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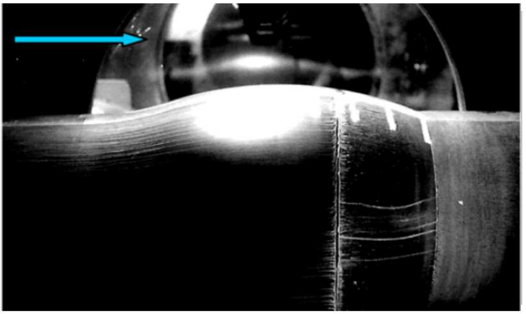

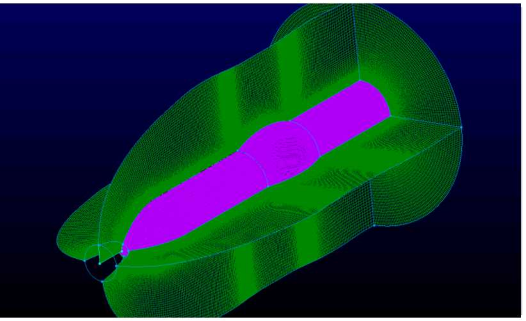

Revisiting the Bachalo-Johnson Axisymmetric Transonic Bump

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Workshop on High Reynolds Number Flow Simulations on Exascale Platforms

Argonne National Laboratory, September 2018

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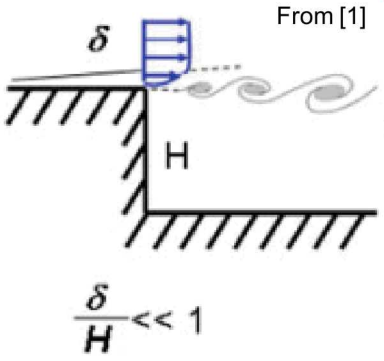
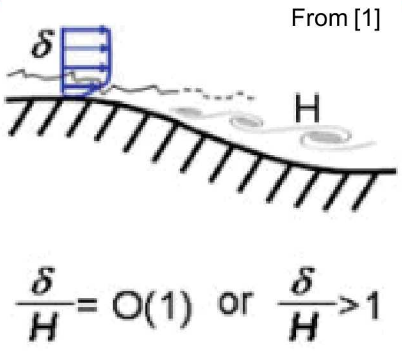
Motivations

- RANS simulations ill-suited for flow separation/dynamic loading
- High cost of DNS at high Re forces use of various LES approaches:
  - Wall-resolved LES (WRLES)
  - Wall-modeled LES (WMLES)
  - Detached eddy simulation (DES)
  - Zonal DES (ZDES)
  - …many other approaches
- These all have difficulty with flow-induced, rather than geometry-fixed, separation
- Separation point moves in time, coupled to fluid flow
- Models show error in pressure distribution and skin-friction

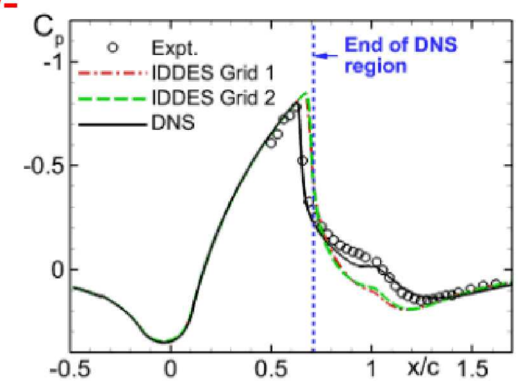


Separation point fixed by geometry

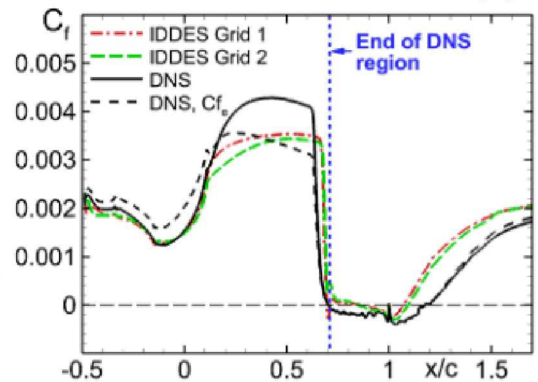


Separation point flow-induced

From [2]



