Summary of the 1st AIAA CFD Transition Modeling and Prediction Workshop

Jim Coder
University of Tennessee Knoxville

Advanced Modeling & Simulation (AMS) Seminar Series
NASA Ames Research Center, March 4, 2021

Workshop Objectives

- Assess the current state of the art in laminar-turbulent transition prediction in an industrial CFD environment
- Determine and document best practices for transitional flow simulations
- Verify transition/turbulence model implementations
- Encourage risk taking by participants and promote improvements to CFD prediction capabilities

Organizing Committee

- Jim Coder (University of Tennessee)
- Doug Stefanski (Oak Ridge National Laboratory)
- Jim Baeder (University of Maryland)
- Meelan Choudhari (NASA Langley)
- Marie Denison (NASA Ames)
- Matthew Tufts (AFRL)
- Andreas Krumbein (DLR)
- Greg Delattre (ONERA)

Agenda Recap

Day One – January 21, 2021 *All times listed are Eastern Standard Time*	
10:00 – 10:05 AM	**OPENING REMARKS**
10:05 – 10:35 AM	**CRM-NLF Overview** **Michelle Lynde** (NASA Langley Research Center)
10:35 – 10:50 AM	**Structured Mesh Families** **Jim Coder** (University of Tennessee) and **Marie Denison** (NASA Ames)
10:50 – 11:05 AM	**CRM-NLF Unstructured Mesh Family** **Steve Karman** (Pointwise)
11:05 – 11:15 AM	**BREAK**
11:15 – 11:30 AM	**Yuki Ide** (JAXA)
11:30 – 11:45 AM	**Norman Krimmelbein** (DLR)
11:45 – 12:00 PM	**Donato de Rosa** (CIRA)
12:00 – 12:45 PM	**BREAK**
12:45 – 1:00 PM	**Andrea Ciarella** (Aircraft Research Association)
1:00 – 1:15 PM	**Eric Laurendreau and Benjamin Barouillet** (Polytechnique Montreal); **Hong Yang and M. Charles-Armand Tatossian** (Bombardier Aerospace)
1:15 – 1:30 PM	**Balaji Venkatachari and Nathan Hildebrand** (NASA Langley Research Center)
1:30 – 1:45 PM	**Mike Piotrowski** (NASA Ames); **Dave Zingg** (University of Toronto)
1:45 – 2:00 PM	**Yong Su Jung, Bumseok Lee and Jim Baeder** (University of Maryland)
2:00 – 2:15 PM	**Marie Denison** (NASA Ames Research Center)
2:15 – 2:45 PM	**BREAK**
2:45 – 3:15 PM	**SPECIAL PRESENTATION** **Geza Schrauf (DLR)**
3:15 – 4:00 PM	**OPEN DISCUSSION**

Day Two – January 22, 2021 *All times listed are Eastern Standard Time*	
9:00 – 9:30 AM	**PLENARY TALK** **Thomas Streit** (DLR)
9:30 – 9:45 AM	**Sang Hyun Park** (KAIST)
9:45 – 10:00 AM	**Gregory Delattre** (ONERA)
10:00 – 10:15 AM	**Zhixiang Xiao and Song Fu** (Tsinghua University)
10:15 – 10:30 AM	**Krishna Zore** (ANSYS)
10:30 – 10:45 AM	**BREAK**
10:45 – 11:00 AM	**Samet Cakmakcioglu** (Turkish Aerospace); **Unver Kaynak** (Yildirim Beyazit University)
11:00 – 11:15 AM	**Jan-Soren Fischer** (Netherlands Aerospace Centre)
11:15 – 11:30 AM	**Jiri Furst** (CVUT)
11:30 – 11:45 AM	**Rui Lopes and Luis Eça** (IST); **Maarten Kerkvliet and Serge Toxopeus** (MARIN)
11:45 – 12:00 PM	**Marian Zastawny and Chris Nelson** (Siemens)
12:00 – 12:45 PM	**BREAK**
12:45 – 1:45 PM	**EXPERIMENTALIST PANEL DISCUSSION** *Moderator:* **Dr. Richard Wlezien** (Missouri S&T) *Panelists:* **Marco Costantini** (DLR); **Austin Overmeyer** (US Army CCDC AvMC); and **Ed White** (Texas A&M)
1:45 – 2:00 PM	**BREAK**
2:00 – 3:00 PM	**DATA SUMMARY AND OPEN DISCUSSION**

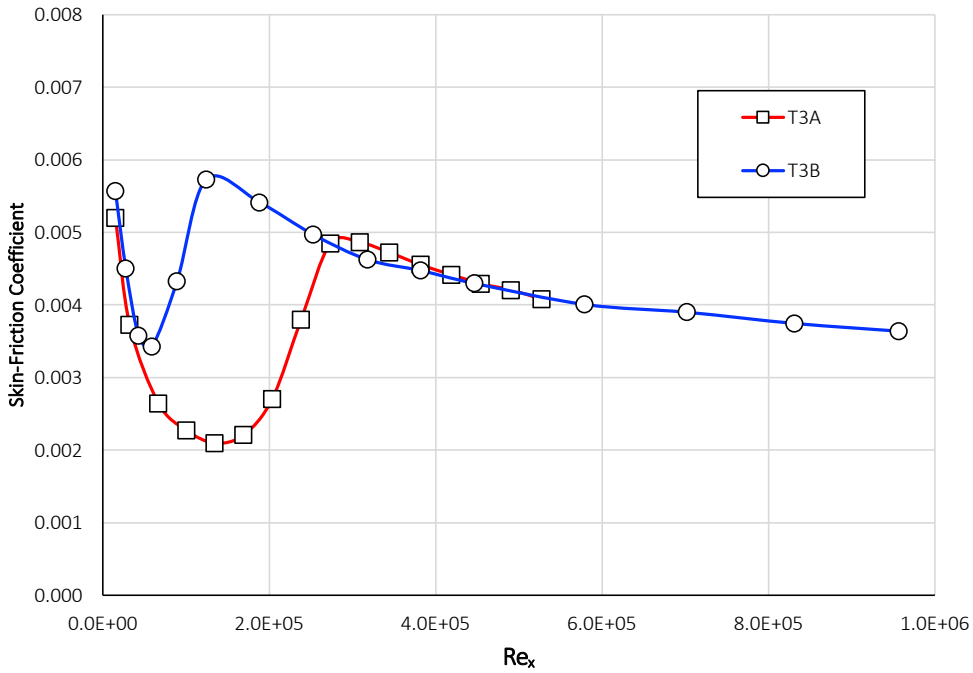
Case 1 – ZPG Flat Plate

Bypass transition cases based on ERCOFTAC T3A and T3B cases

Free-stream turbulence decay is a significant consideration

- Grid dimensions and inlet conditions tightly coupled
- Very large eddy-viscosity values required

Grid resolution studies requested for both cases

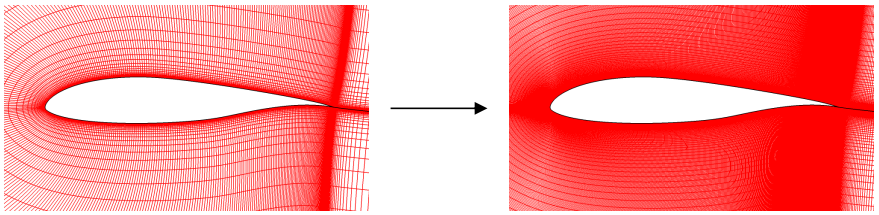


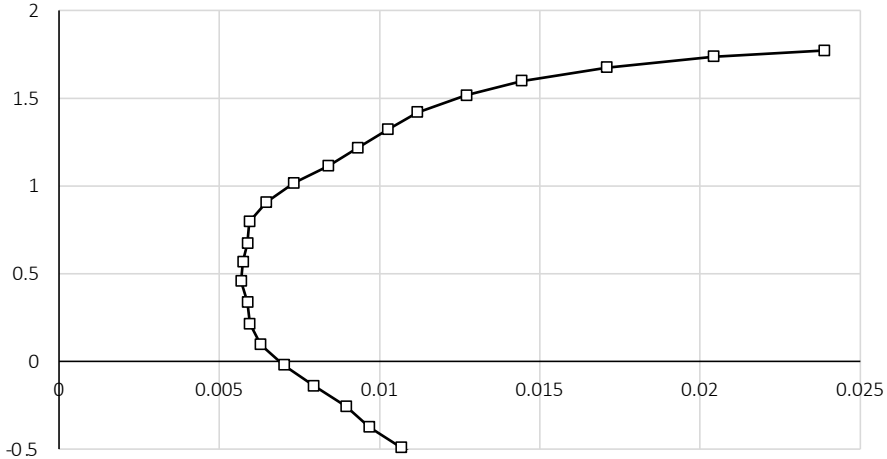
Case 2 – NLF(1)-0416 Airfoil

Two-dimensional case with natural transition under pressure gradient

- Force/moment and transition location data available from NASA LTPT experiment

Grid resolution study at two alphas and alpha sweep with medium-resolution grid requested





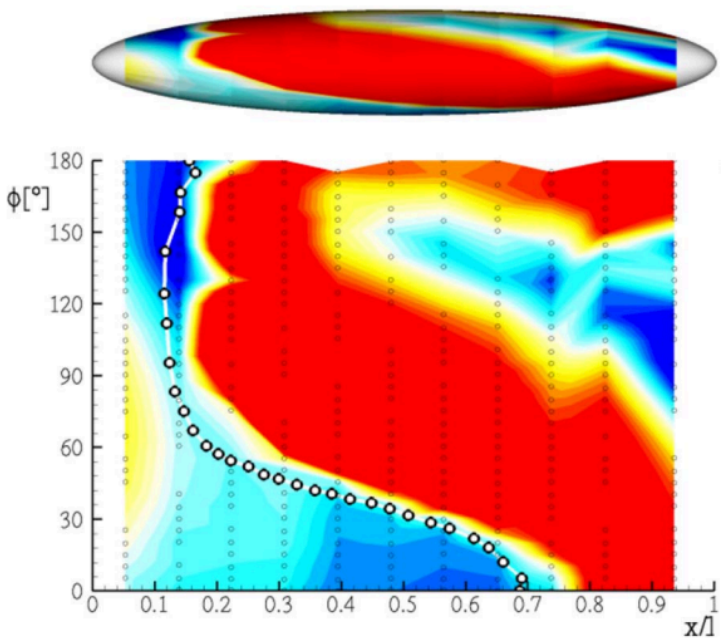
Case 3 – 6:1 Prolate Spheroid

Three-dimensional, axisymmetric geometry at inclination

- Experimental skin-friction measurements available

Both crossflow and streamwise mechanisms are prominent

Alpha sweep with medium-resolution grid requested with optional grid-refinement study



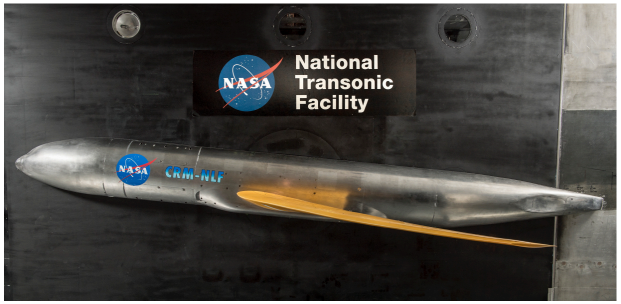
Case 4 – CRM-NLF

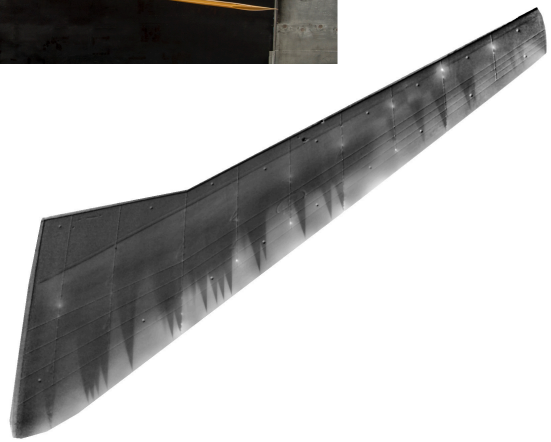
Continues the legacy and traceability of using the CRM for prediction workshops

Commercial transport wing designed to achieve extensive laminar flow at flight Reynolds numbers and lift coefficients

Three-dimensional, shock-dominated flow with multiple transition mechanisms

Grid-resolution study and alpha sweep requested





Data Summary Overview

- Data submitted by 18 participant teams ahead of workshop
  - 7 government, 4 industry, 7 academia
  - Additional representation from mixed teams

- Strong international participation
  - USA, Canada, Germany, UK, France, Portugal, Netherlands, Czechia, Italy, Turkey, India, China, Japan
  - Only 1 US university

Data Plotting

- Letters used as plotting symbols to denote specific participants in a random, but consistent, order
  - Participant key currently being withheld
- Data are color-coded to characterize the type of turbulence/transition model used
- **Each participant used a different model**
  - Prevented true code-to-code verification

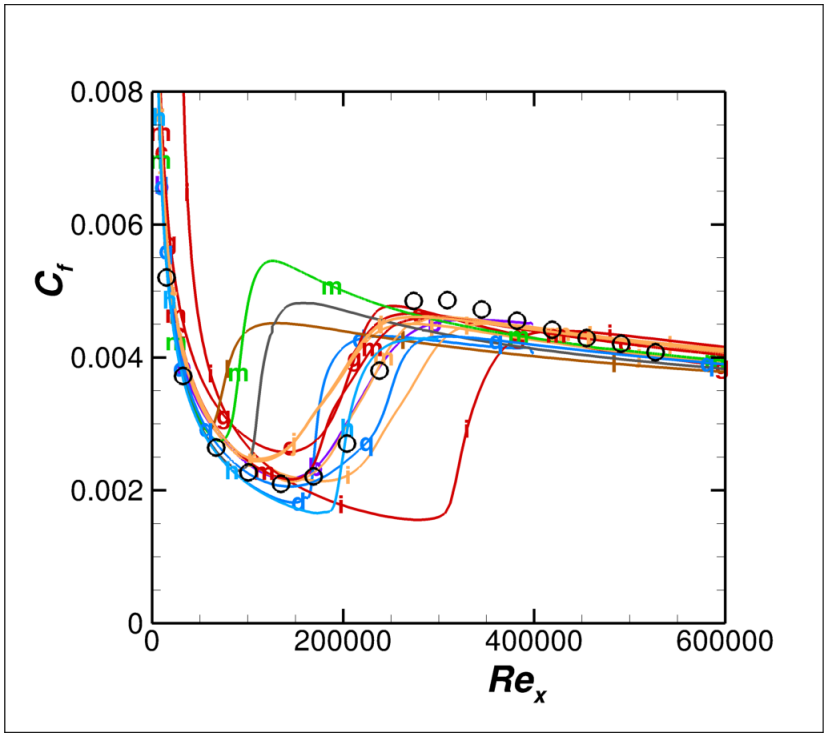
Turbulence and Transition Models

- Linear Stability with SA
- Linear Stability with SST and RSM
- γ-$Re_{\theta t}$ (LM2009) with SST
- γ(MS2015) with SST
- γ-$Re_{\theta t}$ (LM2009/LM2015)+CF(He) with SST and RSM
- γ-$Re_{\theta t}$ (LM2009)+CF+ with SST
- γ(MS2015)+CF(He) with SST
- AFT2017b with SA
- γ-$Re_{\theta t}$ (sLM2015) with SA
- MB + CF(He) with SA (Medida/Baeder)
- B-C with SA (Bas/Çakmakçıoğlu: algebraic transition model)
- Lag Elliptic Model

