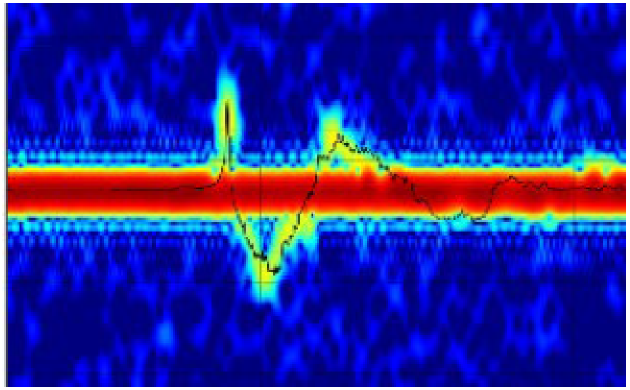
Surface Waves in Brittle Materials: Experiments and Simulations

NLV-014-16, Year 1 of 1



Michael Pena[1], Jason McDonald[2], Sikhanda Satapathy[2], Brendan O'Toole[3], Mohamed Trabia[3], Richard Jennings[3], Matt Boswell[3]

[1]National Security Technologies, LLC, [2]US Army Research Laboratory, [3]University of Nevada Las Vegas

Acknowledgments: Abel Diaz[1], Alex Suddreth[1], Scott Myers[1], Rand Kelly[1]

This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program.

SDRD

NEVADA NATIONAL NNSS SECURITY SITE

Understanding failure mechanisms in ceramic materials

- Boron carbide is the armor ceramic with the greatest potential for revolutionary improvements
- The material has high-hardness and a high Hugoniot Elastic Limit
- Has a low theoretical density (30% less than SiC)
- However, it shows a pronounced loss of strength at high-impact velocities

See it.
Experimental

Understand it.
Modeling

Control it.
Processing

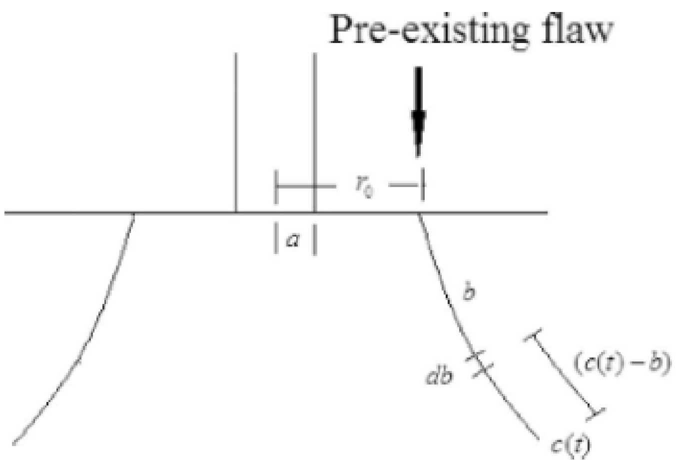
→ *Design* it.

Mechanism-Based Materials by Design Strategy for MEDE

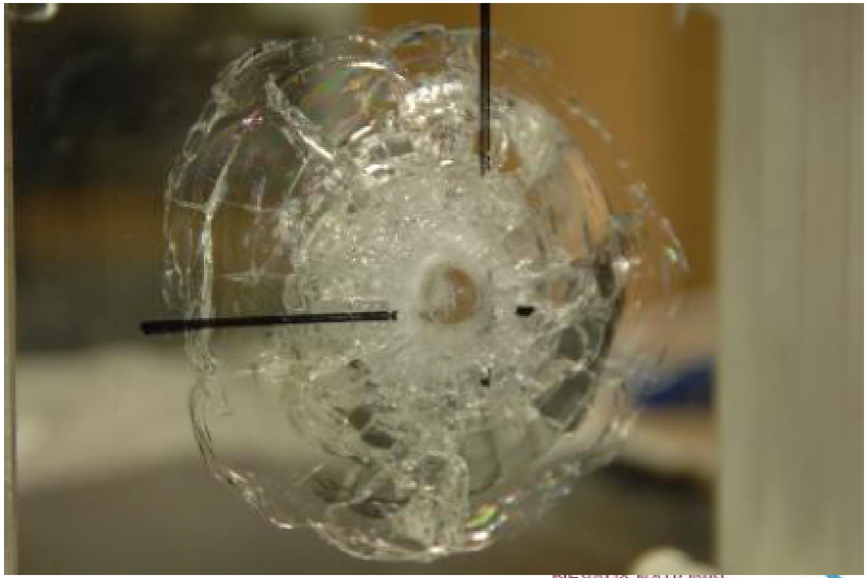
http://www.arl.army.mil/www/pages/1419/1419_MEDE%20Overview.pdf

V&V of Material Models – Surface Wave Failure Mechanism

- High-speed projectile impacts induce complex surface waves, which generate multi-stress loading on the target
- It is thought the interaction of these waves with surface defects and flaws may contribute to initial crack growth and the onset of failure in brittle materials such as ceramics and glass
- Initial attempts using finite element modeling to accurately simulate these impacts have been *unsuccessful*.
- There is a lack of experimental data that directly observe this phenomena

