DESIGN OF ACTIVE FLOW CONTROL AT THE WING/PYLON/ENGINE JUNCTION

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2ND GENERATION ACTIVE WING

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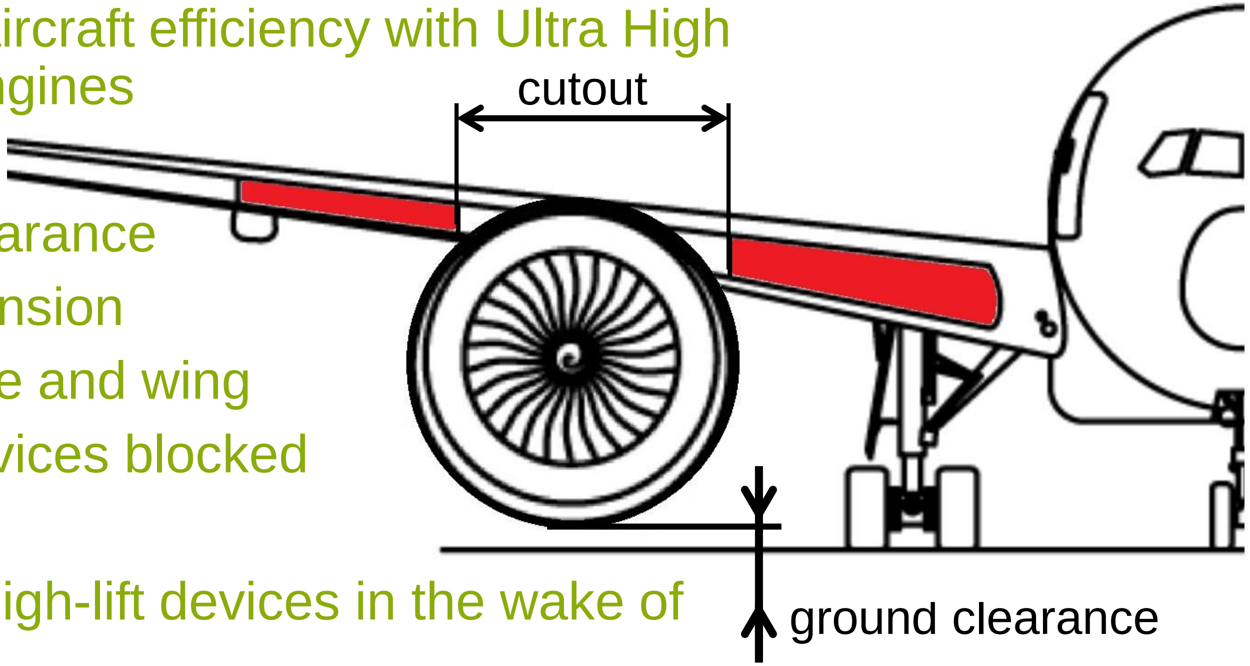
Outline

- Motivation
- Baseline geometry and flow
- Pulsed blowing actuation
- Synthetic jet actuation
- Full aircraft scale evaluation
- Summary and conclusions

MOTIVATION

Motivation

- Modern transport aircraft configuration with engines mounted under the wing
- Further increase of the aircraft efficiency with Ultra High Bypass Ratio (UHBR) engines
- Larger nacelle diameter
- Problem with ground clearance
- Heavy landing gear extension
- Closer coupling of engine and wing
- leading edge high-lift devices blocked by the engine nacelle
- Cutout of leading edge high-lift devices in the wake of the nacelle



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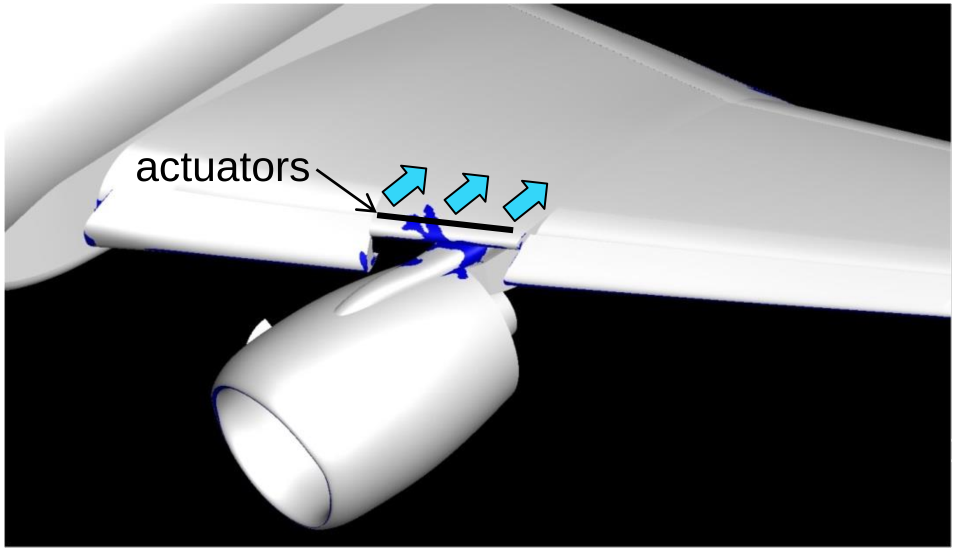
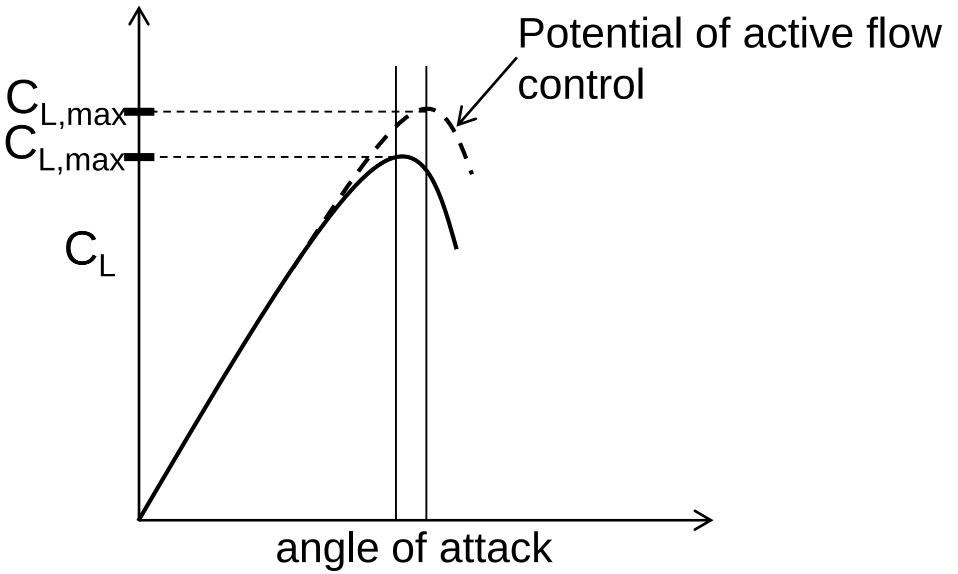
Motivation

- Separation in the wake of the nacelle triggers the total wing stall which limits the $C_{L,max}$
- $C_{L,max}$ is a sizing parameter of the high-lift system
- Heavy high-lift system counteracts benefit by UHBR
- Local separation can be suppressed by active flow control
- $C_{L,max}$ increases which allows a downsizing of the high-lift system
- Increase of overall aircraft efficiency by local application of active flow control





