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Modern CFD Validation for Turbulent Flow Separation on Axisymmetric Afterbodies

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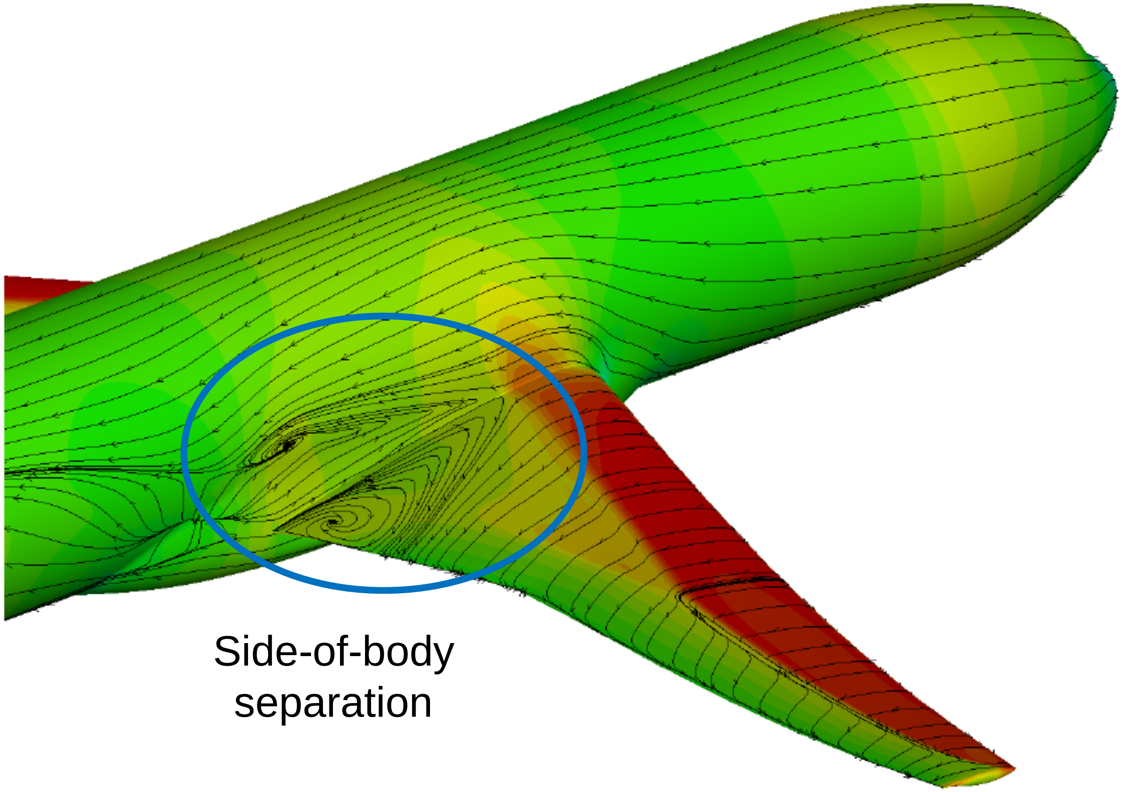
Outline

1. Test Case Motivation
2. *A Priori* RANS Guidance
3. Risk-Reduction Test Setup
4. Summary and Future Work
5. Questions and Answers

Motivation: NASA CFD Vision 2030 [1]

[1] NASA CR 2014-218178.



Side-of-body separation

5th AIAA CFD Drag Prediction Workshop
(New Orleans, 2012)
NASA Common Research Model

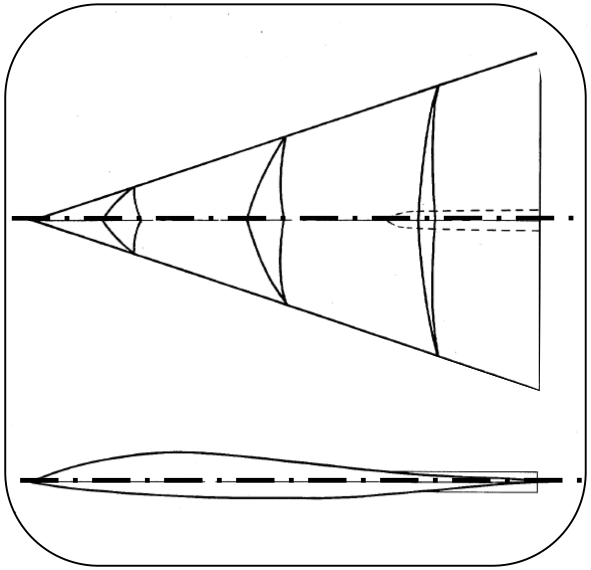
- Need for improved CFD modeling/validation of smooth-body turbulent flow separation
- Need for fundamental experiments designed specifically for CFD validation
- Support range of cases:

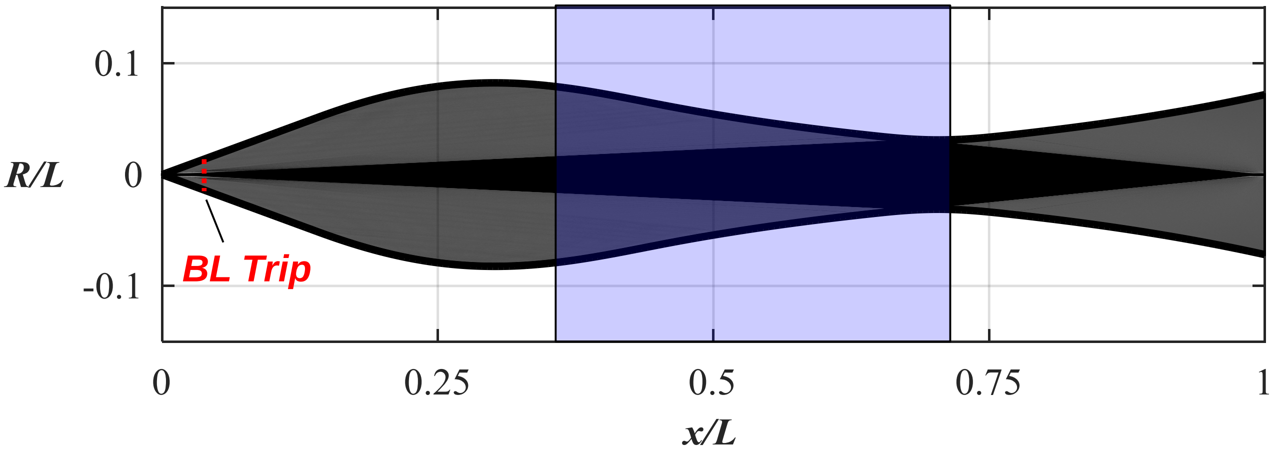
attached flow →
partially separated →
large separation