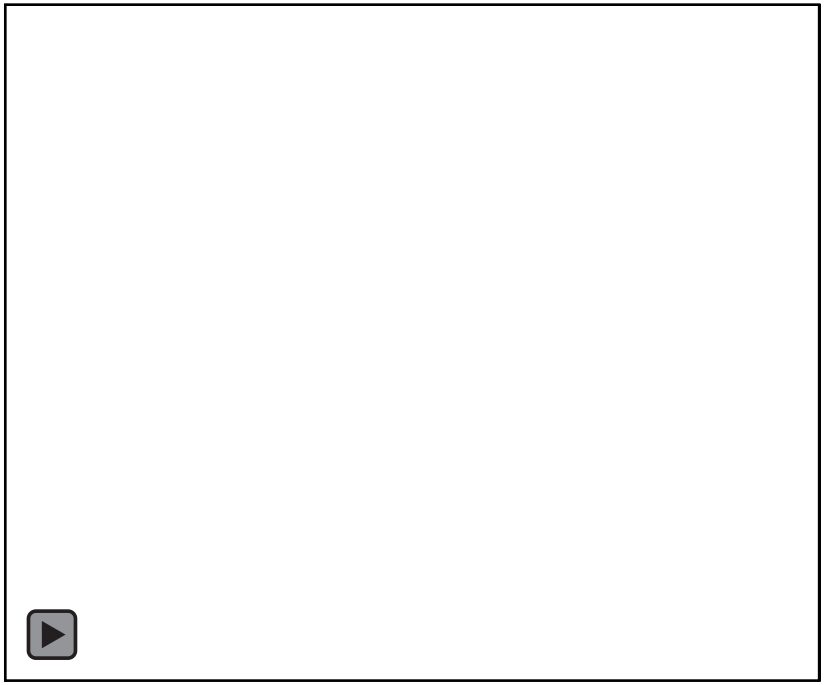


J. McDonald, S. Satapathy, *International Journal of Impact Engineering* 93, July 2016.



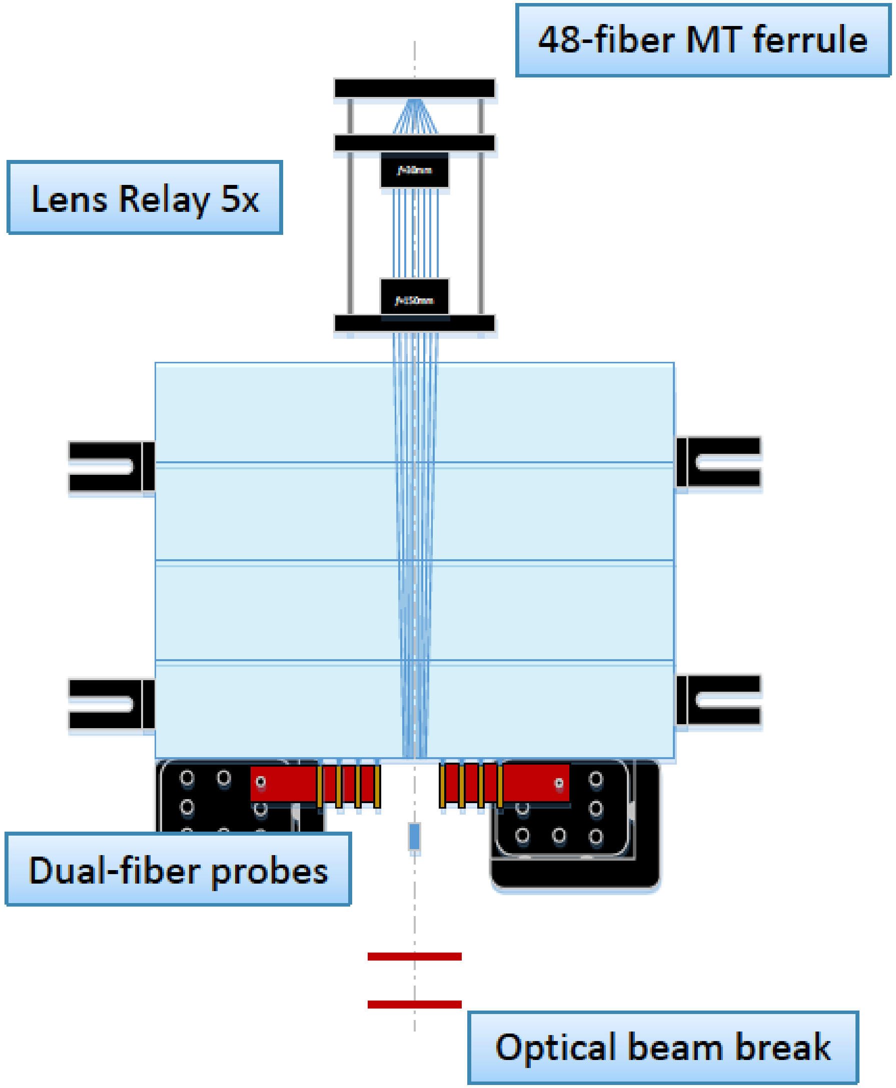
Experiments

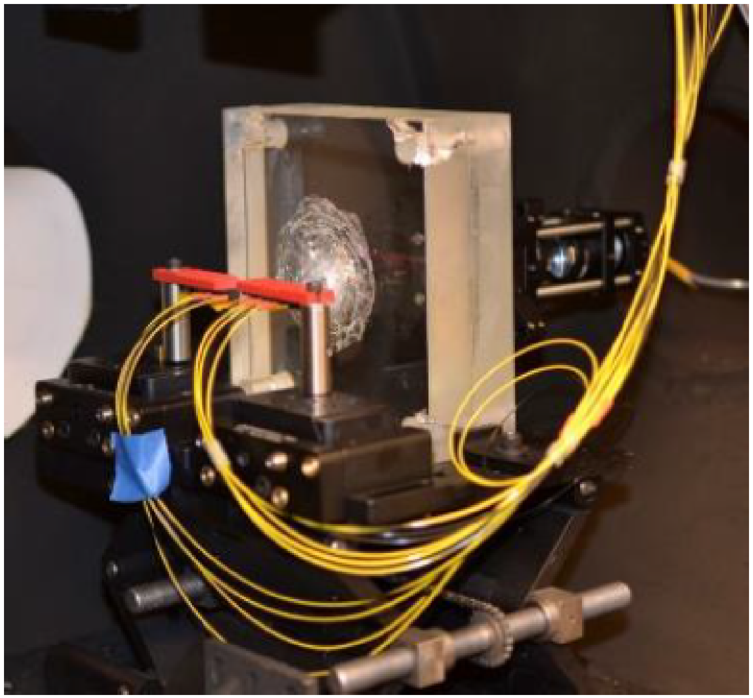
- Shots conducted at UNLV Gas Gun facility
  - Gun modified for single-stage operation
  - Lexan on glass impact velocities of 400 m/s and 800 m/s
  - Schott Borofloat glass used in lieu of boron-carbide armor
- MPDV Gen1 systems
  - 8 dual-fiber probes looking at front surface, plus 8 single-fiber looking from rear
- High-speed video
  - Specialized Imaging Kirana and Vision Research Phantom cameras
- Simulations conducted by ARL
  - Laplace-transformed base framework