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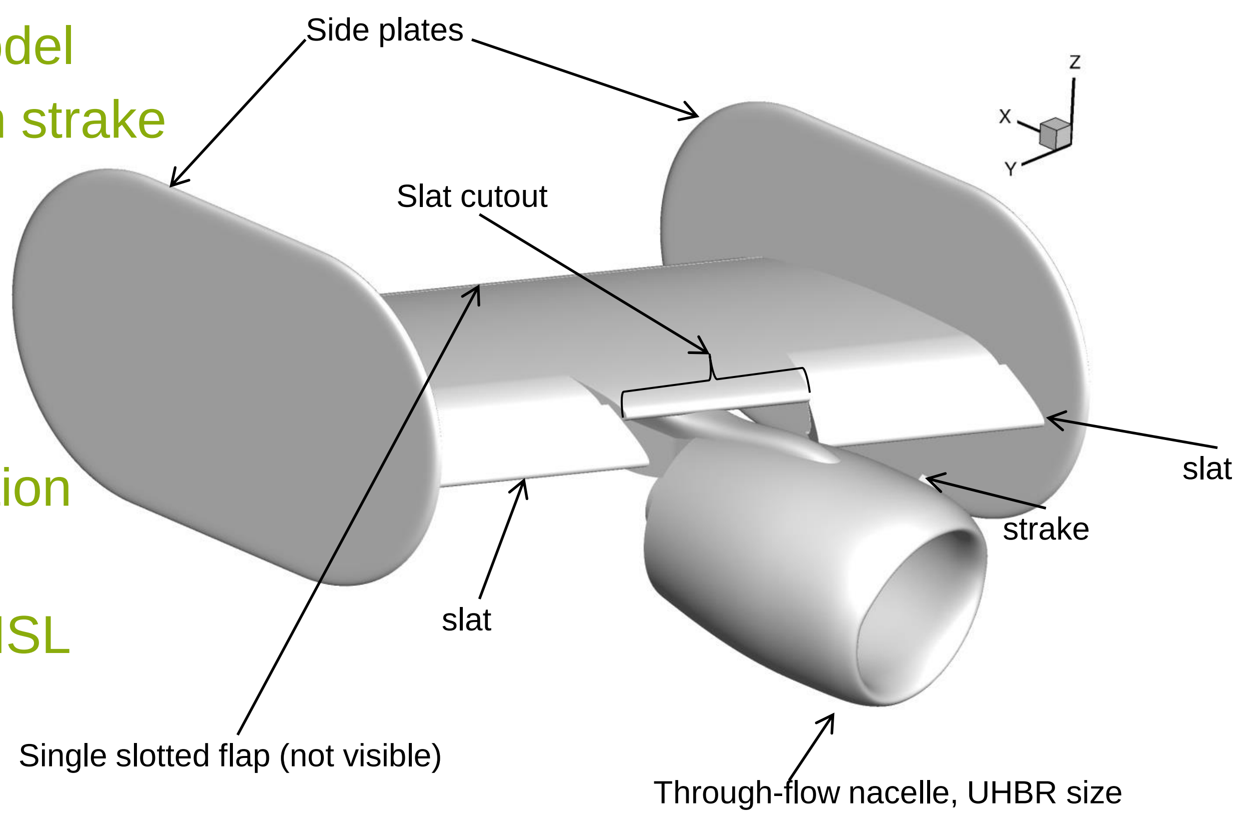
BASELINE GEOMETRY AND FLOW

Wind Tunnel Geometry

- Full scale 2.5D model
- UHBR nacelle with strake
- Wing span: 5.8m
- Chord: 3.29m
- DLR F15-profile
- Sweep angle: 28°
- Landing configuration
- M=0.2
- ISA condition on MSL
- Re=$15x10^6$

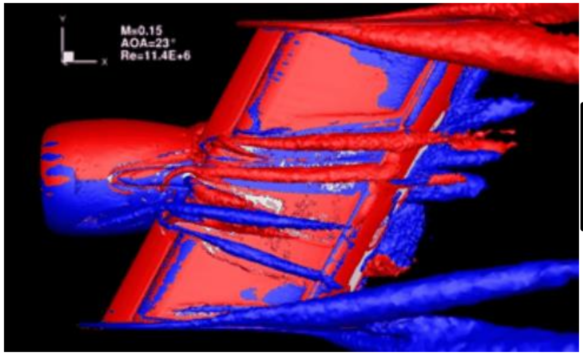


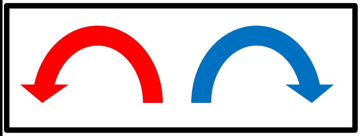
Realistic vs. Wind tunnel configuration

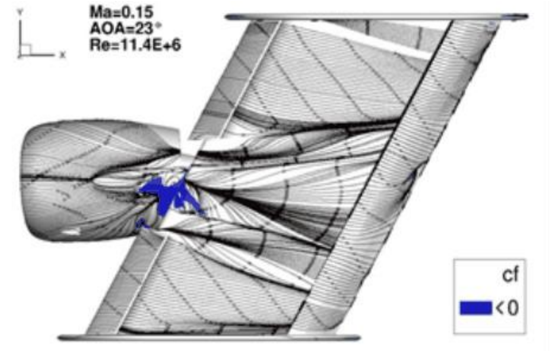
- Vortex structure depends on the level of simplification
- Separated areas similar – from pylon axis inboard
  - Mirrored!

