Drag Workshop Results Using CFL3D

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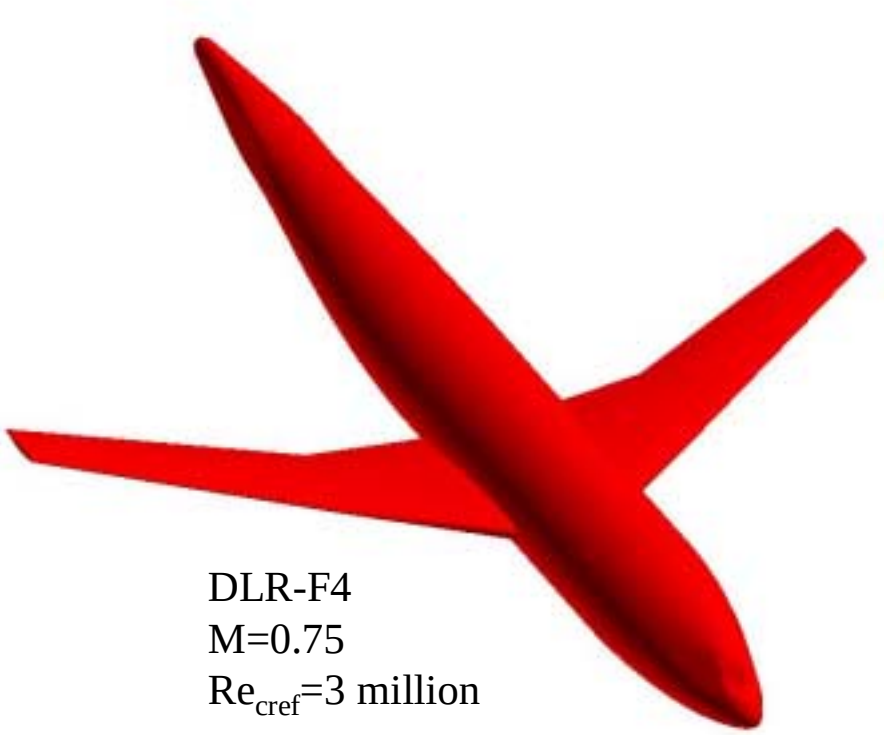


DLR-F4
M=0.75
Re_{cref}=3 million

Issues addressed

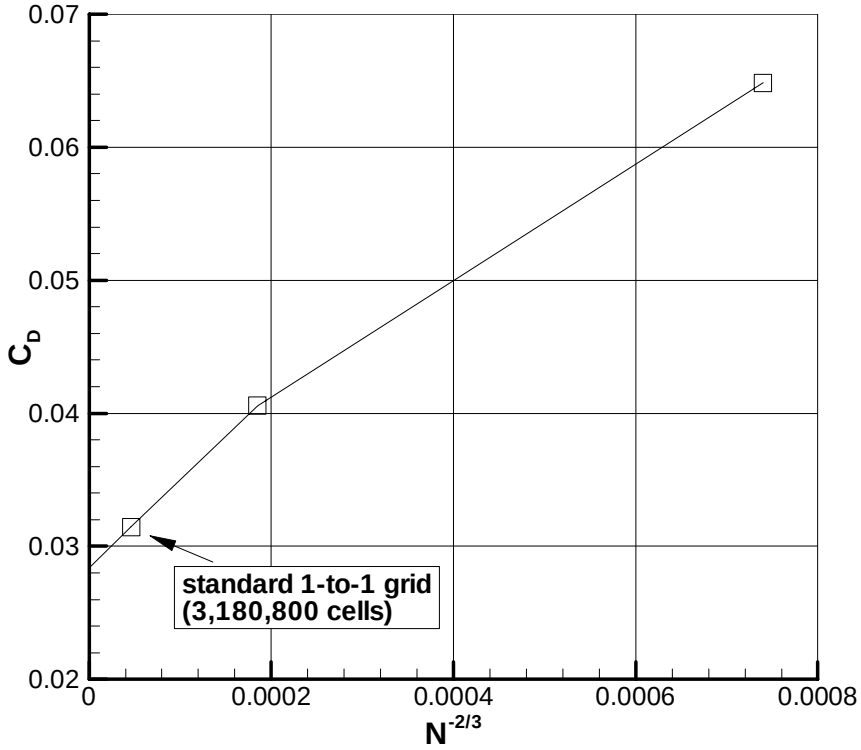
- Effect of grid (1-to-1 vs. overset)
- Comparison of 3 turbulence models
- Issue of transition for supposedly “fully turbulent” computations
- Effect of different versions of SA model

CFL3D V6.0

- Upwind, implicit 3-factor AF
- Finite volume, multigrid
- FDS (Roe)
- Globally 2^{nd} order spatially accurate
- Multi-block capabilities, including 1-to-1, patched, and overset
- Parallel (MPI)

