Description of a Website Resource for Turbulence Model Verification and Validation

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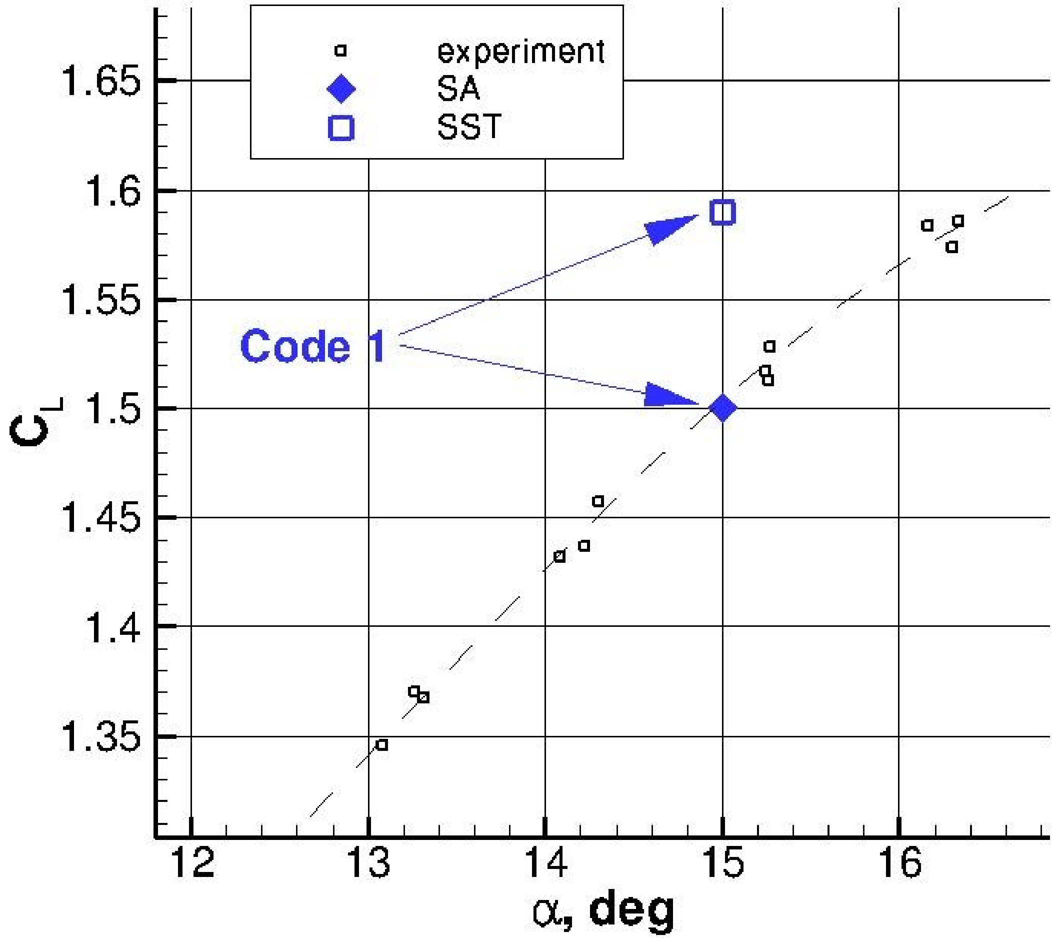
Outline

- Introduction
  - The need for the website
  - Survey summary
- Turbulence modeling resource website
  - Description of turbulence models
  - Verification cases
  - Validation cases
  - Other resources
- Future Plans

Introduction

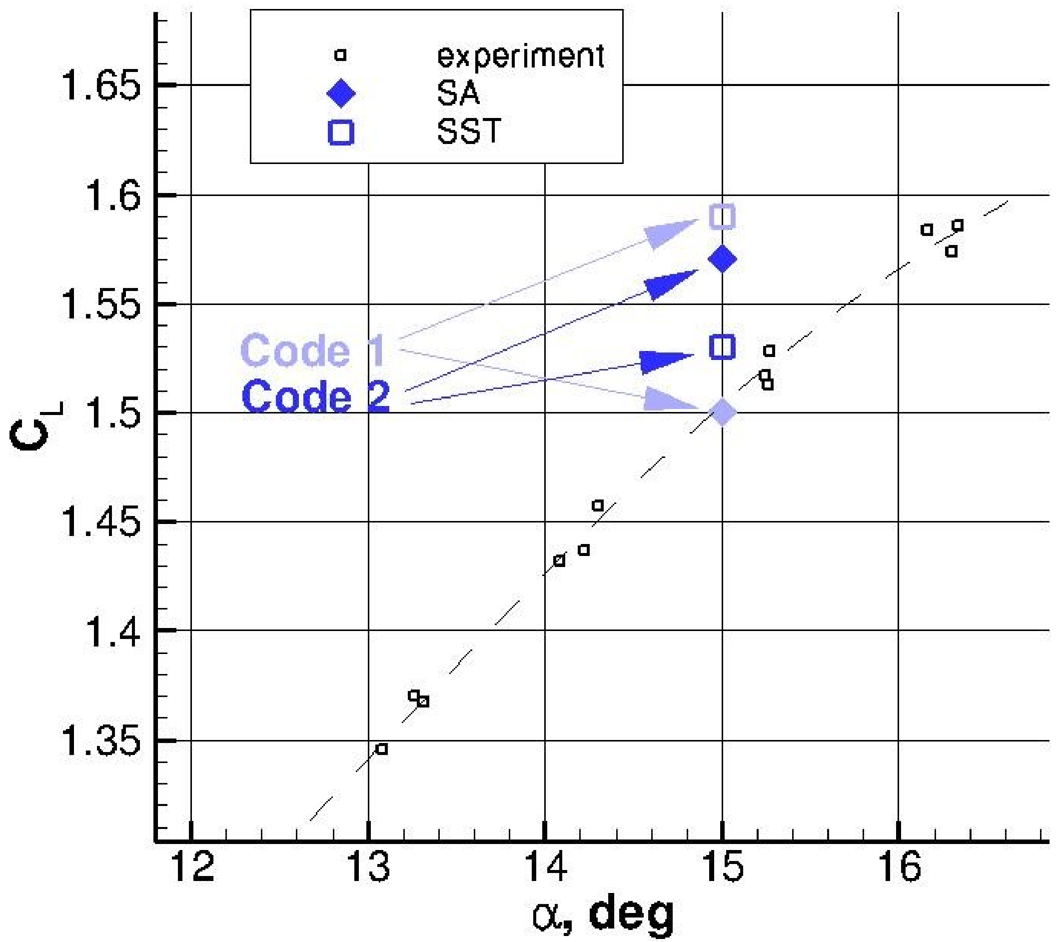
- Need for improved turbulence modeling "usage" practices in the CFD community
  - inconsistencies in model formulation or implementation in different codes make it difficult to draw firm conclusions from multi-code and multi-turbulence model CFD studies
  - naming conventions and processes to insure model implementation consistency
- Also want to avoid difficulties & inconsistencies that can occur when attempting to implement models from papers/reports

Fabricated example



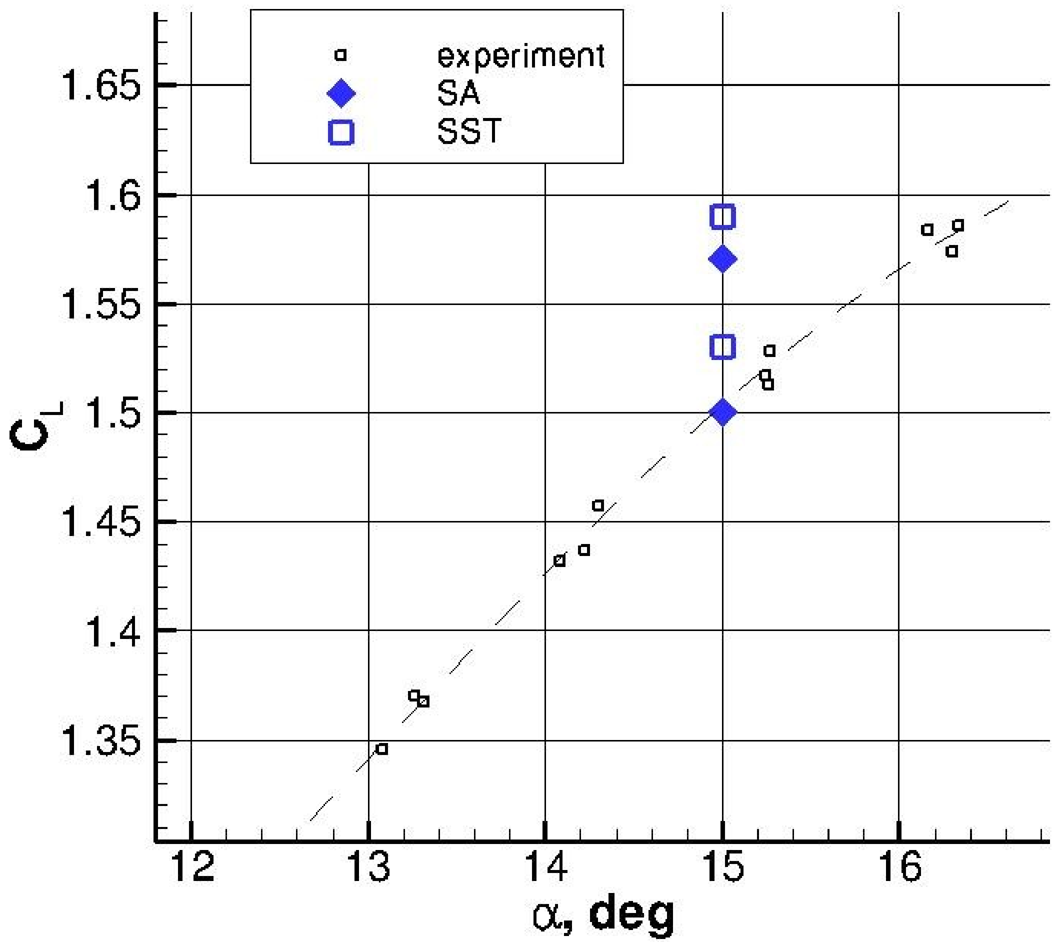
"SA is a better model than SST for this case"

