Numerical Study of a Transonic Wingtip Flow

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The 30th International Symposium on Shock Waves
July 19–24, 2015

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Outline

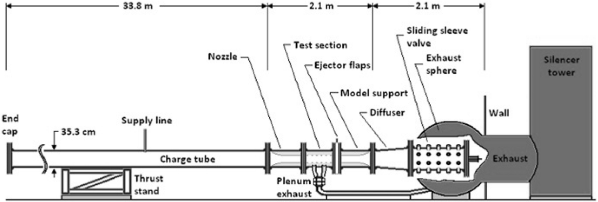
Importance of transonic testing

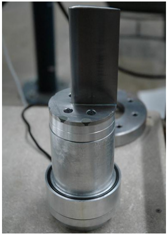
Figure: NASA/Boeing concept.

Figure: NASA/Lockheed Martin concept.

- Push toward more efficient and sustainable aircraft.
- New, unconventional designs are being proposed.
- Designs must be evaluated.
- Experiments can't be replaced.

Ludwieg tube





- AEDC donated tunnel to UTA in 1976.
- Short duration facility ($\approx$ 100 ms).
- Dynamic loading of force balances.
- Porous walls.
- Surface flow visualization.

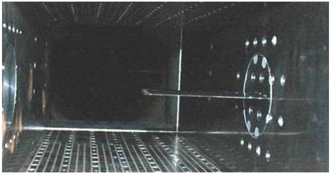
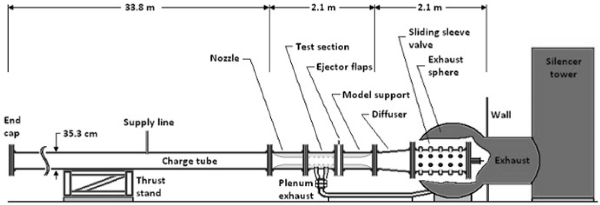
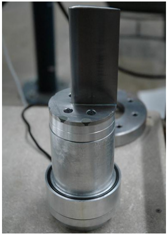


Figure: Test section with wall-mounted wingtip.

Ludwieg tube





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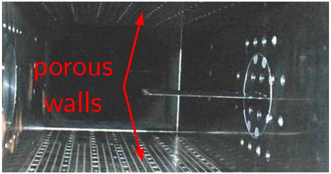

Figure: Test section with wall-mounted wingtip.

Objectives and methodology

For this study as a whole:

Objectives:

- To account for stress waves propagating through the tunnel by using a dynamic calibration.
- To use CFD to validate experimental force measurements.
- To draw deeper insights into the flowfield using a combination of EFD and CFD data.

Methodology:

1. Force measurements with and without calibration.
2. Experimental surface flow visualization.
3. RANS solution of entire test section.

Mesh generation

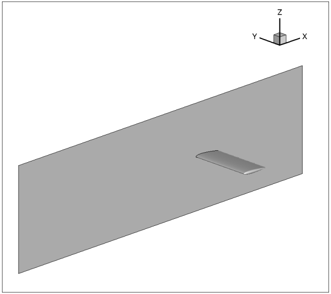

Figure: Geometry.

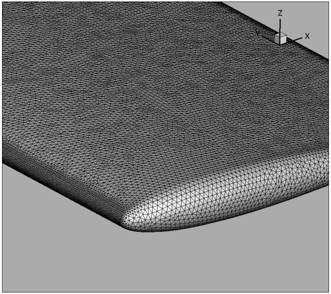

Figure: Surface mesh.

- Surface mesh generated using Pointwise.
- Volume mesh generated using AFLR3.
- Wall y^+ was set to 1.

Flow solver

NASA's FUN3D (Fully Unstructured Navier-Stokes 3D) flow solver.

- Node-base finite-volume code.
- Capable of 2D/3D simulations.
- Speed regimes from subsonic to hypersonic.
- Turbulence model: Spalart–Allmaras.

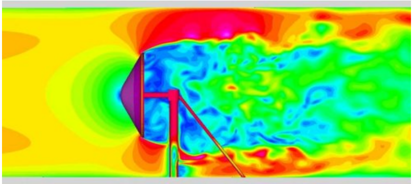

Figure: Hypersonic Inflatable Aerodynamic Decelerator (fun3d.larc.nasa.gov).

