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Fluid-Structure Interactions on a Slender Cone at Mach 8

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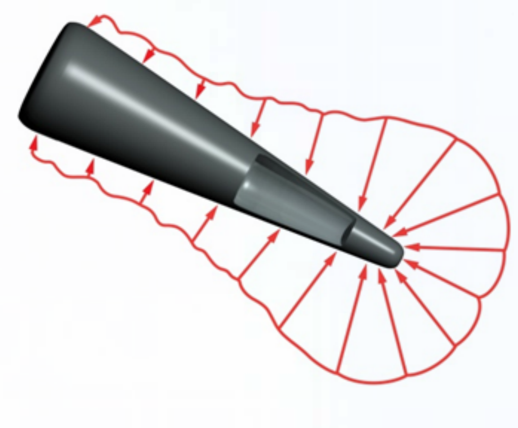
Motivation

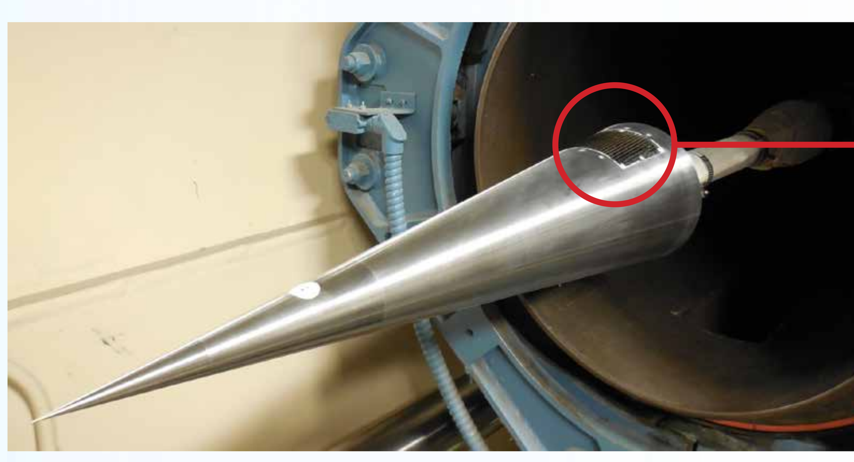
- Internally carried payloads experience intense vibrations from transitional pressure fluctuation loading, which can damage internal components.
- It is of prime importance to understand the fluid/structural coupling that occurs between the flow and the vehicle.
- New experimental data are required for physical discovery to understand how these vibrations are generated and to support the development of predictive models



Unsteady pressure drives transitional loading on RV's

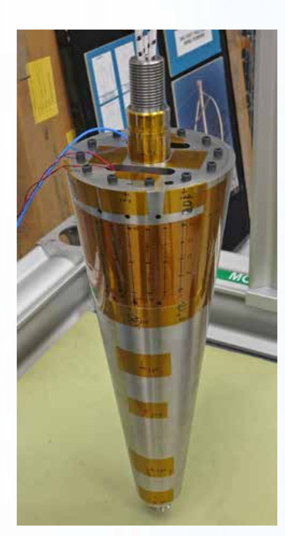
Experiment Design

- We have designed a coupled fluid/structure interaction experiment to measure the input pressure loading and resulting structural response of a thin panel on a cone at Mach 8.
  - The panel configuration can be changed to vary its structural natural frequencies.
  - The panel loading can be changed from laminar to transitional to turbulent boundary layers.
- Panel vibration is suspected to be driven by turbulent spots that form during boundary-layer transition.