Fabricated example



"But this code indicates the opposite"

Fabricated example

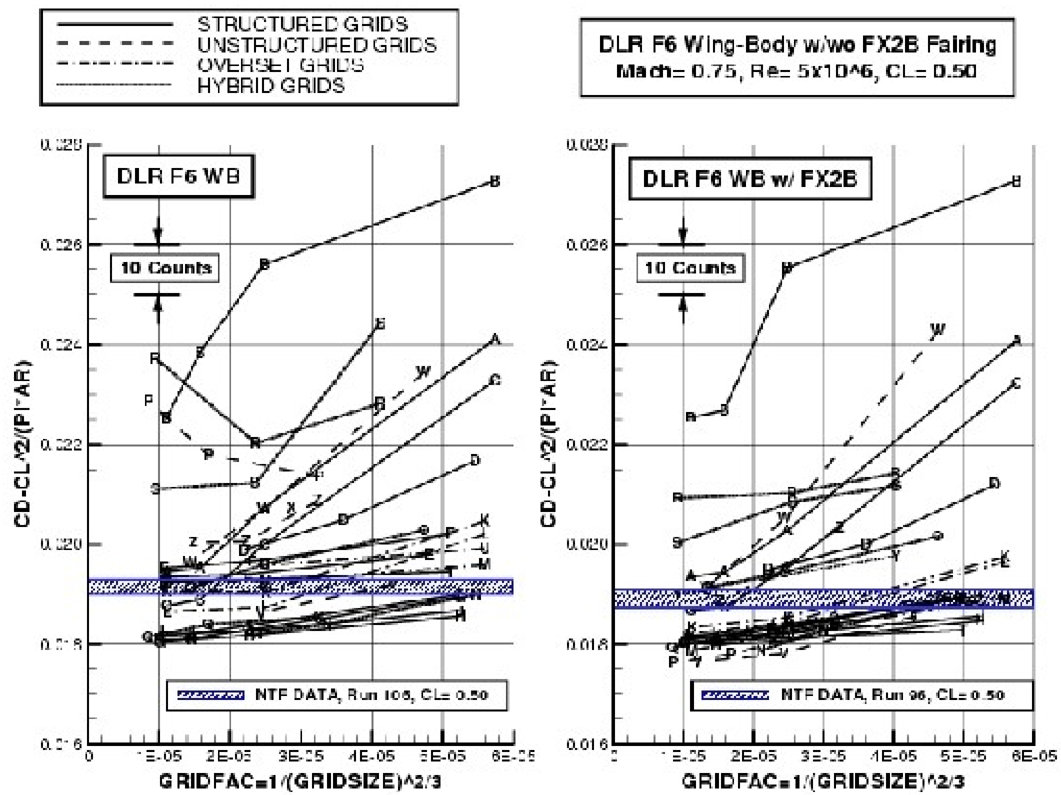


"The two models must be essentially the same"

What we want to try to avoid

Example from Drag Prediction Workshop

Most codes used “same” turbulence model, yet obtained different results



from Vassberg et al, AIAA Paper 2008-6918, August 2008

Introduction, cont'd

- Turbulence model benchmarking working group (TMBWG) established
  - under Fluid Dynamics Technical Committee

- Survey conducted (more on next page)

- NASA website established
  - http://turbmodels.larc.nasa.gov
  - a resource for finding and verifying turbulence models
  - this type of effort was also called for at a major turbulence modeling workshop held in 2001 (NASA/CR-2001-210841)

Surveys

- Administered both to TMBWG members (9 people) as well as to respondents in industry (108 people)
- Details given in Appendix in the paper
- Some highlights:
  - Even with advances in LES & DNS, largest percentage believe RANS will be in wide use for 10-20 years.
  - Majority (68%) felt RANS is critical for research, development, and design.
  - Existing RANS models are reasonably accurate for simple flows, but not for complex flows (in which many expect to see improvement in next 10 years).
  - Most (59%) had little confidence that the same model in multiple codes will yield the same results.
  - Most (77%) felt need for improved documentation & expanded benchmarking of turbulence models.
  - Larger percentage felt benchmarking emphasis should be complex flows as opposed to simple flows.

Primary purpose of website

- Provide a central location where widely-used Reynolds-averaged Navier-Stokes (RANS) turbulence models are described and selected validation results given
- Provide simple test cases and grids, along with sample results (including grid convergence studies) from one or more previously-verified codes
- List accepted versions of the turbulence models as well as published variants
  - Establish naming conventions in order to help avoid confusion when comparing results from different codes
- Serve as forum for new turbulence model ideas

Turbulence model descriptions

GENERIC NAME	MODEL NAME	FEATURE
Spalart-Allmaras 1-eqn	SA	Standard published version
	SA-Ia	Standard version with trip term
	SA-noft2	Standard version without ft2 term
	SA-RC	Rotation and curvature version
	SA-Catris	Compressible version
	SA-Edwards	Edwards-modified version
	SA-fv3	Unofficial version (discouraged)
	SA-salsa	Extended for nonequilibrium flows
	SA-comp	Modified for compressible mixing layers
	SA-rough	Rough wall version

Turbulence model descriptions

GENERIC NAME	MODEL NAME	FEATURE
Menter k-omega SST 2-eqn	SST	Standard original published version
	SST-V	Standard version with vorticity production
	SST-2003	Slightly modified version from 2003
	SST-sust	Version with sustaining terms
	SST-Vsust	Sustaining terms & vorticity production
Wilcox k-omega 2-eqn	Wilcox2006	2006 version
	Wilcox2006-V	2006 version with vorticity production
	Wilcox1998	1998 version
	Wilcox1998-V	1998 version with vorticity production
	Wilcox1988	1988 version
	Wilcox1988-V	1988 version with vorticity production

Turbulence model descriptions

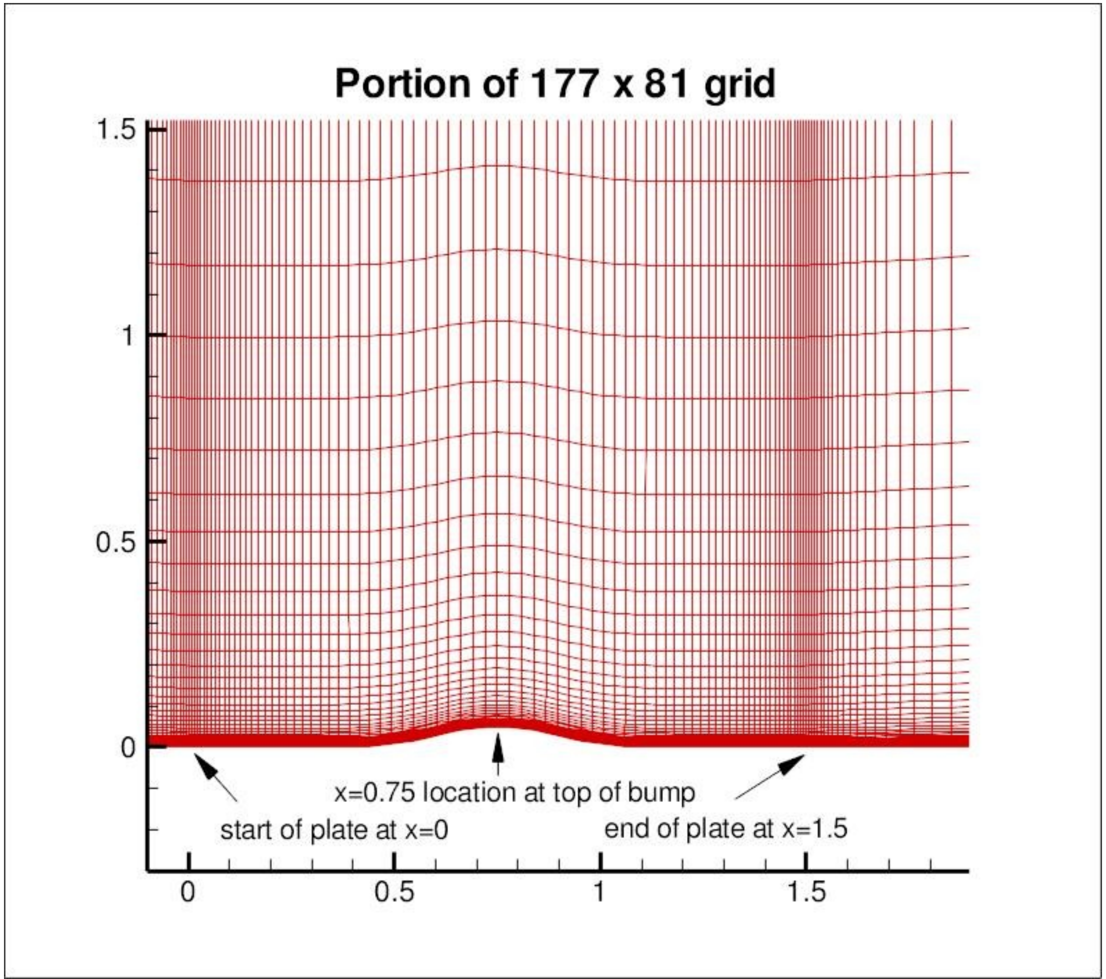
GENERIC NAME	MODEL NAME	FEATURE
Explicit Algebraic Stress k-omega 2-eqn	EASMko2003	2003 version from NASA
	EASMko2003-S	2003 version with approx strain production
	EASMko2001	2001 version (different sigma_k and gamma)
	EASMko2001-S	2001 version with approx strain production
	EARSMko2005	2005 version from HUT
	EARSMko2005-CC	2005 version with curvature correction
	EARSMko2005a	2005 version with improvement for 3-D
	EARSMko2005a-CC	2005 with curvature & improvement for 3-D
Shur et al 1-eqn	Nut-92	Official version
	Nut-92-FD	Earlier version (different for rough walls)

