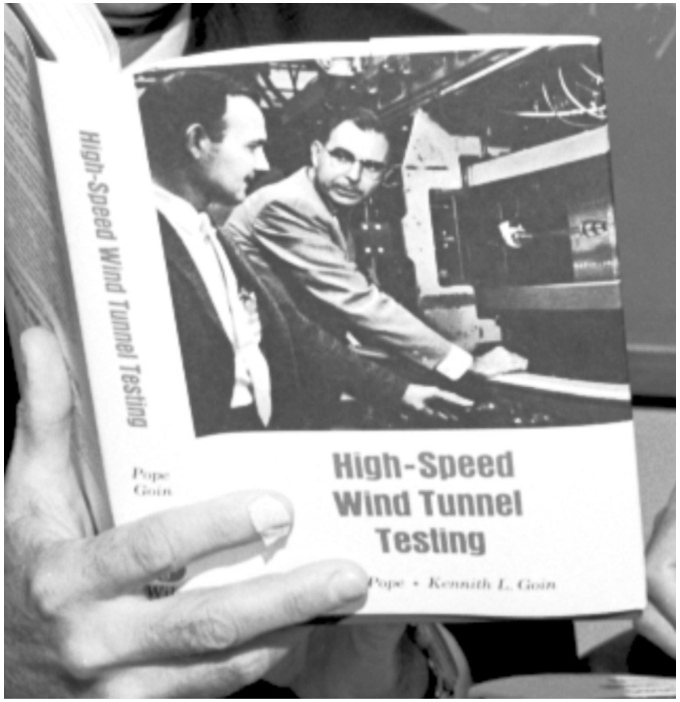
SAND2018-2080PE

Sandia's Wind Tunnels: Advanced Capabilities for Testing and Research

Steven Beresh
Engineering Sciences Center
Sandia National Laboratories
Albuquerque, NM

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and 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.

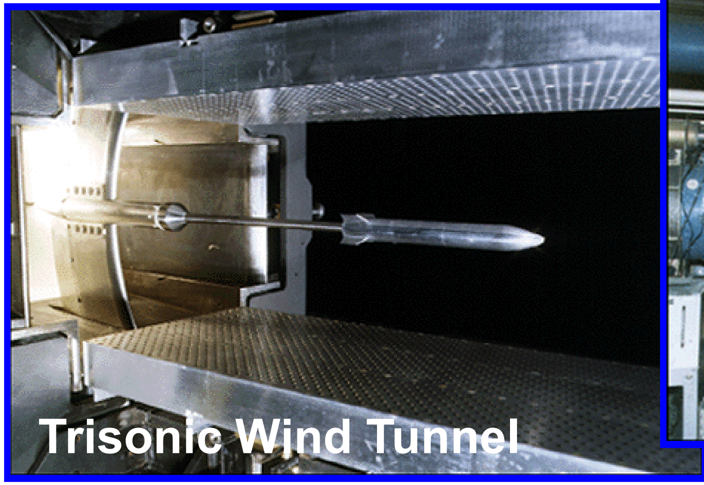
Sandians literally wrote the book on high-speed wind tunnel testing.

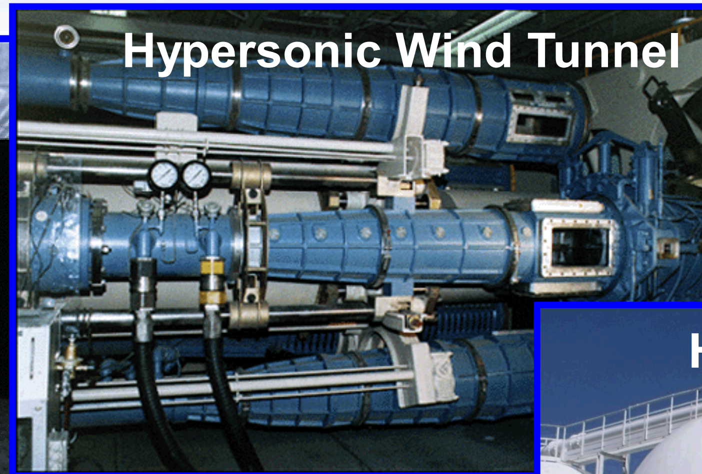


Alan Pope and Ken Goin, 1965

Laboratories

Experimental Aerosciences Facility





Trisonic Wind Tunnel (TWT)

- Mach 0.5 – 3
- Gravity bombs, missiles

Hypersonic Wind Tunnel (HWT)

- Mach 5, 8, 14
- Re-entry vehicles, rockets

High-Altitude Chamber (HAC)

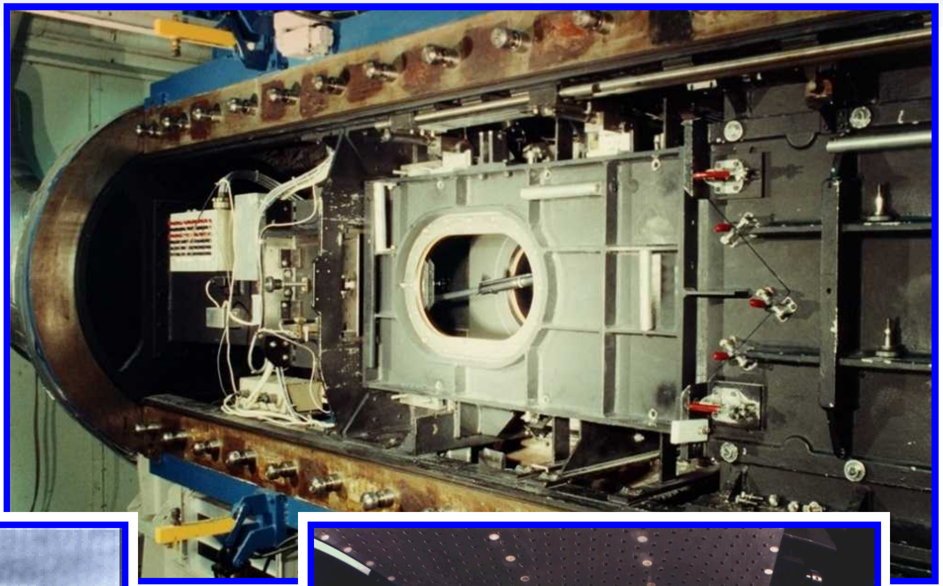
- Satellite components

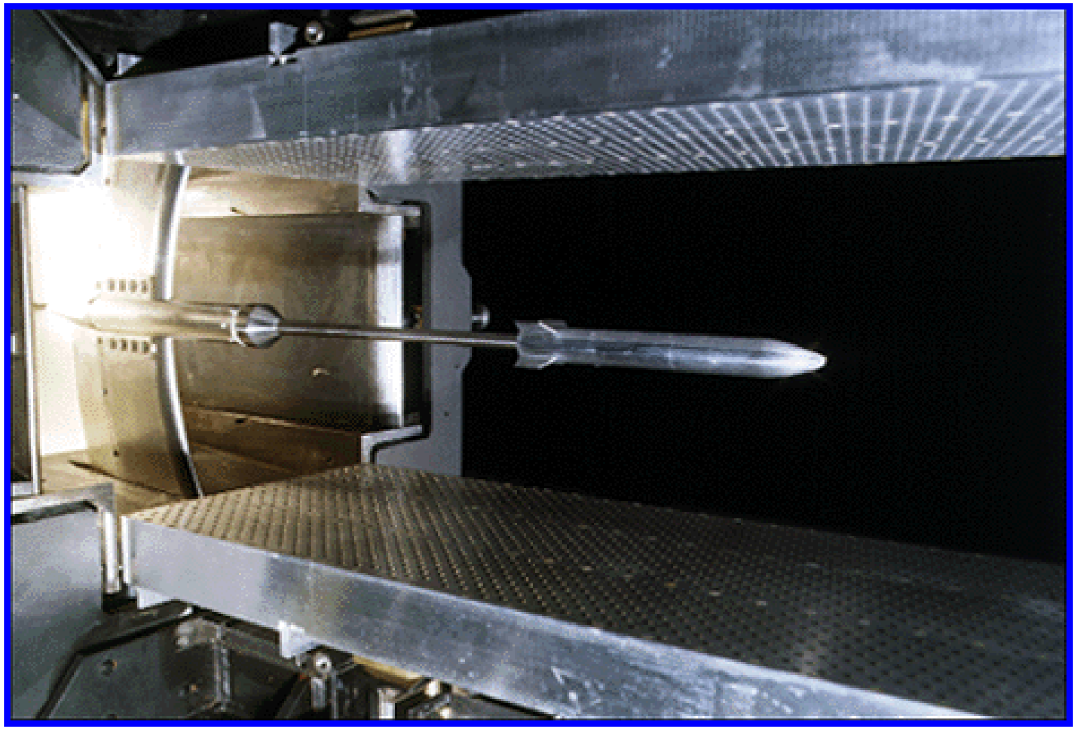
Multi-Phase Shock Tube (MST)

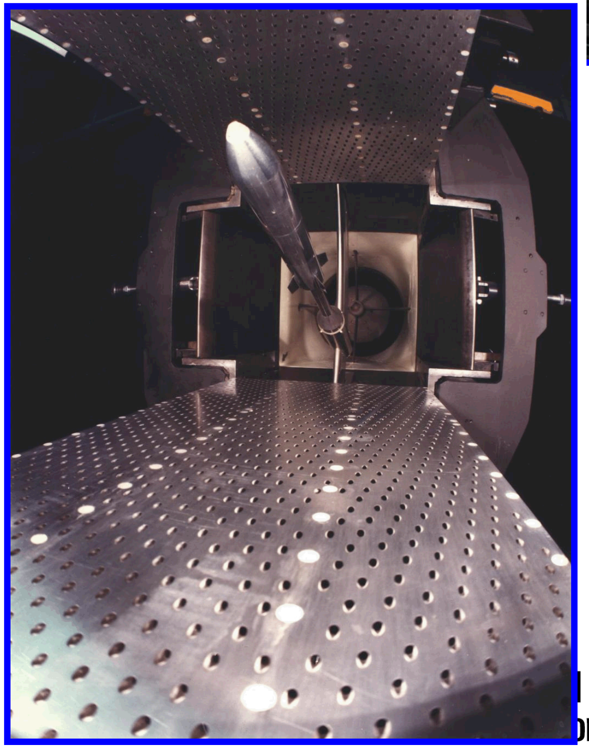
- Explosives research

Trisonic Wind Tunnel (TWT)

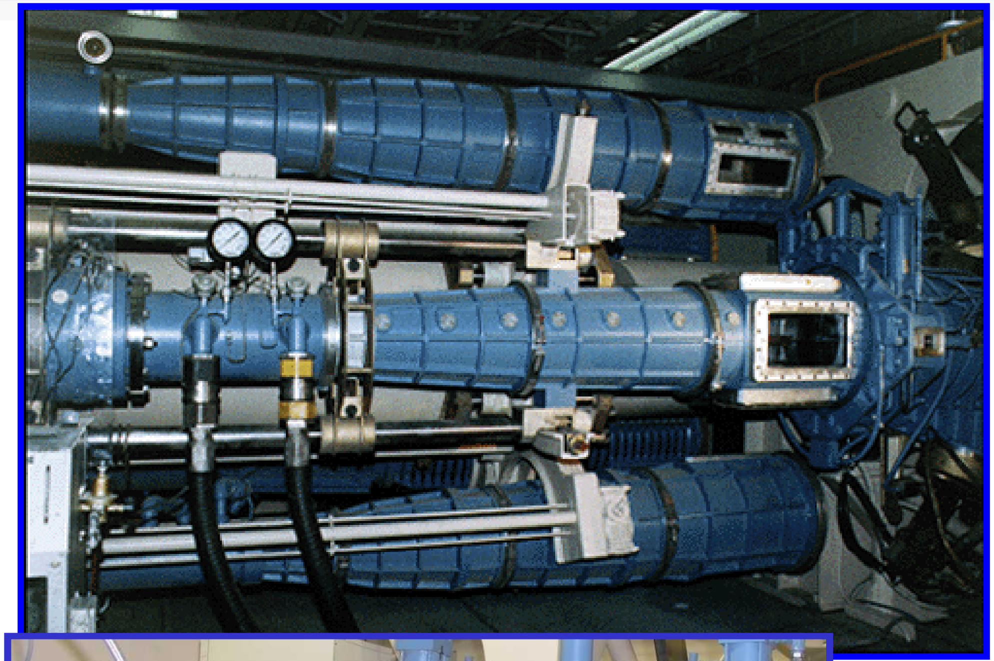
- Blowdown to atmosphere
- M_∞ = 0.5 - 1.3, 1.5, 2.0, 2.5, 3.0
- Re = 3 - 20 × 10^6 /ft
- Run times: 20 - 120 seconds at 20 - 30 minute intervals
- 12" × 12" test section