Vortices | **Separation areas**

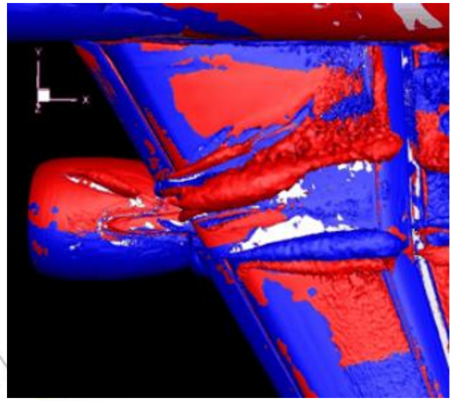
Baseline Configuration

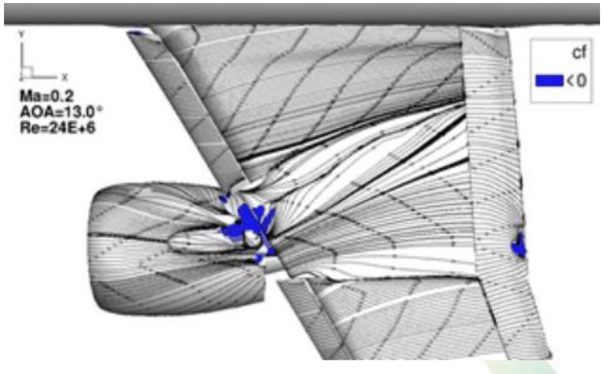






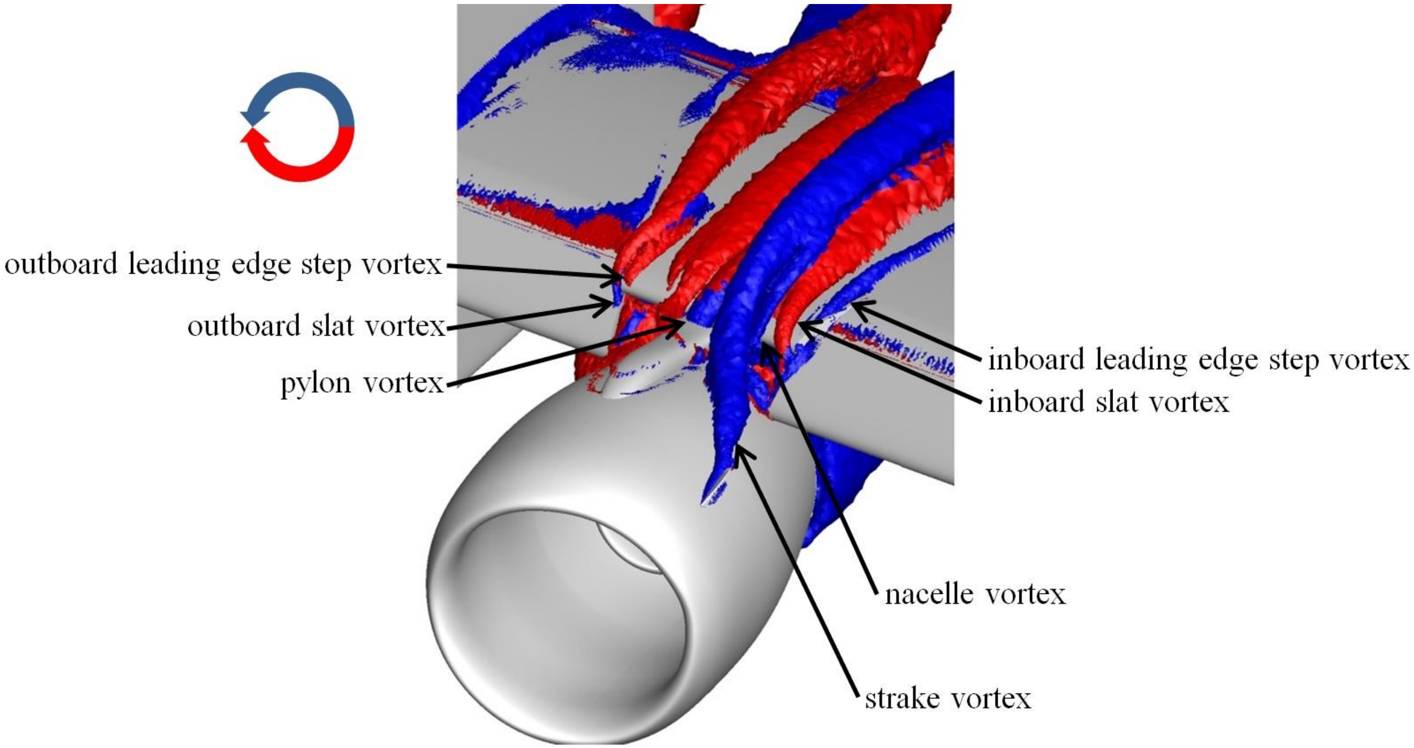
Realistic Configuration





Results: Baseline Flow

- Vortices at pre-stall conditions
- made visible with the λ_2-criteria
- Sense of rotation made visible with ω_x



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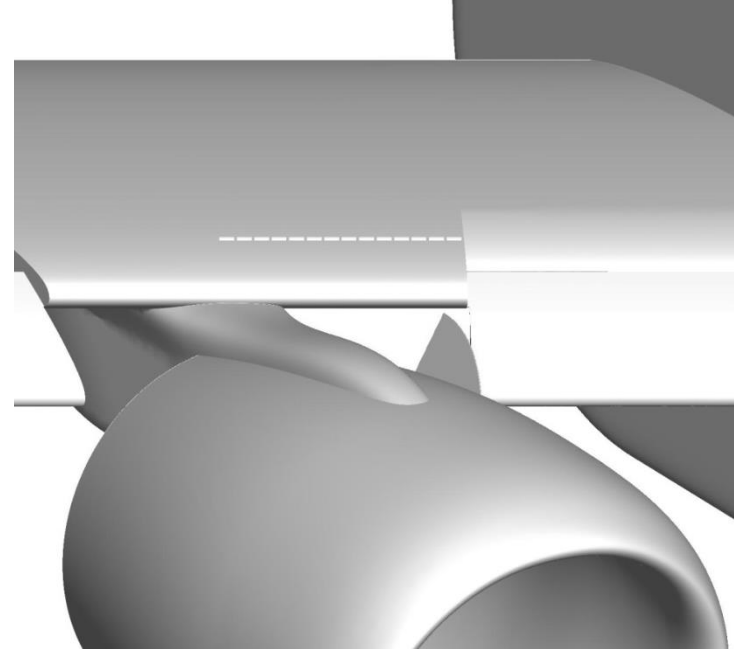
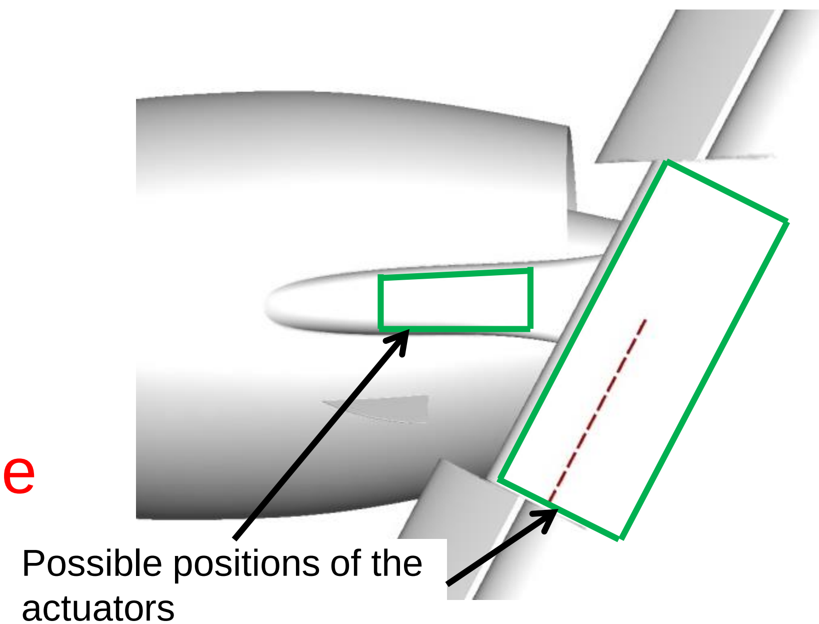
PULSED BLOWING

PJA - design problem

- Pulsed jet actuators
  - Air injected
- Design parameter of the actuators
  - Slit size
  - Number of actuators
  - Blow velocity
  - Pulse frequency
  - Blowing direction
- Position of the actuators
- Position of the strake