2,000,000 frames/sec

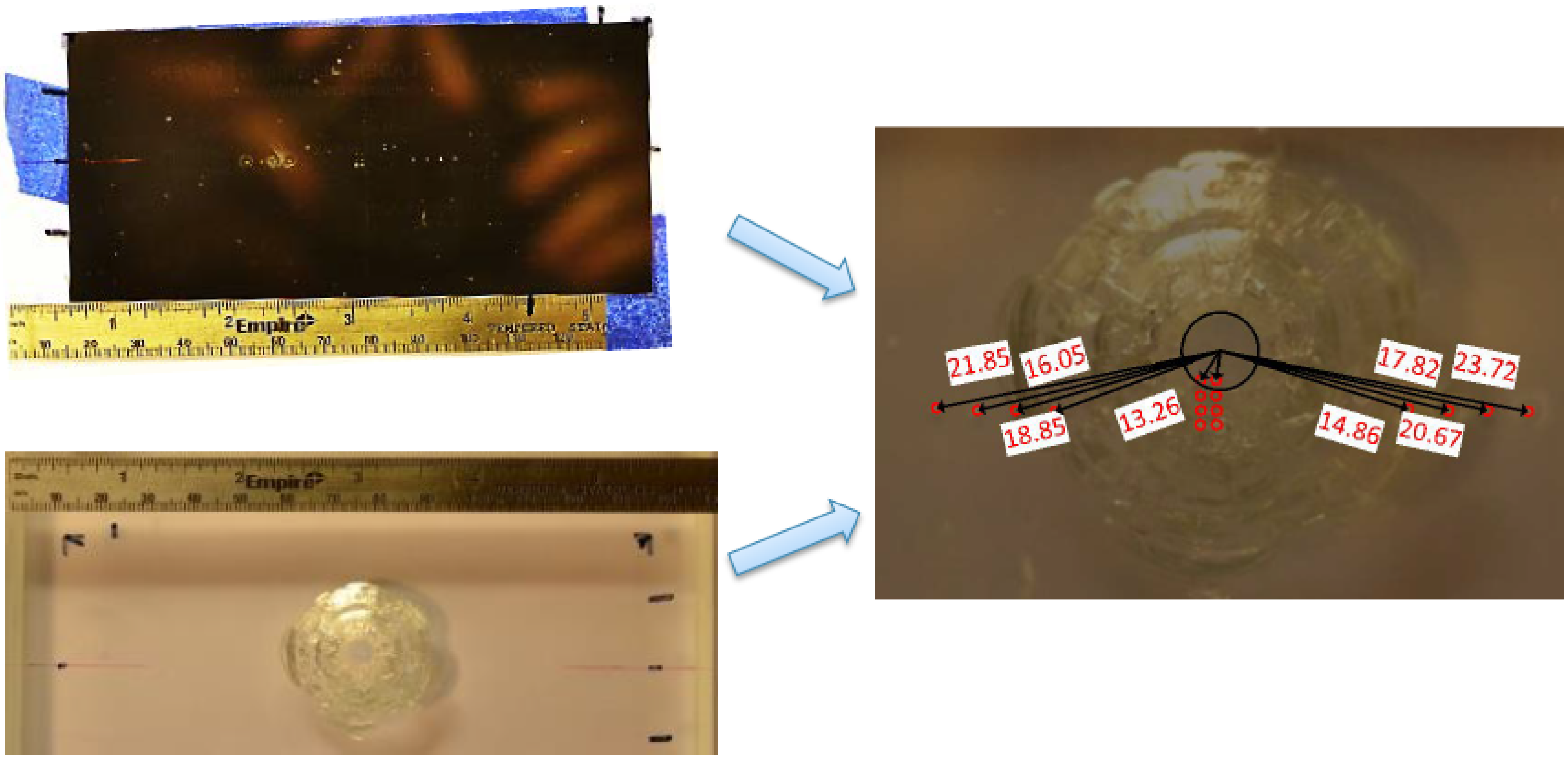
Target Setup





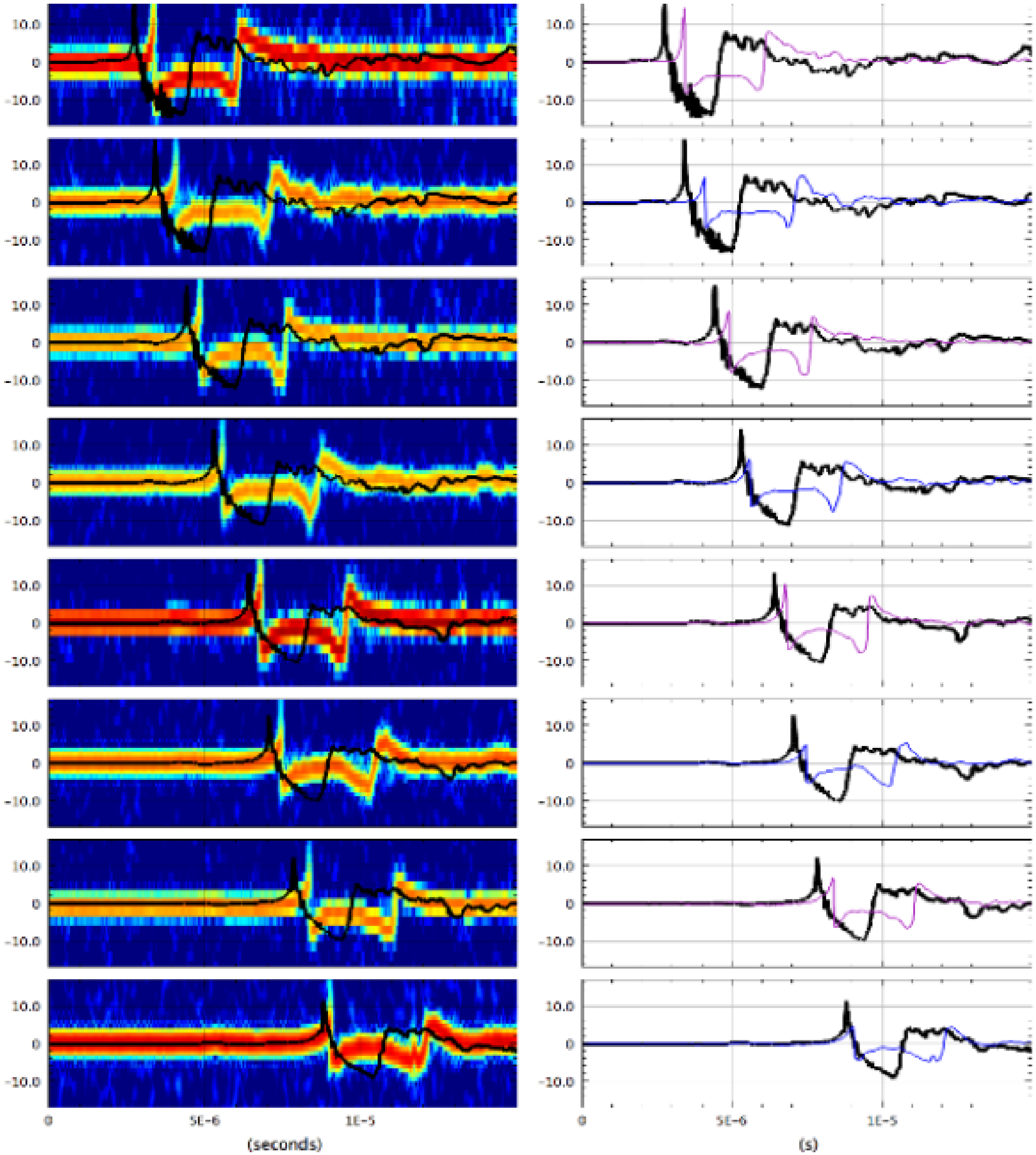
- 8 front surface probes
  - Aligned to horizontal axis
  - Staggered 11–32 mm
  - 1–2 mm from surface
- 8 rear probes
  - MT ferrule image
- Trigger from 2nd beam break

Probe Location Measurement



- Zap-It laser burn paper to mark relative probe positions
- Place reference marks on burn paper and target
- Scale image, set opacity, and invert horizontally
- Align burn paper to target