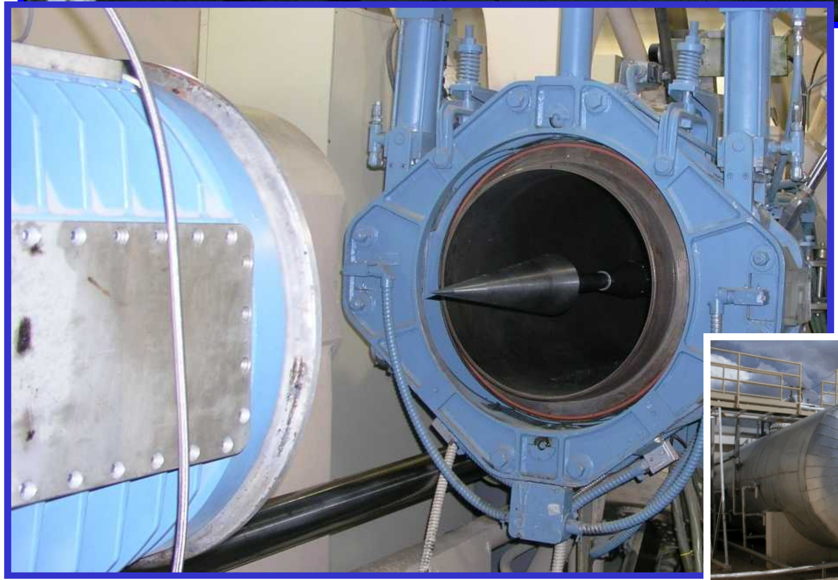




Hypersonic Wind Tunnel (HWT)



- **Blowdown to vacuum**
- **Mach 5, 8, and 14**
  - o air at Mach 5
  - o N_2 at Mach 8 and 14
- **Re = 0.2 - 10 x 10^6 /ft**
- **Run times: ~45 sec at 45 minute intervals**
- **18" diameter test section**
- **T_0 to 2500°R (1400 K)**



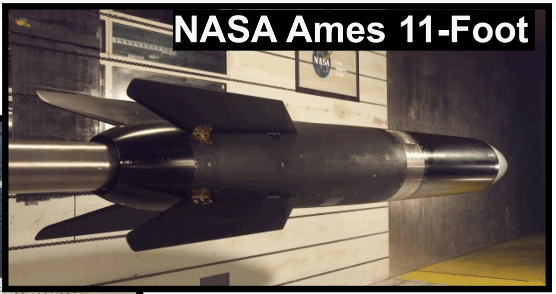
National Laboratories

External Wind Tunnel Testing

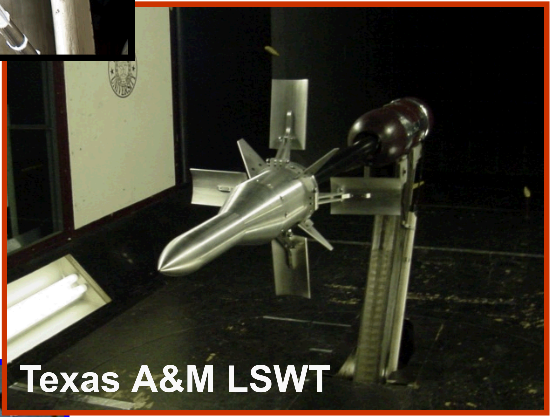
Sandia also conducts tests in external wind tunnels when necessary.

- Different speed regime
- Larger scale
- High temperature

We are simultaneously a facility operator, our own internal customer, and an external customer.


NASA Ames 11-Foot


AEDC 16T


Texas A&M LSWT


Purdue Quiet Tunnel


Ames AHF Arc Jet


Lockheed Martin HSWT

Sandia recently has invested considerable funds modernizing our tunnel infrastructure.

- High-pressure air tanks
- Compressors, dryers, and filters
- Refurbished vacuum tanks
- Data acquisition electronics
- Refurbished flow heaters
- Electrical service for heaters
- Valves and regulators for gas handling
- Control system (in progress)

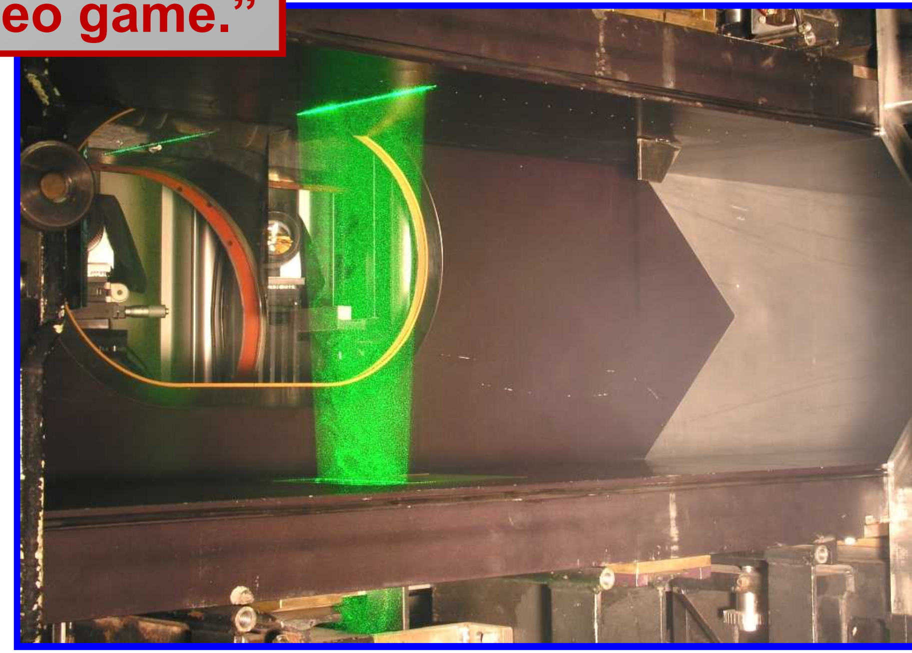
…and much more!

Laboratories

Much of our focus in our laboratory is on advanced diagnostics.

"Without validation, CFD is just a video game."

Data acquisition ~1950



Data acquisition ~21st century

Experimental data are the foundation on which Sandia's modeling and simulation capability is built.

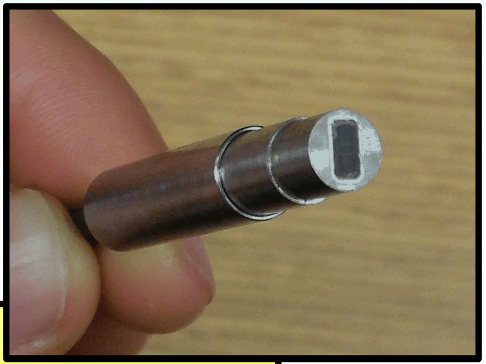
- Provide scientific discovery as well as validation data.
- Do we even know the physics we're trying to model?

Modern instrumentation in wind tunnels vastly transcends traditional measurement of aerodynamic coefficients.

Next generation sensors are emerging.

MEMS technology provides new, smaller sensors.

- Improves frequency response and spatial resolution.
- Allows new parameters to be measured.



Shear stress sensors:

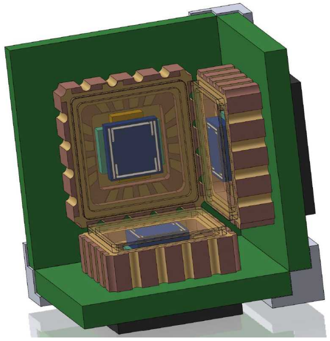
- New technology from Interdisciplinary Consulting Corp (IC2).
- Direct measurement using optical interrogation of a floating element.

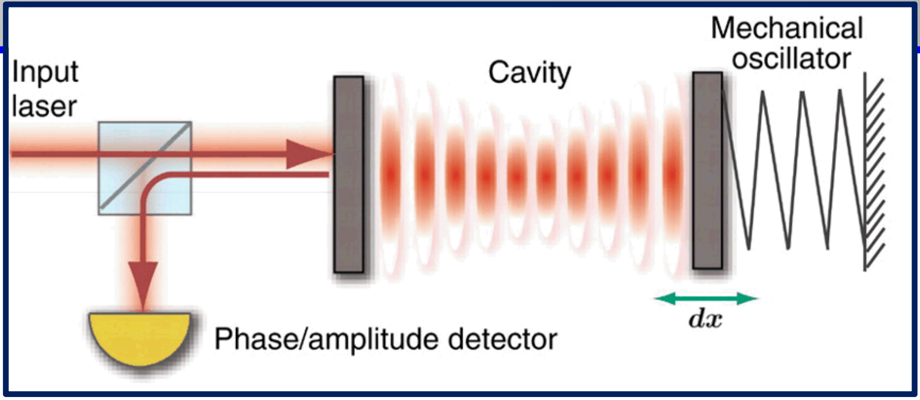
Current *accelerometers* are too large (6-mm cube) and too slow (10 kHz).

- Limits investigation of structural dynamics in *fluid/structure interaction*.

New sensors leverage NOMS (nano-optomechanical systems) technology.

- Sandia is building a tri-axial accelerometer smaller than an apple seed.
- Allow vibrational measurement of structures at previously impossible locations.





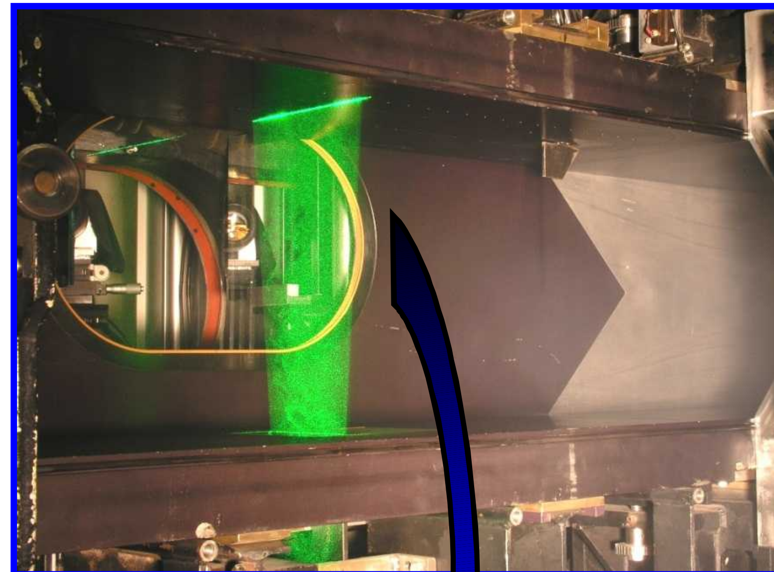
Particle Image Velocimetry (PIV) has emerged as our most widely used measurement.

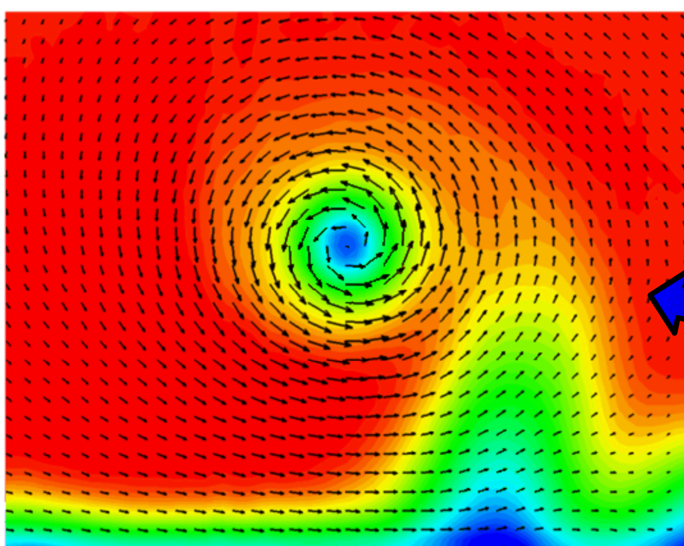
PIV provides CFD-like quantitative flowfield definition, but with experimental data.

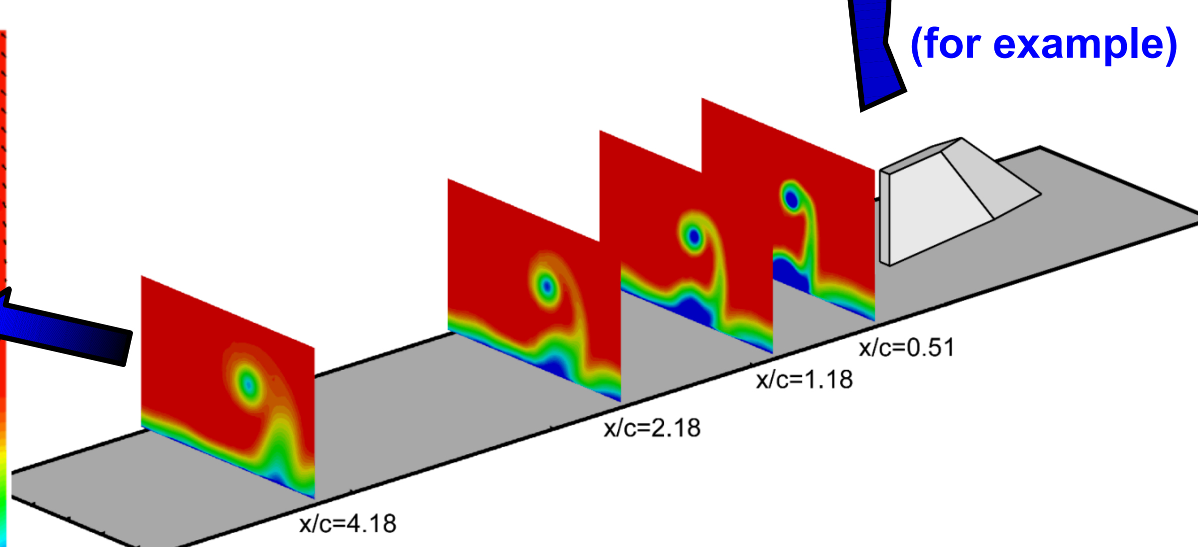
- Measures a plane of three-component velocity vectors.
- Can be reduced to mean velocity fields, turbulence quantities, flow structures, etc.

