SAND2019-0060C

Revisiting the Bachalo-Johnson Axisymmetric Transonic Bump

Kyle P. Lynch, Matt F. Barone, Nathan Miller, Steven J. Beresh

Turbulence Modeling Benchmarking Working Group, AIAA SciTech 2019

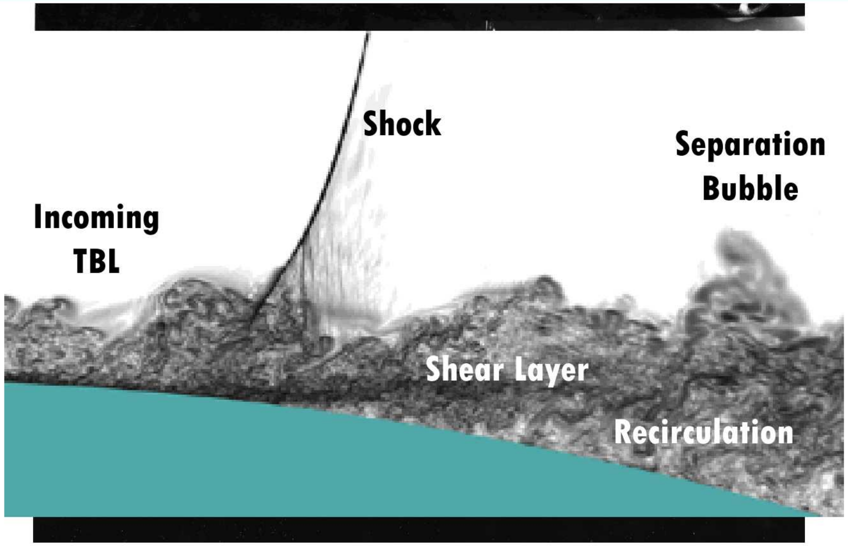
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

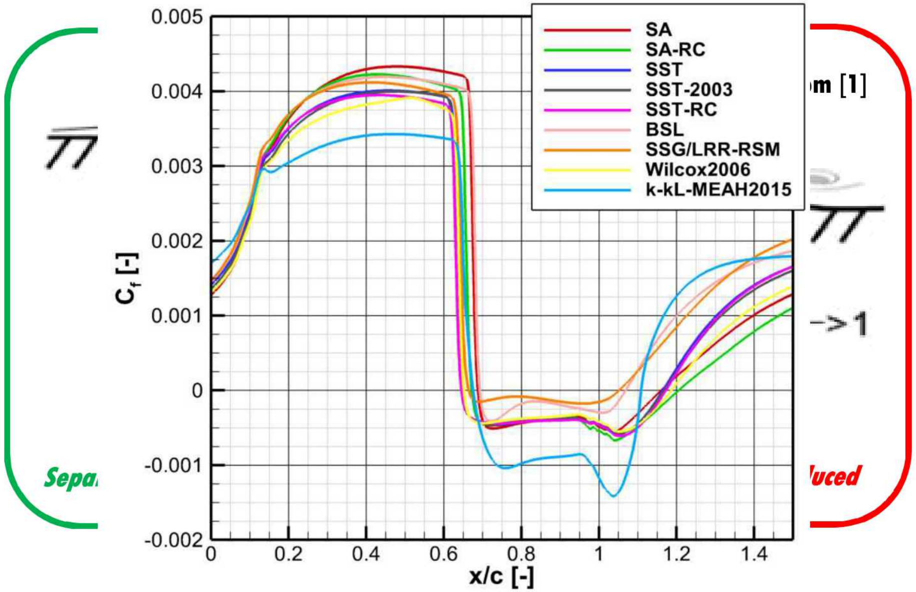
SAND XXX-XX

Sandia National Laboratories

Motivations

- **The Bachalo-Johnson experiment is a benchmark for turbulence models.**
- **Smooth, axisymmetric hump creates pressure gradient and shock, leading to *flow-induced separation.***
- **Variety of physics: ∇p , high M=0.875, high Re=2.7e6, shocks, separation.**
- **RANS models underestimate Reynolds stresses, leading to errors in velocity deficit and skin friction.**
- **Advanced methods (LES/IDDES/WMLES) also show significant scatter in separation location and extent**
- **Establishing a DNS 'ground truth' difficult due to high Re**

