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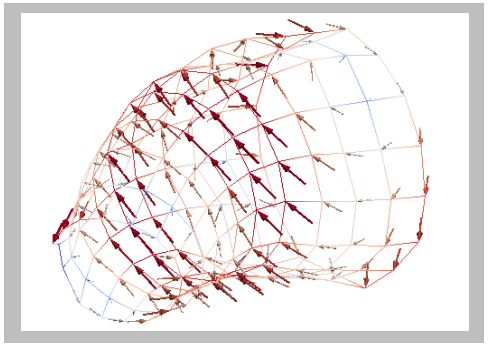

Modal Testing of a Nose Cone using Three-Dimensional Scanning Laser Doppler Vibrometry

Dan Rohe

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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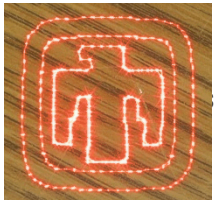
SLDV at Sandia National Laboratories



- Scanning Laser Doppler Vibrometry (SLDV) has advantages over traditional sensors:
  - Non-contact measurement
  - Can achieve fine measurement point resolution
  - Quicker and more precise than a roving accelerometer or hammer test
- Sandia has been operating a 1D SLDV for years, but use has been limited:
  - Always measures in the direction of the laser beam
  - Subject to unfamiliar optical issues such as signal dropout and speckle noise
  - Limited channel count
- Sandia has recently upgraded to a 3D SLDV:
  - Can compute full 3D responses from measurements in 3 directions
  - Hardware improvements since the last system was purchased may limit unfamiliar optical issues
  - Increased channel count

- Goal: Perform a test to help determine the capabilities and limitations of the new SLDV system.

Testing to Determine SLDV Capability

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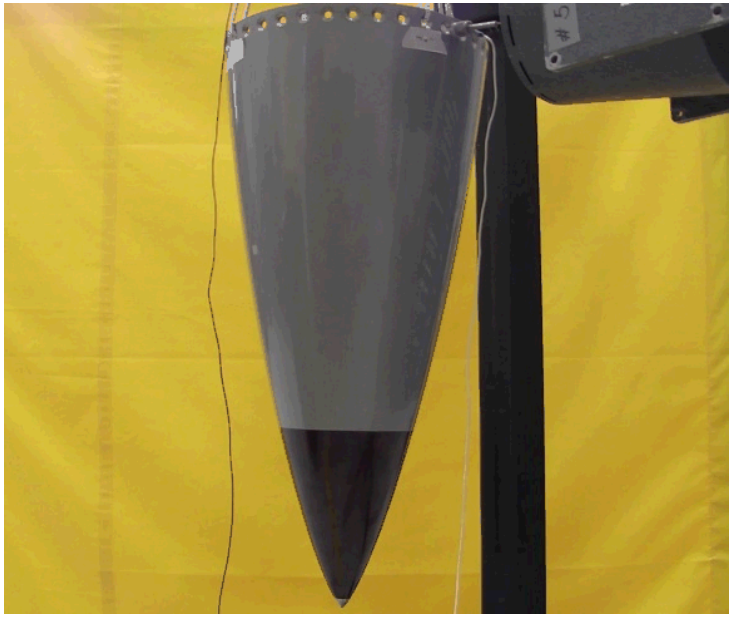
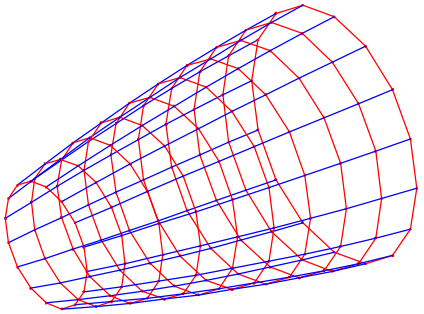
Test article chosen to challenge the laser systems:

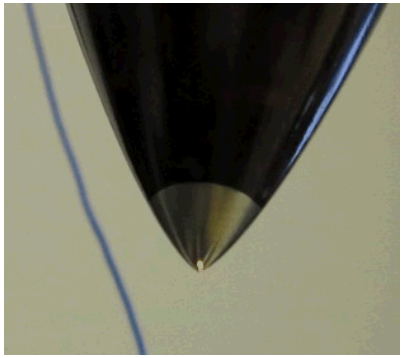
- Light and dark glossy surfaces
- Conical shape allows investigation of angle of incidence
- Symmetry creates closely spaced modes
- Poor alignment features
- Requires multiple scans to measure all sides

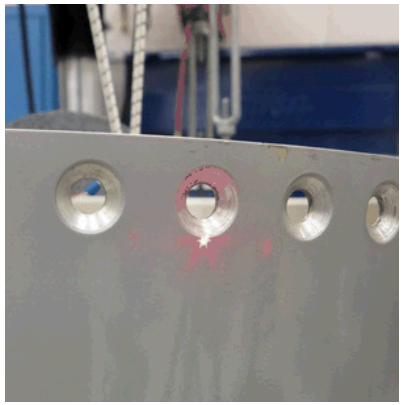


Test Setup

- Three tests:
  - Baseline: Old System 1D
  - 1D with New System
  - 3D with New System
- Created a test geometry
  - 16x10 grid
  - First axial station on darker surface
- No surface preparation
- Tip and ring of holes used for laser alignment, large uncertainty
- Shaker used to excite the structure near the ring of holes.
- Drive point measured with force gauge and accelerometer.



