APC-IV Case 1 results using Simcenter STAR-CCM+

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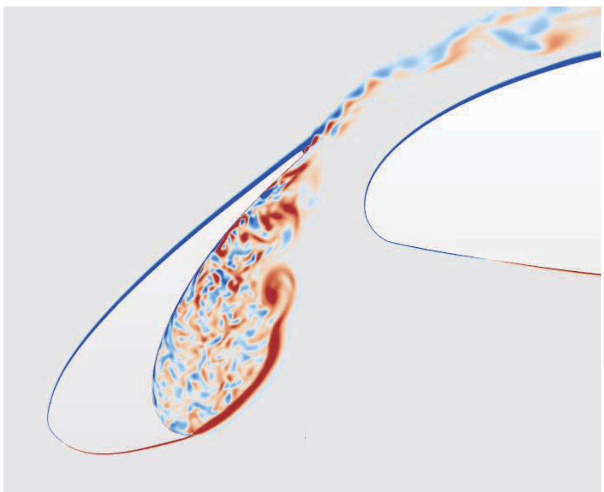
Simcenter STAR-CCM+
Solver overview

- STAR-CCM+ 12.06, double precision
- Cell-centered, finite-volume discretization
  - Can handle arbitrary polyhedral cell topologies
  - Uses reconstruction to calculate gradient at cell faces
- Density-based coupled solver
  - Implicit scheme with Newton-type linearization
  - Inviscid flux using the Roe scheme
  - AMG to solve linear system
  - Solution acceleration techniques
    - Grid Sequencing Initialization
    - Expert Driver
- Spalart-Allmaras (SA) turbulence model
  - *Not* coupled to flow equations



30P30N, 2d
Grid Convergence

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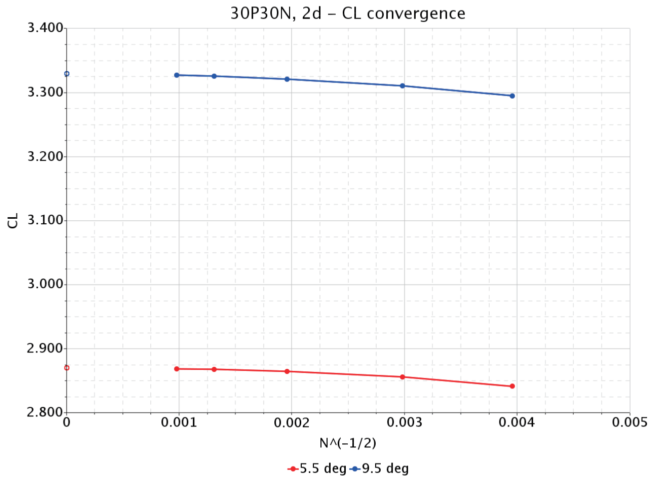
Ingenuity for life

- Committee grids show good convergence
- CL convergence:
  - Varies by <1% across grid family
  - Varies by 0.02% (5.5º) & 0.05% (9.5º) between L4/L5 grids
  - GCI = 0.011% for 5.5º case



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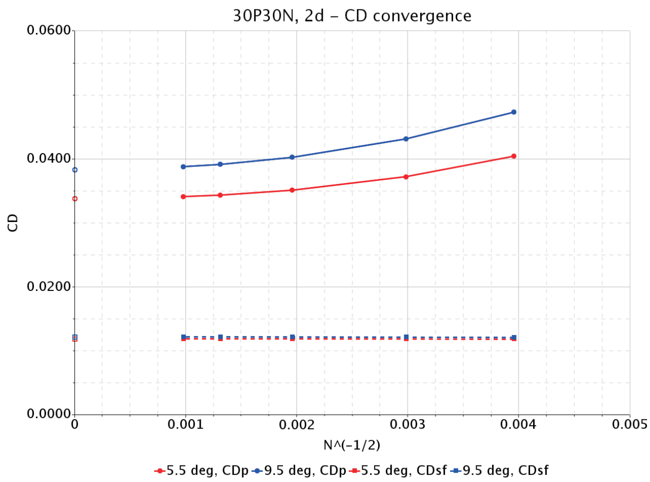
  - GCI = 0.011% for 5.5º case
- CD convergence:
  - Variation in CDp ~2 orders more than CDsf
  - Varies by 0.49% (5.5º) & 0.66% (9.5º) between L4/L5 grids
  - GCI = 0.53% for 5.5º case