Verification cases and grids

- How to achieve consistency in turbulence model implementation?
  - Decided to create series of "verification cases"
  - Show how 2 or more independent codes with the same turbulence model go to the same result as grid is refined
  - Provide grids for others to use
  - Provide solutions for others to compare against
  - Simple, analytically-defined geometries, no separation, easy to converge fully
- Current verification cases:
  - 2D zero pressure gradient (ZPG) flat plate
  - 2D planar shear
  - 2D bump in channel
  - 3D bump in channel

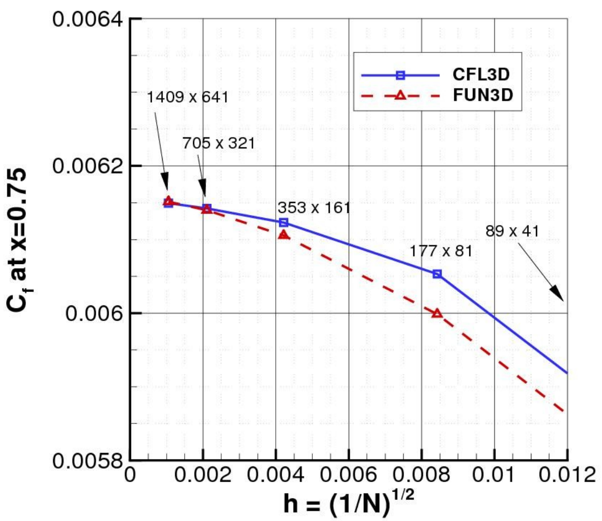
2D bump in channel

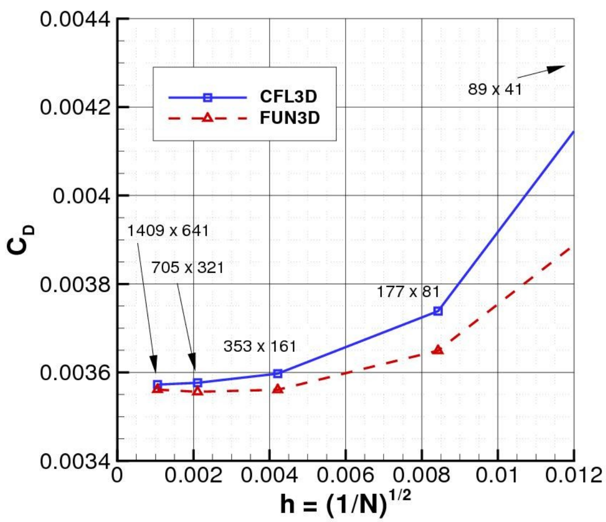
- M=0.2, Re=3 million (L=1)
- Sequence of 5 grids of the same family
  - 1409 x 641 (finest), 89 x 41 (coarsest)