Case 1 – ZPG Flat Plate

- **Participant Data**
  - **13 data submittals**
    - 6 N. America, 5 Europe, 2 Asia
    - 5 Government, 4 Academia, 2 Industry, 2 Industry/Academia
  - **Grid types**
    - 10 committee-provided structured
    - 2 custom structured
    - 1 custom unstructured

Case 1A – T3A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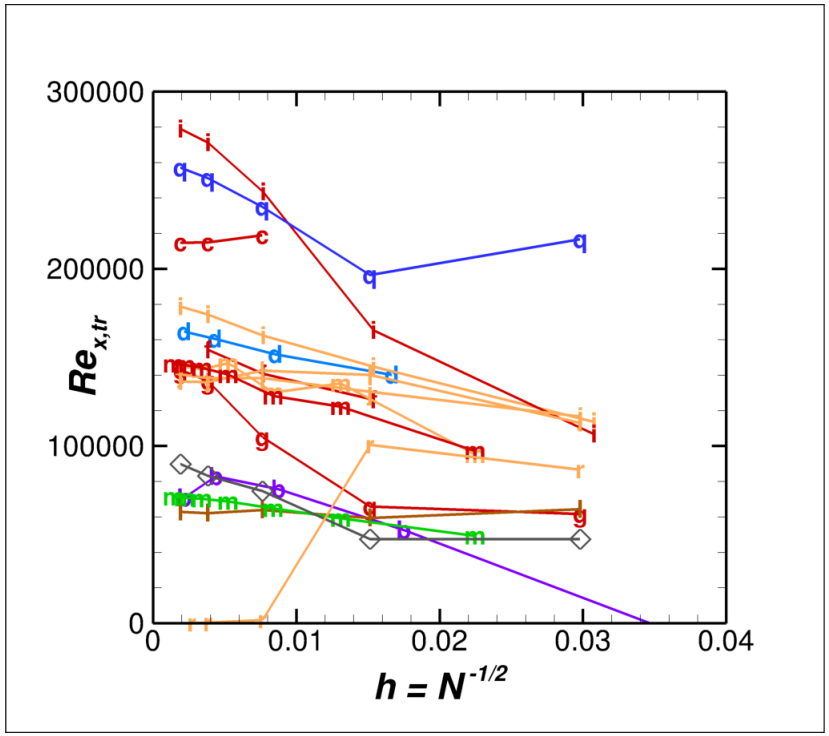
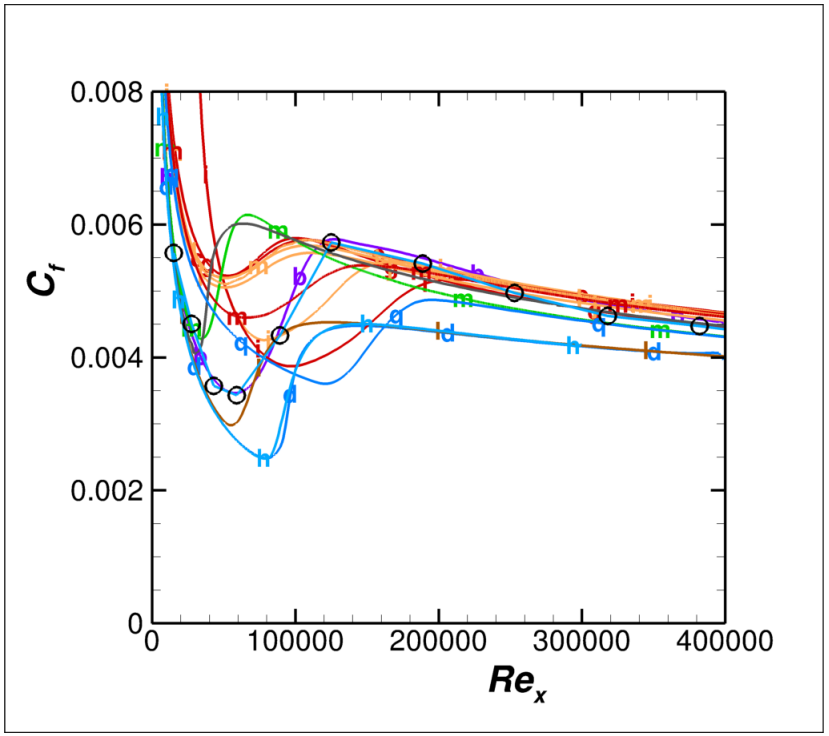
0.006
0.004
0.002
0
C_f
0
200000
400000
600000
Re_x


300000
200000
100000
0
$Re_{x,tr}$
0
0.01
0.02
0.03
0.04
$h = N^{-1/2}$

Case 1B – T3B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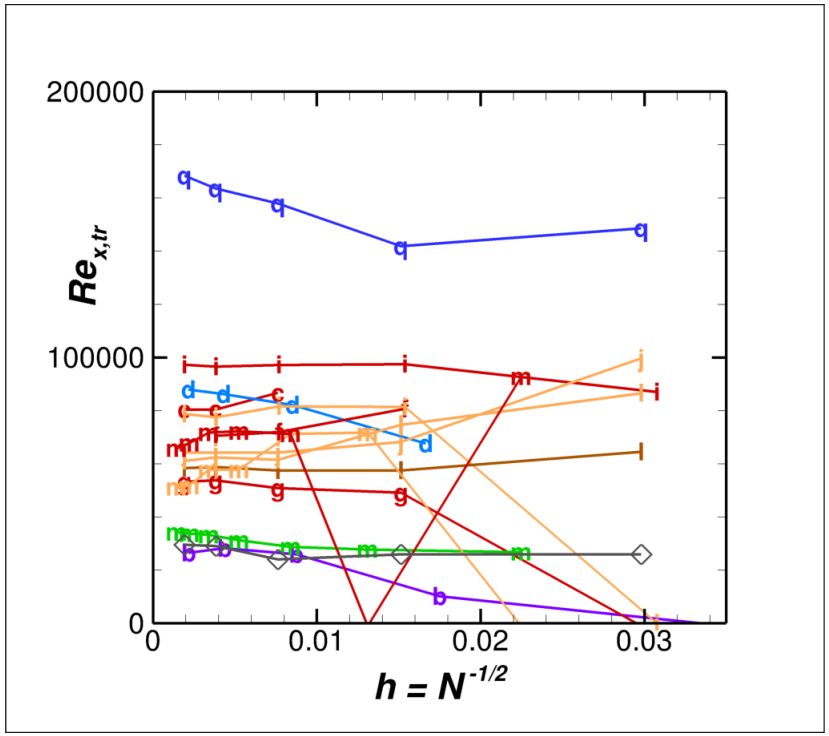
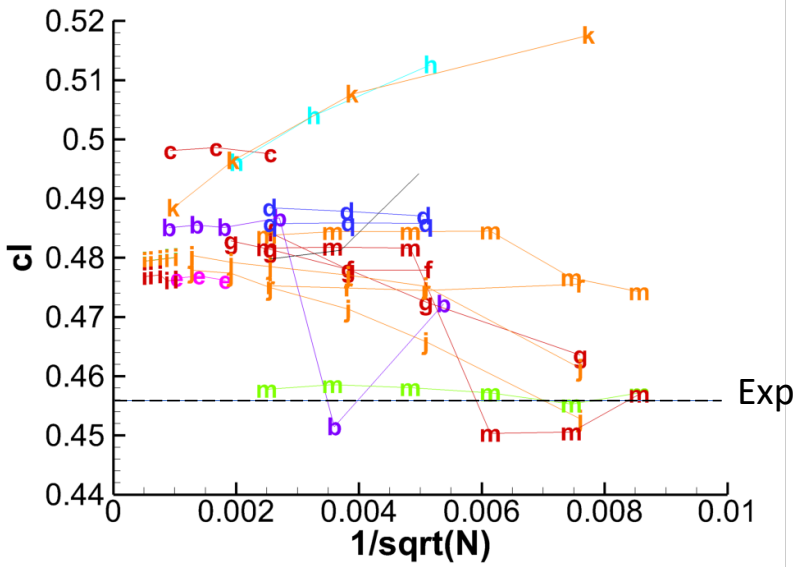
0.006
0.004
0.002
0
C_f
0
100000
200000
300000
400000
Re_x

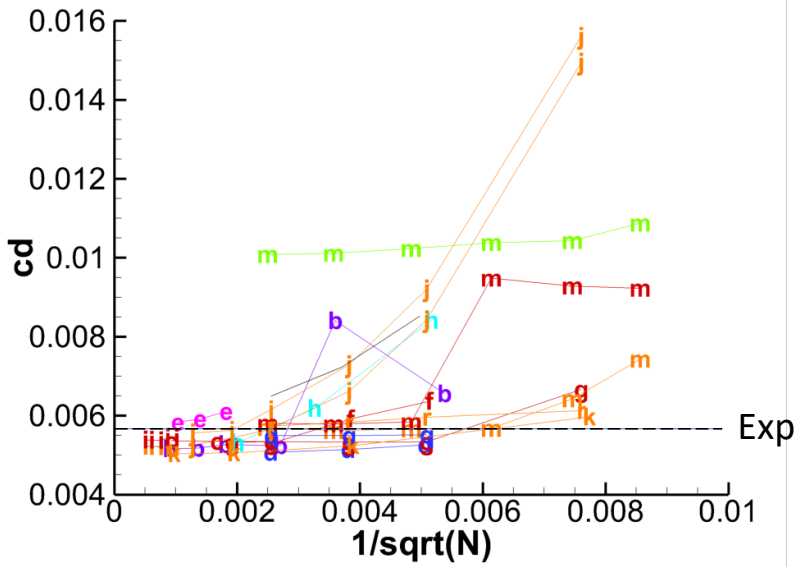

200000
100000
0
$Re_{x,tr}$
0
0.01
0.02
0.03
$h = N^{-1/2}$

Case 2 – NLF(1)-0416

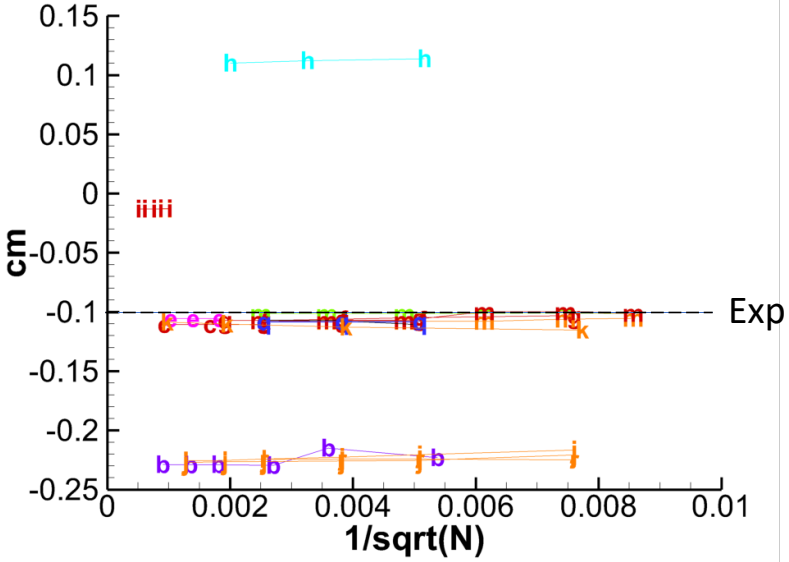
- **Participant Data**
  - **14 data submittals**
    - 6 N. America, 6 Europe, 2 Asia
    - 6 Government, 4 Academia, 2 Industry, 2 Industry/Academia
  - **Grid types**
    - 8 committee-provided structured
    - 4 custom structured
    - 2 custom unstructured

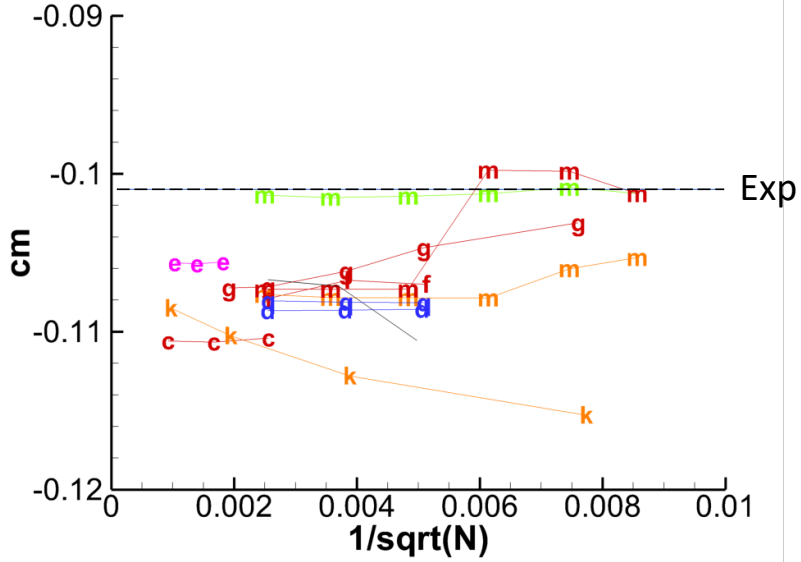
Case 2A – Grid Convergence (α = 0°)



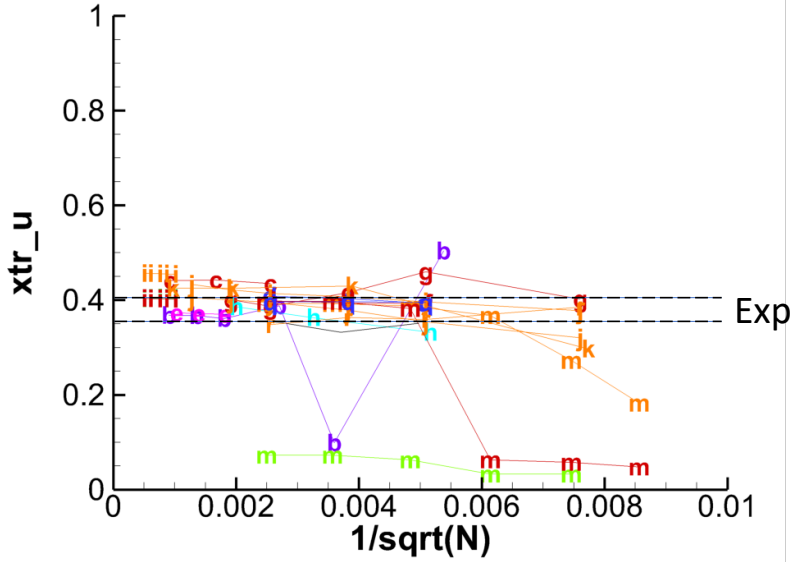


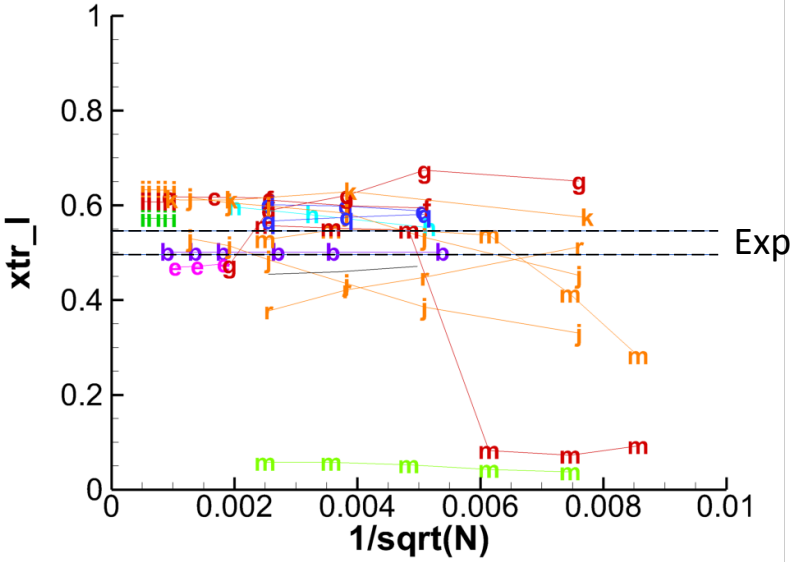
Case 2A – Grid Convergence (α = 0°)