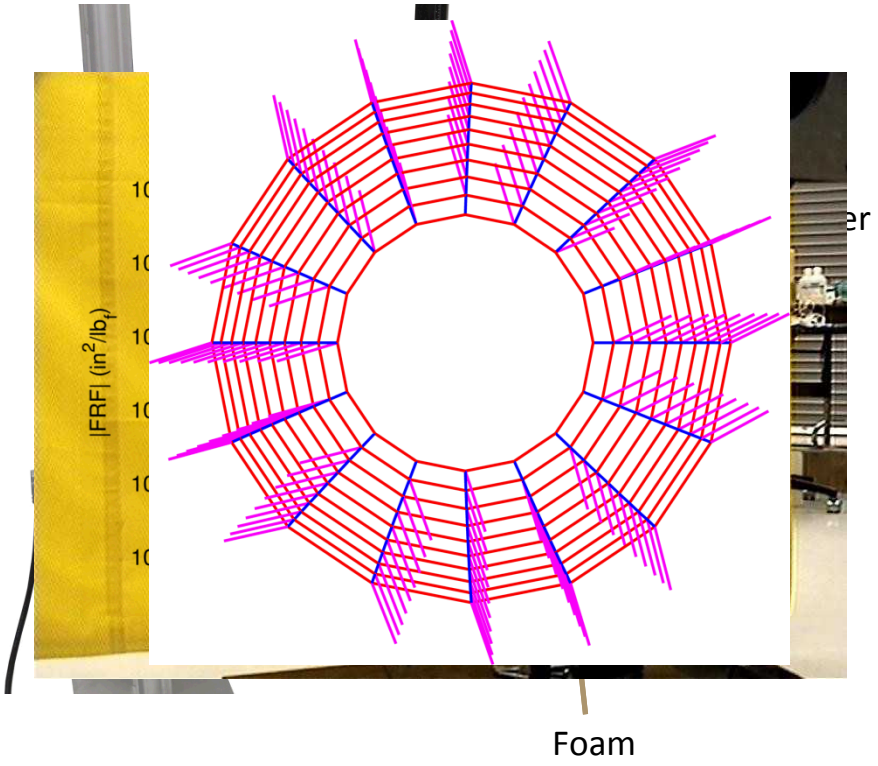




Baseline Test Setup

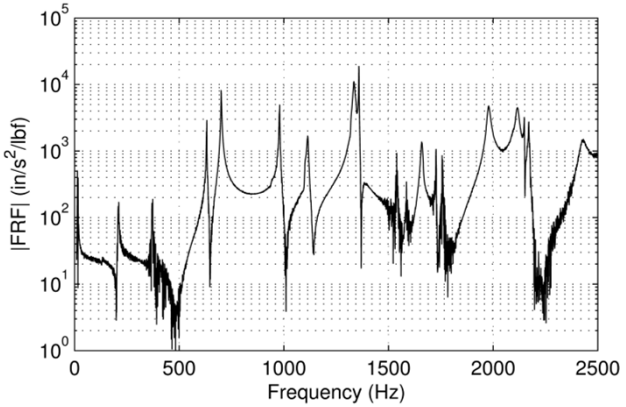
- PSV-400 1D SLDV
- Test article distance: 1.35m (53 in)
- Average alignment error of 1.3mm computed (compare to 50-60mm grid spacing)
- Four scans used to measure all sides
- Maximum angle of incidence: 55˚
- Bandwidth: 2000 Hz, 1.25 Hz resolution
- Random Excitation, 20 averages per point (up to 100 total averages due to signal enhancement settings)
- System clearly struggled with dark surfaces (10 of 16 points were not measured)

Test Setup



1D Test with New System Setup

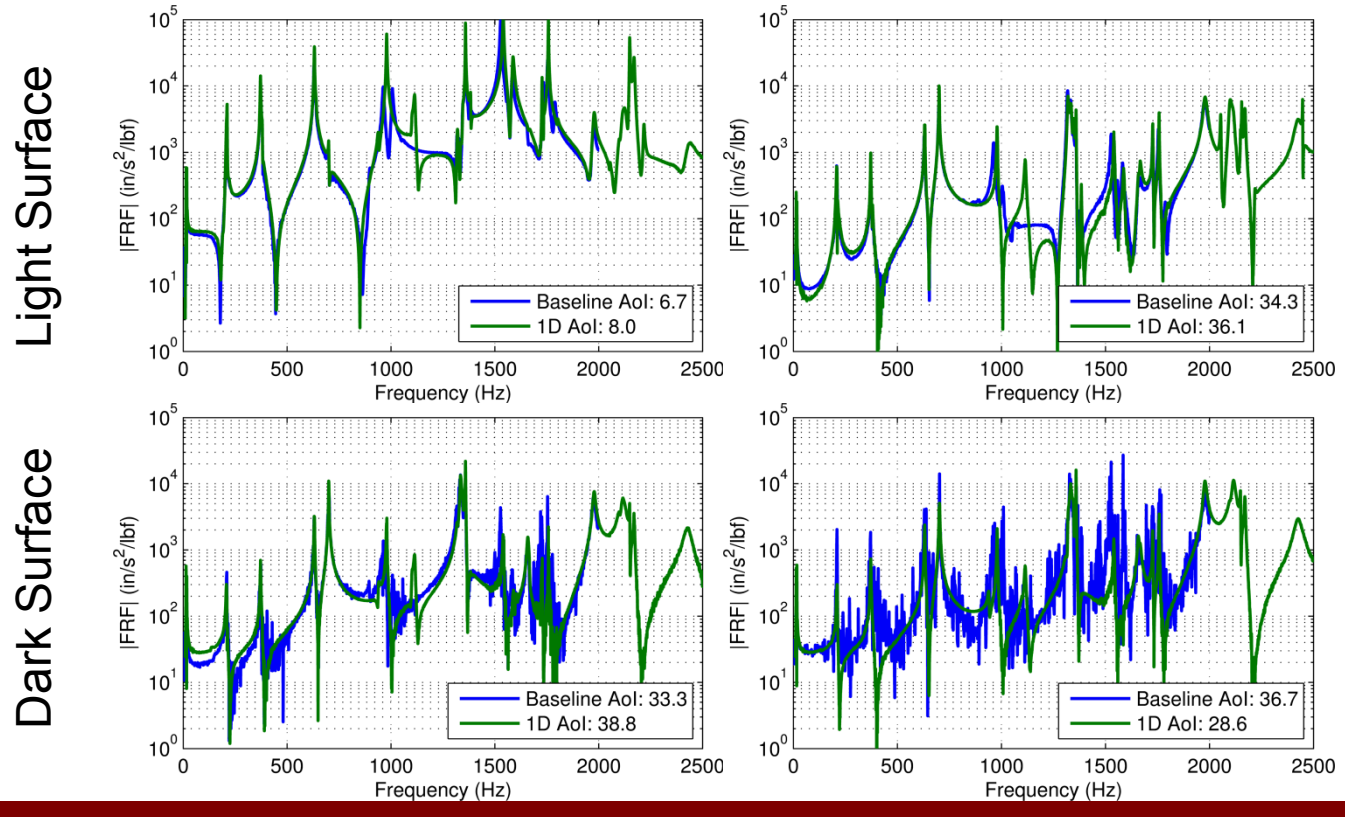
- PSV-500 1D SLDV
- Test article distance: 1.29m (50 in)
- Average alignment error of 2.6mm computed (compare to 50-60mm grid spacing)
- Four scans used to measure all sides
- Bandwidth: 2500 Hz, 0.78 Hz resolution to try to separate modes
- Pseudorandom Excitation, 5 averages per point to save measurement time
- Obvious improvements to hardware compared to previous generation
  - Measured up to 6 circumferential stations
  - Measured clean FRFs on the darker surface