Mesh adaptation

- Feature-based mesh adaptation used to ensure mesh-independent solution.
- Metric used in adaptation was based on Mach number.
- Total number of cells decreased from 37 million to 27 million.
- Flow solver convergence improved.
- Mesh frozen below $y^+ \approx 300$.

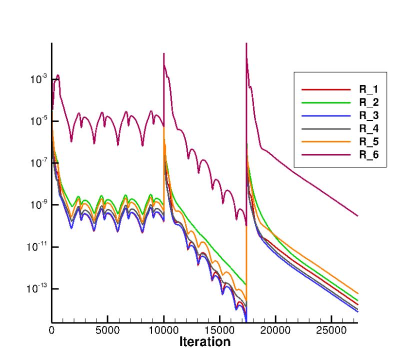

Figure: Sample residual convergence.

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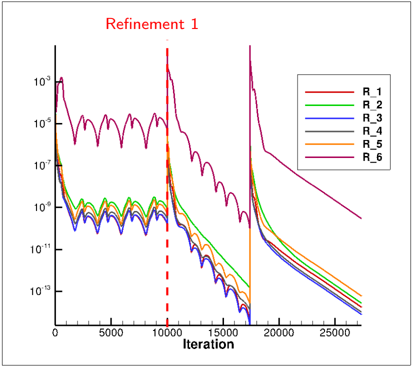

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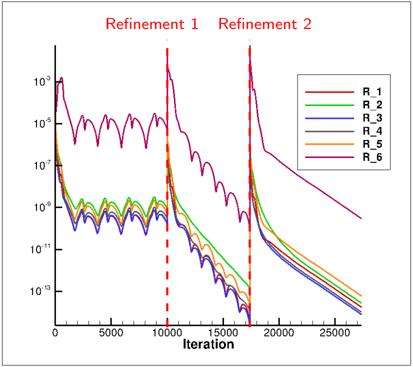

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Mesh adaptation, cont.

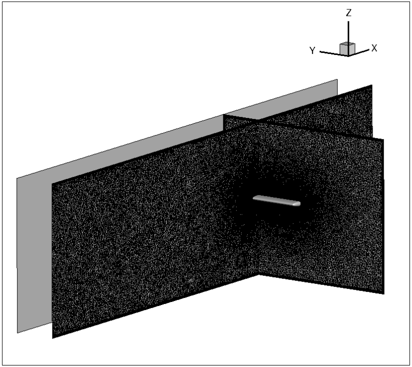


Figure: Original mesh.

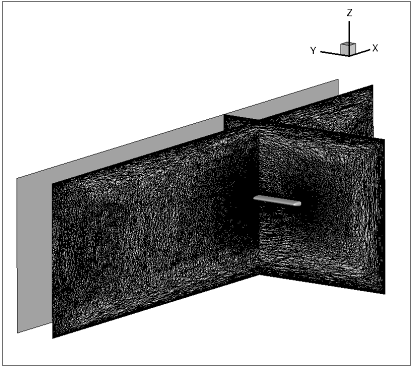
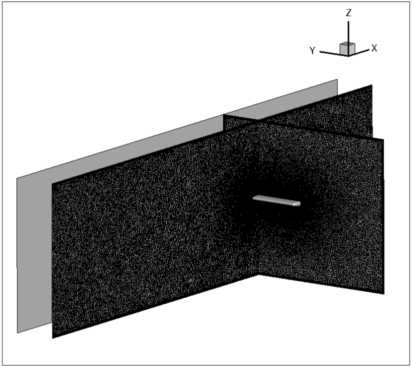


Figure: Adapted mesh.

Mesh adaptation, cont.