Bridging the Fluid/Structure Gap

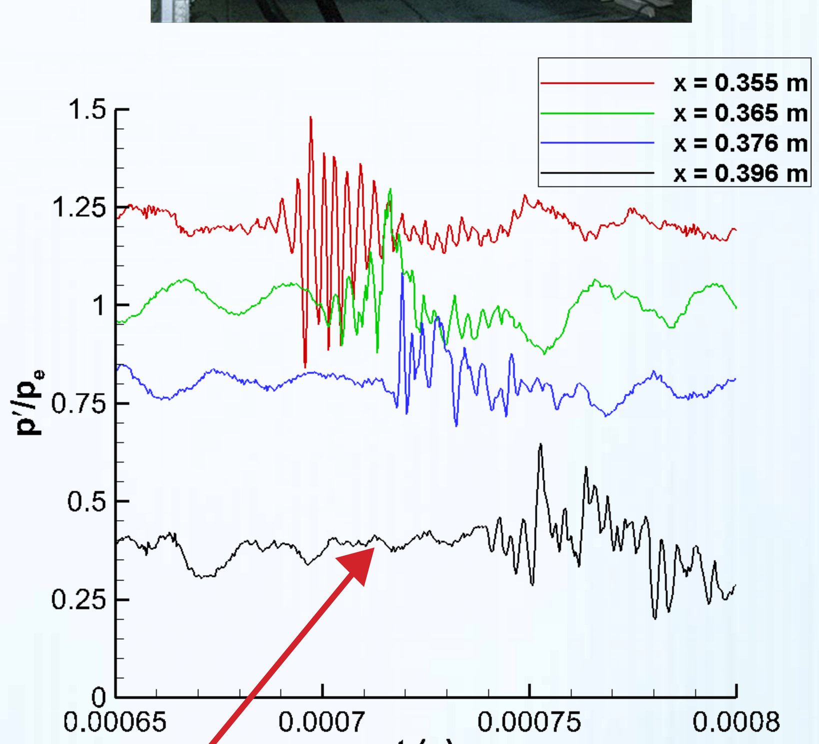
- We have been able to bridge the fluid-structure gap by collaborating with structural dynamics experts at Sandia.
  - Assistance designing panel configurations.
  - Fabrication of composite panel by Sandia's 'Microsystem Packaging and Polymer Processing' department.
  - Structural dynamics group conducted hammer tests to identify structural natural frequencies of panel configurations

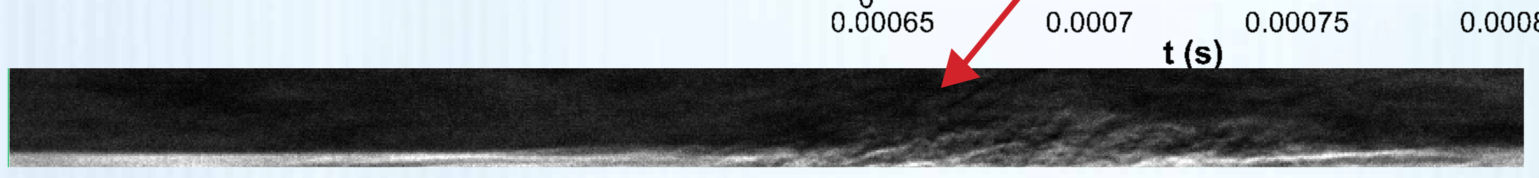


Advanced Diagnostics

- All tests are conducted in Sandia's Hypersonic Wind Tunnel (HWT) at Mach 8.
- Visualize boundary-layer disturbances with a high speed schlieren system.
  - 20 ns exposure time.
  - Frame rates up to 100's of kHz.
- Characterize panel input loading using high-frequency pressure transducers.
  - Used to compute boundary-layer statistics including the turbulent burst rate
- Measure panel response with internal accelerometers