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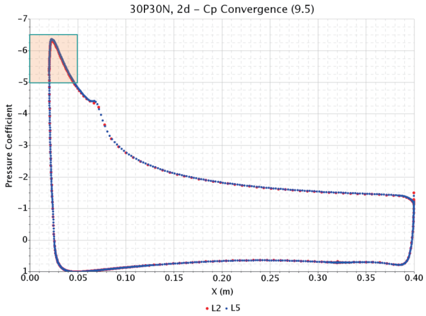
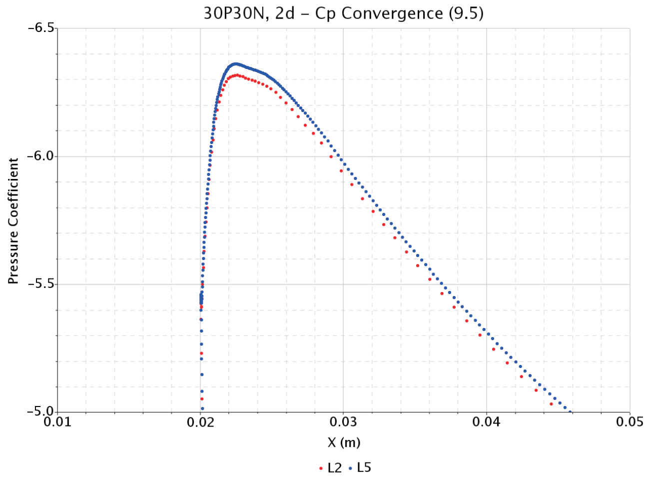
Cp profiles (9.5º) show very little slight differences

- Largest discrepancy is at suction minimum
  - L5 grid has Cp ~0.05 lower
  - Difference decays downstream





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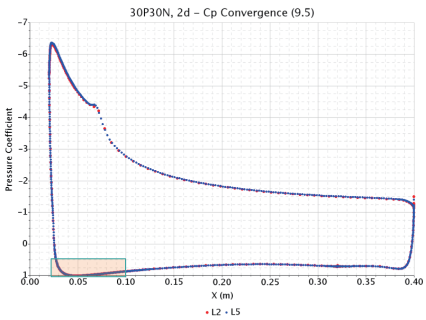

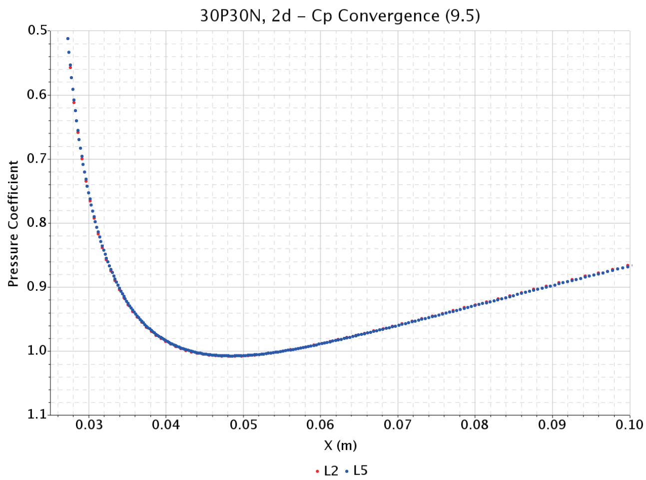

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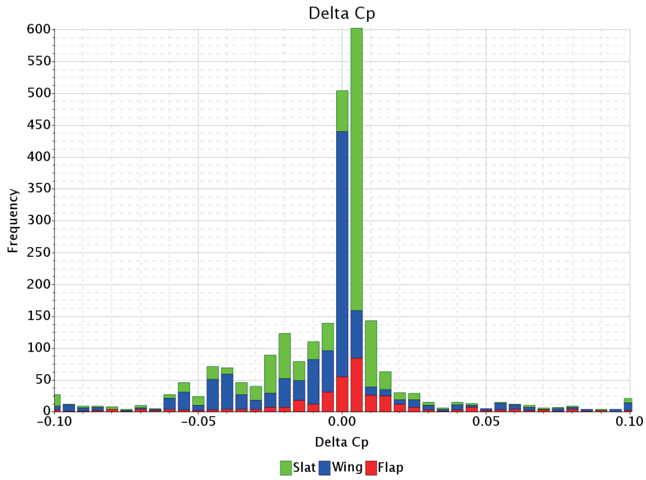
  - Difference decays downstream
- No discernible difference at stagnation point
- Histogram plot shows that majority of surface faces show very little difference between L2 & L5 grids
  - Distribution biased towards negative values
    - Likely related to suction minimum



