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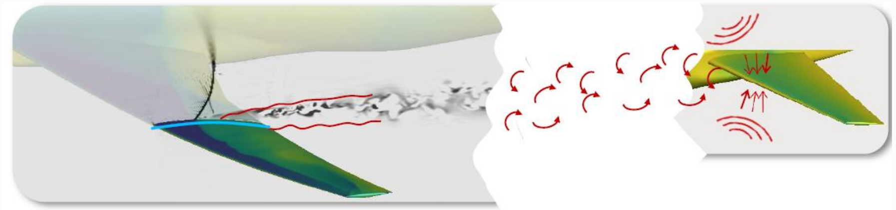

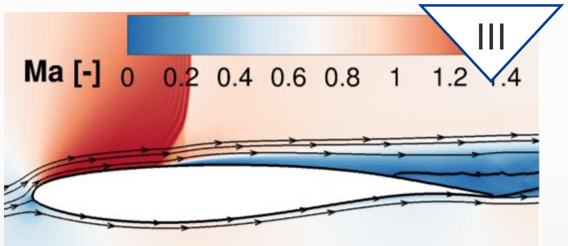

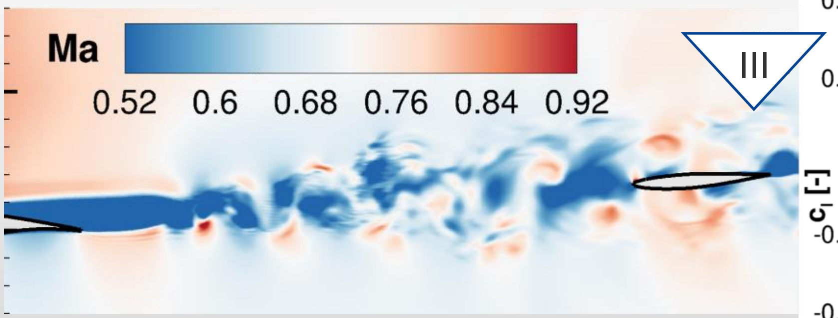

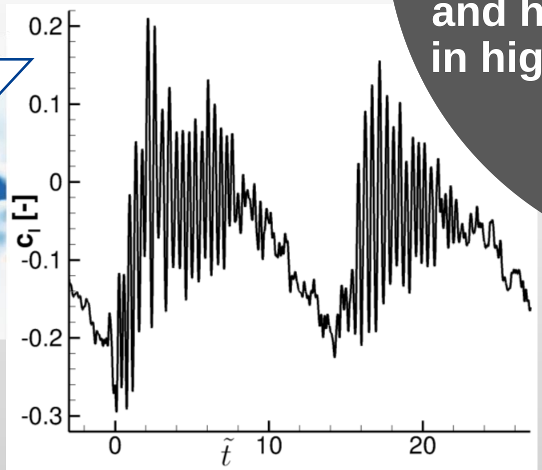

SuperMUC-NG
Status and Results Workshop
2023

Project “INTERACT” (*pn98wo*)

Interactions between wing wake and horizontal tail plane flow in high-speed stall conditions

10.05.2023

Johannes Kleinert
University of Stuttgart

Structure

1 Motivation: Transonic Buffet and High-Speed Stall

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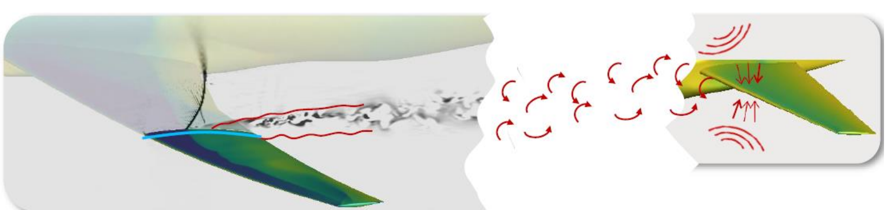
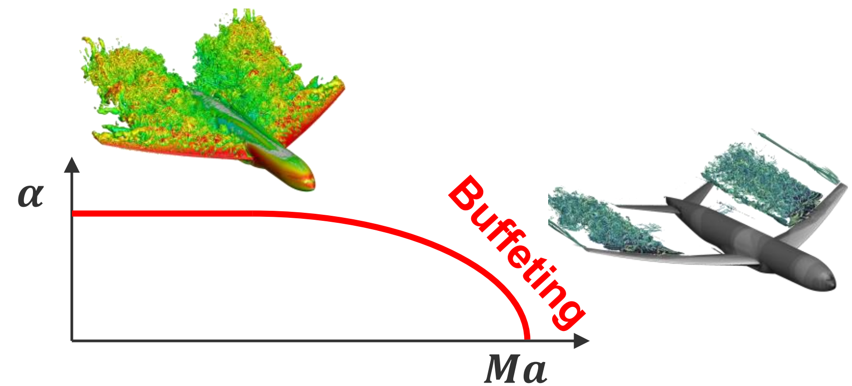
Video