FRF measured with the new SLDV system in 1D mode on the darker surface at an AoI of 66 degrees

Comparison between Generations

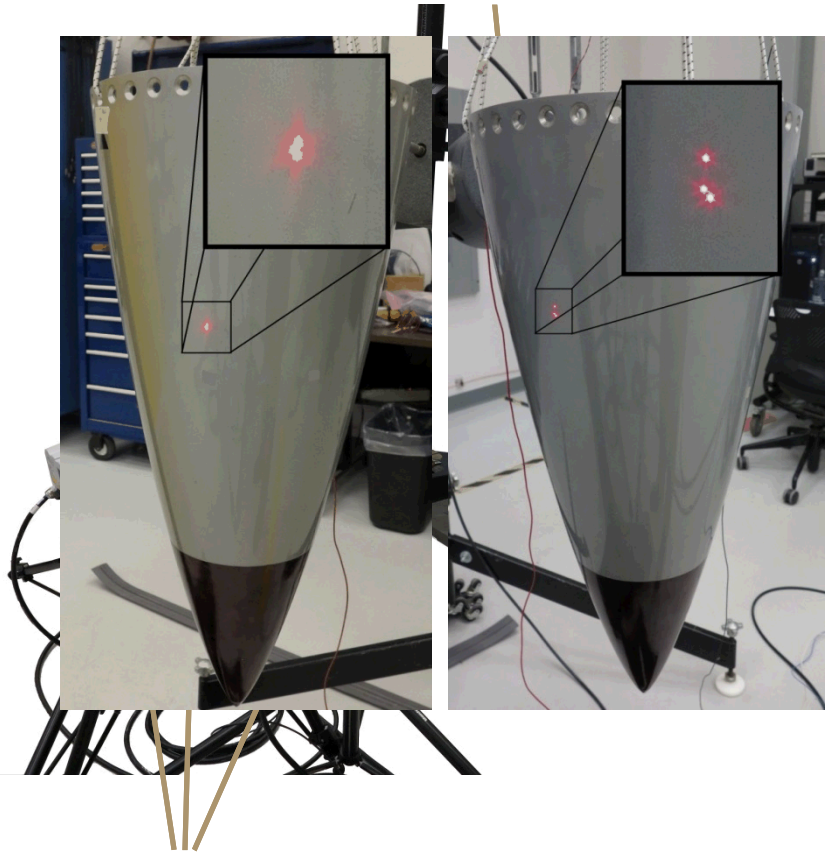
- Computed actual measurement directions from laser alignment data for 1D scans
- Qualitatively compared FRFs at points where measurement directions were within 10 degrees



3D Test with New System Setup

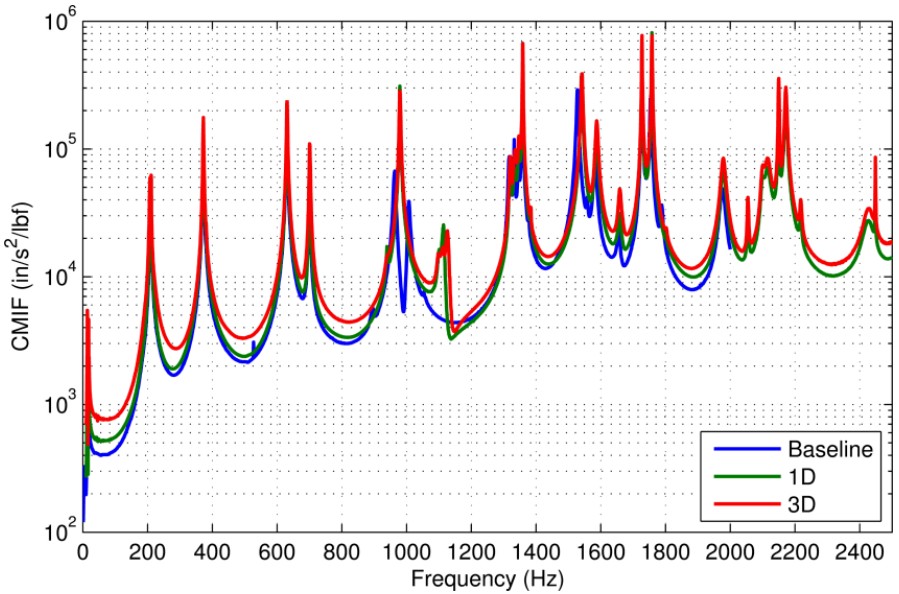
- PSV-500 3D SLDV
- Test article distance: 1.42m (56 in)
- Average distance between two laser heads: 0.65m (25 in)
- Average alignment error of 2.0mm computed
- Video triangulation used to move points on top of one another
- Four scans used to measure all sides
- Bandwidth: 2500 Hz, 0.78 Hz resolution to try to separate modes
- Pseudorandom Excitation, 5 averages per point to save measurement time

