Introduction to the Collaborative Testing Challenge

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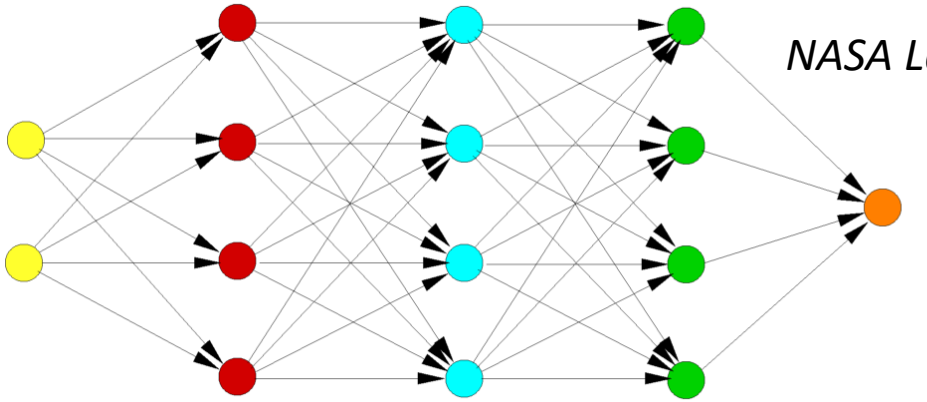
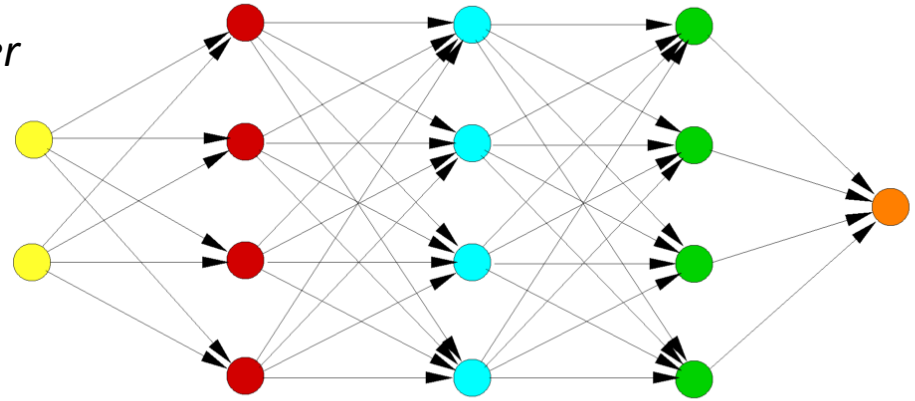




2022 Symposium on Turbulence Modeling: Roadblocks, and the Potential for Machine Learning

Motivation

- Traditional RANS is known to be inadequate for reliable prediction of separated and other “difficult” flows
- Much work is ongoing in the research community to attempt to improve RANS models using data-driven techniques
  - By their very nature, these improvements are typically only applicable to cases that are very similar to those they were trained for
  - We seek improved turbulence models that can be used more generally and confidently in predictive situations <- this is ultimately what is needed
    - (Imagine trying to apply the model to a high-lift aircraft configuration!)
- Our own attempts to achieve a broadly-applicable model enhancement using FIML methodology (AIAA 2022-0937):
  - Unsuccessful
    - Improving one flow inevitably made some other flow much worse
    - Inappropriate or inadequate feature selection?
    - Insufficient coverage of the training data? (a common complaint)

Motivation, cont'd

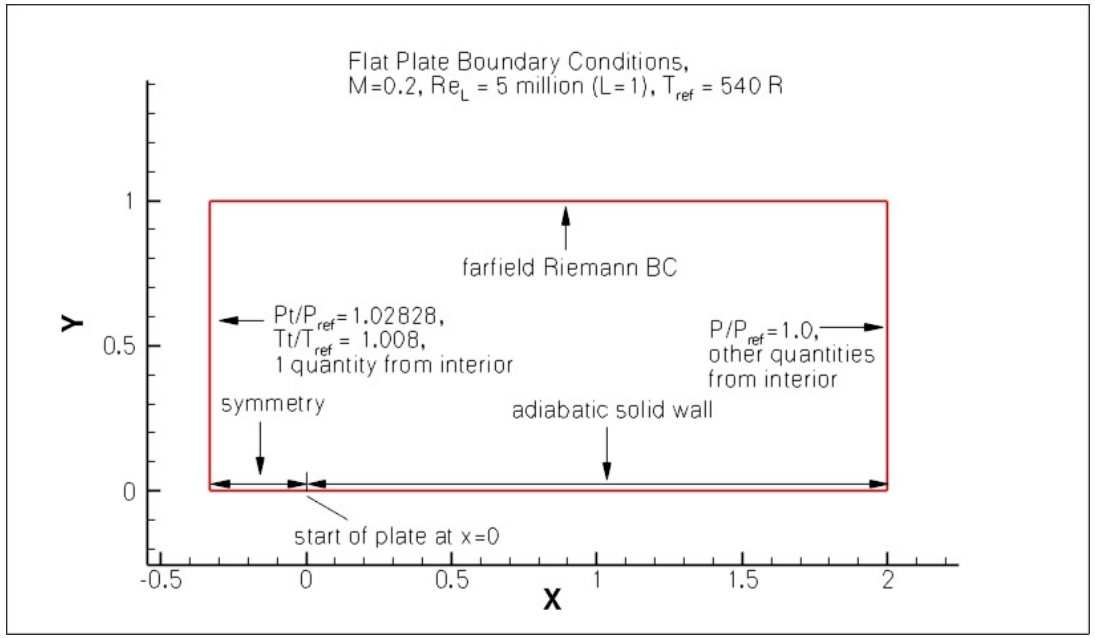
- The "Collaborative Testing Challenge" was conceived as an integral part of this symposium
  - Get broad range of experts to try to achieve data-driven turbulence models that work well for a broad range of simple test cases
  - Nonthreatening, noncompetitive, friendly environment
    - We know this is a difficult challenge!
    - There is no right answer
    - We seek to encourage discussion, ideas, future collaborations

