TC I.3: 3-Element high-lift airfoil

Coordinated by DLR

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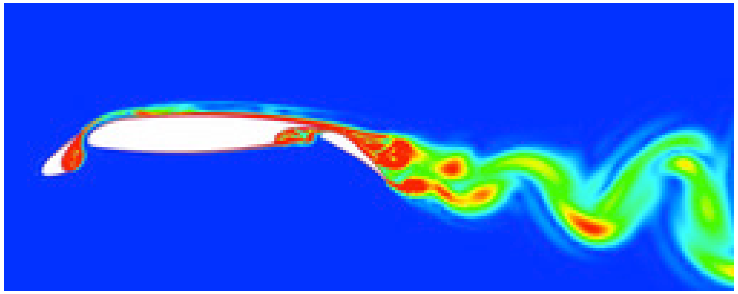
Introduction



- DLR-F15 3-element airfoil investigated in the DLR project LEISA (Low noise exposing integrated design for start and approach, 2005-2008)
- Measurements in the low-speed wind-tunnel Braunschweig (NWB) with a model with chord length c = 0.6m, span = 2.8m, and thus AR = 4.66.
- complex interactions of local separations (both geometry- and pressure-induced) at considered AOA = 6°
- used in ATAAC project as *Application Challange* AC01
  - large effort spent on preliminary RANS computations to find suited settings (angle of attack correction, transition locations, …)
  - however, suitablity as validation case was still doubted…

- depending on hybrid modelling strategy, grey areas may occur in attached, mildly and strongly separated regions
  - ➢ useful to test both non-zonal and embedded mitigation approaches

Geometric description / Description of available reference data

Geometry:

- ascii file with point data of airfoil geometry (still on ATAAC website)
- farfield extent of 100 chords (as given in mandatory grid shown later)

Reference data:

- measured mean surface pressure c_p in different spanwise sections
- measured total pressure profiles in wake (not used in ATAAC)
- measured acoustic data from microphone wall arrays from 1kHz to 0.5MHz
- "consolidated" SST-RANS results from DLR and NTS for mandatory grid

➢ Note: due to experience from ATAAC, comparison CFD vs. experiment (i.e. validation) is not primary goal. Instead, focus is set on model-to-model and code-to-code comparisons.

Design and assessment parameters / Description of errors and known uncertainties

Assessment parameters:

- c_p distributions can be compared with measurements (with all care!)
- for comparisons of simulations, consider the following parameters:
    - mean surface distributions of c_p and c_f
        - ➢ lift/drag coefficients, separation/reattachment locations
    - wall-normal mean velocity and Reynolds-stress profiles along the airfoil (locations to be defined)
    - $c_{p,RMS}$ on whole or in points along surface (locations to be defined)
    - PSD spectra of velocity and/or pressure at various points on the surface and in the field (locations to be defined)

Uncertainties:

- due to large 3D / wind-tunnel effects and uncertain transition locations in the experiment, this case is not proposed for experimental validation