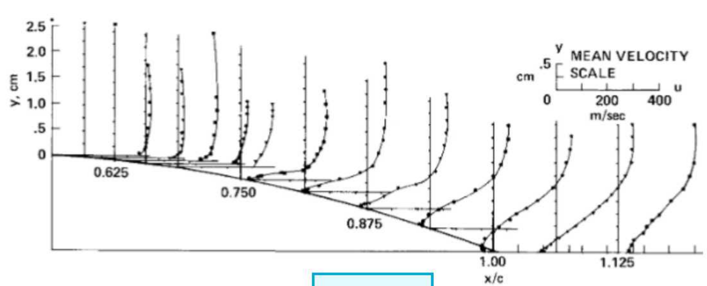


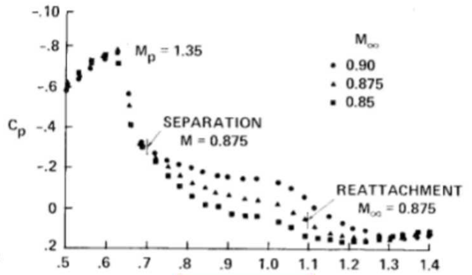


[1] Bachalo and Johnson (1986) Transonic, turbulent boundary-layer separation generated on an axisymmetric flow model. *AIAA J* 24.
[2] Spalart et al. (2017) Large-eddy and direct numerical simulation of the Bachalo-Johnson flow with shock-induced separation. *Flow Turb Comb* 99.

Motivations

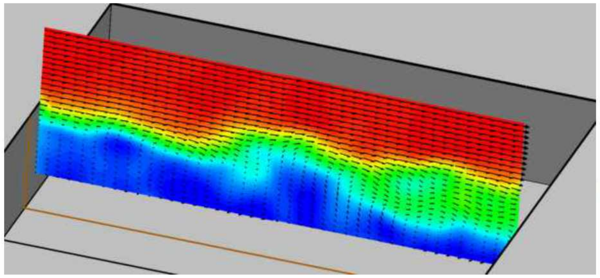
- **Only available data is from single publication in 1986.**
- **Limited boundary condition information, *no skin friction.***
- **Substantial improvements in diagnostics in 32 years:**
  - **Particle Image Velocimetry**
  - **Pressure-Sensitive Paint**
  - **Oil-Film Interferometry**
- **The physics are still relevant, so why not revisit this experiment?**
- **Modify for current needs:**
  - **Re=1e6 to make DNS tractable.**
  - **Analytical model geometry.**
  - **Solid walls to ease simulation boundary conditions.**
  - **Measure shear stress**

