Oral presentation | Turbulence simulation (DNS,LES,RANS)
Turbulence simulation(DNS,LES,RANS)-II
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[9-B-01] Wall-Modelled Large-Eddy Simulation of the Aerospatiale A-airfoil at Near Stall Conditions

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Wall-Modelled Large-Eddy Simulation of the Aerospatiale A-airfoil at Near Stall Conditions

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Background

- We are interested in advancing WMLES capabilities and understanding current limitations.
  - Wide-spread finite volume solvers (https://www.openfoam.com).
  - High-order GPU-enabled solvers (https://neko.cfd).
- Goal: application to aerospace, marine technology, and meteorology.
- Currently well-validated for zero-pressure gradient boundary layers.

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The Aerospatiale A-airfoil at $Re_c = 10^7$ and $13.3°$AoA

- Wall-resolved LES data from (Tamaki and Kawai, 2023).
- No separation in the mean, but clear APG effects.
- Highest Re-number to date.
- A good WMLES test case?
- Selected as a common test case for the WMLES workshop at SciTech.

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Setup for spectral element simulations

- Nek5000 with KTH_Framework tooling.
- CG SEM solver with user-selectable basis order.
- Structured hexahedral meshes.
- Wall-stress model using Spalding's law of the wall.
- Neumann boundary condition on wall-parallel components.
- Vreman SGS model (also tested Sigma).
- h can be set to arbitrary value: spectral interpolation.

Setup for spectral element simulations

- Variable timestep targeting CFL $= 2$.
- BDF2 + OIFS time integration.
- We use $h = 0.1\delta_{99}$ in the turbulent region and $\approx$ distance to first node in the laminar.
- So, relying here on δ_{99} data from WRLES.

- We start with polynomial order 3 (so linear for pressure) to get rid of the TE vortex.
- Then switch to order 5, run a few c/U_∞ to get rid of the transient.
- Finally average across about $4c/U_\infty$.

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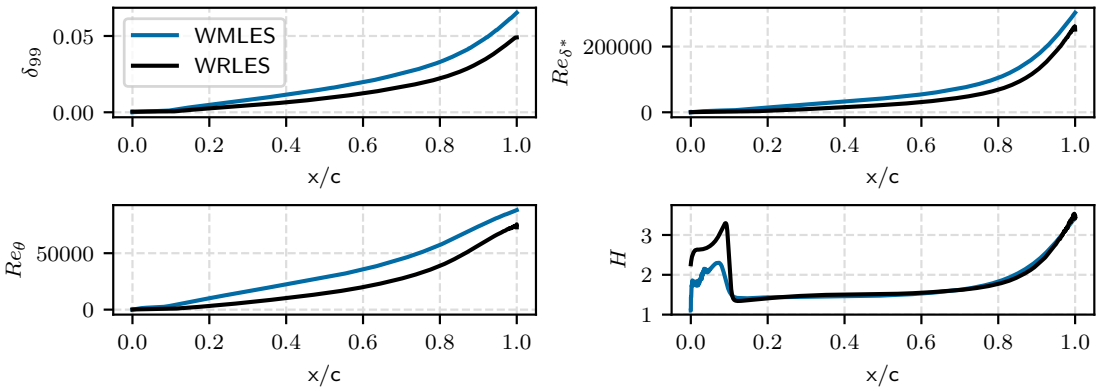
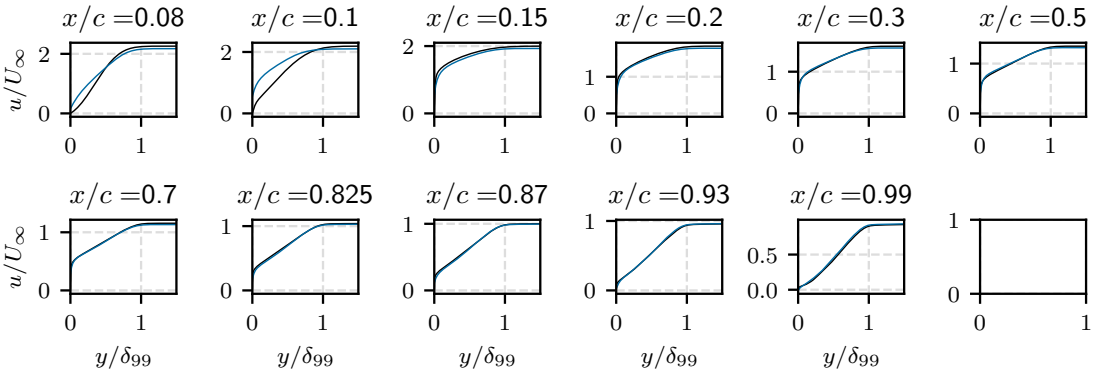
SEMS Results, boundary layer thickness

- BL grows too fast right from the start. So, in reality $h < 0.1\delta_{99}$!
- Remarkably good shape factor in the turbulent region.
- I use the method by Griffin, Fu and Moin. We *must* report this!