Waisted Body-of-Revolution (1970)

Axisymmetric Converging Flow with APG [2]

- Example of higher-*Re* test case
- Analogy to **cambered delta wing**
- Turbulence modeling issues in “waist” region
- Mainly considered attached flow
- RAE 8 × 8 ft Wind Tunnel:
  $0.6 < M < 2.8$; $5 \times 10^6 < Re_L < 2 \times 10^7$

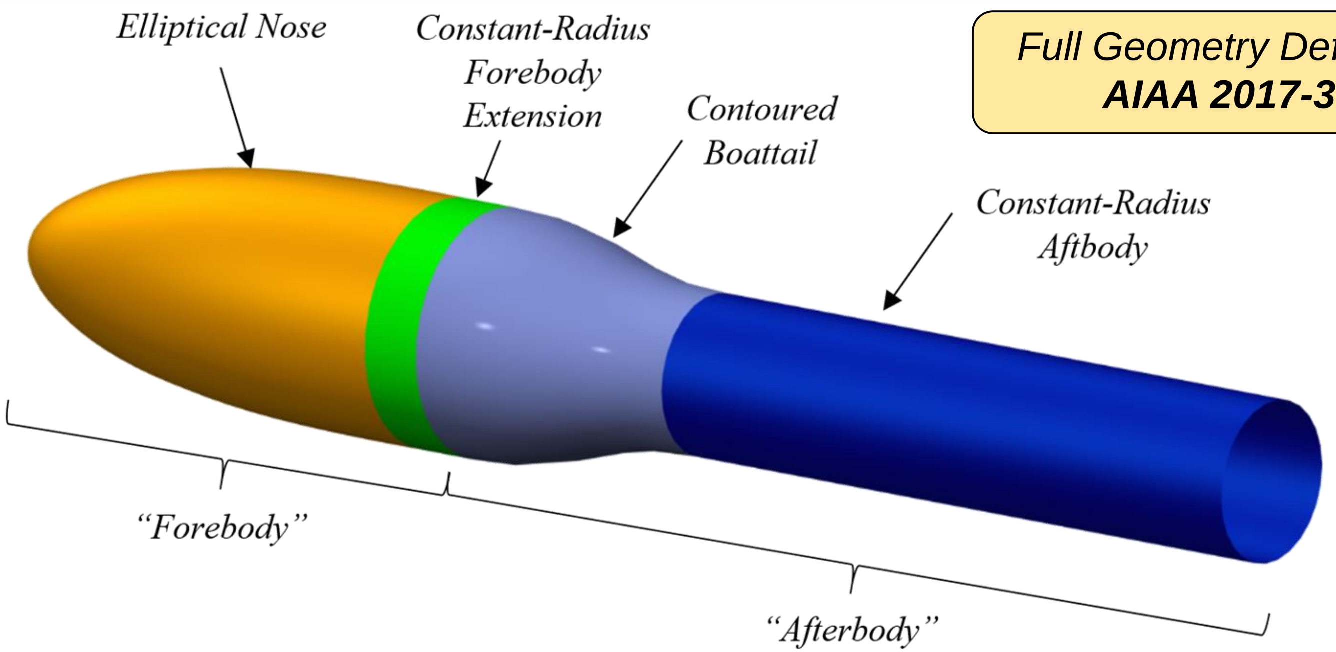




[2] Winter, K.G., Rotta, J.C., and Smith, K.G., 1970, "Turbulent Boundary Layer Studies on a Waisted Body of Revolution in Subsonic and Supersonic Flow," R&M No. 3633.

Test Case Concept: NASA Axisymmetric Afterbody

Full Geometry Definition in ***AIAA 2017-3792***



- **Axisymmetric:** no intersection with sidewall corner flows
- **Wider validation domain**: sting-mount to access higher Reynolds number facilities

- **Parametric body:**
  - Analytical shape; continuous second derivative
  - Extendable forebody
  - Interchangeable afterbody (*cf*. Presz and Pitkin [3])