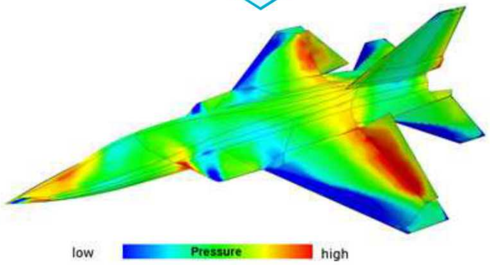




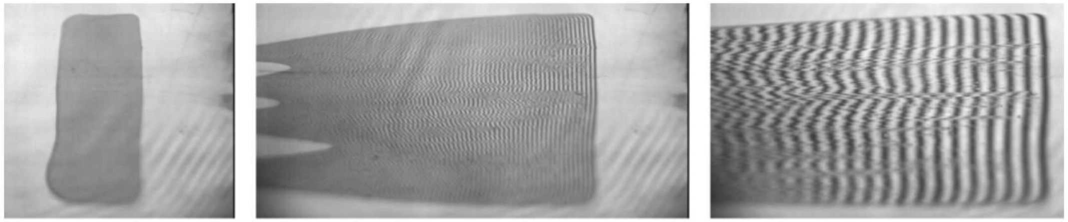
PIV

PSP





OFI

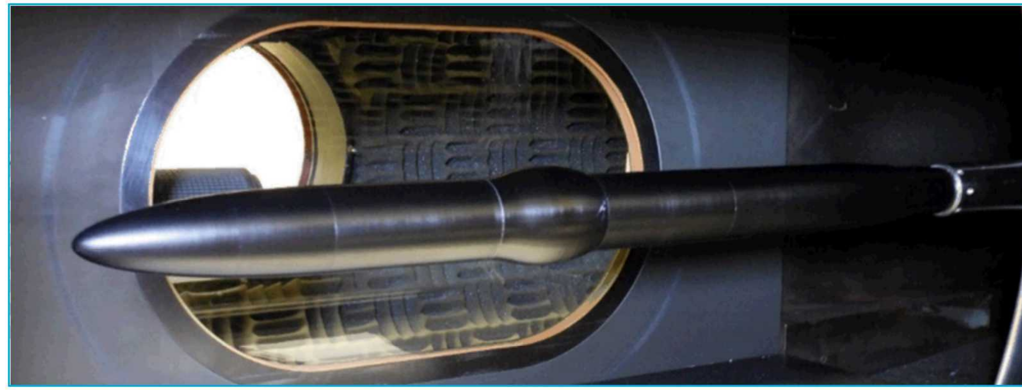


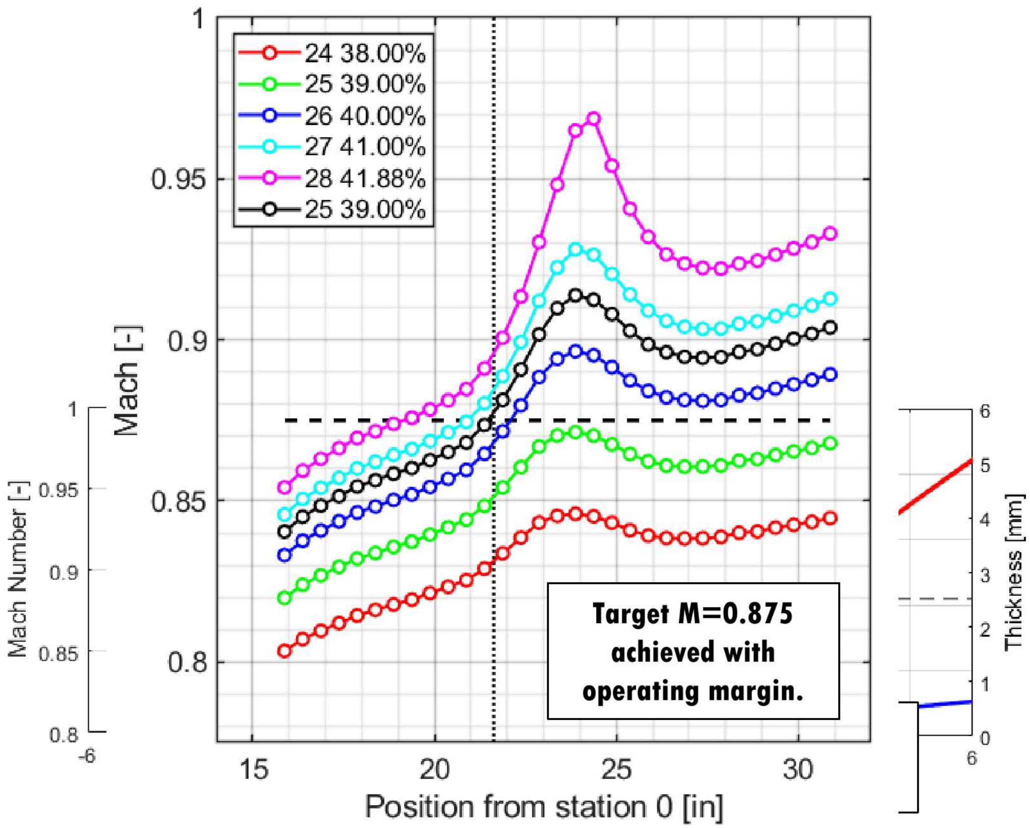
From [3]

[3] Naughton and Hind (2013) Multi-image oil-film interferometry skin friction measurements. *Meas Sci Tech*

Experiment Design

- **Model requirement: match flow/geometric quantities of [3]**
  - **$M_\infty = 0.875$, $Re_c = 1$ million**
  - **$h/d = 1/8$; $c/d = 4/3$; $\delta/h = 0.42$**
- **Sandia TWT is smaller facility (1 ft x 1 ft) than original experiment at NASA Ames (2 ft x 2 ft and 6 ft x 6 ft)**
- **Constrained design problem:**
  - ***d* large for diagnostics**
  - ***d* limited by tunnel blockage**
  - **Solid walls required**
- **Developed analytical geometry definition, optimized to maximize diameter**