- Transonic Flow: locally supersonic flow → compression shock → flow separation
- **Transonic Buffet**: Coupled oscillation of a shock and the shock-induced separation
- May cause structural vibrations (“Buffeting”) that endanger structural integrity
  → Limits flight envelope (“**High-Speed Stall**”)
- Experimental and numerical studies since several decades now, open questions remain regarding mechanisms, especially in 3D for swept wings
- Advanced, lighter designs with less margin (reduced stiffness, new configurations)
  → Better understanding of mechanisms and influencing factors required
- Impact of the separated flow from the wing on the tail plane not studied extensively yet





2 Framework: DFG FOR 2895

- **DFG Research Unit 2895**:
  "*Unsteady flow and interaction phenomena at High Speed Stall conditions*"
- Research questions:
  - Nature and mechanism of 3D buffet on swept wings
  - Influence of an Ultra High Bypass (UHBR) nacelle
  - Interaction of wing wake with horizontal tail plane (HTP)
- 7 numerical and experimental subprojects,
  each with different focus (here: subproject 4)
- HGF/DLR funded Measurement Project:
  Transport aircraft configuration (XRF-1 by Airbus)
  in the European Transonic Wind Tunnel (ETW) [A]
- Detailed measurements:
  Tandem wing configuration [B]
  (Trisonic Wind Tunnel, RWTH Aachen)

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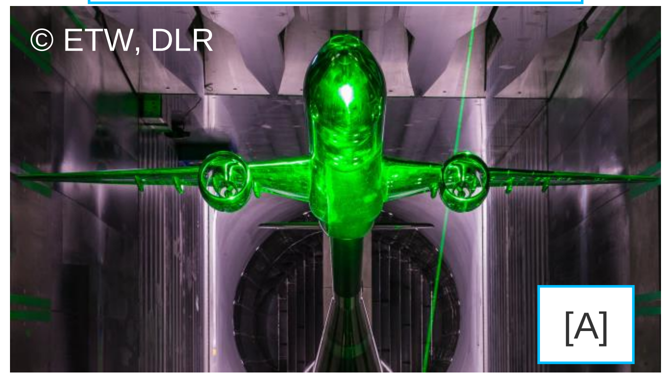

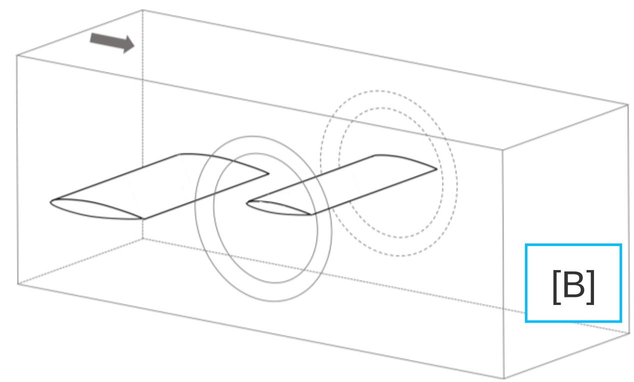

3 Wake Tail Plane Interactions for a Tandem Configuration

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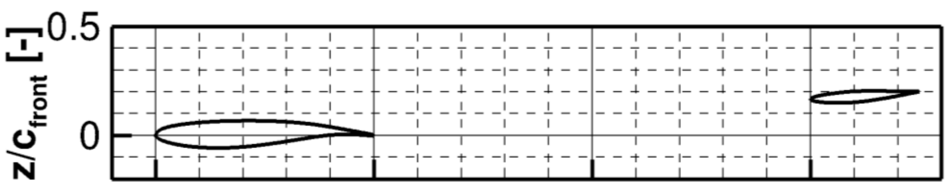
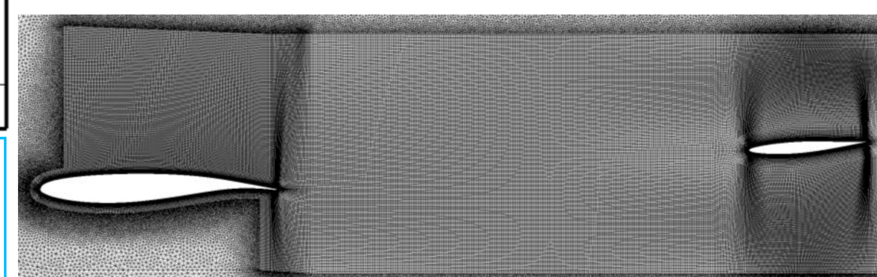
- **Tandem wing configuration** consisting of two un-swept, un-tapered wing segments
  - Front segment: OAT15A ($c_{OAT} = 150\ mm$), rear segment: NACA64A110 ($c_{NACA} = 75\ mm$)
  - Horizontal spacing between segments: $2 \cdot c_{OAT}$; vertical spacing between segments: $1/6 \cdot c_{OAT}$
  - Inflow conditions according to experiment in Trisonic Wind Tunnel in Aachen: $Re_{OAT} = 2 \cdot 10^6$, $Ma_\infty = 0.72$, $\alpha_{OAT} = 5°$
- **CFD:** Zonal hybrid RANS-LES simulations (DLR TAU code): Resolution of turbulence in the wake
  - Mesh resolution (wake): $0.7\%\ c_{OAT}$, span-wise extent: $49\%\ c_{OAT}$ ($17 \cdot 10^6$ grid points)
  - Time step: 1/150 c_{OAT}/U_∞
  - Typical simulation of ~10 buffet cycles: ~$3 \cdot 10^6$ core-h on SuperMUC-NG / Hawk (HLRS Stuttgart)