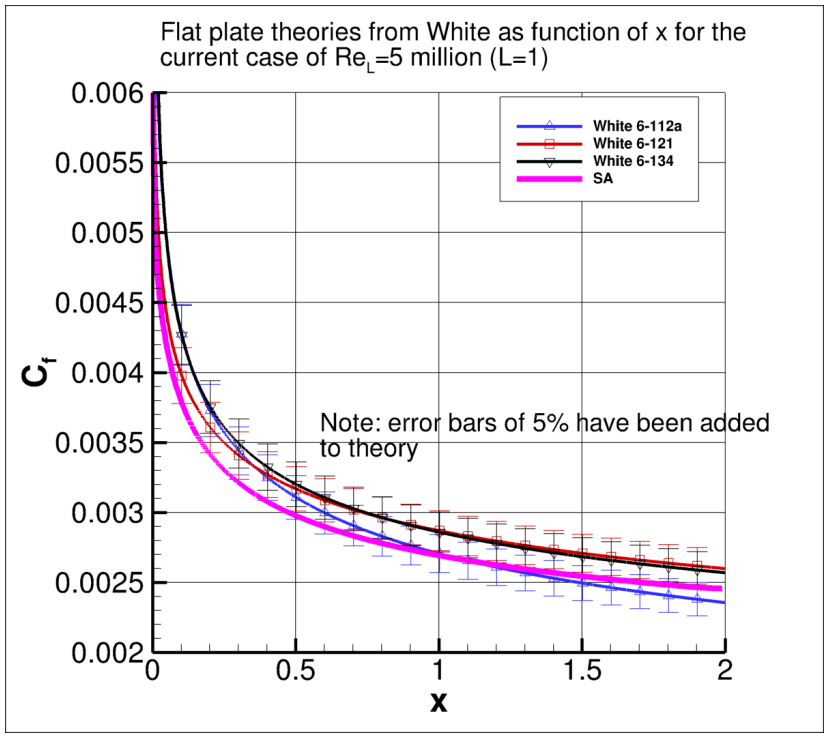
- Ground Rules: Each participant to apply their best turbulence model scheme (framework) derived from a data-driven (or other) approach to a range of flows specified by the conference organizers

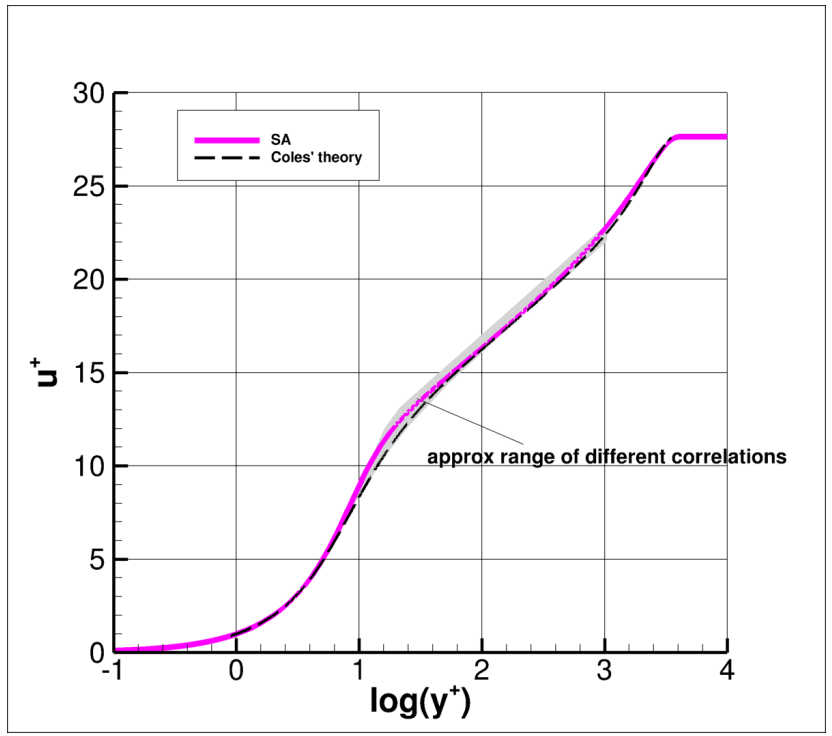
Test Cases

- To be a valid entry, the same turbulence model must be applied to each of the following cases (use the same grids employed for the results shown on the Turbulence Modeling Resource (TMR) website if possible):
  - **2DZP**: 2D Zero Pressure Gradient Flat Plate Validation Case
    - Show (1) C_f vs. x and (2) u^+ vs. $\log(y^+)$ at x=0.97; compare with theory
  - **2DFDC**: 2D Fully-Developed Channel Flow at High Reynolds Number Validation Case
    - Show u^+ vs. $\log(y^+)$ at x=500; compare with theory
  - **ASJ**: Axisymmetric Subsonic Jet
    - Show (1) u/U_{jet} vs. x/D_{jet}, (2) u/U_{jet} vs. y/D_{jet} at 5 specified stations, and (3) $u'v'/(U_{jet}^2)$ vs. y/D_{jet} at 5 specified stations; compare with experiment
  - **2DWMH**: 2D NASA Wall-Mounted Hump Separated Flow Validation Case
    - Show (1) C_p vs. x/c, (2) C_f vs. x/c, (3) u/U_{inf} vs. y/c at 7 specified stations, and (4) $u'v'/(U_{inf}^2)$ vs. y/c at 7 specified stations; compare with experiment
  - **2DN00**: 2D NACA 0012 Airfoil Validation Cases (4 separate cases)
    - Angles of attack = 10, 15, 17, and 18 deg.
    - Show (1) C_L vs. alpha, (2) C_D vs. C_L, (3) C_p vs. x/c, and (4) C_f (upper surface) vs. x/c; compare with experiment (except for C_f)

