EUROLIFT Test Case Description for the 2nd High Lift Prediction Workshop

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CFD High Lift Prediction Workshop

Outline

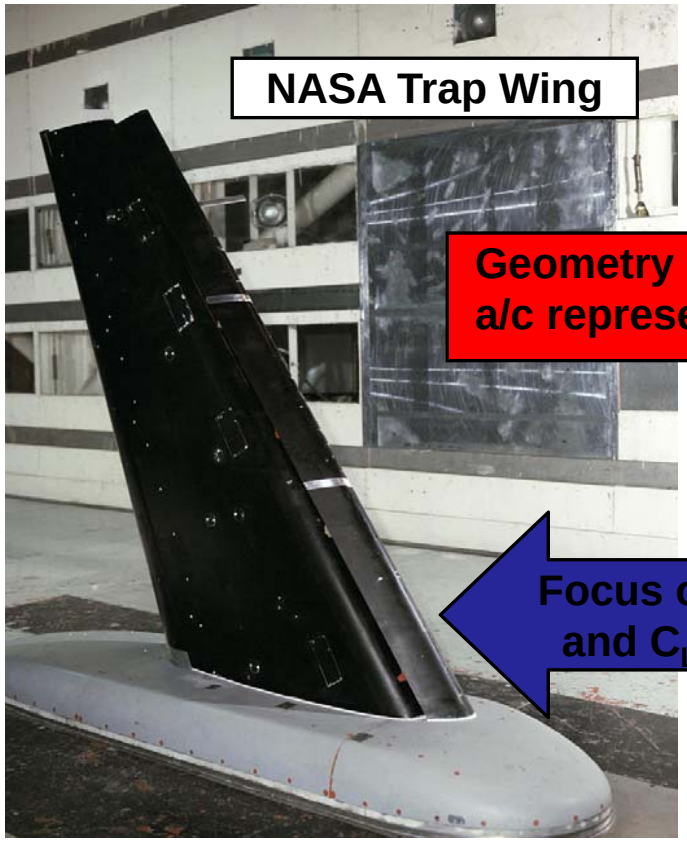
- Motivation and objective (now and then)
- DLR-F11 (KH3Y) configuration, CAD-model, and windtunnel test set-up
- Experimental results for low Reynolds number conditions (B-LSWT)
  - Pressure distributions at and beyond $C_{L,max}$
  - Oil flow evidence - separation locations and extent
  - Off-body velocity fields by PIV
  - Transition detection by IR and HF
- Experimental results for high reynolds number conditions (ETW)
  - Pressure distributions at and beyond $C_{L,max}$
  - Reynolds-number scaling effects
- Conclusion and outlook

EUROLIFT - Objective revisited (AIAA 2003-3794)

- **Deeper *understanding* of 3D high lift flow with special regard to the Re-No dependency of maximum lift up to flight conditions**
- ***Assessment of simulation capabilities* of ‚state-of-the-art' CFD tools on a transport aircraft high lift configuration with special regard to:**
  - **Scatter of results of different numerical approaches**
  - **Capability to simulate maximum lift determining effects**
  - **Prediction of the Re-No. influence using dedicated LSWT and ETW test results**
  - **Prediction of the effect of setting variations**
  - **Simulation of configurative details (increased complexity)**
- **Creation of a suitable *high lift validation database***

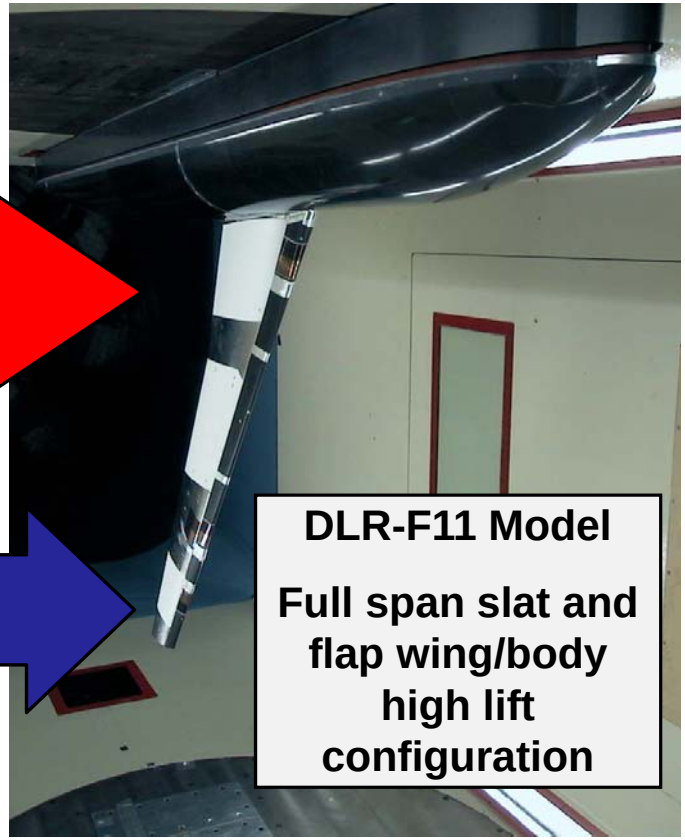
Motivation and Objective within HighLiftPW

Incorporation of Re-No. scaling effects



Geometry step towards more a/c representat. high lift config.

Focus on appr./ldg. settings and C_{Lmax} determination



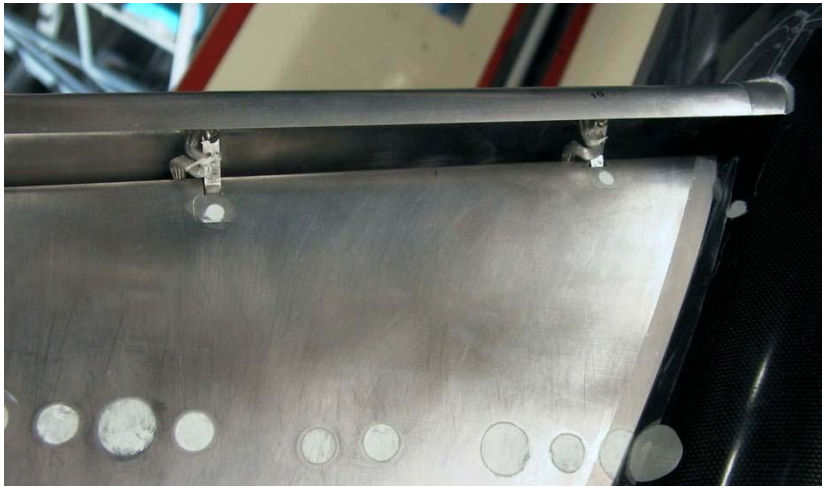
Exploration of existing database

Consideration of more model details

EUROLIFT DLR-F11 Model Stage 0 - KH3Y Specification

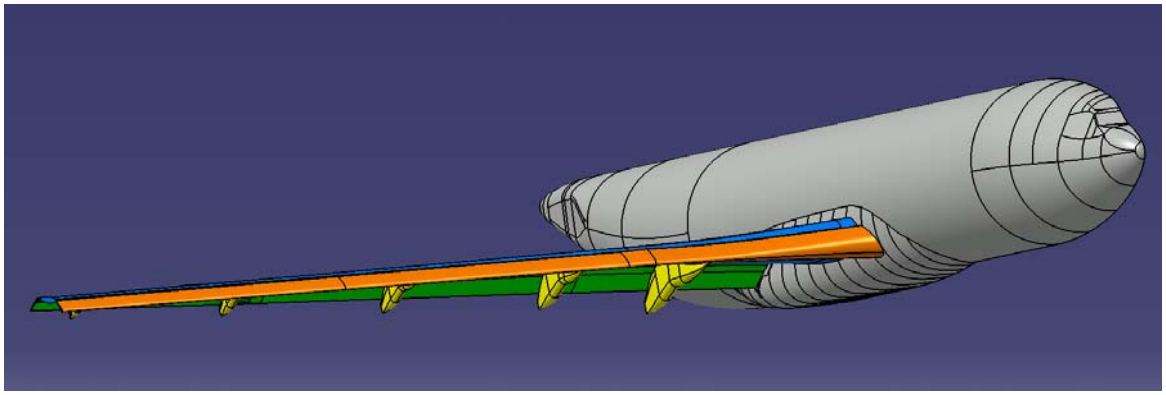
- **Main dimensions and specification of DLR-F11 high lift model:**
  - half span : $s = 1.4$ m
  - wing reference area: $A/2 = 0.42$ m^2
  - reference chord : $c_{ref} = 0.347$ m
  - aspect ratio : $\Lambda = 9.35$
  - taper ratio : $\lambda = 0.3$
  - ¼ chord sweep : $\varphi_{25} = 30^o$
  - fuselage length : $l_{Fu} = 3.077$ m

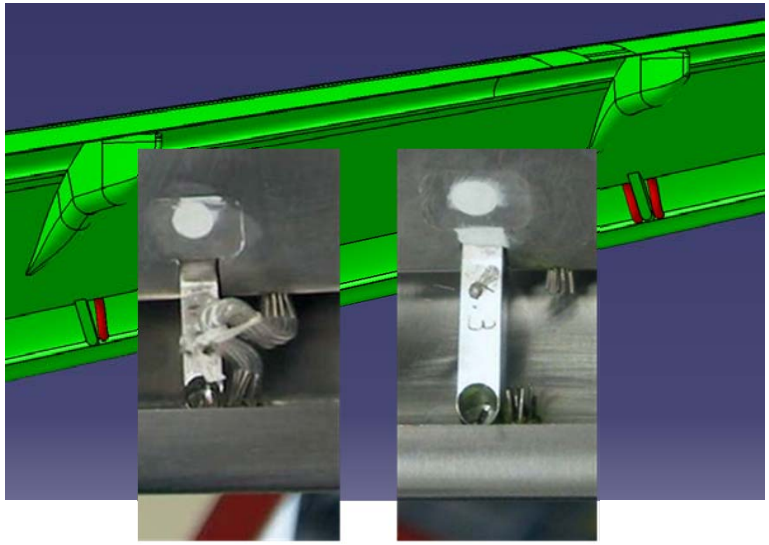
- **High lift system (landing, WP9)**
  - full span slat and flap, no gap at WB junction
  - slat deflection : $\delta_s = 26.5^o$
  - flap deflection : $\delta_f = 32.0^o$
  - no gap at WB junction