Error in C_p



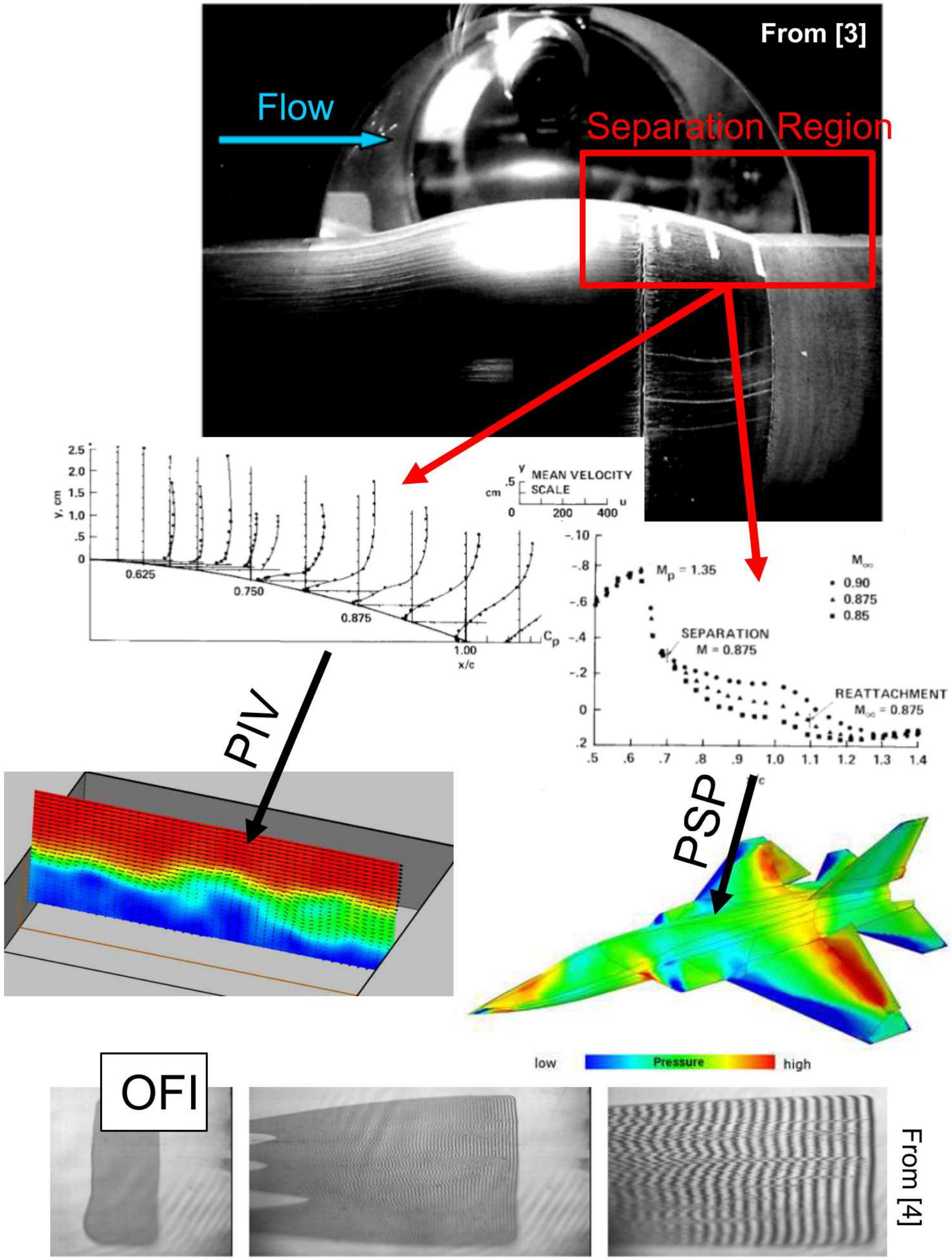
Error in C_f

[1] Deck (2012) Recent improvements in the zonal detached eddy simulation (ZDES) formulation
[2] Spalart et al. (2017) Large-eddy and direct numerical simulations of the Bachalo-Johnson Flow with Shock-Induced Separation. *Flow Turbulence Combust.*

Motivations

- Data from a *single experiment* performed in 1980s is being relied on to guide many modeling efforts
- Axisymmetric ‘hump’ model
- Substantial improvements in diagnostic technology in 35 years:
  - Particle Image Velocimetry
  - Pressure-Sensitive Paint
  - Oil-Film Interferometry
- Replicate experiment at lower Re to allow DNS comparison and create a modern validation dataset.