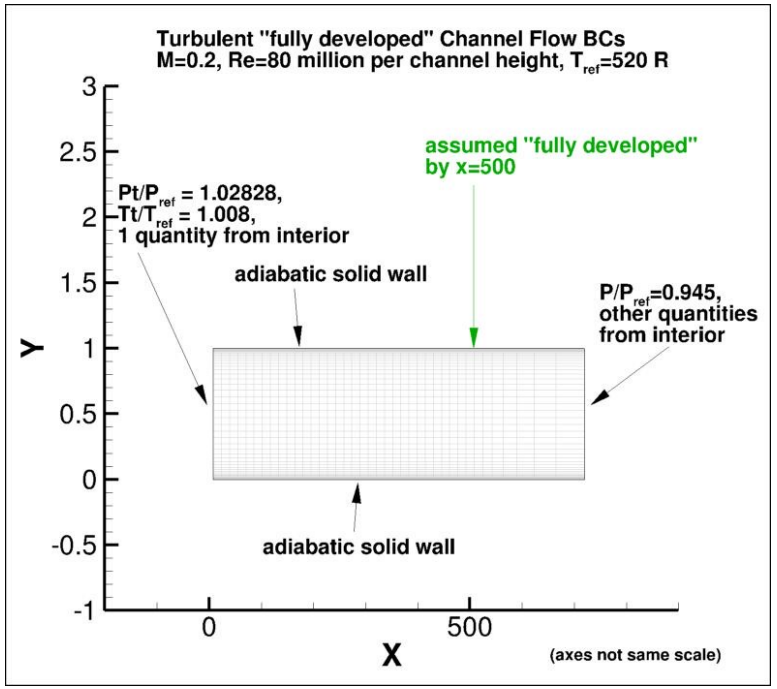
2DZP

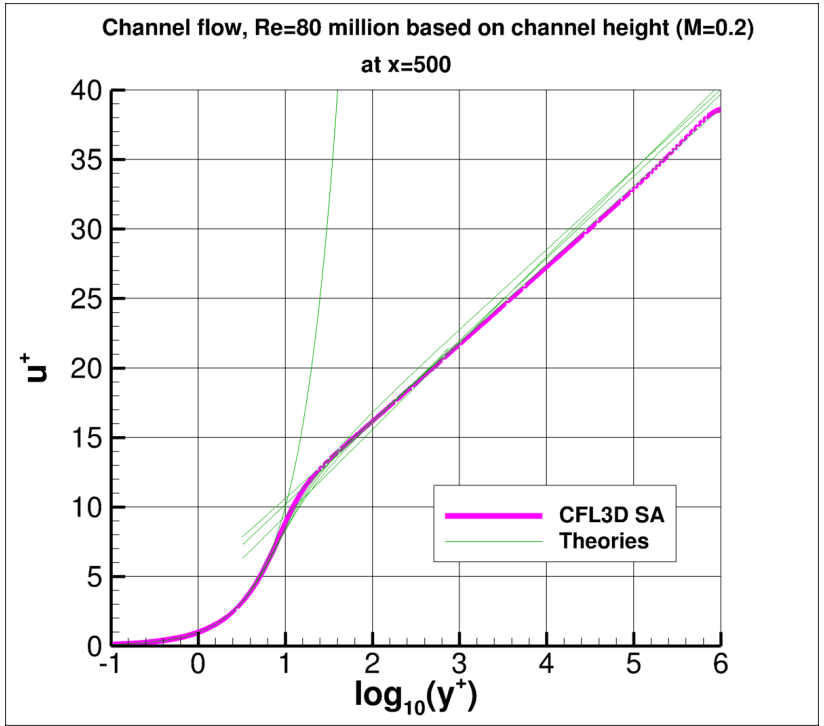

Flat Plate Boundary Conditions,
M=0.2, Re_L = 5 million (L=1), T_ref = 540 R
farfield Riemann BC
Pt/P_ref=1.02828,
Tt/T_ref = 1.008,
1 quantity from interior
P/P_ref=1.0,
other quantities
from interior
symmetry
adiabatic solid wall
start of plate at x=0
Y
X


Flat plate theories from White as function of x for the current case of Re_L=5 million (L=1)
White 6-112a
White 6-121
White 6-134
SA
Note: error bars of 5% have been added to theory
C_f
x

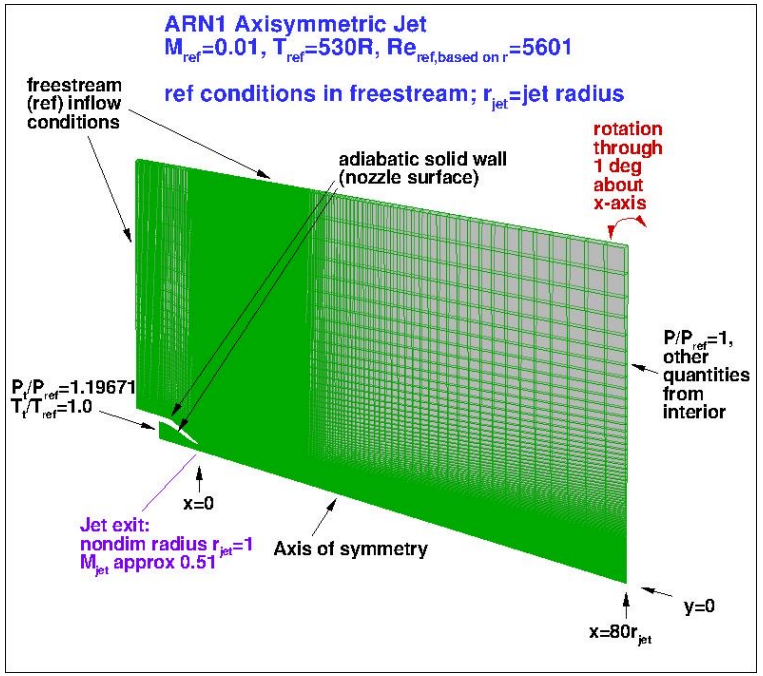

SA
Coles' theory
approx range of different correlations
u+
log(y+)