We have applied PIV to many programs:

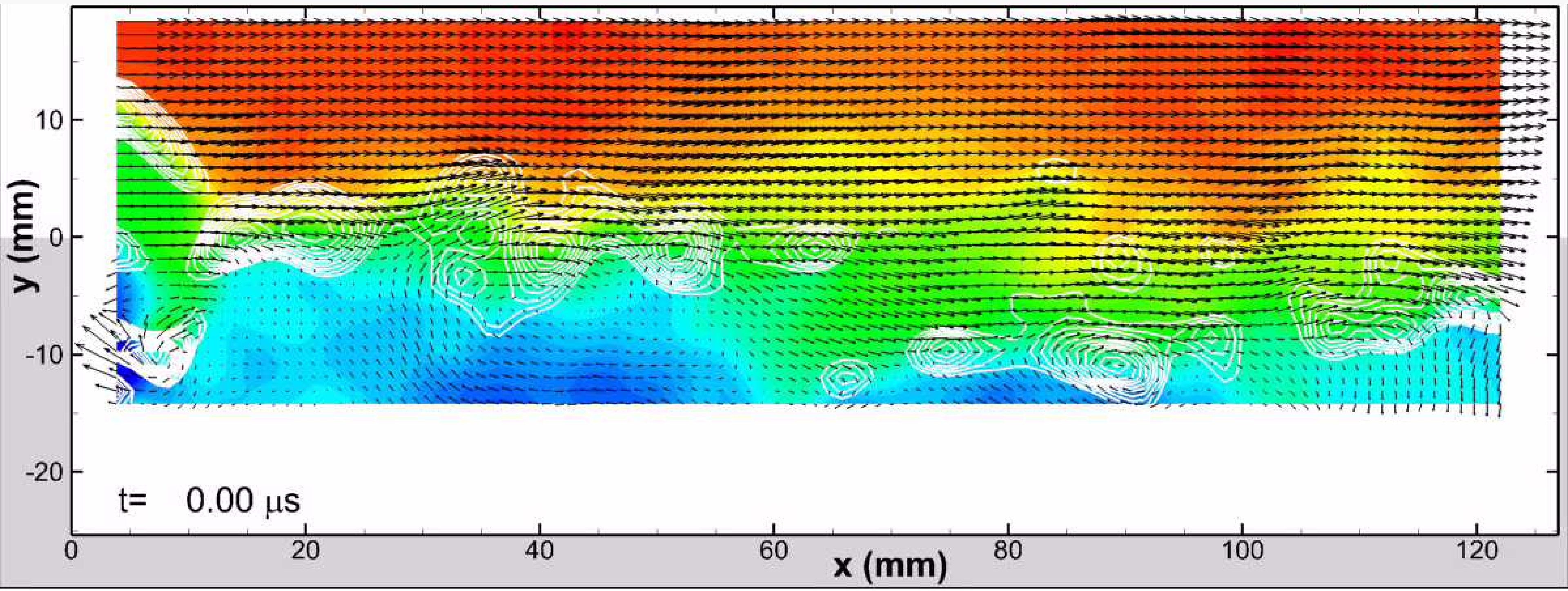
- Fin / fin interaction
- Jet / fin interaction
- Weapons bay aeroacoustics
- Aero-optics







New technologies allow us to acquire PIV movies in high-speed flows.



Example: Mach 0.8 flow over a cavity to represent weapons bay physics.

Each velocity vector is a quantitative measurement and a signal in time, complete with estimated uncertainty.

Lots of physics encapsulated in such data, if only we can learn how to extract them and model them.

A large part of what makes wind tunnel testing modern is the advanced measurement capability now possible.

Sandia National Laboratories

Unsteady Pressure Sensitive Paint (PSP)

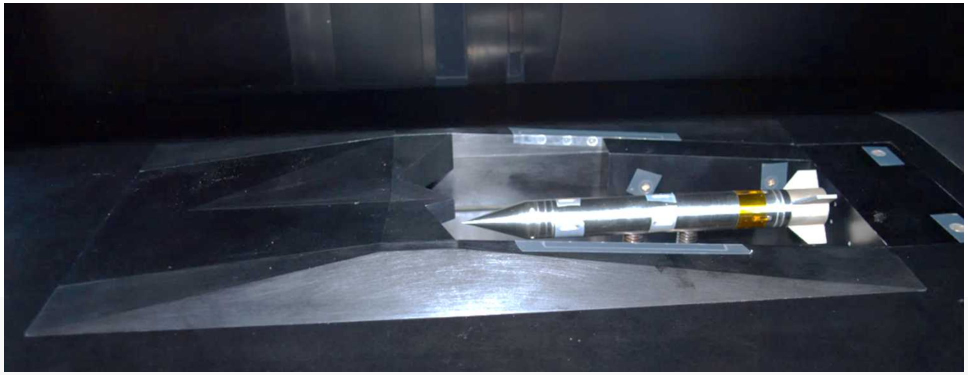
Uses luminescent paints to measure oxygen content.

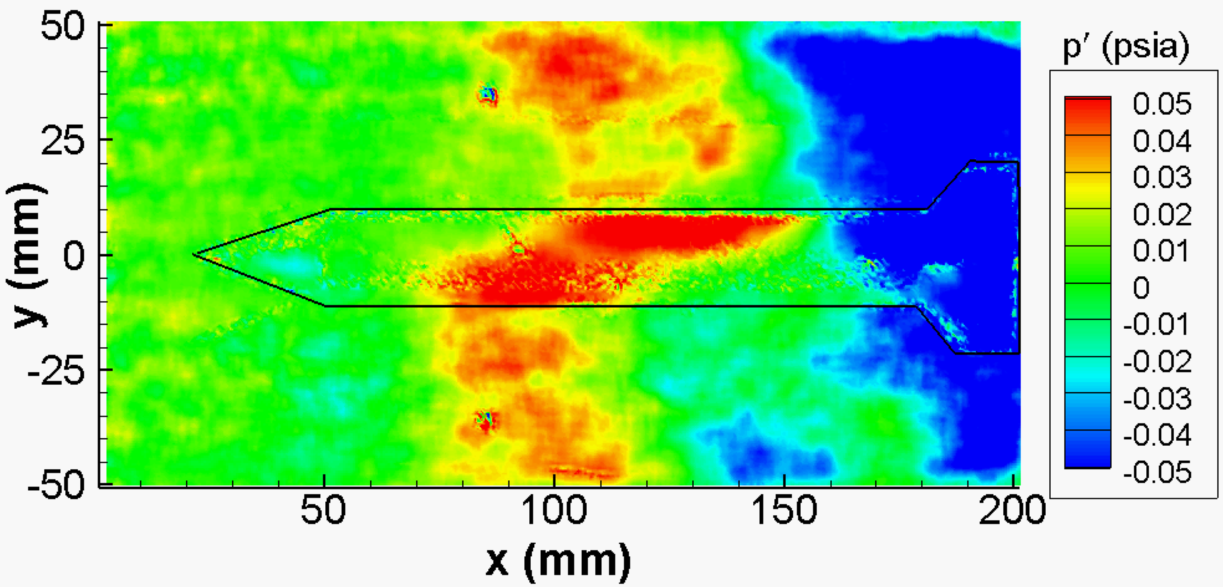
→ **Hence, pressure.**

We now have the capability for fast time response – about 10 kHz.

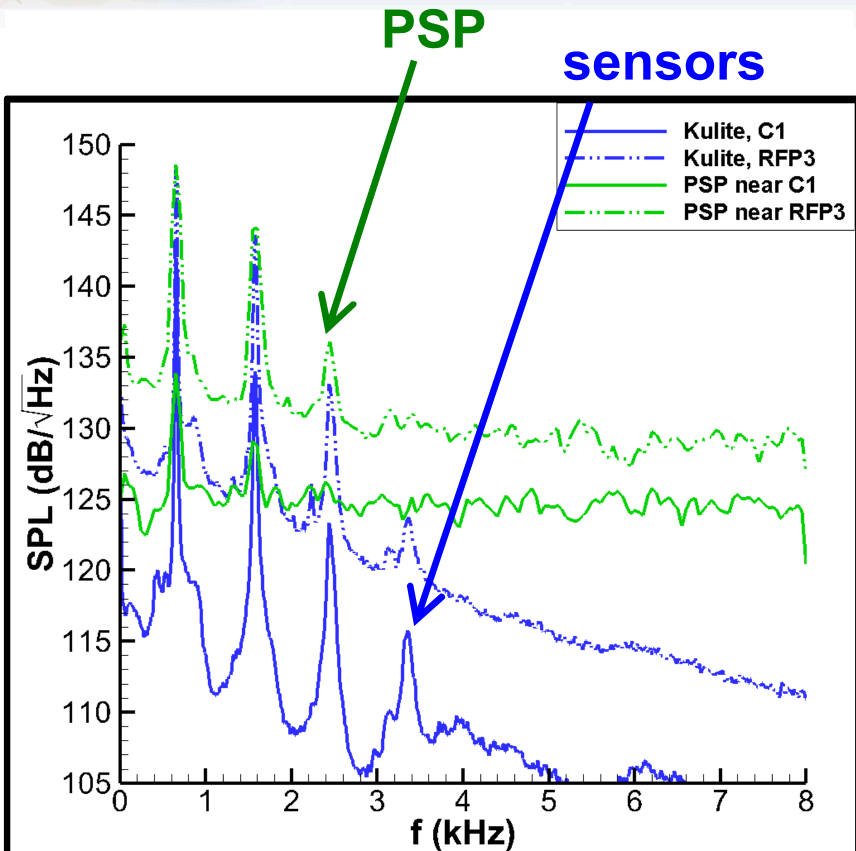
PSP movies of aeroacoustic loading on a store in a modeled weapons bay.

How does this lead to store vibration?



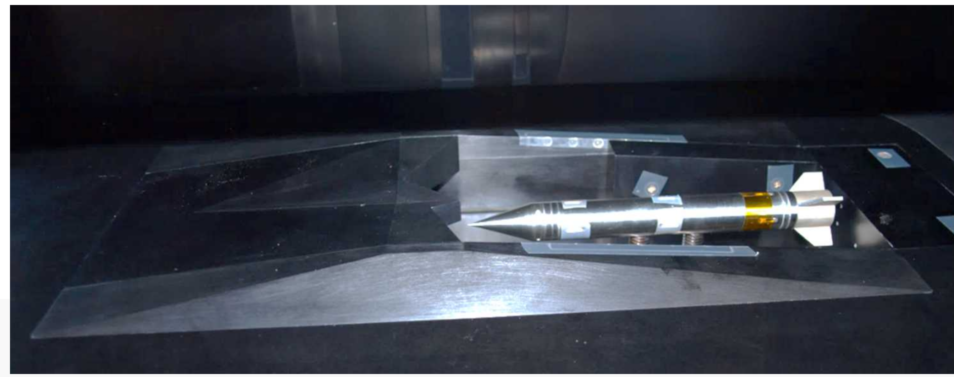


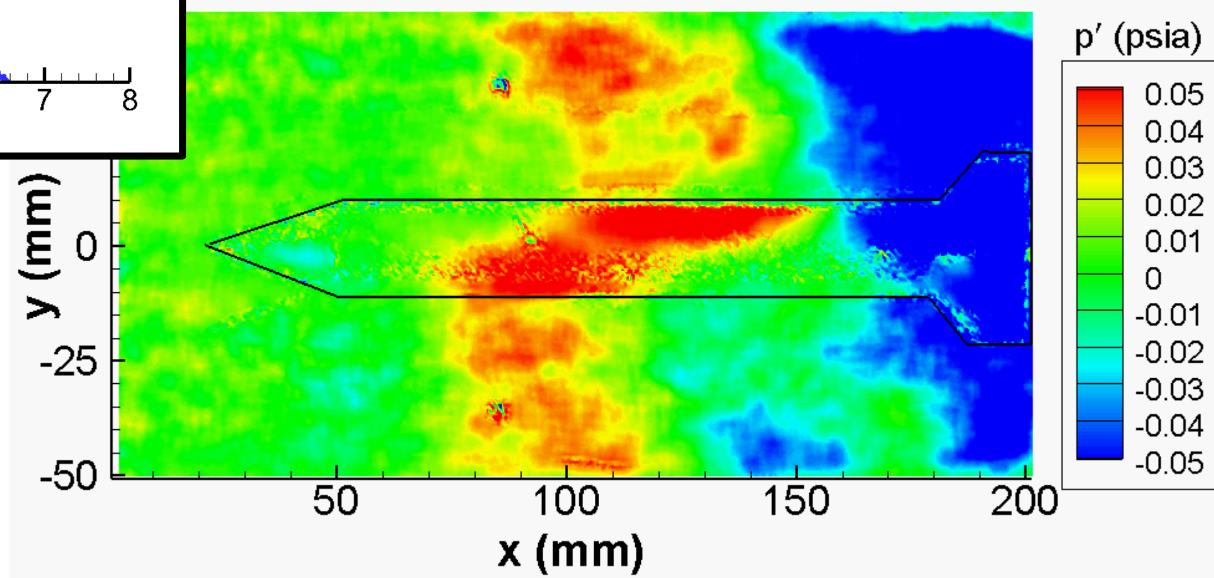
Unsteady Pressure Sensitive Paint (PSP)



PSP movies of aeroacoustic loading on a store in a modeled weapons bay.