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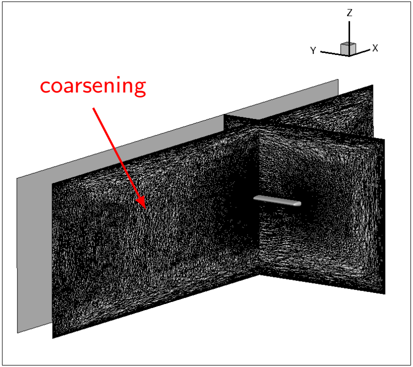

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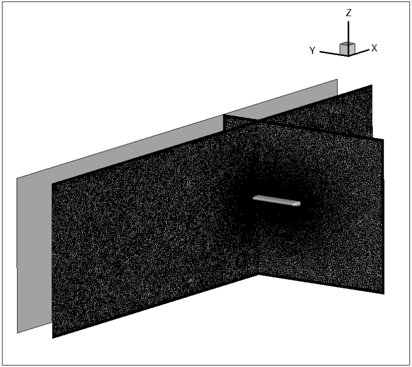

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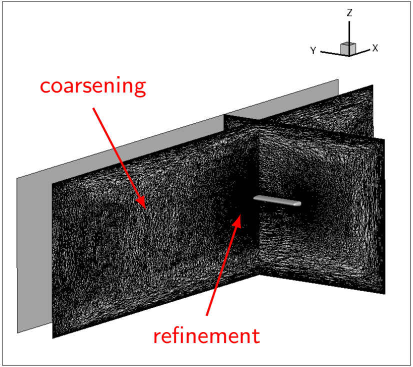


Figure: Adapted mesh.

Modeling porous walls

- Methods have been developed for modeling the flow across porous walls.
- Pressure difference across porous walls:

$$C_p = \frac{p_{\text{inner}} - p_{\text{outer}}}{q_\infty}$$

- For the present experiments $C_p \approx -0.04$.
- Effects of flow across the walls neglected.

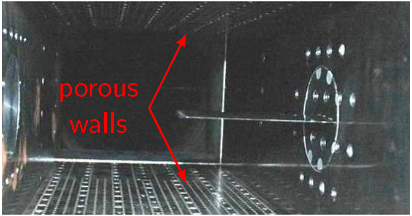


Figure: Test section with wall-mounted wingtip.

Force coefficients

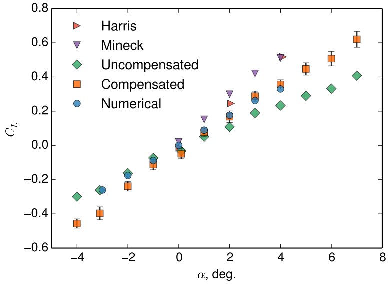


Figure: C_L vs α.

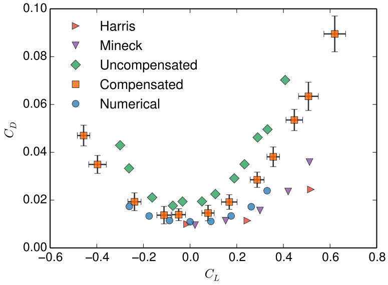
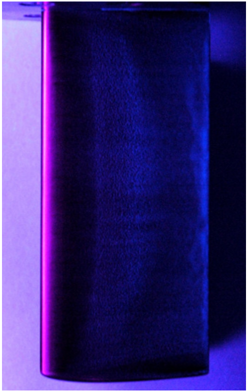


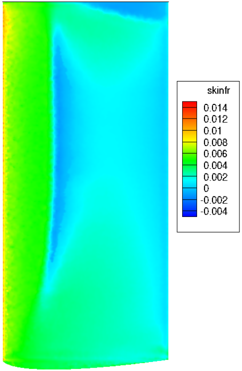
Figure: Drag polar.

- $C_L = L/(q_\infty S)$ and $C_D = D/(q_\infty S)$.
- Harris' results for 2D wing.

Surface flow visualization



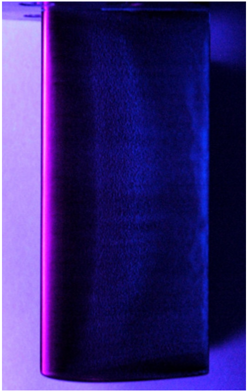
(a) Experiment.



(b) CFD.

Figure: Comparison between experimental and computational surface flow visualization at $\alpha = 4^\circ$ (top view).