Interchangeable HWT nozzles



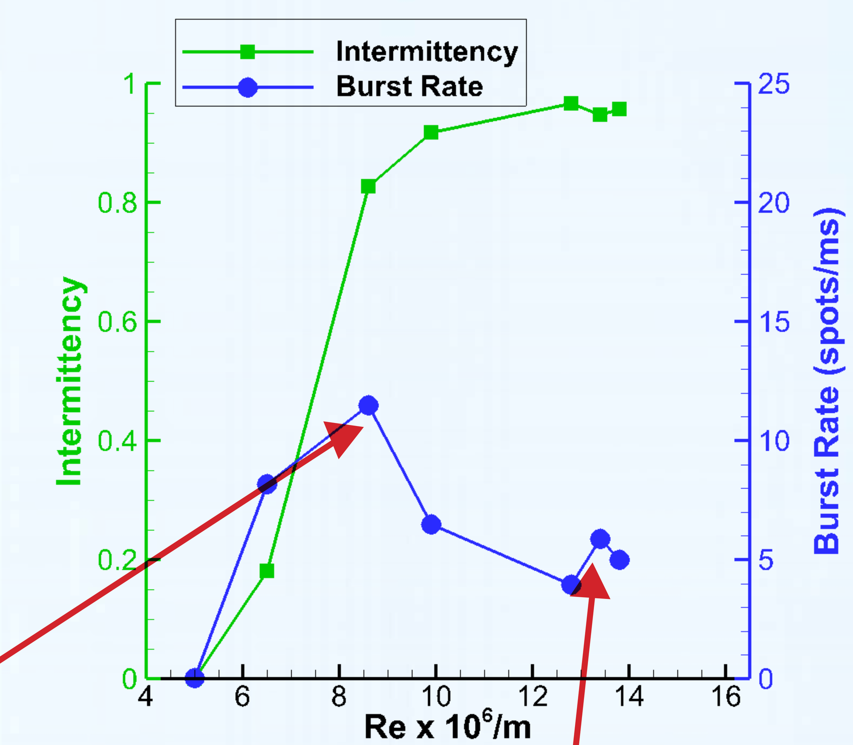


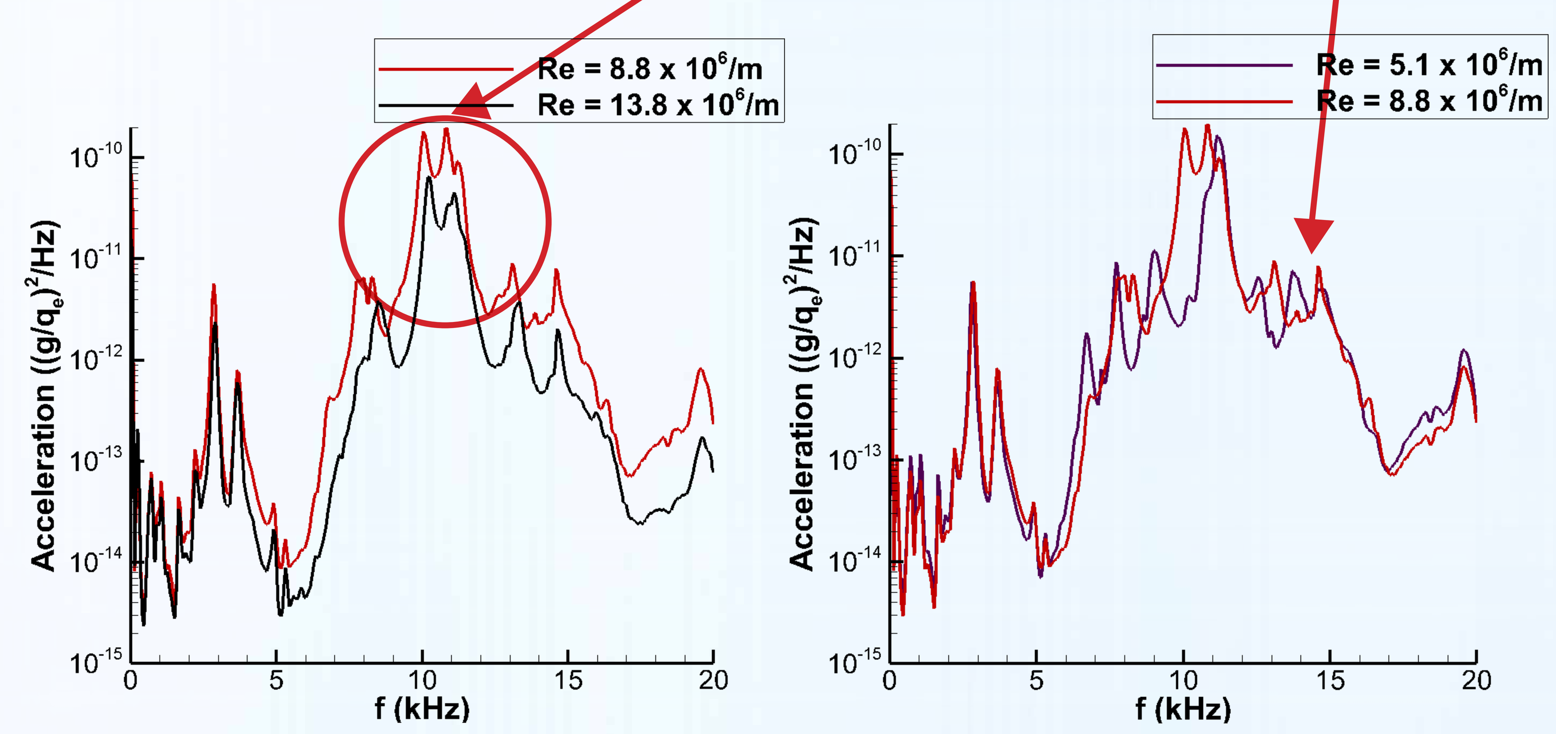
Simultaneous flow field measurements and panel response characterization