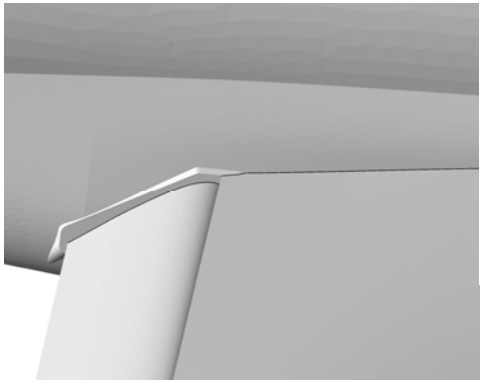


EUROLIFT DLR-F11 Model Stage 0 – CAD Description

- **F11 CAD model refurbished based on model for studies in EC project EUROLIFT:**
  - **consistent with EUROLIFT WB high lift configuration designation is “Stage 0”**
  - **geometrical issues / features see pictures**
  - **optional inclusion through series of CAD datasets**

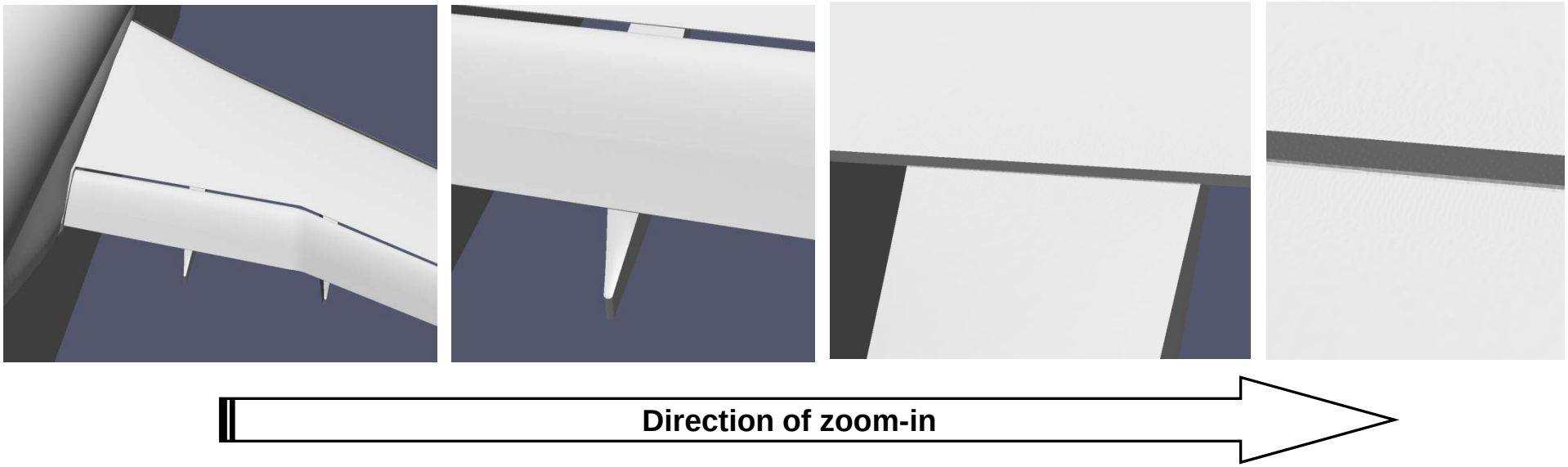






EUROLIFT DLR-F11 Model Stage 0 – CAD Model Variants

- 5 variants with an increasing level of detail have been provided, each with and w/o farfield:
  - Stage 0-1 W/B: aiaa_hl_f11_wbsf.mod.v1_0m.igs
  - Stage 0-2 W/B/SF: aiaa_hl_f11_fsurf_wbsf.mod.v1_0m.igs
  - Stage 0-3 W/B/SF/FTF: aiaa_hl_f11_fsurf_wbsf_ftf.mod.v1_0m.igs
  - Stage 0-4 W/B/SF/FTF/ST: aiaa_hl_f11_fsurf_wbsf_ftf_st.mod.v1_0m.igs
  - Stage 0-5 W/B/SF/FTF/ST/BUN aiaa_hl_f11_fsurf_wbsf_ftf_st_bun.mod.ff.v1_0m.igs
- Edge fillets are optionally available for all variants



EUROLIFT: Wind tunnel Test Campaign in B-LSWT

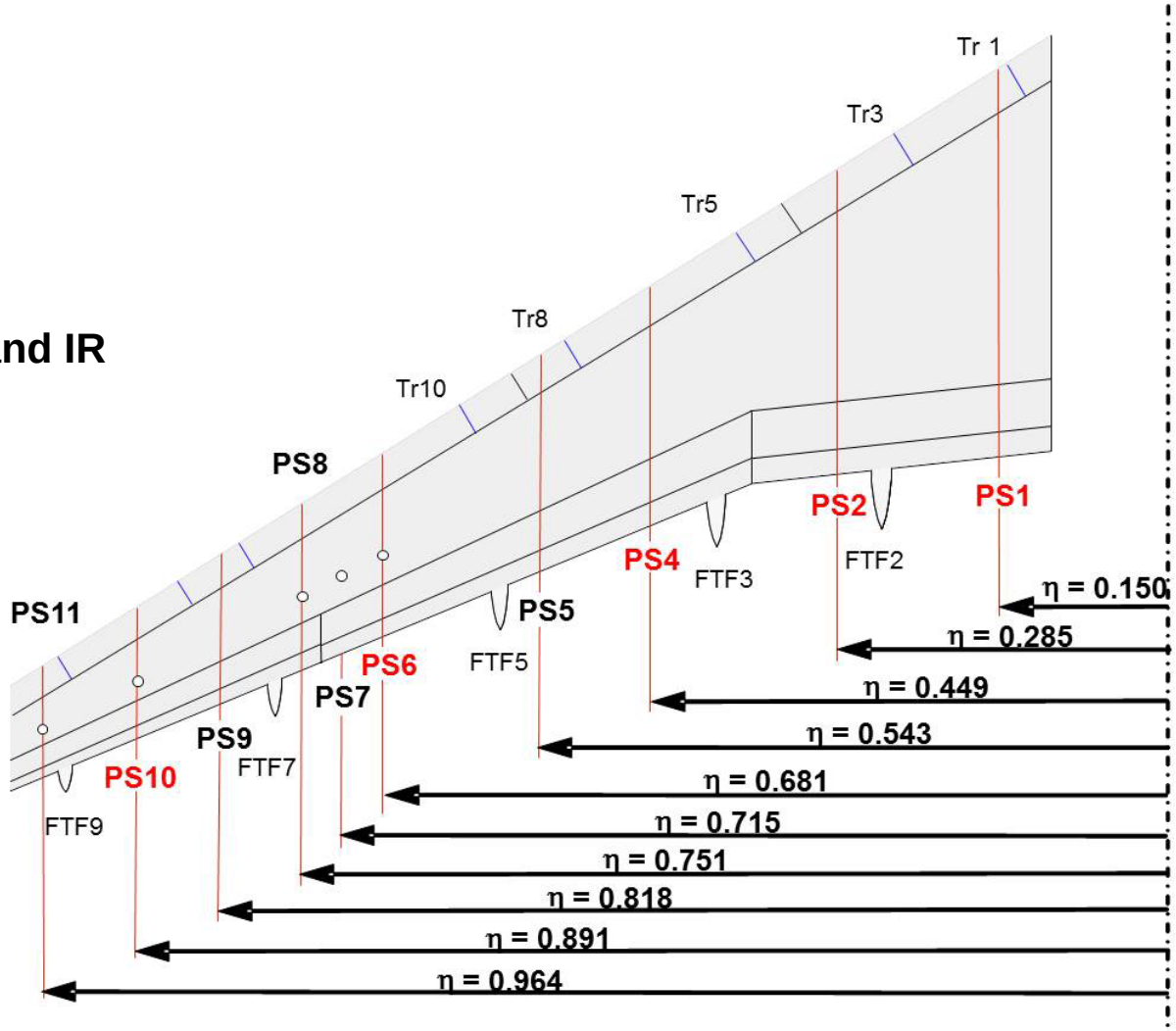
Available experimental evidence:

- Forces, Moments
- Pressure distributions, 10 PS
- Oil flow pictures
- PIV measurements
- Transition information by 4xHFA and IR
- Tuft videos

Onflow conditions:

- atmospheric
- M = 0.175
- Re = 1.35 x 10^6
- α : 0.04° - 20.99°

Test section dimension: 2.1 x 2.1 m



EUROLIFT: Wind tunnel Test Campaign in B-LSWT

Available experimental evidence:

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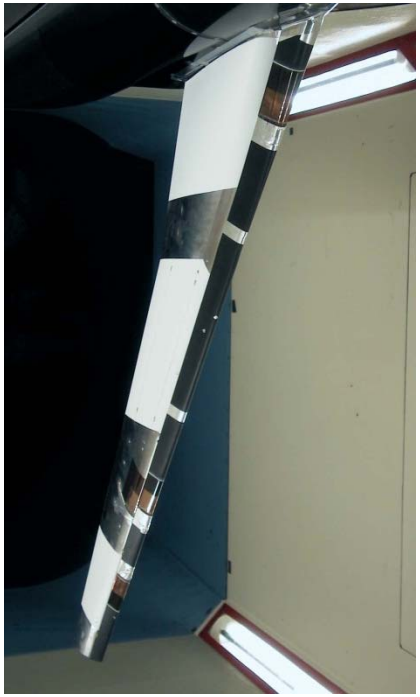
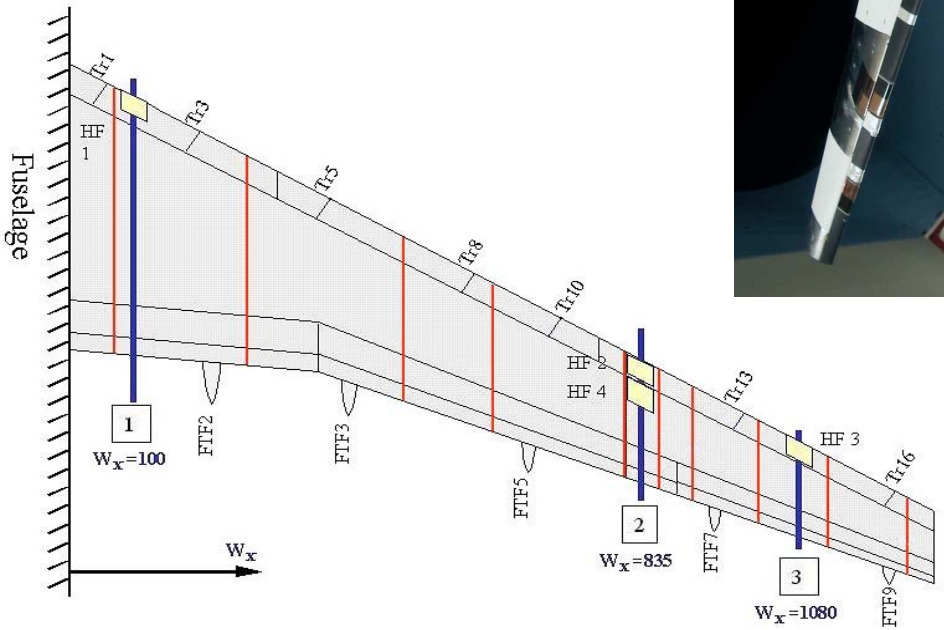


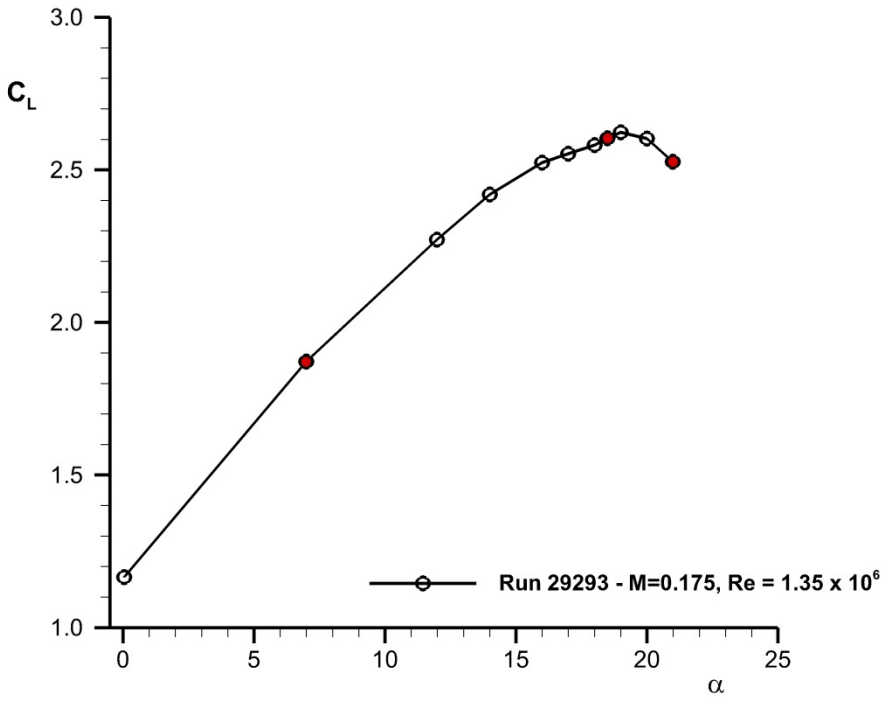


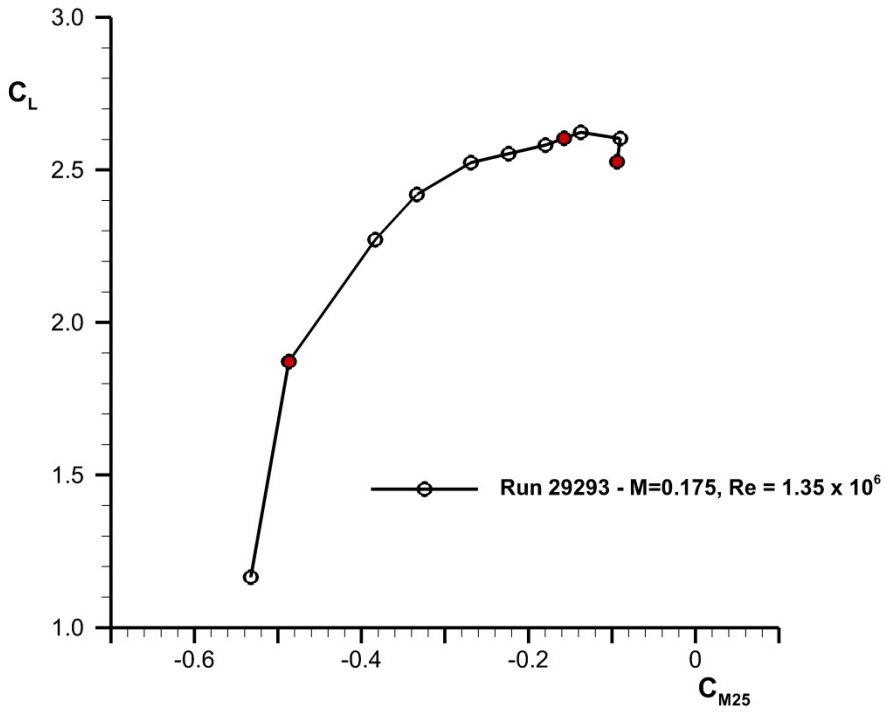
Available experimental evidence vs angle of attack:

α	F&M	C_p	Oilflow	Hotfilm	IR	PIV	Tufts
0.04°	x	x		x	x		Video Tape
6.99°	x	x	x	x	x	x	
11.98°	x	x		x	x	x	
14.00°	x	x		x	x		
16.00°	x	x		x	x	x	
17.00°	x	x		x	x		
18.00°	x	x		x	x		
18.49°	x	x	x	x	x	x	
19.00°	x	x		x	x		
20.00°	x	x		x	x		
20.99°	x	x	x	x	x	x	

Lift and pitching moment curve:

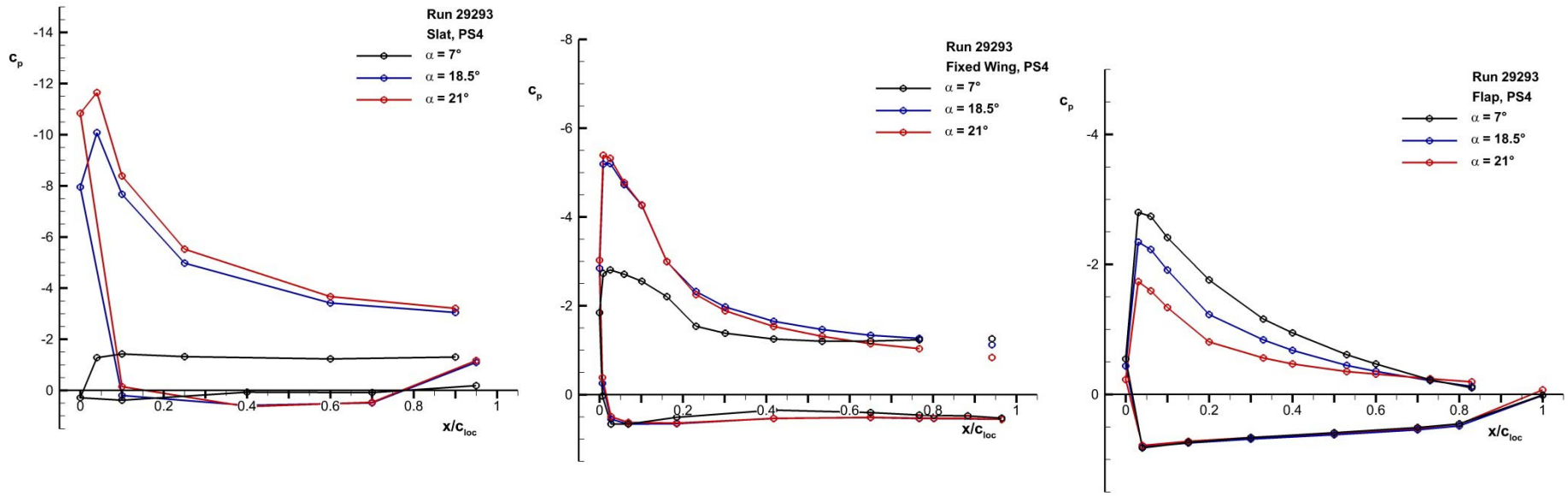
- **Reference angles of attack marked**





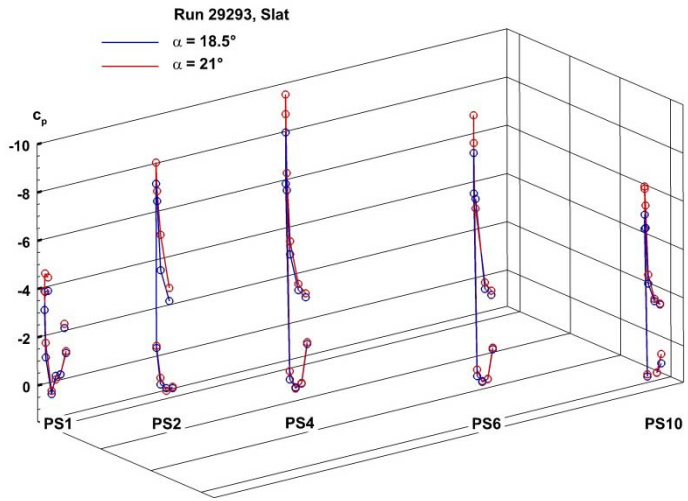
Pressure distributions:

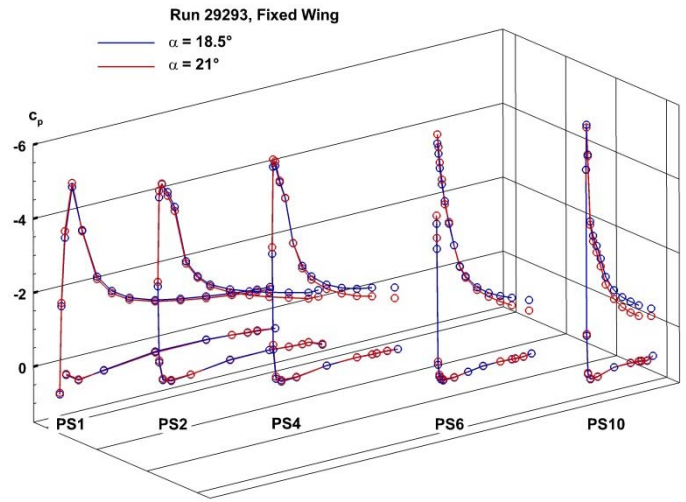
- **Reference angles of attack**

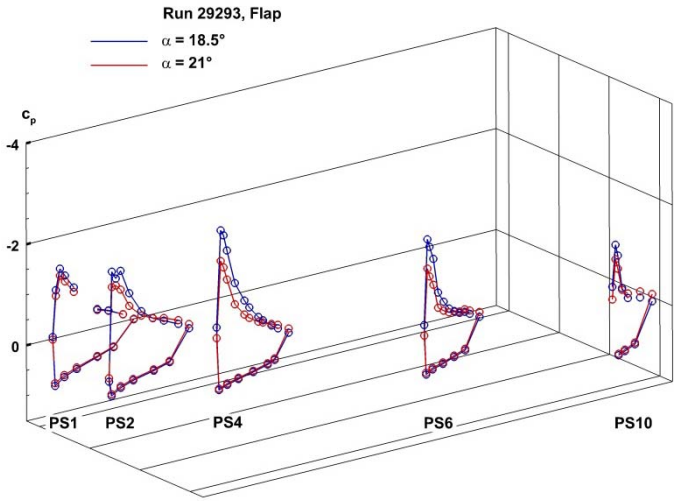


Pressure distributions lined up along span:

- At C_{Lmax} and beyond lift breakdown



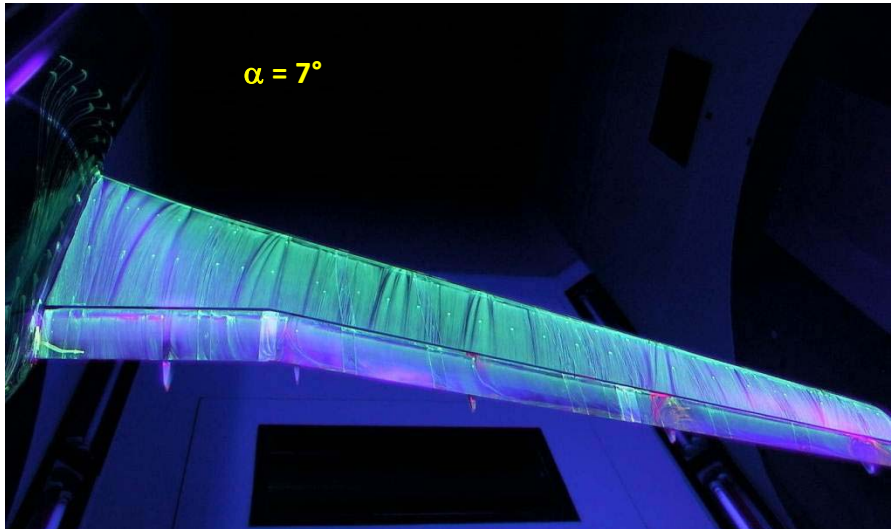


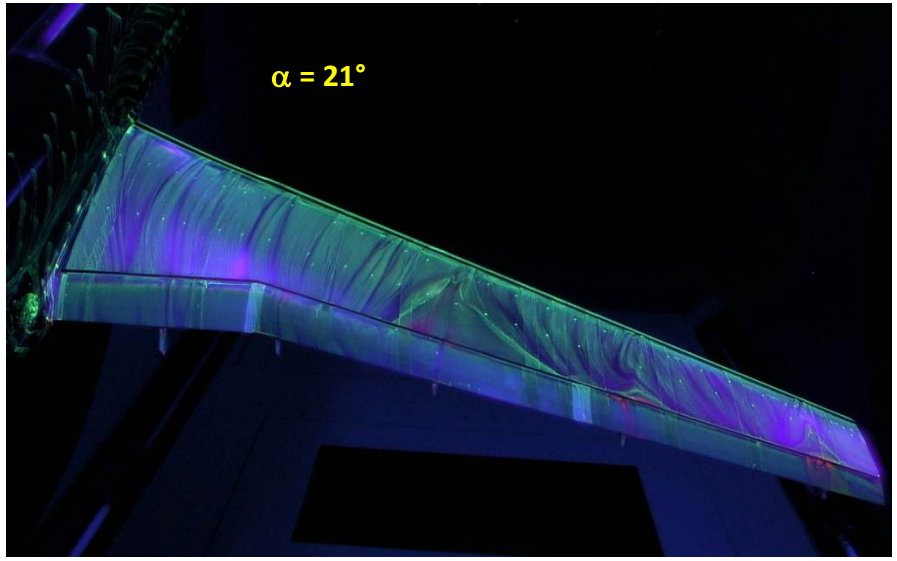


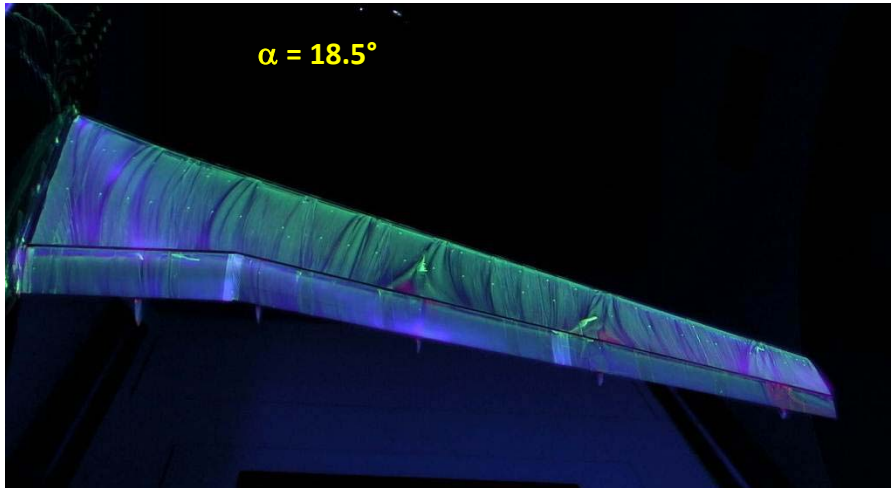
EUROLIFT: Wind tunnel Test Campaign in B-LSWT

Oil flow pictures:

- Reference angles of attack
- Separation starts midboard aft part of wing
- Interference with slat track wake possible

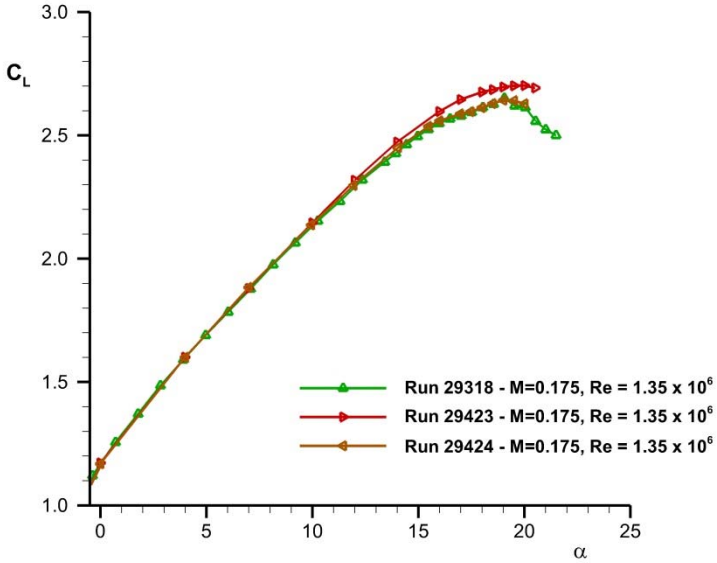


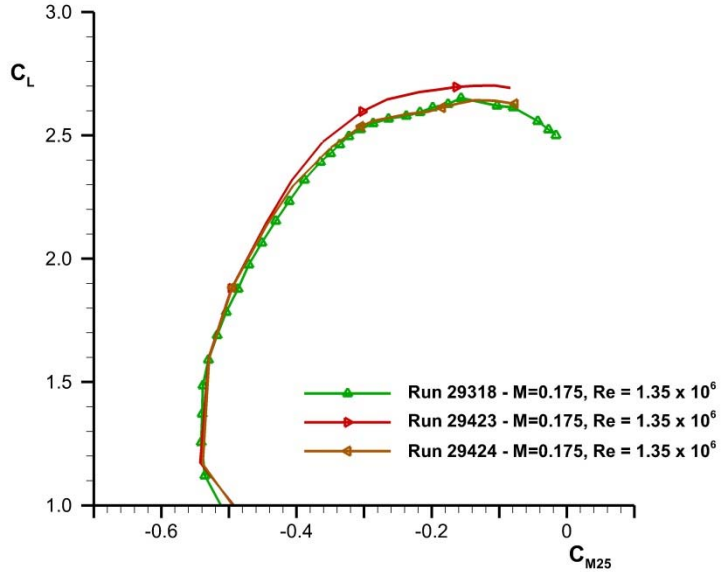




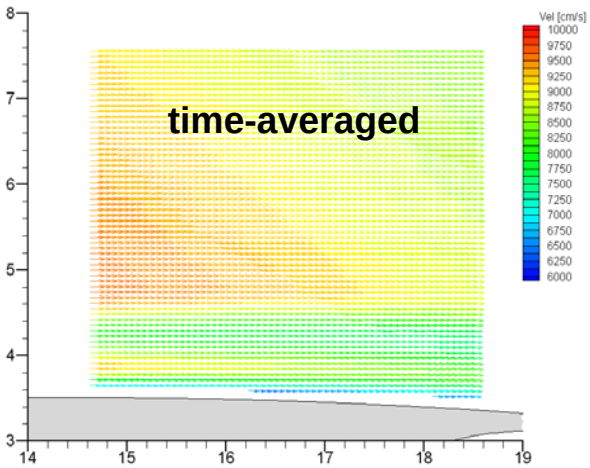
Lift and pitching moment curve:

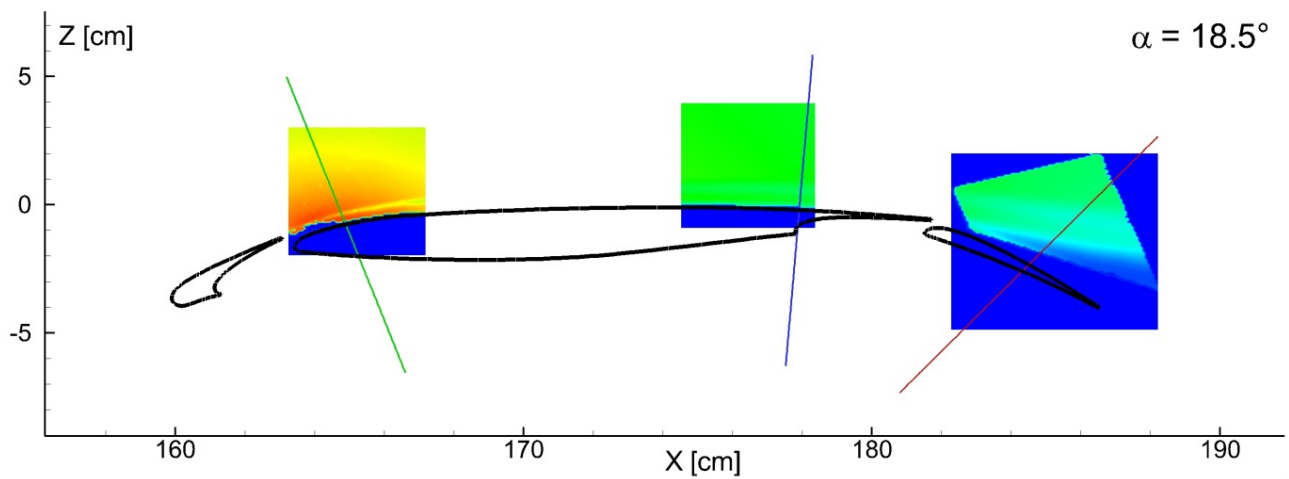
- **Pressure tube bundle influence**

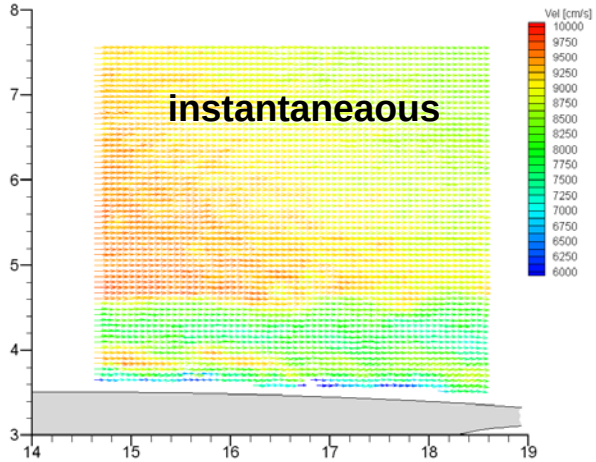


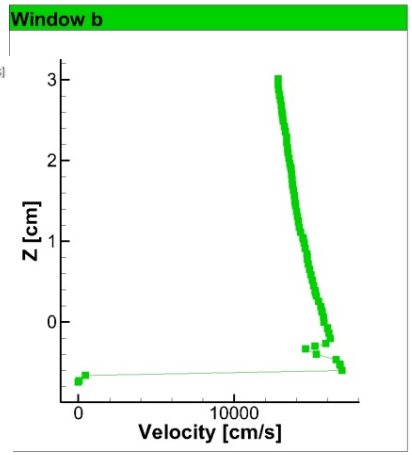


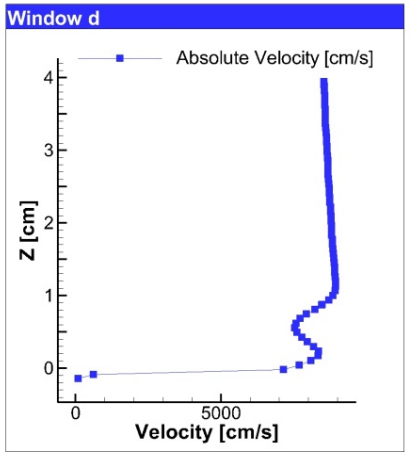
PIV image refurbishment, plane 2:

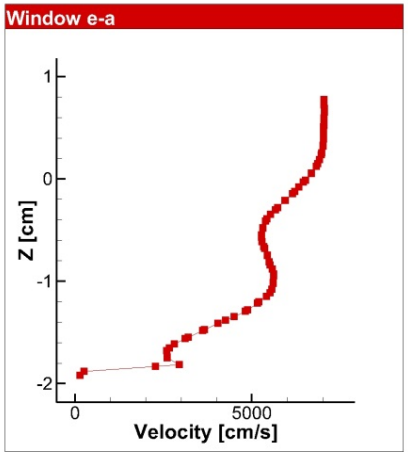






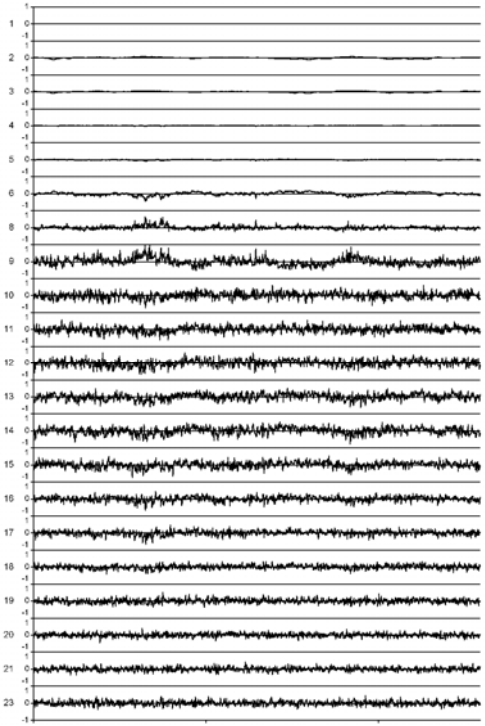


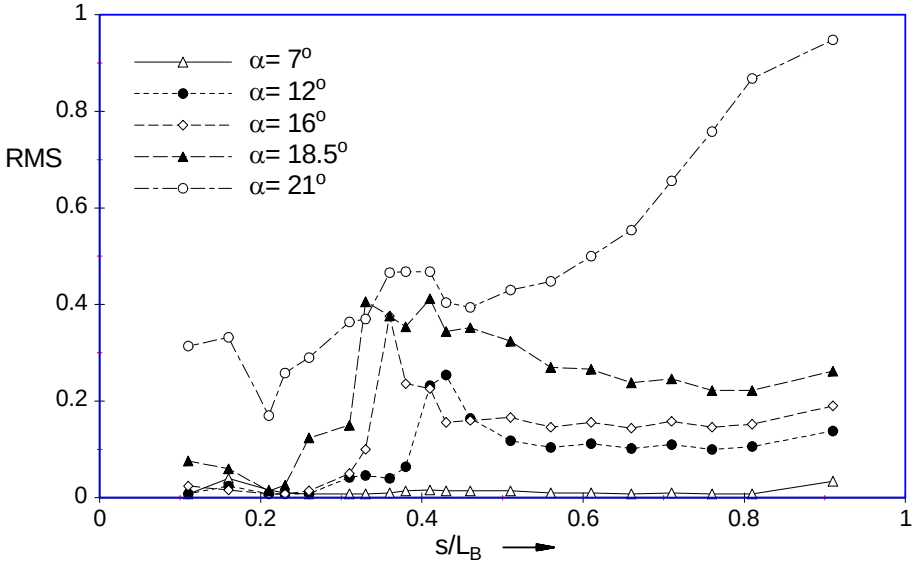


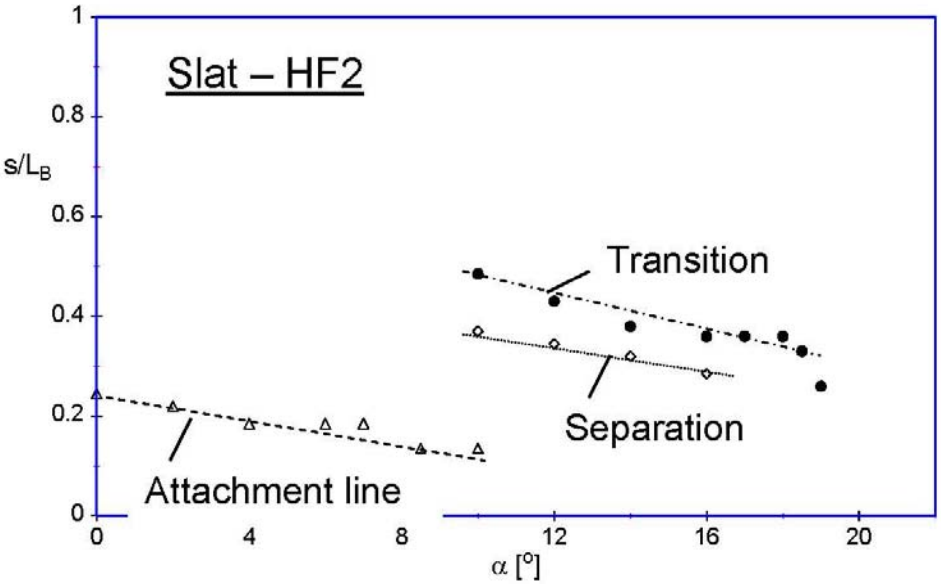


Rudnik, AIAA-2012-2924

HF data and analysis, section 2, slat:





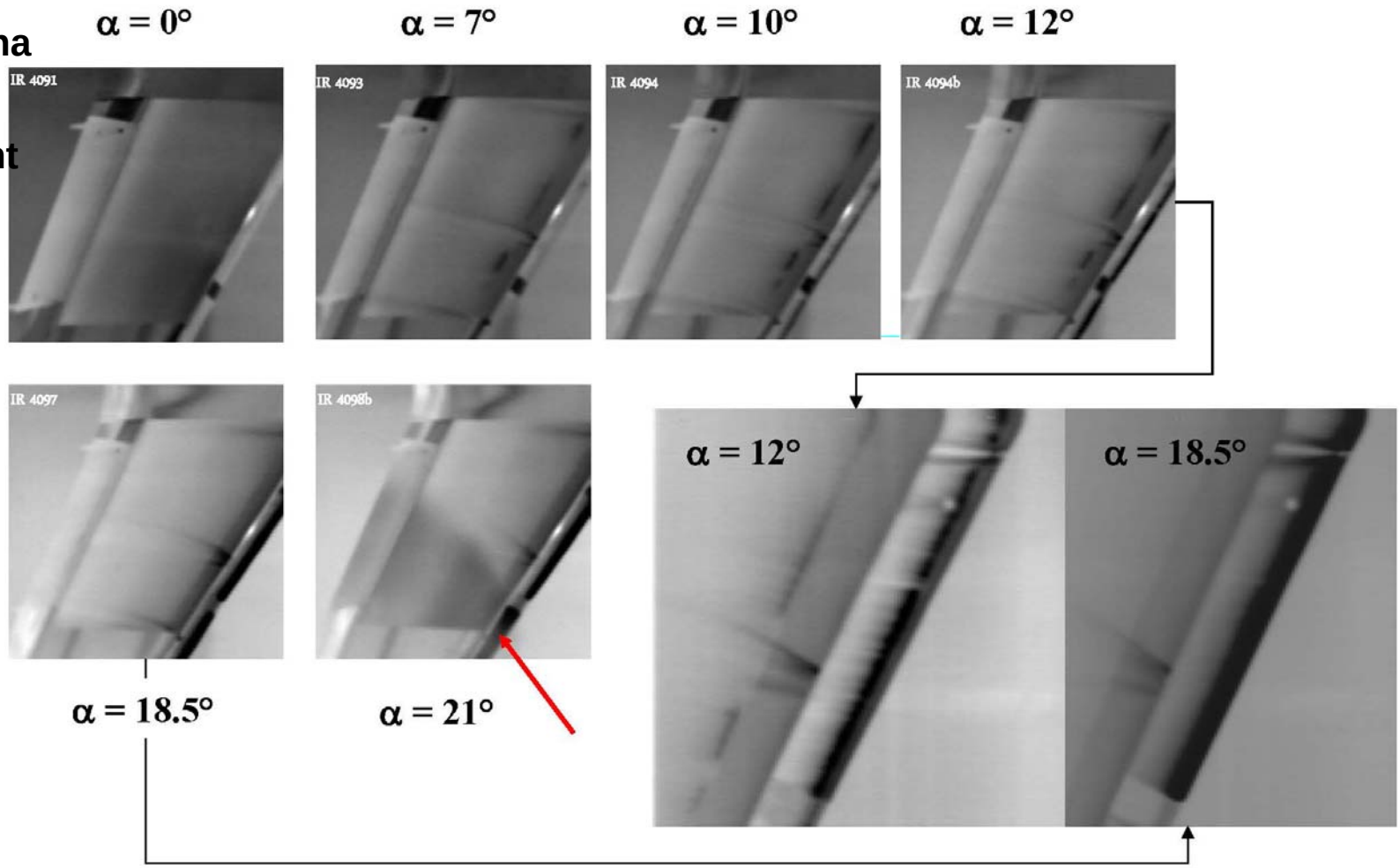


Rudnik, AIAA-2012-2924

EUROLIFT: Wind tunnel Test Campaign in B-LSWT

IR images:

- different perspectives
- US and LS
- some phenomena identified
- needs consistent interpretation
- With HF, PIV



EUROLIFT: Wind tunnel Test Campaign in ETW

Available experimental evidence:

- Forces, Moments
- Pressure distributions, 10 PS
- IR- limited (t.b.c.)
- Tuft videos (t.b.c.)

Onflow conditions:

- cryo and pressurized
- M = 0.176
- Re = 1.51×10^6
- α : -3.2° - 24.24°

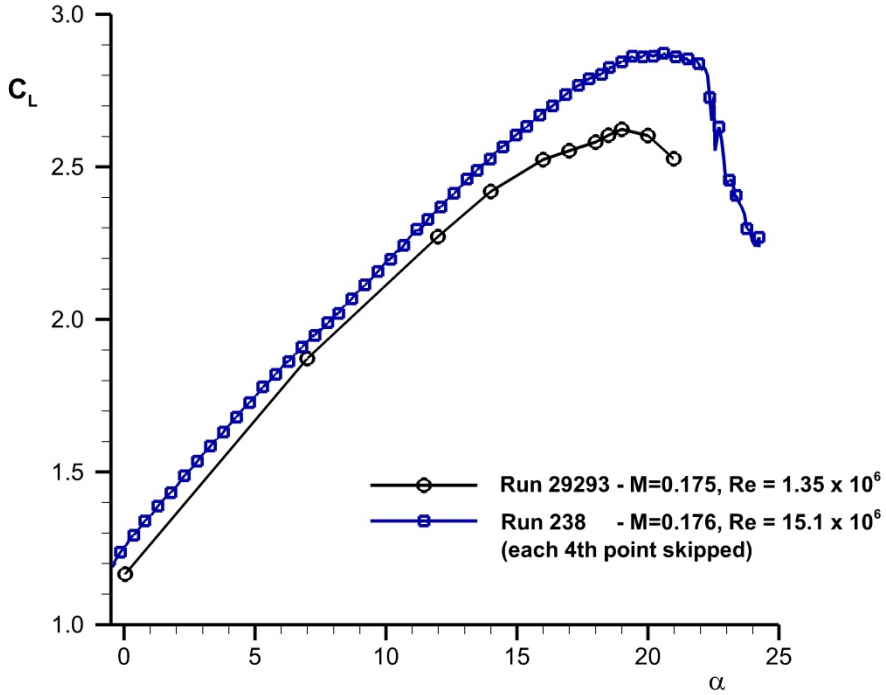
Test section dimension: 2.0 x 2.4 m

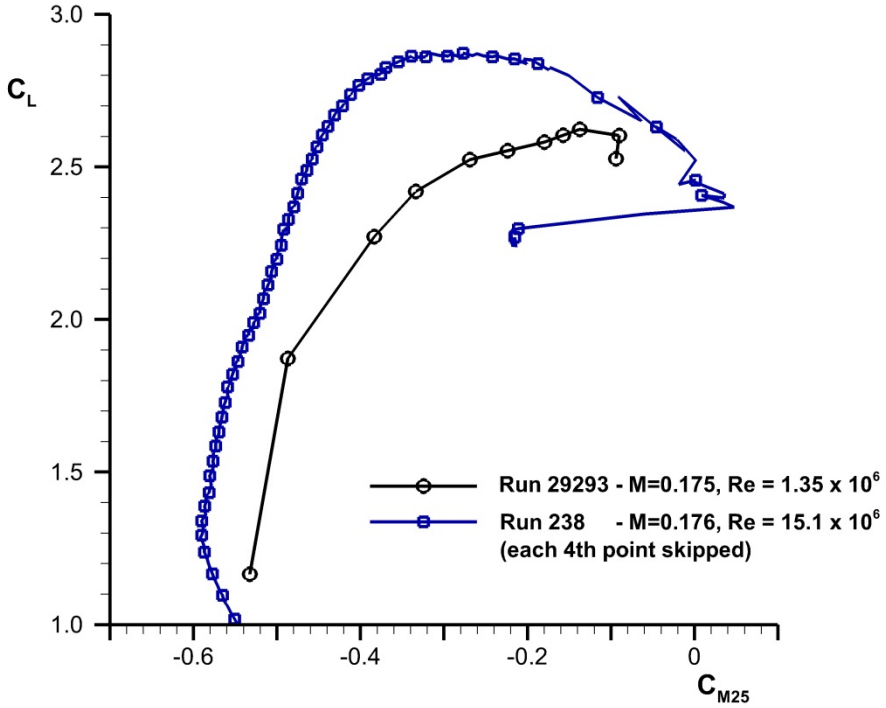
Available experimental evidence vs angle of attack:

α	F&M	C_p	Tufts
0.01°	x	x	Video Tape
7.04°	x	x	
11.97°	x	x	
13.98°	x	x	
15.99°	x	x	
16.98°	x	x	
18.00°	x	x	
18.49°	x	x	
19.00°	x	x	
20.02°	x	x	
20.95°	x	x	

Lift and pitching moment curve:

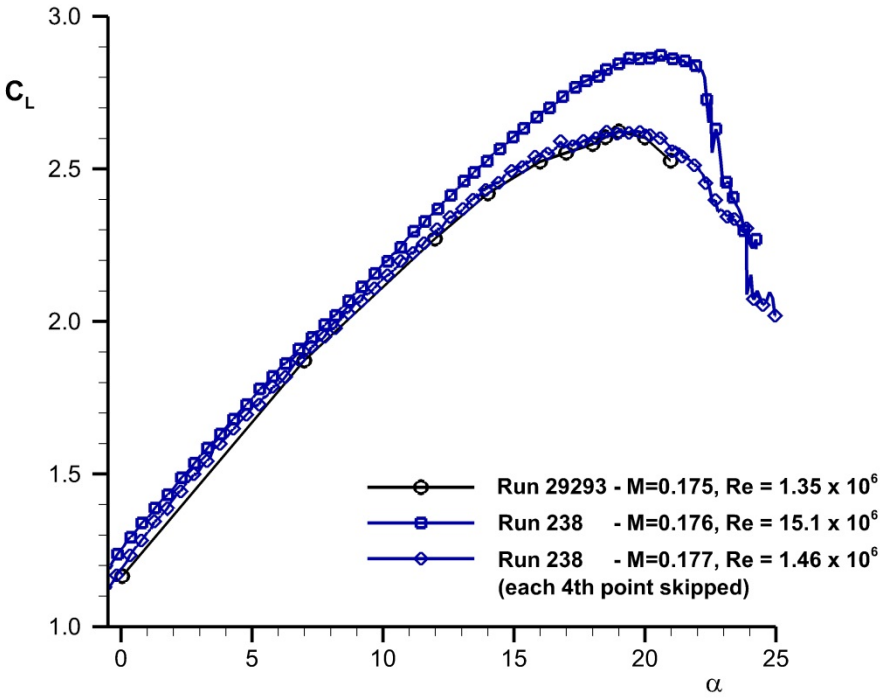
- **Comparison of low and high Re test data: B-LSWT - ETW**

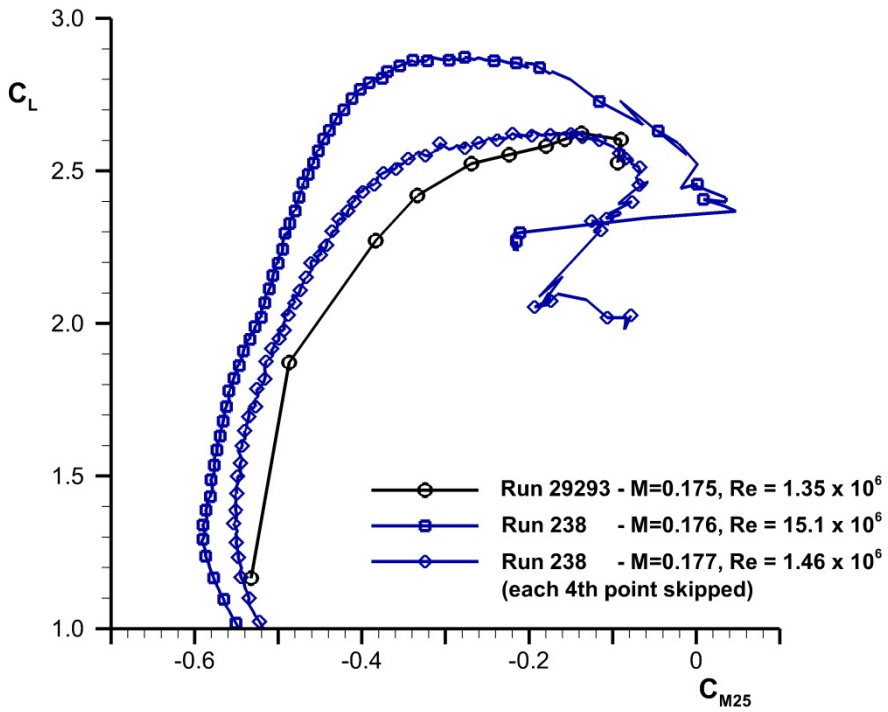




Lift and pitching moment curve:

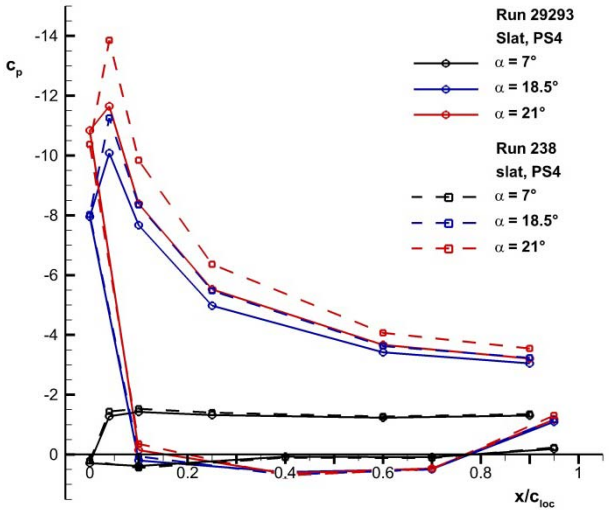
- **Comparison of low and high Re test data: ETW - ETW**

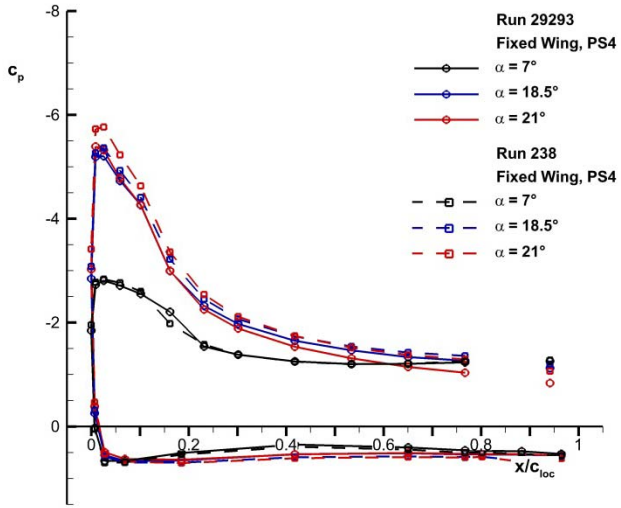


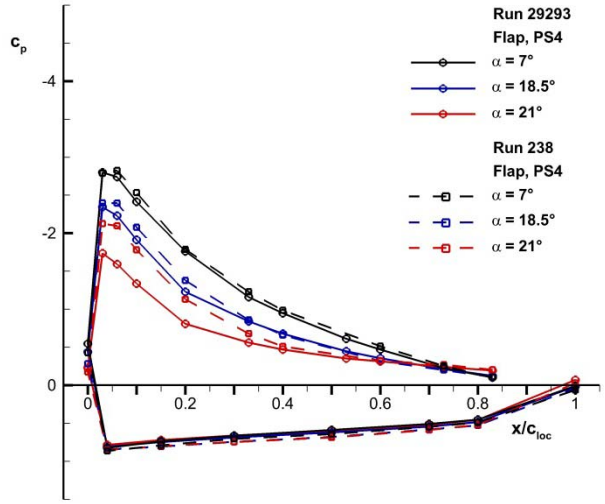


Pressure distributions:

- **Comparison of low and high Re test data, PS4**



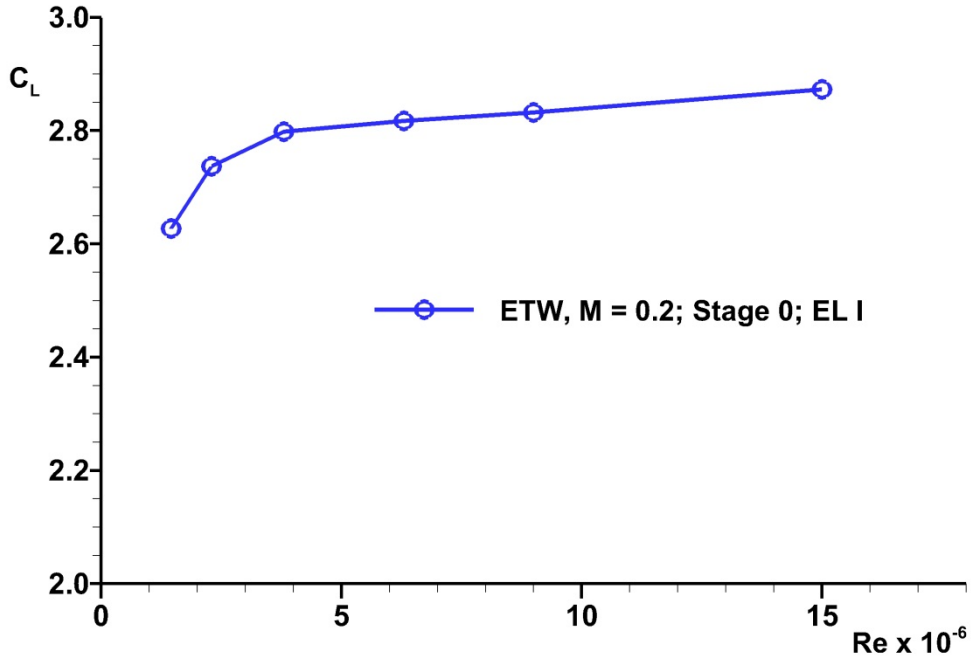




Reynolds-number scaling effects on maximum lift for Stage 0 configuration

- favourable scaling effects
- largest increase in maximum lift for $1.5 \times 10^6 < Re < 4 \times 10^6$
- $\Delta C_{L,max}$ (Re) ~ 30 lcts.
- $\Delta(C_{L,max}) / \Delta(Re) = 0{,}0065$

  for $Re > 4 \times 10^6$



Conclusion

- **Experimental evidence for the DLR-F11 high lift configuration to be used within AIAA HighLiftPW-2 is presented and briefly analyzed.**
- **The configuration features a wing/body model with continuous full span slat and flap in ldg setting, representative for a wide-body commercial aircraft.**
- **A CAD model in various degrees of detail has been refurbished and is provided by DLR**
- **Experimental data of the European project EUROLIFT for low and high Reynolds number conditions (ΔRe ~ 1 OoM) have been made available.**
- **Low Reynolds numbers originate from data B-LSWT, the high Reynolds-number condition data have been measured in the ETW under cryogenic pressurized conditions.**
- **The lift breakdown is triggered in both cases by the aft part of the center wing and the flap.**
- **Back-to back comparison between both tunnels for comparable low Reynolds number shows a good overall agreement in overall lift and drag.**
- **Reynolds number scaling effects are favorable for the considered wing/body configuration**