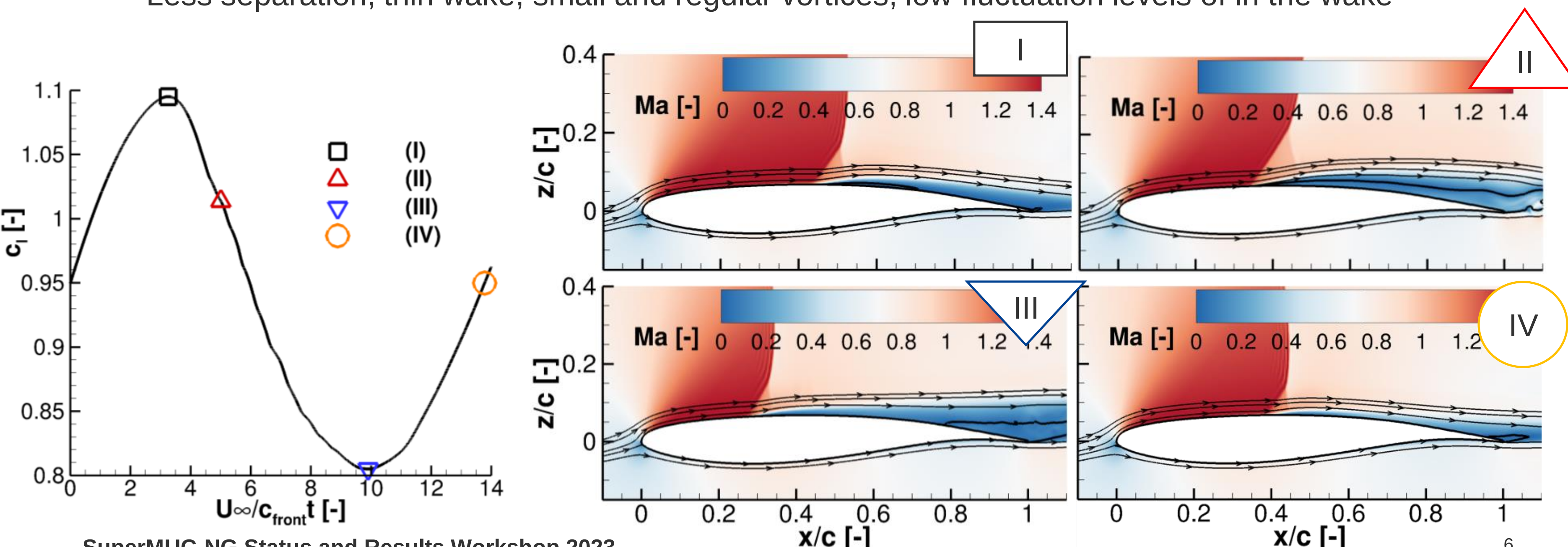


Results submitted for publication:
[Kleinert et al.: "*Wake Tail Plane Interactions for a Tandem Wing Configuration in High-Speed Stall Conditions*", submitted to CEAS Aeronautical Journal, Jan '23, preprint arXiv doi: 10.48550/arXiv.2301.05760]



3.2 Buffet Flow and Wake Characteristics

- 2D buffet on the front wing segment with $f = 118.5\ Hz$ or $Sr = f \cdot c_{OAT}/U_\infty = 0.0745$
- Variation of the characteristics of the separated wake within the buffet cycle
  - Forward shock movement:
    Strong separation, thick wake, large and irregular vortices, high fluctuation levels of in the wake
  - Rearward shock movement:
    Less separation, thin wake, small and regular vortices, low fluctuation levels of in the wake