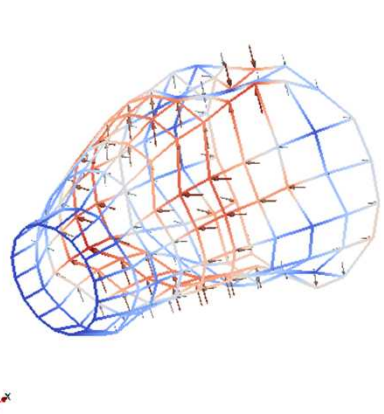
Test Setup



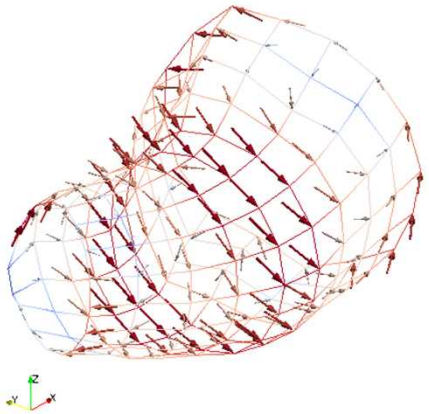
Modal Analysis and Comparison

- Modes fit using SMAC algorithm
- Due to symmetry, mode pairs were prevalent, difficult to extract both because only one input was used
- Results very consistent between tests, except due to differences in bandwidth/frequency resolution
- “In-plane” modes easier to identify with 3D SLDV
- Interesting differences near 1000 Hz





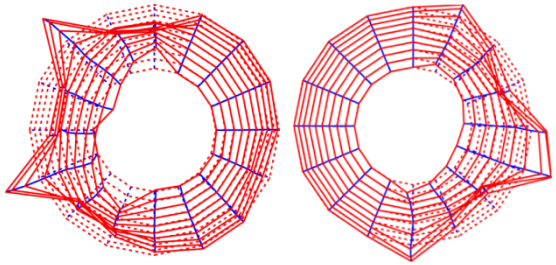
1657.09655762 Hz

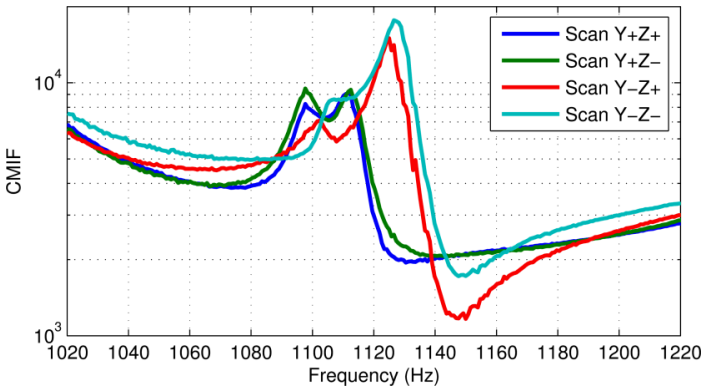


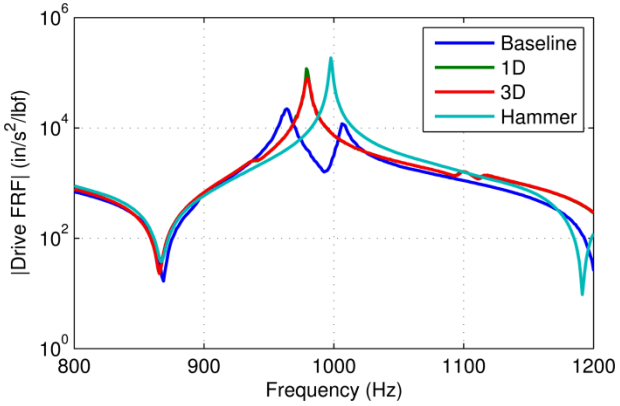
1658.9576416 Hz

What's going on at 1000 Hz?

- Ovaling modes expected in pairs, found 4
- MAC matrix showed high off-diagonals for these modes
- Shifts of >100 Hz found between nominally the same tests
- Shifts of 10 Hz found between scans taken 2 hours apart
- Strange behavior was found to be due to a stinger mode interacting with the test article modes
- Also discovered significant mass-loading effects when an impact hammer was used instead of the shaker