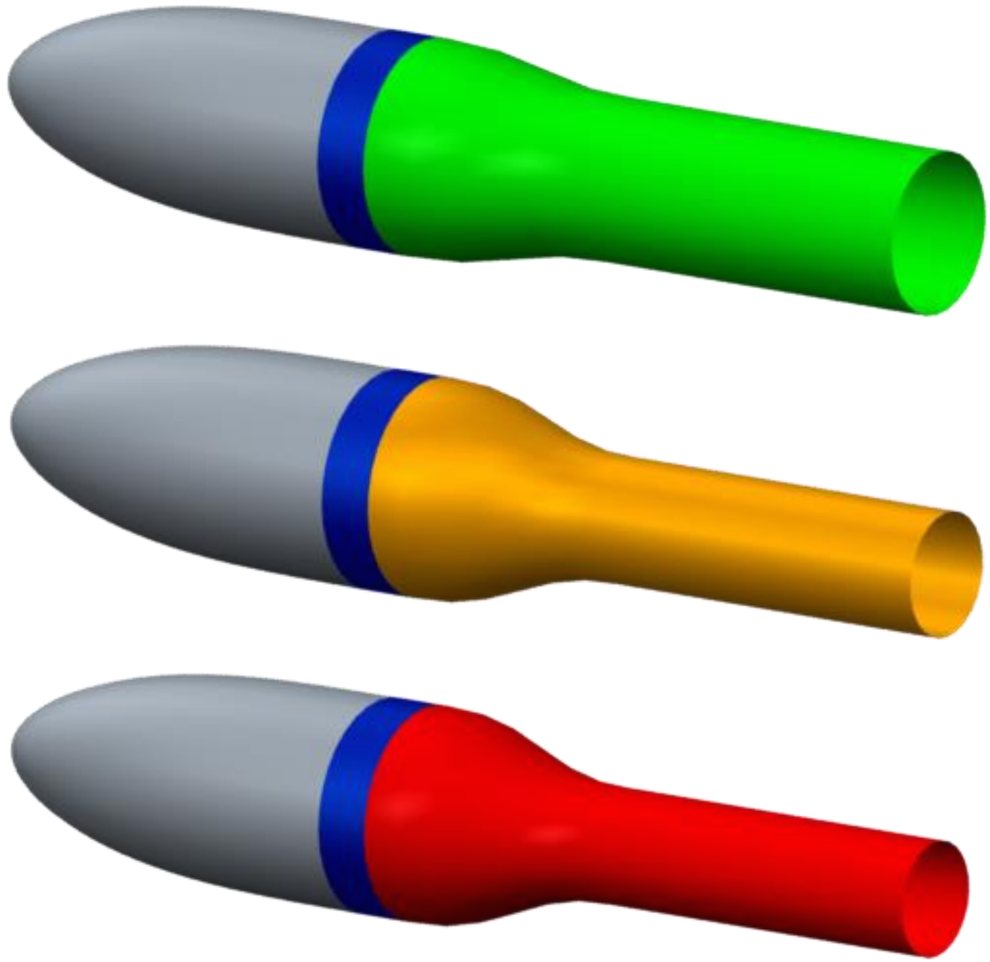
[3] Presz, W.M., and Pitkin, E.T., "Flow Separation Over Axisymmetric Afterbody Models," *J. Aircraft,* Vol. 11, No. 11, 1974, pp. 677-682.

Family of Afterbodies

Decreasing Aft Cylinder Radius

"Slip-Ons"

cf. NASA TN D-4504 (1968)



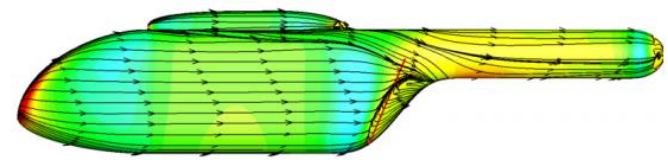
"Attached Flow"

"Incipient Separation"

"Fully Separated"

Axisymmetric Afterbody: Industry-Relevant Configuration

"Hammerhead" Launch Vehicle Buffeting
(NASA Ames)



Helicopter Aft-Fuselage Drag Reduction
(Allan and Schaeffler [4])

Aeropropulsion: Nozzle Afterbodies

[4] Allan, B.G., and Schaeffler, N.W., "Numerical Investigation of Rotorcraft Fuselage Drag Reduction using Active Flow Control," Proceedings of American Helicopter Society 67th Annual Forum, Virginia Beach, VA, May 3-5, 2011.

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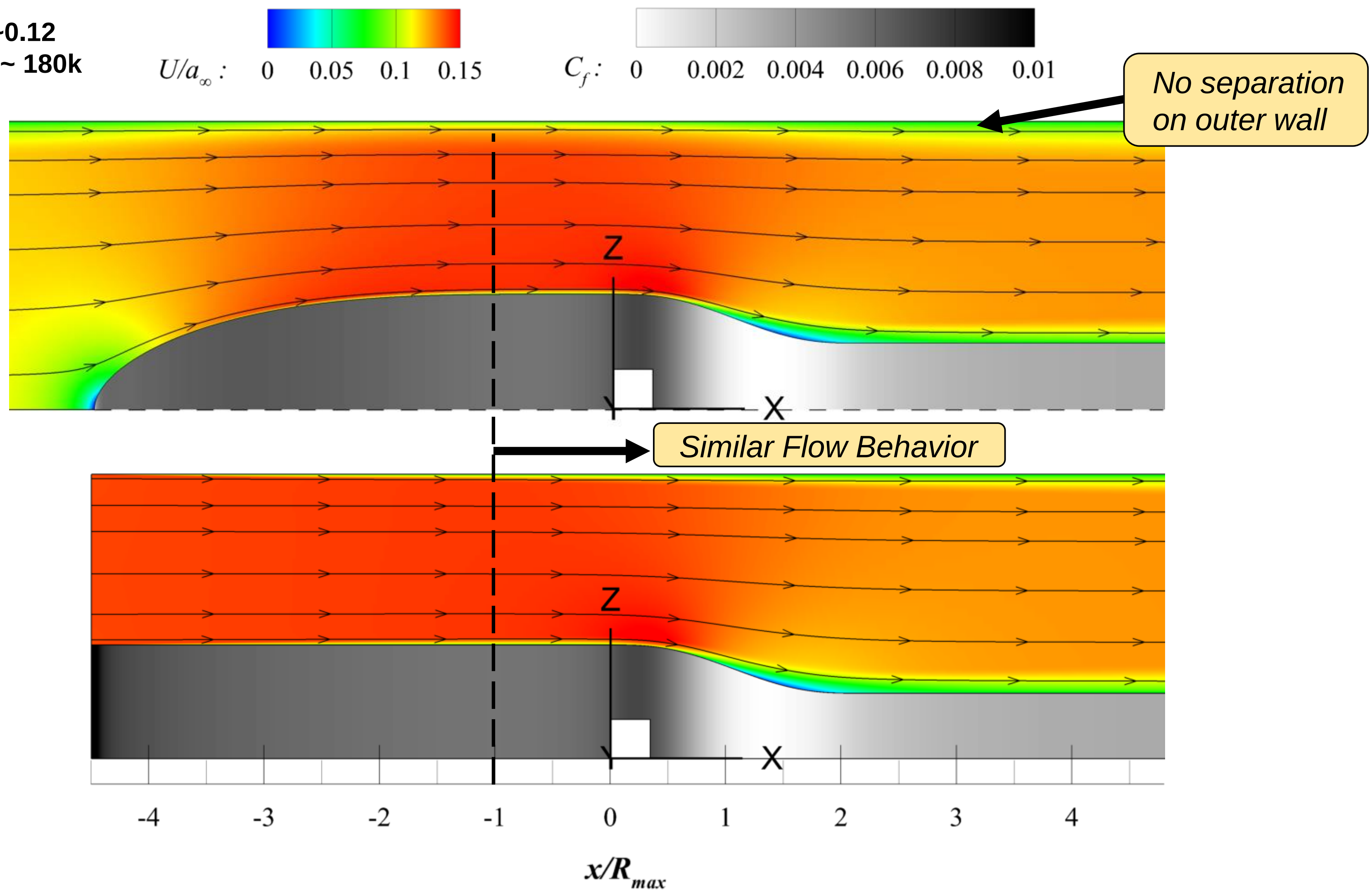
A Priori RANS Studies