Grid convergence
1-to-1 grid, M=0.75, C_L=0.5

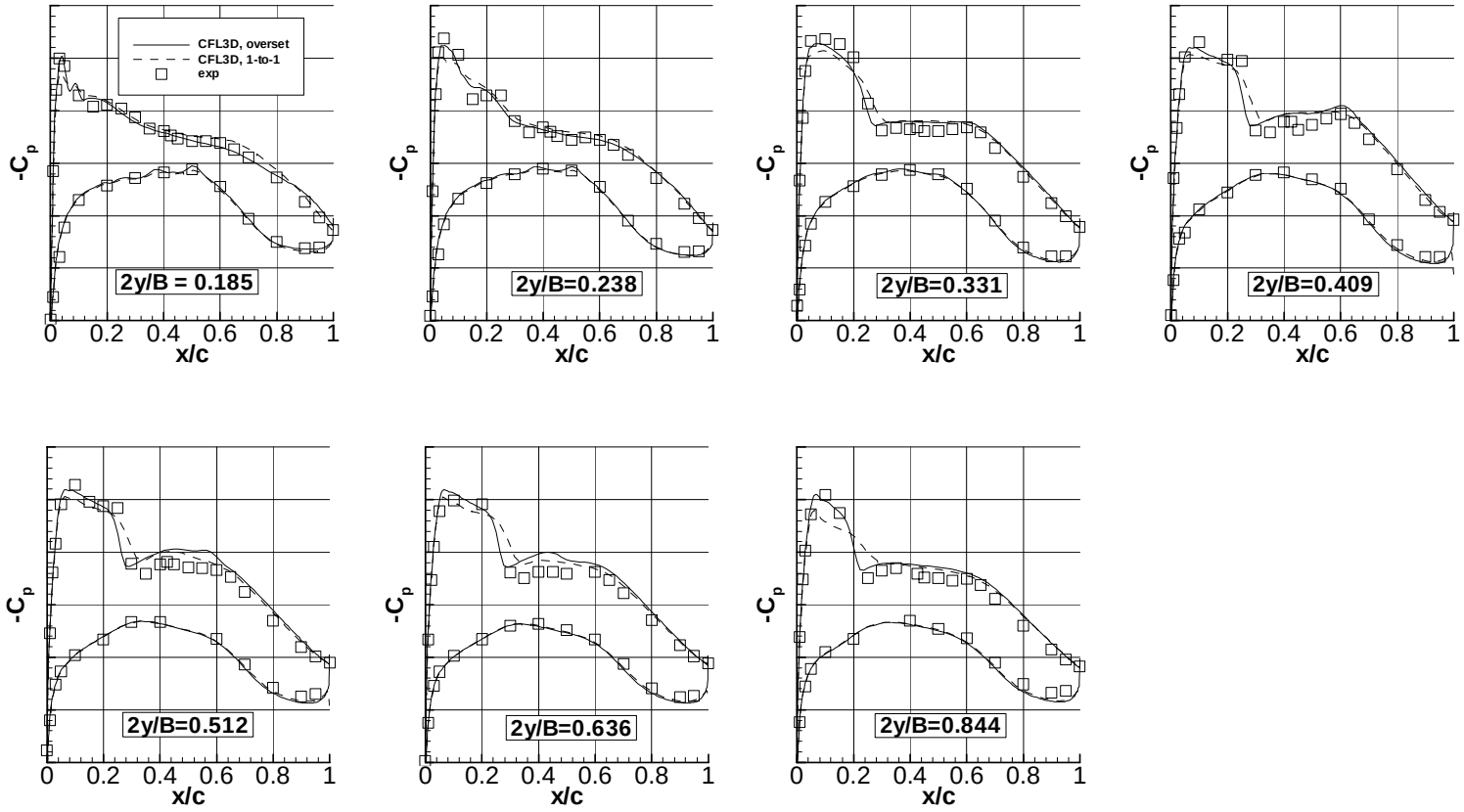
- If every-other-point grid is in asymptotic region for 2nd order global spatial convergence (doubtful), then C_D on fine grid is high by 30 counts!
- A finer-level grid of the same family is needed