How does this lead to store vibration?

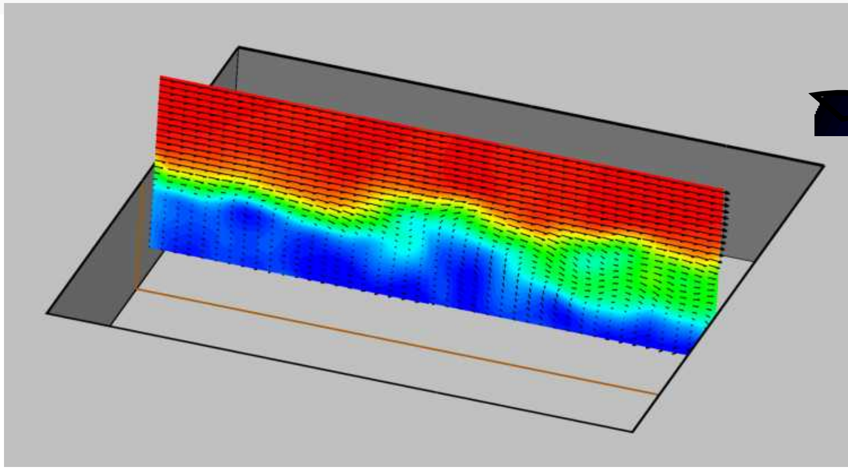




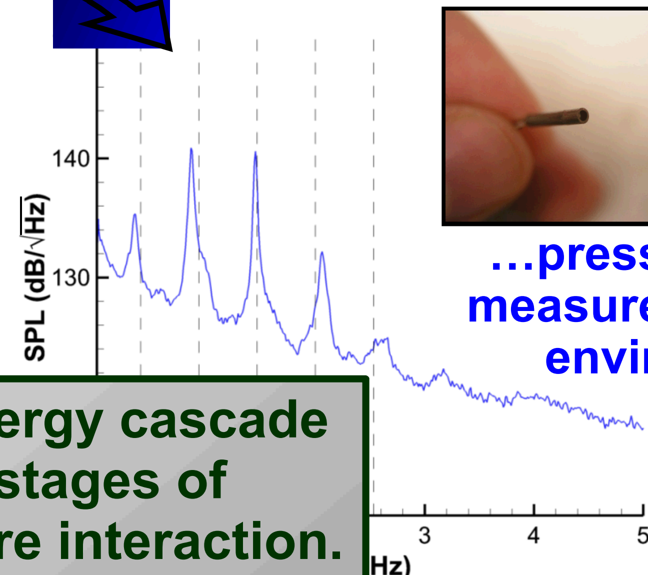
Excellent agreement in resonance frequency and amplitude.

But PSP has higher background noise.

Bring all of these capabilities together

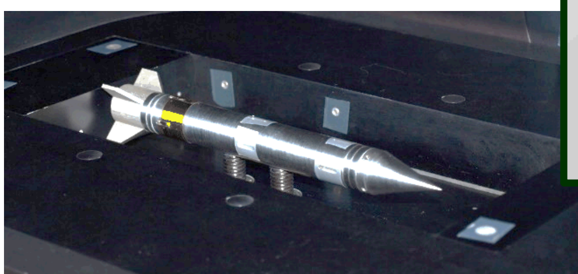


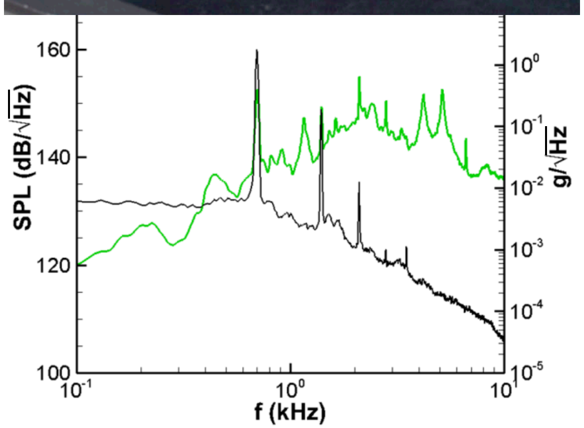
Pulse-burst PIV measures the flow structure…



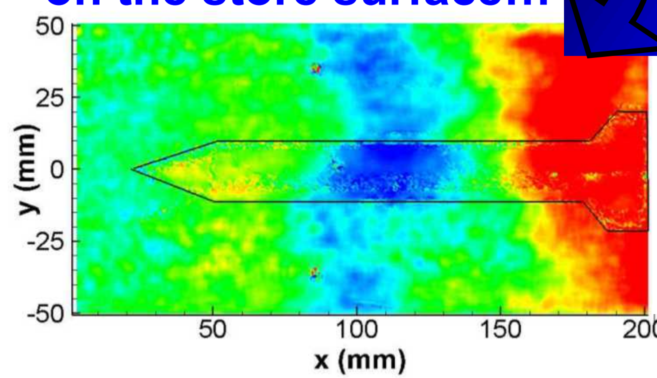
…pressure sensors measure the acoustic environment…

Track the energy cascade through the stages of fluid-structure interaction.





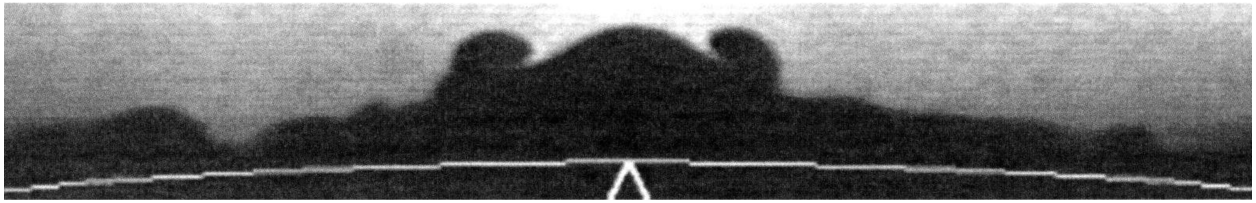
…PSP measures unsteady pressure loading on the store surface…



…and then we can measure the structural response.

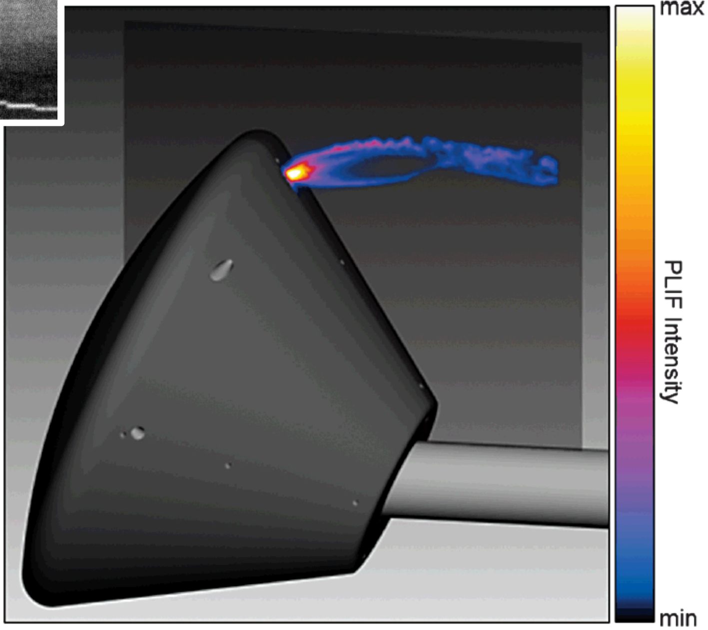
New measurement technologies designed for hypersonic environments.

Our center of gravity is shifting towards hypersonics.



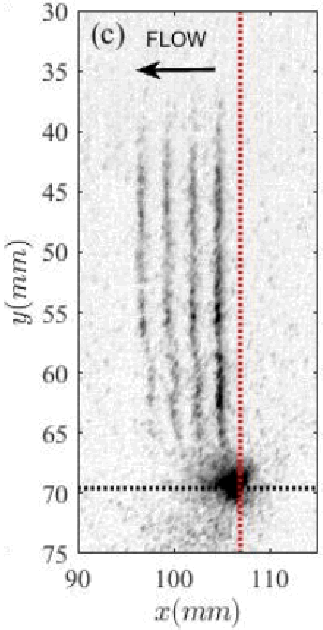
Filtered Rayleigh Scattering (Princeton)

Identifies boundary layer instabilities at Mach 8.



FLEET Velocimetry (Tunnel 9 / Princeton)

Boundary layer velocity profiles at Mach 10.



NO PLIF Technique (NASA Langley)

Track plume from Orion capsule RCS jet

Further investment needed in diagnostics!

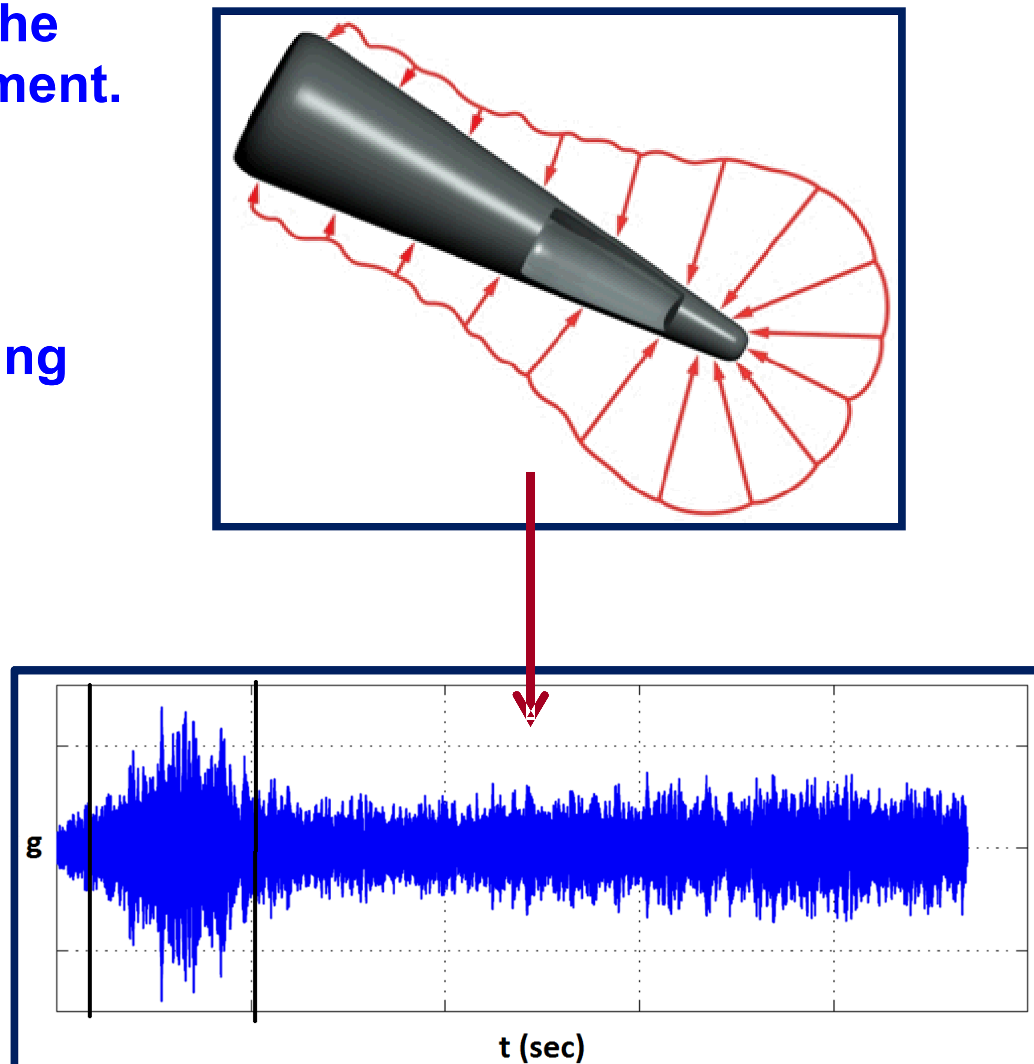
This will allow much more information to be extracted from test facilities.