30P30N, 3d
Grid Convergence

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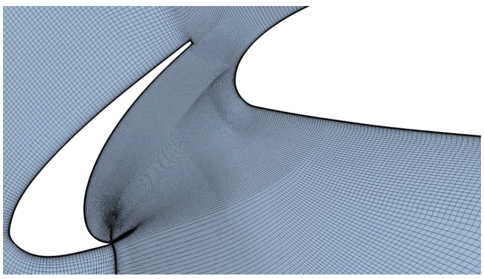
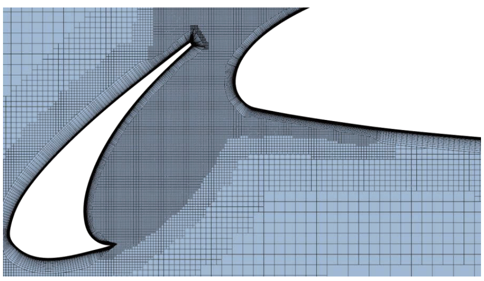
Designed custom grids for 2.5d study

- Uniform spacing in span caused slow AMG convergence
- Cartesian cut-cell with body-fitted prism layers





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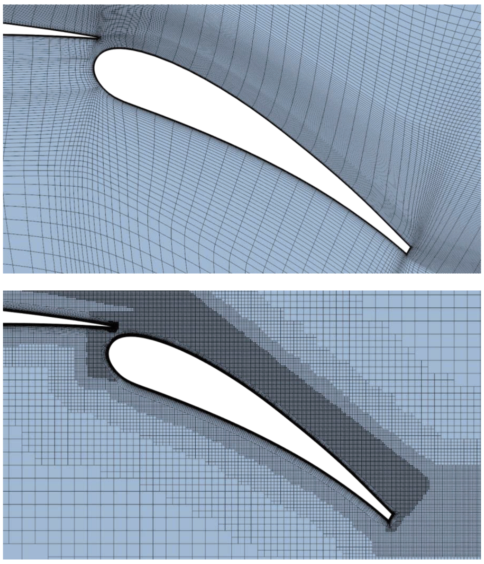

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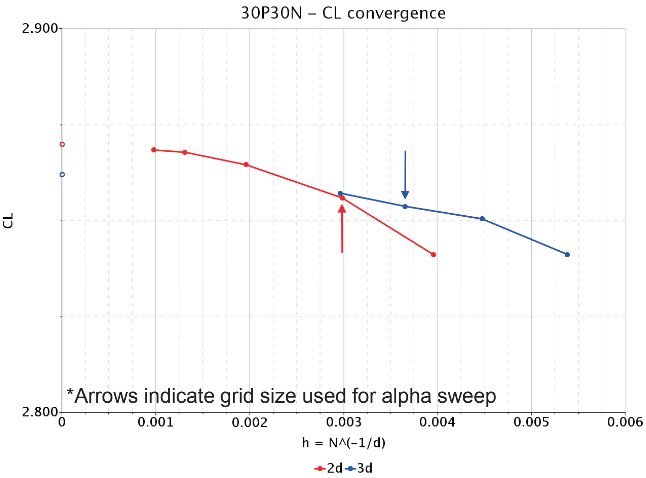
CL convergence
- Comparable lift values at similar resolutions
- Richardson extrapolated values differ by 0.27%