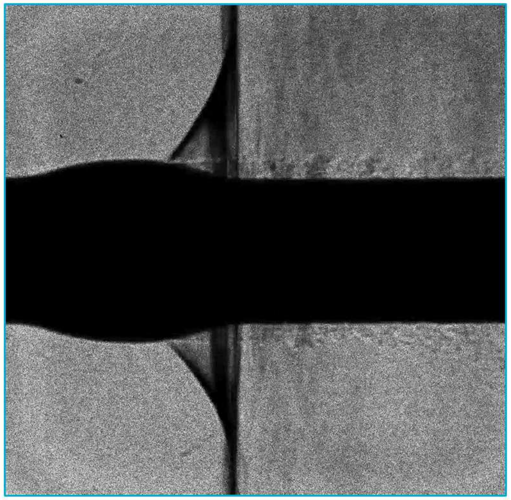


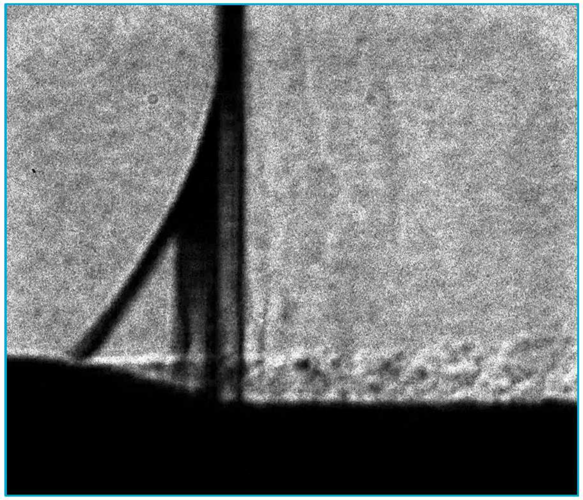


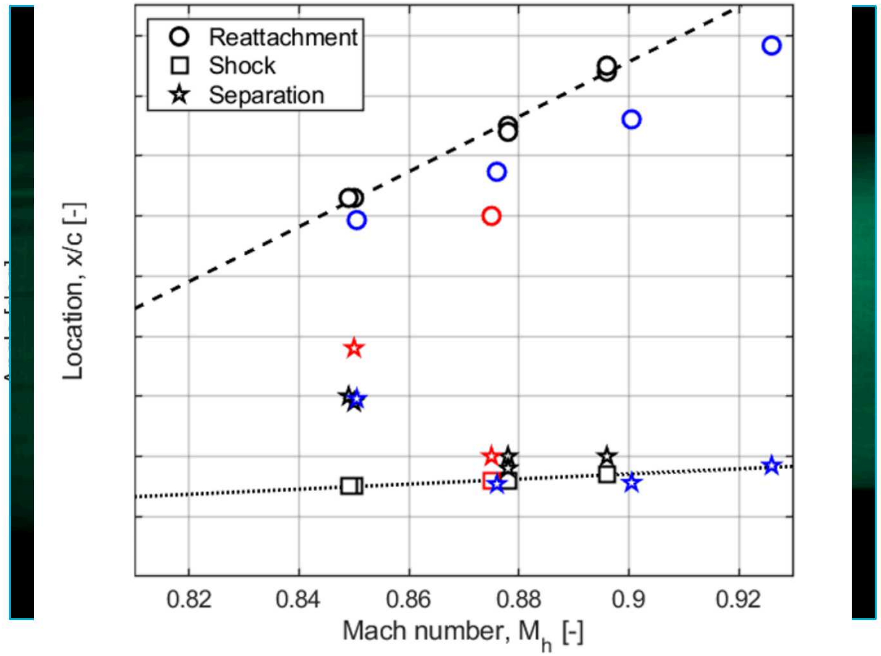
Can meet requirements in Sandia TWT with model of reasonable scale (diameter on order 2 inches)

Experiments: Schlieren/Oil Flow

- **Visualizations used to verify relevant physics being generated.**
- **Schlieren shows steady shock location, coinciding with shear layer/flow separation region**
- **Calibrated oil flow visualization confirms a shock-induced separation and reattachment**
- **Same Mach number trends observed as in [1] and [4]; shock and separation coalesce at M = 0.875.**