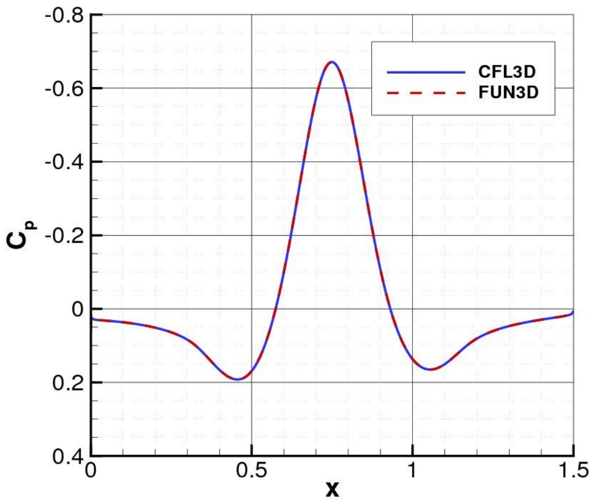


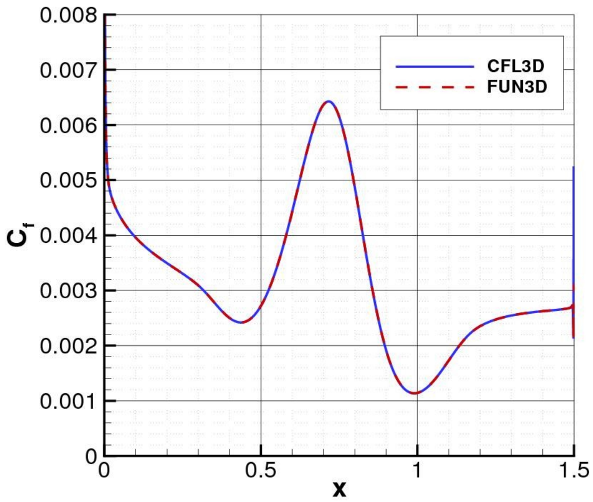
2-D bump in channel, SA model

- Results from 2 independent codes converge as grid is refined



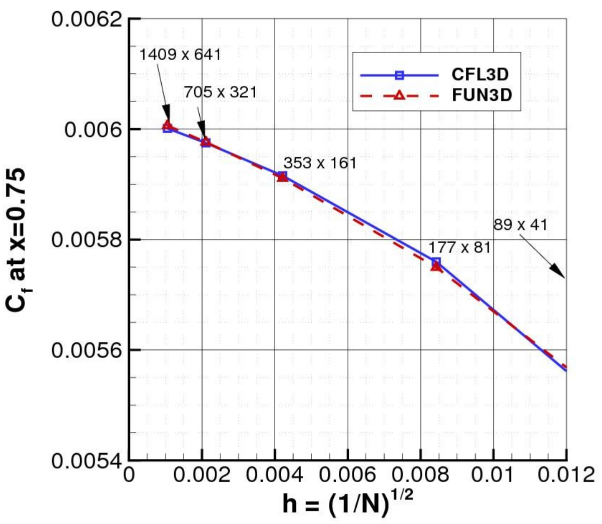


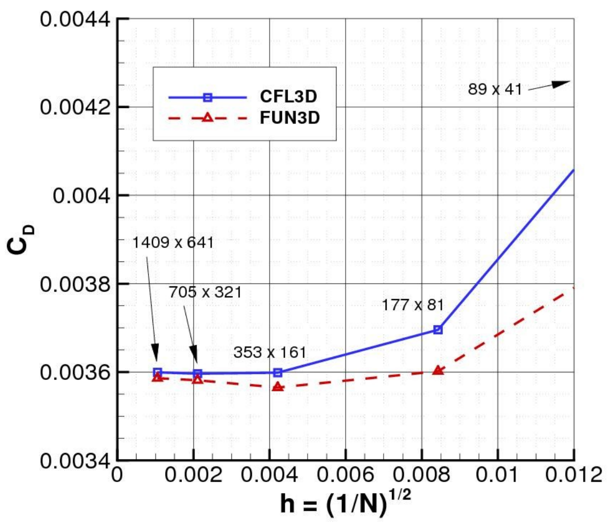


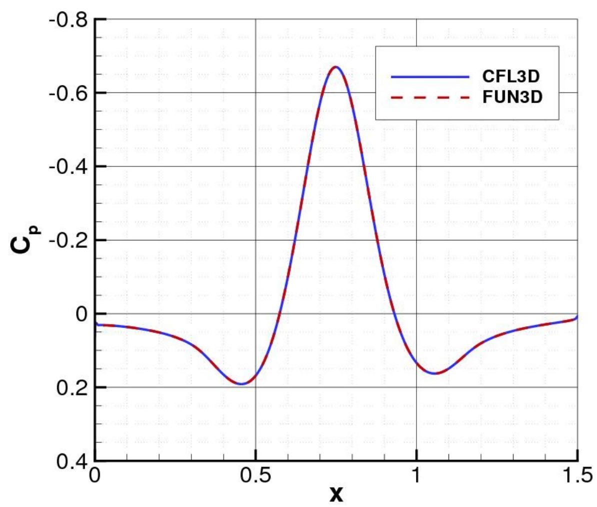


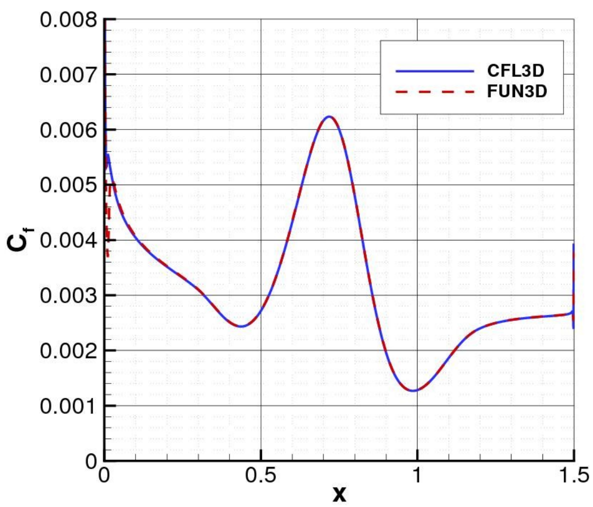
2-D bump in channel, SST-V model

- Results from 2 independent codes converge as grid is refined









Validation cases

- TMBWG decided to focus on 5 simple validation cases for the website
  1. 2-D incompressible ZPG flat plate
  2. 2-D incompressible NACA 0012 airfoil
  3. 2-D incompressible planar shear (Bradbury & Riley)*
  4. Axisymmetric incompressible APG separated flow (Driver)*
  5. 2-D compressible supersonic ZPG flat plate (van Driest)*
- Reasons for choosing simple cases:
  - Easier to ensure fully converged solutions
  - Easier for multiple codes to be employed on same problem
  - Easier to conduct thorough grid-convergence study
  - With complex flows, one is usually not sure whether disagreement is due to turbulence model or something else (insufficient grid density, poor geometric fidelity, BCs, etc.)

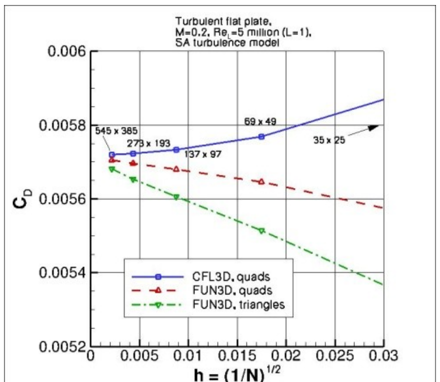
* = tentative

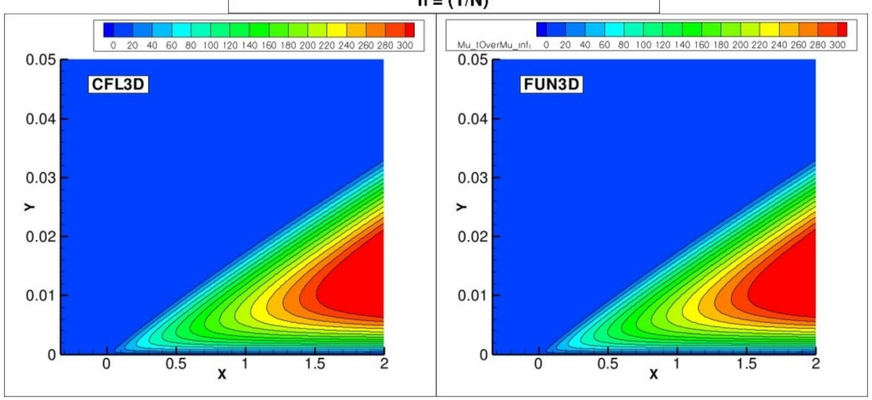
2-D incompressible ZPG flat plate

validation case

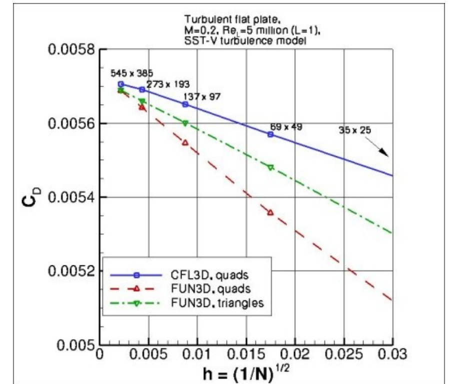
2 codes CFL3D and FUN3D go to same results as grid is refined; both have undergone verification exercises