- Determine boattail angle where turb. model results are ambiguous
  - Searching for a discriminating test case

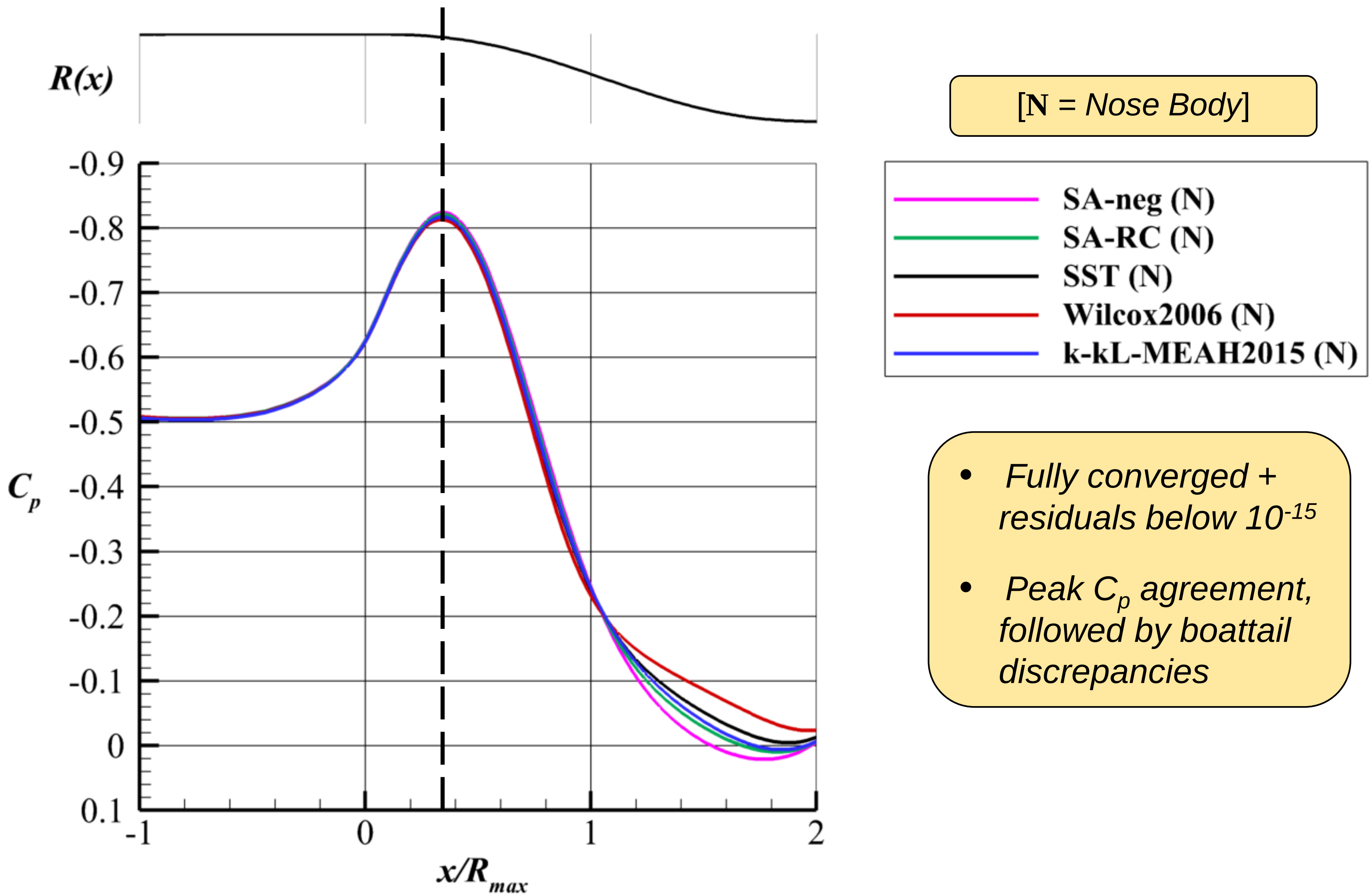
- Compute risk-reduction configuration with tunnel walls
  - NASA Langley 15-Inch Low-Speed Wind Tunnel (15x15 inch cross-section)
  - Approximate square test section by circle that inscribes it
  - Steady RANS
  - Fully turbulent
- Assess sensitivity of afterbody flow to:
  1. Body nose (with/without)
  2. Tunnel boundary layer (with/without)