Our focus is on characterization of the hypersonic aerodynamic environment.

Vehicle vibration results from the strenuous hypersonic environment.

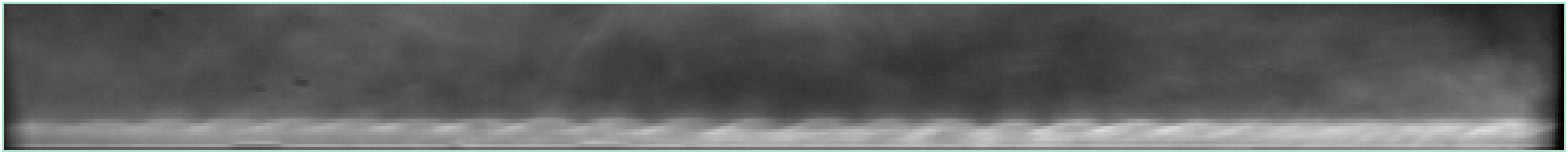
- **May create adverse internal component response.**

We need to determine the loading environment responsible for *fluid/structure interactions*.



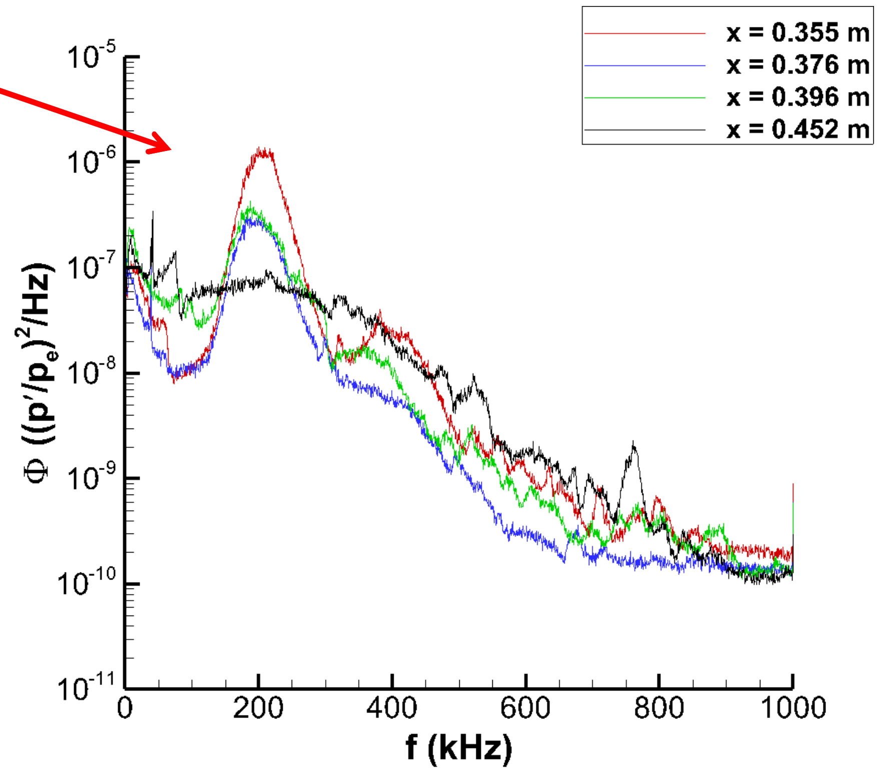
Sandia National Laboratories

Pressure Fluctuations due to Boundary Layer Transition at Mach 8



Schlieren Video

Pressure Traces



Flow alternates between second-mode wave packets and turbulent spots.

Observed in both schlieren videos and simultaneous pressure measurements.

We can use these data to form models of the pressure loading on a vehicle surface.

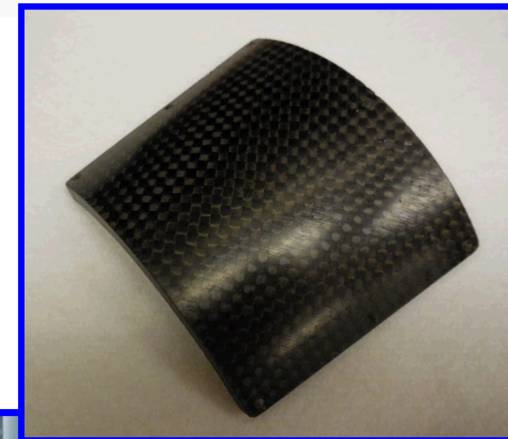
These bursts of correlated fluctuations are a source of aerodynamic vibration.

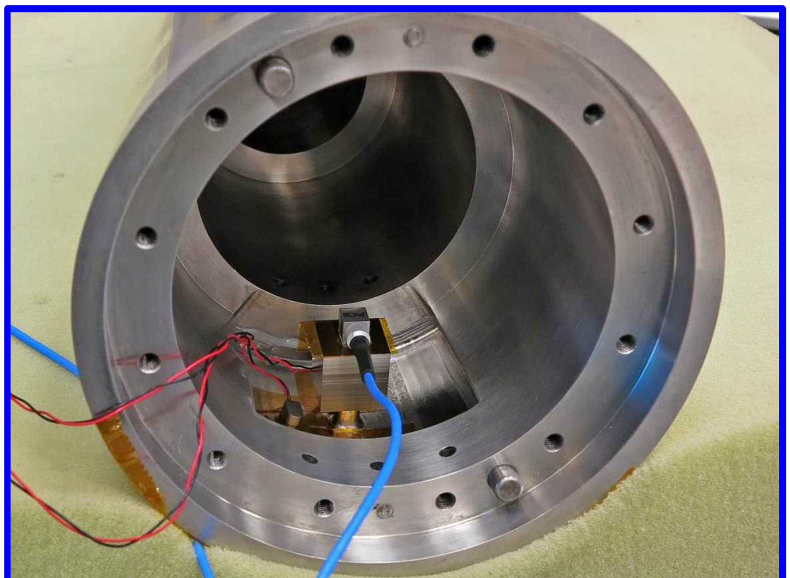
Sandia National Laboratories

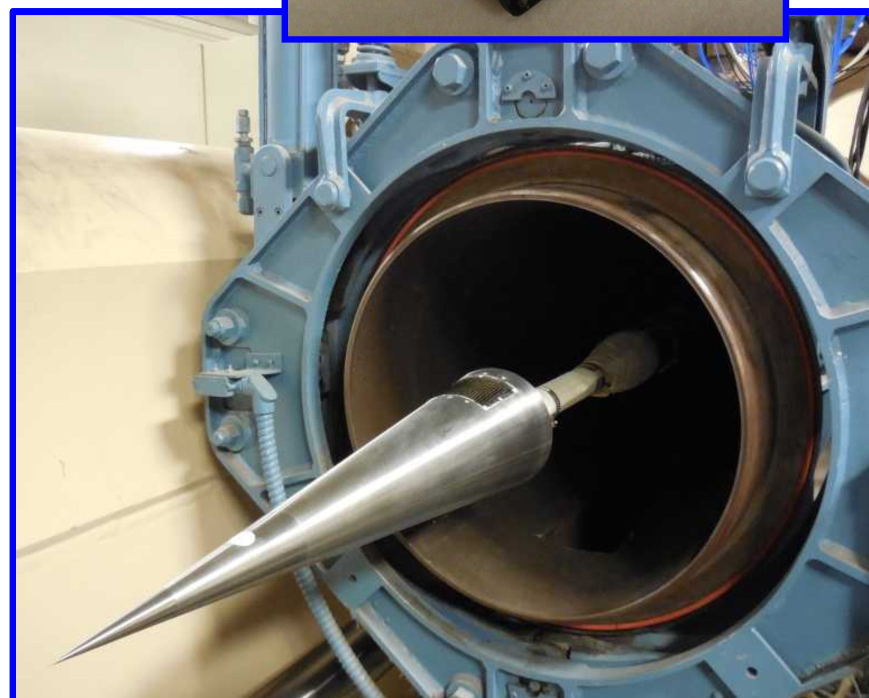
What is the vibrational response to these disturbances?

We designed a new cone model with an integrated thin panel that will vibrate from flow excitation.

Response measured with accelerometers on inside of panel.







A spark perturber was used to create known turbulent spots in the boundary layer.

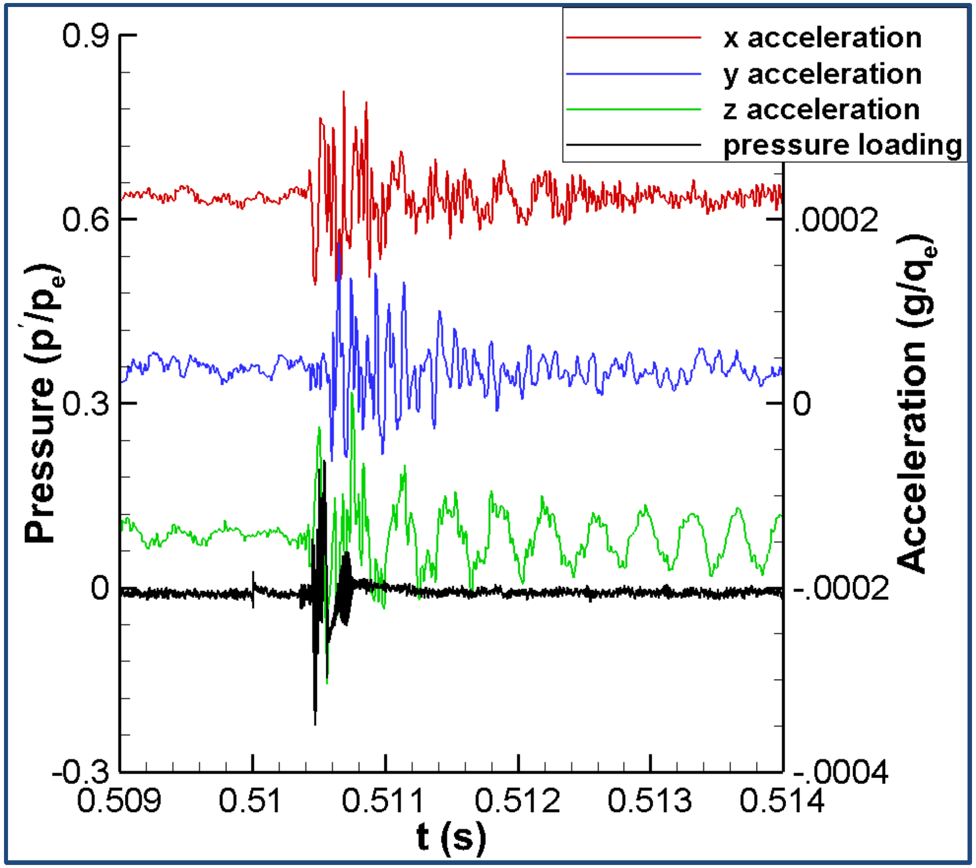
Sandia National Laboratories

Panel Vibration

Passage of a turbulent spot produces a clear vibrational response.

Response lasts longer than forcing input.

We observe a directionally dependent response.



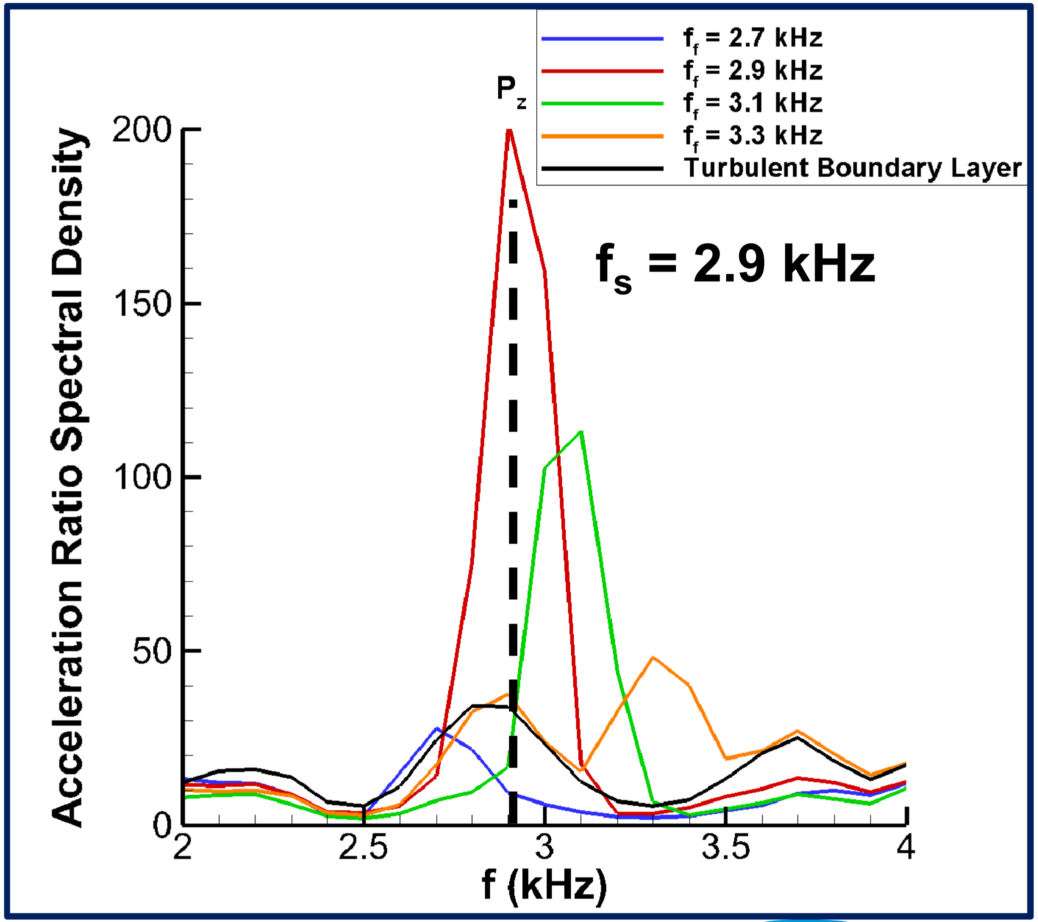
Sandia National Laboratories

Mode-Matched Amplification

Largest panel response occurs when the forcing frequency of the turbulent spot matches a structural natural frequency.