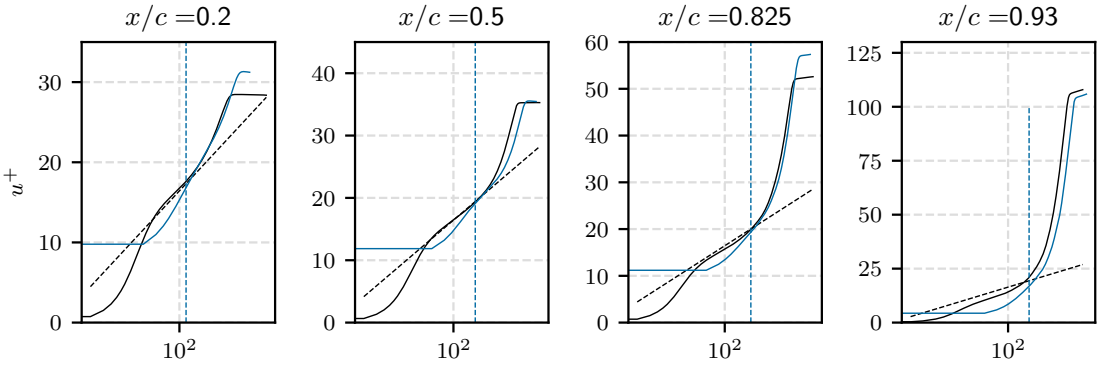
SEM Results, mean velocity in outer scaling

- Excellent results in the turbulent region.
- Interestingly, the results are actually best in the APG region.
- Aligns with the idea that τ_w has a smaller effect on outer layer dynamics?



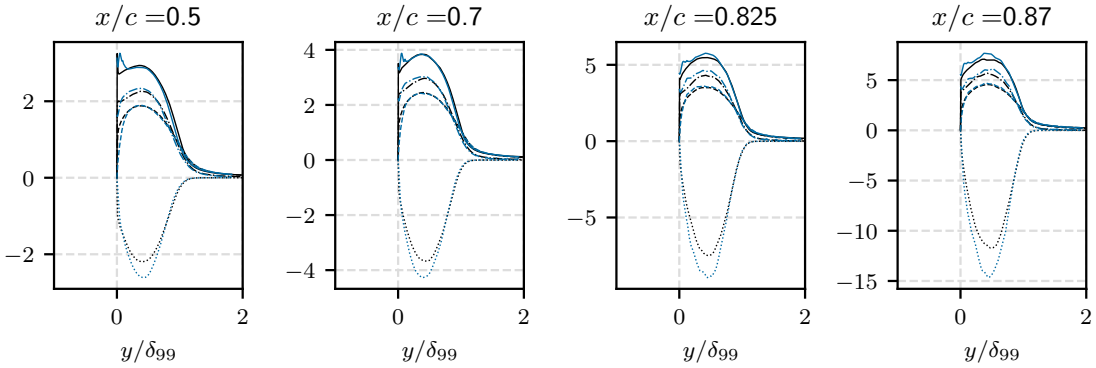
SEM Results, mean velocity in inner scaling

- Quite accurate results, hinting good c_f.
- ”LES buffer layer” eats almost the whole log law.
- SGS model too diffusive near the wall?