Results – 817 m/s Simulations and Experiments



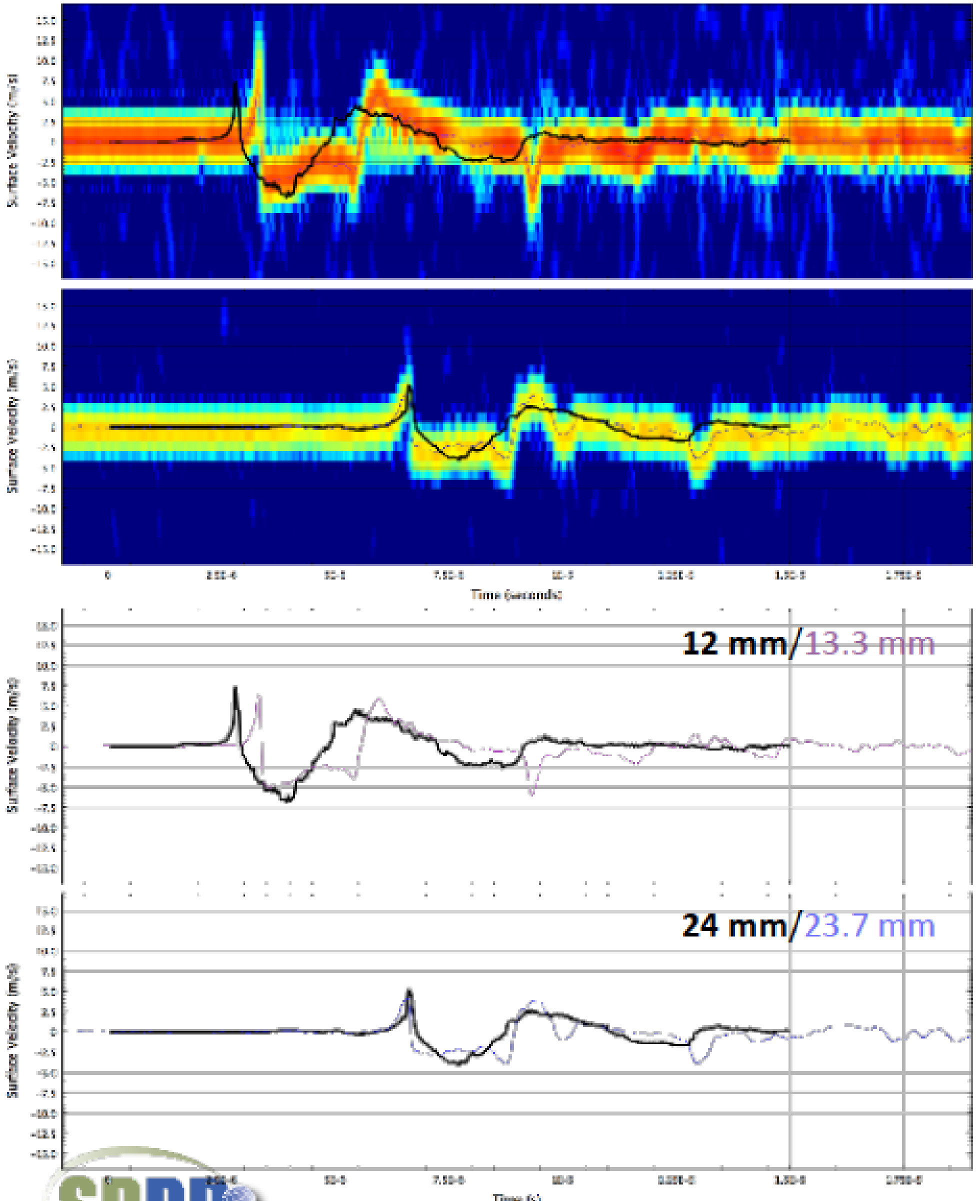
Simulation

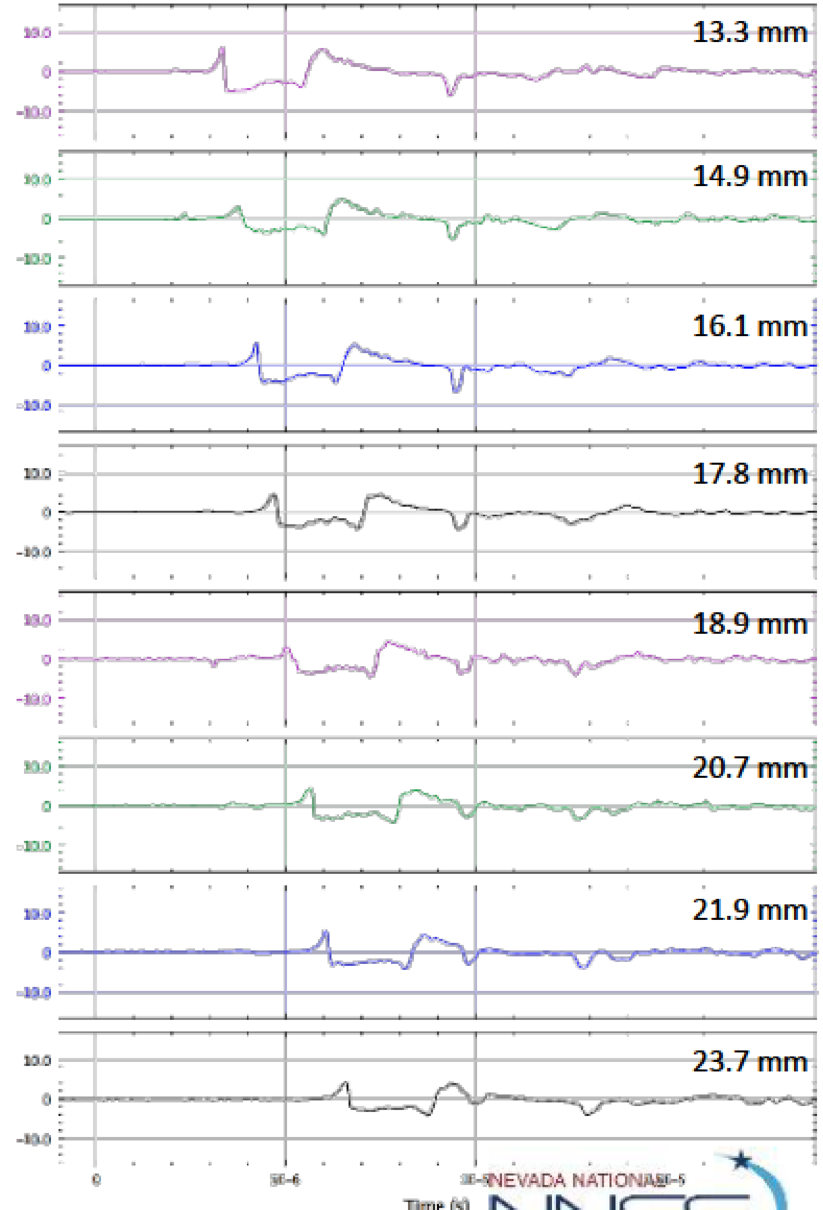
Experiment 8192/256

- Raleigh-wave lateral speed faster in simulations
- Raleigh peak may be too short for accurate extraction, but matches spectrograms