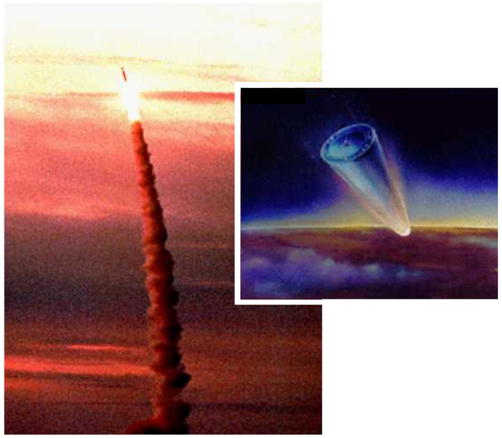
Mode-matched response is 200 times larger than under a laminar boundary layer!

Still much amplification at frequencies close to mode-matching.

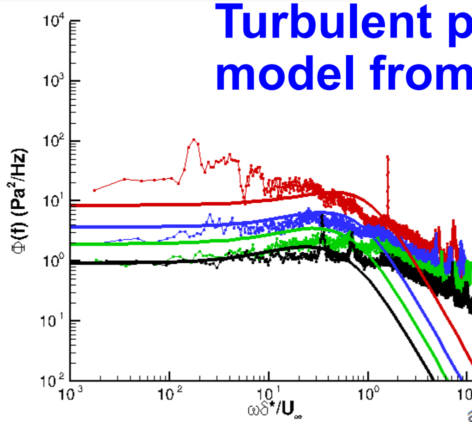


We can use these data to develop science-based predictions of re-entry vibration.

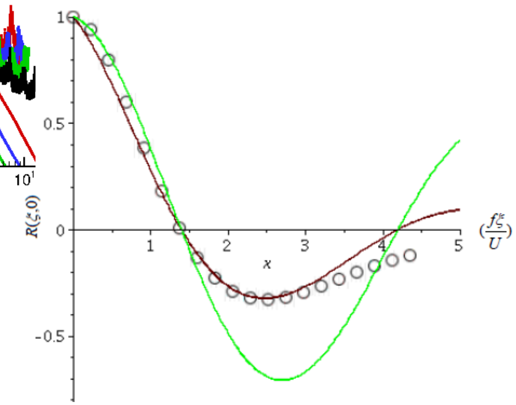
Flight environment (unmeasurable)

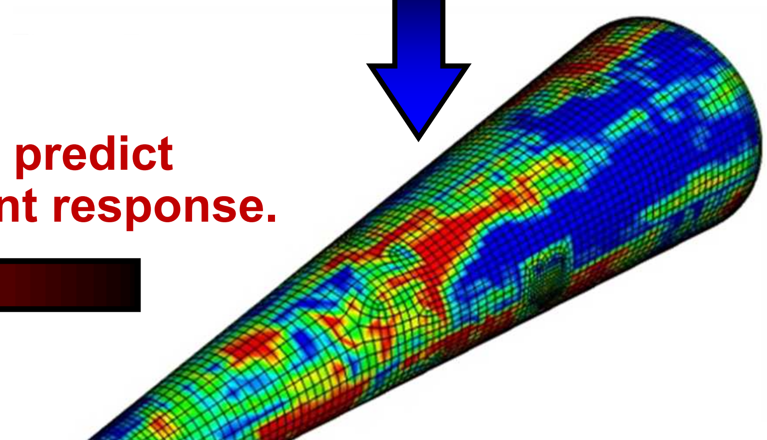


Wind tunnel experiments



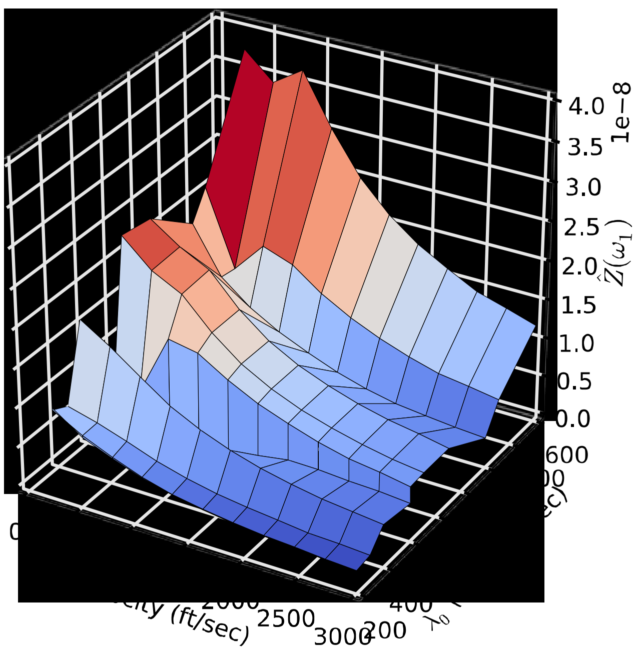
Turbulent pressure fluctuation model from the data.





Spatial and temporal loading prediction.

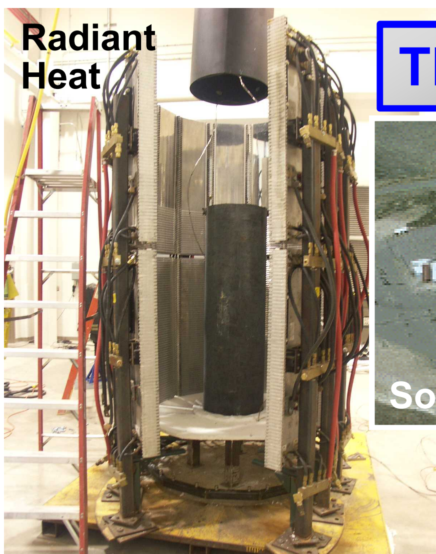
Structural models predict internal component response.



Hypersonic ground testing includes environmental test facilities.

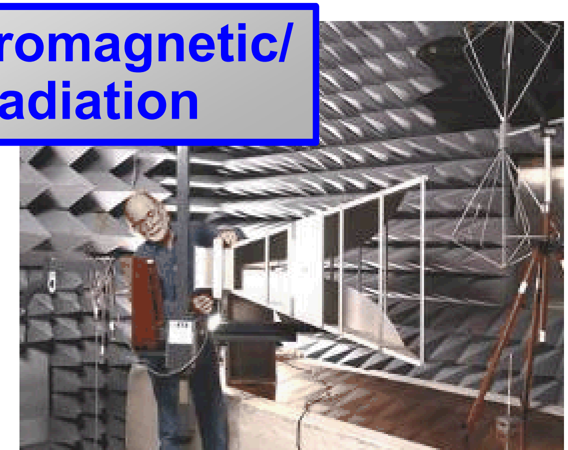
Vibration

Thermal



Mechanical Shock

Electromagnetic/ Radiation



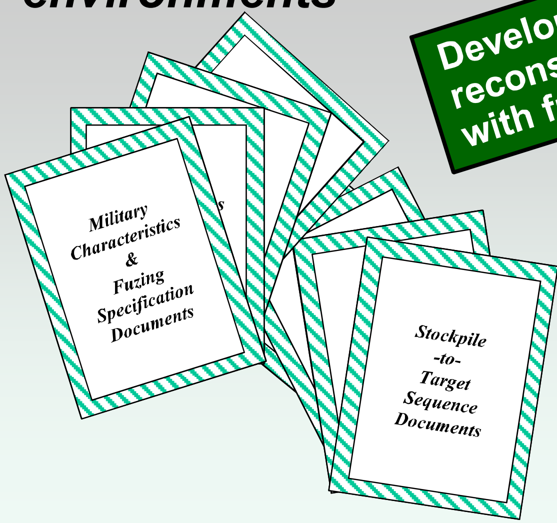
These facilities test the response under environmental specifications, not the actual hypersonic conditions.

Current specifications typically based on old capabilities rather than actual environments.

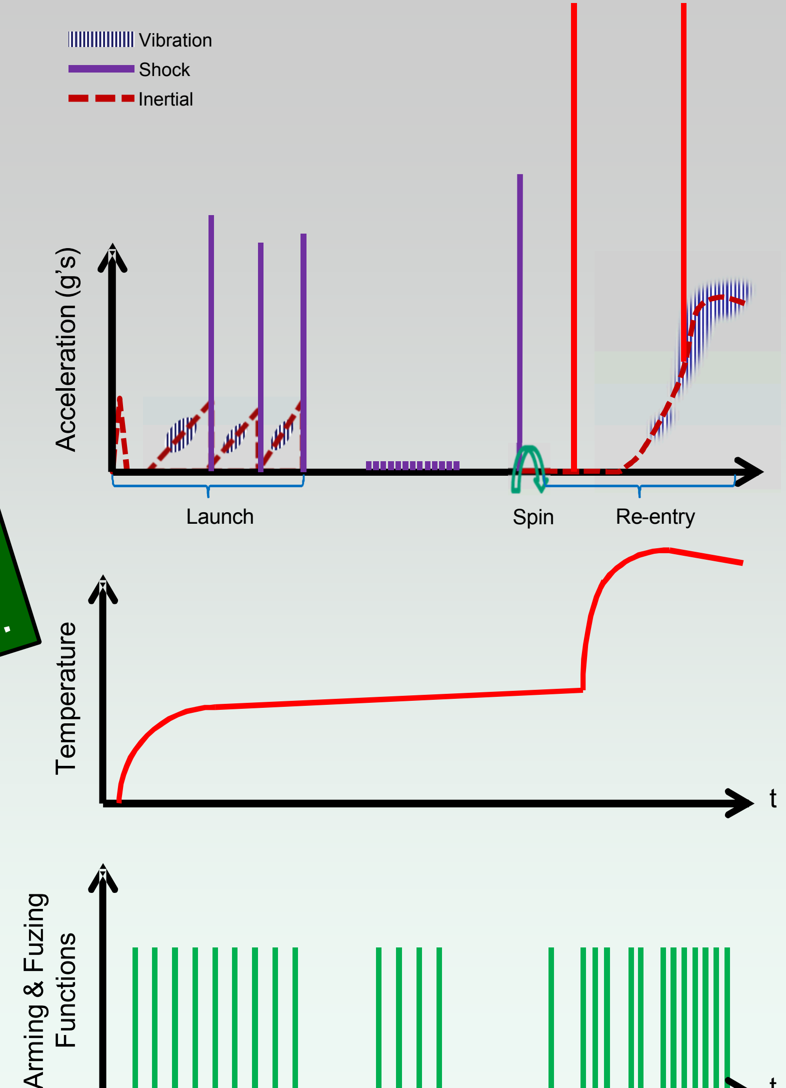
Change thinking from: *"I need to run this test."*

To: *"I need to design & qualify my part for these environments."*

Understand the true environments



Develop test capabilities that reconstruct environments with functional requirements.