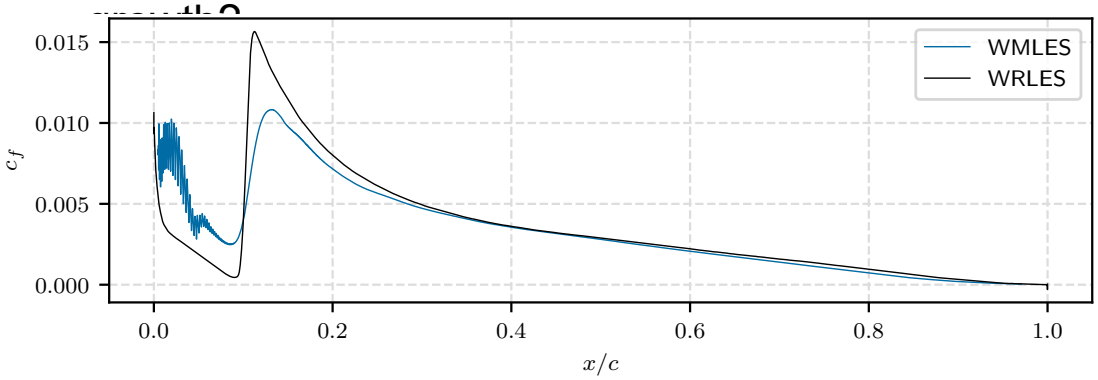
SEM Results, RMS values of velocity

- Excellent agreement for a WMLES.
- It seems capturing the APG-affected TBL is not a big issue for WMLES.
- Closer to the leading edge, the results are poorer.



SEM Results, skin friction coefficient

- Transition at the right place. Seems to be easy for this case. (No tripping!)
- Good agreement in the turbulent region. **But must be due to error cancellation!**
- Oscillation and over-prediction in the laminar region – cause of δ_{99} growth?



Setup for finite volume simulations

- OpenFOAM v2306, pimpleFoam with 3 outer iterations.
- Approx. 150 million hex cells.
- Variable timestep targeting CFL $= 1$.
- BDF2 time integration.
- h set to off-wall cell.
- Cai-Sagaut explicit algebraic wall model.
- Wall stress enforced via change in wall ν_t.
- Sigma SGS model.

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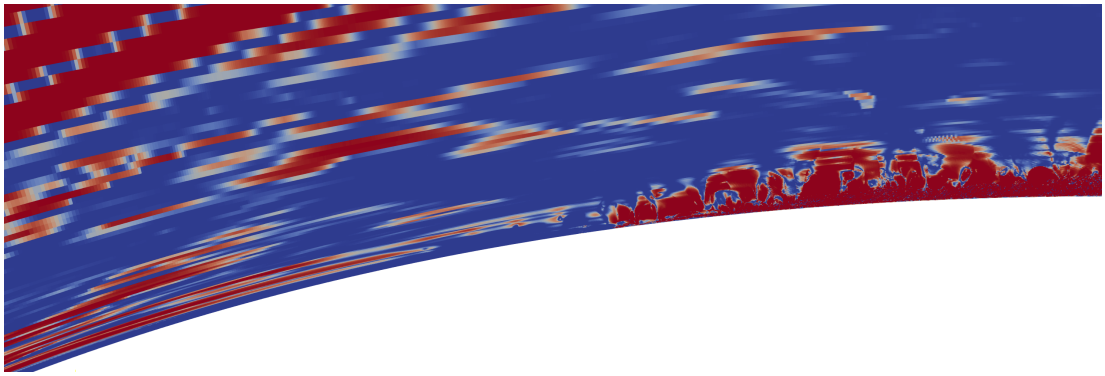
Simple transition indicator

- Use the ν_t from the Sigma SGS model — designed to be 0 in laminar regions.
- Use the ansatz $\tanh(C_1 \nu_t/\nu)^{C_2}$. Provisionally, $C_1 = 75$, $C_2 = 6$.
- The ν_t is quite noisy: spatial averaging across neighbors.
- A lot of false positives outside the TBL. But transition place



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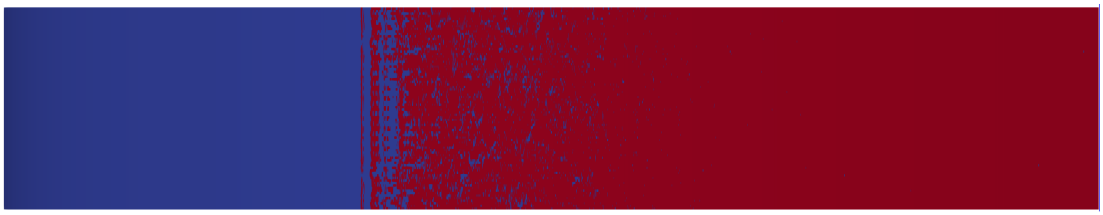