Representative Flowfields: *SA-RC Turbulence Model*

M_{inflow} ~0.12
Re_{Rmax} ~ 180k



Pressure Distribution: *Turbulence Model Differences*

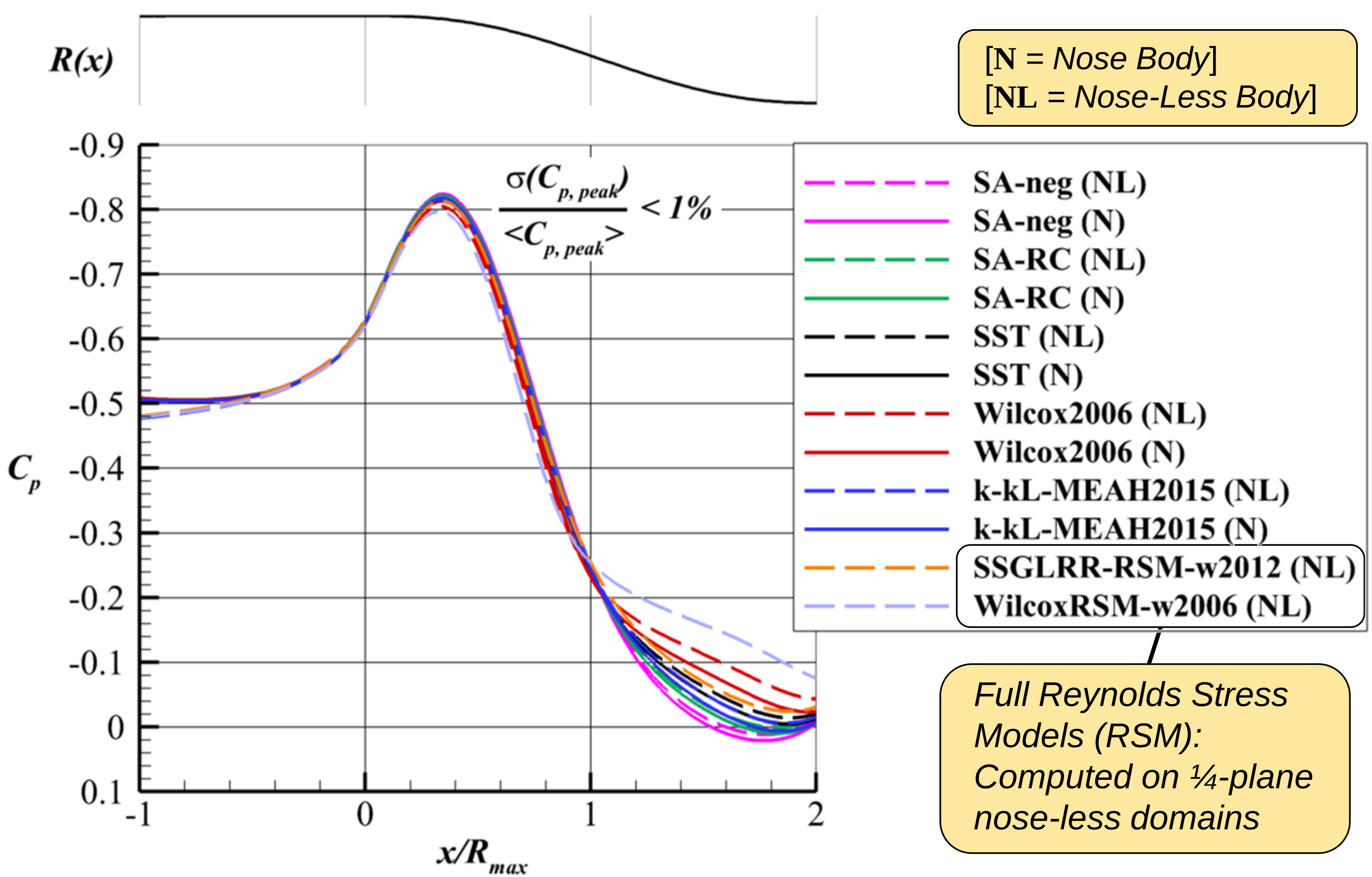


[**N** = *Nose Body*]

- *Fully converged + residuals below 10^{-15}*
- *Peak C_p agreement, followed by boattail discrepancies*

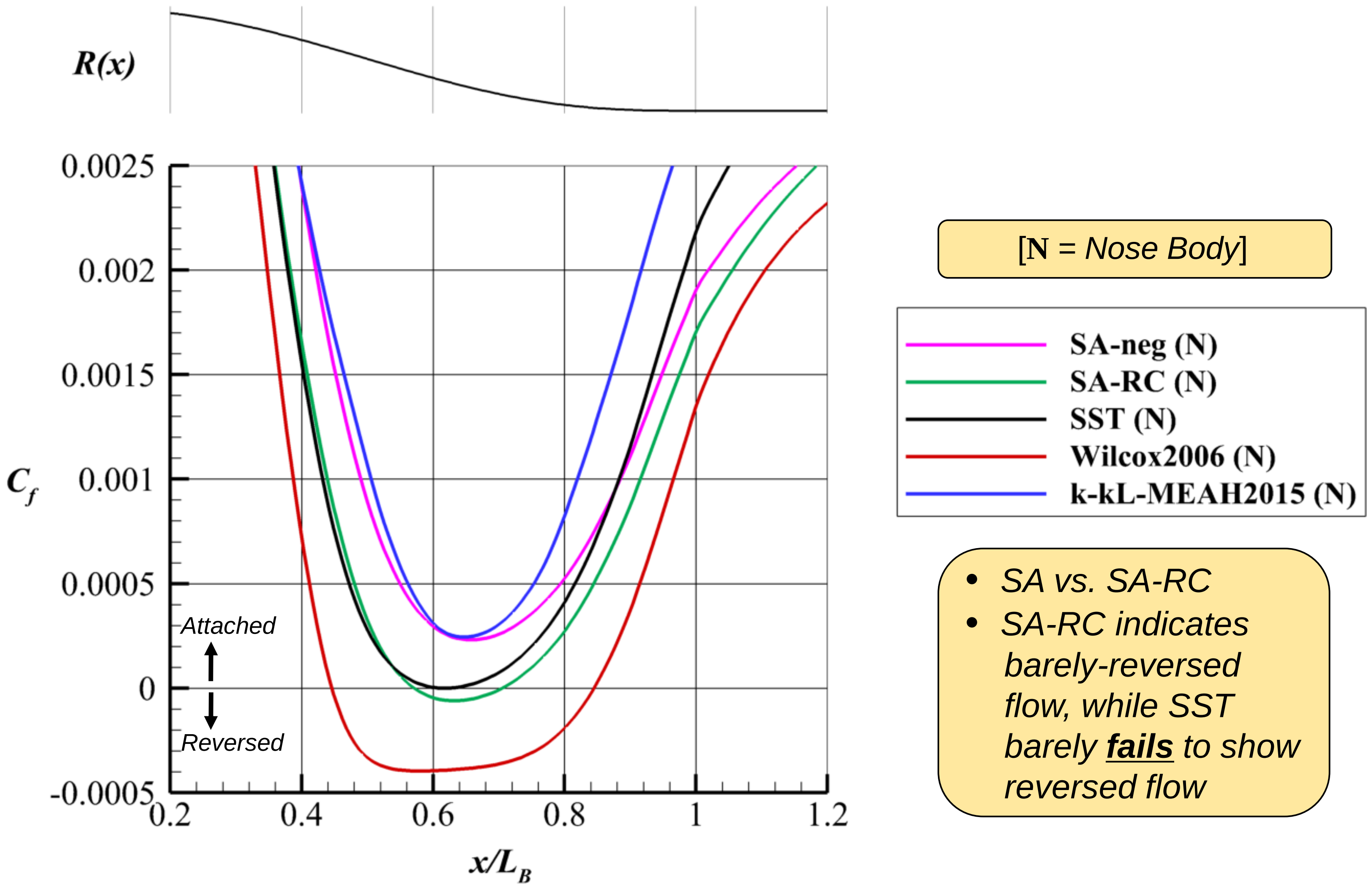
Pressure Distribution: *Turb. Model + Nose Effects*