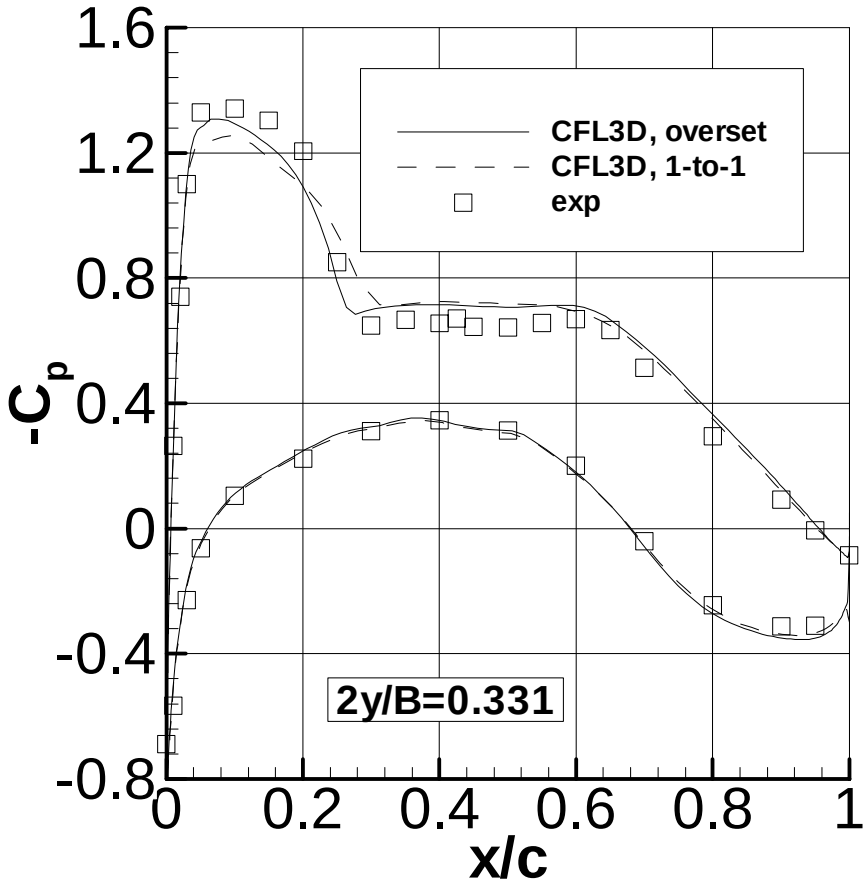
Effect of grid on surface pressures

α=0 deg, M=0.75, Re=3.e6

Drag Prediction Workshop standard grids

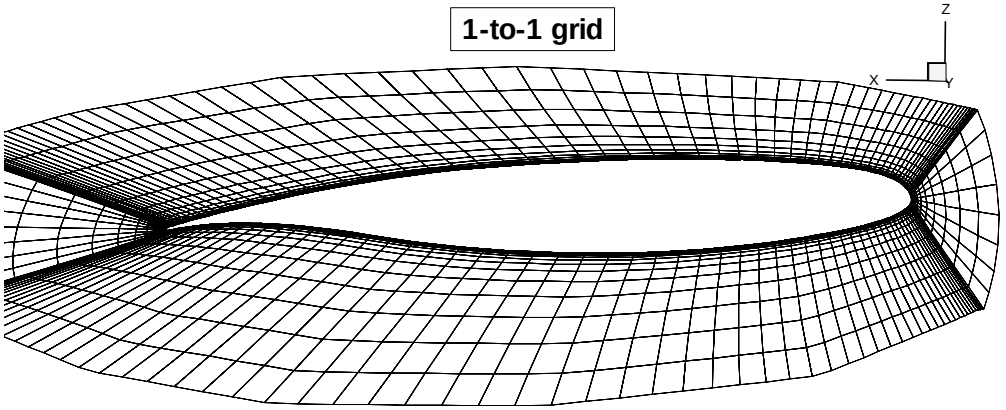


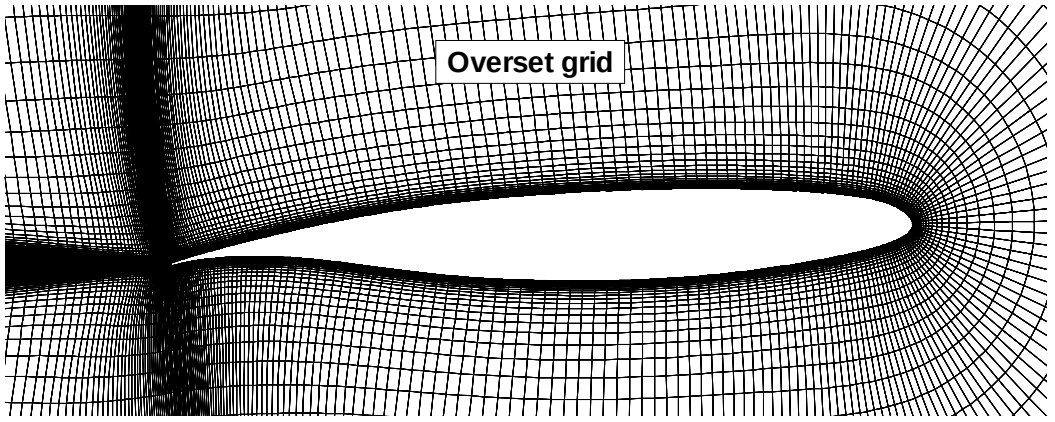
Detail


1.6
1.2
0.8
0.4
0
-0.4
-0.8
$-C_p$
0
0.2
0.4
0.6
0.8
1
x/c
CFL3D, overset
CFL3D, 1-to-1
exp
2y/B=0.331

Grid comparison

near y=230 mm



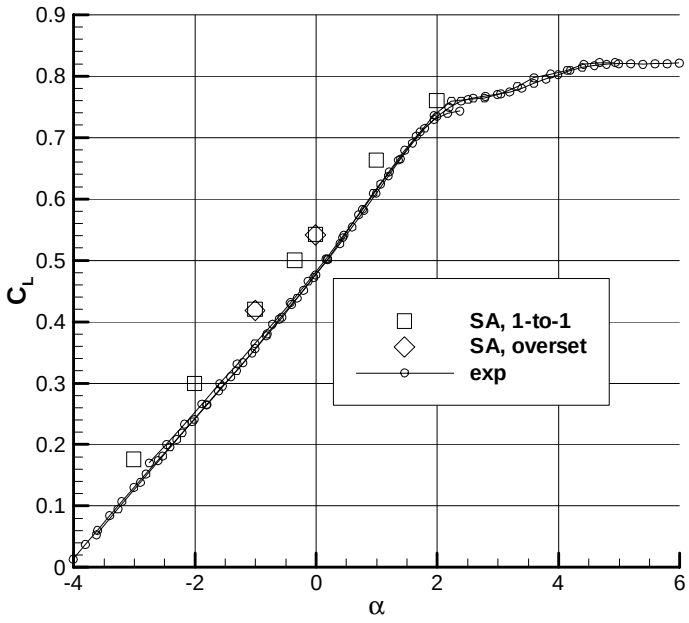


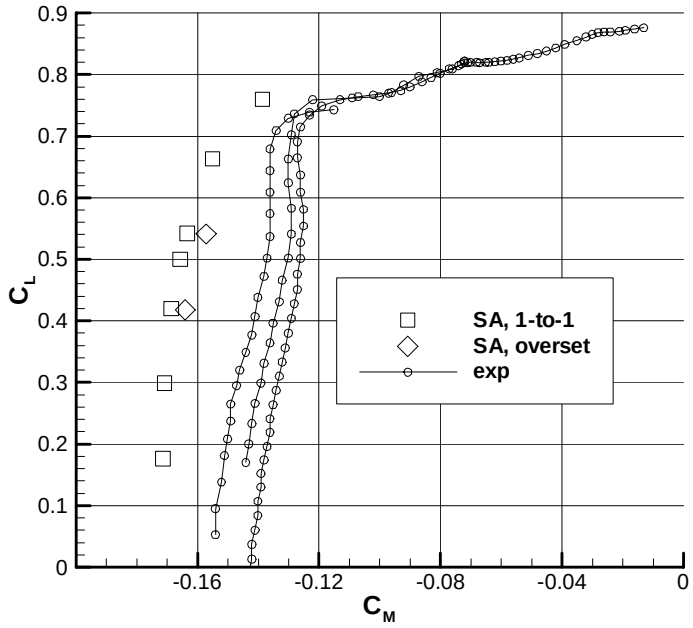
Entire grid:

3.2 million cells
50c extent

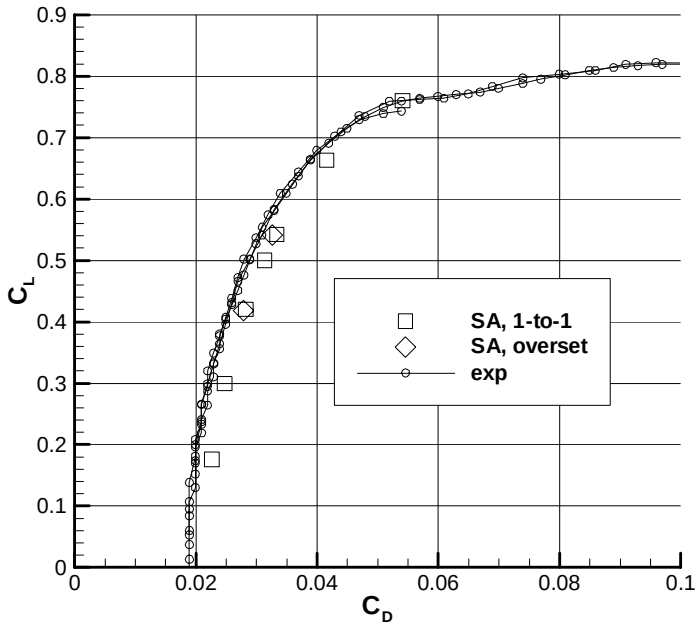
3.7 million cells
170c extent

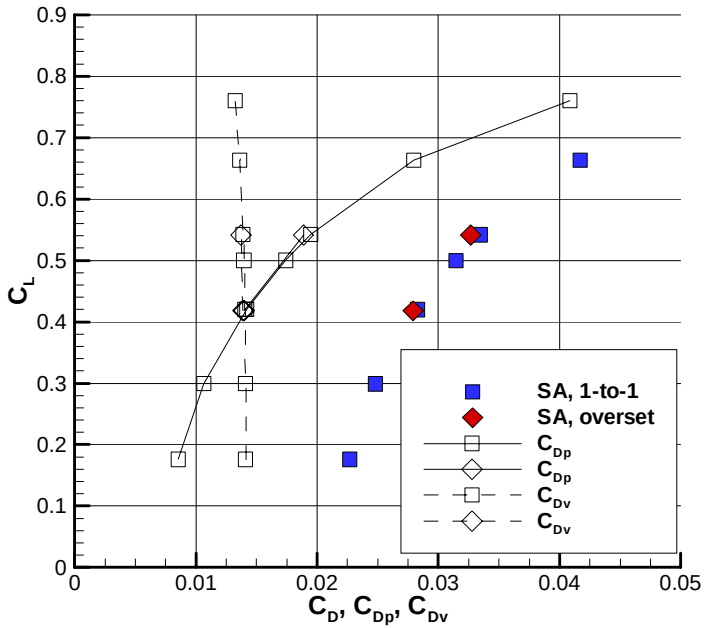
Effect of grid on forces & moments





Effect of grid on forces & moments

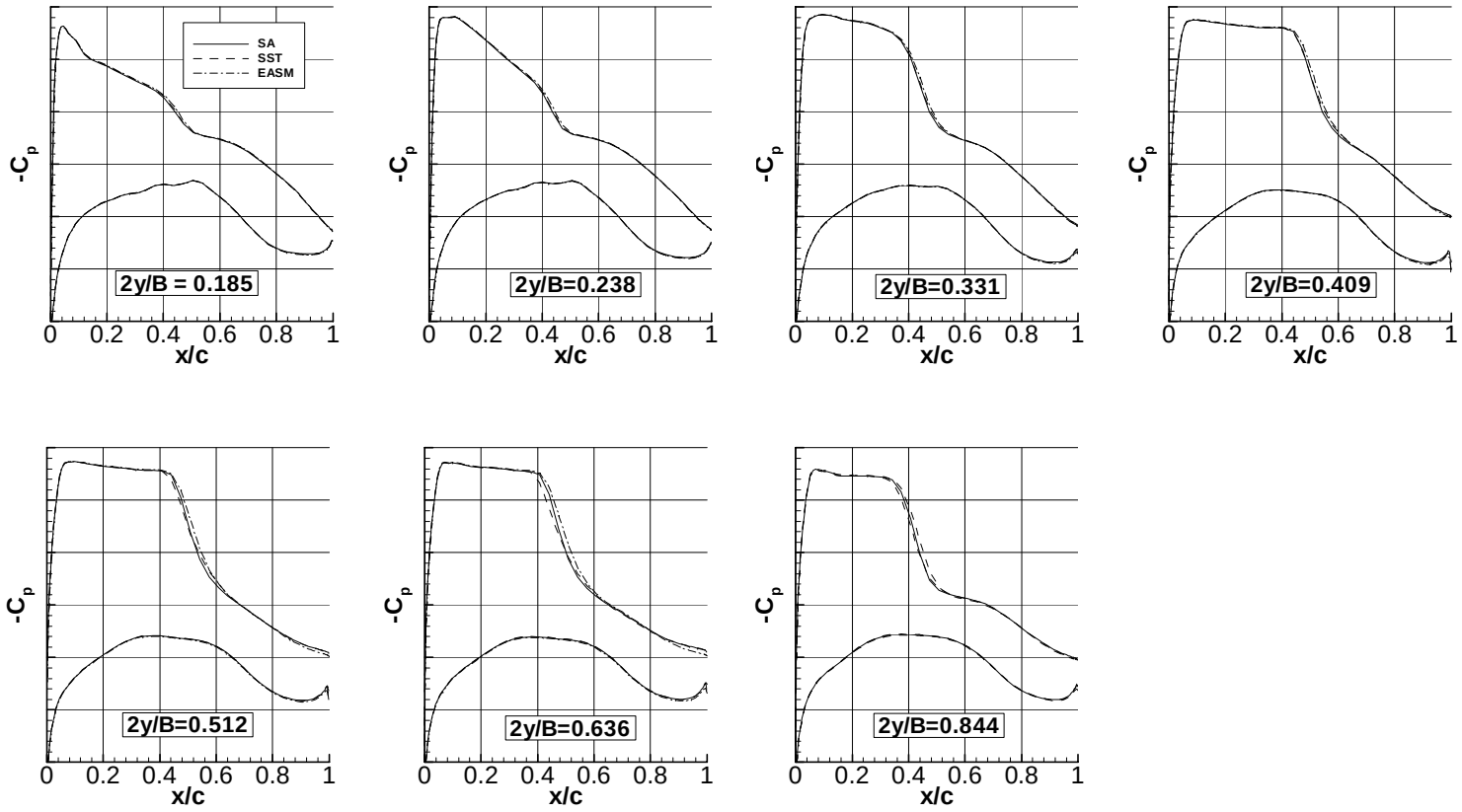




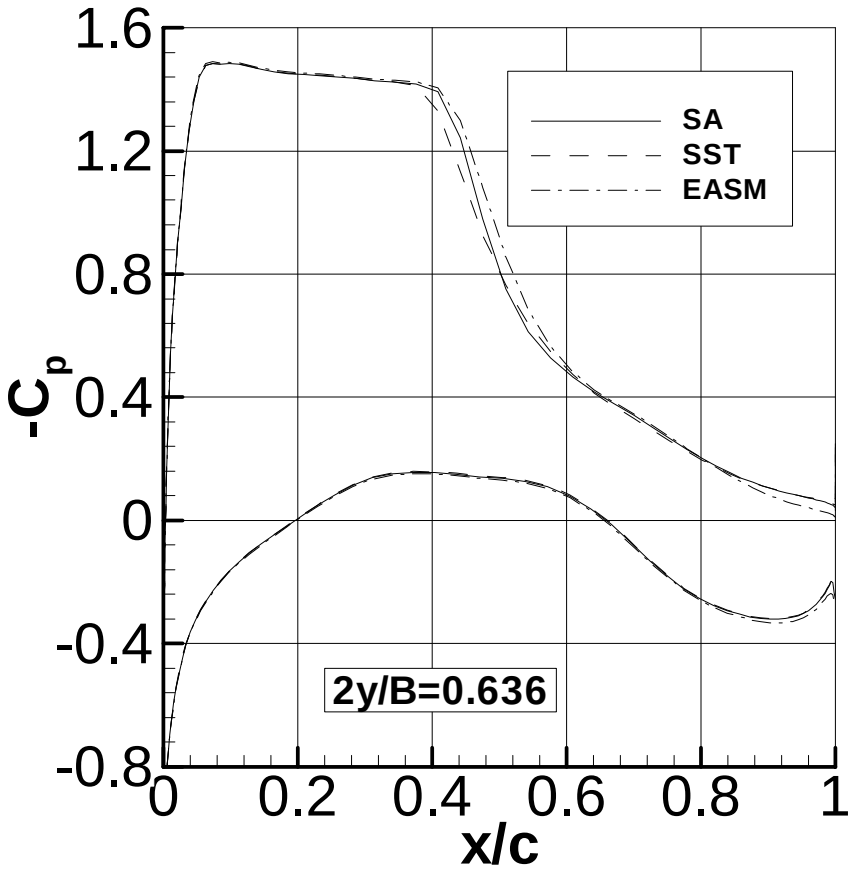
Effect of turbulence model on surface pressures

