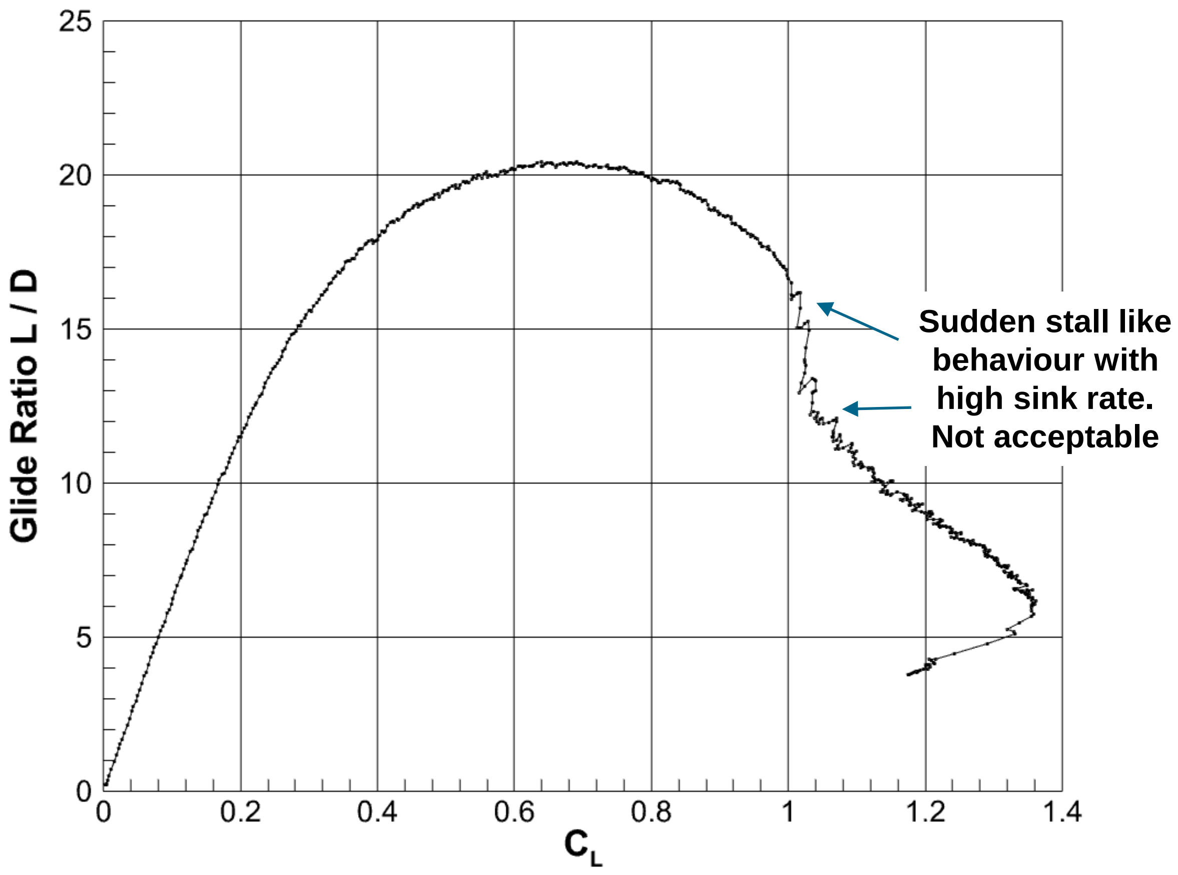


Test Results: Low Speed Lift Curve and L/D

M = 0.2, Re = 14 mil., clean configuration

Conclusion
Improvement of belly-fairing necessary to avoid premature separation at wing root





Summary and Outlook

Summary

- **The concept of a FSW-NLF wing for design M = 0.78 was succesfully verified in ETW test runs**
- **Polars show a substantial drag reduction due to b.l. laminarization**
- **Improvements regarding onset of separation seem to be possible**

Outlook

- **Application of wind tunnel corrections for precise evaluation of performance data**
- **Comparison with CFD results (polars, section pressure distributions etc.)**
- **Assessment of FSW-NLF performance on OAD level (block fuel savings compared to A320 type SMR)**
- **Redesign of belly-fairing to improve stall behavior especially at low speed in clean configuration**