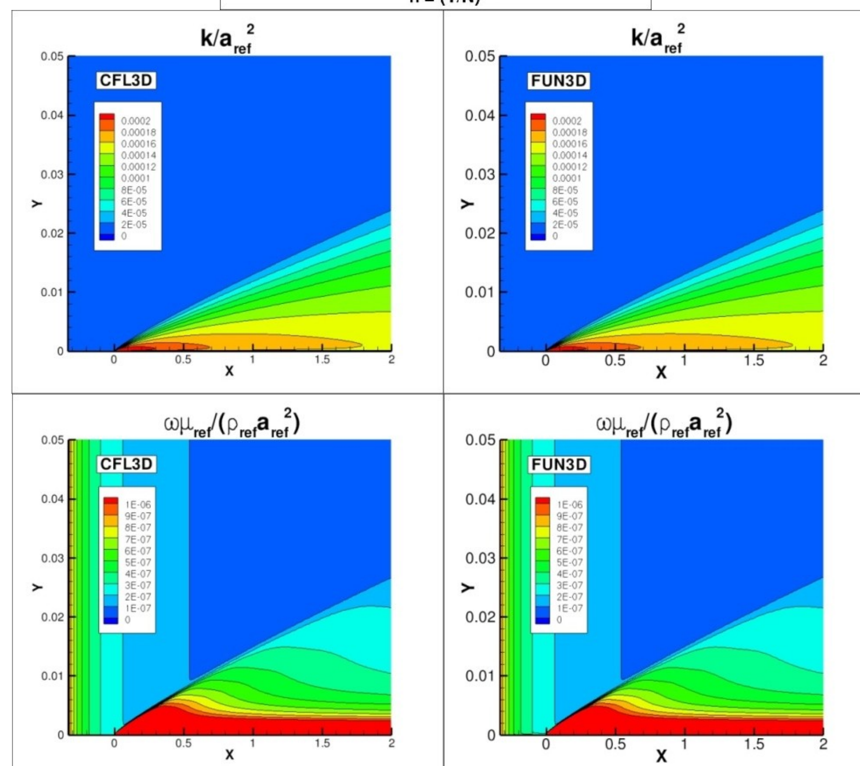
SA



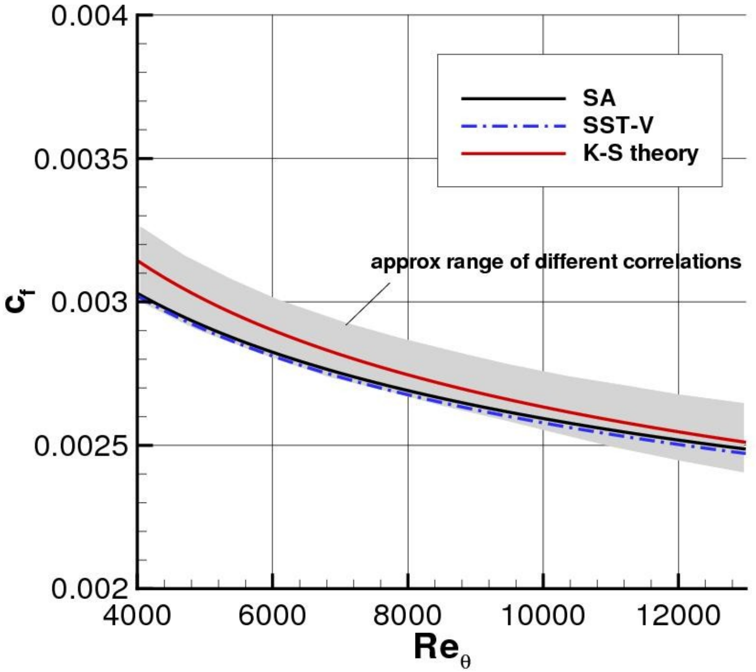


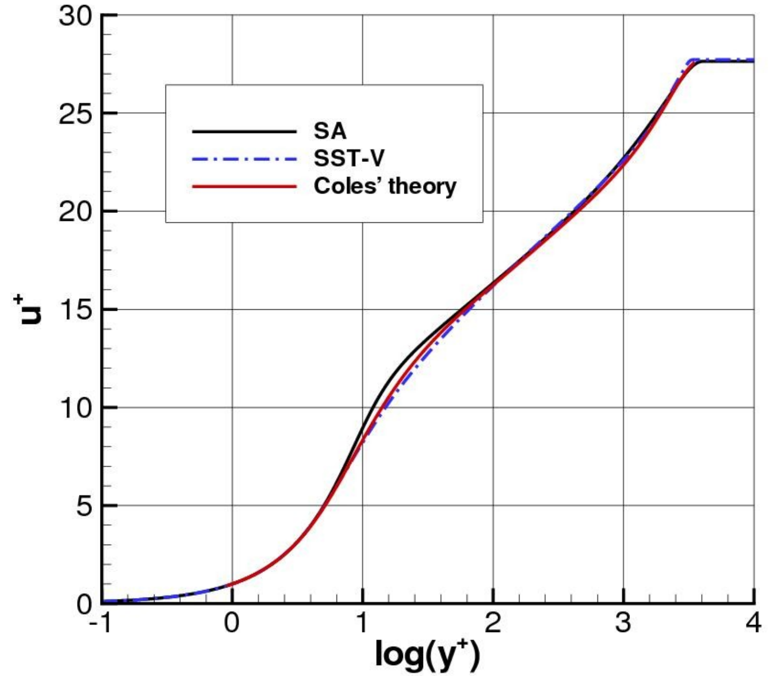
SST-V





2-D incompressible ZPG flat plate
validation case

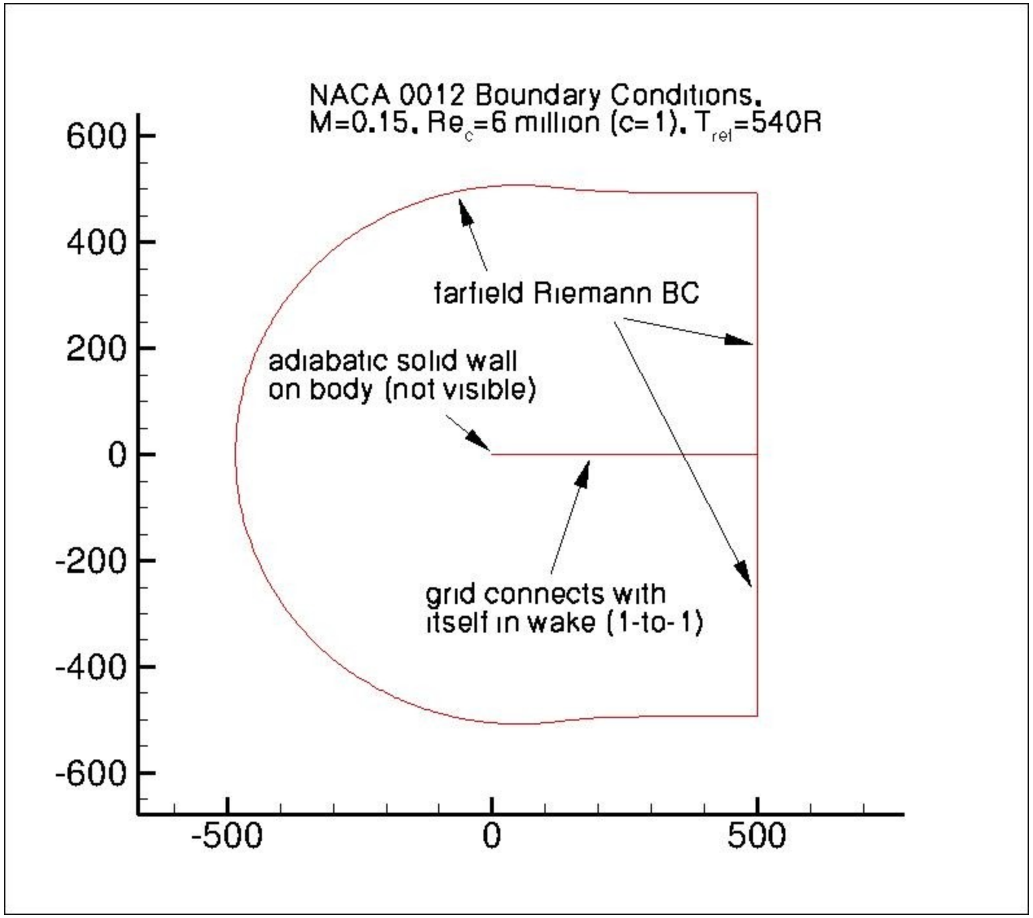


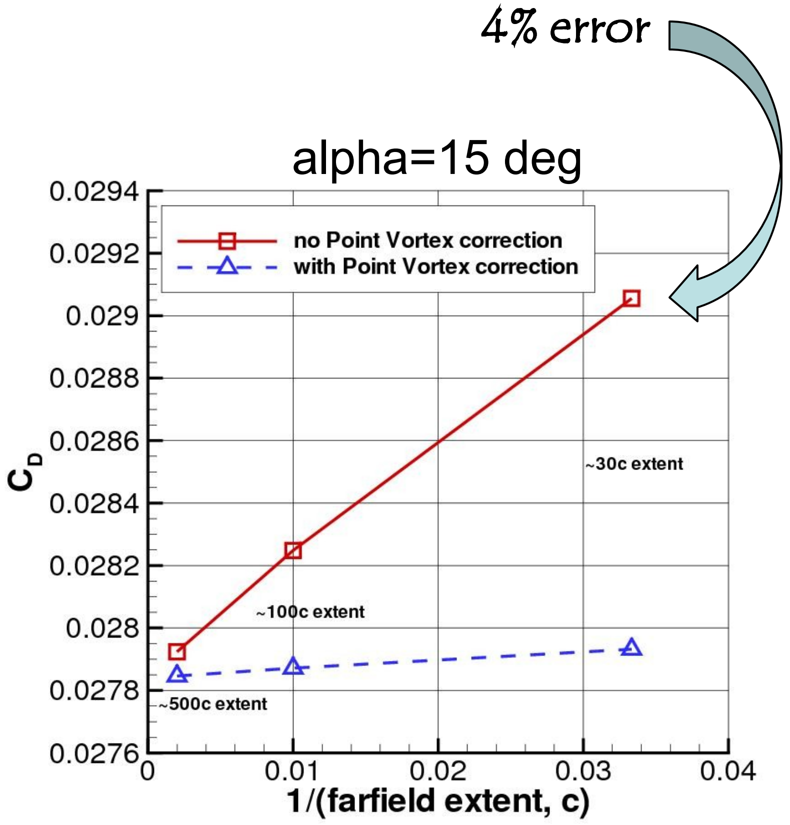


Validation case uses Cf as function of Retheta to avoid issues with transitional flow behavior of different models at the leading edge of the plate