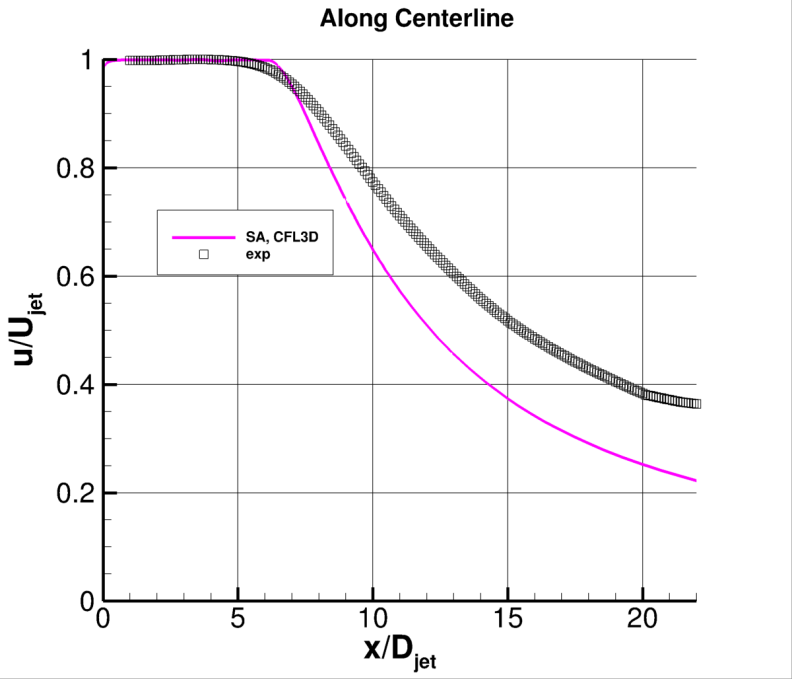
2DFDC

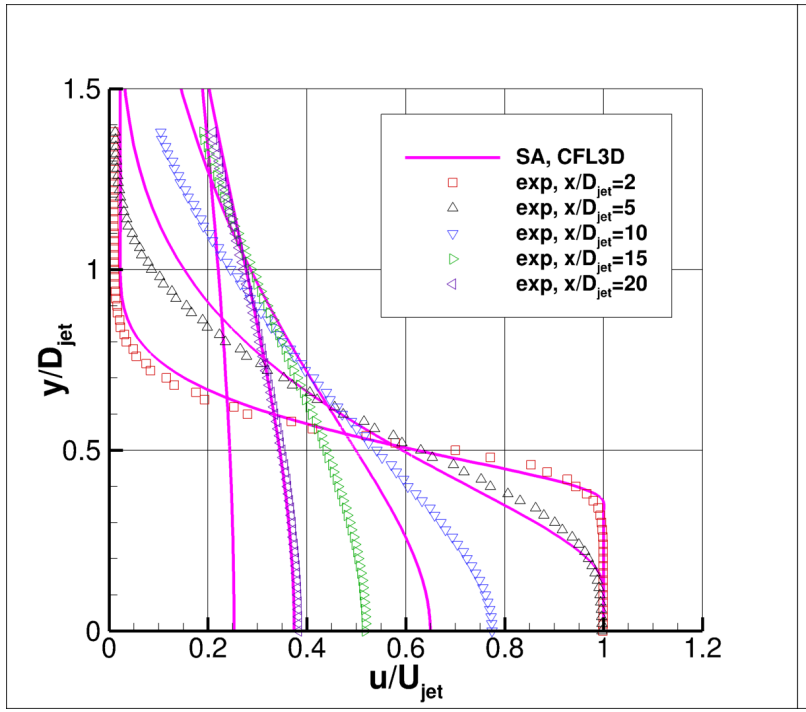

Turbulent "fully developed" Channel Flow BCs
M=0.2, Re=80 million per channel height, T_ref=520 R
assumed "fully developed" by x=500
Pt/P_ref = 1.02828,
Tt/T_ref = 1.008,
1 quantity from interior
adiabatic solid wall
P/P_ref=0.945, other quantities from interior
adiabatic solid wall
Y
X
(axes not same scale)

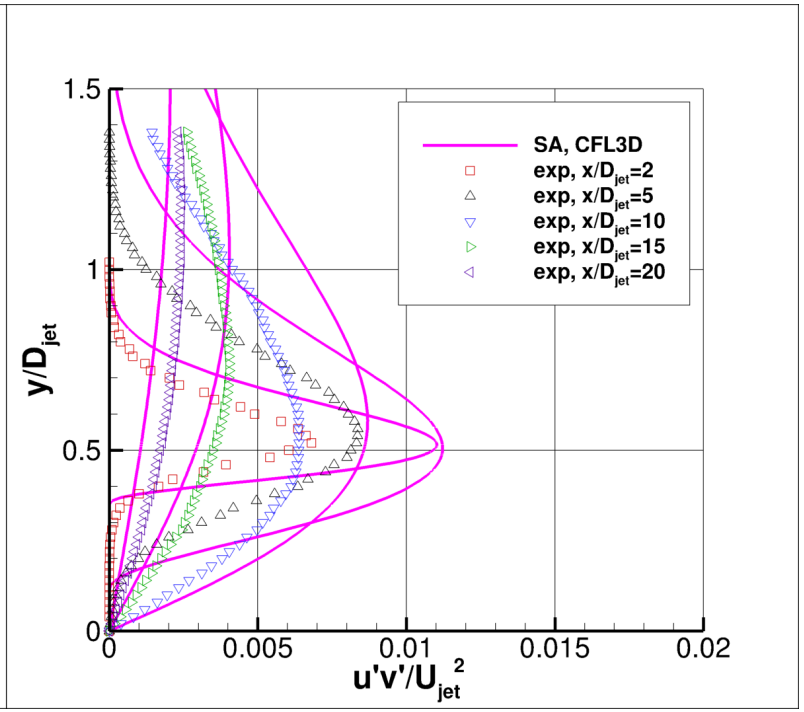

Channel flow, Re=80 million based on channel height (M=0.2)
at x=500
u+
log10(y+)
CFL3D SA
Theories

ASJ

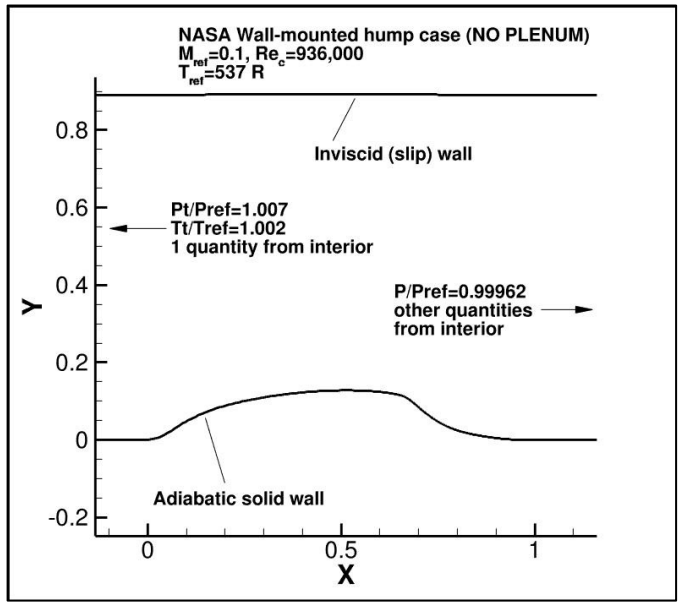

ARN1 Axisymmetric Jet
M_{ref}=0.01, T_{ref}=530R, $Re_{ref,based\ on\ r}$=5601
ref conditions in freestream; r_{jet}=jet radius
freestream (ref) inflow conditions
adiabatic solid wall (nozzle surface)
rotation through 1 deg about x-axis
P/P_{ref}=1, other quantities from interior
P_t/P_{ref}=1.19671
T_t/T_{ref}=1.0
x=0
Jet exit:
nondim radius r_{jet}=1
M_{jet} approx 0.51
Axis of symmetry
y=0
x=80r_{jet}