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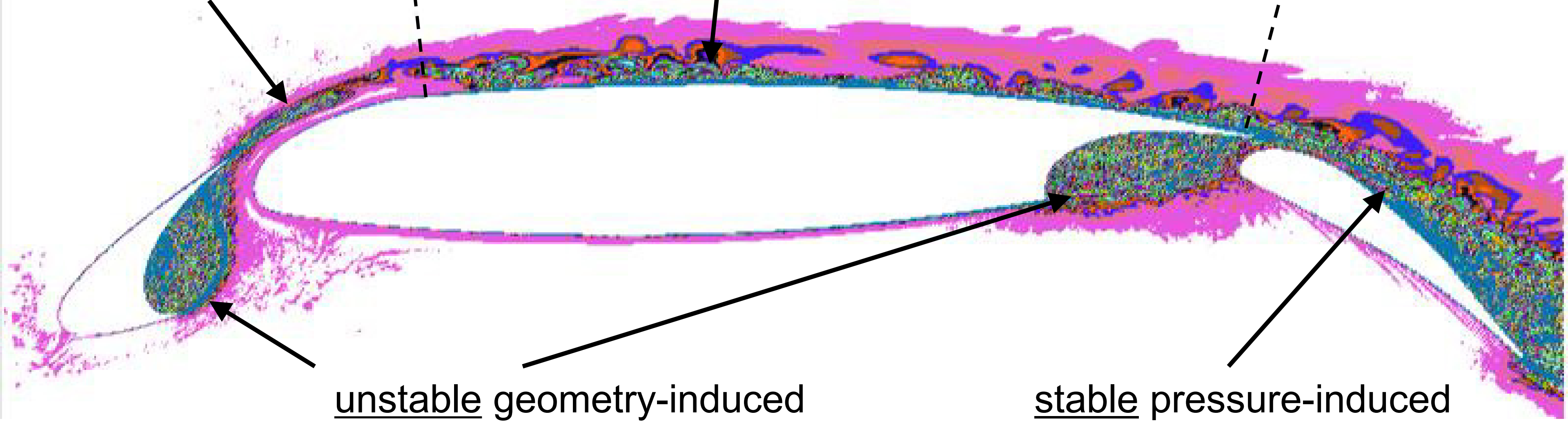
Physical phenomena and modelling challenges / Relevant modelling techniques

<u>stable/unstable</u> free shear layer
- non-zonal mitigation

LES → RANS

<u>stable</u> attached BL
- embedded RANS?