[**N** = *Nose Body*]
[**NL** = *Nose-Less Body*]



Full Reynolds Stress Models (RSM): Computed on ¼-plane nose-less domains

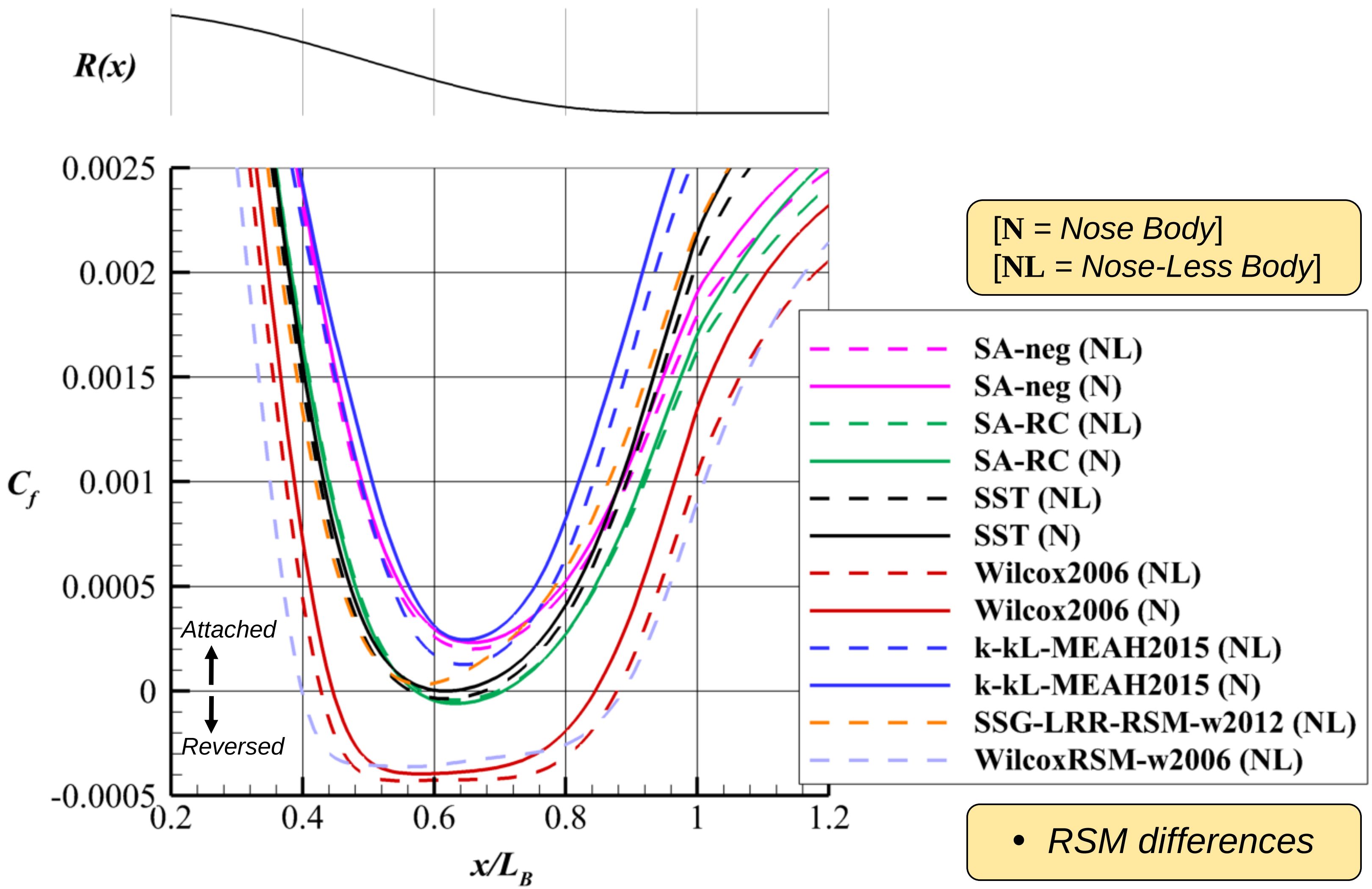
Boattail Skin Friction: *Turbulence Model Differences*



[**N** = *Nose Body*]

- *SA vs. SA-RC*
- *SA-RC indicates barely-reversed flow, while SST barely* ***fails*** *to show reversed flow*