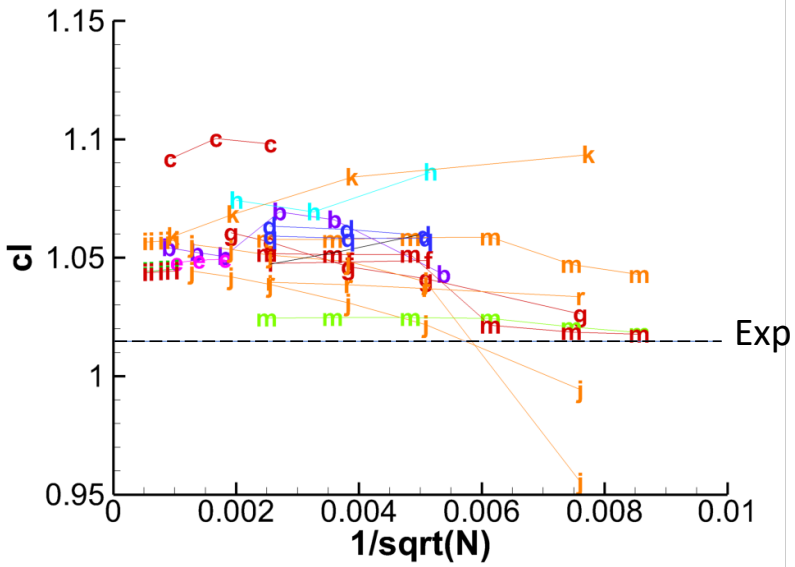


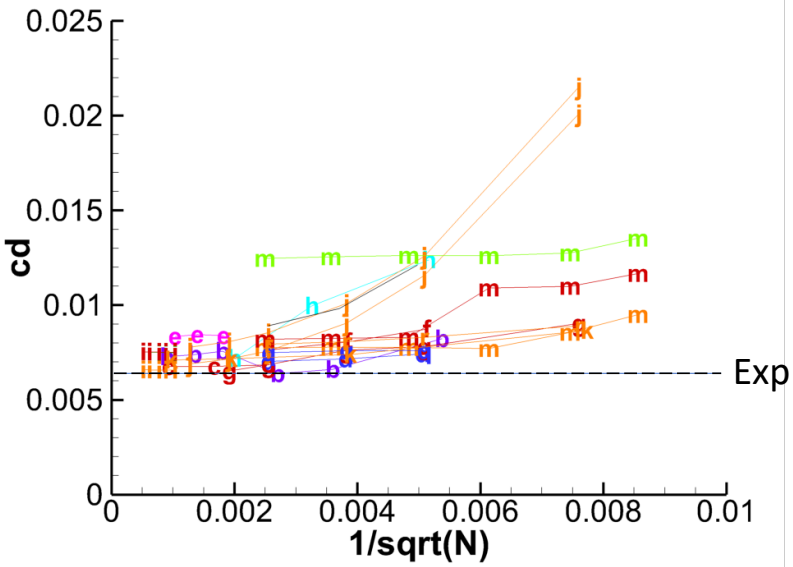
Case 2A – Grid Convergence (α = 0°)



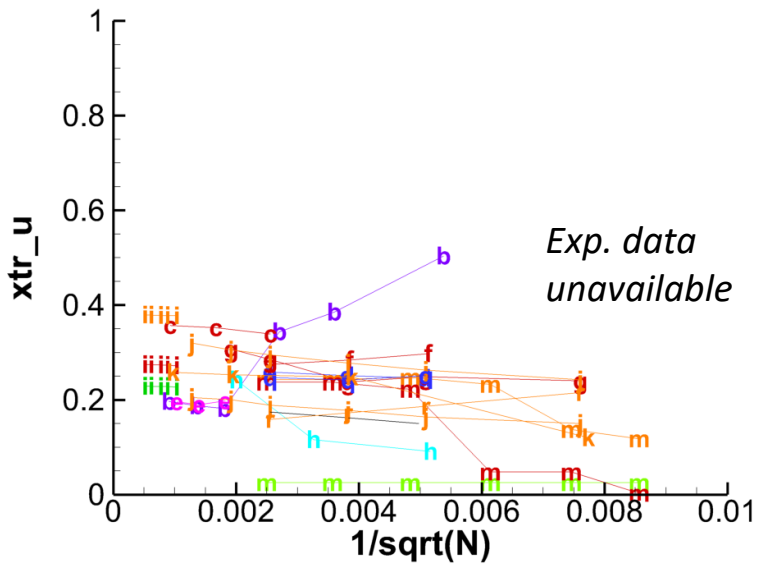


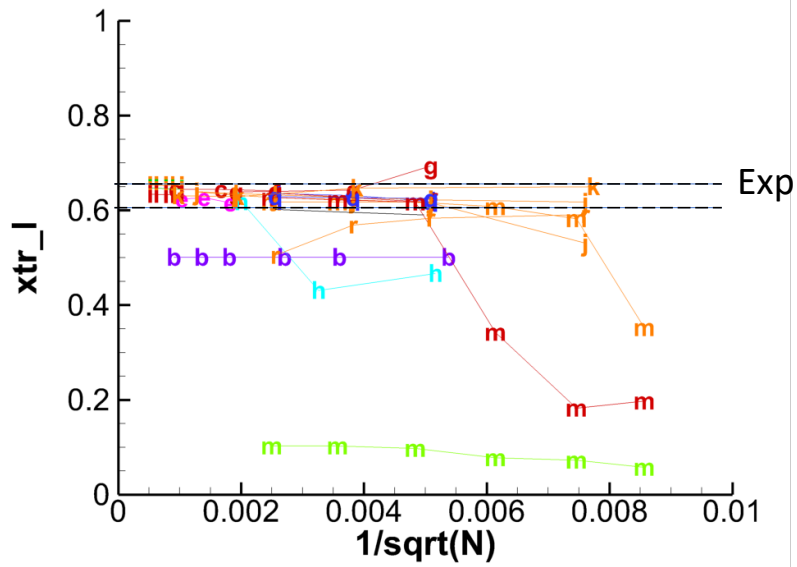
Case 2A – Grid Convergence (α = 5°)



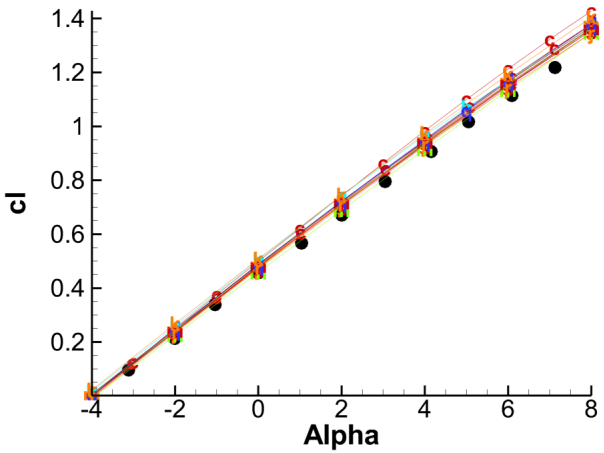


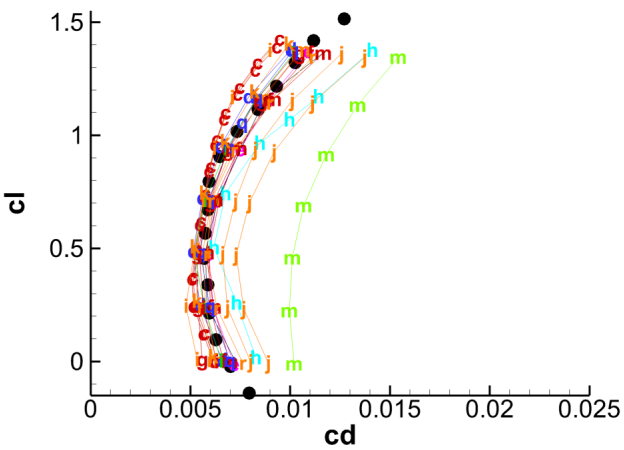
Case 2A – Grid Convergence (α = 5°)

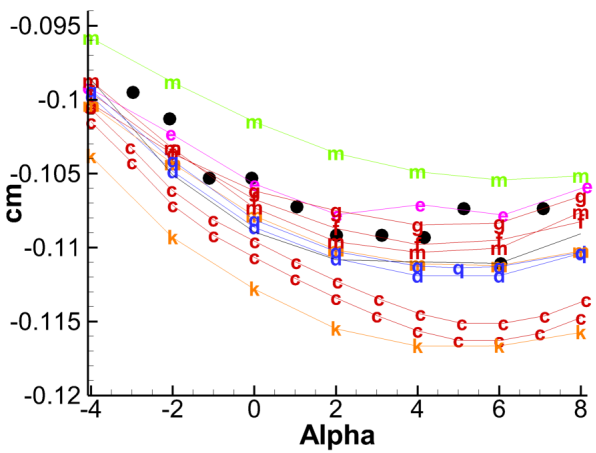




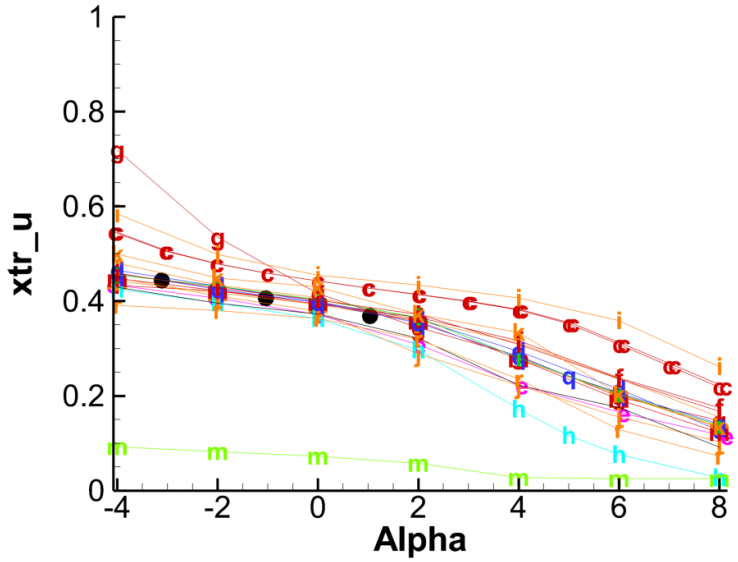
Case 2B – Alpha Sweep

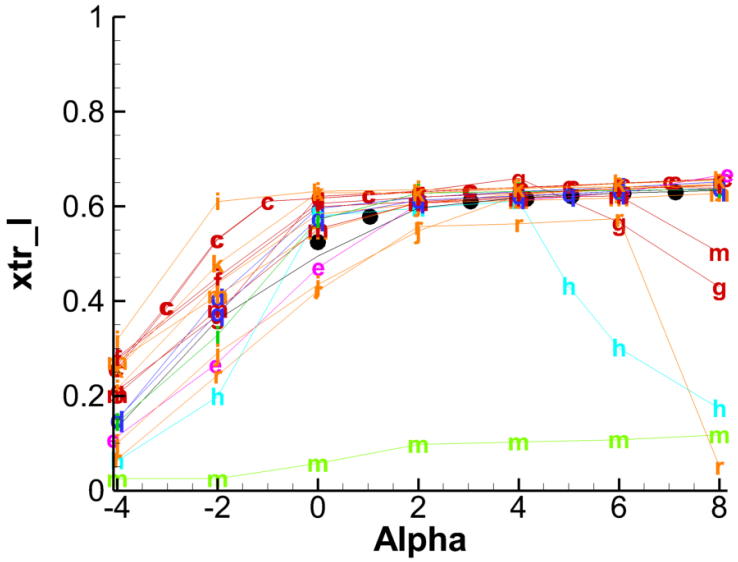






Case 2B – Alpha Sweep





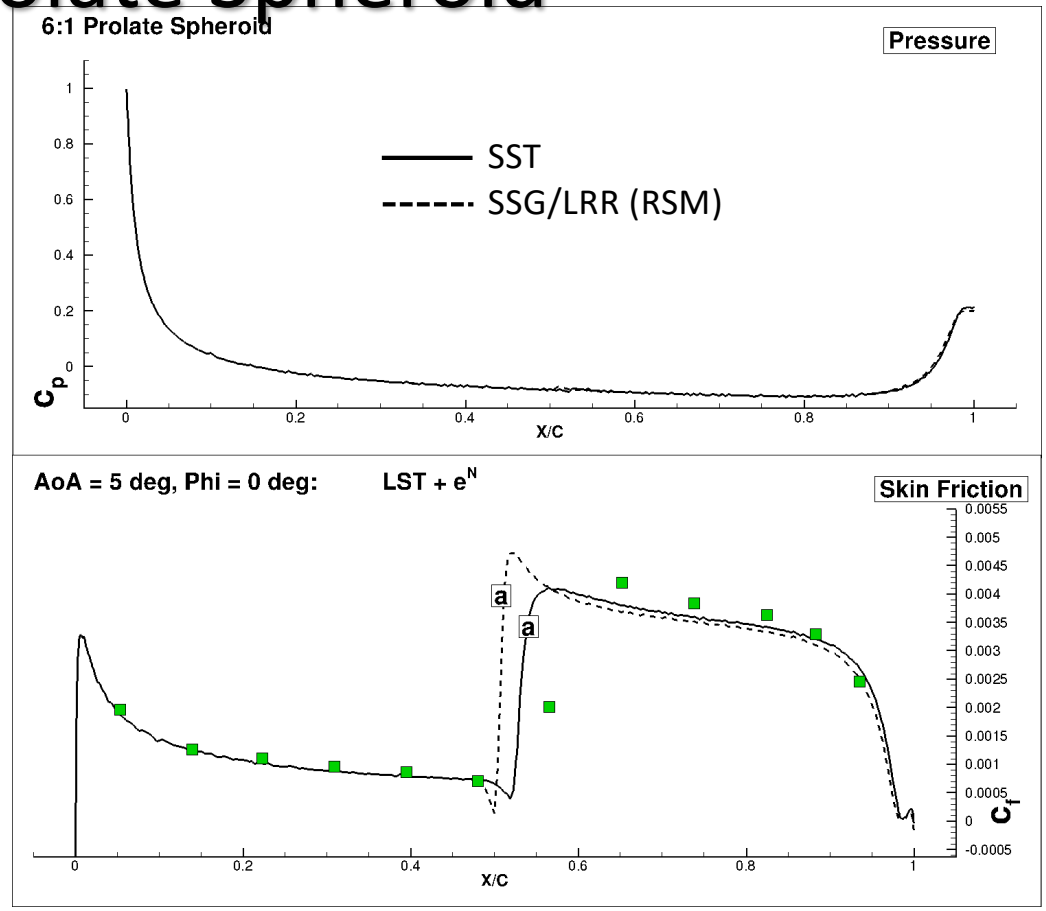
Case 3 – 6:1 Prolate Spheroid

- **Participant Data**
  - **11 data submittals**
    - 5 N. America, 3 Europe, 3 Asia
    - 3 Government, 5 Academia, 1 Industry, 2 Industry/Academia
  - **Grid types**
    - 3 committee-provided structured
    - 3 committee-provided unstructured
    - 3 custom structured
    - 2 custom unstructured

Case 3 – 6:1 Prolate Spheroid

AoA = 5 deg,
Phi = 0 deg:

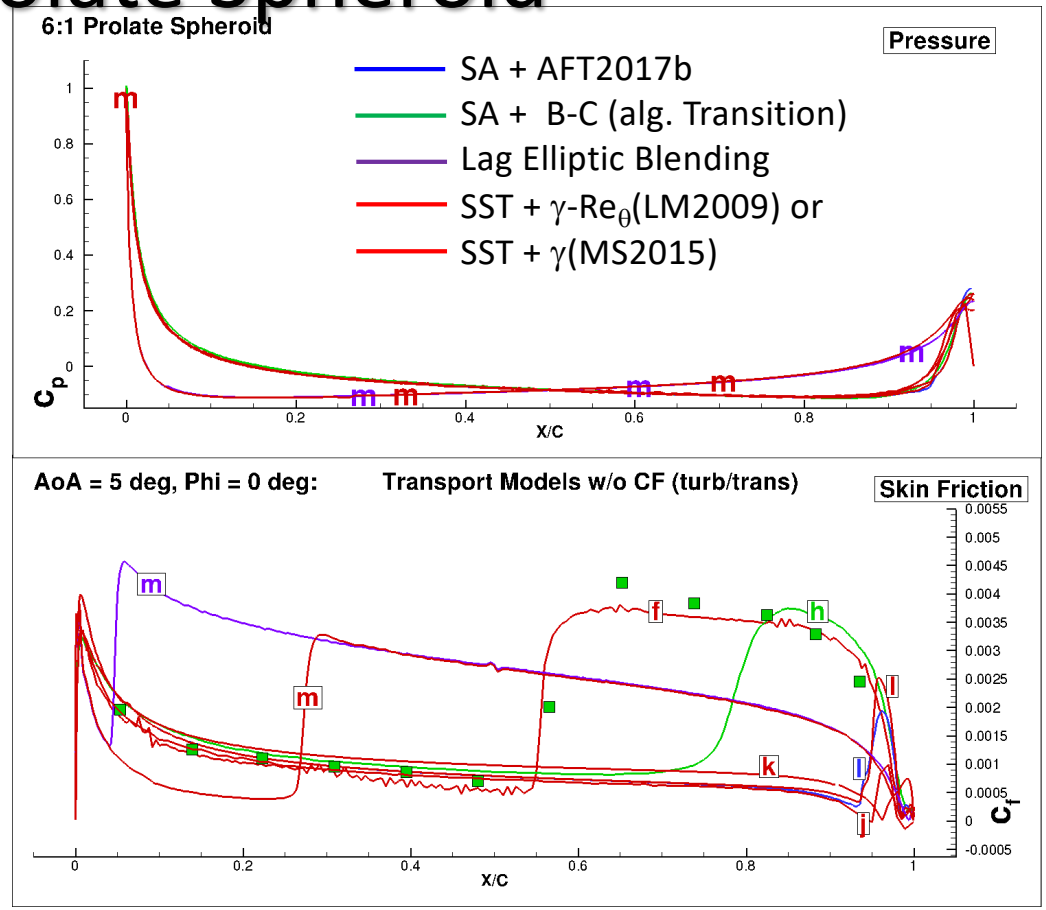
- **LST + e^N**



Case 3 – 6:1 Prolate Spheroid

AoA = 5 deg,
Phi = 0 deg:

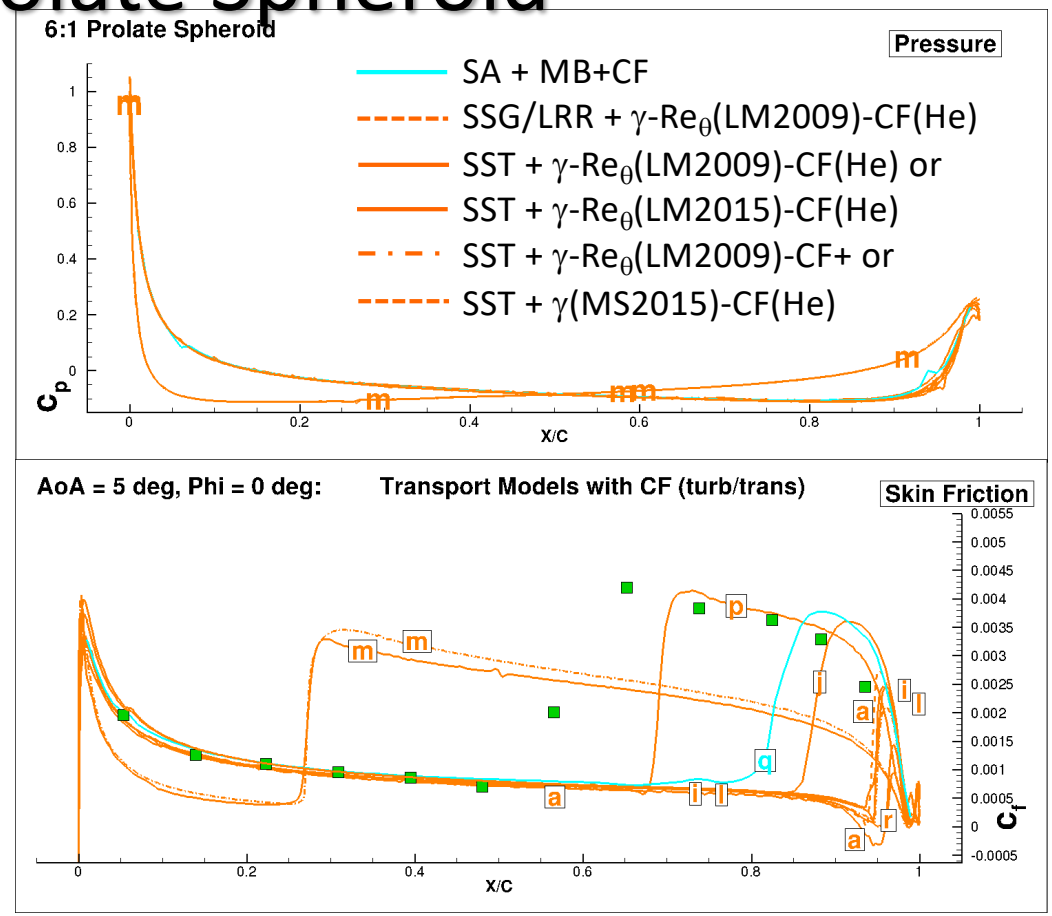
- **Transport Models without CF Transition**



Case 3 – 6:1 Prolate Spheroid

AoA = 5 deg,
Phi = 0 deg:

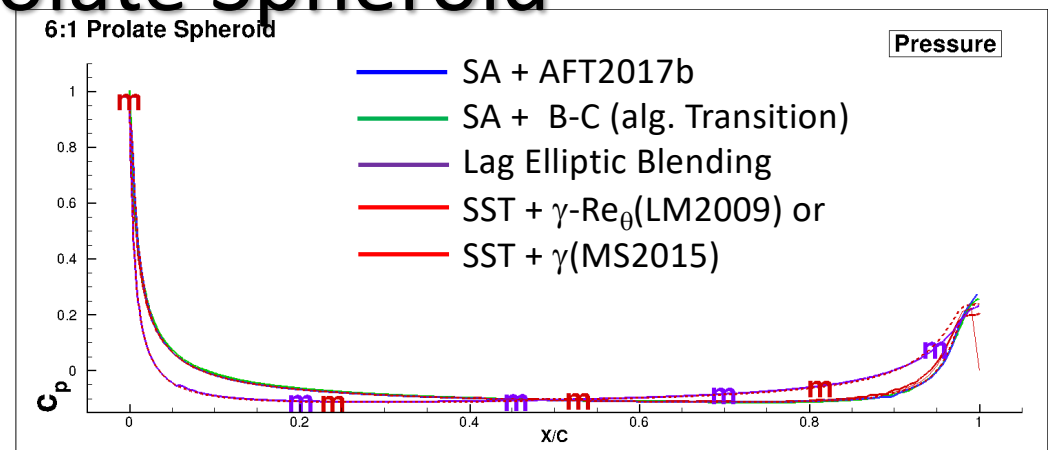
- **Transport Models *with* CF Transition**

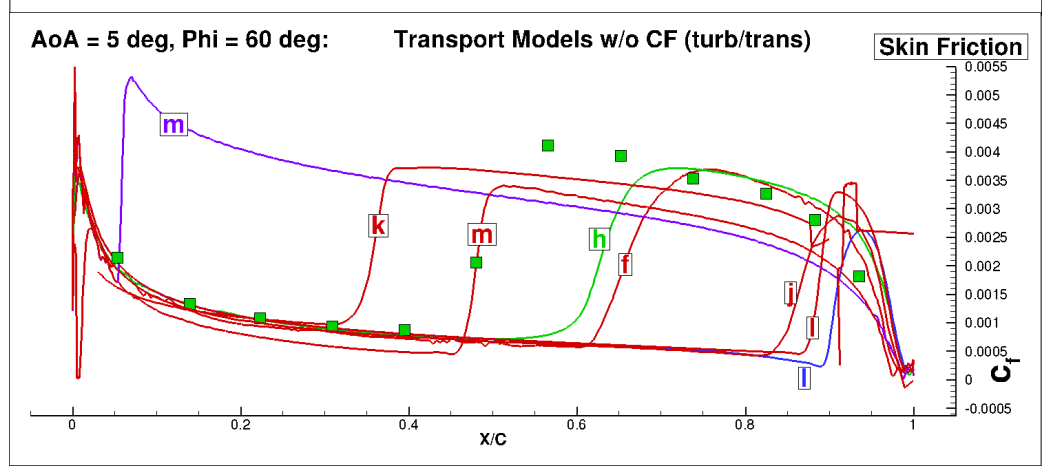


Case 3 – 6:1 Prolate Spheroid

AoA = 5 deg,
Phi = 60 deg:

- **Transport Models without CF Transition**





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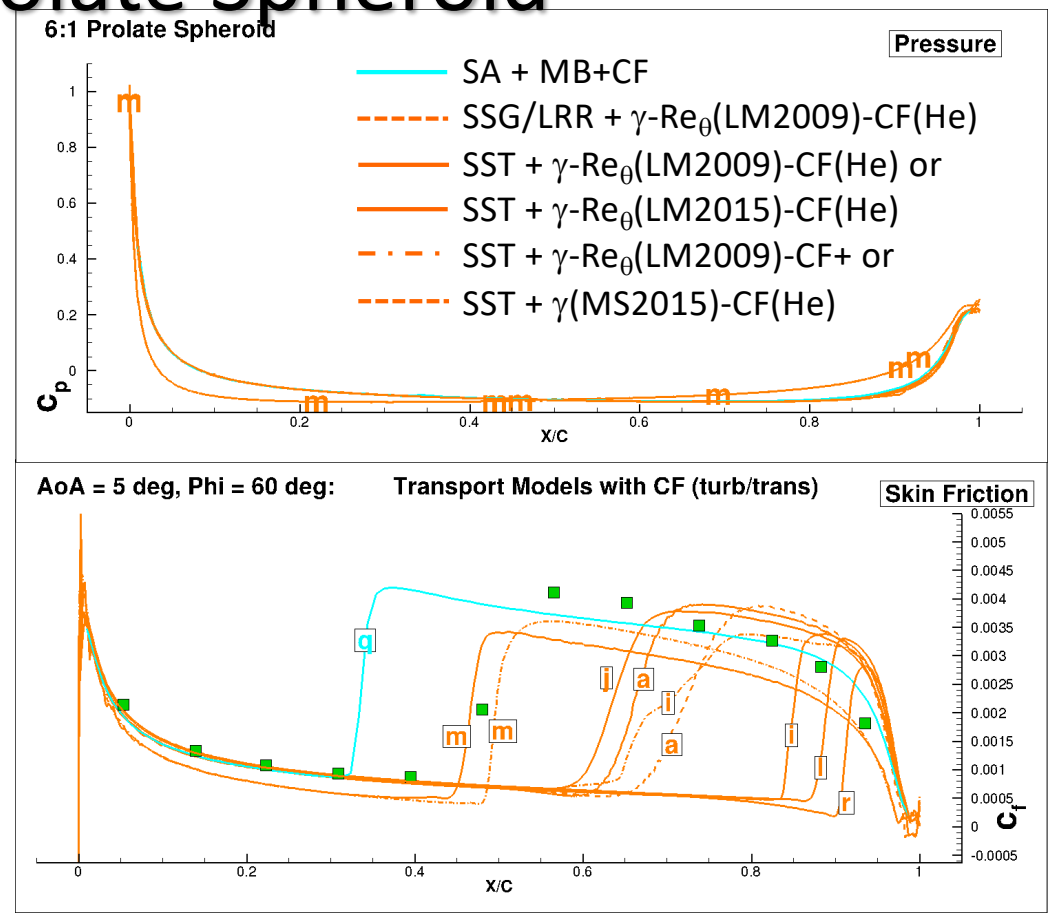
Case 3 – 6:1 Prolate Spheroid

AoA = 5 deg,
Phi = 60 deg:

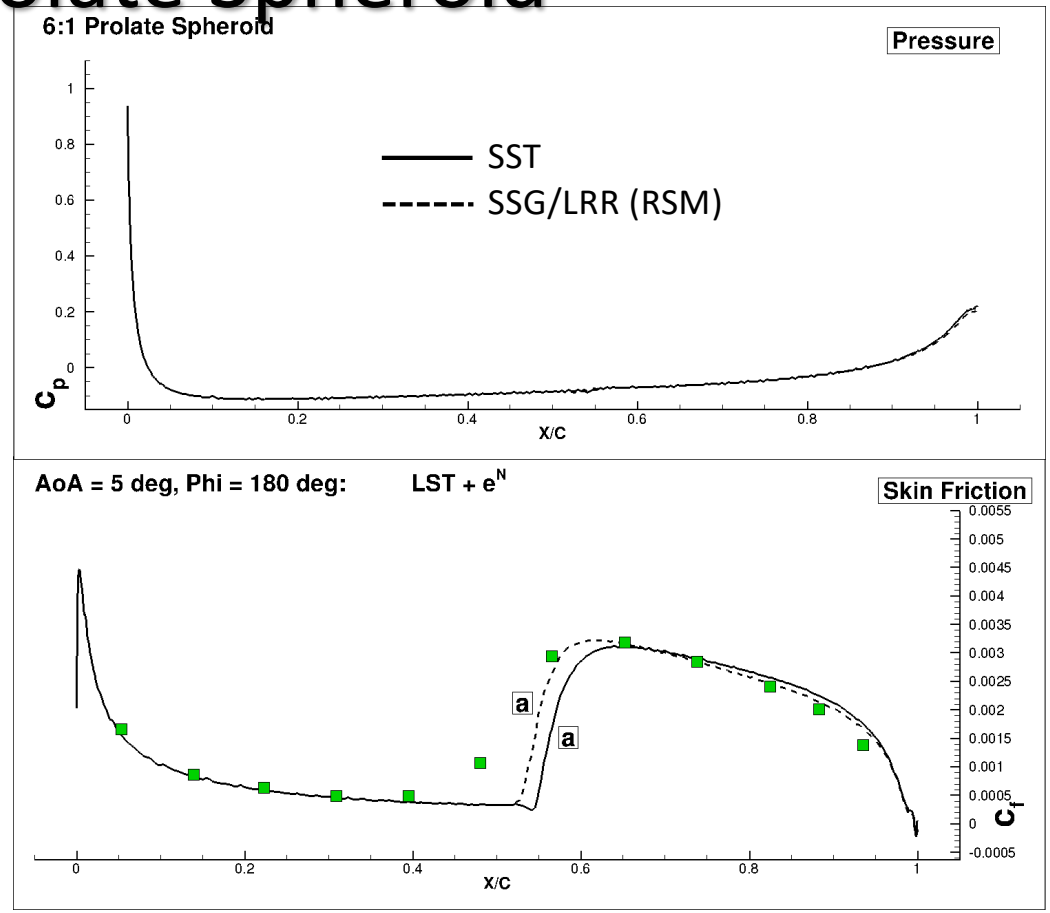
- **Transport Models *with* CF Transition**