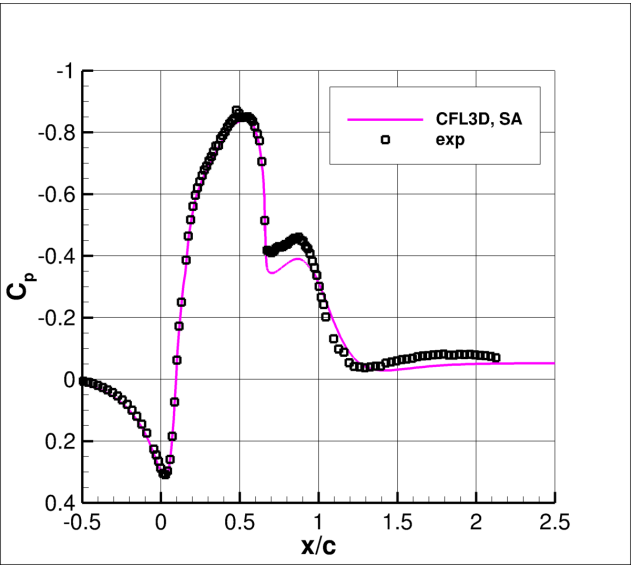

Along Centerline
SA, CFL3D
exp
u/U_{jet}
x/D_{jet}

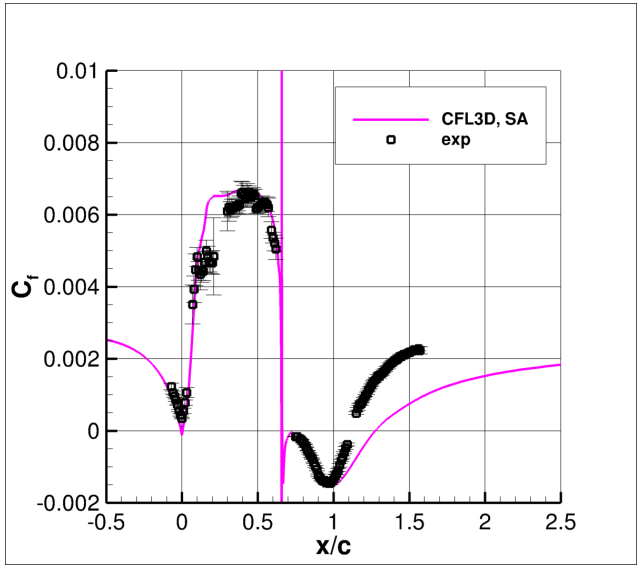

SA, CFL3D
exp, x/D_{jet}=2
exp, x/D_{jet}=5
exp, x/D_{jet}=10
exp, x/D_{jet}=15
exp, x/D_{jet}=20
y/D_{jet}
u/U_{jet}

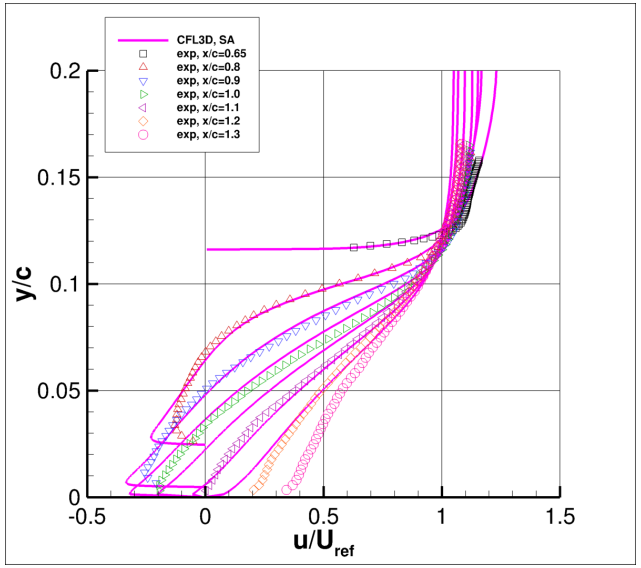

SA, CFL3D
exp, x/D_{jet}=2
exp, x/D_{jet}=5
exp, x/D_{jet}=10
exp, x/D_{jet}=15
exp, x/D_{jet}=20
y/D_{jet}
$u'v'/U_{jet}^2$

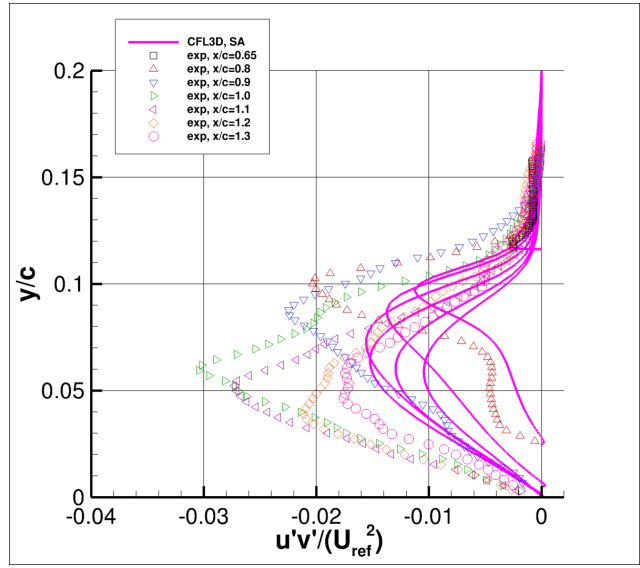
2DWMH


NASA Wall-mounted hump case (NO PLENUM)
M_ref=0.1, Re_c=936,000
T_ref=537 R
Inviscid (slip) wall
Pt/Pref=1.007
Tt/Tref=1.002
1 quantity from interior
P/Pref=0.99962
other quantities
from interior
Adiabatic solid wall
Y
X