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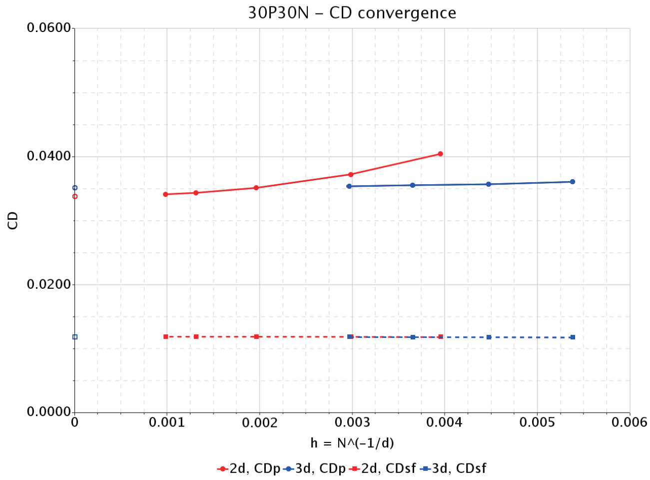
CL convergence
- Comparable lift values at similar resolutions
- Richardson extrapolated values differ by 0.27%

CD convergence
- Skin friction is very similar (±0.4 counts as h → 0)
- Pressure convergence is flatter with custom grid
- Richardson extrapolated values differ by 2.8%
  - Though, custom grid is far away from h = 0

Overall, happy with custom grid for 2.5d study



30P30N
Alpha Sweep

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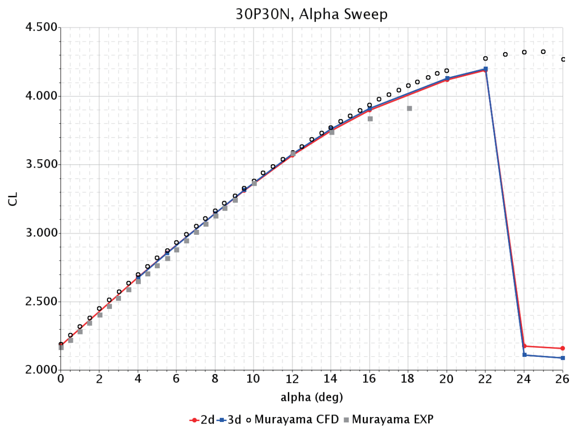
Ingenuity for life

Lift coefficient agrees well between 2d & 3d runs
- Results between CFD & EXP of Murayama
- Max deviation is 0.36% (0.013) @ 14°

2d/3d both separate at highest 2 angles



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Lift coefficient agrees well between 2d & 3d runs
- Results sandwiched between CFD & EXP of Murayama
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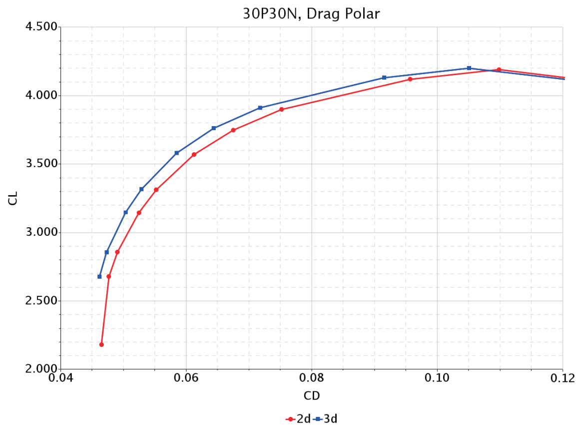
Similar drag values between 2d & 3d
- 3d has consistently lower drag (20-40 counts)



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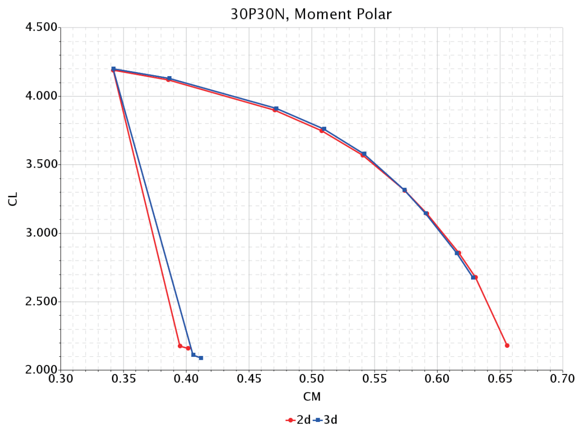
2d/3d both separate at highest 2 angles

Similar drag values between 2d & 3d
- 3d has consistently lower drag (20-40 counts)