- Elastic precursor matched very well
- Pull-back not well matched

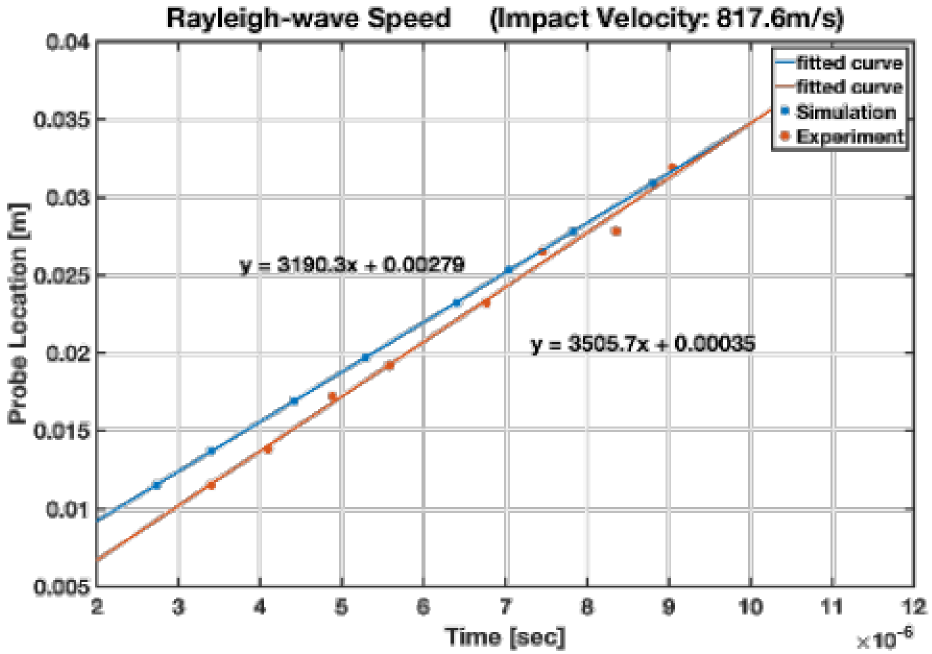
NEVADA NATIONAL NNSS SECURITY SITE

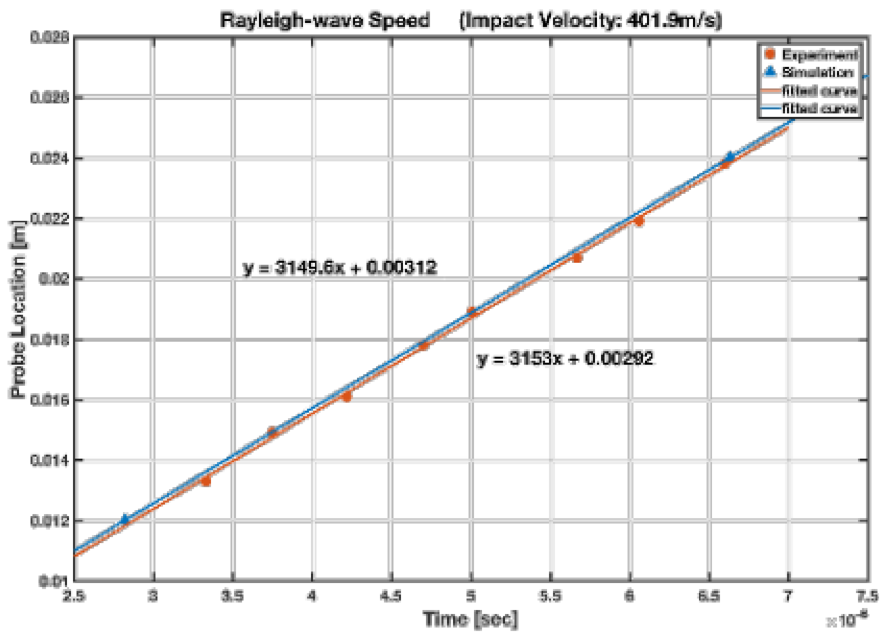
Results – 401.9 m/s Simulations and Experiments