2-D incompressible NACA 0012 airfoil

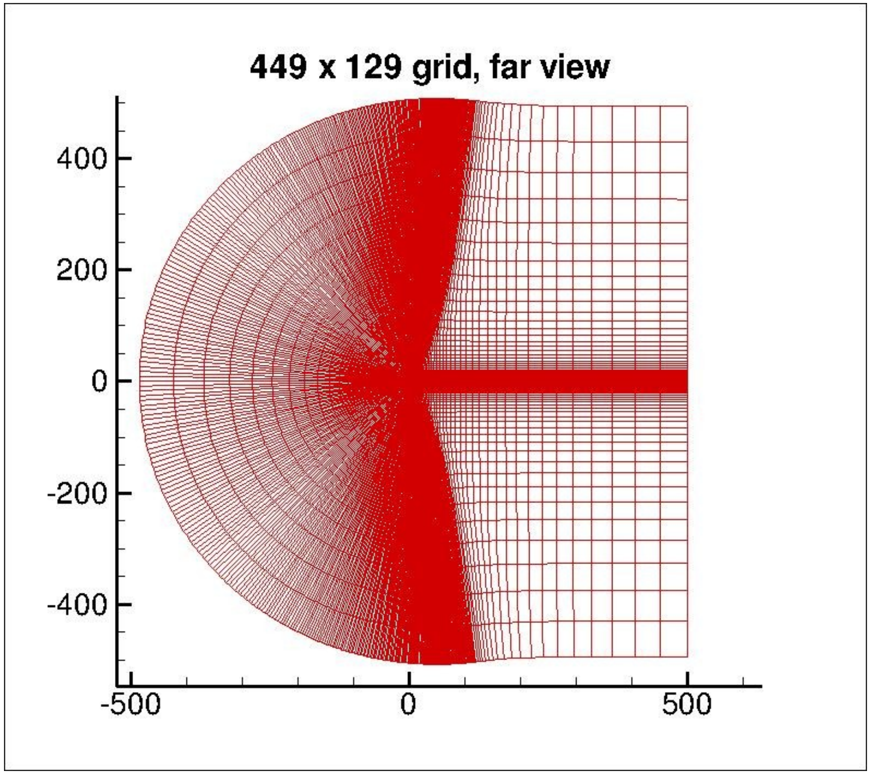
validation case

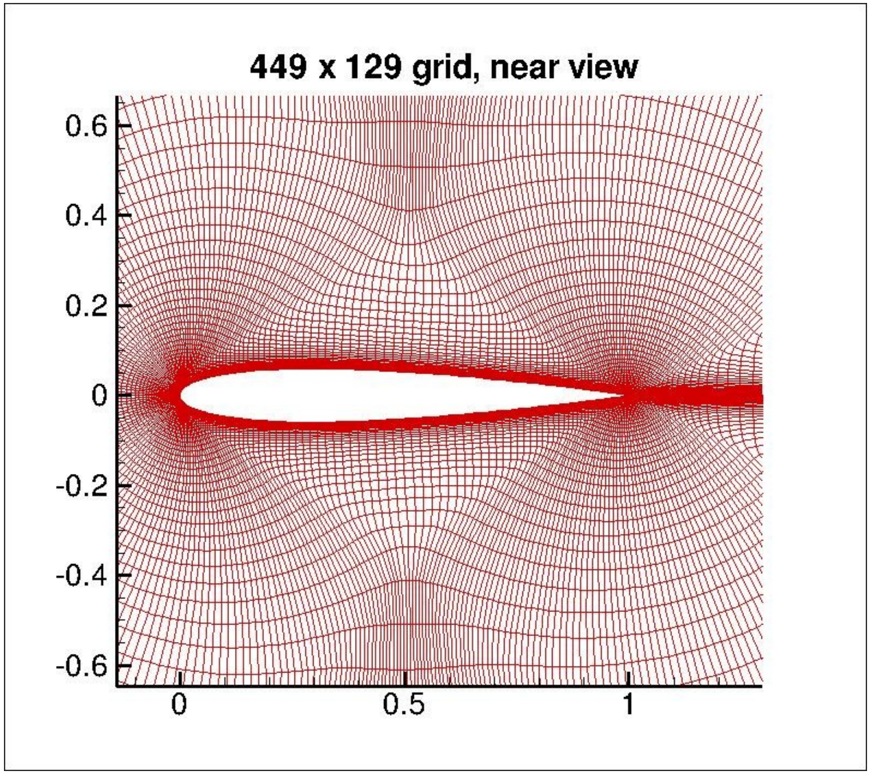




2-D incompressible NACA 0012 airfoil

validation case



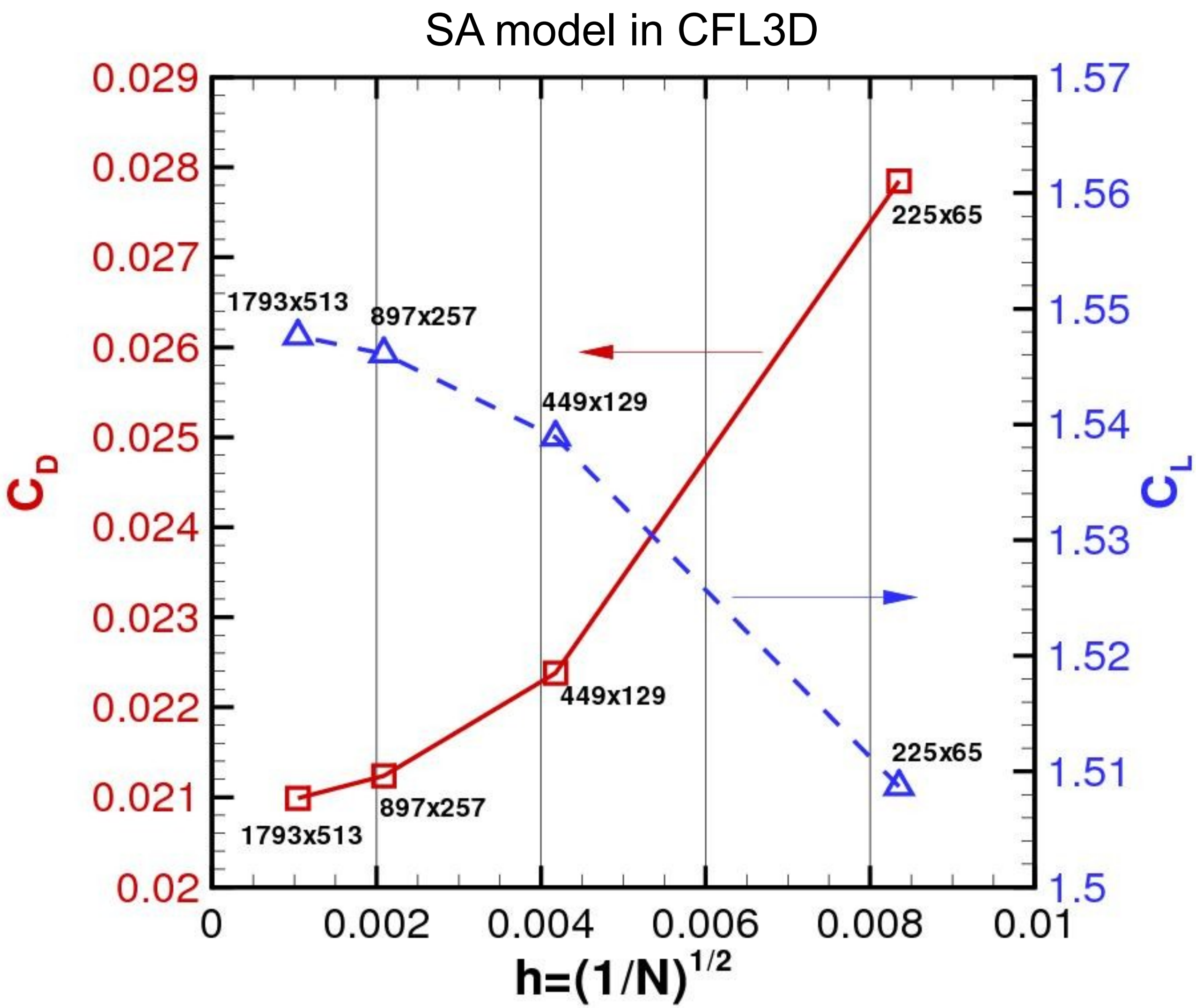


- M=0.15, Re=6 million (c=1)
- Sequence of 5 grids of the same family
  - 1793 x 513 (finest), 113 x 33 (coarsest)

2-D incompressible NACA 0012 airfoil

validation case

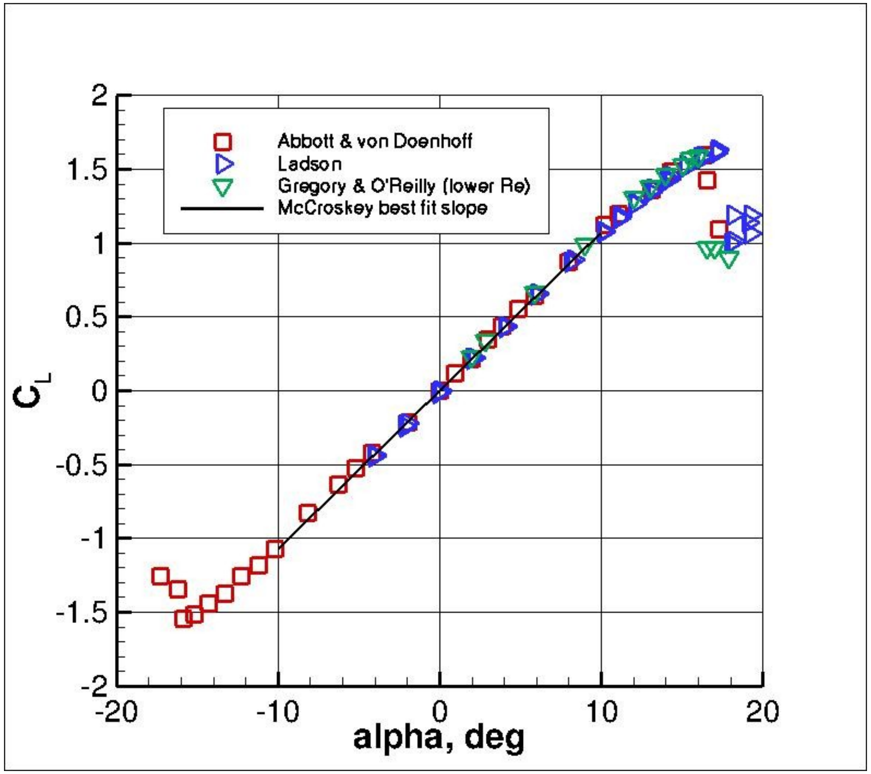
897 x 257 grid:
Lift error = 0.13%
Drag error = 1.52%