α=2 deg, M=0.75, Re=3.e6

Drag Prediction Workshop 1-to-1 standard grid

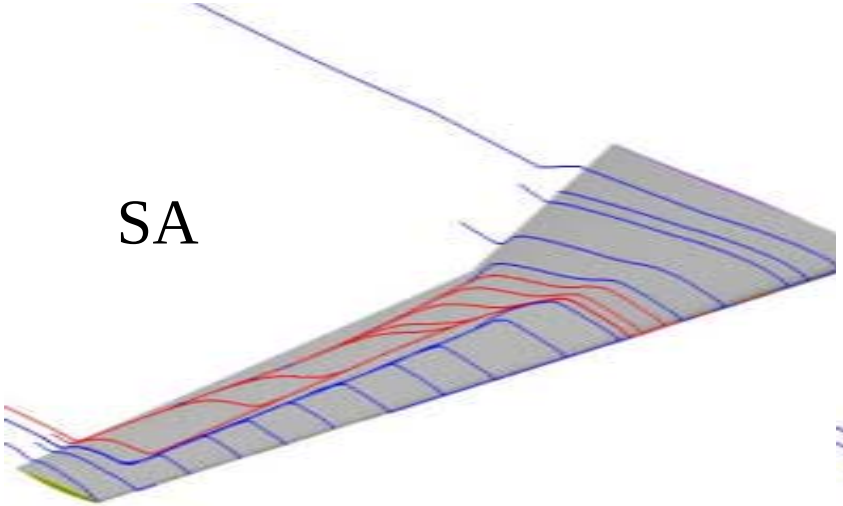


Detail

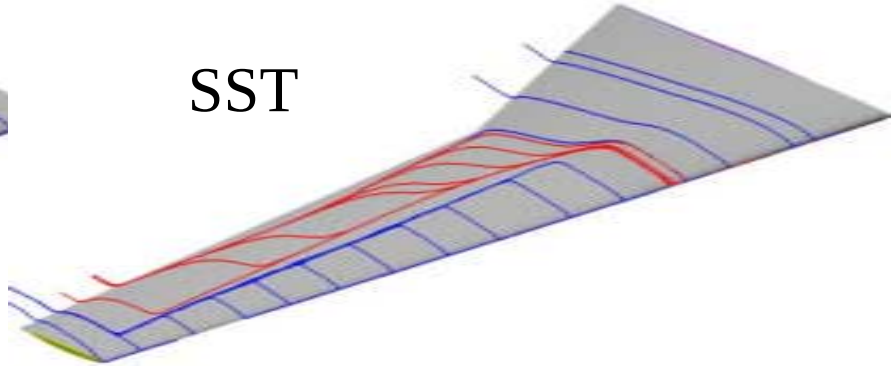


Streamlines at alpha=2 deg

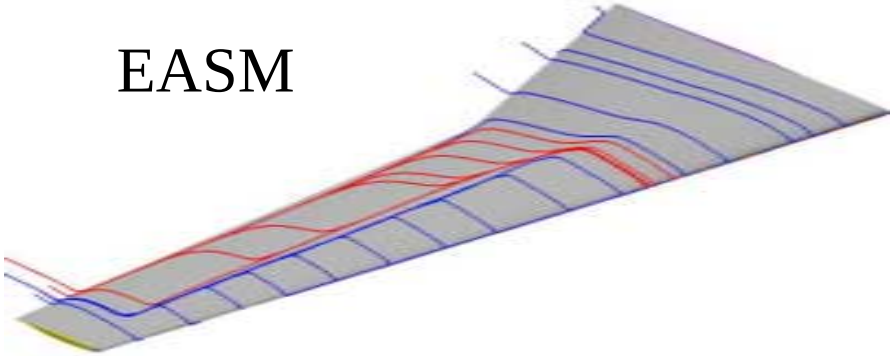
SA



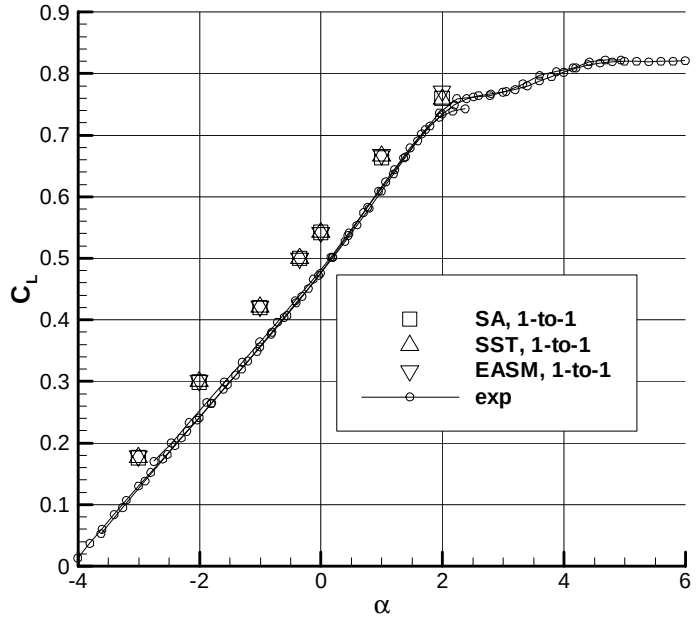