Case 3 – 6:1 Prolate Spheroid

AoA = 5 deg,
Phi = 180 deg:

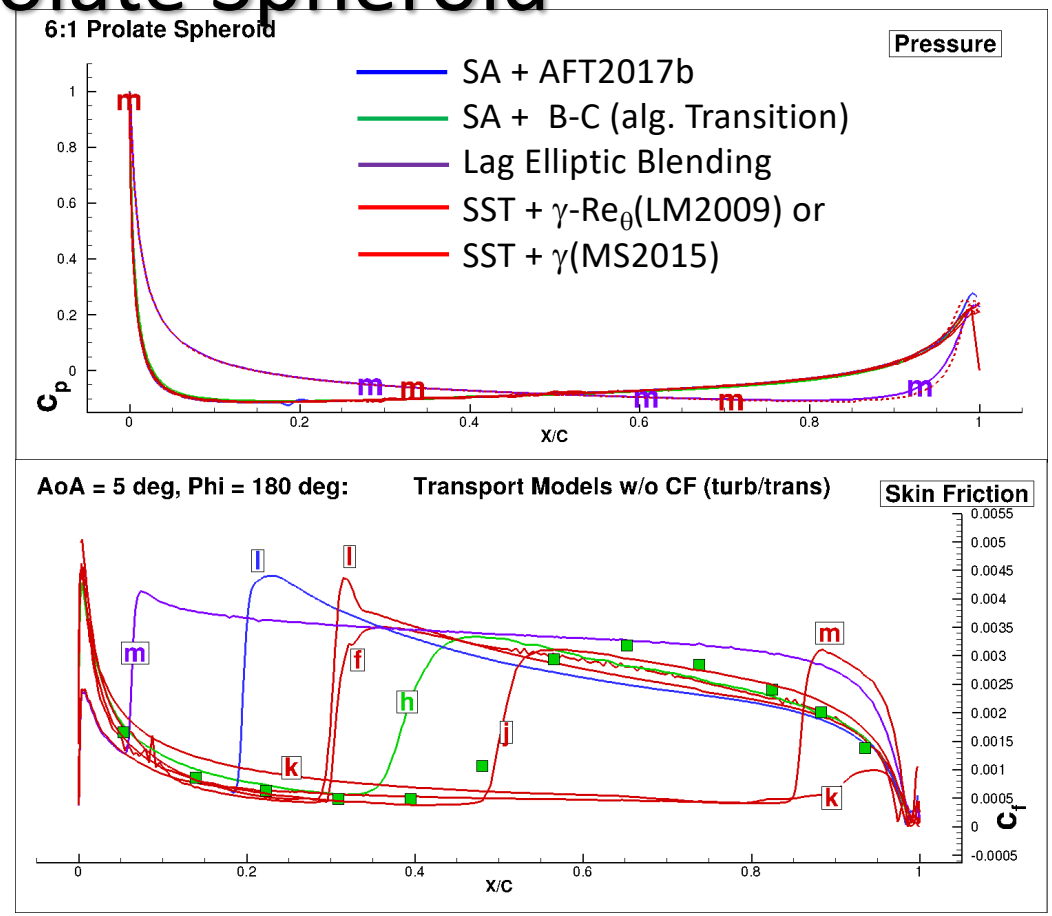
- **LST + e^N**



Case 3 – 6:1 Prolate Spheroid

AoA = 5 deg,
Phi = 180 deg:

- **Transport Models without CF Transition**



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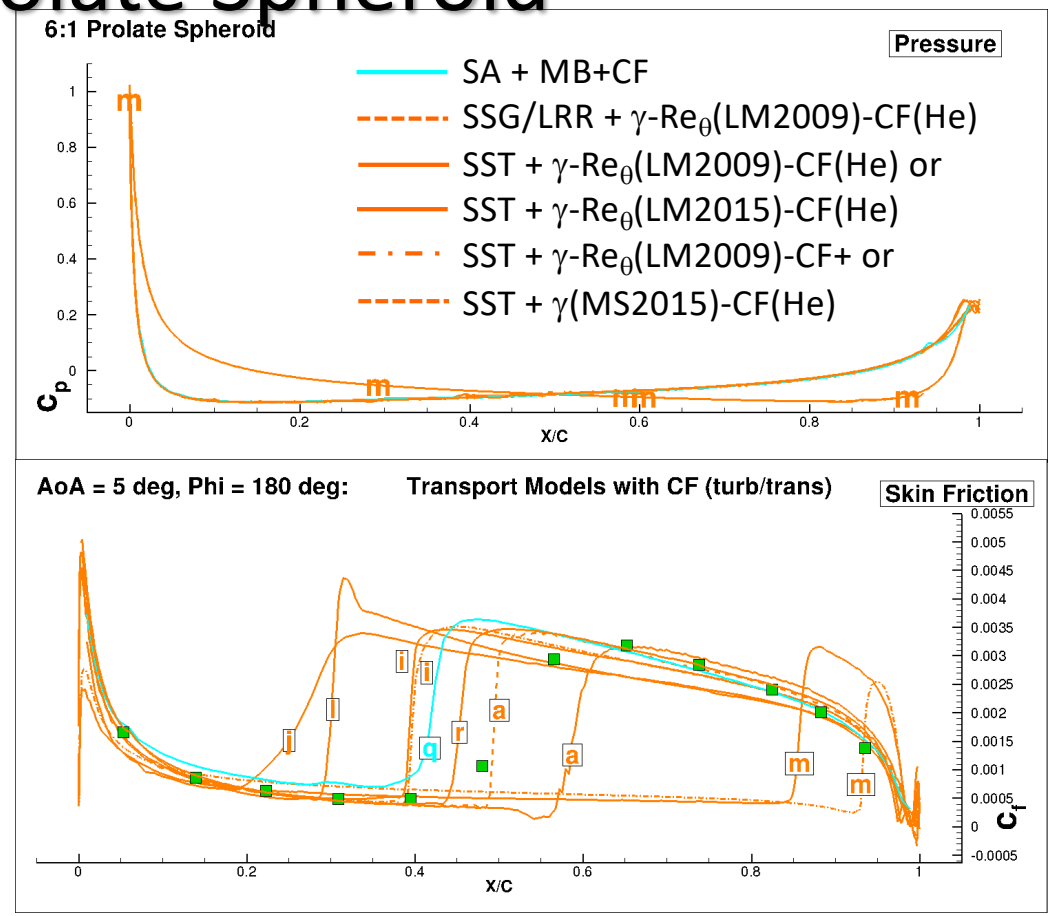
Case 3 – 6:1 Prolate Spheroid

AoA = 5 deg,
Phi = 180 deg:

- **Transport Models *with* CF Transition**

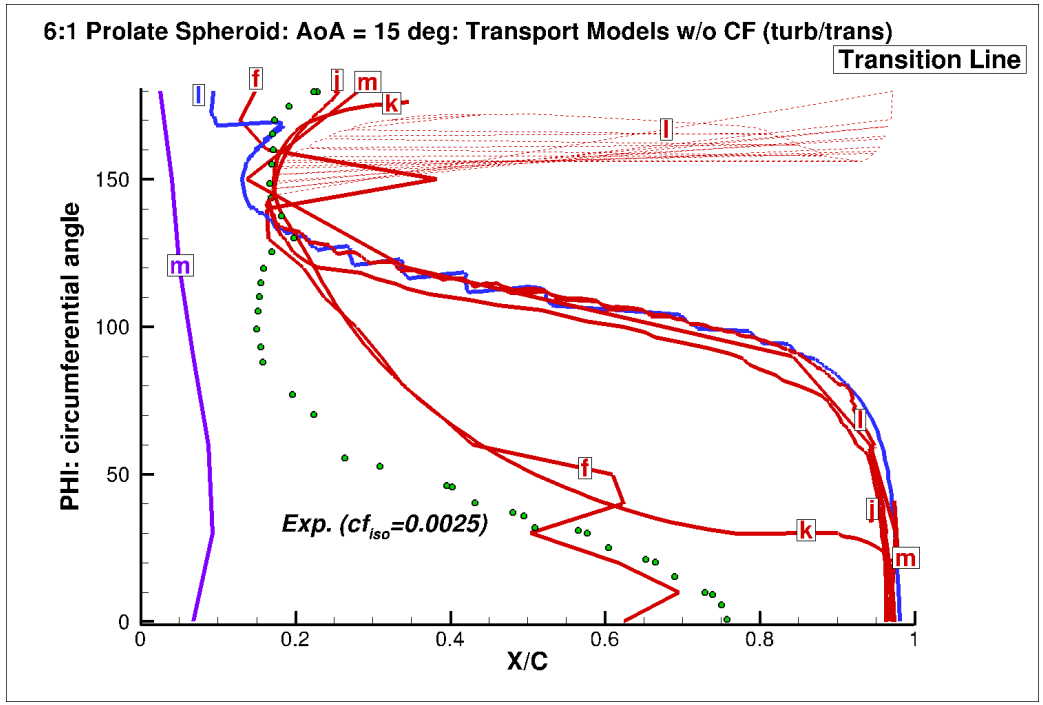


Case 3 – 6:1 Prolate Spheroid

AoA = 15 deg:

- **Transport Models without CF Transition**

SA + AFT2017b
SA + B-C (alg. Transition)
Lag Elliptic Blending
SST + γ-Re_θ(LM2009) or
SST + γ(MS2015)



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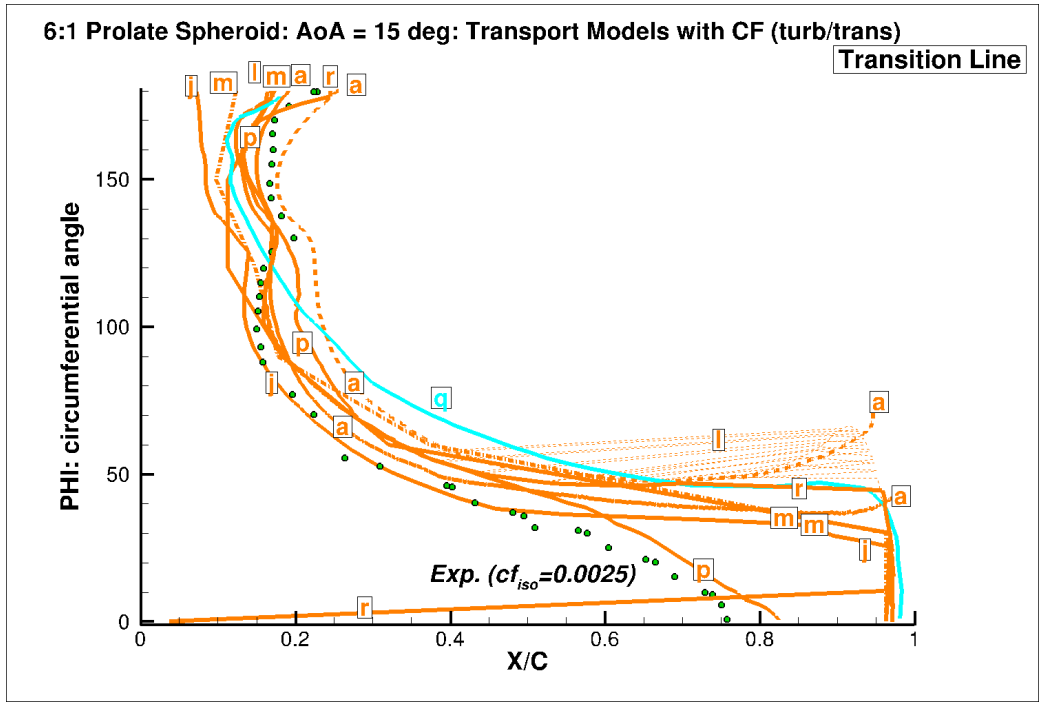
Case 3 – 6:1 Prolate Spheroid

AoA = 15 deg:

- **Transport Models *with* CF Transition**

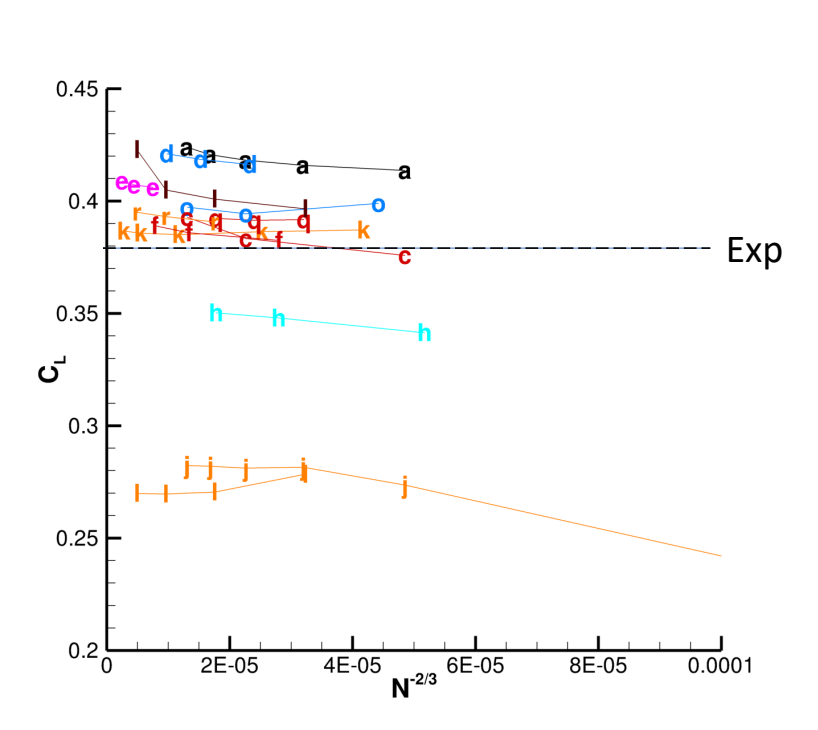
SA + MB+CF
SSG/LRR + γ-Re_θ(LM2009)-CF(He)
SST + γ-Re_θ(LM2009)-CF(He) or
SST + γ-Re_θ(LM2015)-CF(He)
SST + γ-Re_θ(LM2009)-CF+ or
SST + γ(MS2015)-CF(He)