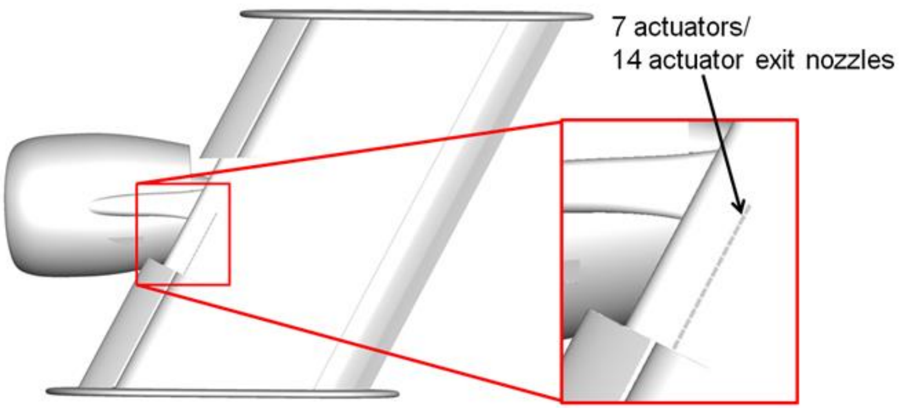
- Very large parameter space

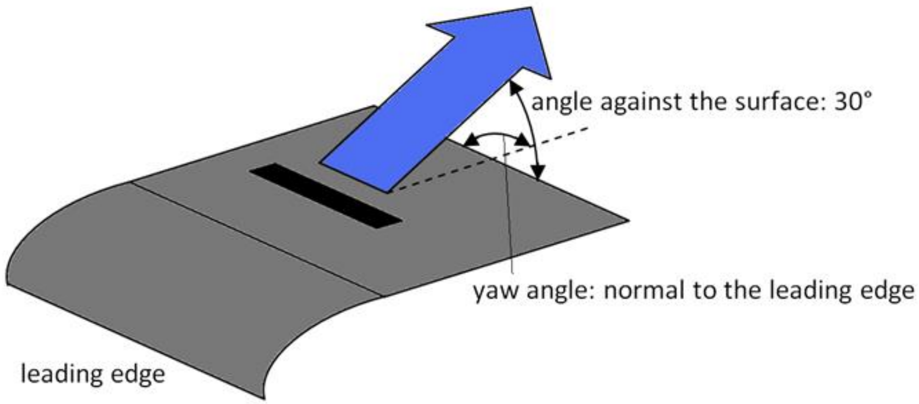




Analysed Configuration

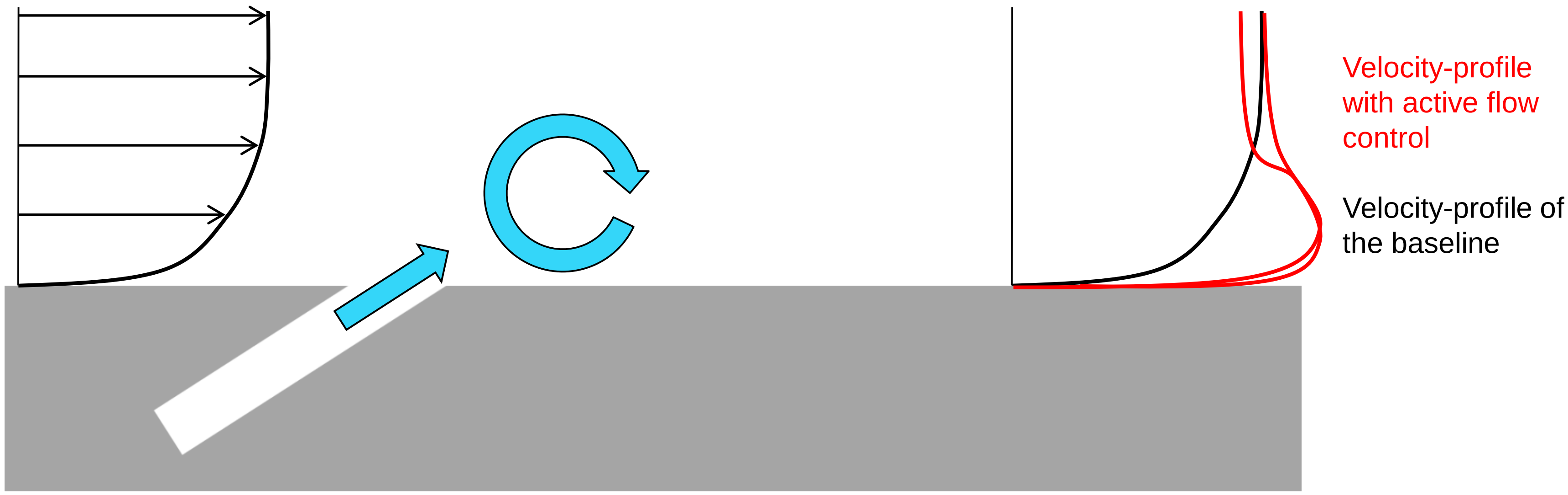
- 7 actuators at the inboard side of the nacelle-wing-junction, total required massflow with pulsed operation: 0.6 to 0.9 kg/s
- Yaw angle: 0°
- Blow angle against the surface 30°: Must be high to reach the free flow to enable the mixing of the boundary layer with the free stream flow





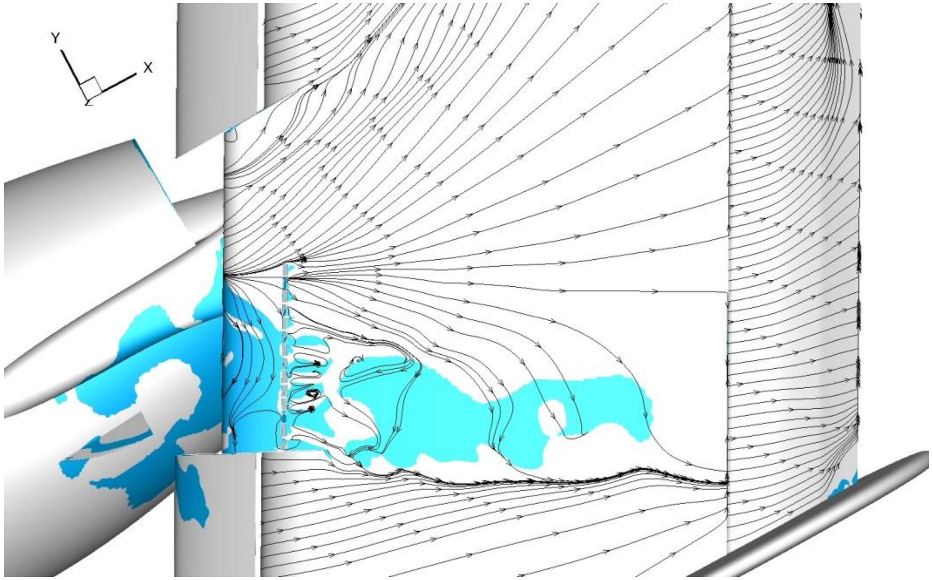
Active Flow Control

- Active flow control → **Active flow separation control** is the **active manipulation of the kinetic energy of the boundary layer**
- Steady blowing directly increases the kinetic energy of the boundary layer
- Pulsed blowing induces vortices which transfer free stream momentum to the boundary layer
- Unsteady blowing can achieve same effect as steady blowing with less air flow

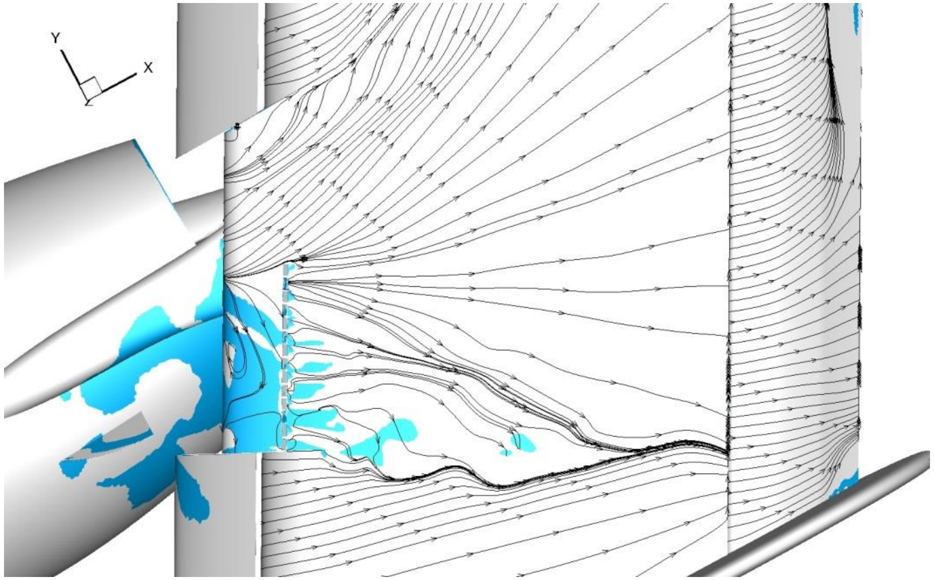


Pulsed Blowing Results: Blowing Velocity

- Exit velocity of 272m/s leads to a suppression of the nacelle-wake-separation
- The introduced impulse with the actuator exit velocity of 200m/s is not sufficient for the suppression of the flow separation



Uj=200m/s (dm/dt=0.62kg/s), f=60Hz

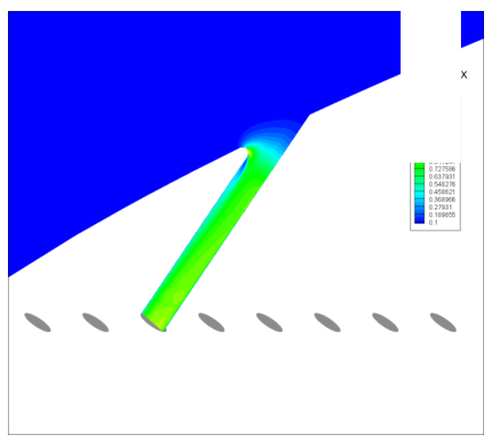


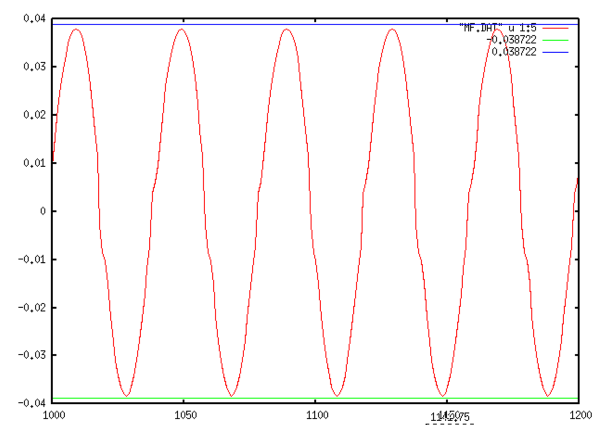
Uj=272m/s (dm/dt=0.84kg/s) , f=60Hz

SYNTHETIC JET ACTUATION

Synthetic jet actuation

- ➢ Synthetic jet – zero net mass flux
  - ➢ No need for pressure source, electricity driven
  - ➢ Suction of air from BL, return with higher energy
- ➢ CFD
  - ➢ Simulated by mass flow inlet/outlet BC
  - ➢ Switching between MF I/O is controlled by step or harmonic function
  - ➢ Peak velocity and frequency
  - ➢ Sonic velocity at the boundary is limit for the BC → peak velocity