SST

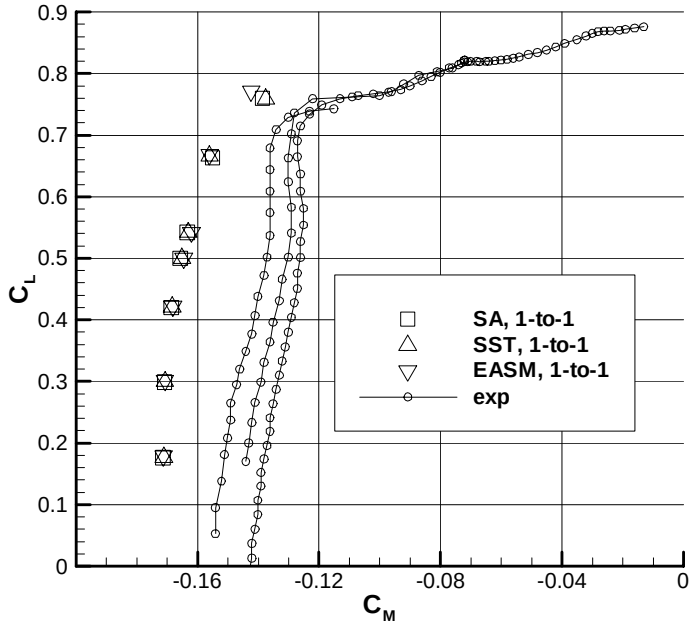


EASM

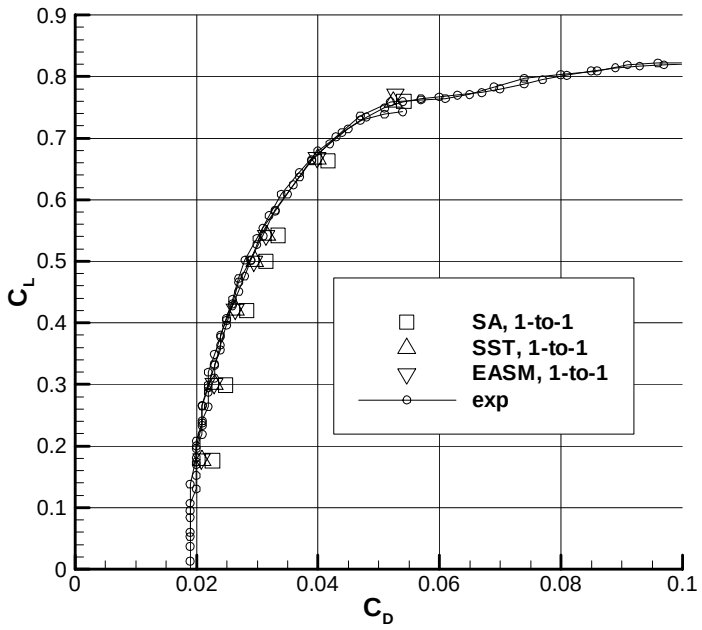


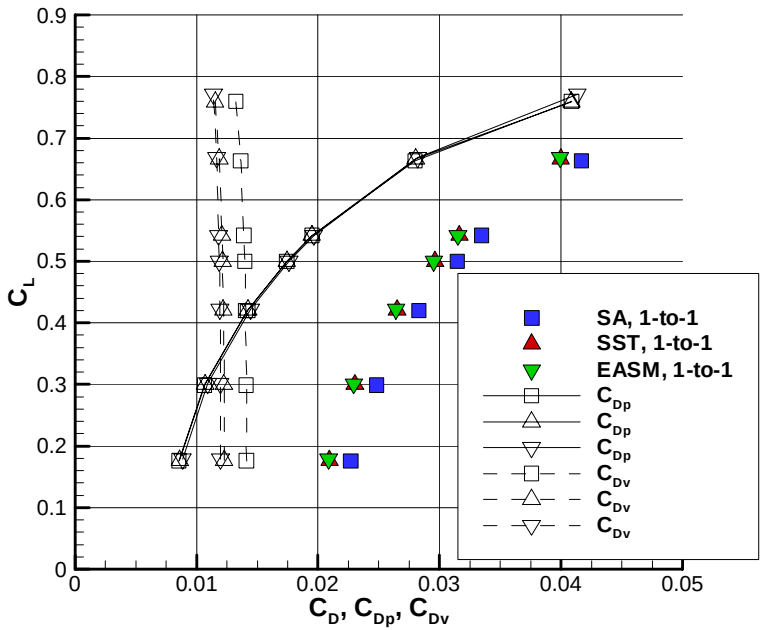
Effect of turbulence model on forces & moments





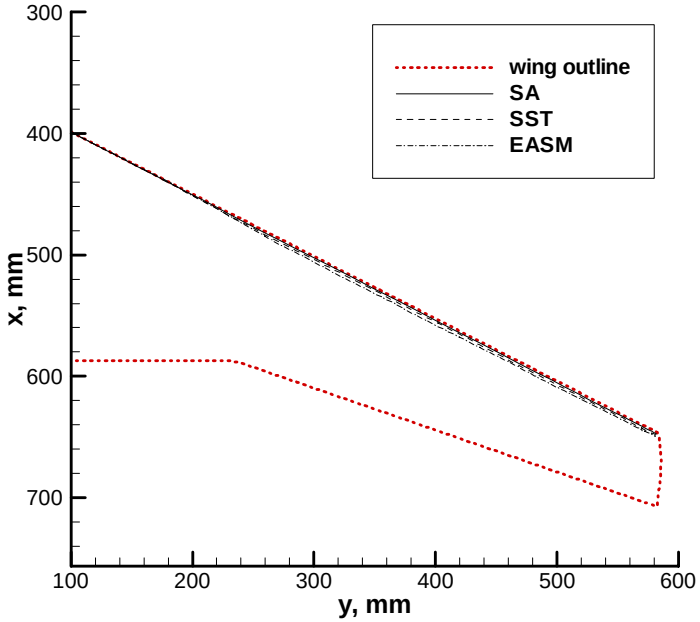
Effect of turbulence model on forces & moments