> *“…the high level of post-separation Reynolds stress measured is considered a clear challenge to RANS models, so that its confirmation is of great interest … A repeat experiment … with modern instrumentation would also have great value, vindicating its excellent design almost four decades ago.”* [2]

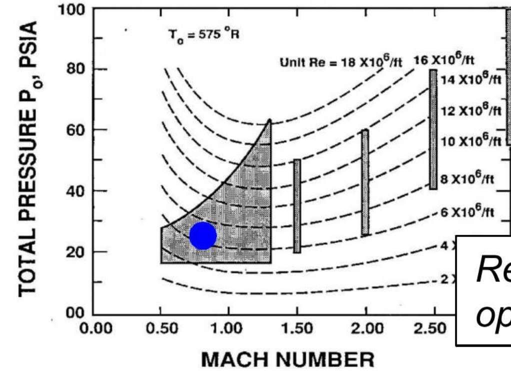


[3] Bachalo and Johnson (1986) Transonic, turbulent boundary-layer separation generated on an axisymmetric flow model. *AIAA Journal*
[4] Naughton and Hind (2013) Multi-image oil-film interferometry skin friction measurements. *Meas Sci Tech*

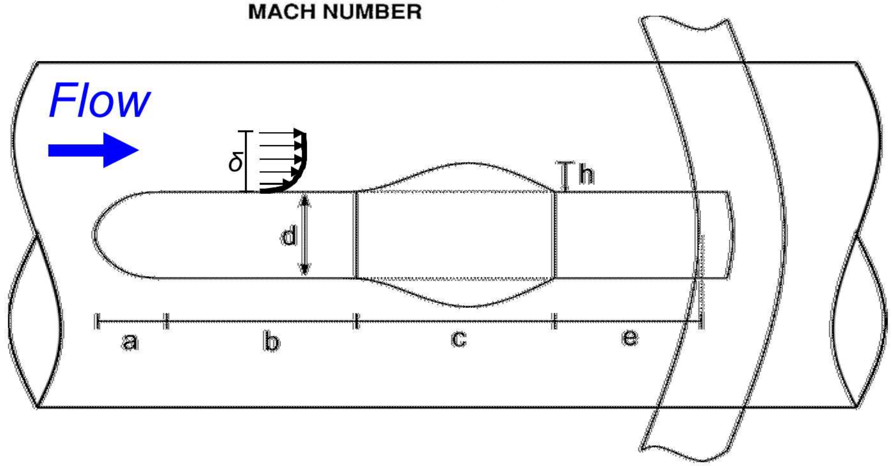
Experiment Design

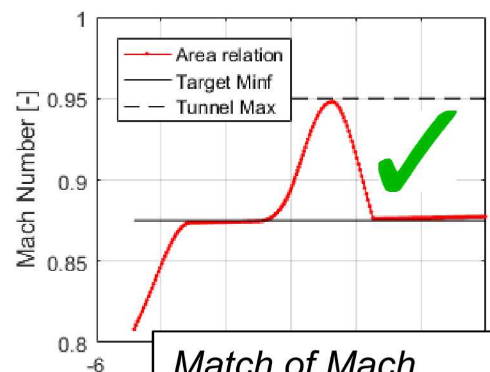
- Model requirement: match flow/geometric quantities of [3]
  - M_{inf} = 0.875, Re_c = 1 million
  - h/d = 1/8; c/d = 4/3; δ/h = 0.42
- Sandia TWT is smaller facility (1 ft x 1 ft) than original experiment at NASA Ames (2 ft x 2 ft)
- Constrained design problem:
  - Diameter *d* large for diagnostics
  - *d* limited by tunnel blockage
  - ***Solid walls requested****