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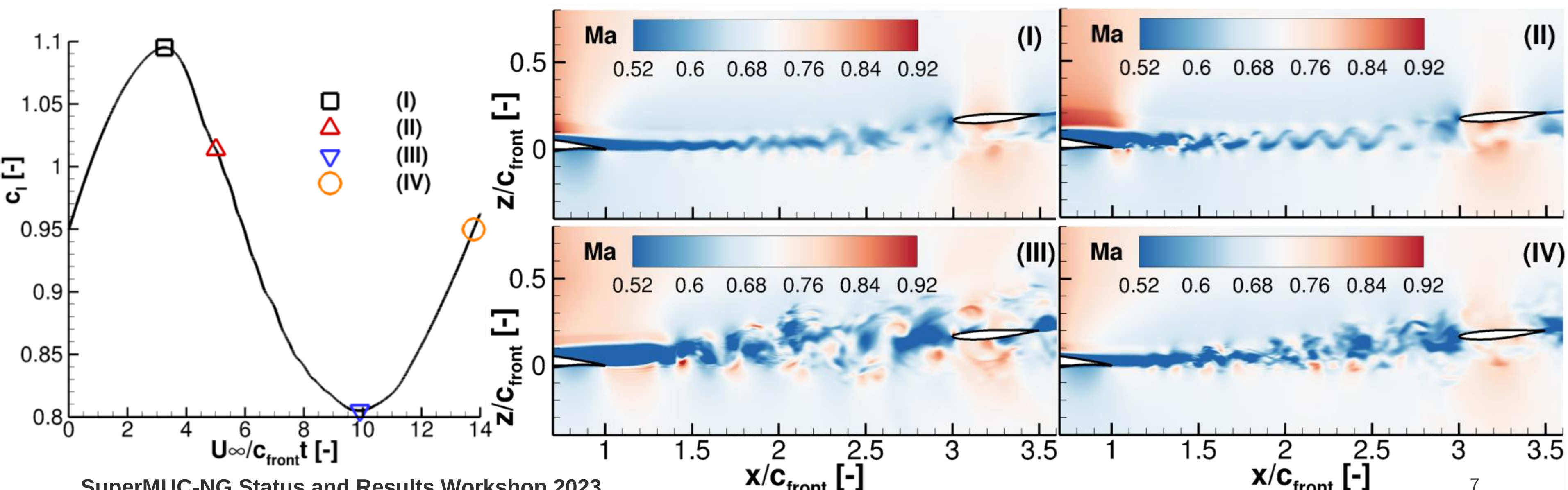
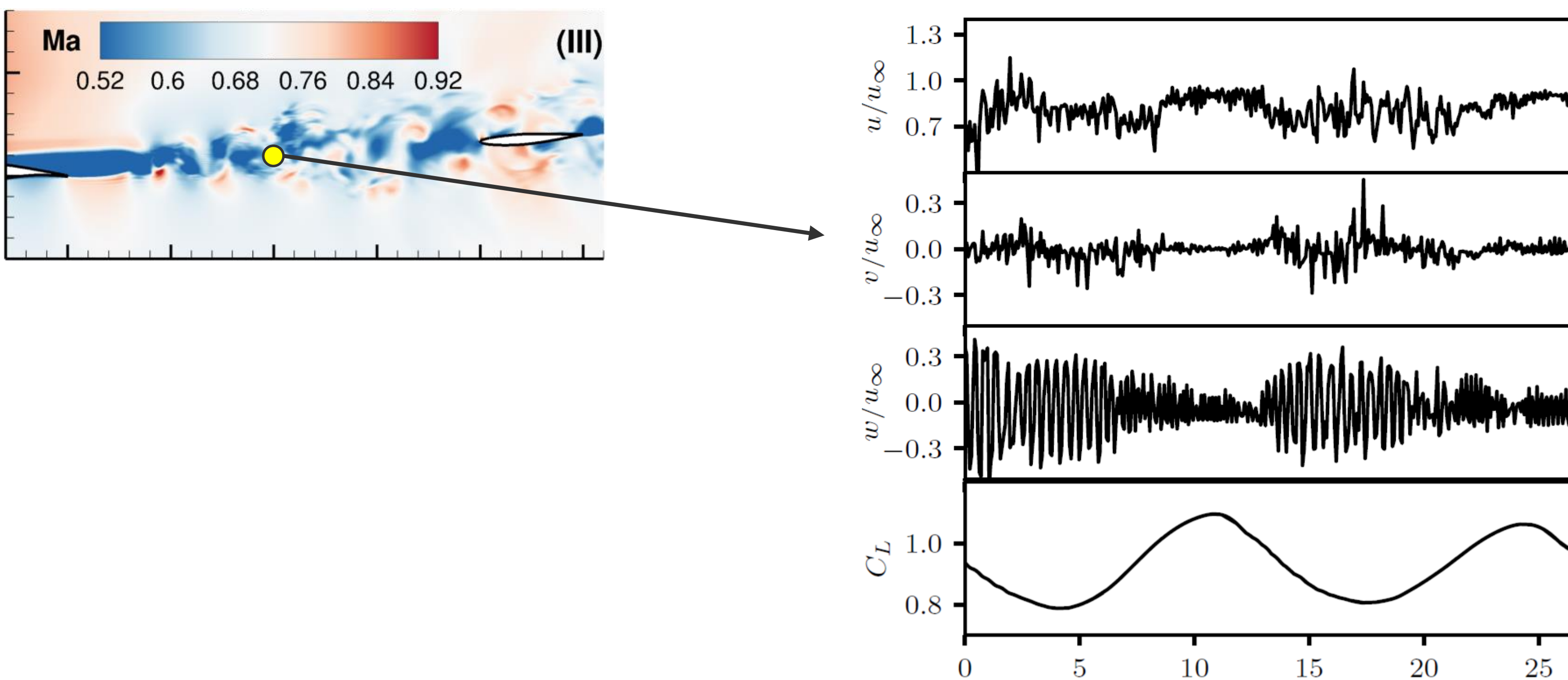


3.2 Buffet Flow and Wake Characteristics

- Turbulent spectra in the wake
  - Dominant peaks at the buffet frequency ($Sr = 0.0745$)
  - Increased levels in the high frequency range at $Sr \approx 1.5 \ldots 8$ due to turbulent fluctuations, broadband but with a peak at $Sr \approx 2.5$
  - Peak at can be associated with vortex shedding using a modal analysis (POD/DMD)