Lessons Learned and Improvements

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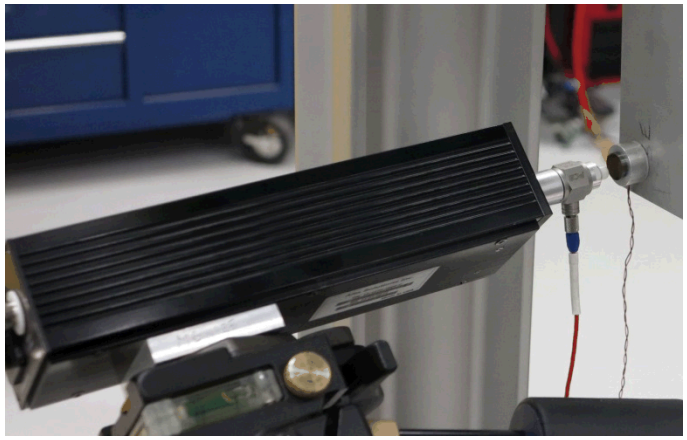
- The PSV-500 seems to be a significant improvement over the PSV-400. Much cleaner signal on difficult surfaces and at higher angles of incidence.
- Alignment points on structure were not sharp features, so uncertainty was introduced into the alignment.
  - High angles of incidence can exacerbate misalignment from a few millimeters to a few centimeters.
  - Video triangulation was successful in converging the laser spots when they were not collocated.
  - Subsequent testing has used a reference object with well-defined alignment points.
- Even with non-contact measurement techniques, still had mass-loading and stinger interactions due to shaker hardware.
  - Smaller force transducers have been purchased
  - Impact testing with SLDV has been utilized

Impact Testing with SLDV

- Impact testing can potentially achieve higher frequency content with less structural modification than shaker testing
- Automatic modal hammers relieve the tedium of impacting a structure 1000s of times
- Drawbacks include:
  - Not very repeatable
  - May not be designed for constant usage
  - Hammer rebound may be measured by the force transducer
  - Impacts can impart large rigid body motion and long ring-downs
- Solution:
  - Smaller modal hammer reduces rigid body motion
  - Less massive hammer results in less inertial loading measured by the force transducer
  - Increase boundary condition stiffness and damping



Conclusions

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- 3D Scanning Laser Doppler Vibrometer is a very useful tool that can drastically reduce testing labor and time for large number of scan points
- PSV-500 hardware seems to be significantly better than the PSV-400 hardware
- By performing this test, SNL was able to identify gaps in its 3D SLDV capabilities and address them before putting the system in place for production testing.

Extra Slides for Subsequent Testing

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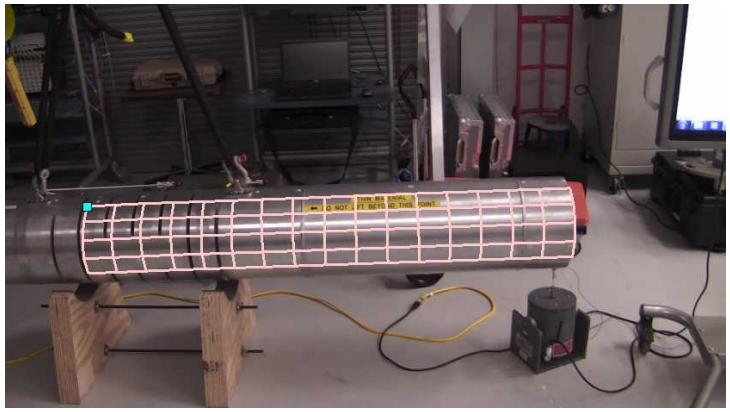
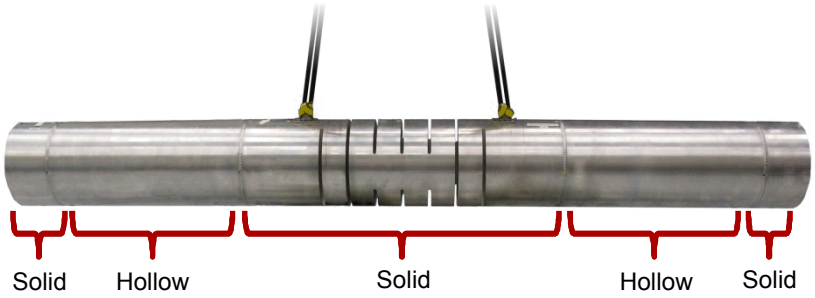
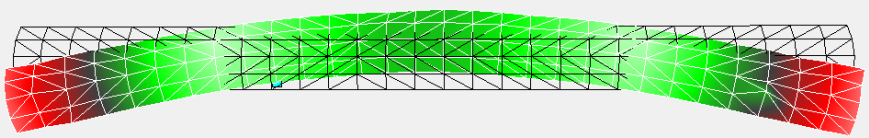
- System was first used in April 2015
- Abstracts Due June 2015
- This talk only encompasses the first 2 months of SLDV use
- Since then we have performed a number of other tests to examine additional features of the SLDV system.

Large Structure Test

- 13” diameter, 120” long cylindrical structure with hollow and solid sections
- Scanned in 2 sections with some overlap
- Due to object’s size, lasers were 2.6m (8.5ft) from the test object so signal return was poor (no surface prep)
- Even with poor signal return, the deflection shapes were still easily observed







