Exploring the Langtry-Menter Transition Model for High Speed Applications Using FUN3D

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2023 AIAA Aviation Forum
San Diego, CA
June, 2023

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Outline

- Introduction
- 2D Flat Plate
- Axisymmetric Cone
- 2D Flat Plate Revisited
- Conclusions

Introduction

- There is an interest within the aviation community to move in the direction of more certification by analysis.
- As a response, the NASA Transformational Tools and Technologies project is currently looking into developing state-of-the-art computational tools for simulating and predicting performance of aerospace vehicles.
- A subset of that research is exploring advanced Reynolds-averaged Navier Stokes (RANS) methods, such as Reynolds stress models and boundary layer transition models.
- In order to investigate boundary layer transition, RANS simulations were performed of an axisymmetric cone that is representative of a generic hypersonic vehicle forebody.

Transition Model

- The Langtry-Menter Shear-Stress Transport (LM-SST) transition model was used for the simulations.
- It utilizes the k-ω SST formulation and solves the equations for
  - Turbulent kinetic energy
  - Specific turbulent dissipation rate
  - Turbulence intermittency
  - Transition Reynolds number

Flow Solvers

- Most simulations used the FUN3D flow solver as it contained the LM-SST transition model.
- FUN3D is a node-based production level code that is developed and maintained at the NASA Langley Research Center.
- It can solve the 2D/3D Euler and RANS equations for incompressible and compressible flows on unstructured grids.
- A subset of “fully turbulent” turbulence models simulations used the Wind-US flow solver.

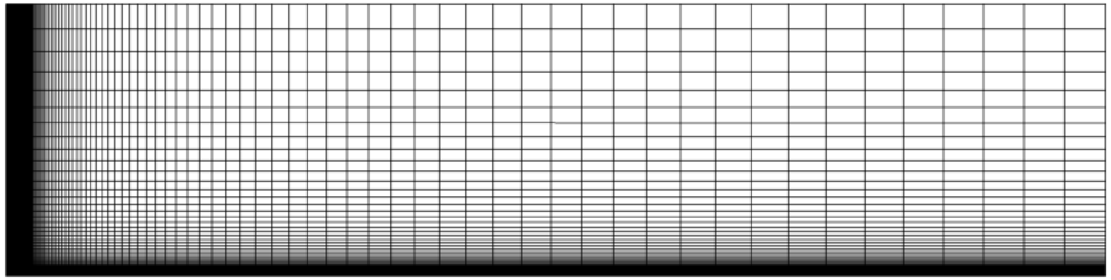
2D Flat Plate*: Overview

- 2D zero-pressure-gradient flat plate previously simulated by others at the 1st AIAA Transition Modeling and Prediction Workshop (TMPW).
- Mean Flow Condition:
  - Mach Number: 0.2
  - Reynolds Number: 6.56×10^5 m^{-1}
  - Total Temperature: 302.4 K
- Turbulence Inflow Conditions:
  - T3A:
    - Turbulent Viscosity Ratio: 11.9
    - Turbulence Intensity: 5.855%
  - T3B:
    - Turbulent Viscosity Ratio: 99.0
    - Turbulence Intensity: 7.216%

* Based on experiment from Roach, P. E., and Brierley, D. H., 1992.