RANS → LES

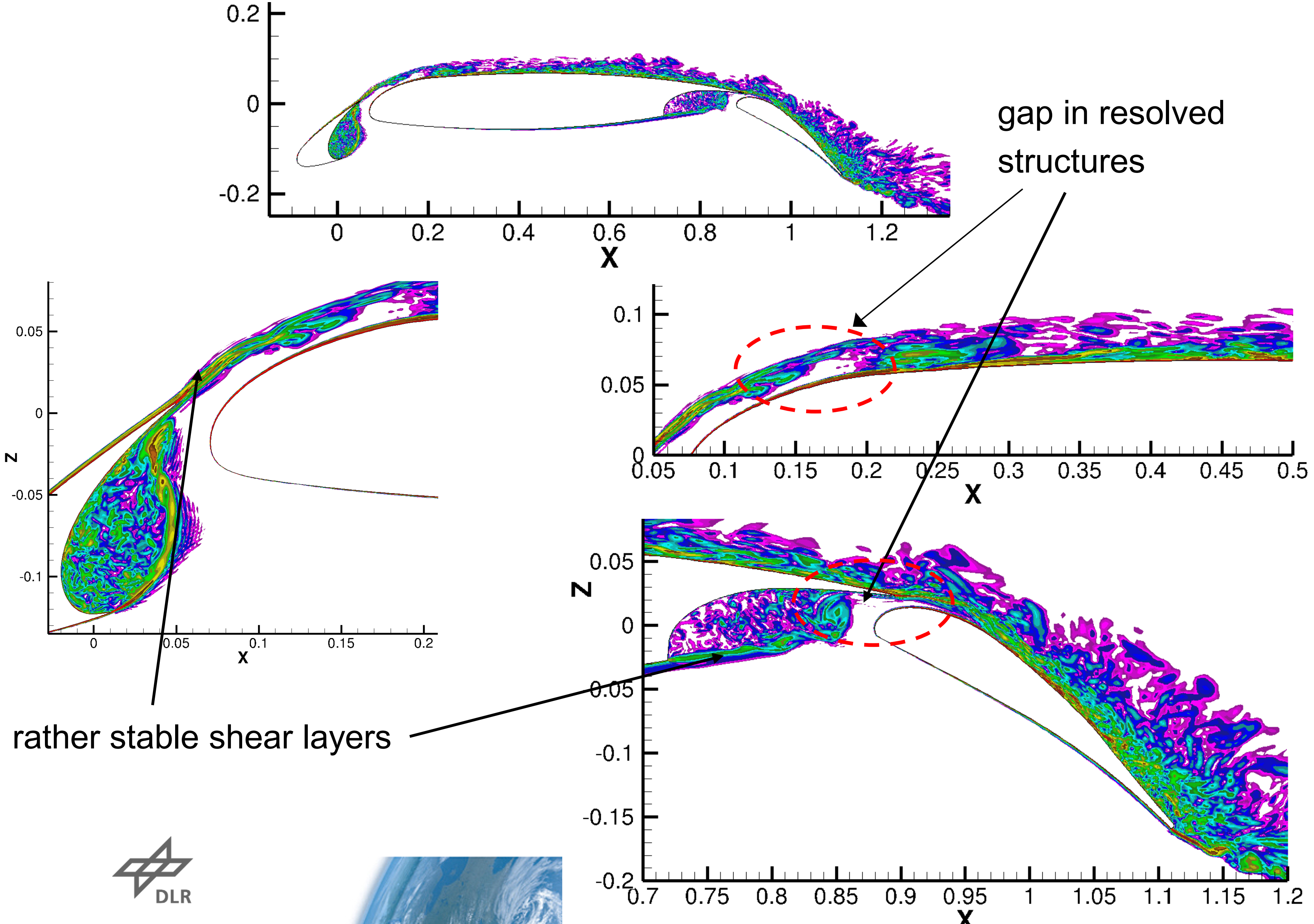


<u>unstable</u> geometry-induced separation
- non-zonal mitigation ?
- embedded LES?

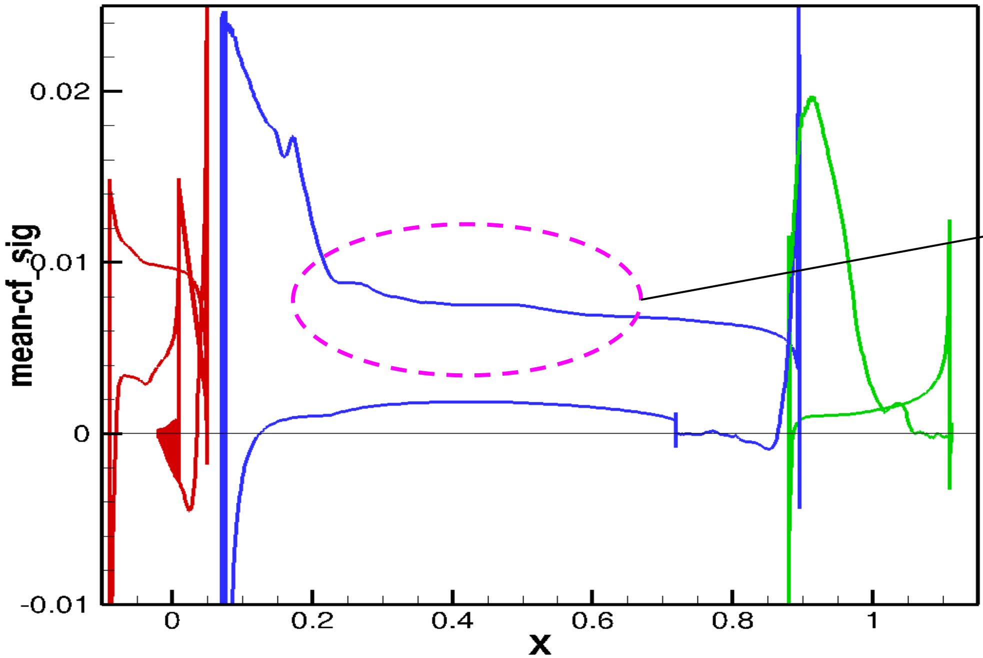
<u>stable</u> pressure-induced separation
- embedded LES

Sample results of full SST.1994 - IDDES

Snapshots of Vorticity Magnitude (DLR)