We can meet the experiment requirements in the Sandia TWT

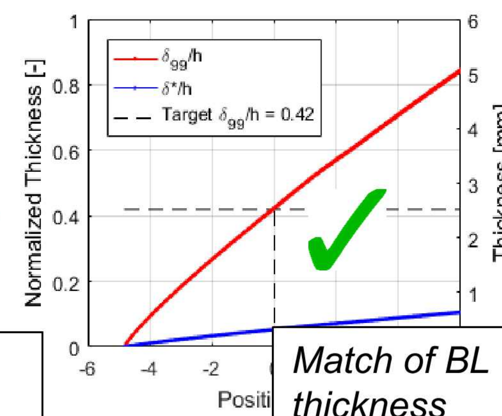


Re/ft within tunnel operating range





Match of Mach number over hump



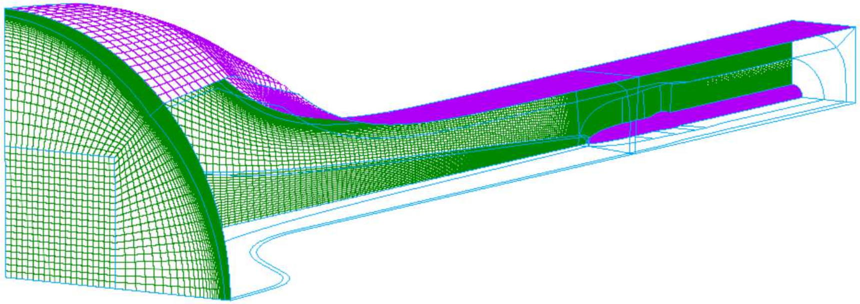
Match of BL thickness

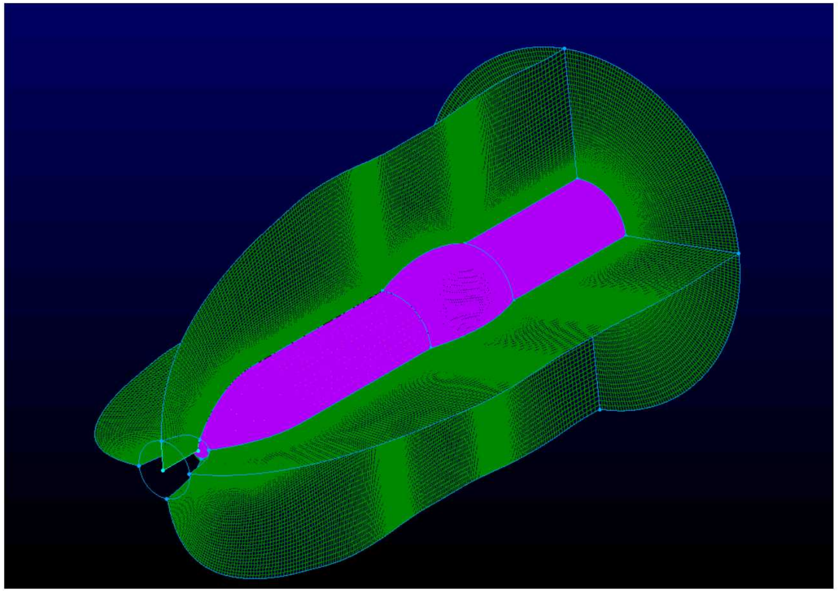
*Typical transonic testing performed with porous or slotted walls to mitigate blockage concerns; difficult to implement as simulation boundary condition.
[3] Bachalo and Johnson (1986) Transonic, turbulent boundary-layer separation generated on an axisymmetric flow model. *AIAA Journal*

Experiment Design

Use simulations to optimize the experiment

- "Model the Test": Model includes the axisymmetric body and wind tunnel geometry
- SST RANS solutions obtained on multiple mesh resolutions
- SIGMA-CFD code – standard second order cell-centered finite volume numerics
- Iterative convergence to steady state
- Boundary conditions: no-slip on the tunnel walls, total conditions on plenum, static back-pressure adjusted to achieve desired Mach number