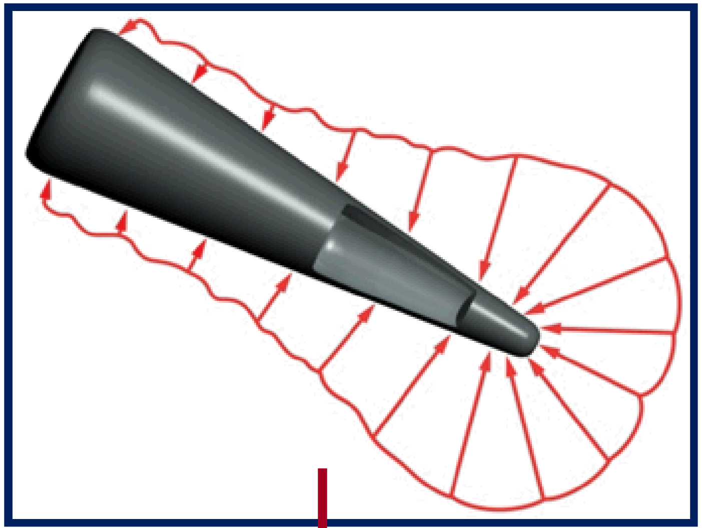


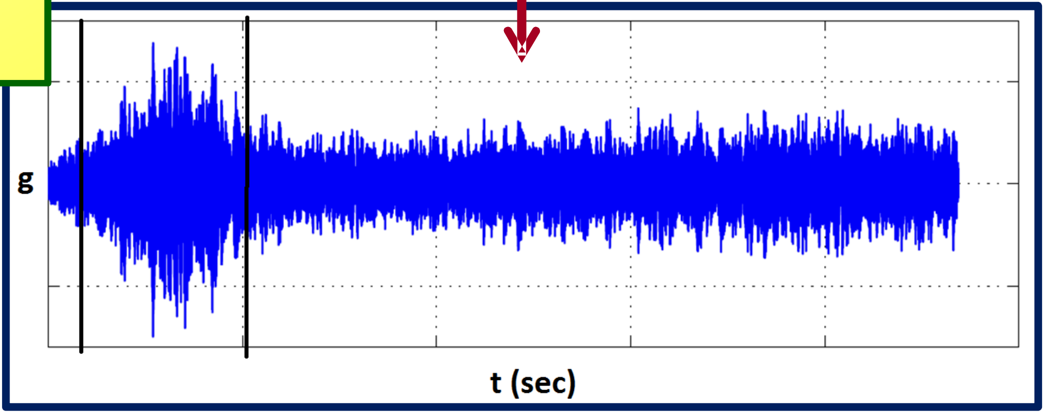
Reentry Vibration Environments

First, use wind tunnels, etc, to reproduce the hypersonic environment as best we can.

Then we need to measure the vibration response.

This is in environmental test facilities.

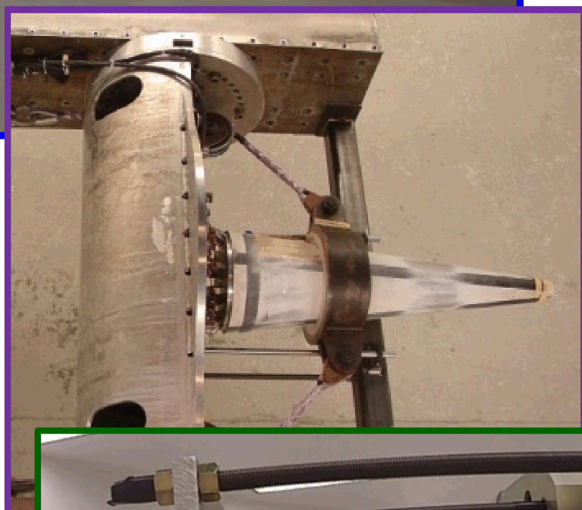


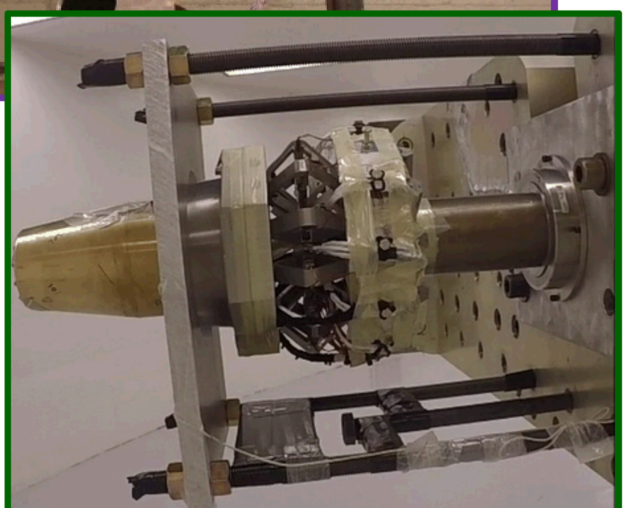


Can we improve our ground testing to better replicate the true flight environments?

Sandia National Laboratories

Combined Environments





Centrifuge:

Acceleration along the primary axis.

Vibrafuge:

Add a shaker table.

Acceleration + vibration.

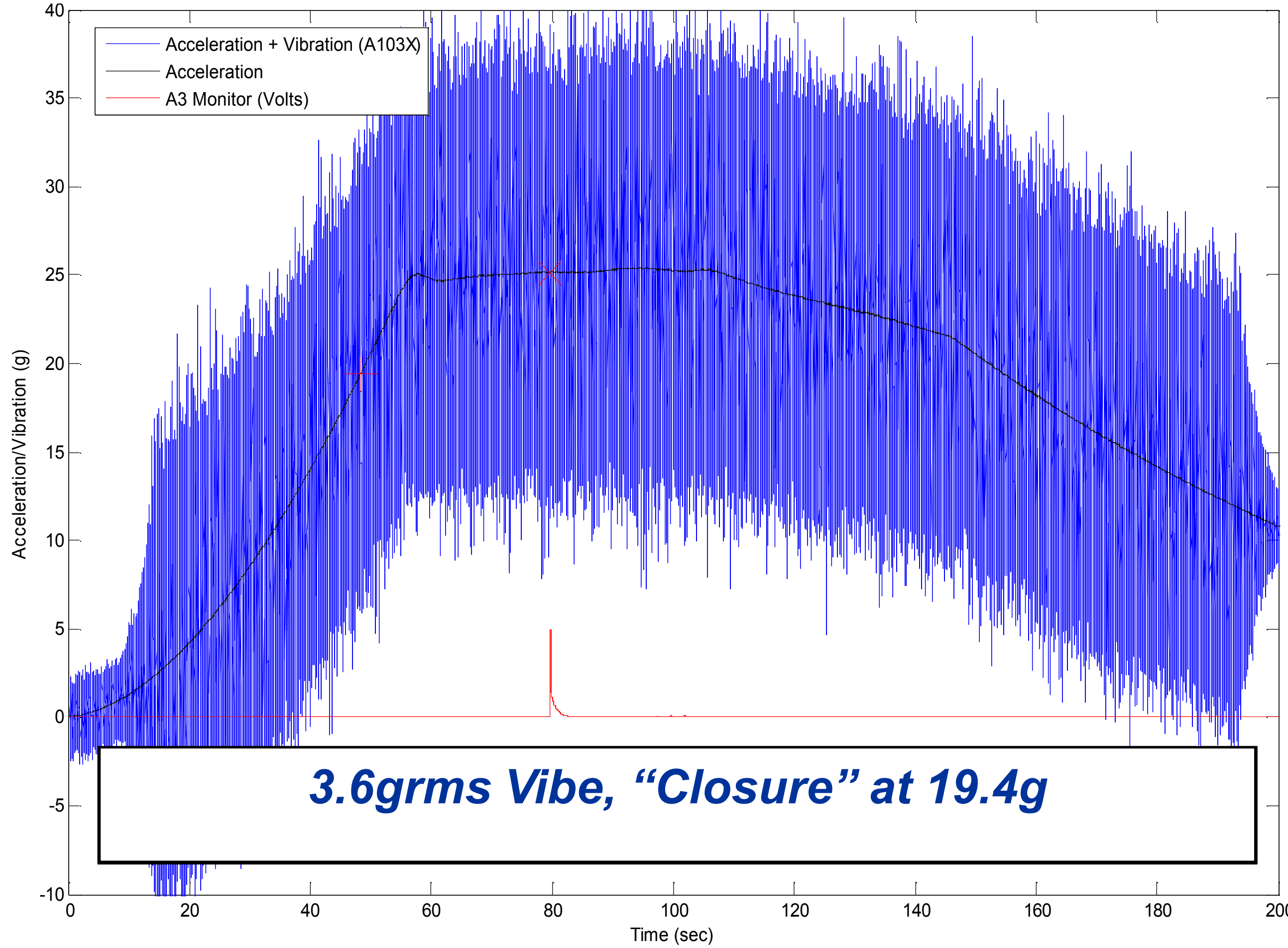
Superfuge:

Add secondary axis spin.

Acceleration + vibration + spin.

Component Function in a Combined Environment

Test of Switch Closure

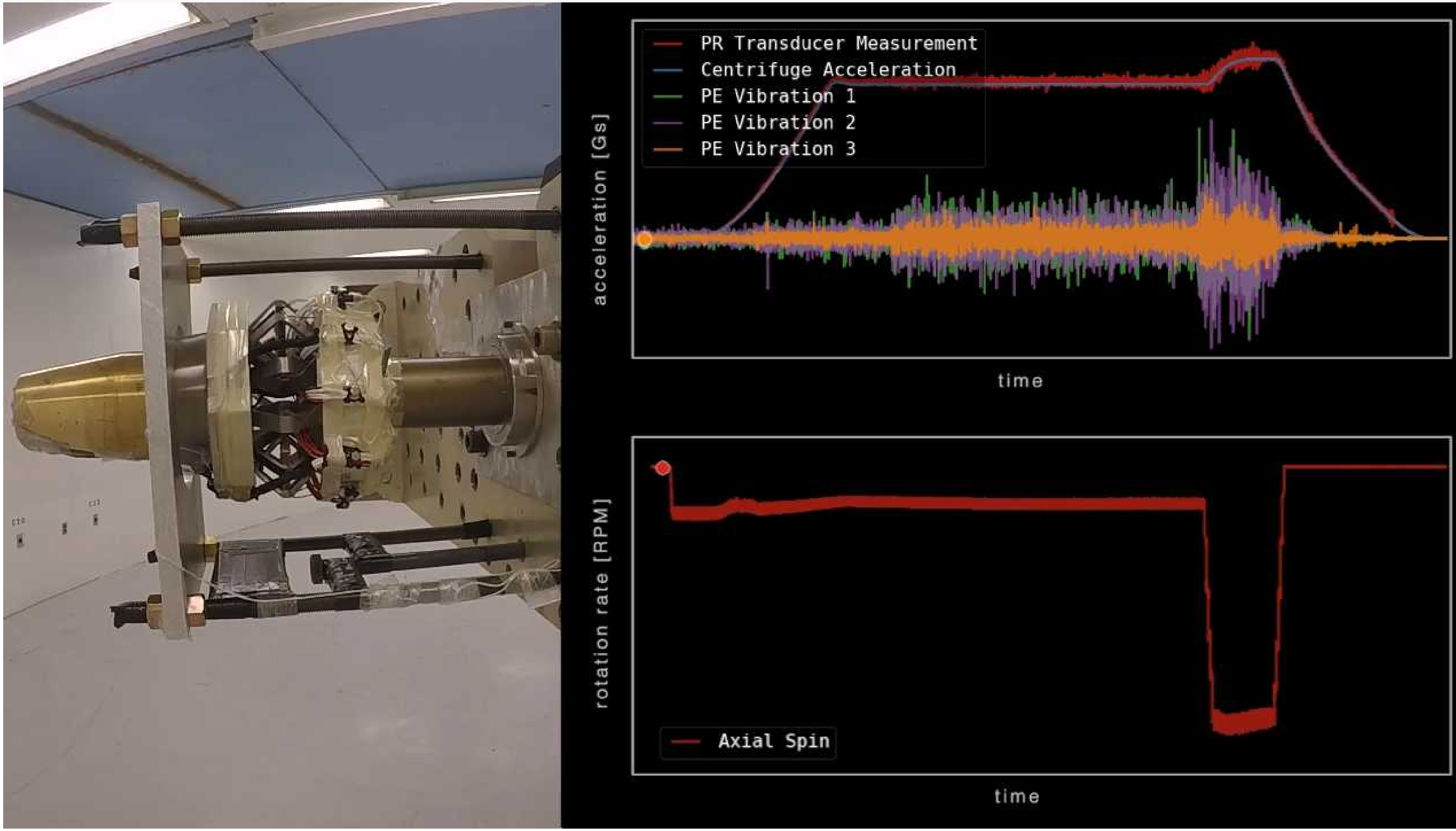


Tests show nearly a *90% chance* the unit responds in a manner that traditional testing would not reveal.

Improvement to ground testing can occur by *combining* test capabilities for greater realism.