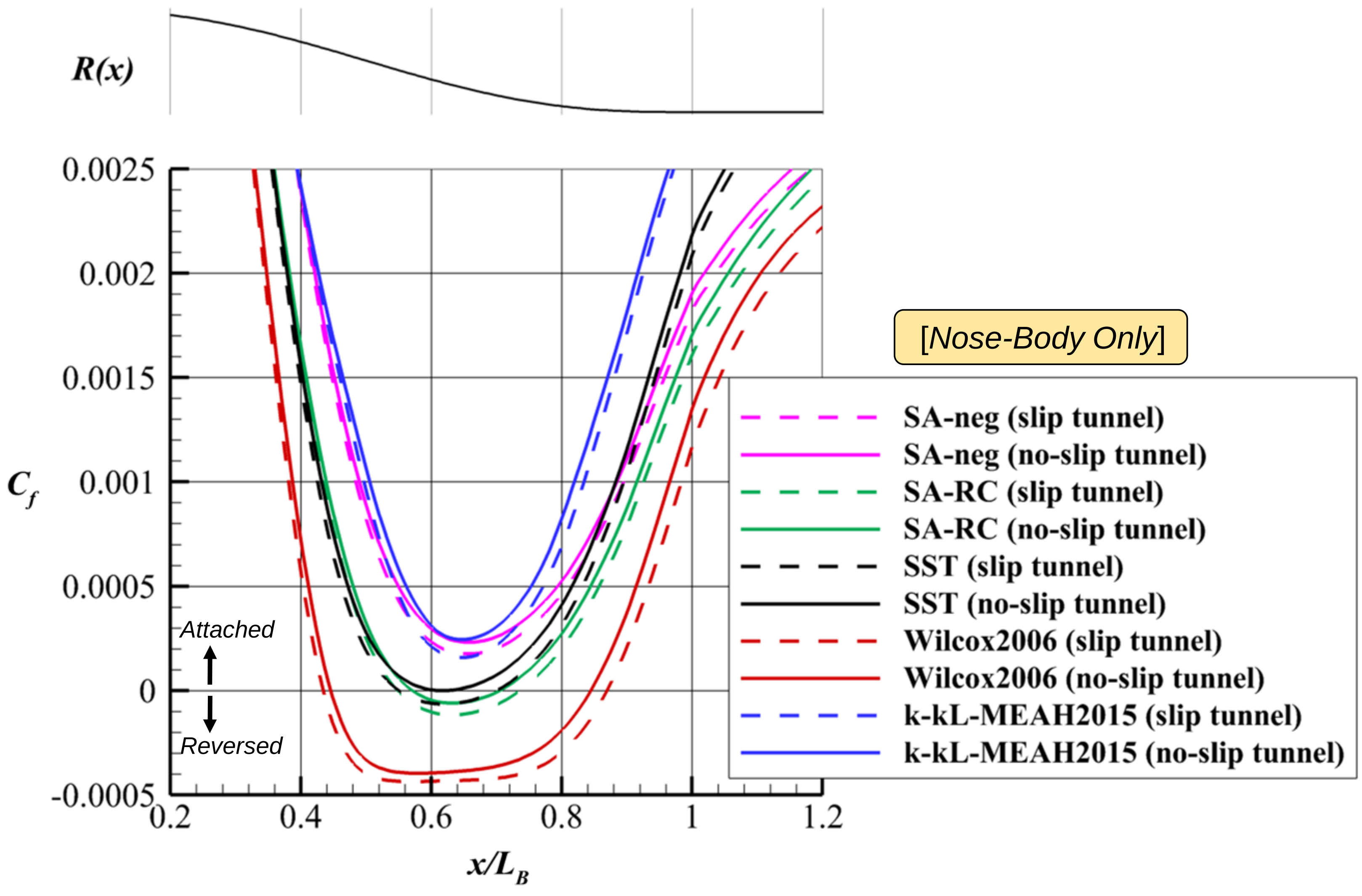
Boattail Skin Friction: *Turb. Model + Nose Effects*



[N = *Nose Body*]
[NL = *Nose-Less Body*]