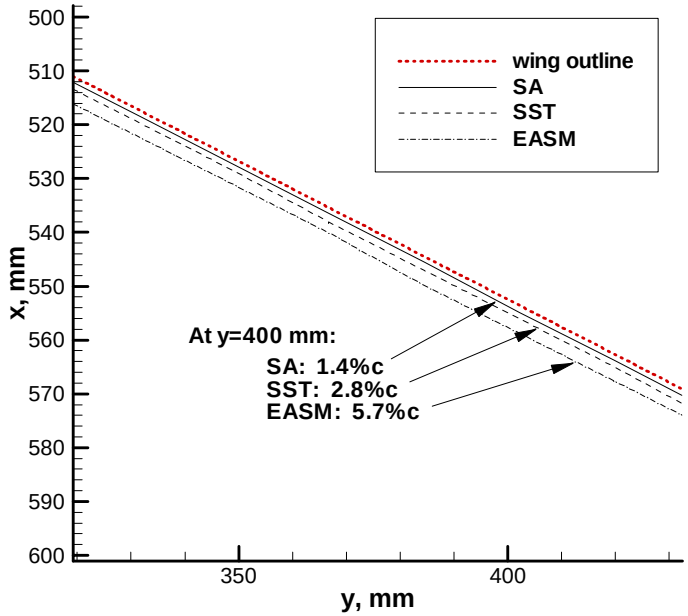




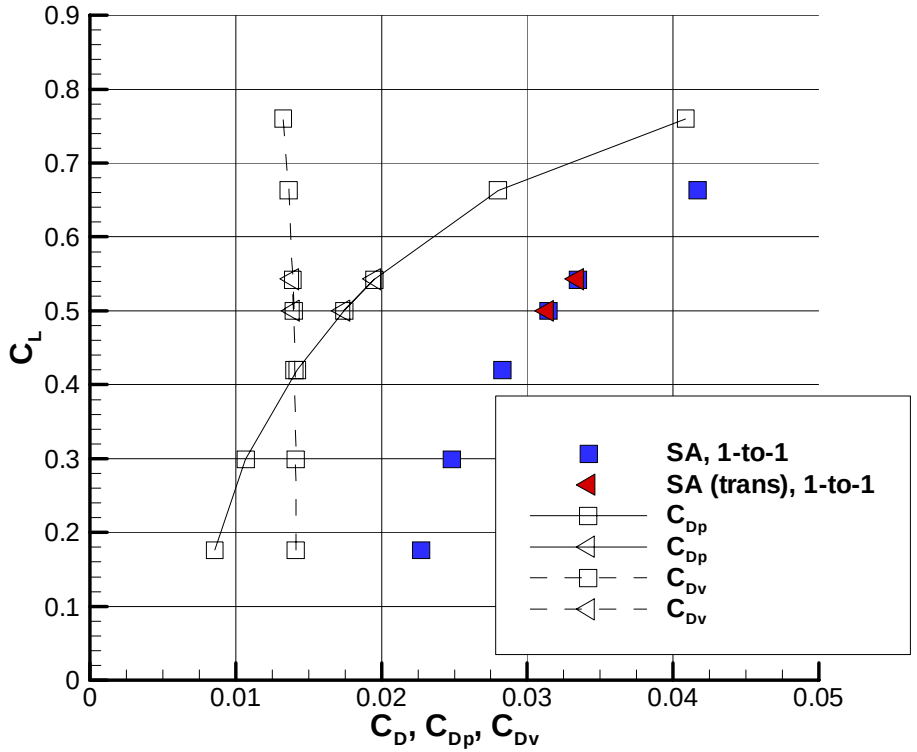
Actual “fully turbulent” transition locations for different turbulence models

alpha=0 deg





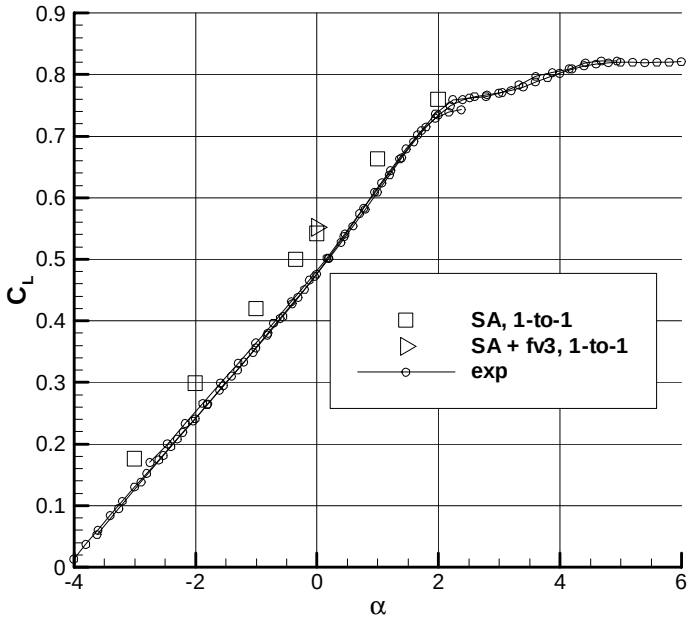
Effect of forcing SA transition to match "natural" transition of EASM