Conclusion

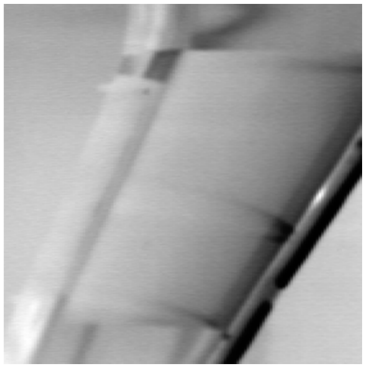
- For low Re conditions, experimental data are available for
  - force and moment
  - oil flow pictures
  - transition information by hotfilms and infrared thermography
  - PIV velocity data

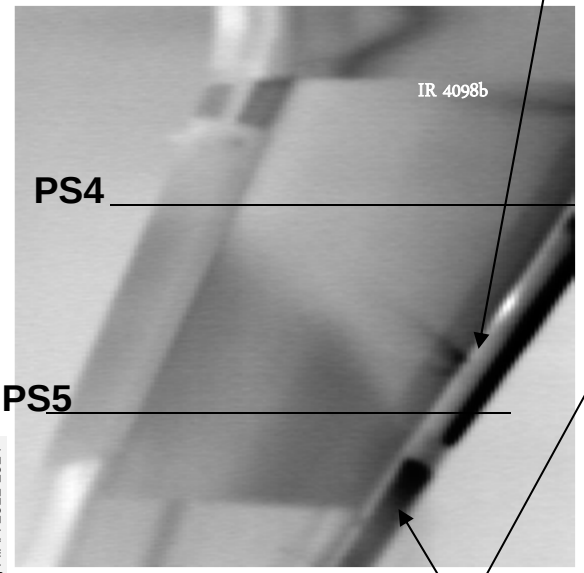
  in various locations of the F11 configuration for a sample of angles of attack up to and beyond maximum lift.
- All but the force, moment, and pressure data need further analysis and interpretation
- Tuft videos recorded on VHS cassettes – need transformation into mpeg
- Out of the F11 Stage 0 database the HighLiftPW organizing committee will select suitable onflow conditions and consistent experimental evidence for the validation exercise

Outlook

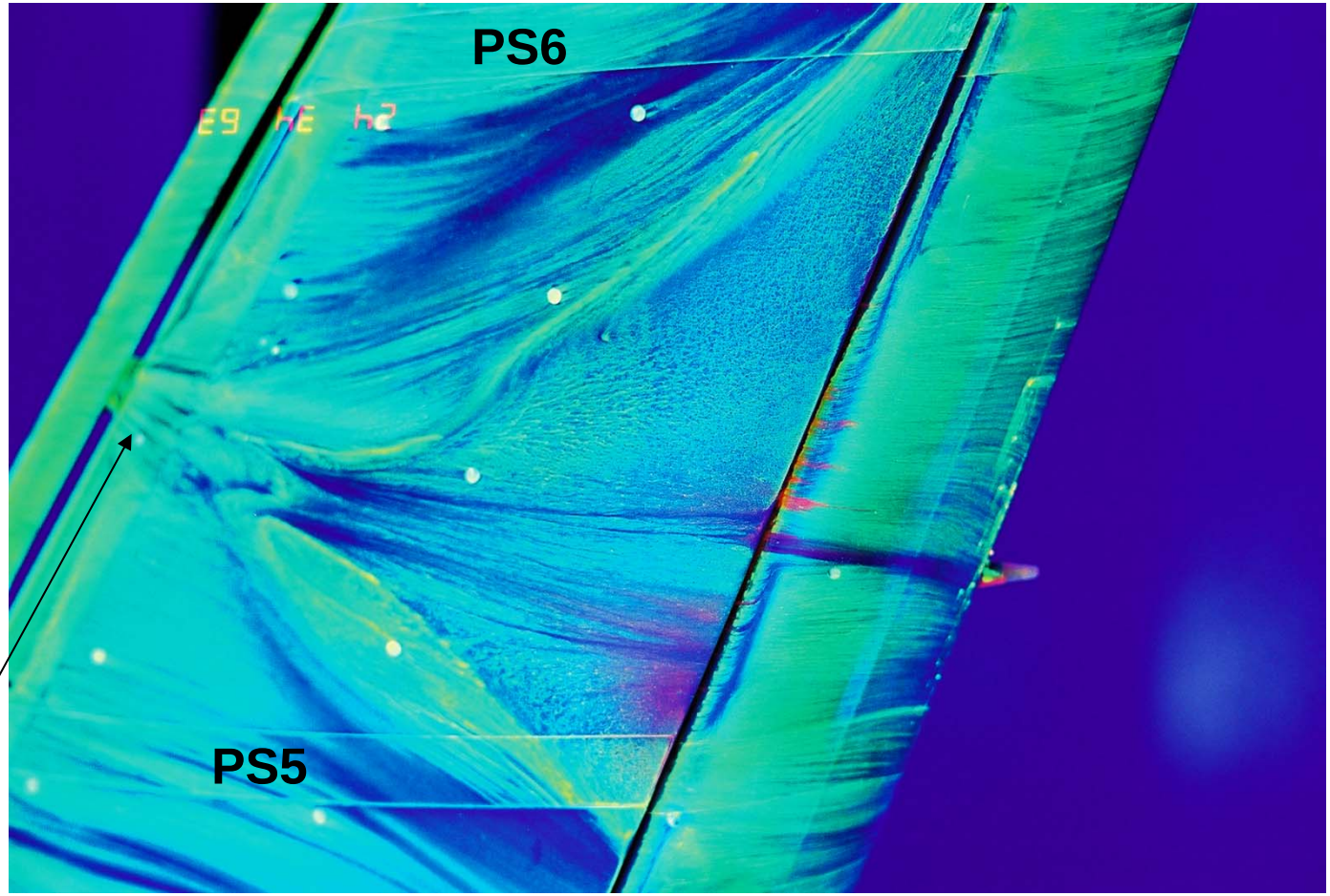
Stall at α = 21° (post-stall) seen as IR and oil flow image

α = 18.5°



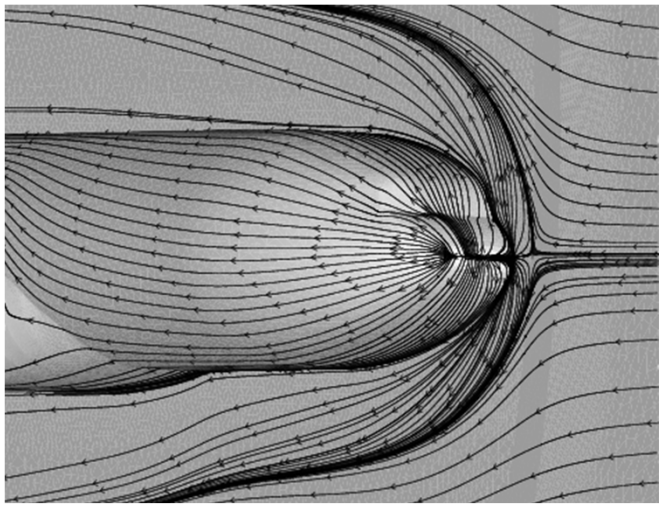


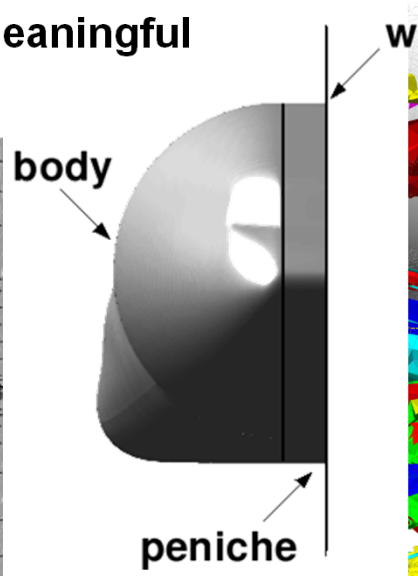
α = 21°

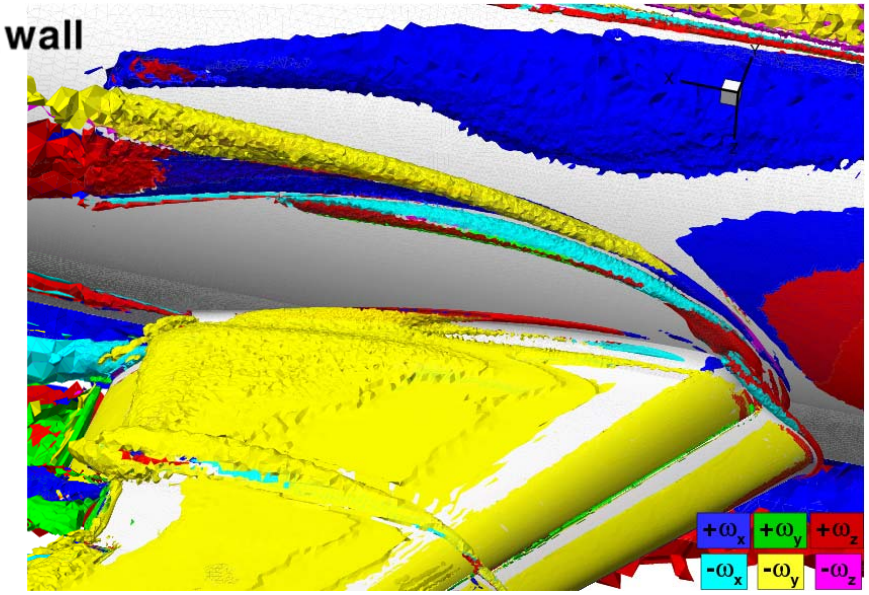


Remarks / Challenges - SOB Bubbles & Slat Tracks

- **Caution at SOB separation bubble analysis for half model tests**
  - **we have two pairs of horseshoe vortices (@WB and @Peniche/Wall)**
  - **if they are close to each other they might interfere**
  - **consideration of wall (not necessarily full w/t) might be necessary**
- **Plain plate at flap/body junction might have a (small) impact on flow topology**
- **Track(pt-bundle) wake interact / stimulate separation**
  ⇒ Consideration in CFD meaningful







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  - ONERA

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