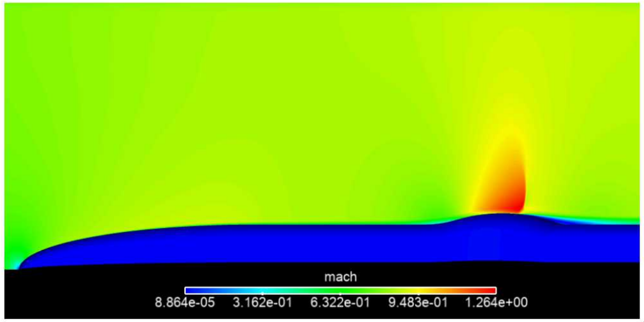




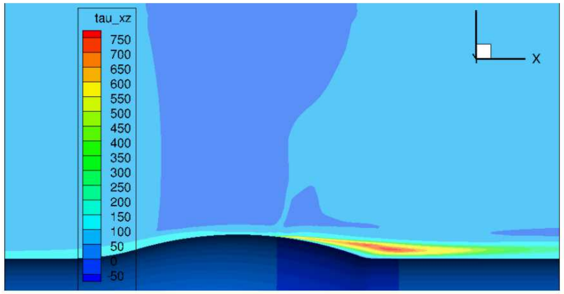
Experiment Design

Simulation greatly helped in multiple aspects of model design and analysis

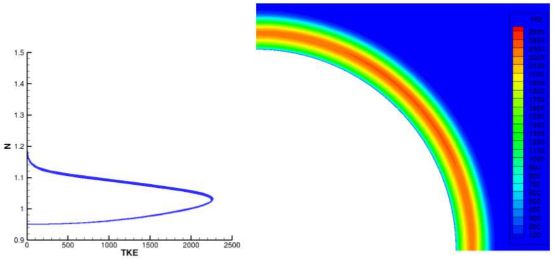
Confirmation of shock-free nose shape



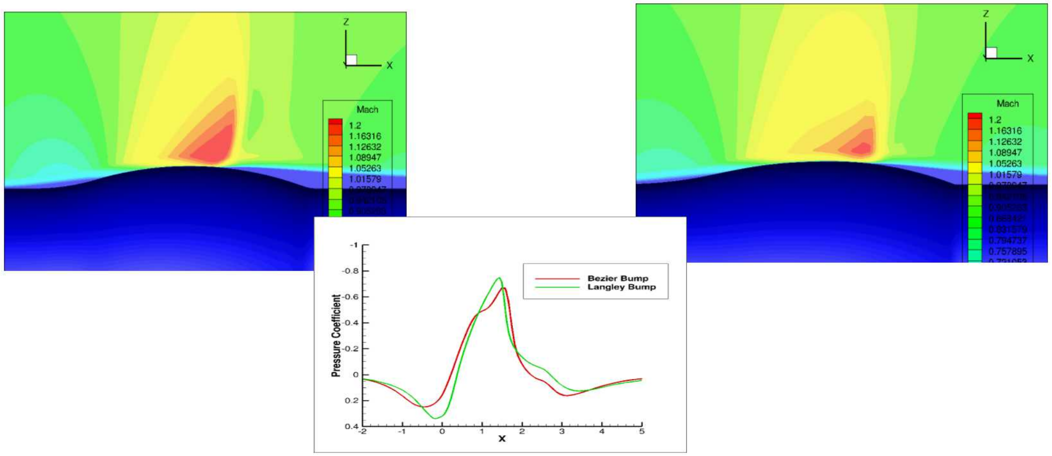
Reynolds stress estimation to set instrumentation requirements