2D Flat Plate: Grids

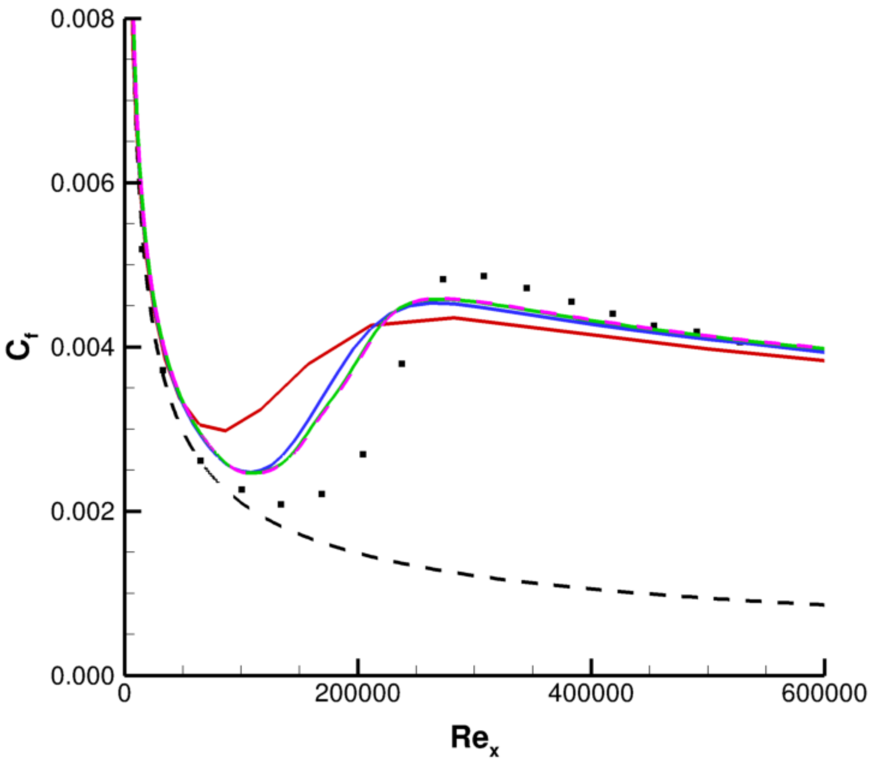
- 2D structured-like grids that were provided by the 1st AIAA TMPW.
- Coarsest Grid:
  - 1.13×10^3 nodes
  - Nominal y^+ of 1.9
- Finest Grid*:
  - 1083.52×10^3 nodes
  - Nominal y^+ of 0.049



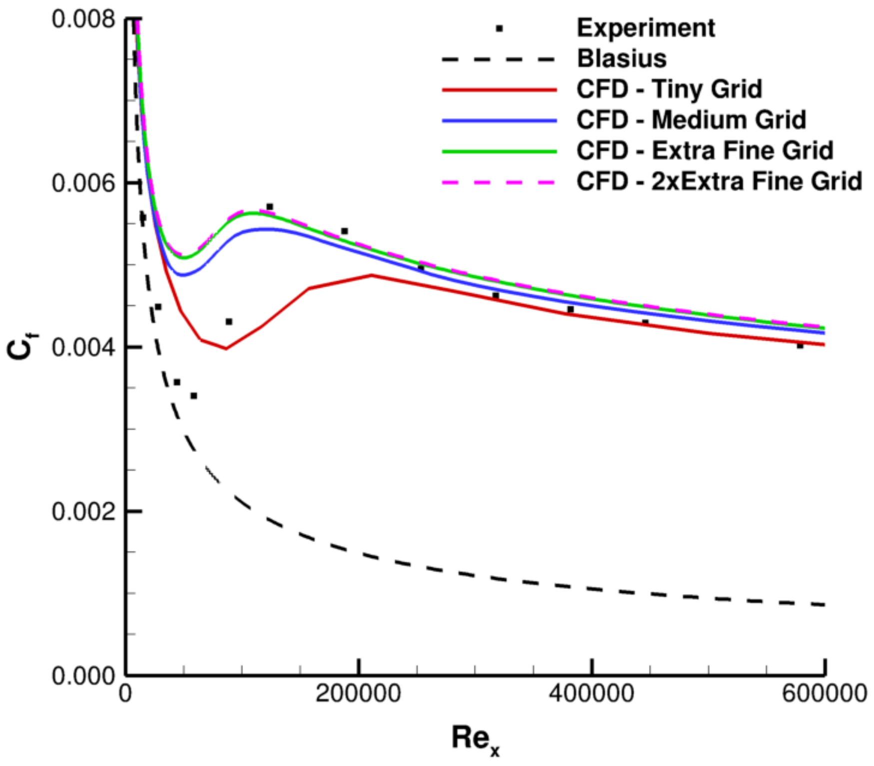
* Grid was one level finer than the finest 1st AIAA TMPW provided grid.