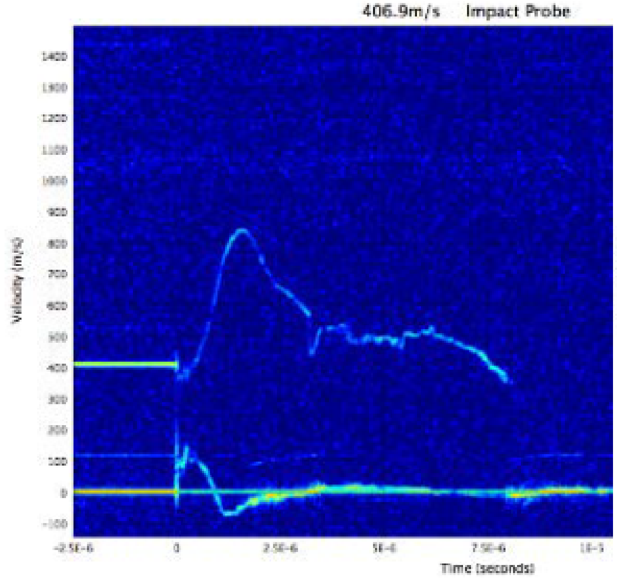
Rayleigh-Wave Lateral Speed Comparison

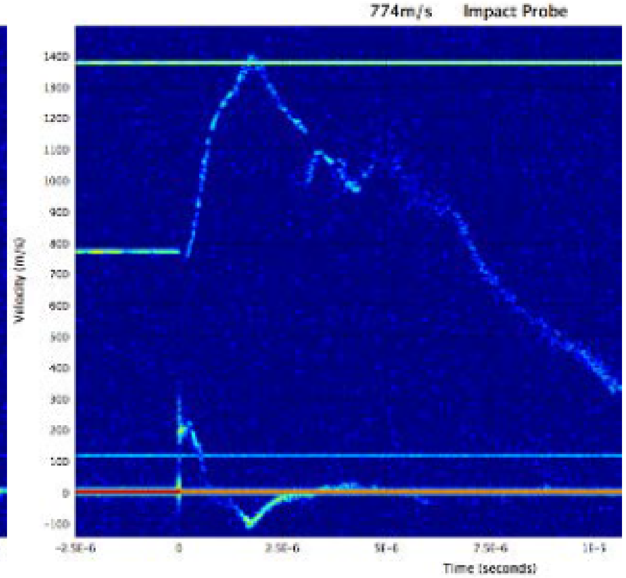




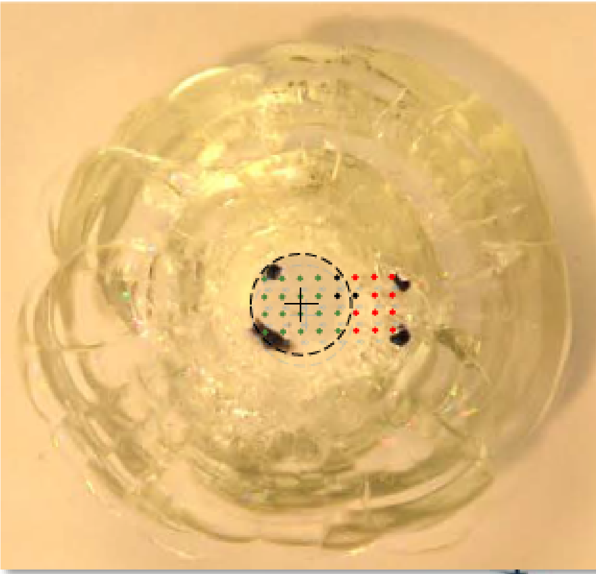
Rayleigh-wave is faster in simulations.