Moment is very similar between two cases
- Max deviation is 0.31% (0.0016) @ 14°



30P30N
Unsteady

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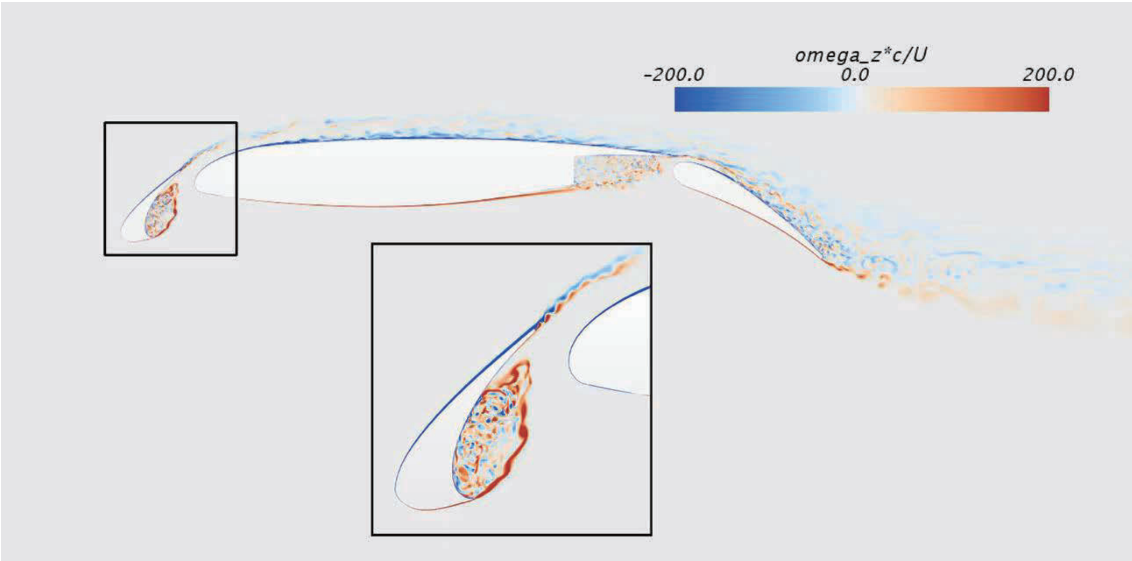

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30P30N
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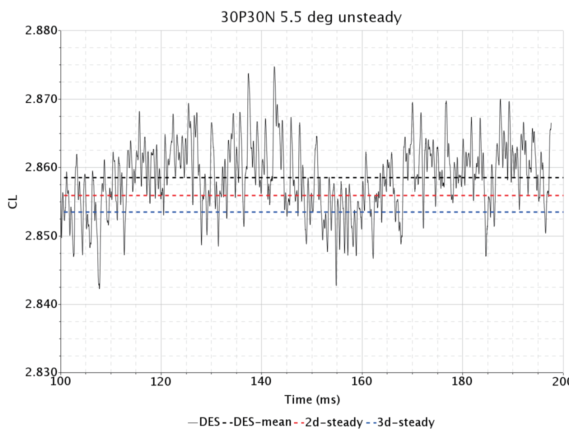
DES result is well predicted by RANS for both CL & CM

- Variation in mean CL & CM is <0.3% for 5.5º
- Variation in mean CL & CM is <0.6% for 9.5º
- RMS of CL is 0.0050 (0.17%)



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30P30N
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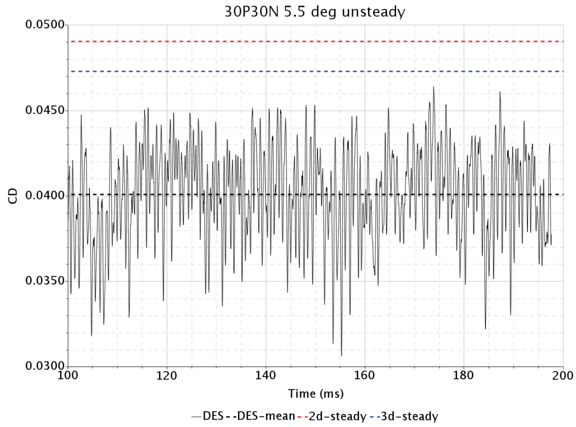
Drag shows much larger variation
- Mean CD is up to 90 counts lower in DES for 5.5º
- RMS of CD is 0.0027 (6.7%)