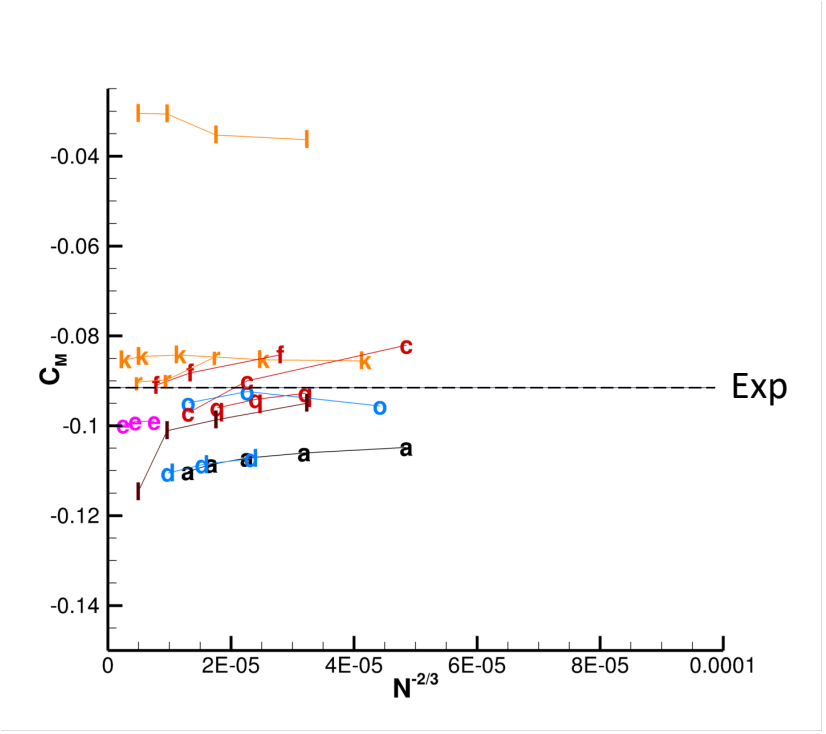


Case 4 – CRM-NLF

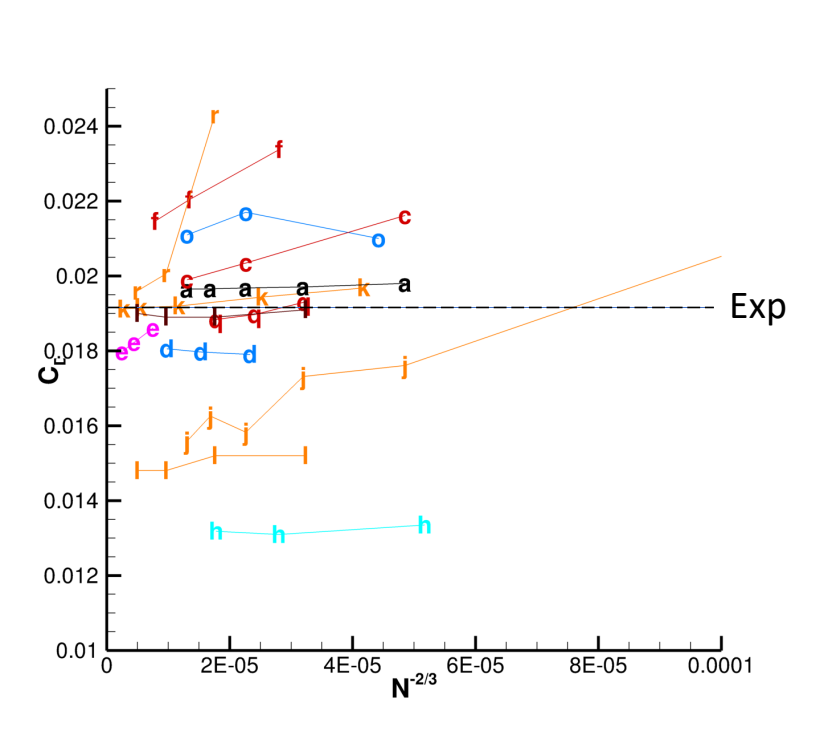
- **Participant Data**
  - **13 data submittals**
    - 6 N. America, 5 Europe, 2 Asia
    - 7 Government, 3 Academia, 1 Industry, 2 Industry/Academia
  - **Grid types**
    - 3 committee-provided structured
    - 3 custom structured
    - 3 committee-provided unstructured
    - 2 custom unstructured

