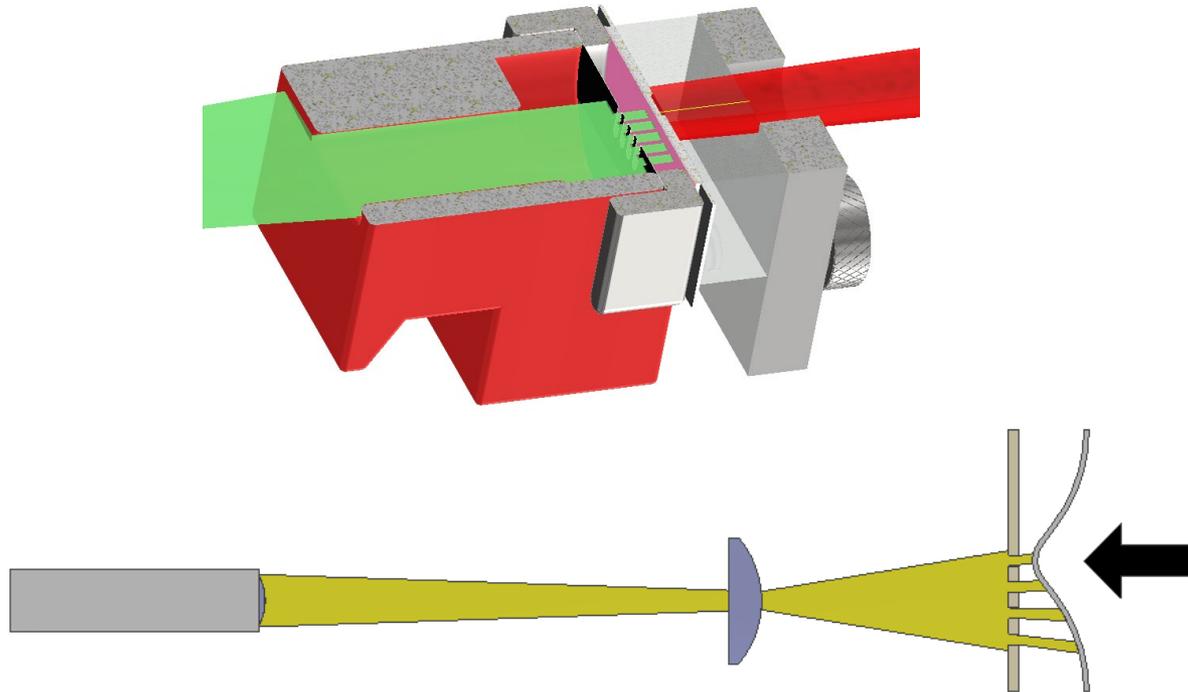


PDV Profilometry



Brian Thurston

The Ohio State University & Applied Impulse Inc.

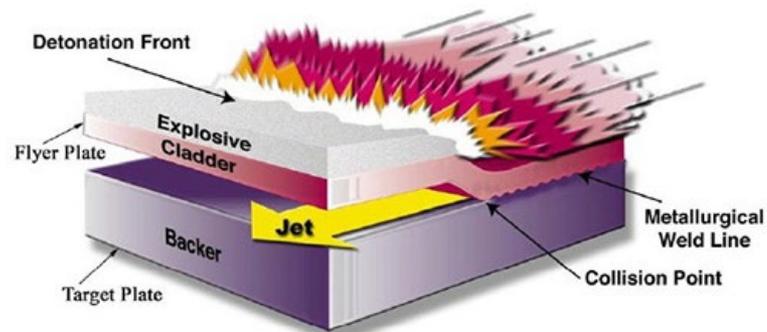
Thurston.56@osu.edu



Our Use Case: PDV for Impact Welding

Impact welding requires high speed propulsion. Several methods have been used.

- Explosives
- Vaporizing Foil Actuator Welding (VFAW)
- Magnetic Pulse Welding
- Spin Impact
- Laser Impact
- Augmented Laser