Some of the variation in drag is likely due to the DES mesh being much finer than the 2d (L2) and 3d (20M) grids
- Grid study showed strong decrease in pressure drag with finer grids
- Transitional flow also reduces skin friction drag (more later)



30P30N
Boundary Layer, 5.5º

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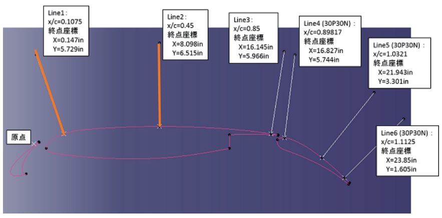
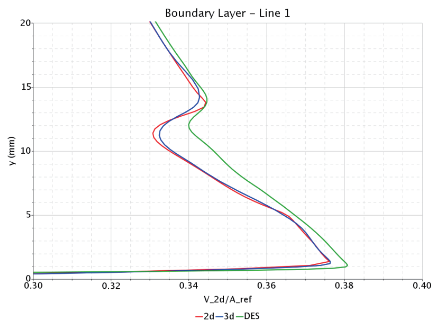
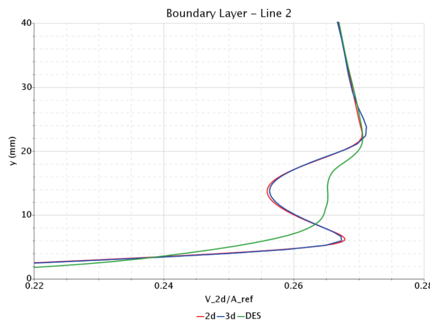
- 2d/3d steady cases agree
- DES predicts more higher peak velocity at station 1
  - Better resolves suction minimum
- DES predicts more diffuse slat wake
  - Especially pronounced at downstream station







30P30N
Boundary Layer, 5.5º

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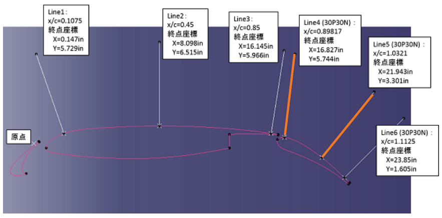
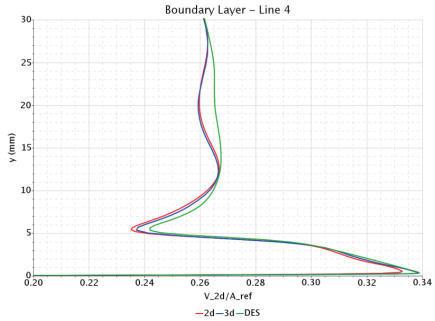
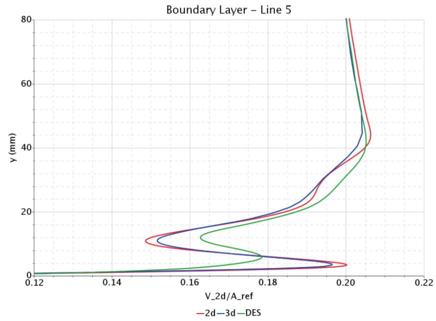
- Similar trends as before
- Slat wake is still visible in steady results
  - Almost entirely smoothed out in DES results
- Wing wake decays significantly by mid-way down flap (station 5)







30P30N
Transition

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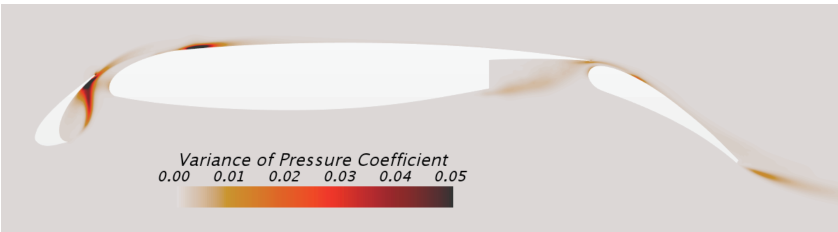