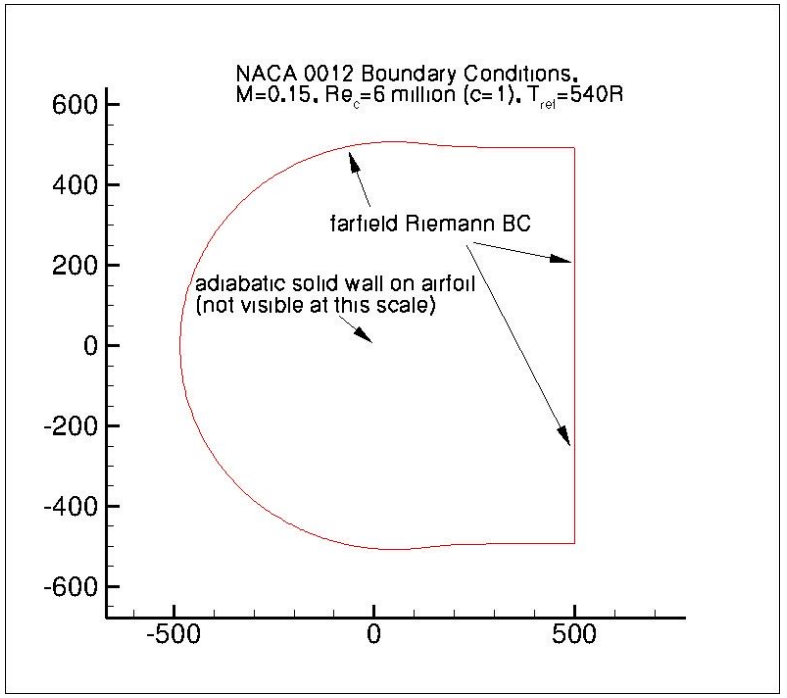

CFL3D, SA
exp
C_p
x/c

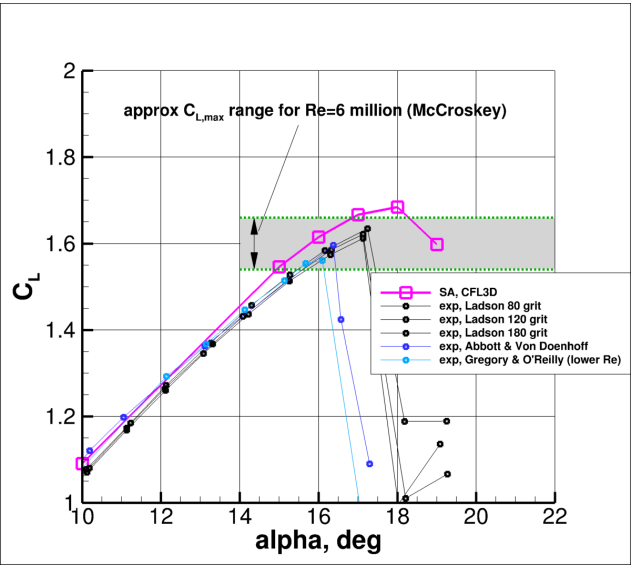

CFL3D, SA
exp
C_f
x/c

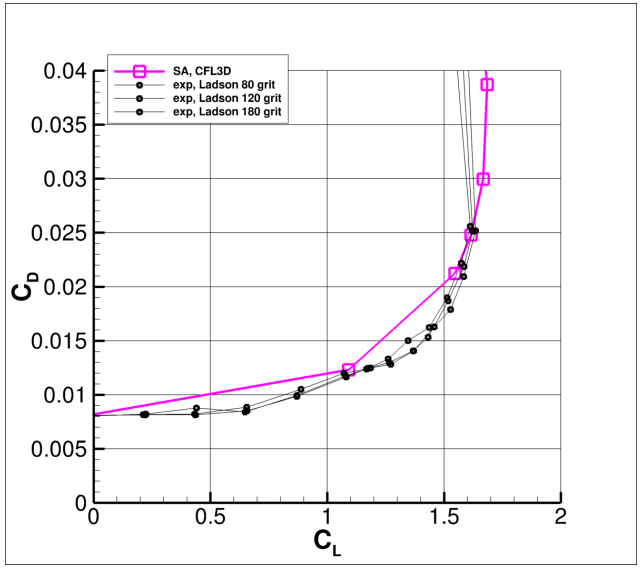

CFL3D, SA
exp, x/c=0.65
exp, x/c=0.8
exp, x/c=0.9
exp, x/c=1.0
exp, x/c=1.1
exp, x/c=1.2
exp, x/c=1.3
y/c
u/U_ref

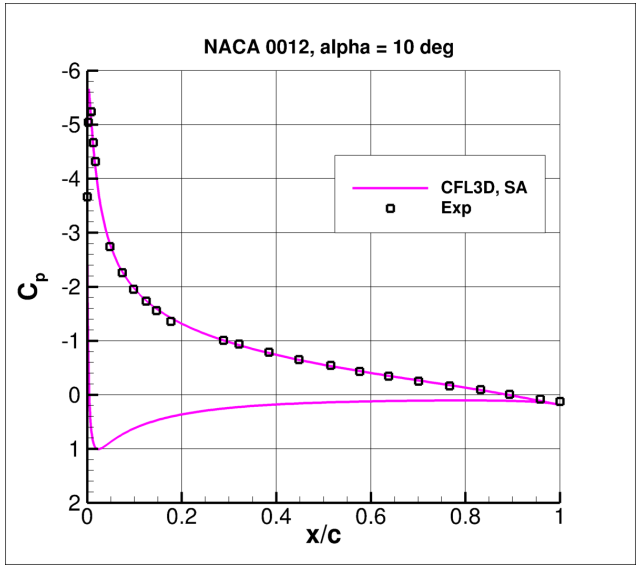

CFL3D, SA
exp, x/c=0.65
exp, x/c=0.8
exp, x/c=0.9
exp, x/c=1.0
exp, x/c=1.1
exp, x/c=1.2
exp, x/c=1.3
y/c
u'v'/(U_ref^2)

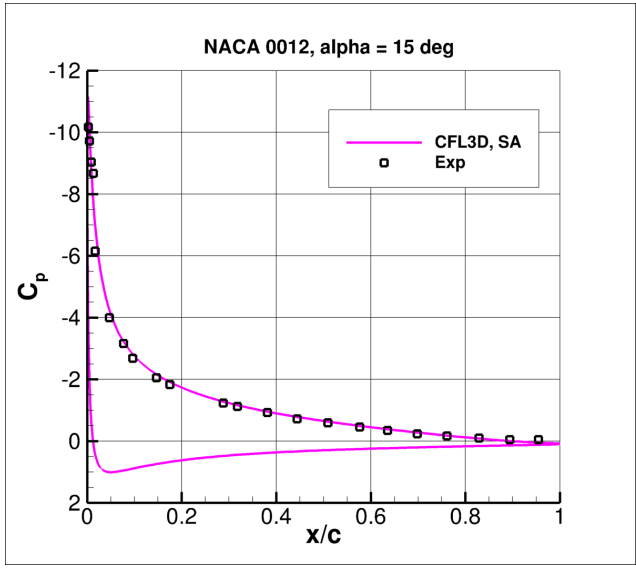
2DN00


NACA 0012 Boundary Conditions.
M=0.15. Re$_c$=6 million (c=1). T$_{ref}$=540R
farfield Riemann BC
adiabatic solid wall on airfoil
(not visible at this scale)
600
400
200
0
-200
-400
-600
-500
0
500


approx C$_{L,max}$ range for Re=6 million (McCroskey)
SA, CFL3D
exp, Ladson 80 grit
exp, Ladson 120 grit
exp, Ladson 180 grit
exp, Abbott & Von Doenhoff
exp, Gregory & O'Reilly (lower Re)
C$_L$
alpha, deg