Surface flow visualization



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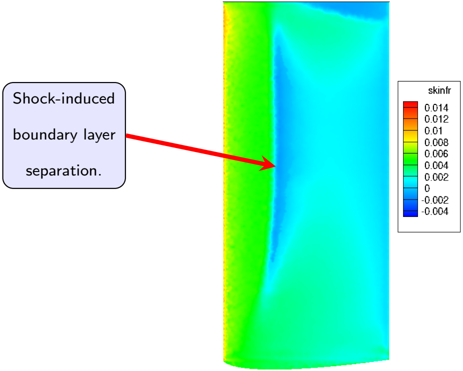

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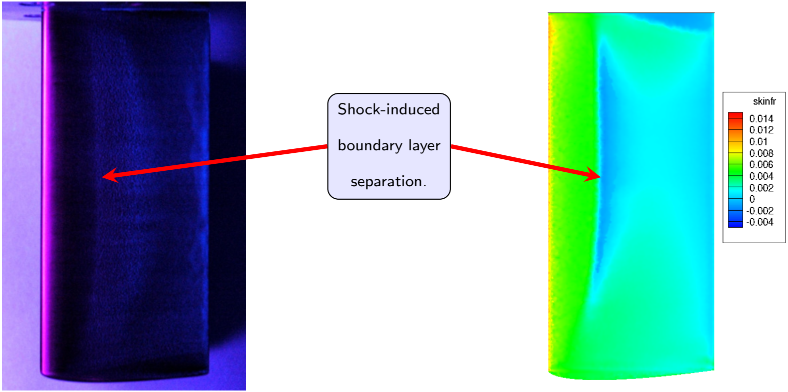

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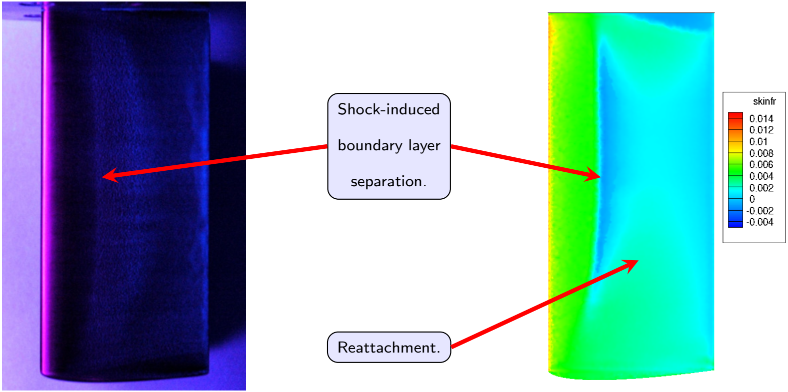

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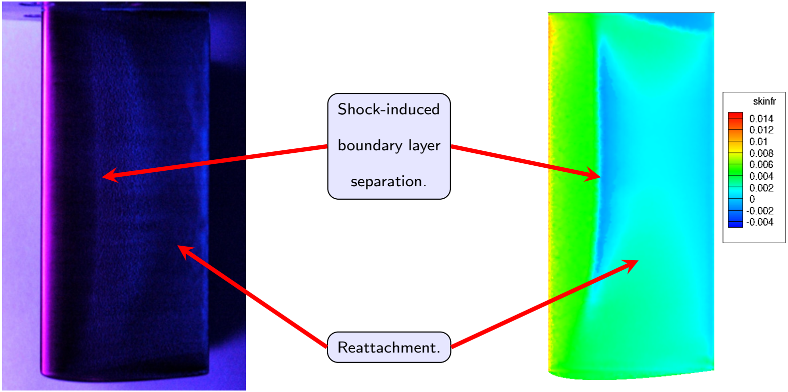