2D Flat Plate: Results

T3A



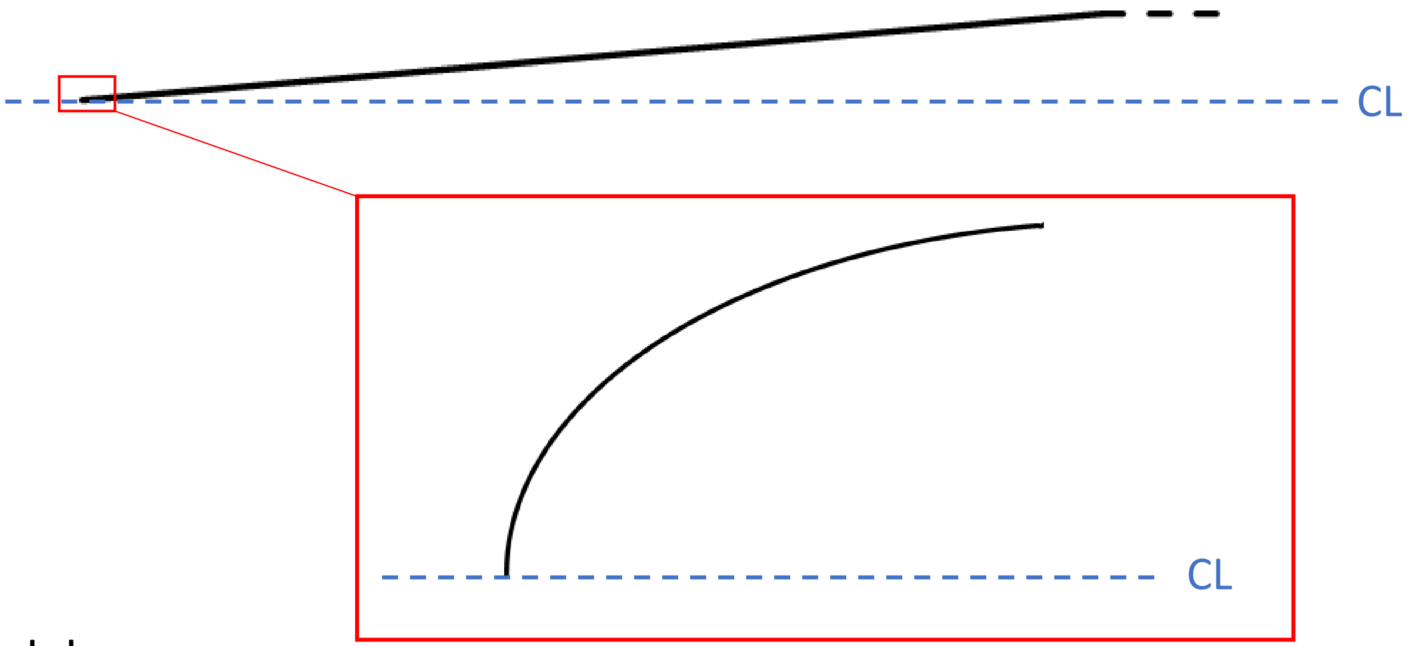
T3B



The predicted transition location is in acceptable agreement with the experimental data and grid independence was achieved on the extra fine grid level.