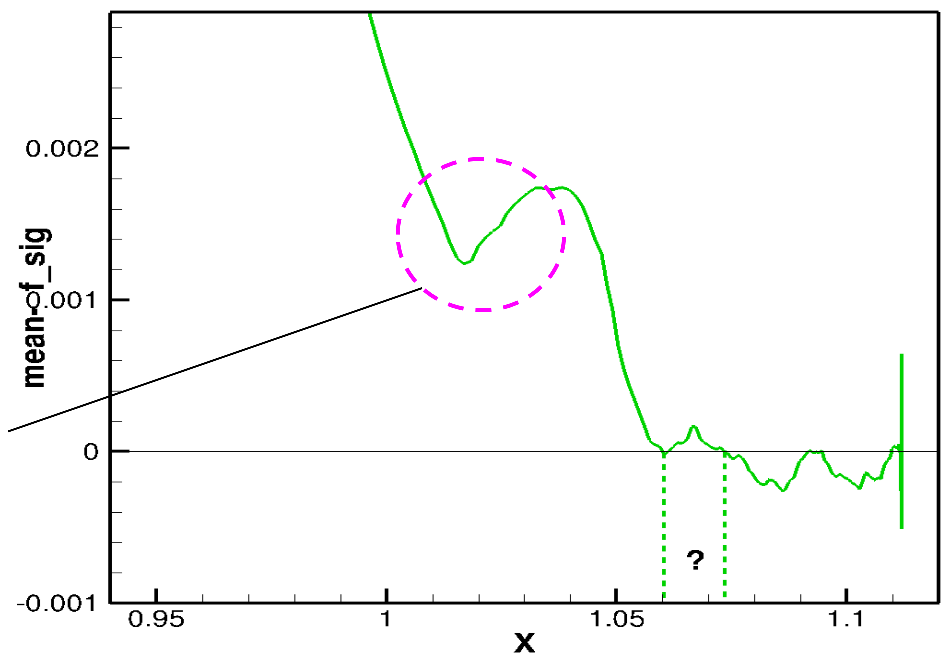


Skin friction coefficient (DLR)



“dent” in c_f on main wing
(similar findings by NTS)

Note: displayed is |c_f| * sign(c_f,x)



c_f “kink” on flap, not seen in RANS
(similar findings by NTS)