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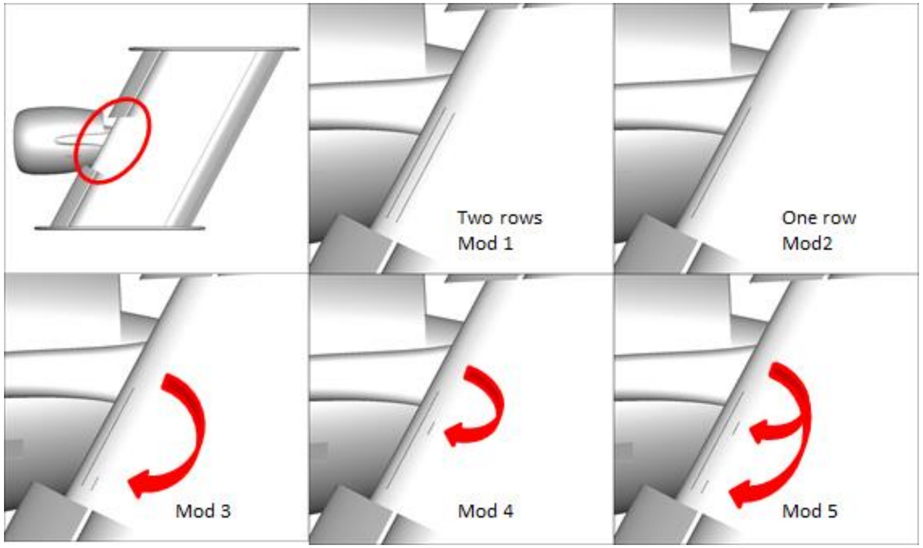
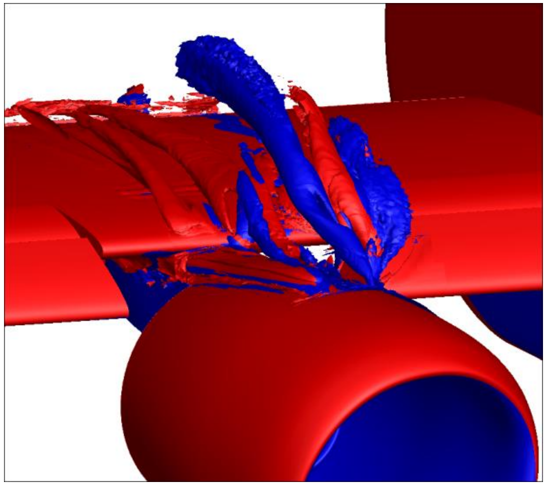
Synthetic jets, set-up



- Circular actuator
  - Actuator's area 5mm^2
  - Pitch angle 30deg
  - Cavity physically modelled
- Five configurations
  - Actuators in two rows
    - between the inboard slat and pylon nacelle's axis
    - 1st row is located at 0.01%c, 85 actuators
    - 2nd row is placed 0.021%c, 84 actuators
    - placed in cascade
  - One row of actuators
  - Three modifications of two rows of actuators
    - Based on structure of vortices



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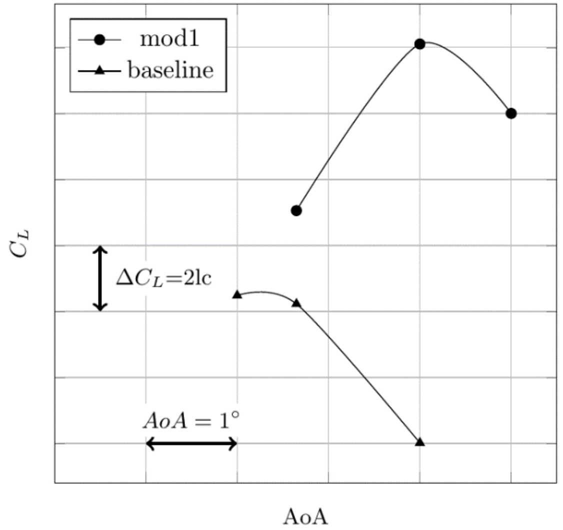
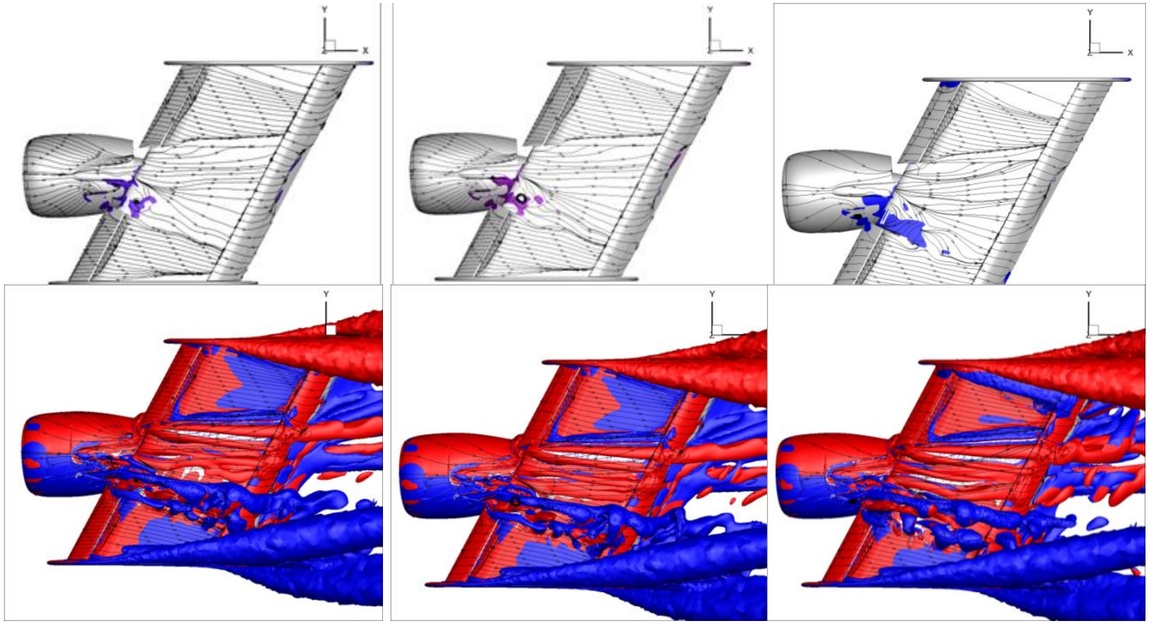
Results – SJA

- Effect of SJA on C_L and flow separation
  - Two rows of actuators
  - Actuation frequency → 100Hz
  - Peak velocity Vj = 150m/s
- Stall angle delayed by about 2 deg
- $C_{L,max}$ improved by about 8 lc