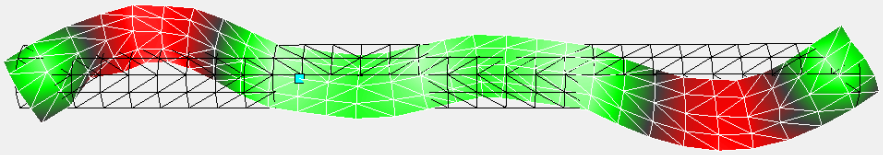
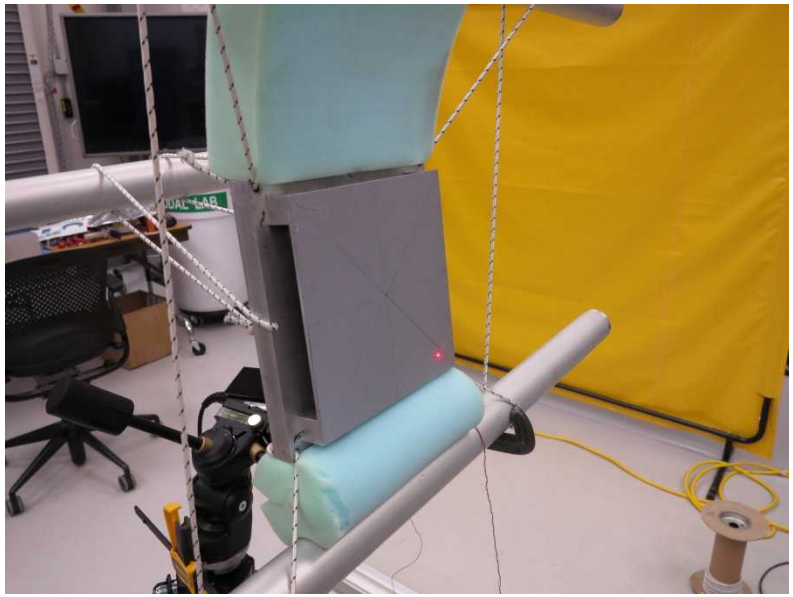
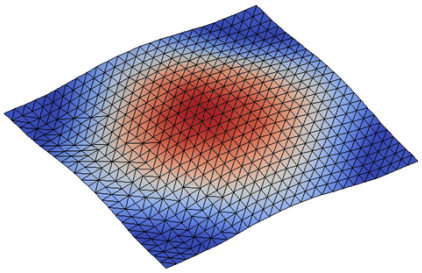


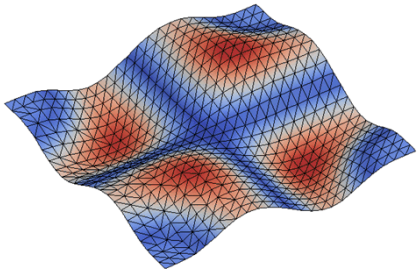
Plate Impact Test

- Plate covered in retro-reflective tape was impacted from the bottom corner on the reverse side
- Bandwidth set to 25 kHz, but difficult to fit modes past 20 kHz due to roll-off of hammer spectrum

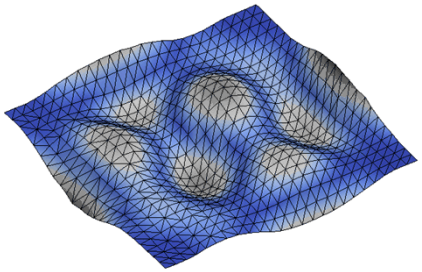




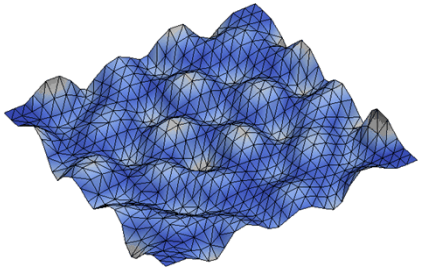
524.283203125 Hz



2090.53271484 Hz



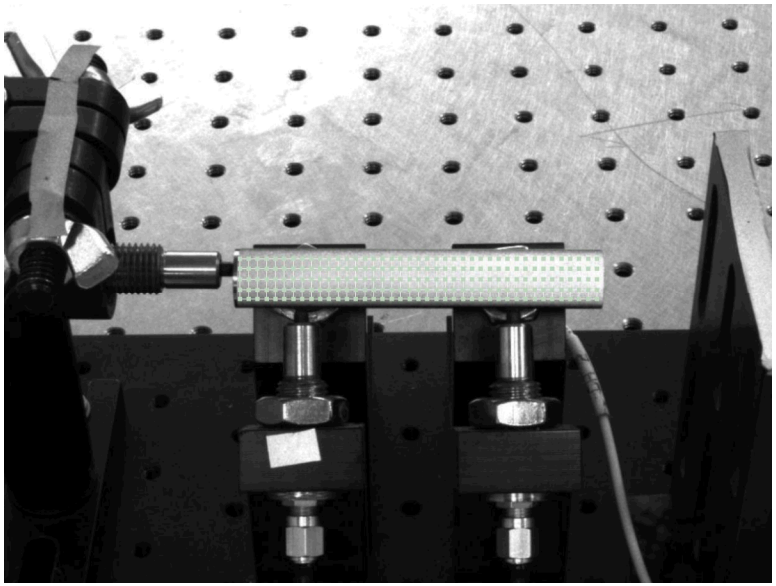
5271.82519531 Hz

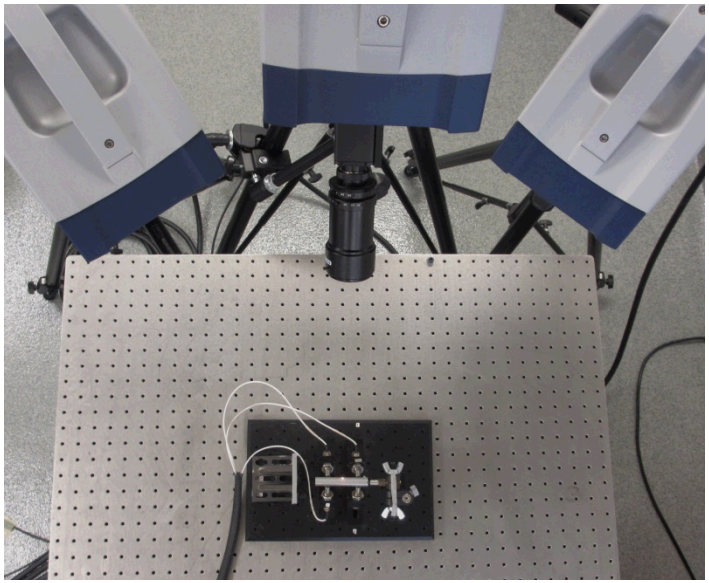


17400.3984375 Hz

Even higher frequencies?