Axisymmetric Cone*: Overview

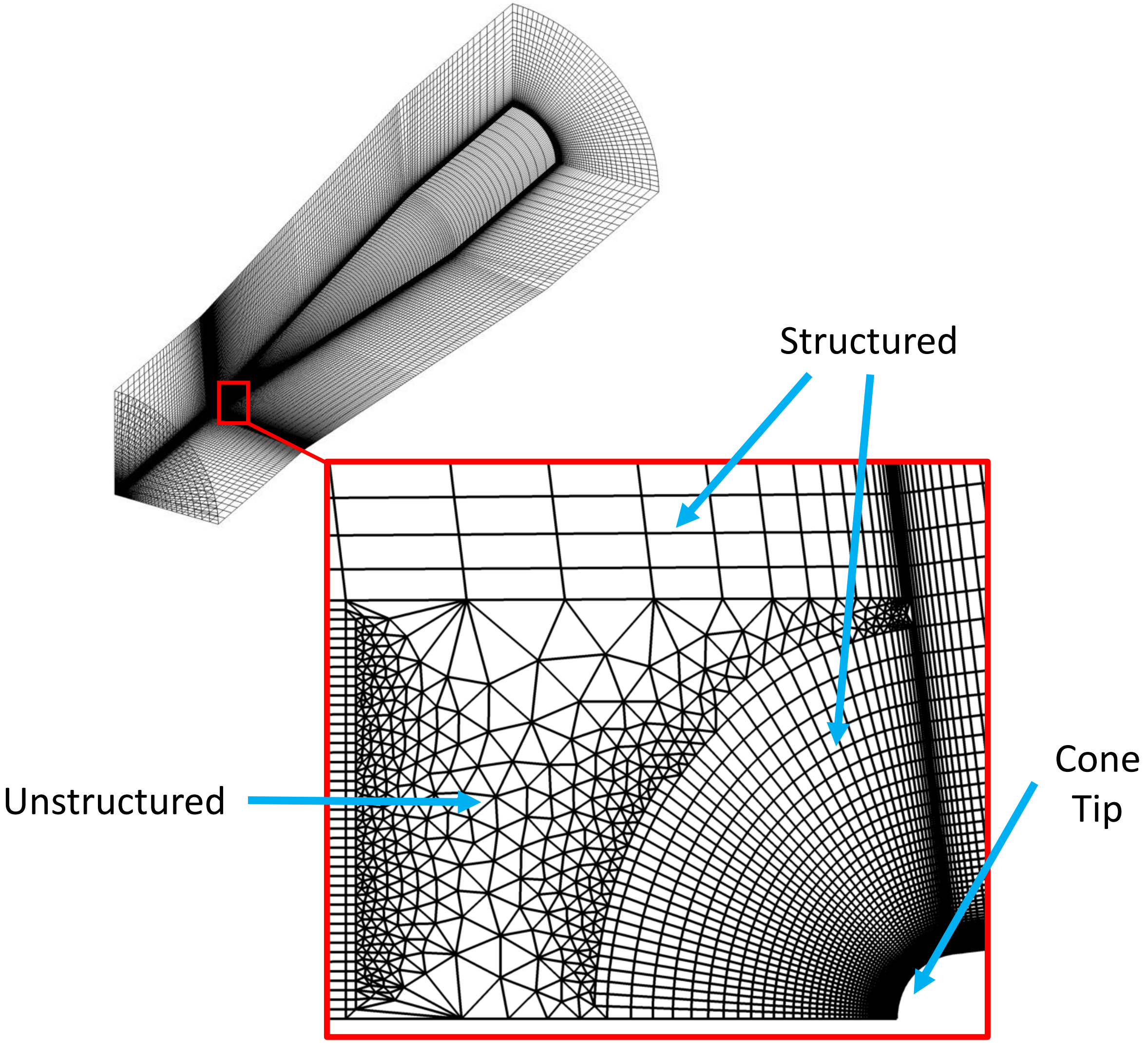
- Zero-pressure-gradient axisymmetric cone
  - 7° half angle
  - Rounded tip
- Mean Flow Condition:
  - Mach Number: 7.93
  - Reynolds Number: 6.60 x 10^6 m^{-1}
  - Total Temperature: 722.00 K
  - Wall Temperature: 303.24 K
- Turbulence Models:
  - Four-equation LM-SST transition model
  - One-equation Spalart-Allmaras (SA)
  - Two-equation Menter Shear-Stress Transport using a vorticity source term (SST-V)