AoA



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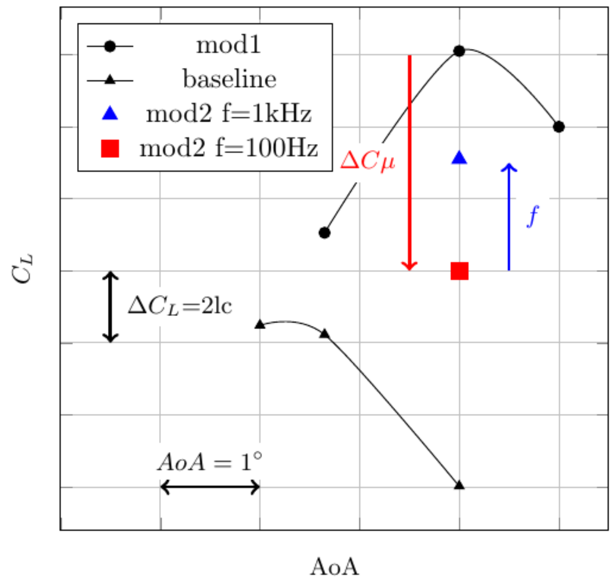
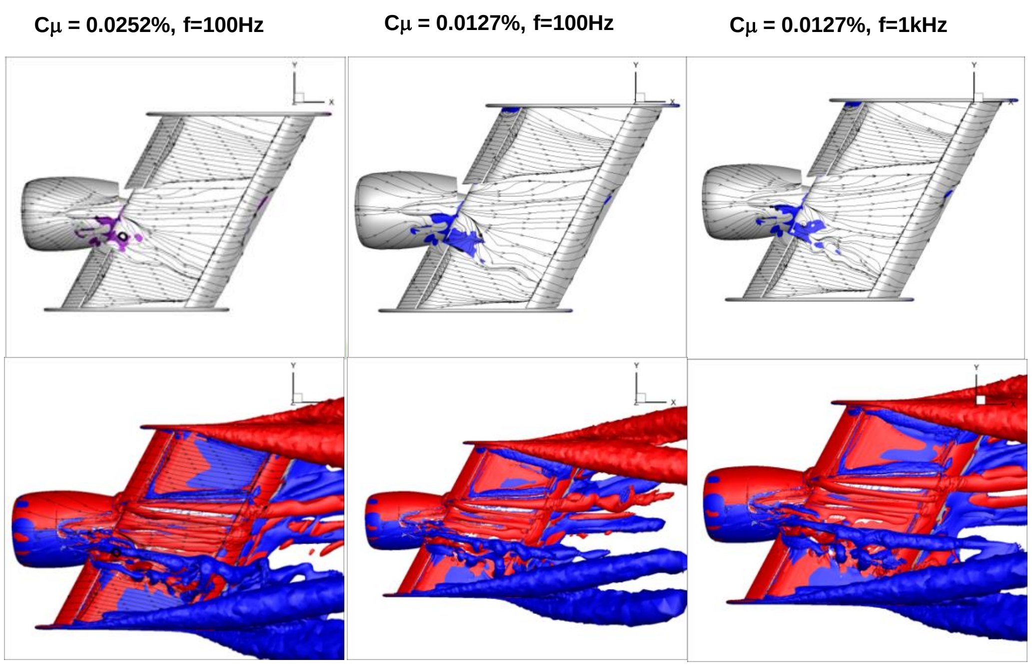
Results – SJA frequency

- One AoA ($C_{L,max}$)
  - Cμ and frequency effect
- One row of actuators
  - Cμ to one half compared to two rows
  - Actuation frequency preserved - 100Hz
  - C_L decreased by about 6lc
- Frequency increased
  - From 100Hz to 1kHz
  - C_L increased by about 3lc





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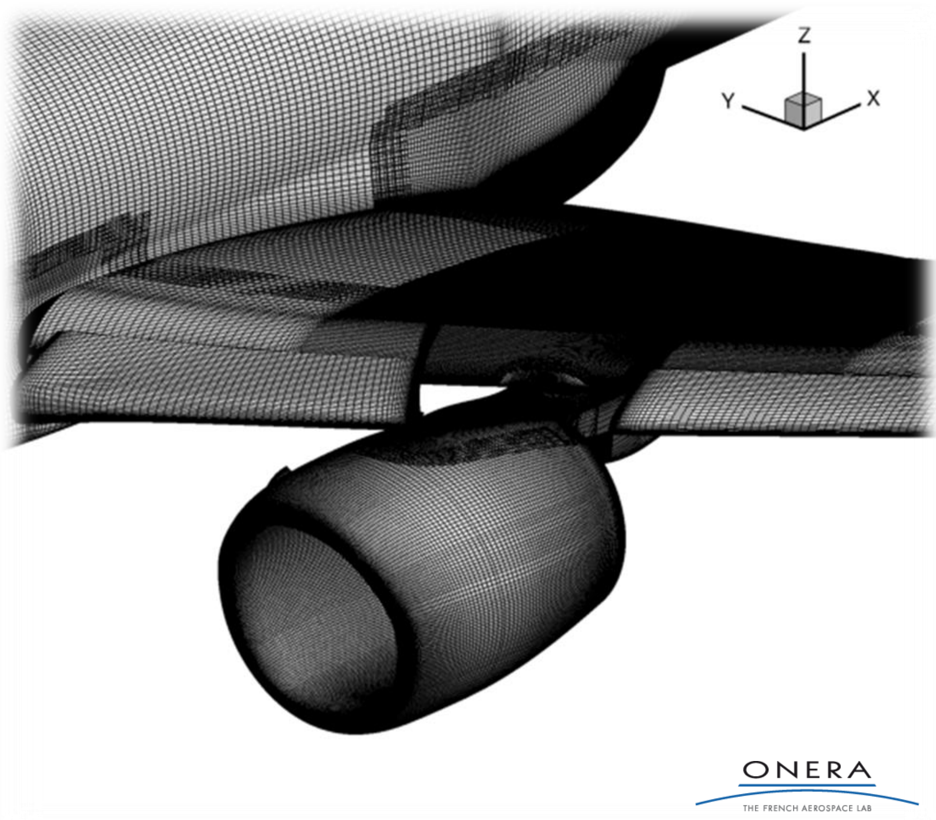
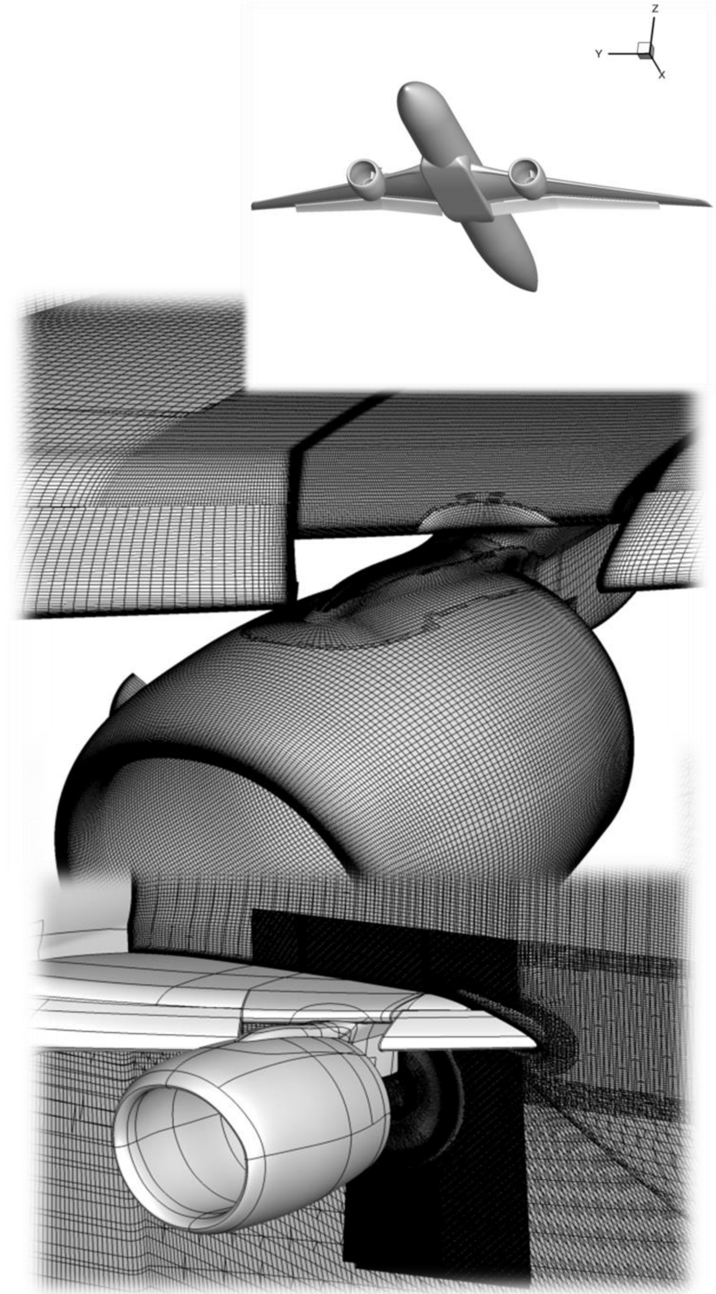
FULL AIRCRAFT SCALE EVALUATION