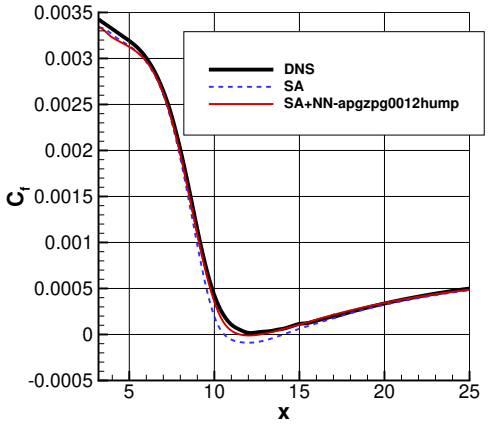

SA, CFL3D
exp, Ladson 80 grit
exp, Ladson 120 grit
exp, Ladson 180 grit
C$_D$
C$_L$

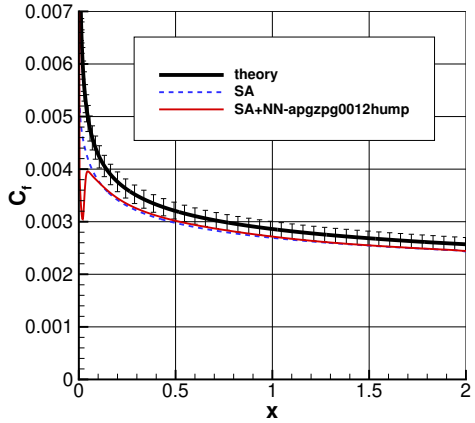

NACA 0012, alpha = 10 deg
CFL3D, SA
Exp
C$_p$
x/c

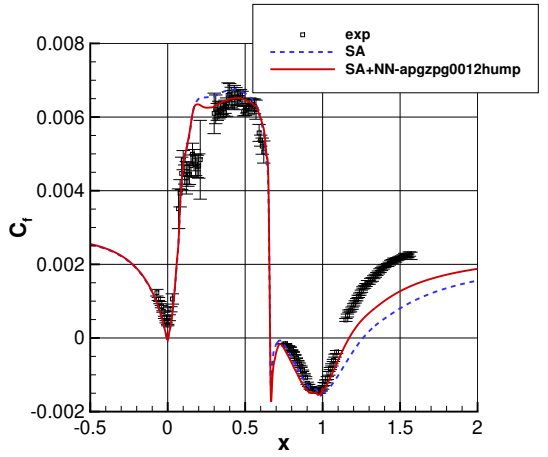

NACA 0012, alpha = 15 deg
CFL3D, SA
Exp
C$_p$
x/c

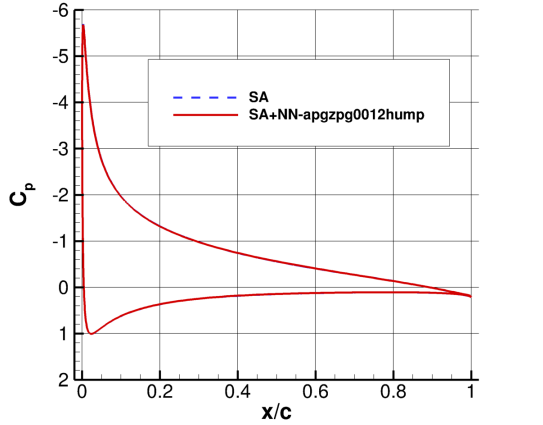
Our Personal Experience Along These Lines

- Our personal experience <u>with somewhat different cases</u> (AIAA 2022-0937) :
  - Neural Network (NN) training done on 4 simple cases (simultaneously):
    - ZPG-APG plate
    - ZPG plate
    - NASA hump
    - NACA 0012 at one AoA