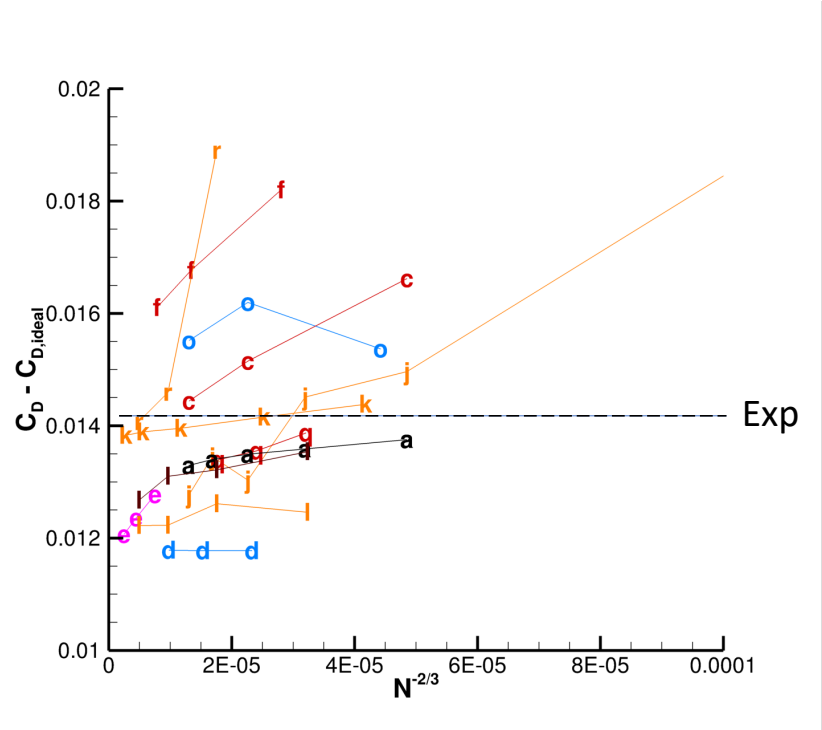
Case 4A – Grid Convergence



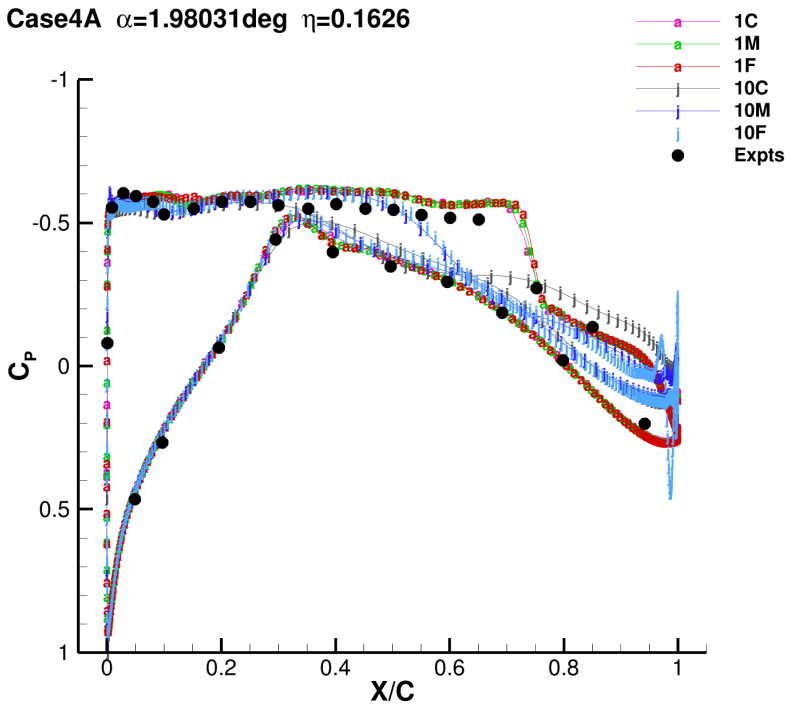


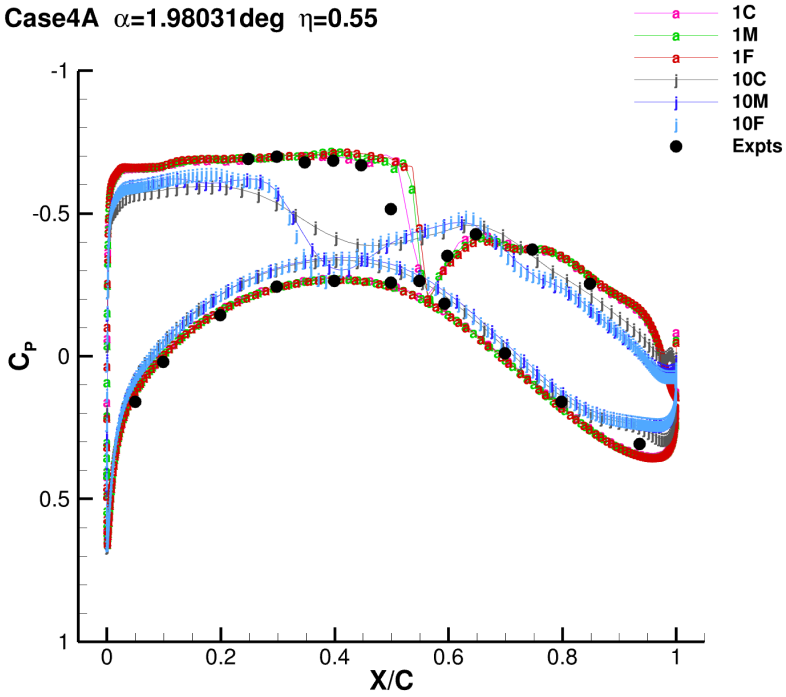
Case 4A – Grid Convergence





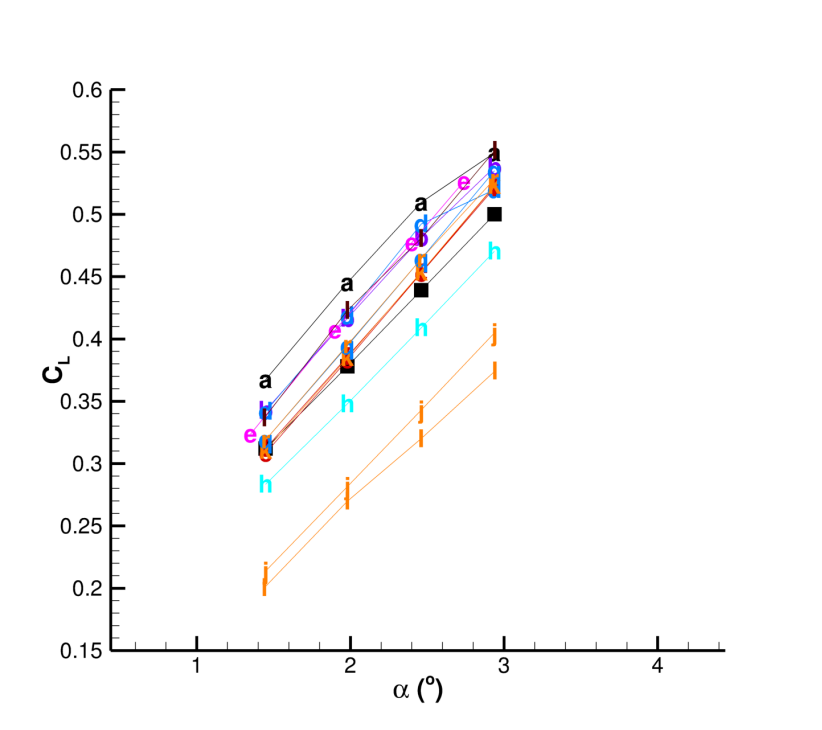
Case 4A – Grid Convergence

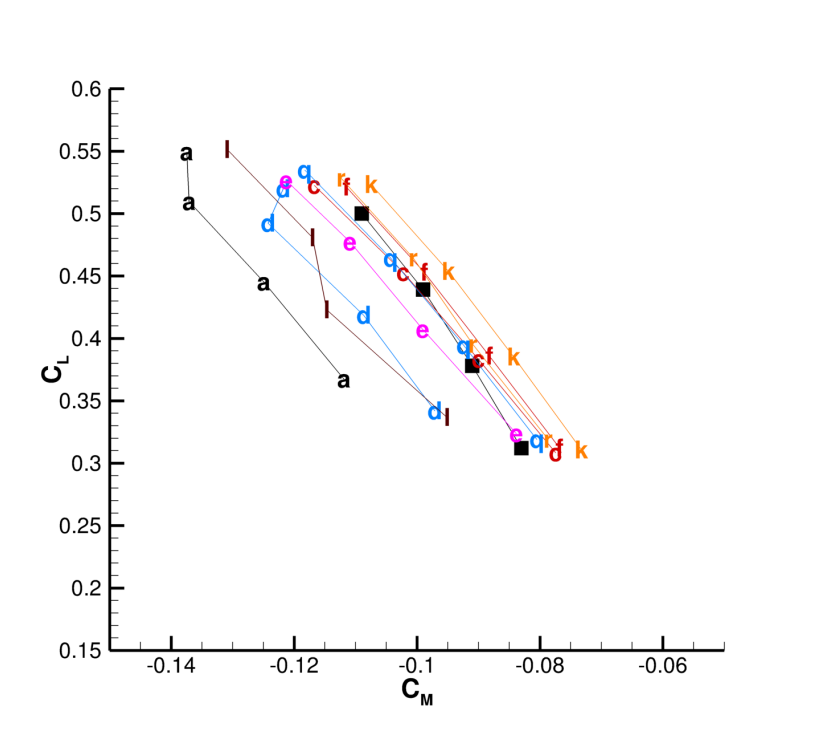




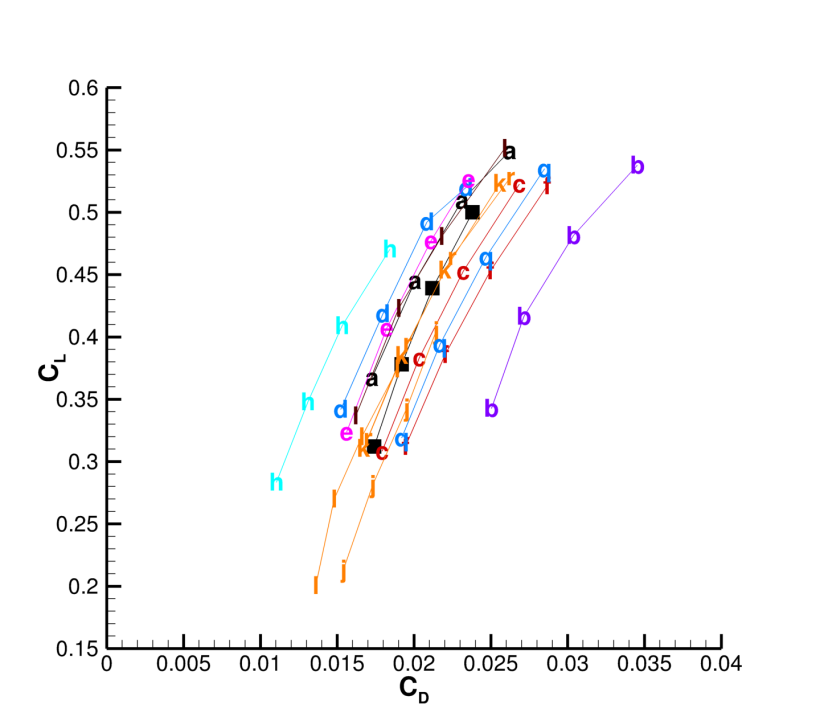
Case 4 – CRM-NLF

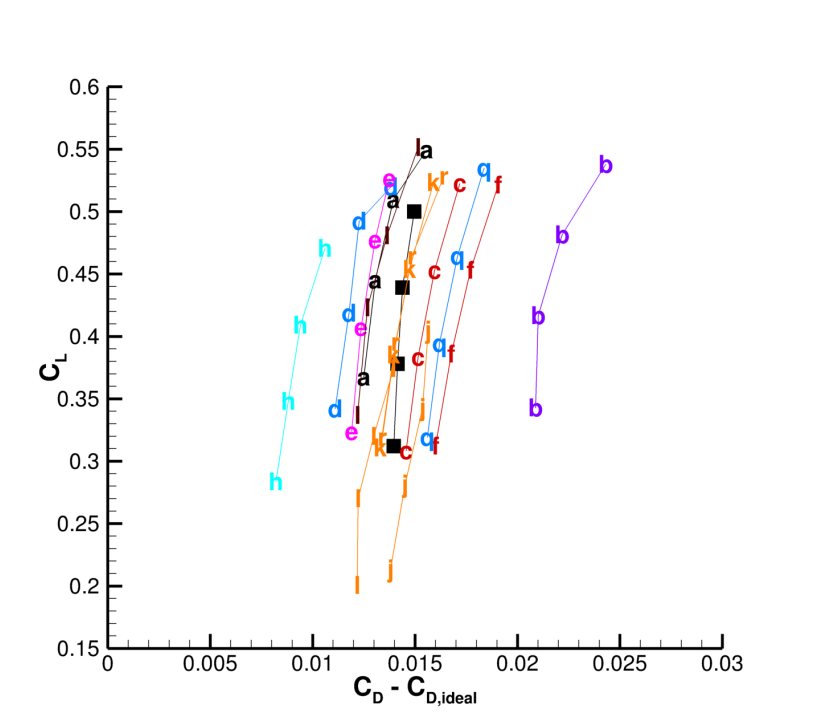
Case 4B – Alpha Sweep



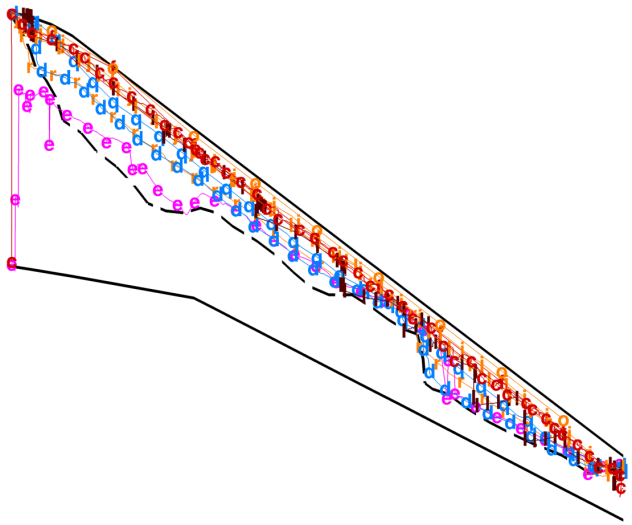


Case 4B – Alpha Sweep

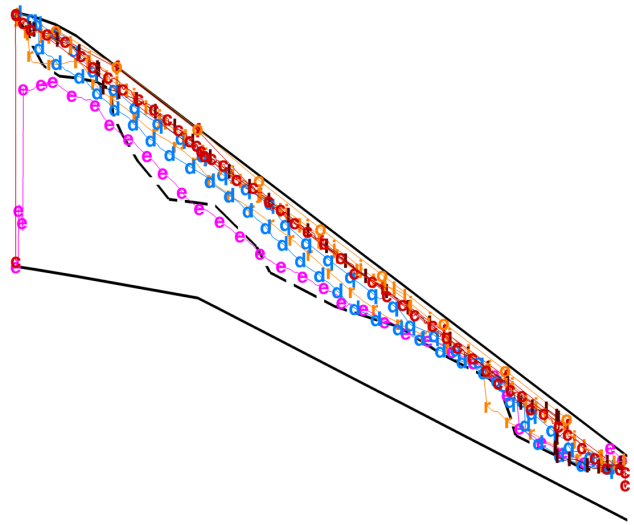




Case 4B – Transition Fronts

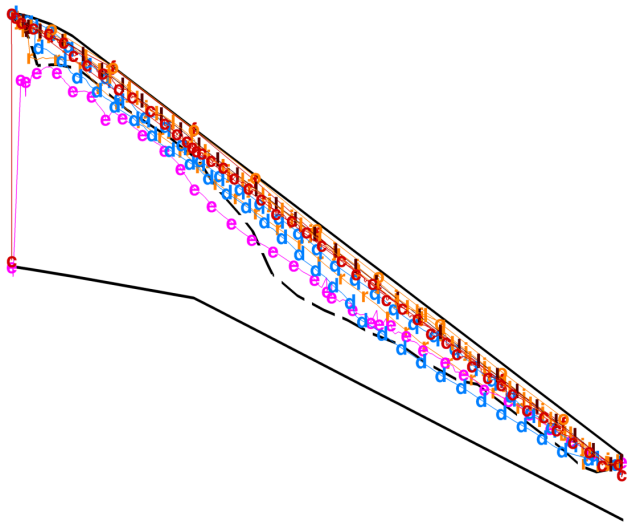


1.45°

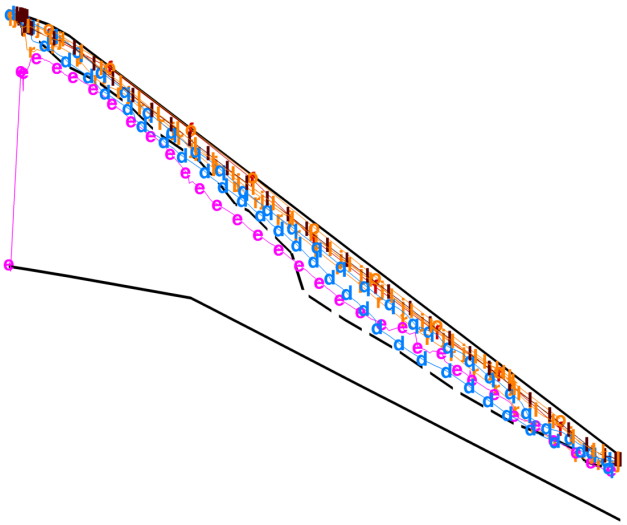


1.98°

Case 4B – Transition Fronts

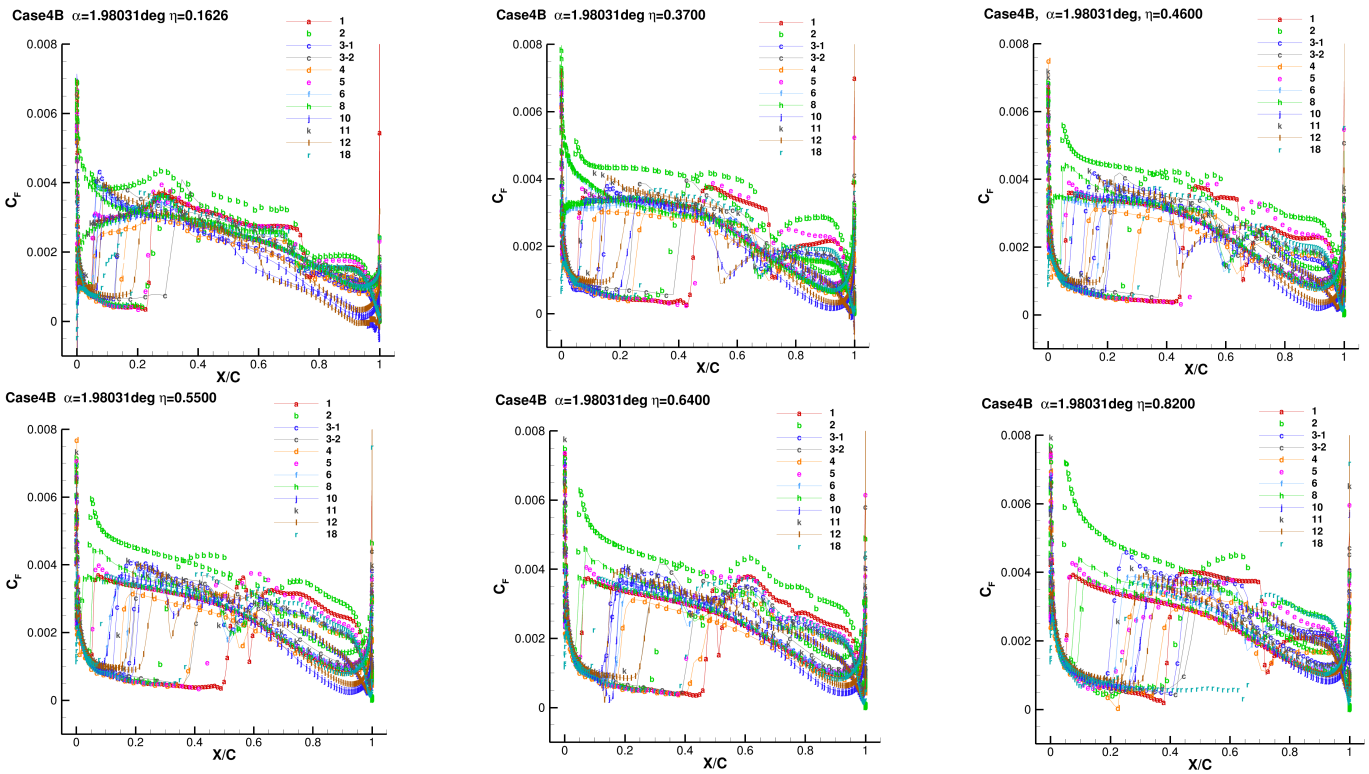


2.46º

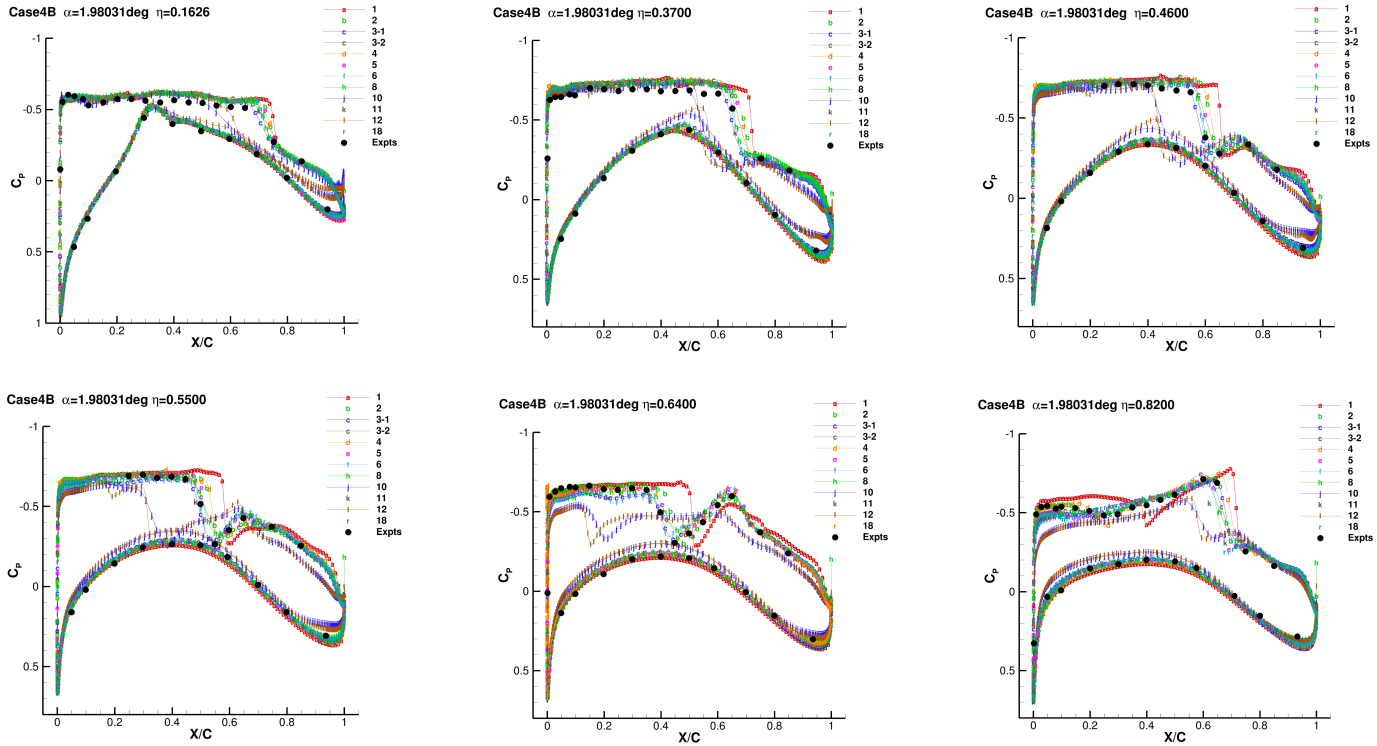


2.94º

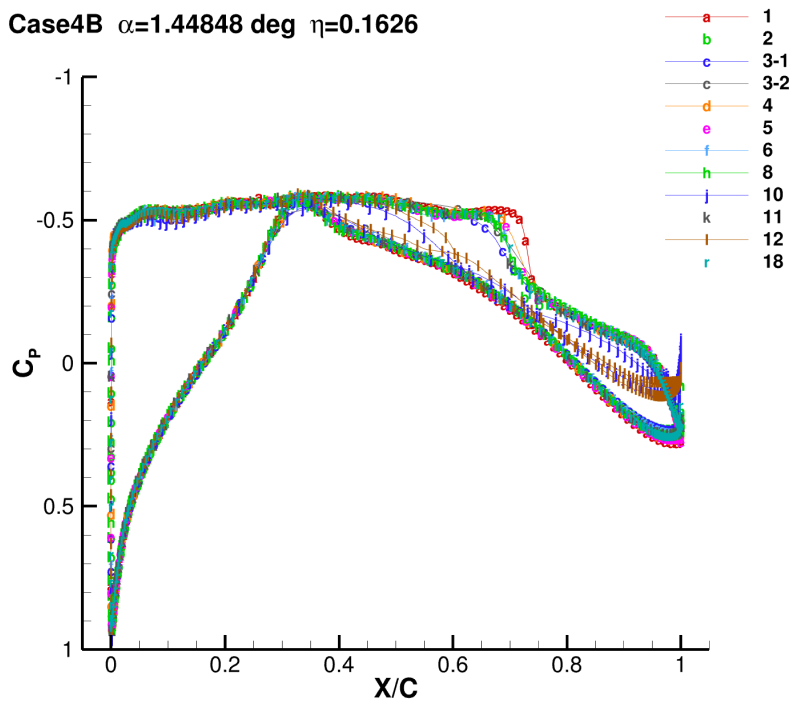
Case 4B – Skin-Friction Distributions at 1.98°