Physical Discovery

- Under a laminar boundary layer, panel shows lowest excitation levels.
- Elevated panel vibrations occur during boundary-layer transition.
  - Elevated response occurs near frequencies similar to the elevated turbulent burst rate at that Reynolds number.
- Panel has a lower vibrational response under more turbulent flow
  - A lower burst rate corresponds to this lower vibration response.
  - Panel sees a higher intermittency, and less switching between laminar and turbulent flow.
- Data helps understand the physical mechanism for increased transitional vibrations.
  - The turbulent burst rate appears to correlate with increased vibration levels.
- Results are being used for model development and validation of Sandia's predictive tools for real vehicles in flight environments

Boundary layer statistics computed from pressure measurements





Elevated transitional vibrations near turbulent burst rate *Lower turbulent vibrations*

Future Tests and Collaborations

- Additional testing will occur in the Purdue Boeing/AFOSR Mach 6 Quiet Tunnel in April 2016.
  - Allows quiet flow experiments where mode matching can be explored.
  - Collaboration supported by an Academic Alliance LDRD.
- Work will continue through the WSEAT reentry program after the conclusion of the ECLDRD in September 2016.
  - There is also interest from AFOSR to fund Sandia to explore potential FSI issues with hypersonic control surfaces.

Conclusions

- We have obtained some of the first measurements of fluid/structure coupling in hypersonic flow, to better understand how the transitional pressure fluctuations result in vehicle vibration.
- First experimental evidence to confirm that the turbulent burst rate correlates to elevated vibration levels.
- Novel data set obtained for development and validation of Sandia's predictive models for flight environments.
- References

  - Fluid-Structure Interactions using Controlled Disturbances on a Slender Cone at Mach 8, K. Casper, S. Beresh, J. Henfling, R. Spillers, and P. Hunter, AIAA Paper 2016-1126, January 2016.
  - Hypersonic Wind-Tunnel Measurements of Boundary-Layer Transition on a Slender Cone, K. Casper, S. Beresh, J. Henfling, R. Spillers, B. Pruett, and S. Schneider, *AIAA Journal, Articles in Advance,* doi: 10.2514/1.J054033, 2015.
  - Pressure Fluctuations Beneath Instability Wave Packets and Turbulent Spots in a Hypersonic Boundary Layer, K. Casper, S. Beresh, and S. Schneider, *Journal of Fluid Mechanics,* Vol. 756, October 2014, pp. 1058-1091.

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