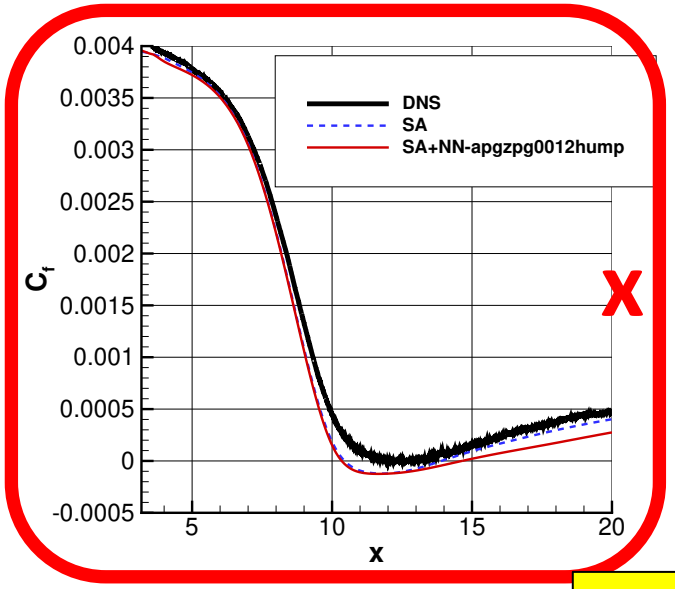




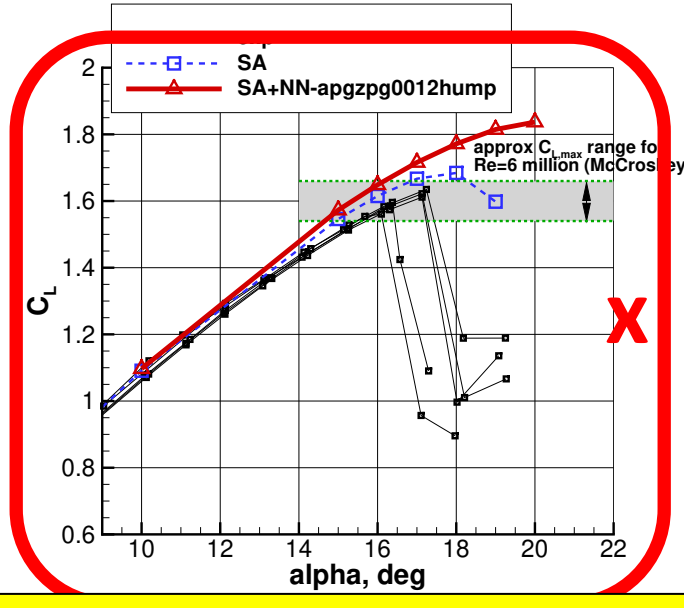


  - Then…

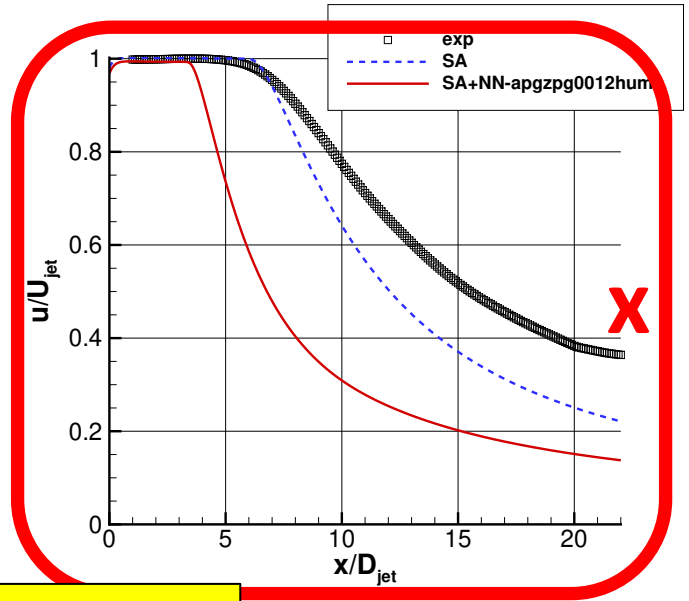
… applied to wide variety of flows NOT in the training



x

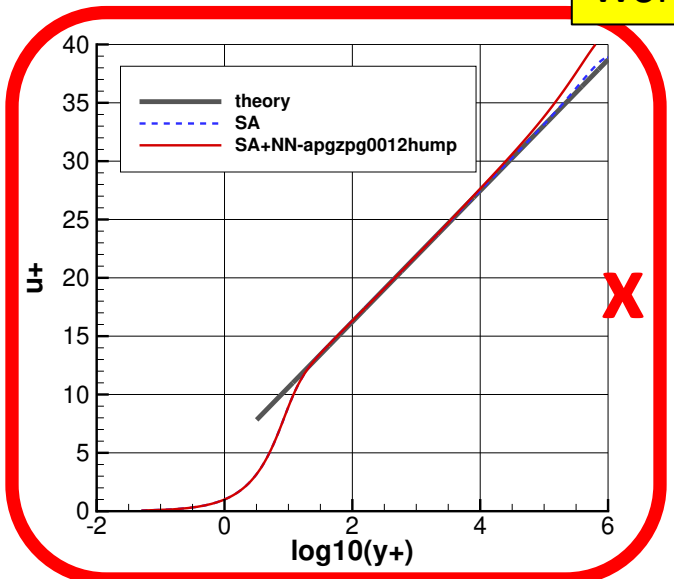


x

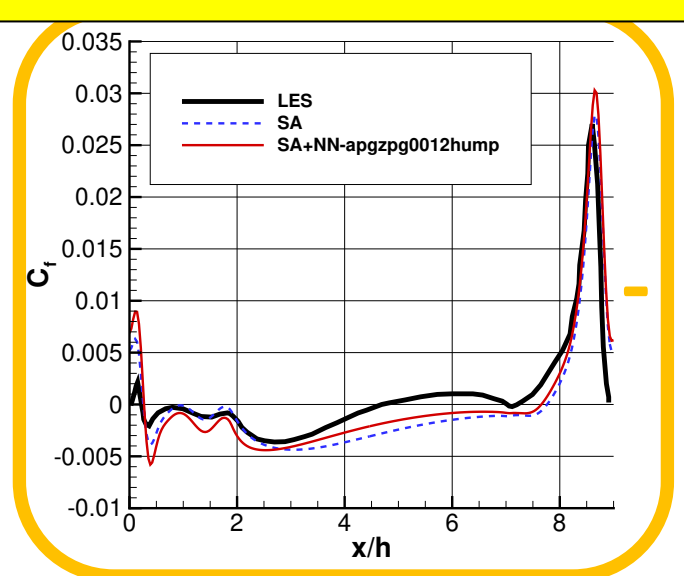


x

Worse than standard SA in 4 out of the 6 cases tested!



x



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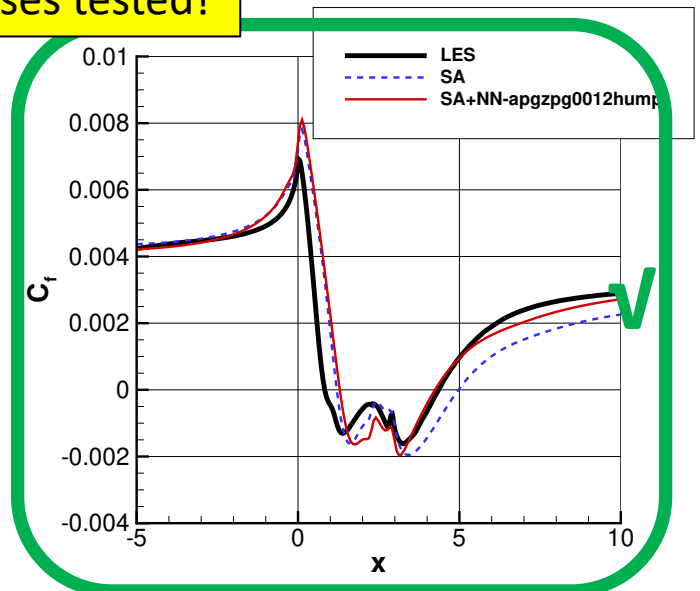

√

x Worse
√ Better
- Wash

Challenge Participants (as of 07/13/2022)

- **Yuan Fang** (University of Melbourne)
- **Yuanwei Bin and Jiaqi Li** (Penn State University)
- **Soufiane Cherroud** (Arts et Metiers Paristech)
- **Richard Dwight** (TU Delft)
- **Eric Parish** (Sandia National Labs)
- **Michael Stoellinger** (University of Wyoming)
- **Venkat Viswanathan** (Carnegie Mellon University)
- **Koushik Marepally** (University of Maryland)

What's Next for the Challenge part of Symposium

- 8 talks total
  - 5 of them are combination "symposium talks" + "challenge method/results" (1/2 hr each)
  - 3 of them are solely on "challenge method/results" (15 min each)

- 1 hour general discussion about the Challenge at the end

Questions to ask/think about

- If the usual machine learning techniques were used, what cases were used in the training? (all? some?)
- How “good” were the results compared to each theory/experiment?
- Were the results “better”/”similar”/”worse” than existing traditional RANS turbulence models (e.g., SA, SST, SSGLRR-RSM)?
- What would happen if the trained model were used on a completely different TMR case?
- Could others implement this model in their RANS codes?
- Does the model consist of codable equations, or is it a NN or black box?