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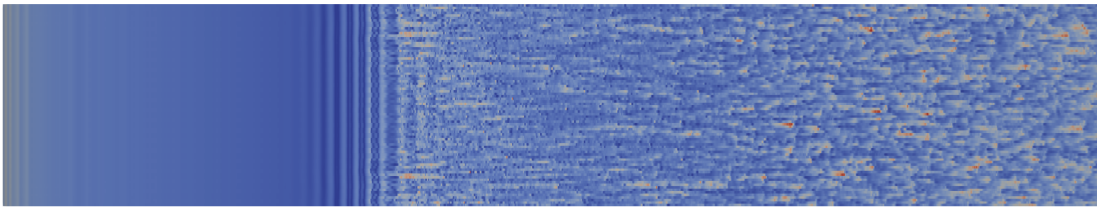
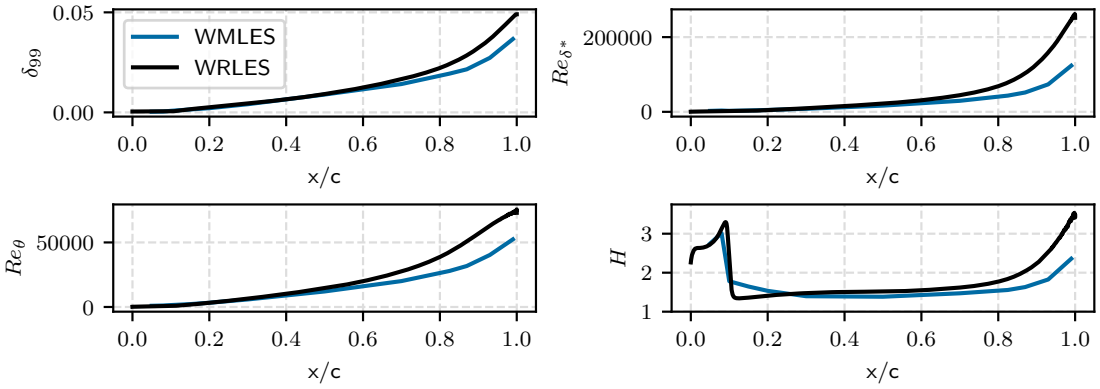


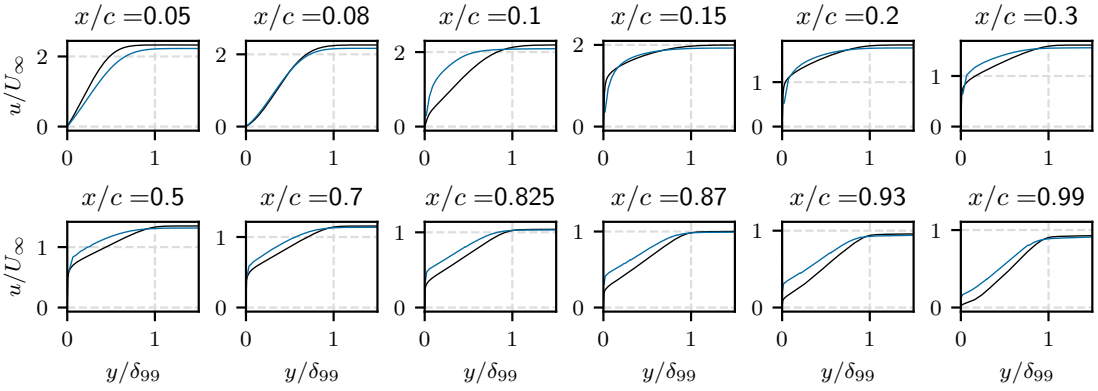
FVM Results, boundary layer thickness

- Correct growth before the pressure gradient effects kick in!
- Pressure gradient effect is too weak.



FVM Results, mean velocity

- Note quite as accurate as the SEM overall.
- But better prior to transition.



Conclusions

- Soft indication that SEM is doing a better job than FVM in the outer layer.
  - At similar DoF numbers.
  - Great accuracy in the APG region.
- The main issue remaining for SEM is to treat the laminar / transition region.
  - Leads to erroneous growth rate, among other issues.
- A simple transition indicator based on the Sigma model tested in FVM.
  - Seems to do a pretty good job, but parameter values may be case dependent.
- Future:
  - Scheme / resolution adjustments for better FVM results?
  - Implement indicator in SEM.

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