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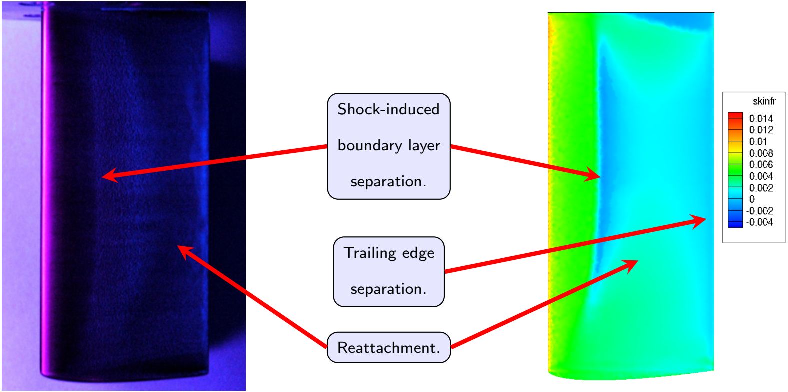

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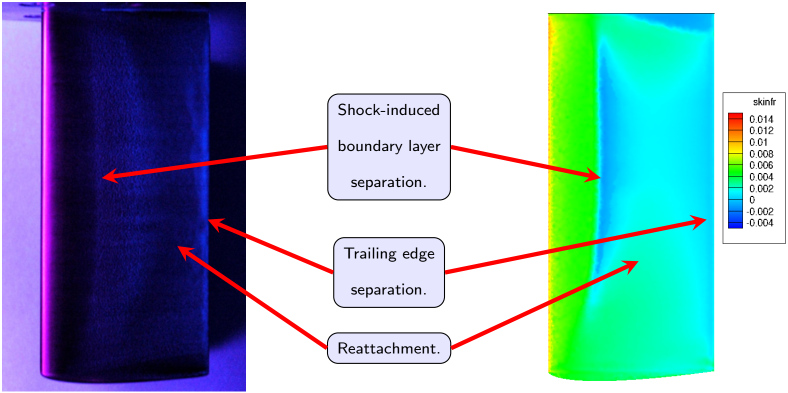

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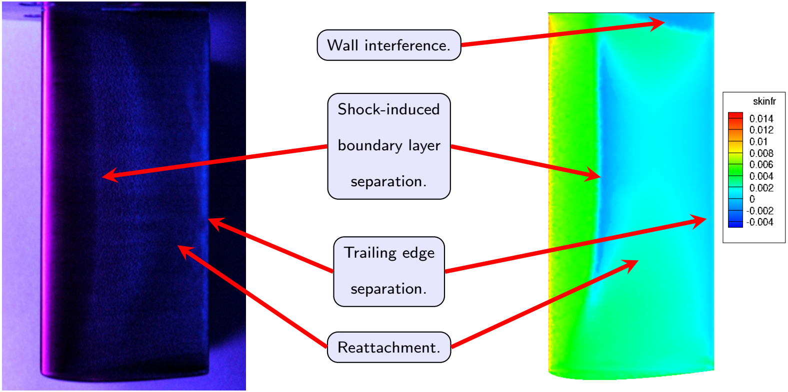

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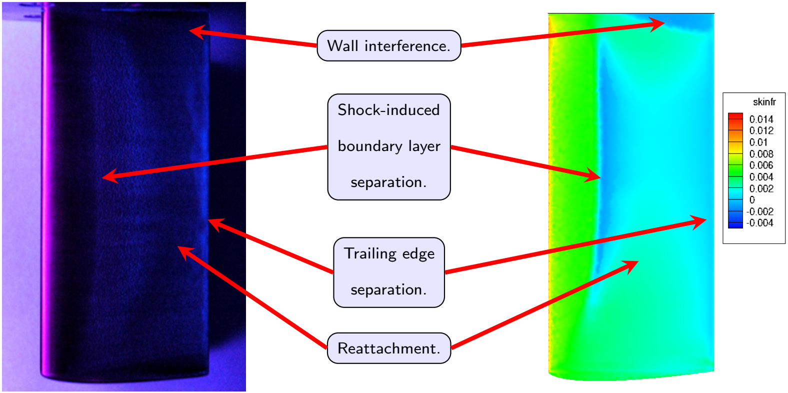

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Conclusions

- Numerical results agree well with experimental results in terms of force coefficients and flow visualization.
- A more accurate interpretation of the surface flow visualization was made possible using CFD data.
- Dynamic calibration was effective.
- Results demonstrate the feasibility of using more complex models for calibration in conjunction with CFD.

Questions?