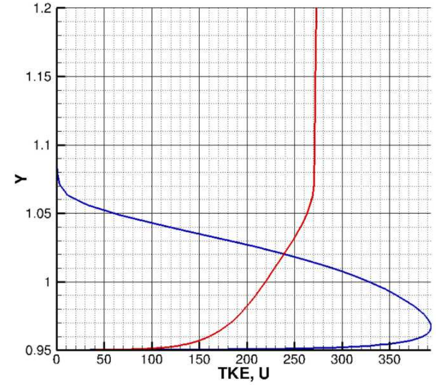
Quantification of axisymmetry



Examining alternative bump shapes



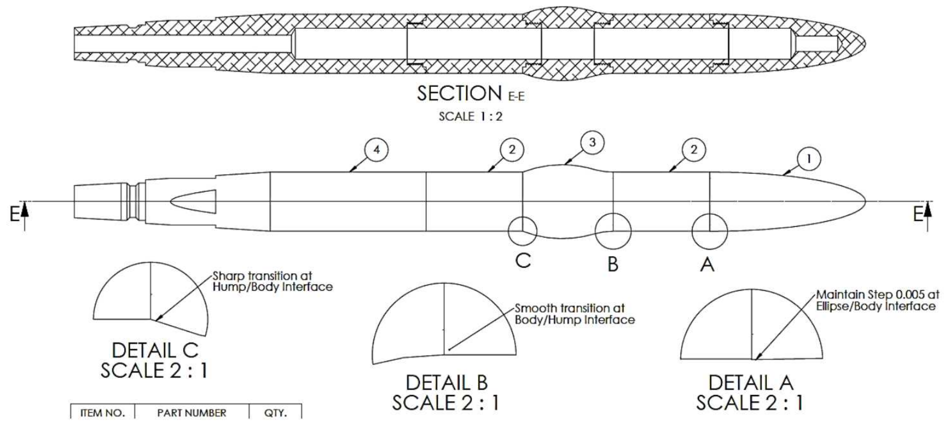
Obtaining desired upstream BL thickness

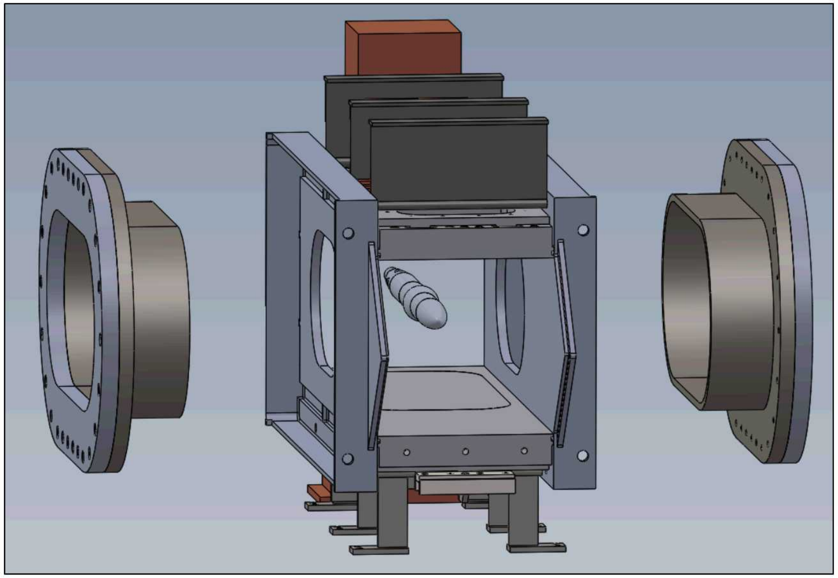


Next Steps: Experiments

A busy 2019 in the tunnel!

- Initial model sent out for manufacture; expected end of September
- First steps: turbulence intensity quantification, BL characterization
- Remainder of year: separation region characterization:
  - Particle Image Velocimetry
  - Fast Pressure Sensitive Paint + Transducers
  - Oil Film Interferometry





Characterized tunnel environment and inflow are a major focus: will make the datasets well-suited for sim-experimental comparisons

Next Steps: Simulations

- New simulations of geometry to be performed using Sandia codes
- DNS/LES studies to characterize transition and upstream boundary layer development.
- WMLES and Hybrid RANS/LES simulations to quantify flow unsteadiness and separation
- Collaboration: Identical simulations by Phillipe Spalart (Boeing)
- LES and DES using various turbulence models and corrections
- Limited DNS: Lower Re allows DNS of a large segment

Combined experimental and DNS reference provides unique validation dataset for model verification and development