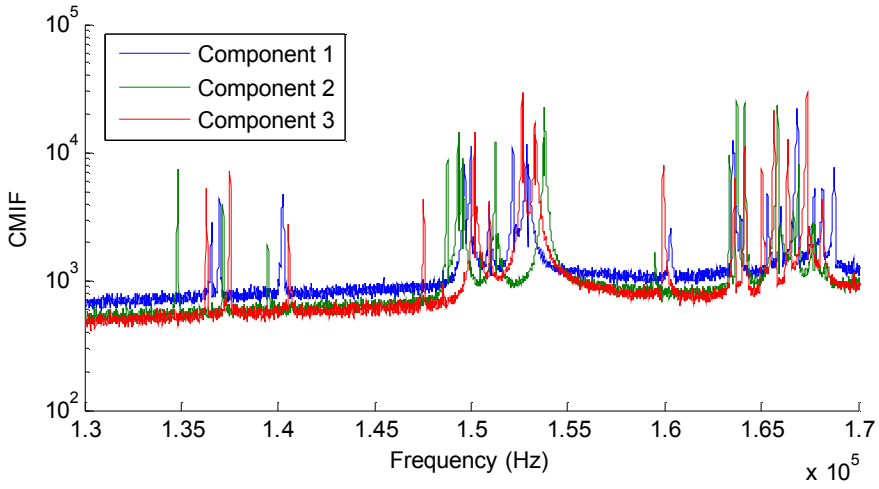
- Piezo-actuators can be used to excite structures up to very high frequencies
- A cylinder used for ultrasonic testing was characterized using the high frequency data acquisition system
- Customers were interested in the ordering of modes between 130-170 kHz
- Data was taken out to 200 kHz

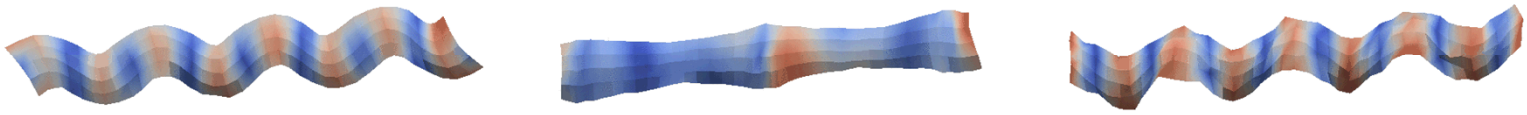




Results from High Frequency Test

- 3D capabilities allowed identification of bending, torsion, and axial modes
- Measuring force from a piezo is difficult, input voltage was used as the reference instead.
- Piezo was simply in contact with the part, some evidence of coming out of contact during the measurement; generally poor coherence.





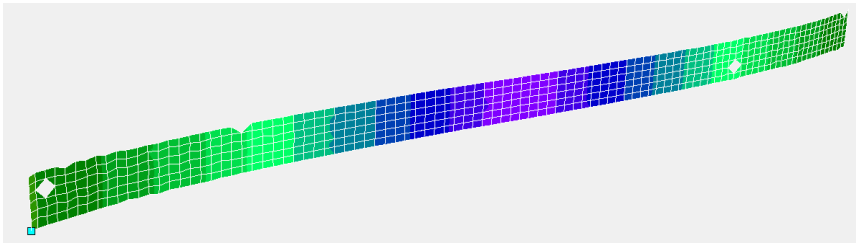
134822.890625 Hz

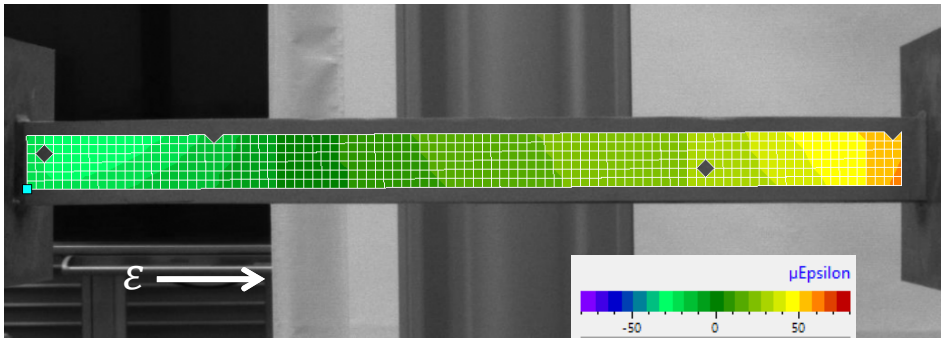
153774.015625 Hz

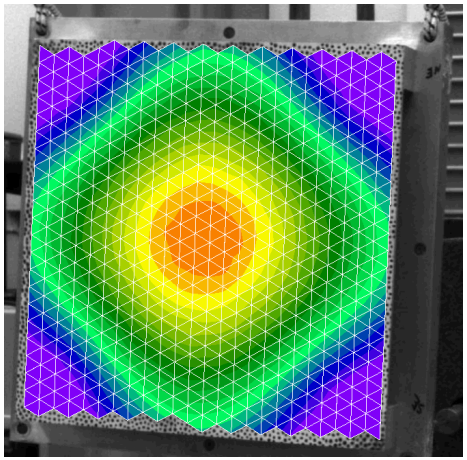
159455.4375 Hz

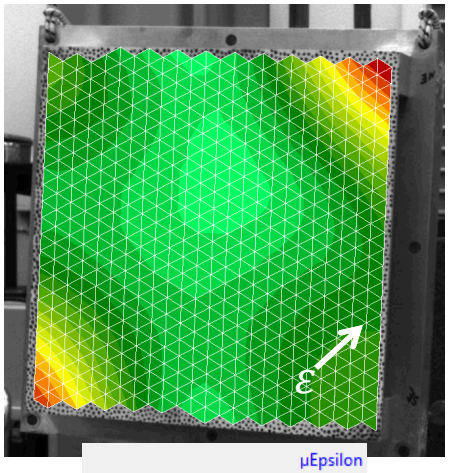
Strain Computation from 3D SLDV

- Polytec markets a strain post-processor that computes strain from 3D SLDV data
- Testing laboratories have had mixed success using this package
- Strain values can vary wildly based on filtering parameters in the post-processor
- Limited to small strain, non-destructive tests due to stationary laser spot and sequential scanning
- Strain is transformed to global coordinate system, which is not very intuitive for curved structures.