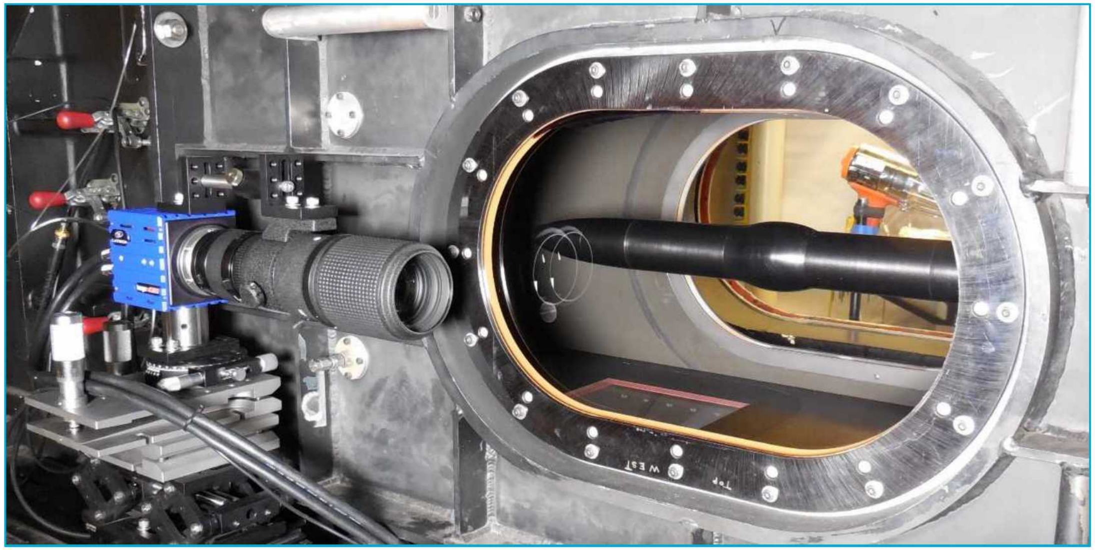


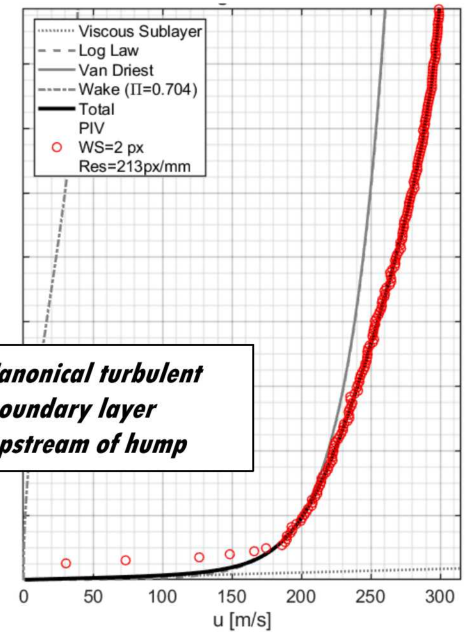
Much smaller scale and solid walls, but observing same target physics and trends.

[4] Horstman and Johnson (1984) Prediction of Transonic Separated Flows. *AIAA J* 22.

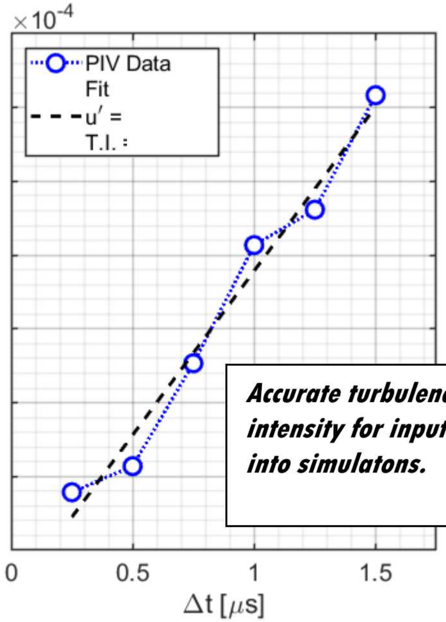
Experiments: PIV

- PIV characterizes incoming boundary layer, tunnel turbulence intensity, and separated region statistics.
- Small BL and hump requires high resolution: macro imaging and teleconverters yield 270 px/mm
- Enough resolution to measure into TBL buffer layer, apply fits for C_f and δ.
- Multiple Δt strategy for turbulence intensity independent of measurement noise
- Sweep along separation region for high resolution turbulence statistics