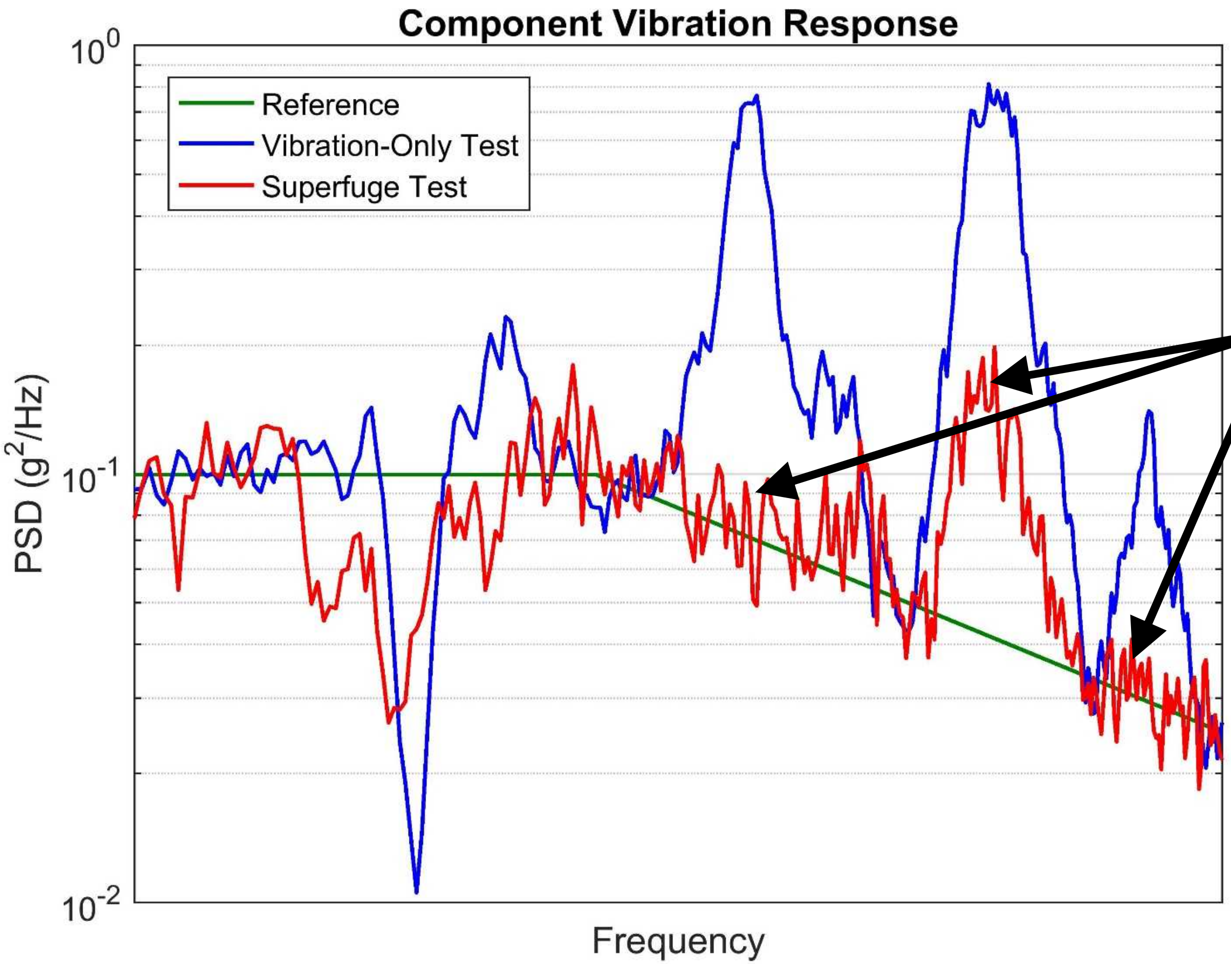
Sandia National Laboratories

What happens when we add spin?



What happens when we add spin?

Inertial + spin + vibe causes significant changes in unit response.

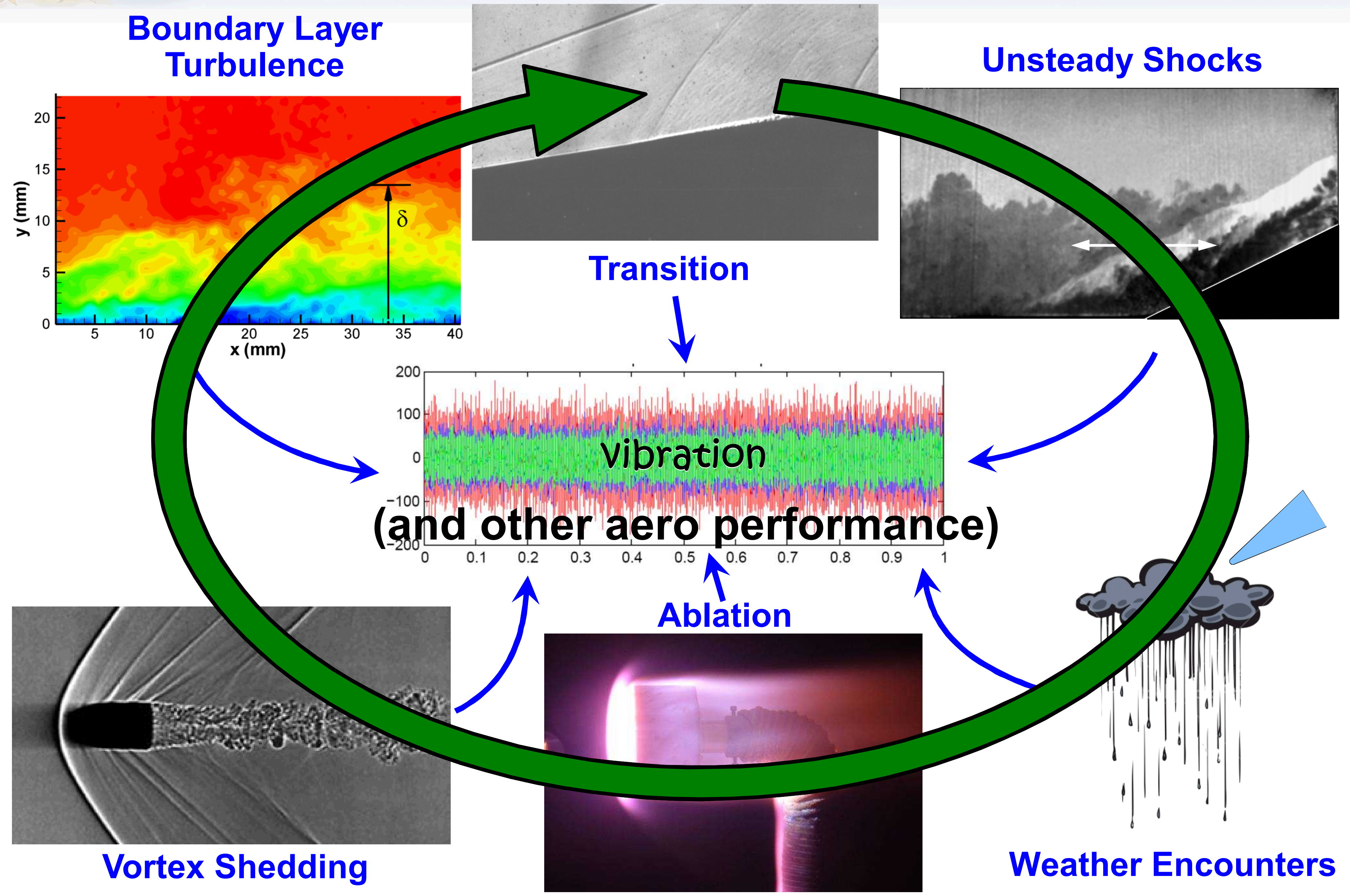


High spin rate suppresses off-axis response.

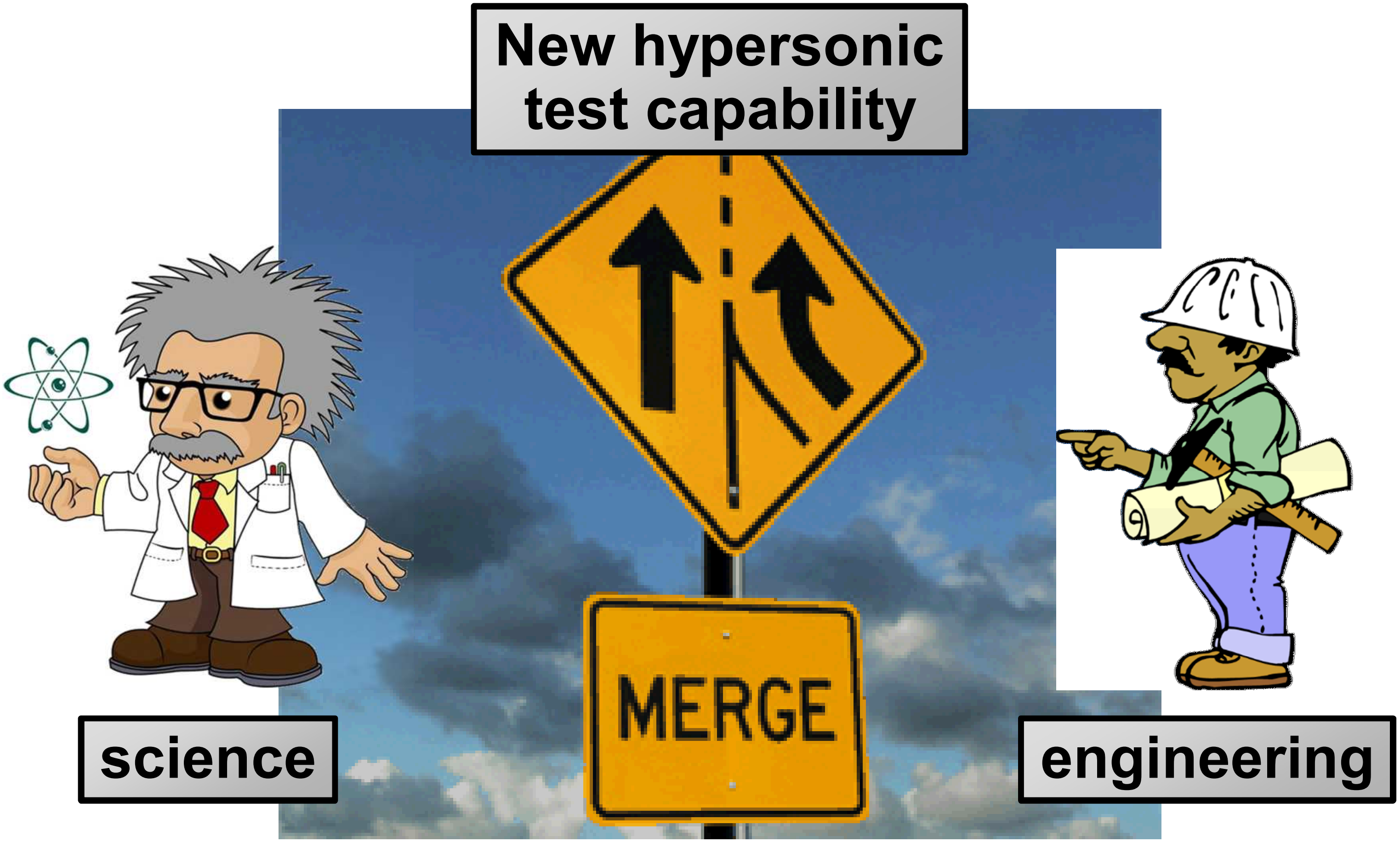
Future work: Add thermal.

Sandia National Laboratories

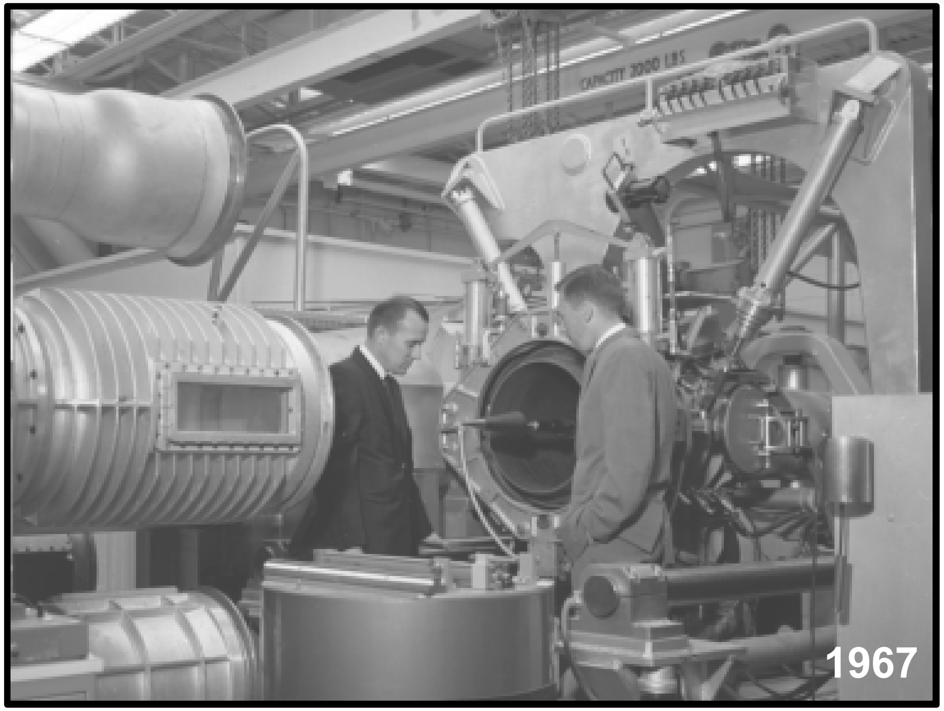
Combined Environments in Aero Testing



Our approach is to blend testing and research.



Sandia's wind tunnels have a long history of contributing to the nation.



Even in an era of computational simulation for engineering practice, ground testing remains key to aerospace technology.

Our mission is not just aerodynamic characterization of vehicles, but also providing data to develop and validate modeling and simulation.

New experimental technologies allow us to do things we never could have imagined a generation ago.