Geometry and grids

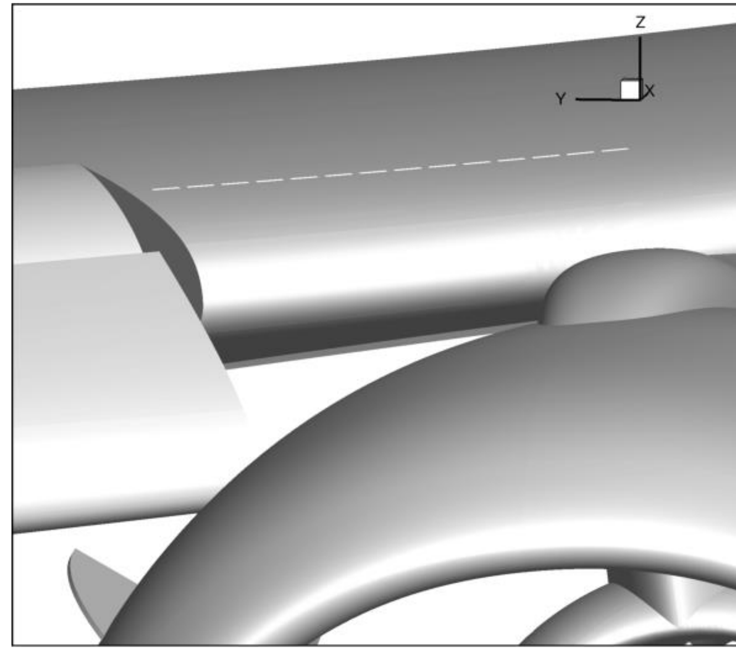
- Realistic configuration
  - Structured Overset grid (ca 70 mil cells)

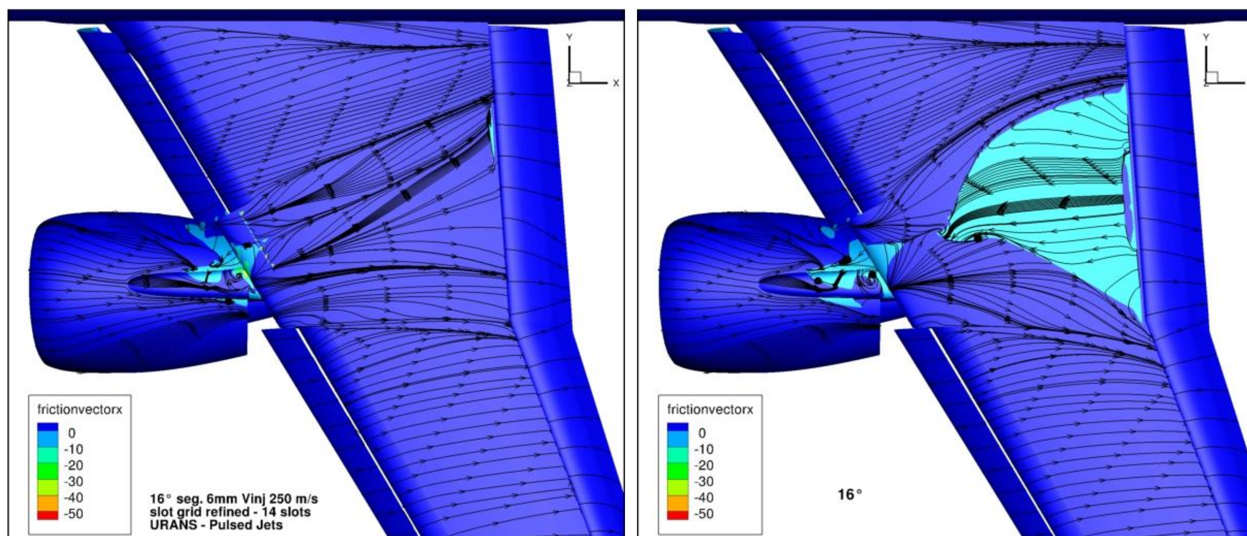




AFC setups

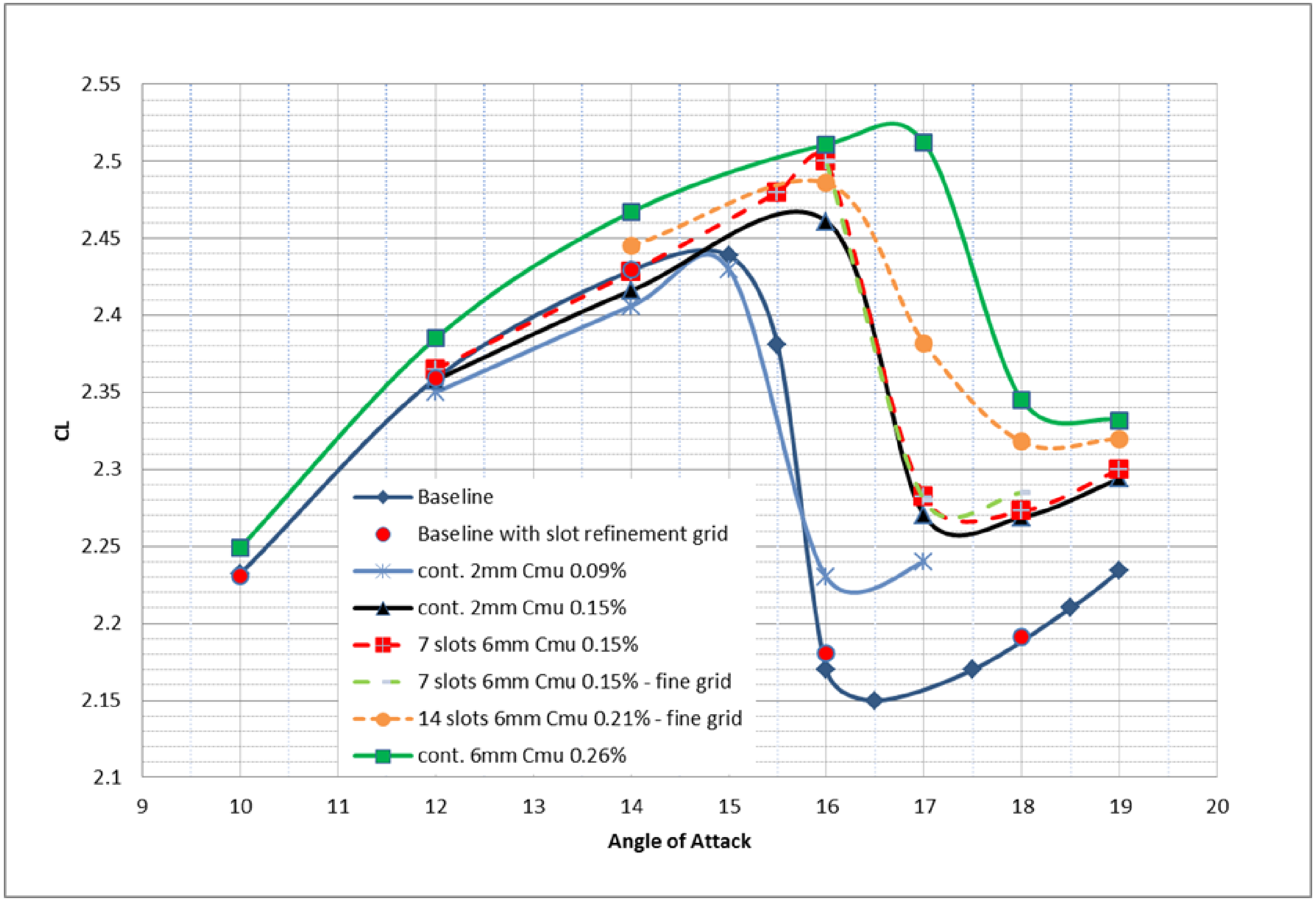
- Steady and pulsed jet blowing slots
  - Variation of slot width (2-6 mm)
  - Jet outlet velocity
  - Influence Cµ
- Pulsed jet blowing
  - f=60 Hz, Phase shift
  - Reduced Cµ compared to steady blowing