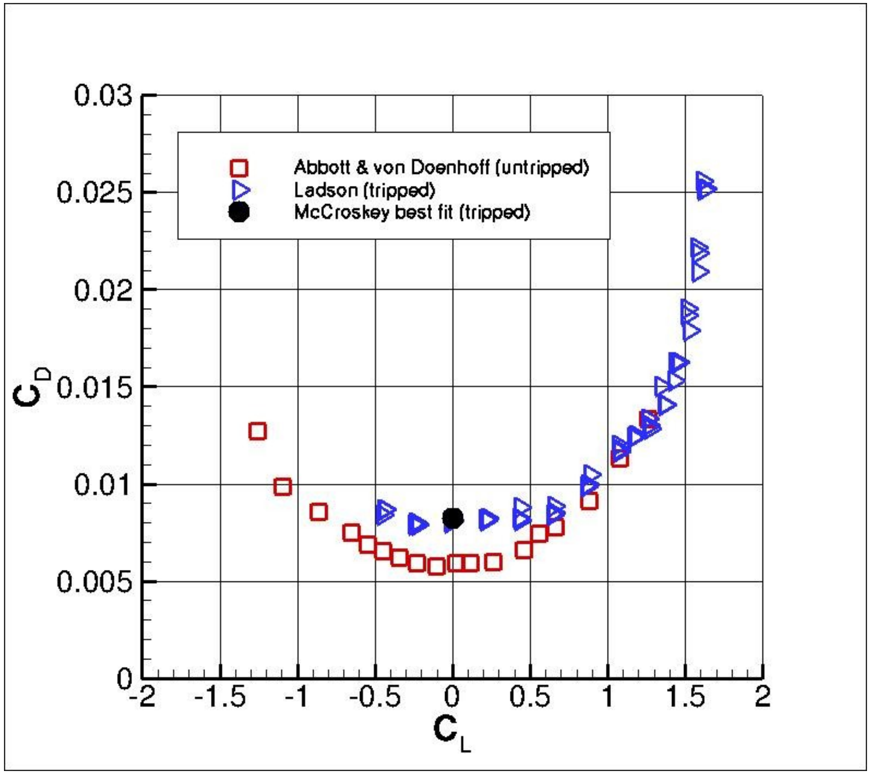


2-D incompressible NACA 0012 airfoil

validation case

Re = 6 million



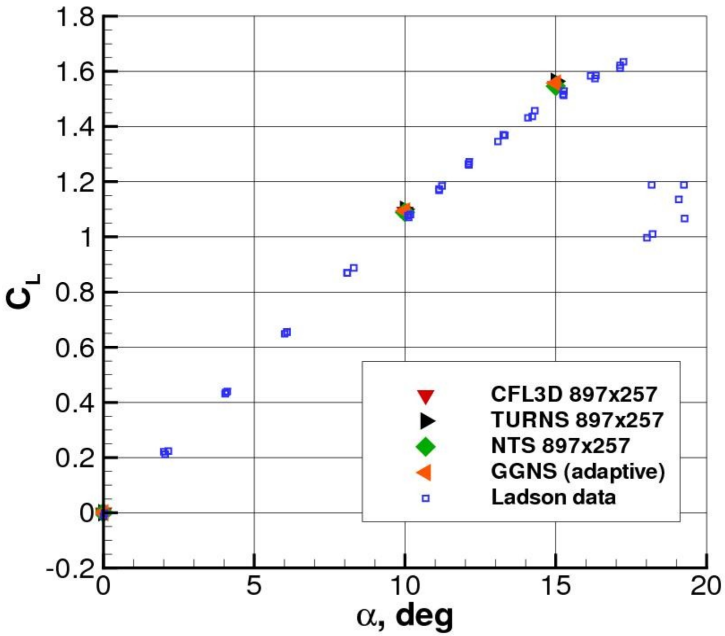


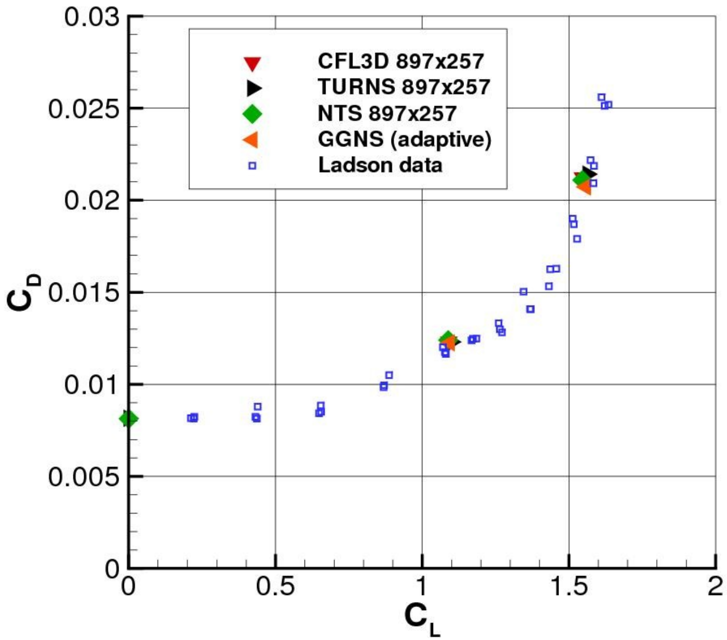
Fully turbulent CFD computations best compared with tripped data (at wind tunnel Reynolds numbers)

2-D incompressible NACA 0012 airfoil

validation case

- 4 independent CFD codes used for <u>SA model</u>
  - CFL3D (NASA Langley)
  - TURNS (Stanford & U Maryland)
  - NTS (NTS, Russia)
  - GGNS (Boeing)
- Latter 3 codes have not undergone verification procedure yet





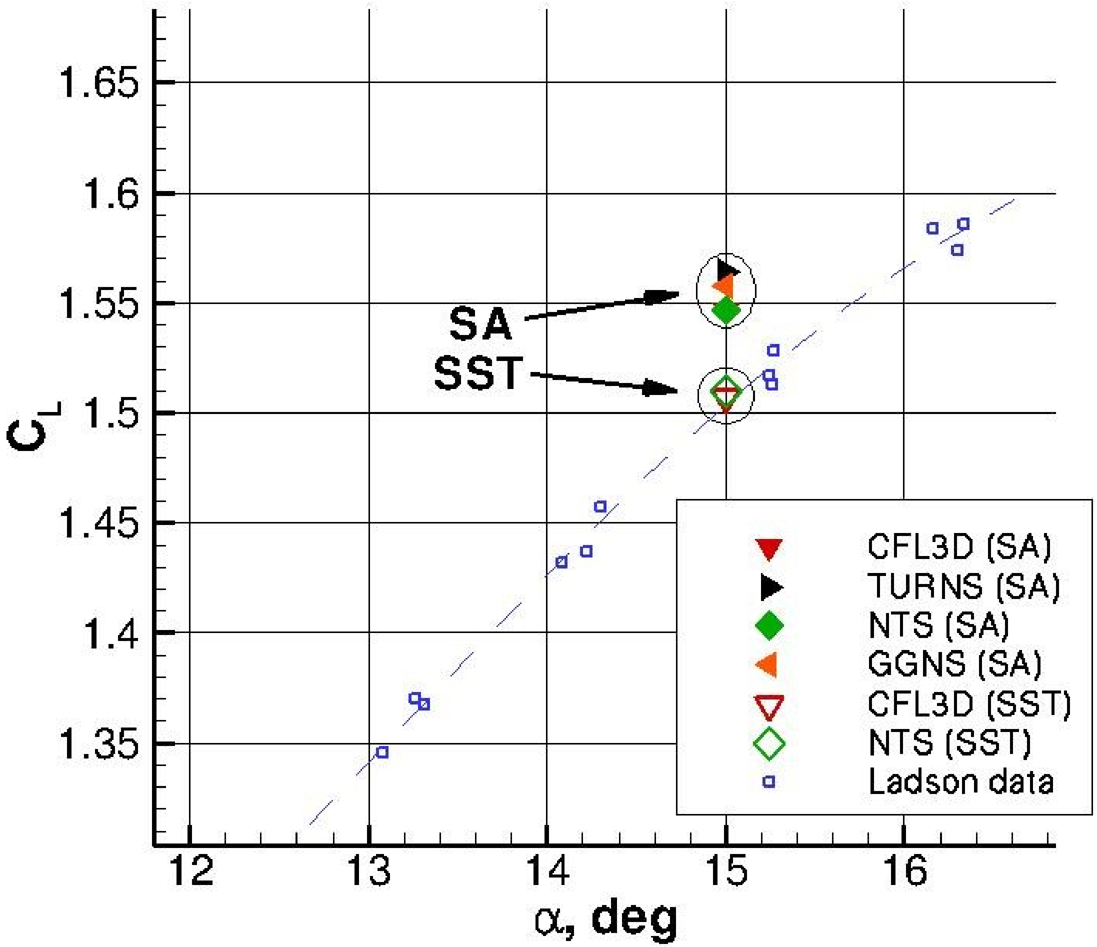
very close agreement (not perfect)

2-D incompressible NACA 0012 airfoil

validation case

Meaningful evaluation of turbulence models would be possible if one could run fine enough grids and if:

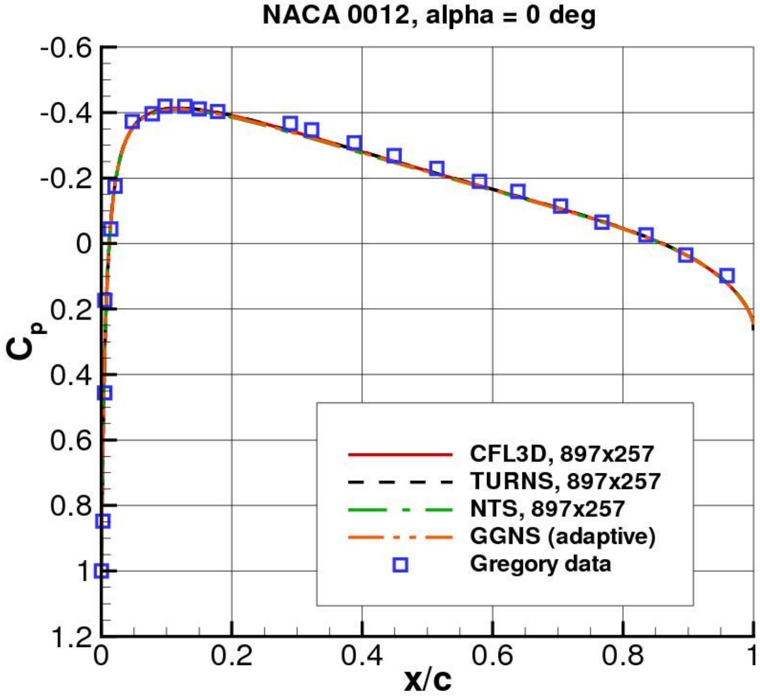
code-to-code differences << model differences