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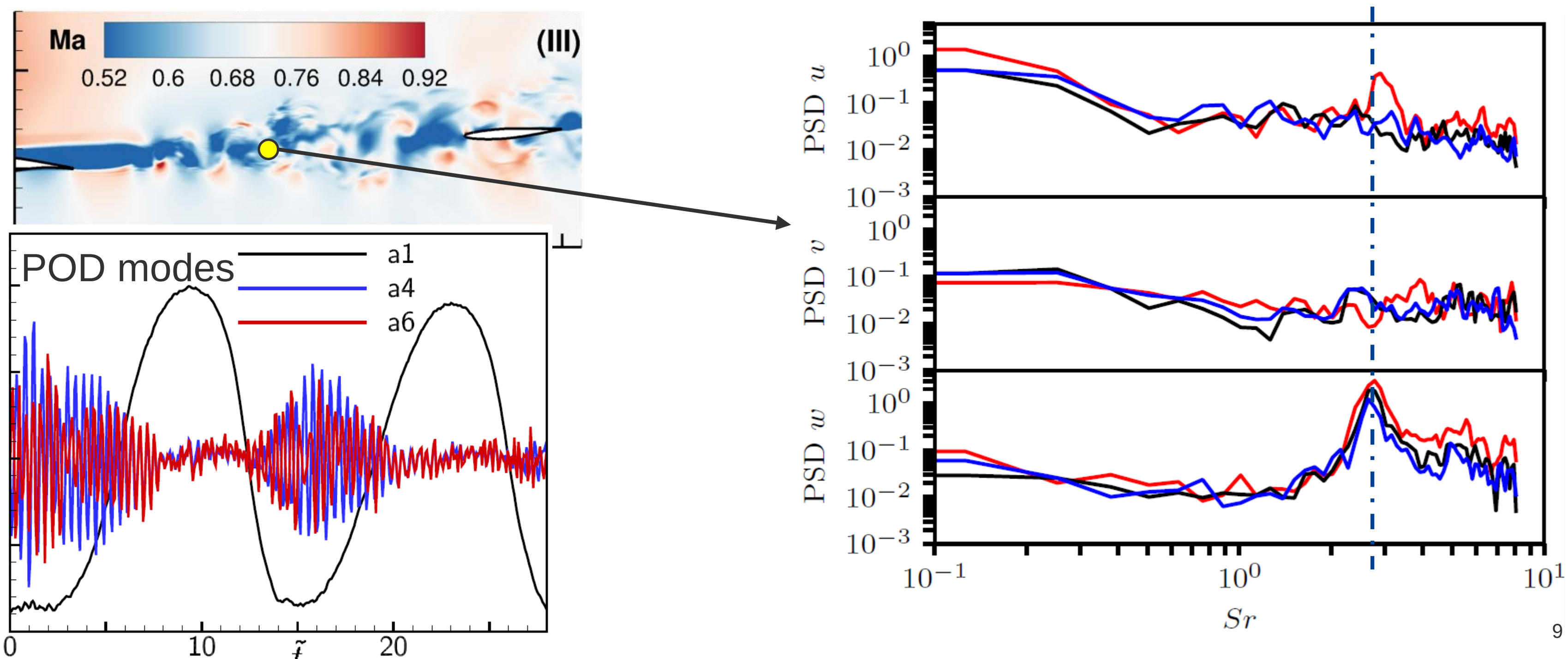

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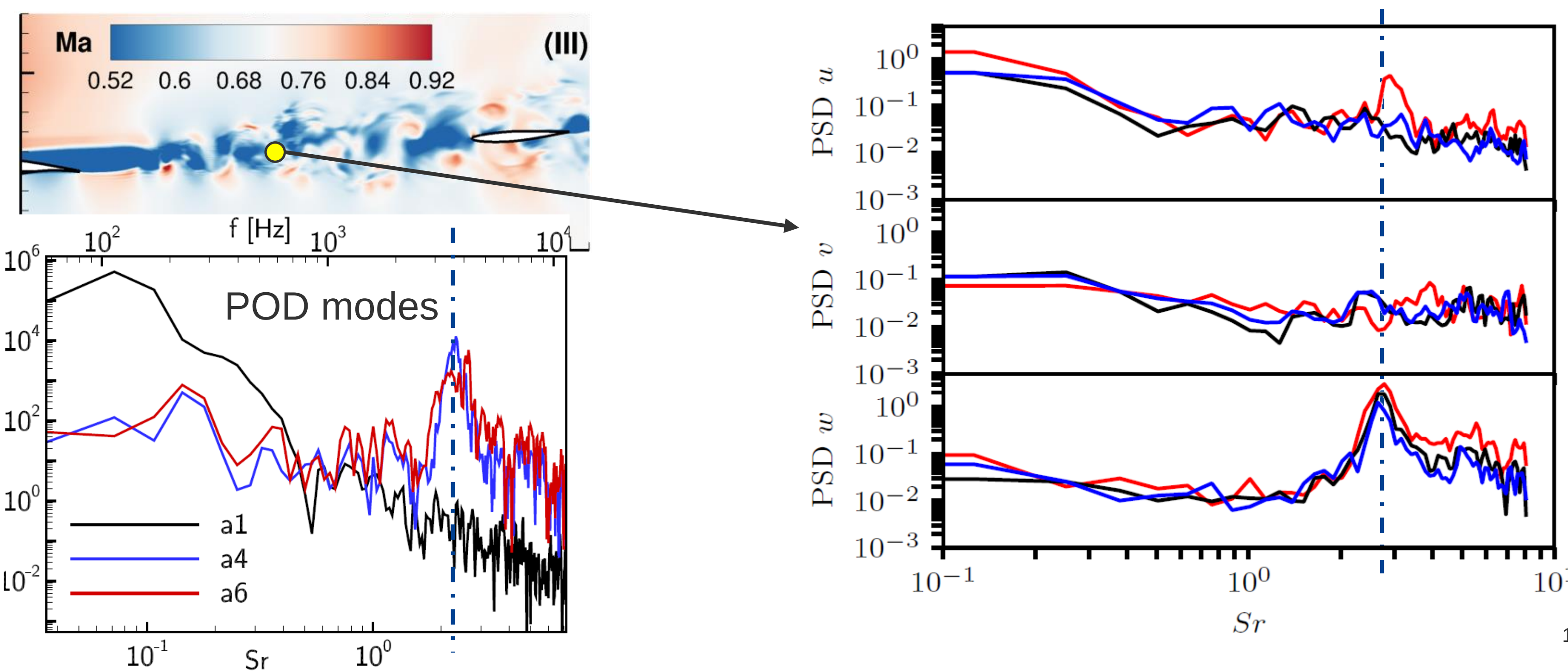