Results of Steady blowing calculations

- Effect of Cμ and grid refinement



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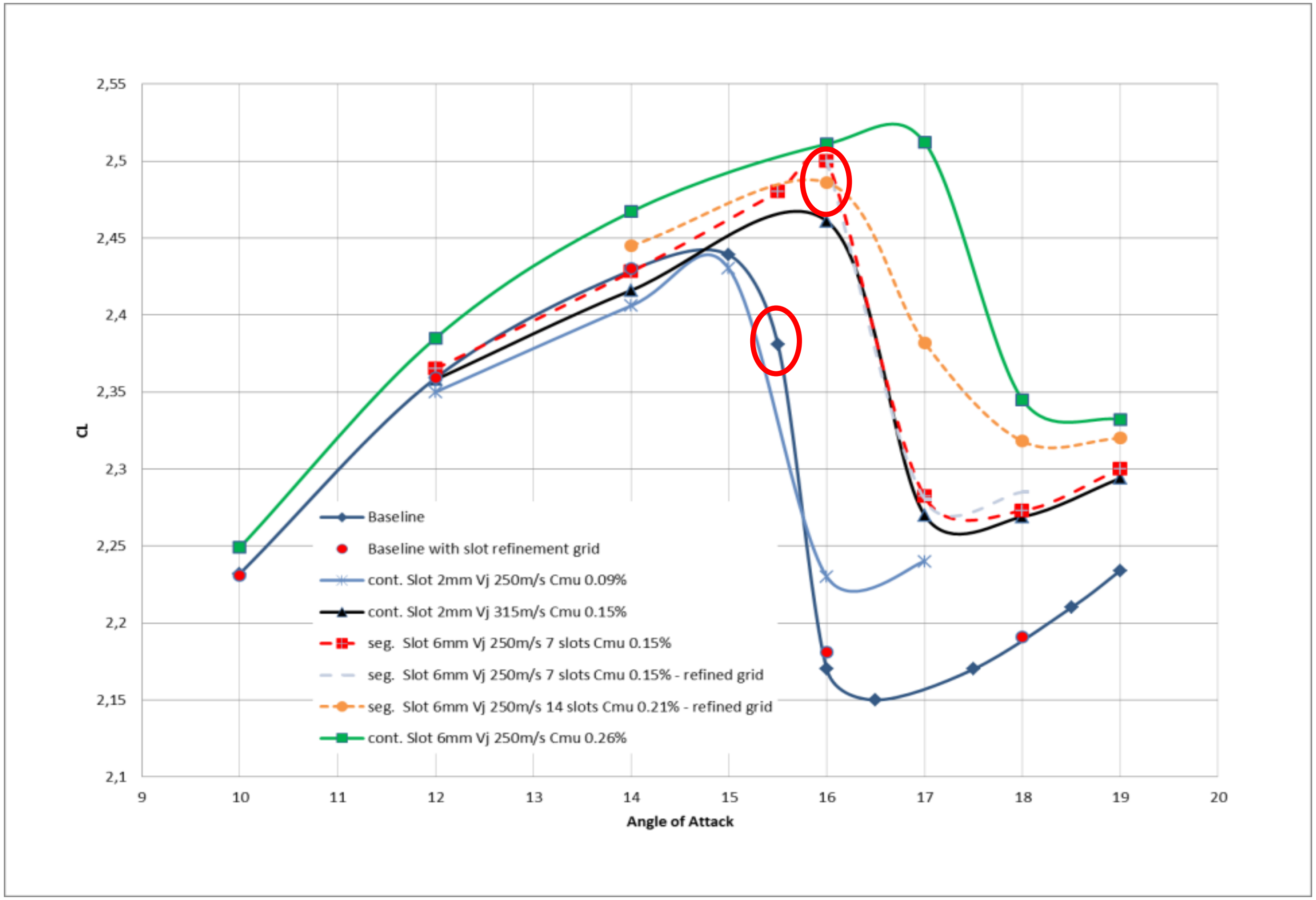
Selected cases for URANS calculations

- From RANS with steady blowing to URANS



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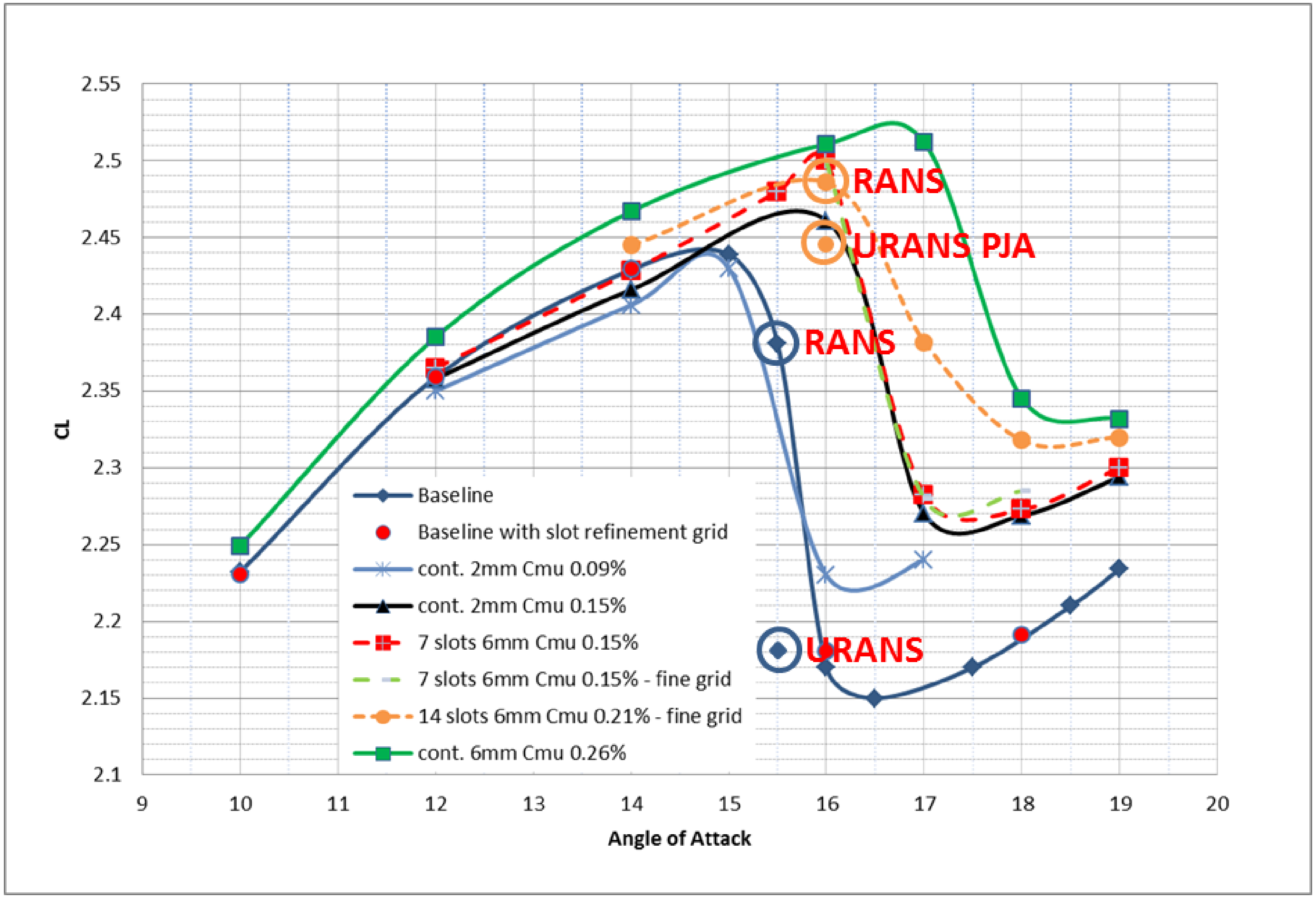
Results of URANS calculations

➢ Differences at the stall region – (U)RANS bls., CB / PJ)



SUMMARY AND CONCLUSIONS

Summary and Conclusions

- CFD tools in theory
  - Provide insight into flow behaviour, vortex structure, separation areas
  - Parametric studies
  - Promising results in terms of separation reduction, $C_{L,max}$ increment
- Practical issues
  - Lenghty unsteady calculations
  - Gap between time scales related to the aircraft and to the AFC
  - Results close to stall - needs to be verified by experiment

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THANK YOU FOR YOUR ATTENTION!

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