Canonical turbulent boundary layer upstream of hump

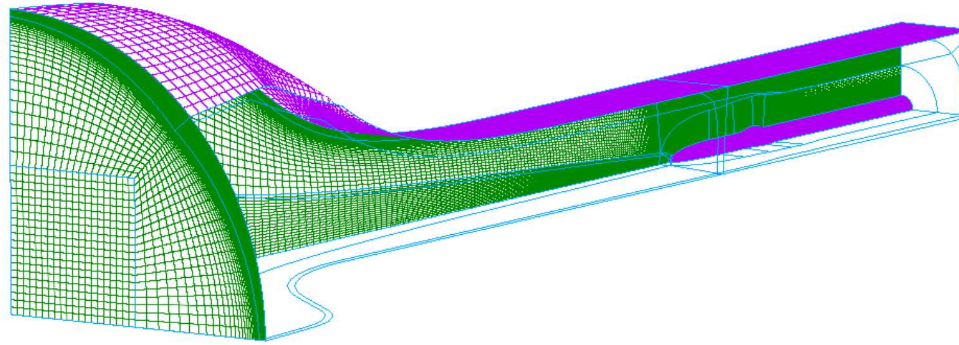


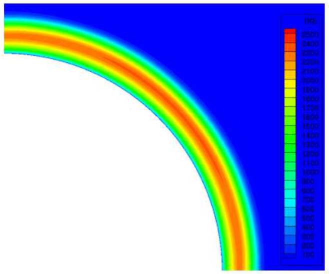
Accurate turbulence intensity for input into simulatons.

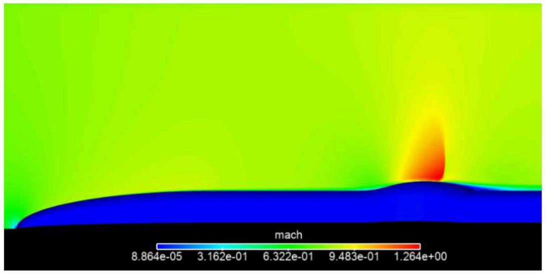
RANS Simulations

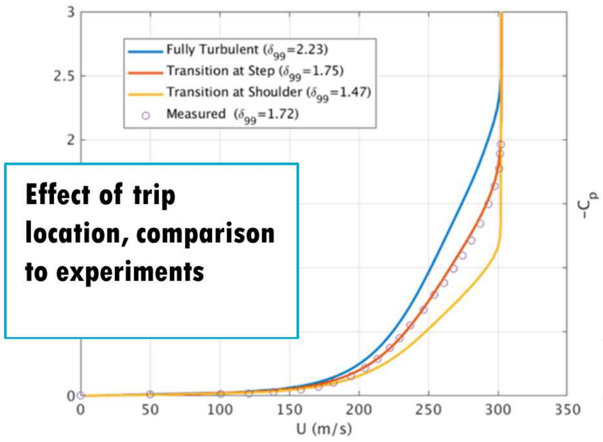
- **Simulations used to optimize model design:**
  - **Confirmation of shock-free elliptical nose shape.**
  - **Quantification of axisymmetry**
  - **Alternative bump shapes**
  - **Estimates of upstream BL**
- **Calibration effort using experimental data:**
  - **Outflow BC: backpressure**
  - **Tunnel wall BL transition**
  - **Model trip effectiveness**
  - **Reynolds number effects**
  - **Adiabatic wall effects**

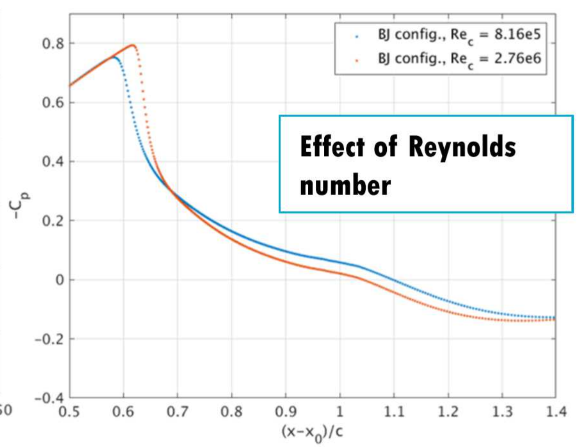
Calibrating out these variables allows focus solely on effects of turbulence models











CFD Challenge

- **New experimental data gives opportunity to evaluate state-of-the-art approaches**
- **Proposing 'blind' CFD challenge, but geometry and boundary conditions provided.**
- **Participants can use any RANS and/or advanced (WMLES/DES/LES) approach.**
- **How do these different approaches fare, particularly when they cannot be calibrated to experimental data *a priori?***
- **Sandia computational team unanonymized, given access to data: How much improvement does known experimental data provide?**
- **Challenge through 2020, present at SciTech 2021.**