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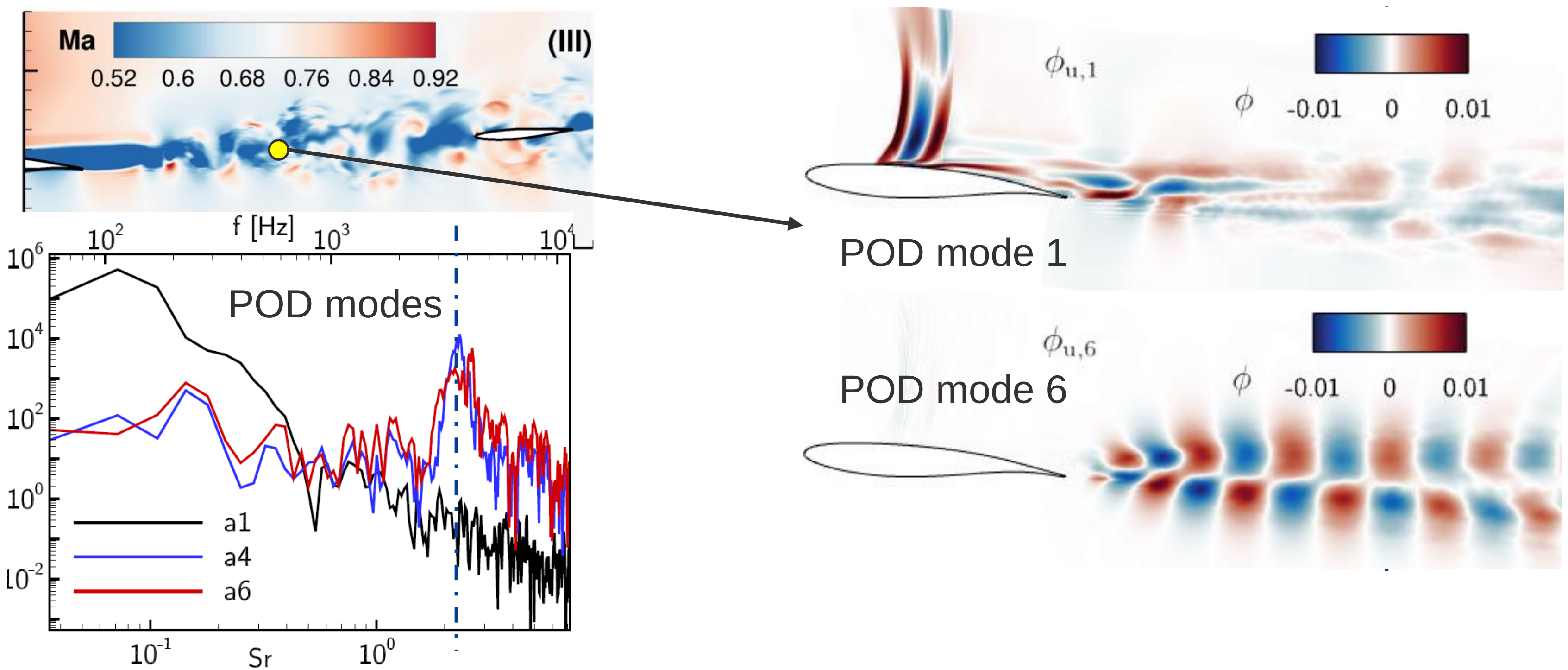
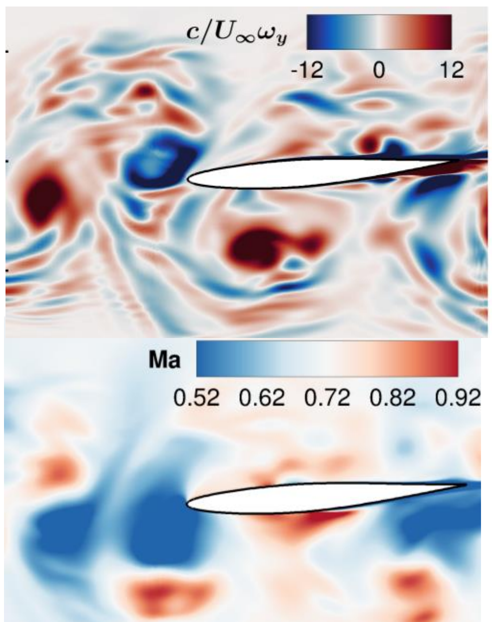
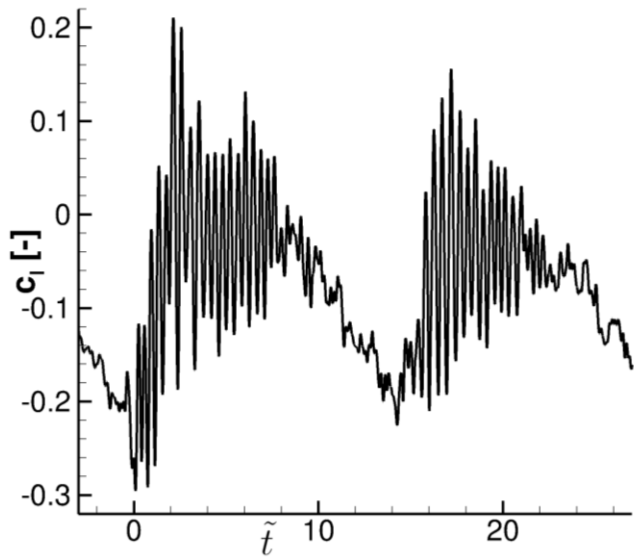
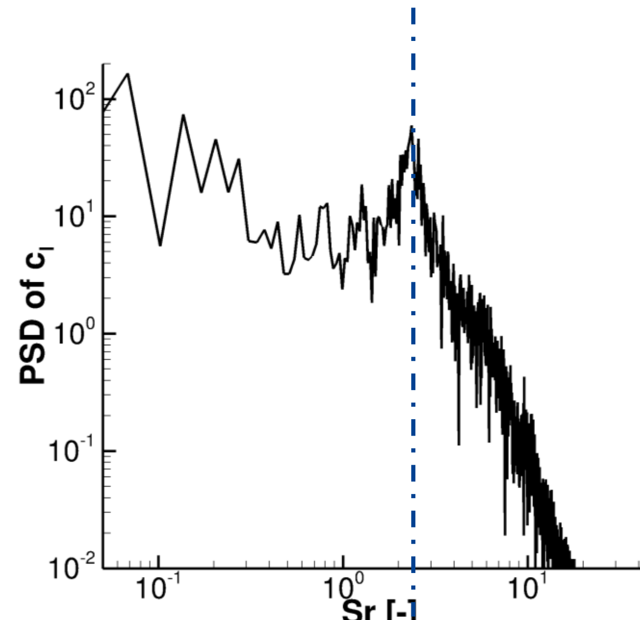