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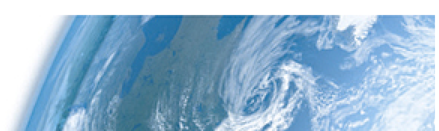
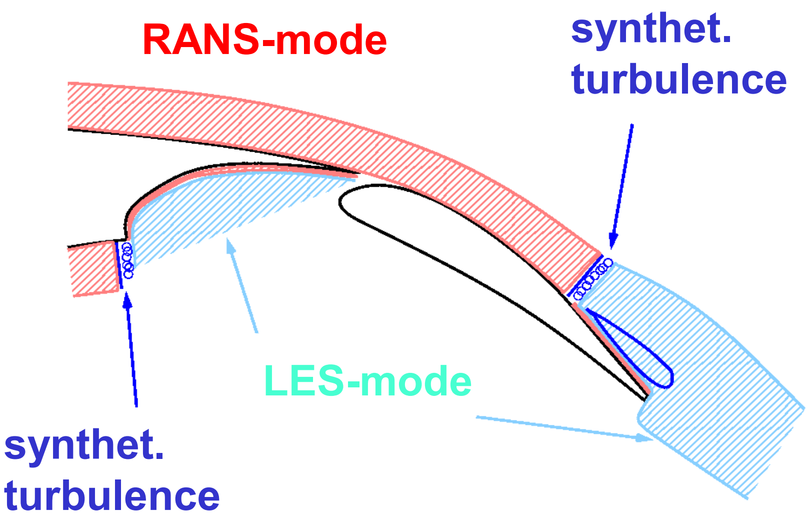
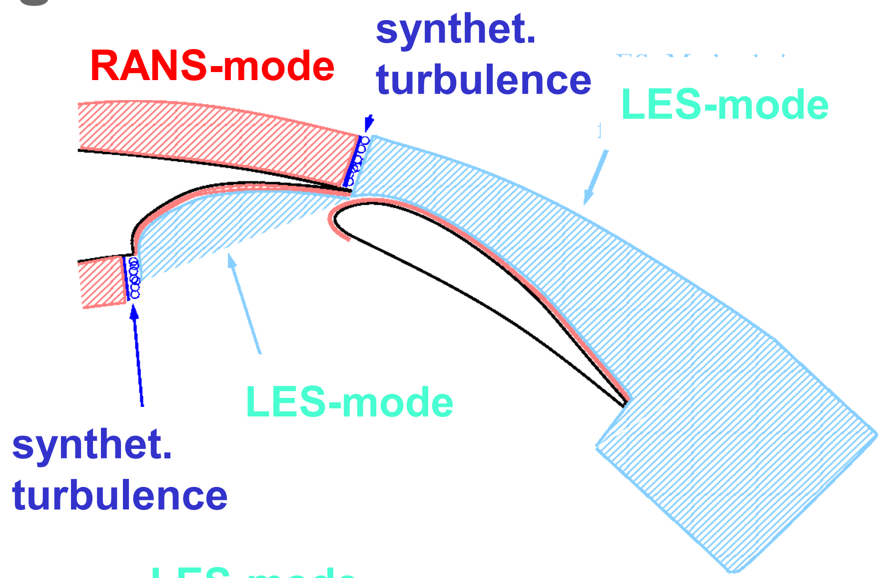
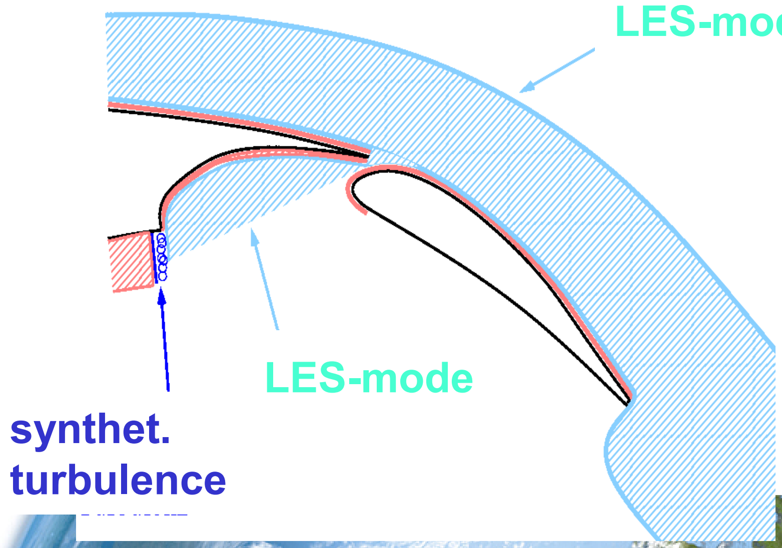


Possible embedded configurations







Pictures provided by T. Knopp

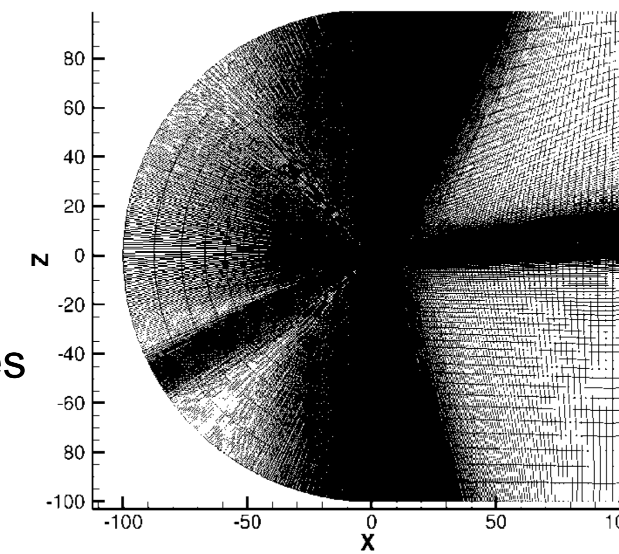
Flow and boundary conditions / Grids

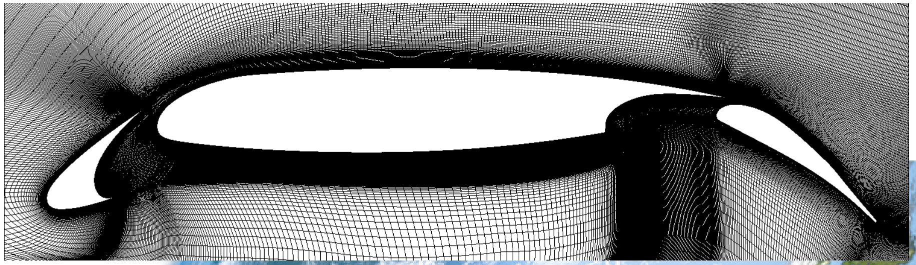
Boundary conditions:

- Mean flow: Re = 2.094 Mio., Ma = 0.15, $\alpha = 6^\circ$
- Turbulence: laminar freestream, e.g. $(\nu_t/\nu)_\infty = 0.1$, $Tu_\infty = (2/3\ k_\infty)^{1/2}/U_\infty = 1 \cdot 10^{-3}$ (however, this should not affect most models!)
- fully turbulent BLs on airfoil surface
    - may be unphysical, but preferable for code-to-code comparisons

Mandatory grid (suggested)**:**

- structured grid provided by NTS for IDDES
- span size L_z = 0.08 c with 100 grid cells, ~ 27 mio. cells total
- farfield distance at 100 chords
- Note: contains (some) non-orthogonal grid lines



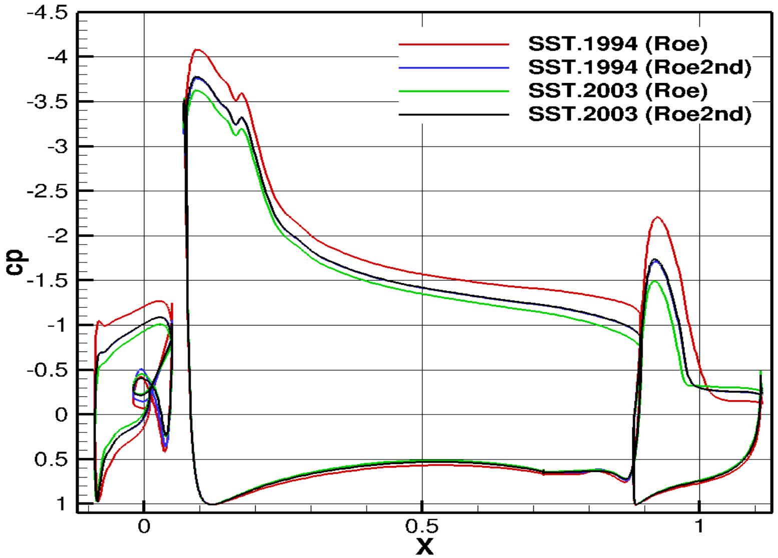


Computational guidelines

- spatial domain extent and discretization as given in mandatory grid

- Temporal settings:
  - suggested time step: $\Delta t = 2 \cdot 10^{-4}\ c/U_\infty$
  - initial transient phase (starting from RANS solution): > 4 CTU
  - averaging time: > 10 CTU

- 2nd-order discretization of turbulence equations required?
  - ➢ large impact on RANS results even on mandatory (IDDES) grid
  - ➢ found by both DLR and NTS



Mandatory and optional results

Mandatory results:

- mean surface values (c_p, c_f) and field profiles (velocity, Reynolds stresses)
- distinction between modelled and resolved turbulence
- $c_{p,RMS}$ in points along surface (locations to be defined)
- visualizations of turbulent structures via Q-criterion

Optional results:

- PSD spectra of velocity and/or pressure (locations to be defined)
- $c_{p,RMS}$ distribution on surface
- spanwise two-point pressure correlations
- …?

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References

[1] Wild, J., Pott-Pollenske, M. (2006) *An Integrated Design Approach for low Noise exposing high-lift devices*. AIAA paper 2006-2843

[2] Reuß, S., Knopp, T., Schwamborn, D. (2012) *Hybrid RANS/LES simulations of a three-element airfoil*. NNFMMD, Vol. 117: Progress in Hybrid RANS-LES Modelling.

[3] Deck, S., & Laraufie, R. (2013). *Numerical investigation of the flow dynamics past a three-element aerofoil*. Journal of Fluid Mechanics, 732, 401–444.