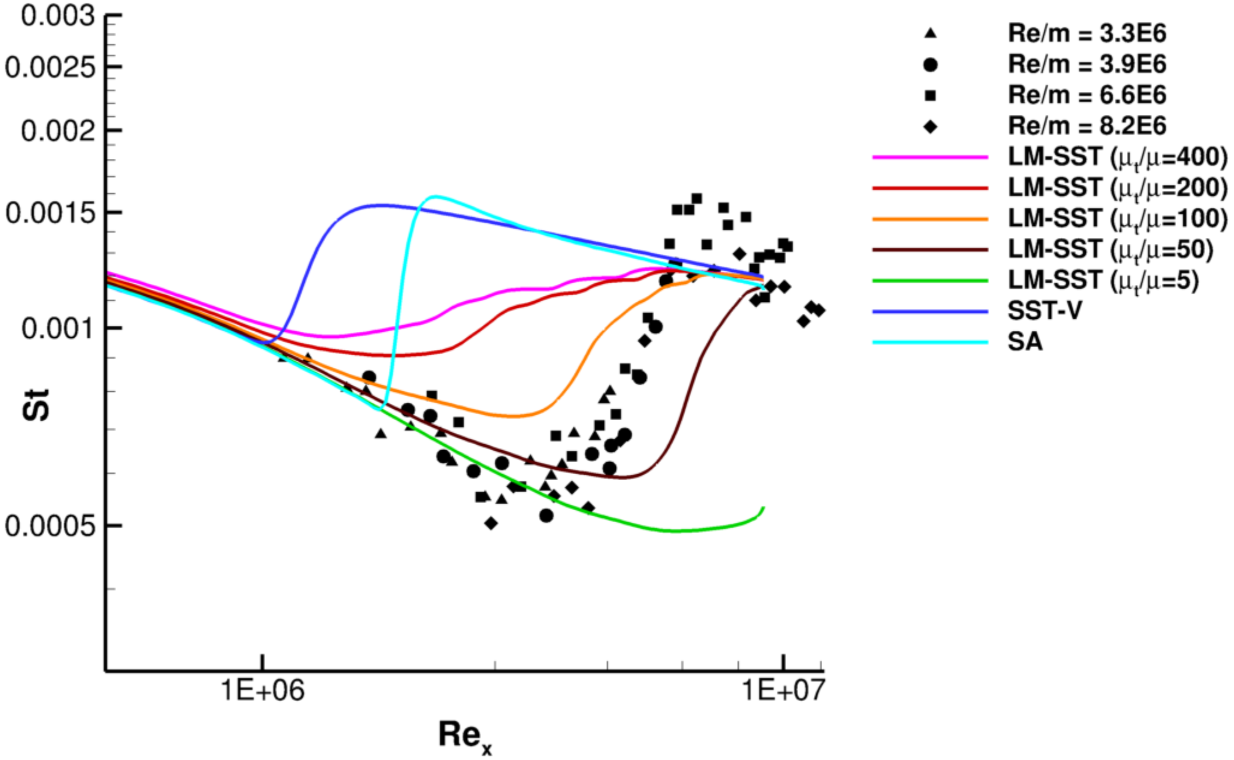
* Based on experiment from Kimmel, R. L., 1993.

Axisymmetric Cone: Grids

- Quarter-symmetry unstructured grids
  - Mostly structured-like, except around the cone tip
- Coarsest Grid:
  - 1.13×10^6 nodes
  - Nominal y^+ of 0.20
- Finest Grid:
  - 96.53×10^6 nodes
  - Nominal y^+ of 0.20



Axisymmetric Cone: Turb. Parameter Study*



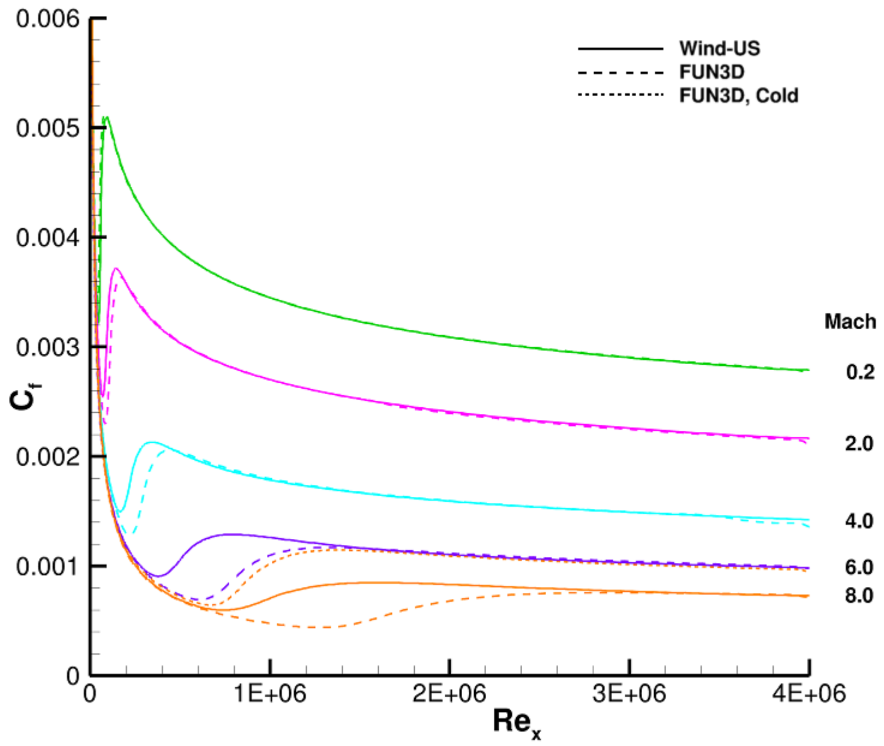
- The transition model can reasonably predict the transition location in agreement with the experiment.
- The predicted transition location is highly sensitive to the incoming turbulent viscosity.
- The “fully turbulent” SA and SST-V models predict transition.