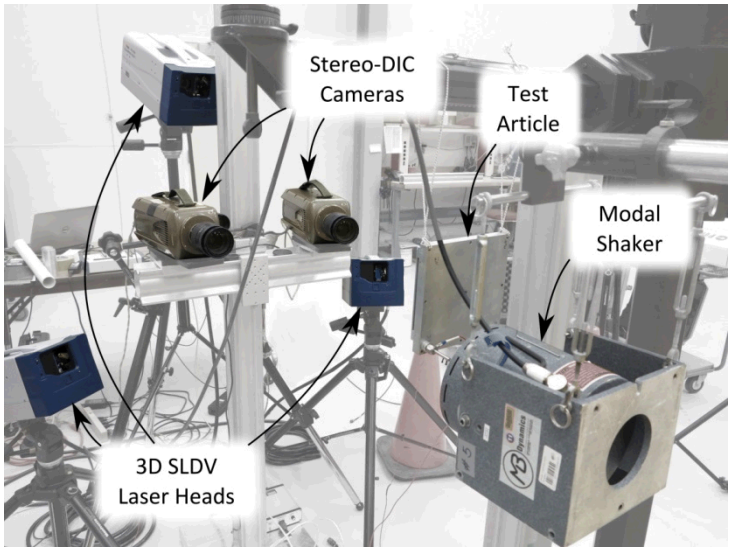


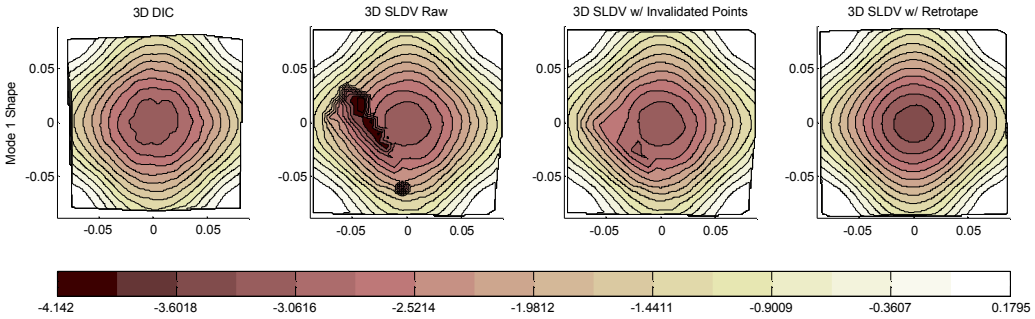


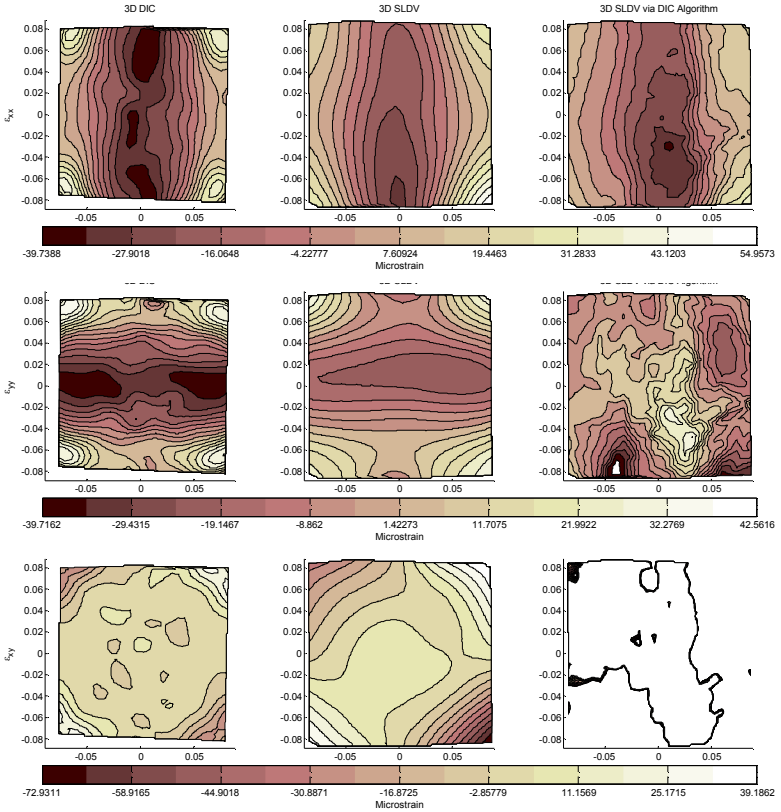


SLDV/DIC Comparison Test

- Partnered with Sandia DIC expert to perform comparison between modal and strain capabilities







Scripting through COM interface

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- A lot of effort has gone into improving 3D SLDV capabilities by writing scripts and utilities to automate tedious tasks.
- Scripts have been written to automate 2D alignment, place measurement points, and automatically generate a report in LaTeX.
- Scripts have also been written to ‘draw’ using the lasers.