- *RSM differences*

Boattail Skin Friction: *Effect of Tunnel Boundary Condition*



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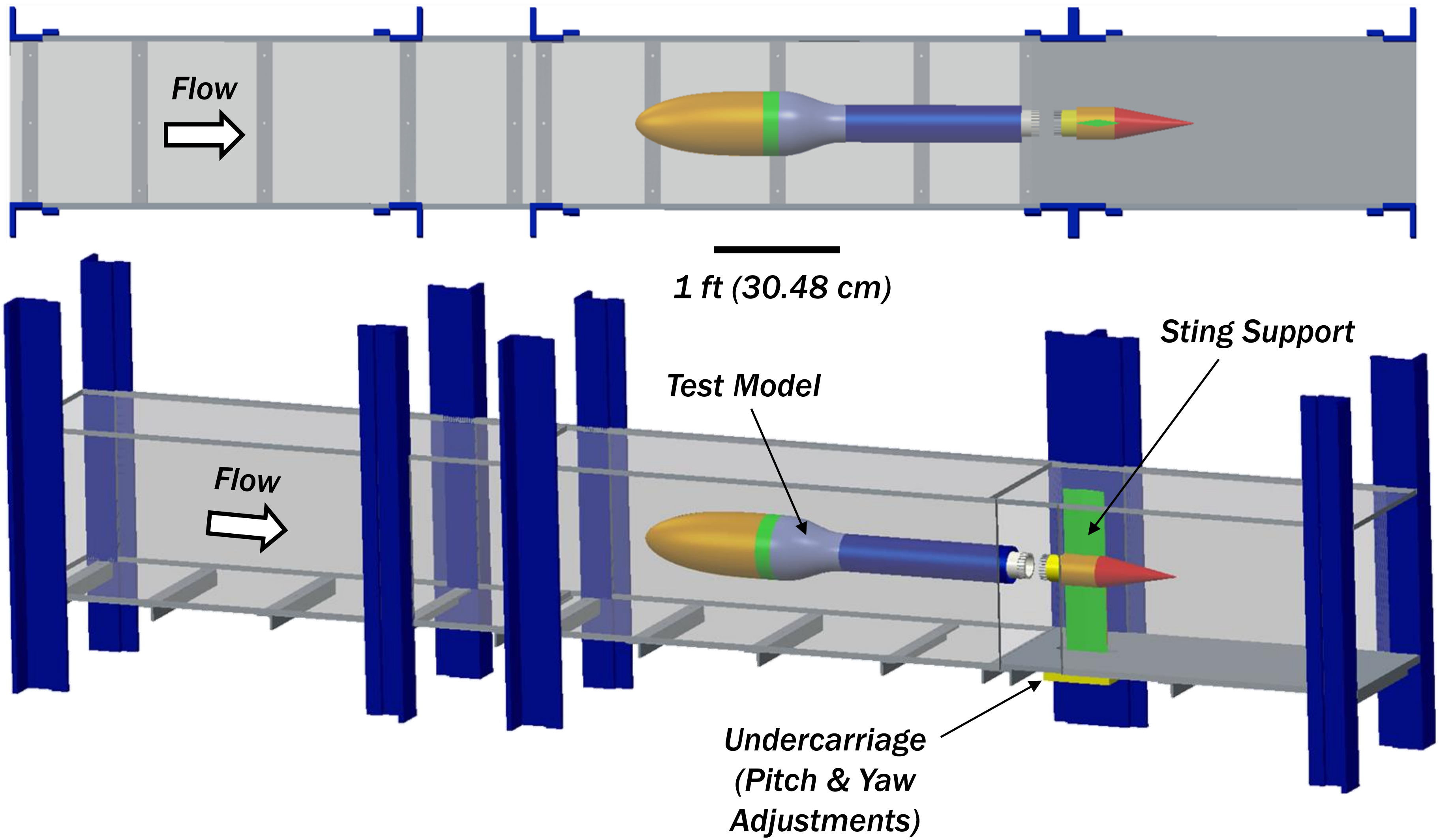
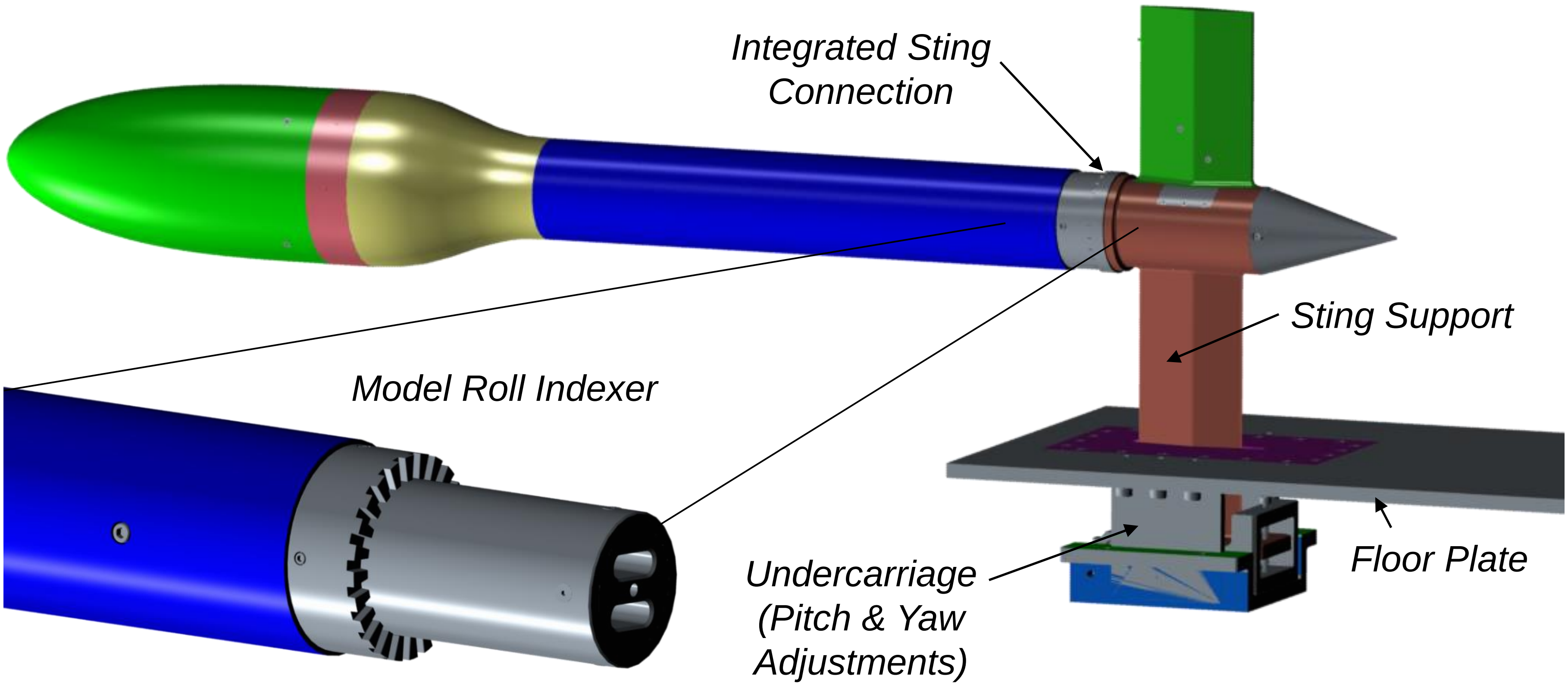
Risk-Reduction Experimental Setup: *NASA Langley 15-Inch LSWT*



Risk-Reduction Test Model Assembly (Courtesy: Vincent LeBoffe, NASA LaRC)



(Useful for rotating point-sensors around circumference)

Summary and Future Work

- Development of new CFD validation test case for smooth-body turbulent separation based on parametric body-of-revolution.
- Design guided by *a priori* RANS studies searching for critical disagreement among turbulence models.
- Assessment of sensitivity to:
  1. body nose (with/without)
  2. tunnel wall boundary layer (with/without)

  in which effects were smaller than overall disagreement among models.

- Must now pursue “truth case”: Appear to be twin paths for experiment (nose-body) and LES/DNS (nose-less body).

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