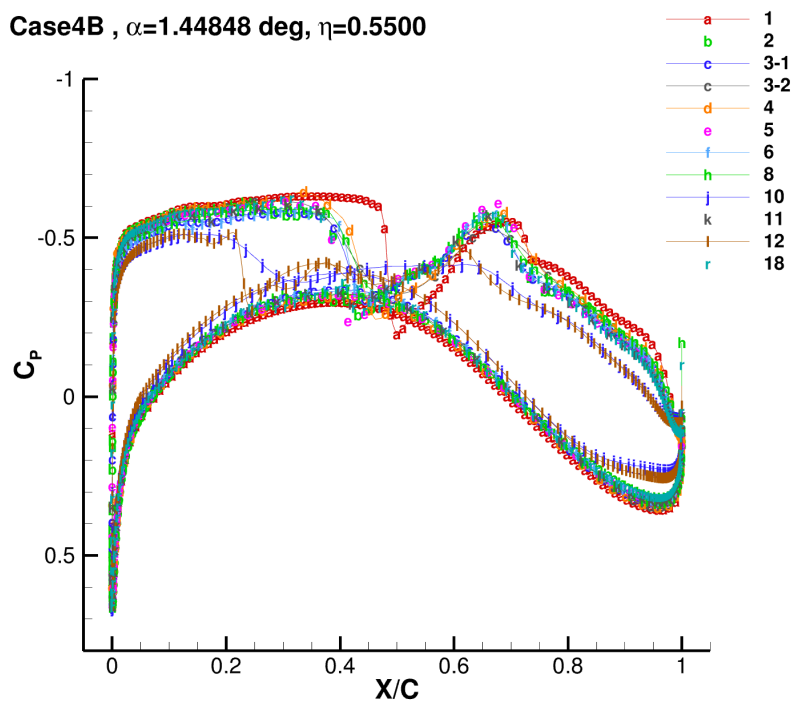


Case 4B – Pressure Distributions at 1.98°

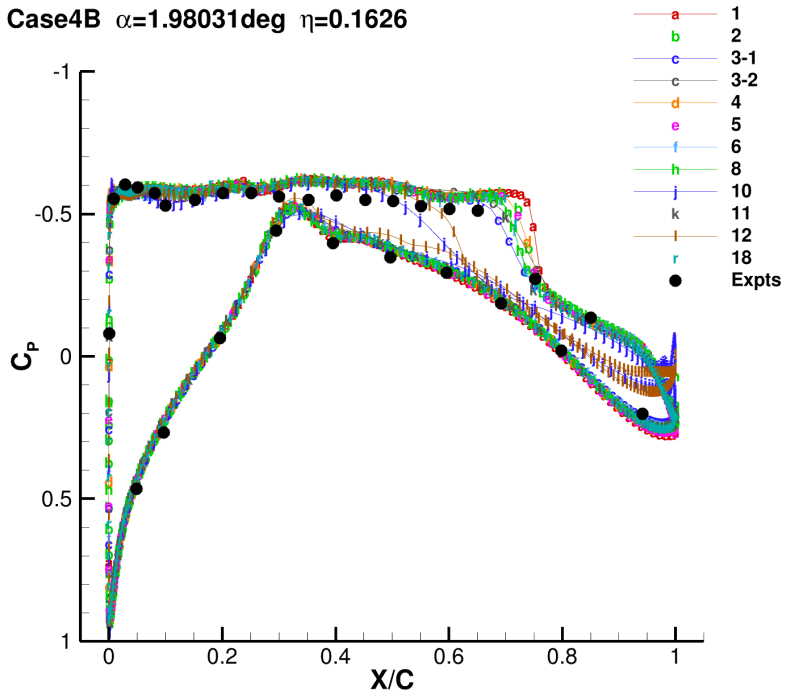


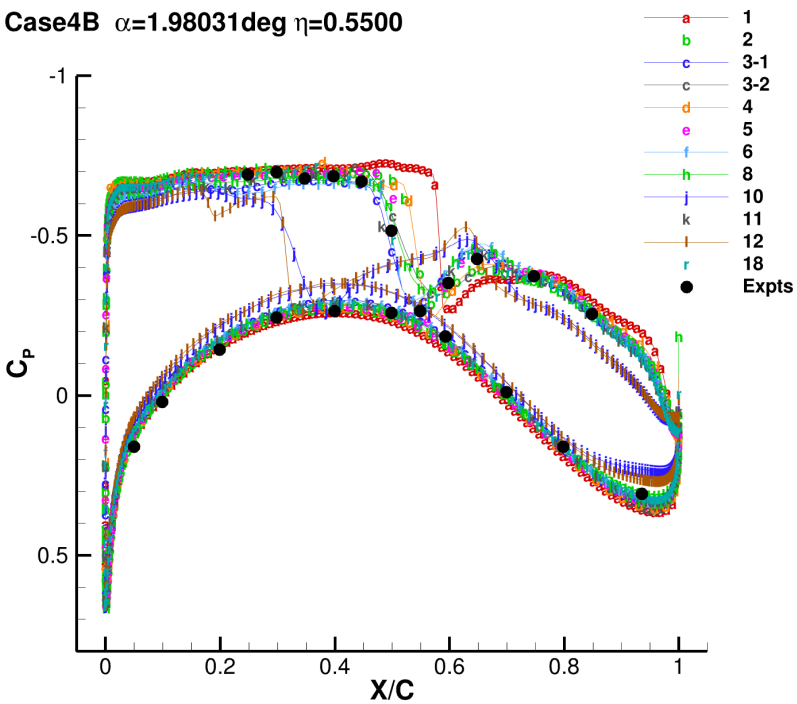
Case 4B – Pressure Distributions



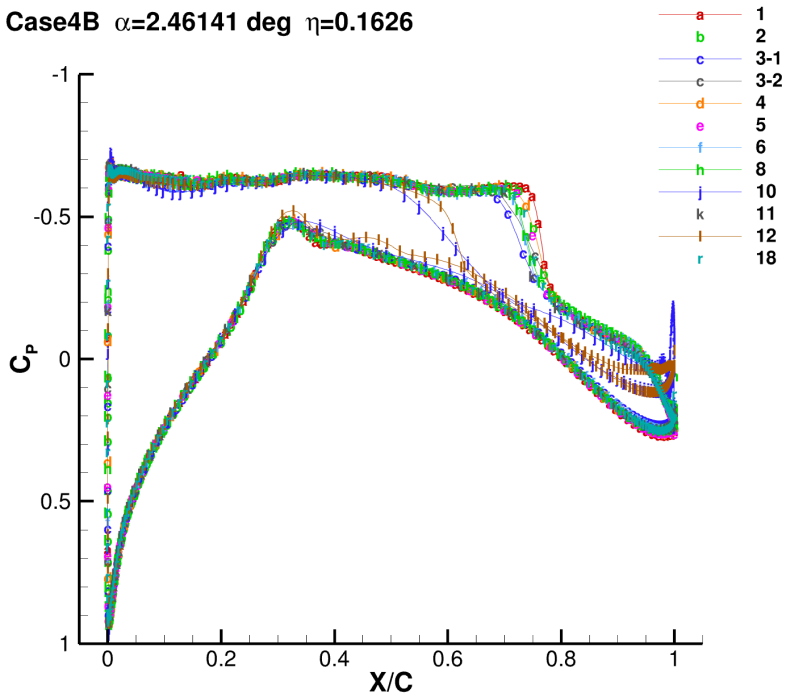


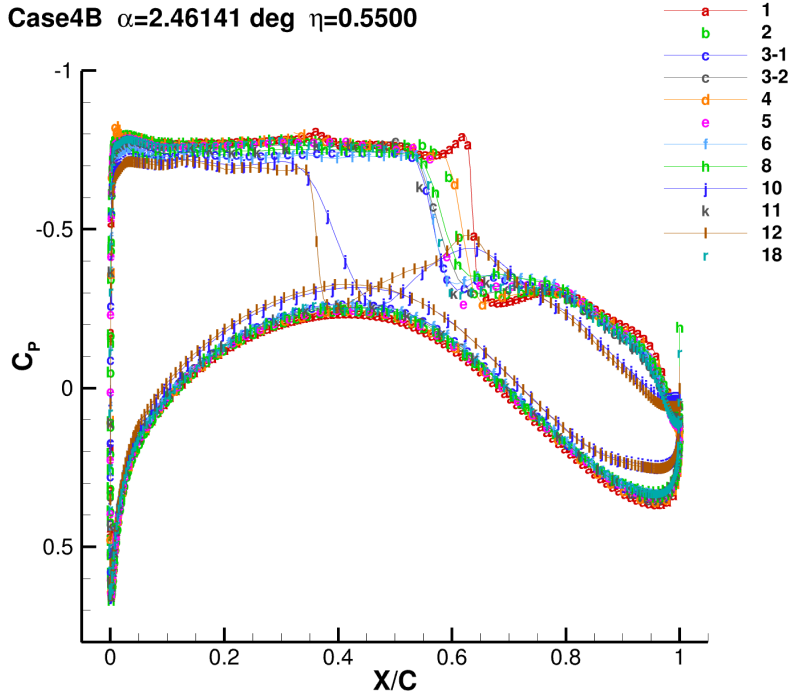
Case 4B – Pressure Distributions



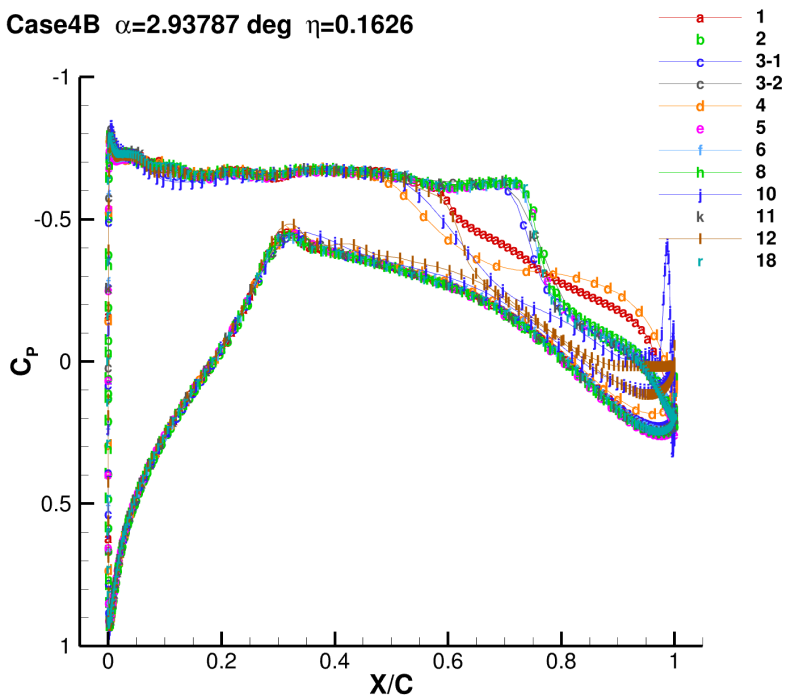


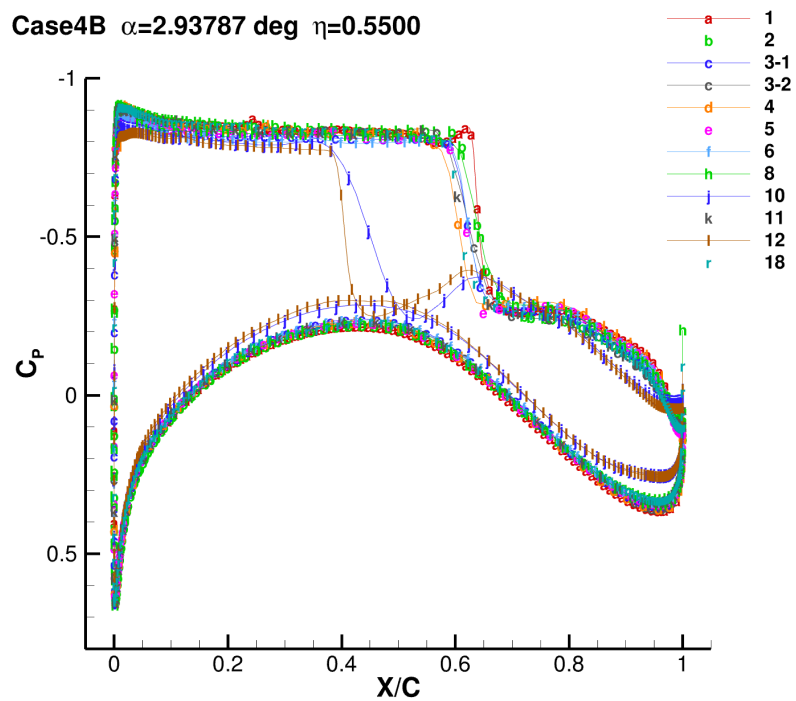
Case 4B – Pressure Distributions





Case 4B – Pressure Distributions



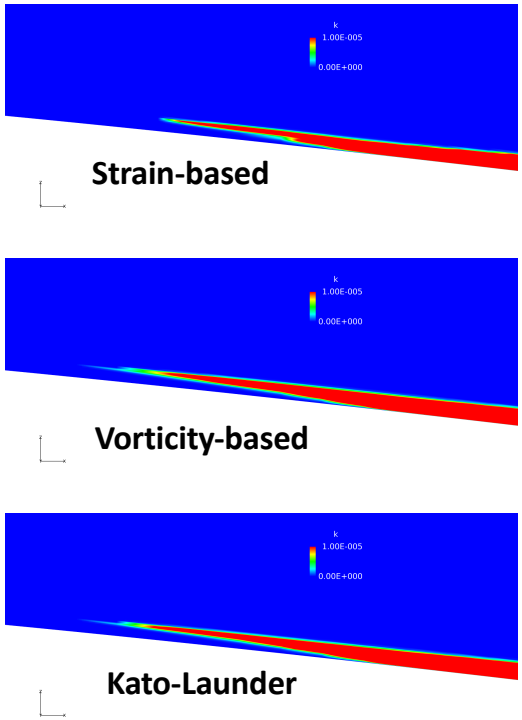


Observations and Next Steps

Code Verification

- **Transition model verification is still an open question**
  - Many custom variants within each modeling framework
  - Coupling with different turbulence models can lead to very different results on the same case
    - Even subtle variants have an impact
  - Strong coupling between transition point and mean flow

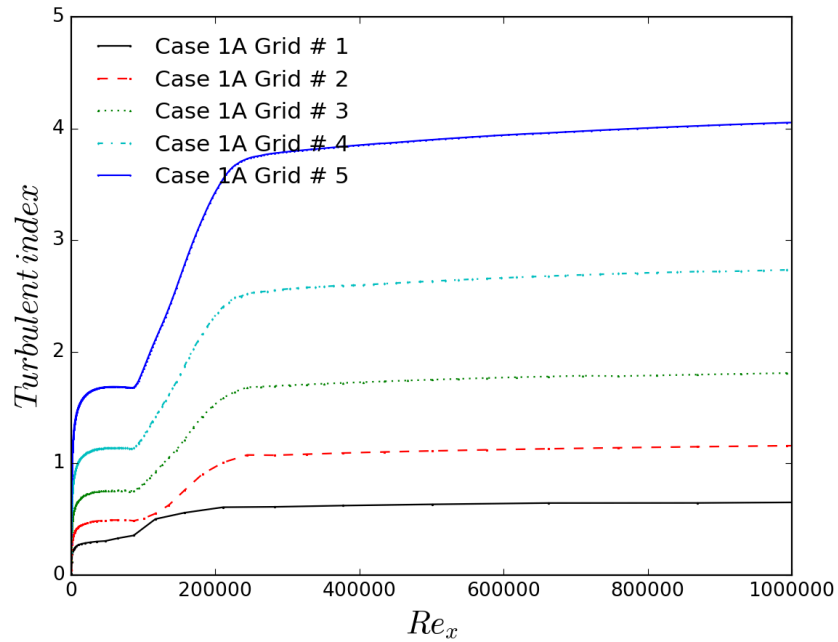
NLF(1)-0416, SST-LM2009



Data courtesy of Jared Carnes (UTK)

Code Verification

- Transition location is not a robust verification metric
  - Too much uncertainty for verification
  - Theoretical shortcomings of turbulence index identified
- Skin-friction at fixed location is better, but…
- **Participants need to have the same models implemented!**



Data courtesy of Marie Dension (NASA ARC)

Model Validation

- RANS-based transition modeling is reduced-order by its nature
  - Lack a well-stated PDE like we have for TKE
- Model performance is dependent on the calibration reference
  - Machine Learning provides an opportunity, but needs knowledgeable user
- We have incomplete characterization of test conditions
- **What is the "truth" answer we are aiming for?**

Assessment of Objectives

- ✓ Assess the current state of the art in laminar-turbulent transition prediction in an industrial CFD environment
- — Determine and document best practices for transitional flow simulations
- ✗ Verify transition/turbulence model implementations
- ✓ Encourage risk taking by participants and promote improvements to CFD prediction capabilities

Next Steps

- Participants are encouraged to submit updated results, and presentations will be posted very soon (release pending)

- Workshop-focused Special Session at AIAA SciTech 2022
  - Disseminate workshop outcomes to a broader community
  - Encourage participants to document their results as technical papers

- "Workshop 1.5" targeted for Special Session at Aviation 2022
  - Focus on numerics and model verification

Acknowledgments

- All participants, panelists, attendees, and organizers for helping to bring this to fruition
- Michelle Lynde (NASA LaRC) for assisting with CRM-NLF data and information
- Steve Karman of Pointwise for generating the unstructured CRM-NLF meshes
- AIAA for hosting and being incredibly flexible during the planning

The 1st AIAA CFD Transition Modeling and Prediction Workshop was a success