Failure Front

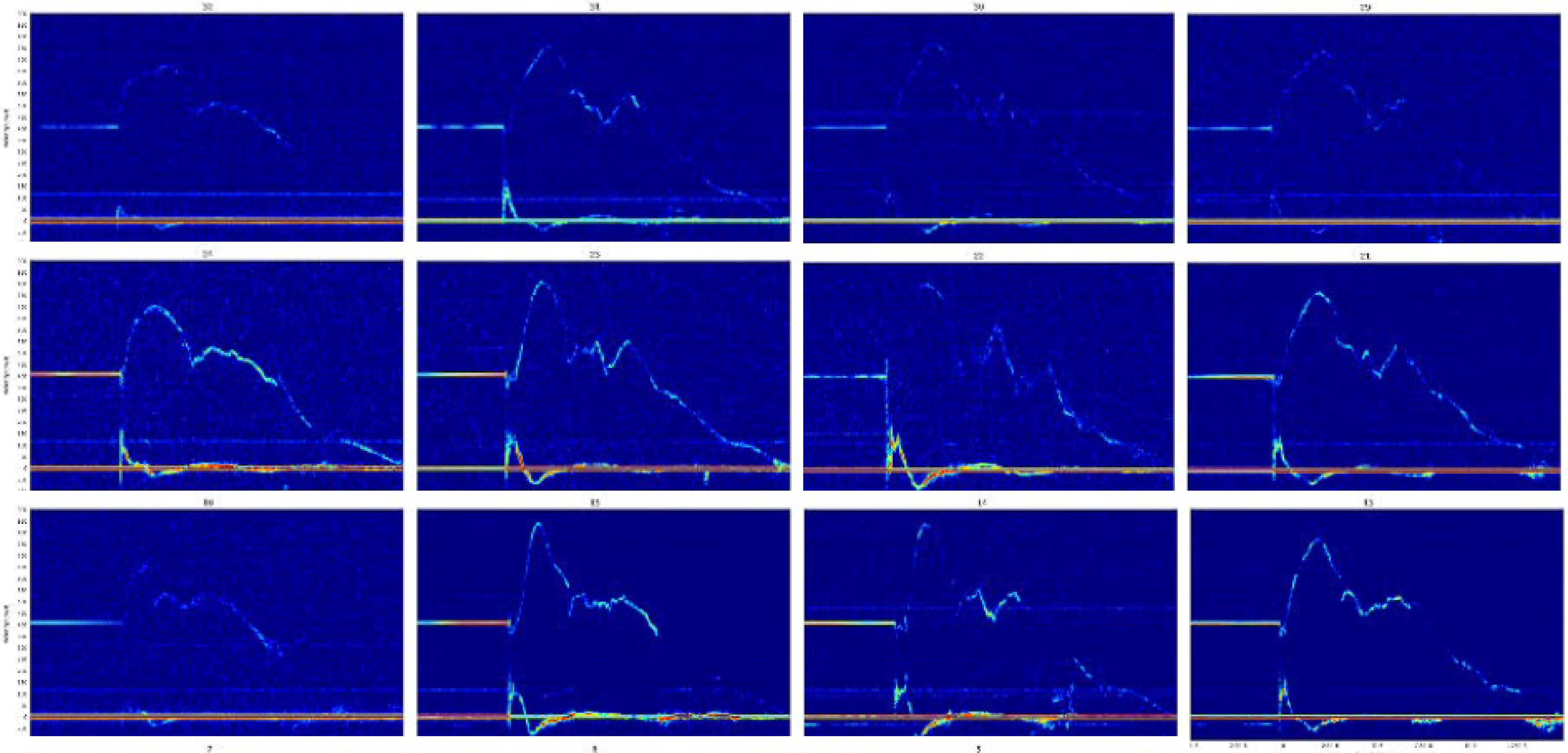


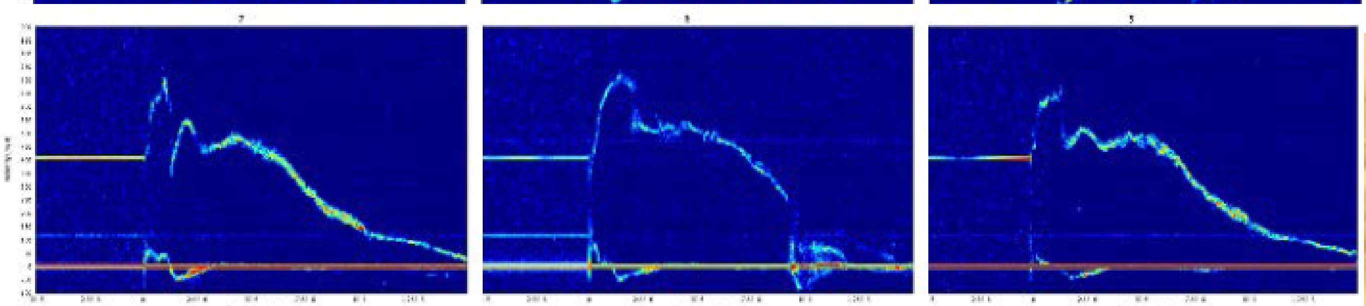


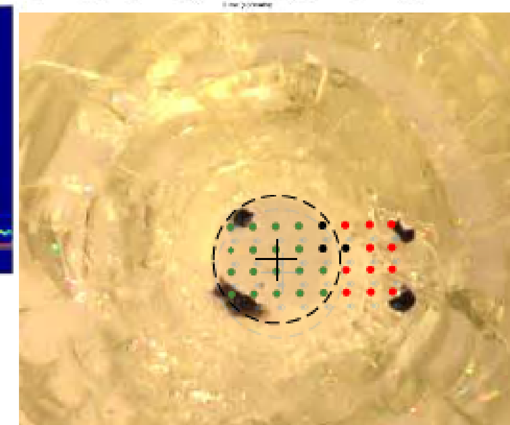
- Impacted surface remained intact and transparent. Displaces ~5–6 mm.
- Annulus around impact surface immediately fractures, produces no velocity records
- PDV able to record impact surface and failure front



Failure Front







Summary

- Collected:
  - 15 shot records of surface waves
    - ~400 m/s and ~800 m/s
  - Total of approx. 60 velocity traces
  - 4 failure front records
  - 8 high-speed videos
- Raleigh peak-velocity and elastic precursor matched simulations relatively well
- Pull-back and lateral velocity needs adjustment

Remaining Work

- Complete surface wave simulations
- Conduct failure front simulations

Impact

- Submitted abstract to 40th International Conference and Expo on Advanced Ceramics and Composites, Jan. 2017
- Anticipate to present at Mach Conference, Apr. 2017
- Work will be used in thesis for UNLV grad student, Matt Boswell
- Memorandum of Understanding in place until March 2018
  - Extend simulation framework to ceramic armor performance (and surface-treatments)
  - ARL has expressed interest to continue work