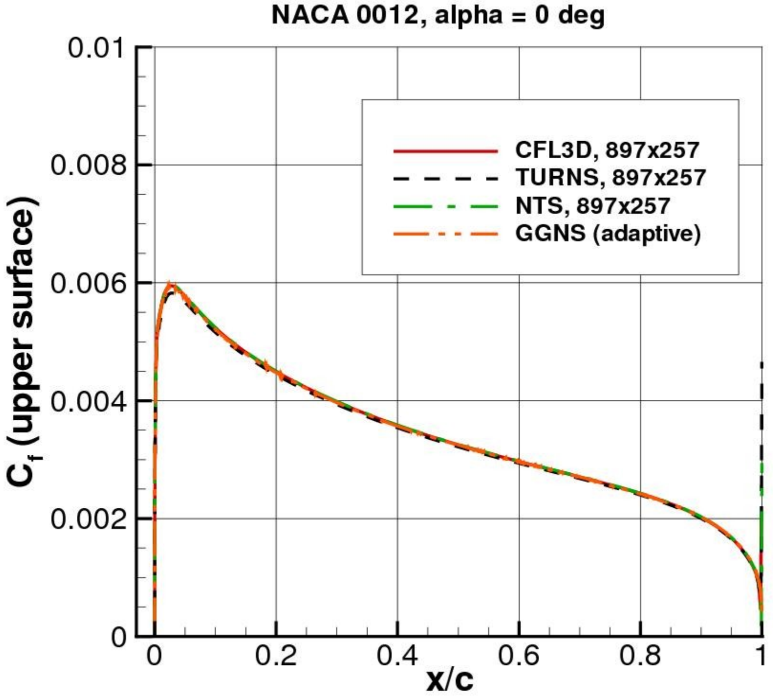


SST results are preliminary

2-D incompressible NACA 0012 airfoil
validation case

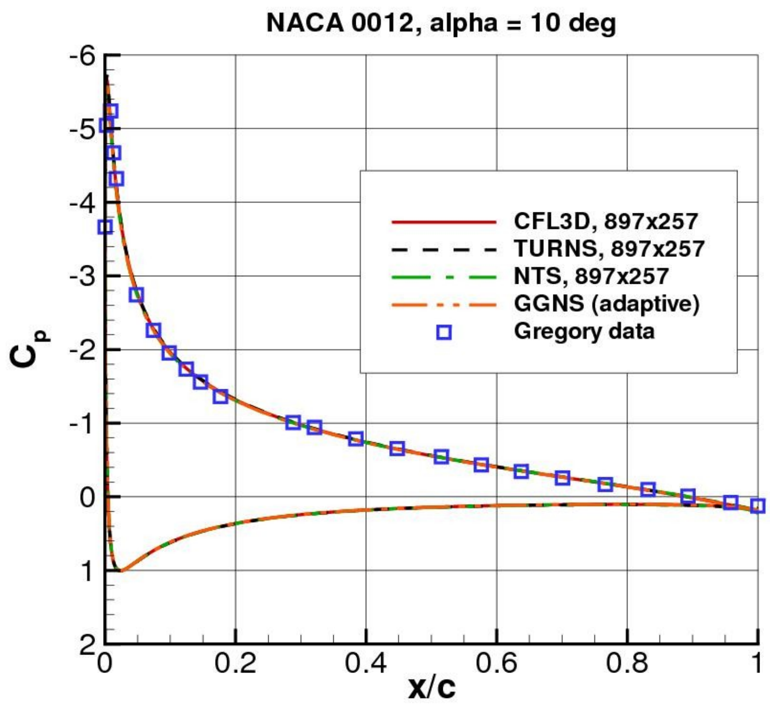
SA model

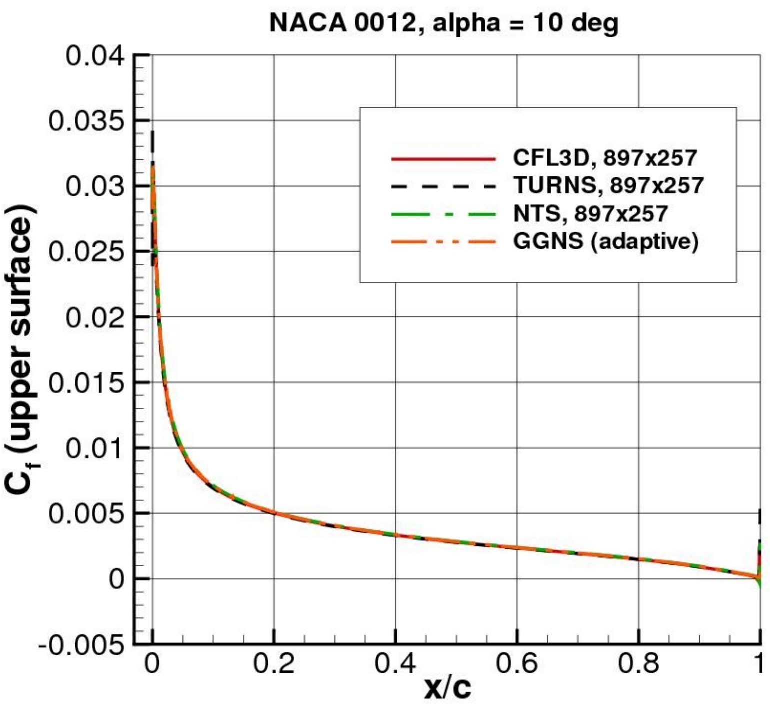




2-D incompressible NACA 0012 airfoil
validation case

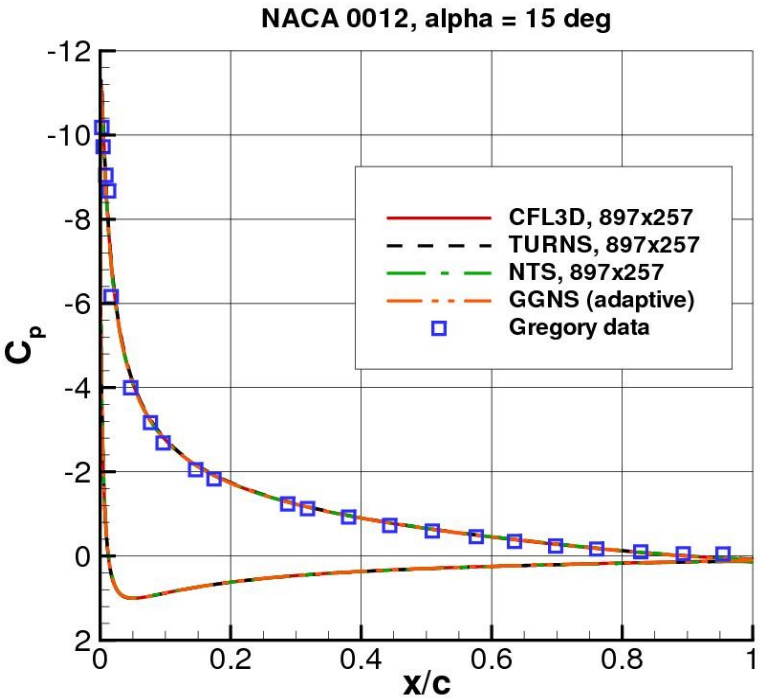
SA model

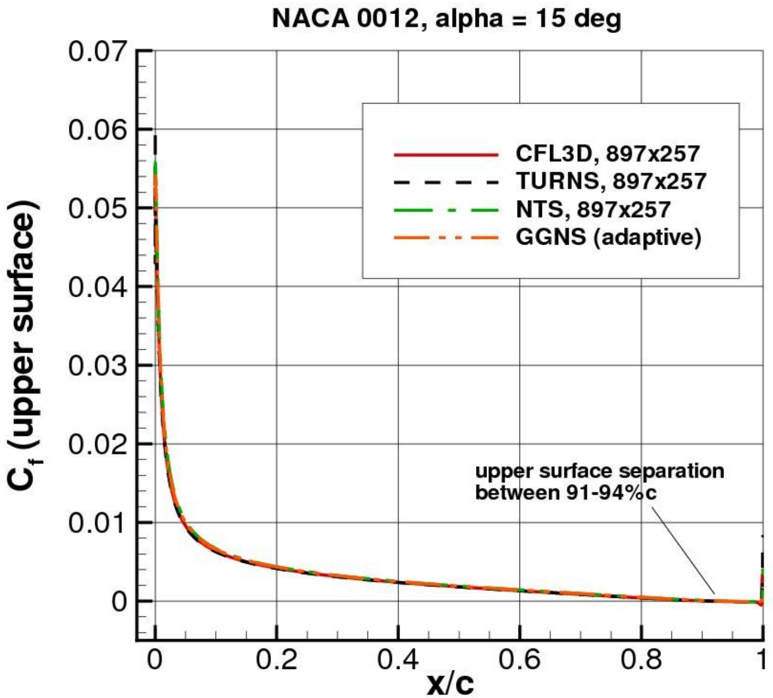




2-D incompressible NACA 0012 airfoil
validation case

SA model





Other resources on the website

- Validation database archive
  - Turbulent flow experimental and simulation databases are included from Bradshaw, P., Launder, B. E., and Lumley, J. L., “Collaborative Testing of Turbulence Models,” Journal of Fluids Engineering, Vol. 118, June 1996, pp. 243-247.
    - Incompressible Flow Cases from 1980-81 Data Library
    - Compressible Flow Cases from 1980-81 Data Library
    - More recent databases (courtesy P. Bradshaw) also included
- Collection of turbulent manufactured solutions
  - From “Workshop on CFD Uncertainty Analysis” series
  - Manufactured Fortran function files, courtesy Luis Eca, IST (Lisbon)
    - Spalart-Allmaras (SA-noft2), Menter one-equation, Menter BSL, standard k-epsilon, Chien k-epsilon, TNT k-omega

Future plans for website

- Expand number of turbulence models described / referenced
- Complete the set of 5 planned validation cases
  - Compute each with at least 2 independent CFD codes
  - Ensure that results agree when using the same model
  - Initial focus: Spalart-Allmaras and Menter SST models
- Expand verification & validation cases to include other turbulence models
- Additional verification or validation cases as need arises

Conclusions

- There is a need to establish consistency in turbulence modeling across multiple codes in the CFD community

- Website http://turbmodels.larc.nasa.gov addresses consistency, verification, & validation
  - Documents model versions & establish naming conventions
  - Includes 4 verification cases, including full grid convergence studies (provides grids and solutions for easy reference)
  - Easily-accessible one-stop location that will document performance of various models for a suite of 5 representative validation cases (provides grids and solutions for easy reference)