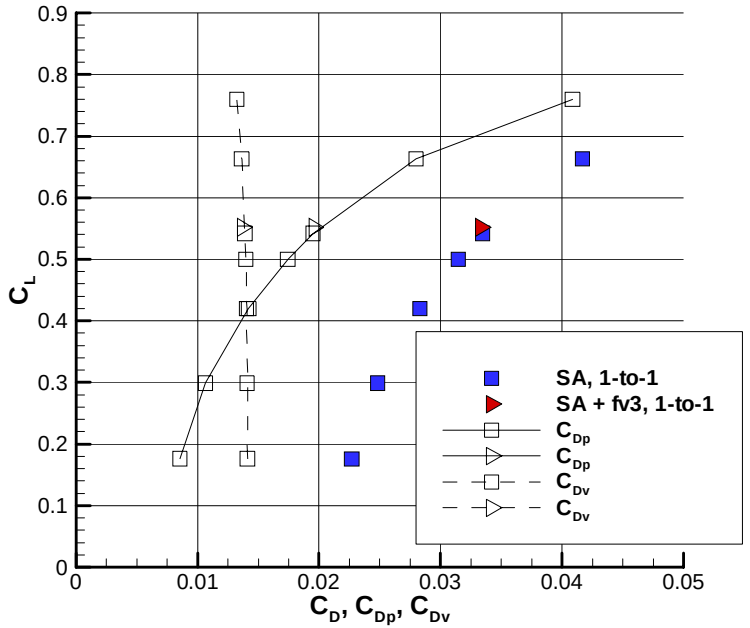


Effect of SA version on transition

- 2 versions of SA in wide use:
  - SA (Ia): "official" version in Aerospatiale Journal
  - SA+fv3: "unofficial" version resulting from a Spalart e-mail in early 90's
- SA (Ia) transitions very near L.E.
  - Typically 1 – 2 % c for alpha=0 deg case
- SA+fv3 delays transition for low Re (1-10 million)
  - 7 – 8 % c or more for alpha=0 deg case (OVERFLOW results similar)
  - Seems to show more sensitivity to grid & free stream turbulence level chosen

Effect of SA version on forces





Summary

- Grid issues
  - Official 1-to-1 grid too coarse to resolve pressures (L.E. & shock under-resolved)
  - Nonetheless, global forces & moments similar to those using better quality overset grid; at alpha=0:
    - C_D: ~8 count difference (2.4 %)
  - Family of grids (2 or 3 for each type) needed for grid sensitivity study

Summary, cont'd

- Turbulence model comparison (1-to-1 grid)
  - SST & EASM give lower C_D than SA by <20 counts (8.7 % difference at –3 deg, 3.3 % difference at +2 deg)
  - Primarily due to lower friction drag

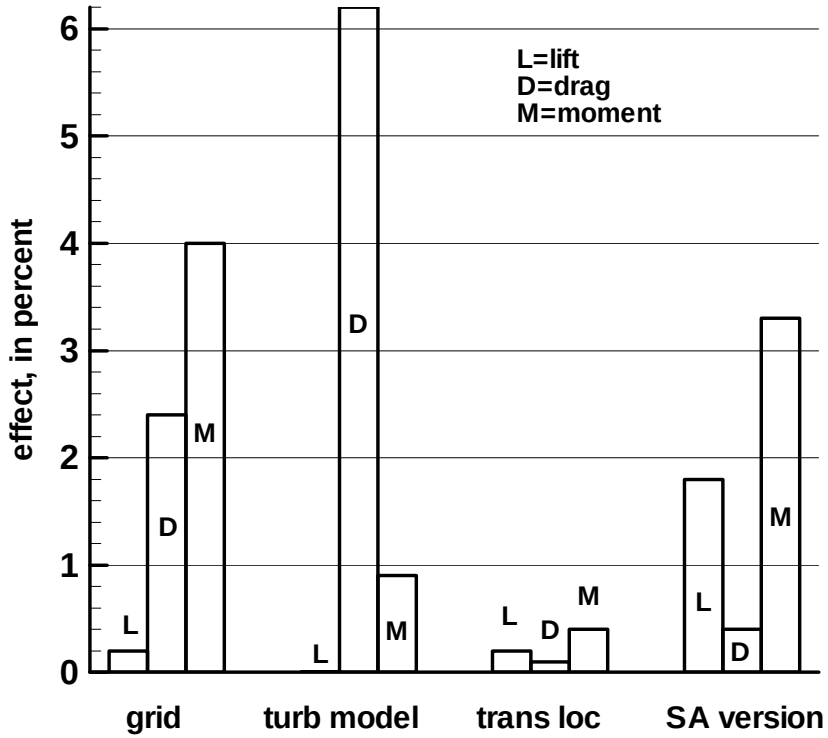
Summary, cont'd

- "Fully turbulent" is misnomer
  - All turbulence models "transition" on their own
  - At low Re (order 1-10 million), transition is not at the leading edge! E.g., for alpha=0:
    - SA: 1-2 %c typical
    - SST: 2-5 %c typical
    - EASM: 2-7 %c typical
  - Effect is small: forcing SA to transition at EASM location changes C_D by <1 count (0.1 %)

Summary, cont'd

- Two versions of SA are known to be present in today's U.S. production codes
  - SA + fv3 (unofficial version) widely used, can delay transition significantly for low Re (order 1-10 million) compared to official SA (Ia)
  - Effect for alpha=0:
    - Delta C_D=1.4 counts (0.4 %)

Summary of effects at alpha=0



Conclusions

- Good quality grid a MUST
  - It is possible to miss details in C_p yet do reasonably well on forces and moments
  - Right answer for wrong reasons? – only a grid study using a family of grids will tell
- SA, SST, EASM turbulence models give very similar results for this case (but still ~20 count drag difference)
- CFD transition location should always be checked
- Better version control and consistency checks are needed for turbulence model coding

Comments on EASM

- Nonlinear explicit algebraic stress model, k-omega form (AIAA 2000-4323)
- More robust than earlier versions of EASM
- Roughly 40 % more expensive than SA
- As good as SA and SST for aerodynamic thin-shear flows, but better for flows where nonlinear and curvature effects are important
- Validation on-going

Recommendations for future workshops

- Give out family of successively finer grids for a required grid study
  - Grid study needed for CFD validation of this type
  - Some participants do not have 3D grid generation capability
  - "Official" grids ensure consistency
  - For wing body: 7 million, 3 million, 1.5 million cells? (structured)
  - Structured grids should be multigriddable
- Include surface Cps as part of required results
  - Integrated quantities hide things that could be helpful in evaluation
- More fixed-alpha cases and fewer fixed-C_L cases
  - Fixed alpha cases are easier to run & better for comparing code-to-code
- To ensure transition location is not a cause of variability:
  - Force transition at specified locations (harder), or…
  - Include high Re (order 50 million) fully turbulent case (easier)