3.3 Wake Tail Plane Interactions

- Interaction of the wake with the rear wing segment
  - Low-frequent oscillation of the rear segment's lift ($\Delta c_l = 0.5$) due to the variation of the front wing's downwash
  - High-frequent lift fluctuations caused by the wake's vortices ($\Delta c_l = 0.4$); amplitudes and frequencies vary within the buffet cycle according to the current fluctuation levels in the wake

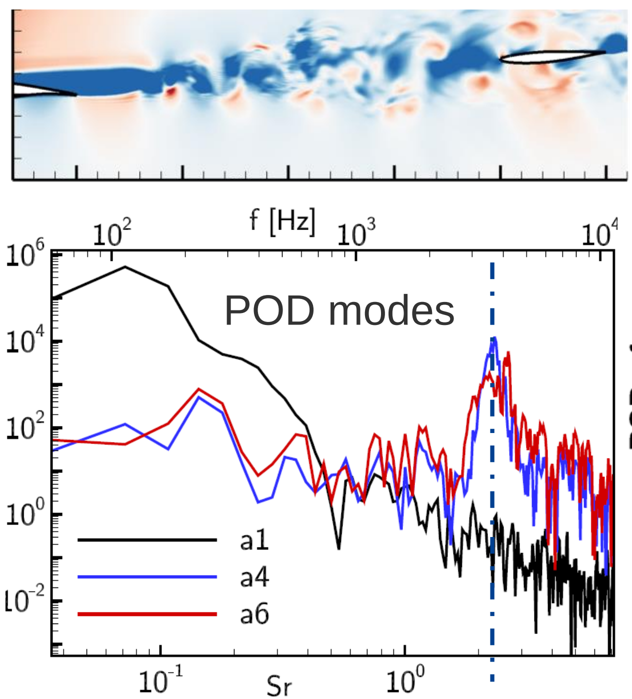


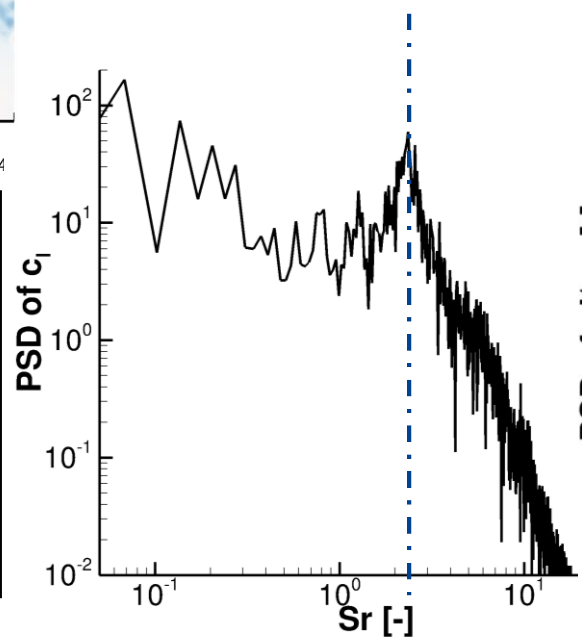


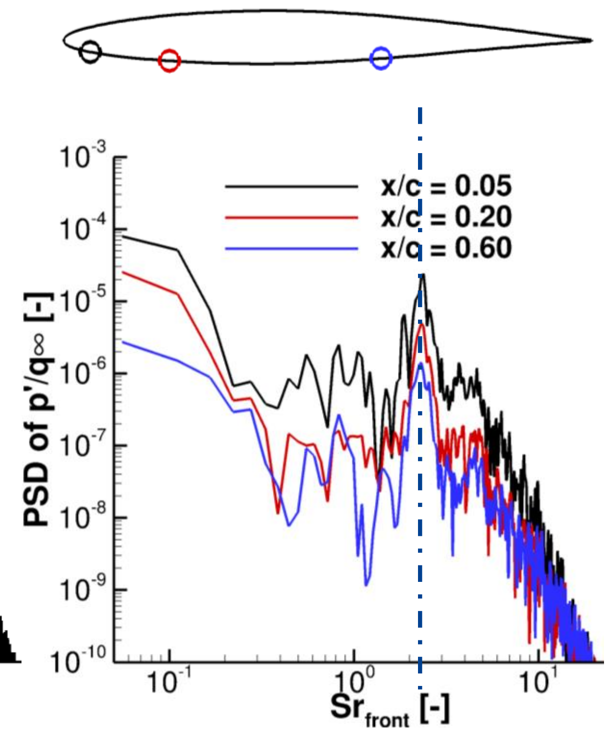


3.3 Wake Tail Plane Interactions

- Loading and surface pressure oscillations correlate with the turbulent fluctuations in the wake
  - Increased levels at ($Sr \approx 1 \dots 5$) with peak at $Sr \approx 2.5$
  - Highest fluctuation levels at leading edge, decreasing intensity with increasing chord position due to dissipation of the vortices