* Coarse grid was used for the study.

2D Flat Plate Revisited: Overview

- Geometry: 2D zero-pressure-gradient flat plate
- Mean Flow Mach Numbers:
  - 0.2, 1.0, 2.0, 4.0, 6.0, and 8.0
- Grid: extra fine grid
- Flow Solvers:
  - FUN3D
  - Wind-US
- Turbulence Model:
  - SST-V

2D Flat Plate Revisited: Results



- Transition is predicted to occur almost immediately at the lower Mach numbers while moving downstream at subsequent Mach numbers.
- After Mach 2.0, the two codes start to diverge in their predicted transition locations.
- The predicted transition location from the axisymmetric cone agrees reasonably well with the Mach 8.0 cold case.

Conclusions

- The primary objective of this work was to explore the LM-SST transition model on an axisymmetric cone that was representative of a generic hypersonic vehicle forebody.
- The transition model was able to reasonably predict transition for precursor simulations of a Mach 0.2 flat plate at two different turbulent inflow conditions.
- The axisymmetric cone simulations showed high sensitivity of the inflow turbulent viscosity on the predicted transition location, with small variation in turbulence intensity.
- Revisiting the flat plate at higher Mach numbers, the “fully turbulent” SST-V turbulence model predicted transition for Mach numbers greater than 2.0.

Acknowledgements

- The authors would like to thank:
  - The NASA Transformational Tools and Technologies Project for supporting this work
  - The NASA High-End Computing Program for providing supercomputing resources

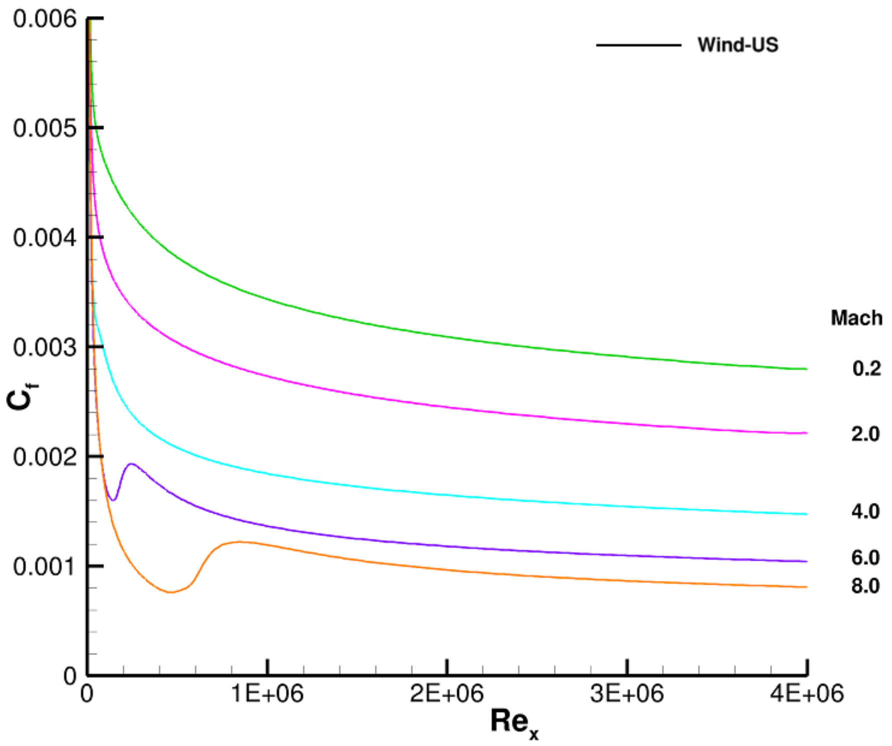
NASA

Backup

Axisymmetric Cone: Turb. Parameter Study

Inflow		Cone Tip
μ_t/μ	*I* (%)	*I* (%)
5.0	1.25	0.303
50.0	1.25	0.803
100.0	1.25	0.959
200.0	1.25	1.078
400.0	1.25	1.155

2D Flat Plate Revisited: SA Results



- Earlier transition is observed compared to the SST-V solutions.