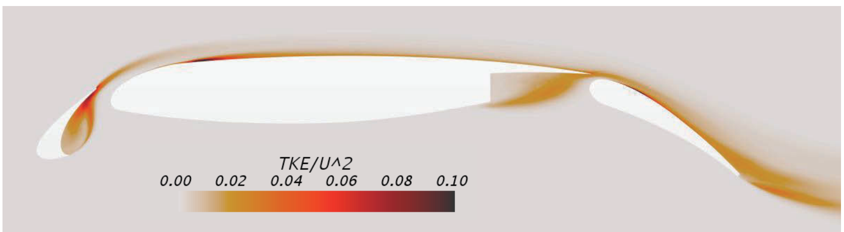

30P30N
Transition

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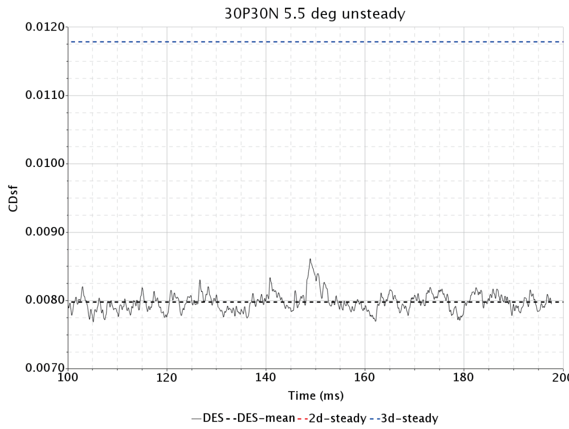
- Significantly lower skin friction drag in the DES case
  - Almost 40 drag counts
  - SA model did not account for transition
    - Interested to go back and re-run using SST with the $\gamma - Re_\theta$ or γ transition models



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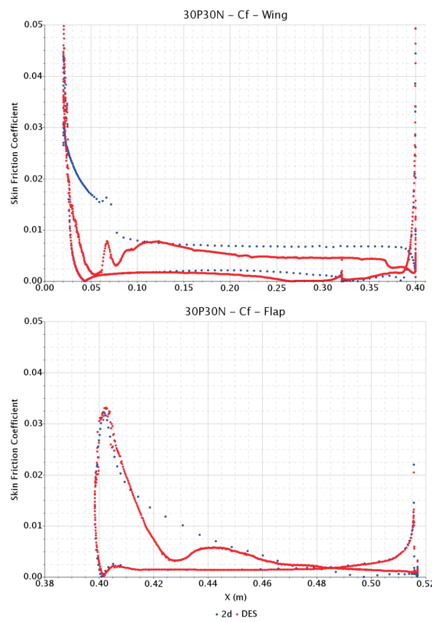
- Skin friction magnitude on both the wing and the flap show clear laminar regions
  - Wing skin friction recovers but then remains lower than RANS results downstream of transition
  - Flap transition limited to small pocket



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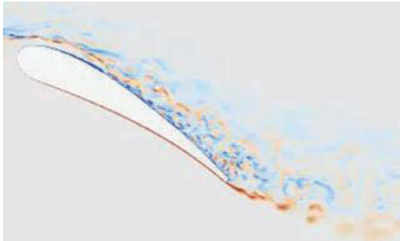
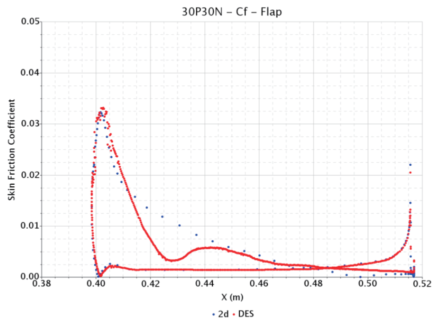
  - Wing skin friction recovers but then remains lower than RANS results downstream of transition
  - Flap transition limited to small pocket
    - Animation suggests highly unsteady transition
    - Inviscid flow core in wing-flap gap suppresses transition
    - Wake vortices activate transition





Conclusion

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- A detailed aerodynamic analysis of the case 1 conditions has been presented
  - The unsteady case was run using DES
- Grid convergence was demonstrated for the 2d & 3d steady cases at 5.5º and 9.5º
- An alpha sweep was conducted using both the 2d and 3d grids
  - Lift and pitching moment were very similar between the two grids
  - The 3d results consistently had slightly less drag than the 2d results
- The 5.5º condition was further investigated by comparisons to an unsteady DES simulation
  - Lift was quite close between all 3 cases
  - Drag was significantly lower due to:
    - The presence of transition on the wing & flap
    - The finer resolution of the DES mesh better resolving the suction minimum on the main wing