4 Conclusion

- Hybrid RANS/LES simulations of wake tail plane interactions for a tandem wing
  - Significant variation of the wake characteristics within the buffet cycle
  - Turbulent spectra in the wake dominated by low-frequent oscillations at the buffet frequency ($Sr = 0.0745$) and high-frequent fluctuations at $Sr \approx 1.5 \dots 8$ associated with wake vortices
  - Dominant vortex shedding mode at $Sr \approx 2.5$
  - Impingement of the wake onto the HTP causes lift oscillations
  - HTP loading and surface pressure oscillations correlate with the turbulent fluctuations in the wake

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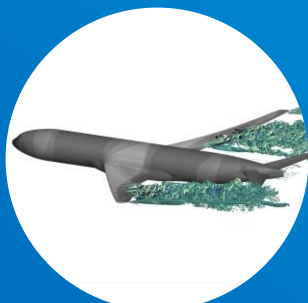
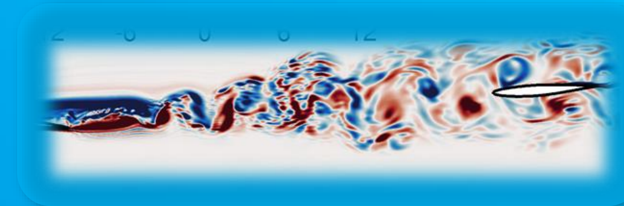
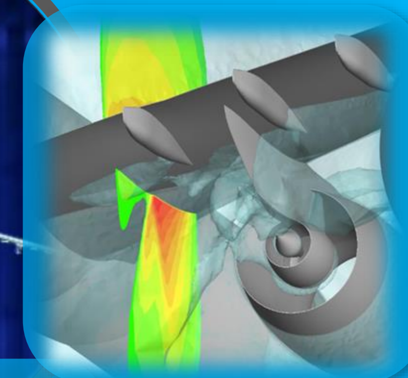
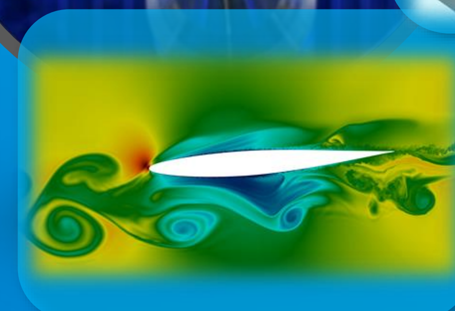
Thank you!









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