<https://www.totalmateria.com/page.aspx?ID=CheckArticle&site=ktn&NM=475>

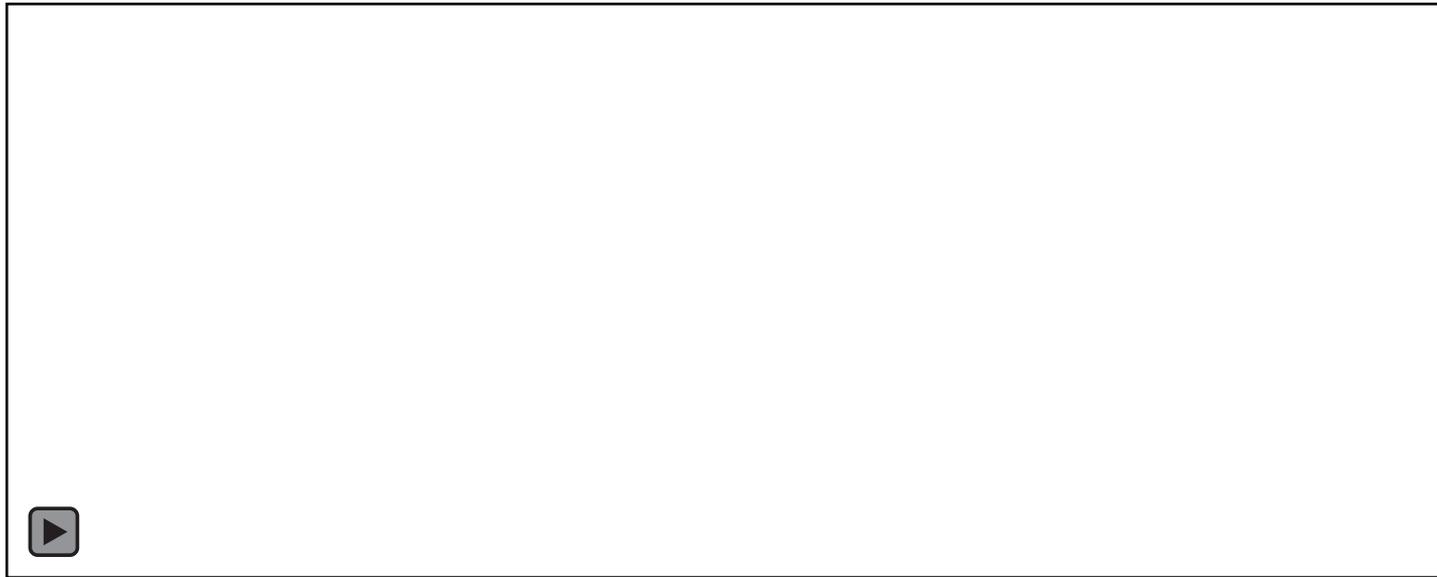


Requirements for Impact Welding

Impact welding requirements:

- Sufficient impact angle (2-28°)
- Sufficient normal velocity (>200m/s)
- A Standoff Gap for flyer acceleration

P. Groche, M. Becker and C. Pabst, "Process window acquisition for impact welding processes," Materials and Design, vol. 118, pp. 286-293, 2017.

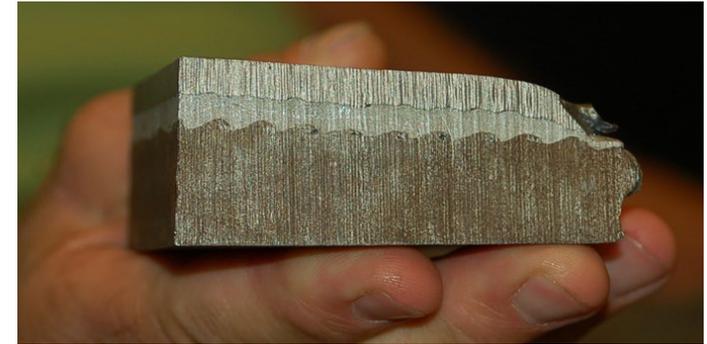


Manny Gonzales – TMS 2023

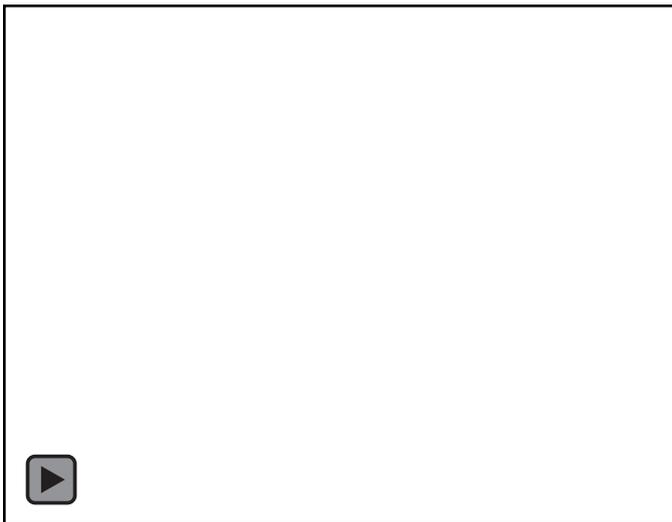


Bonding Mechanisms

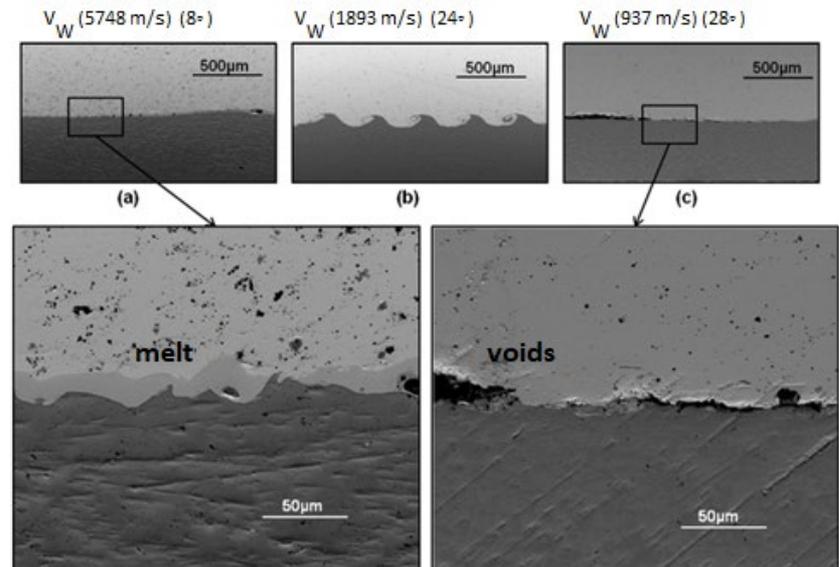
- Cold Welding
- Melting + Solidification
- Mechanical Joining



<https://awo.aws.org/2016/05/taking-the-explosion-out-of-explosion-welding/>



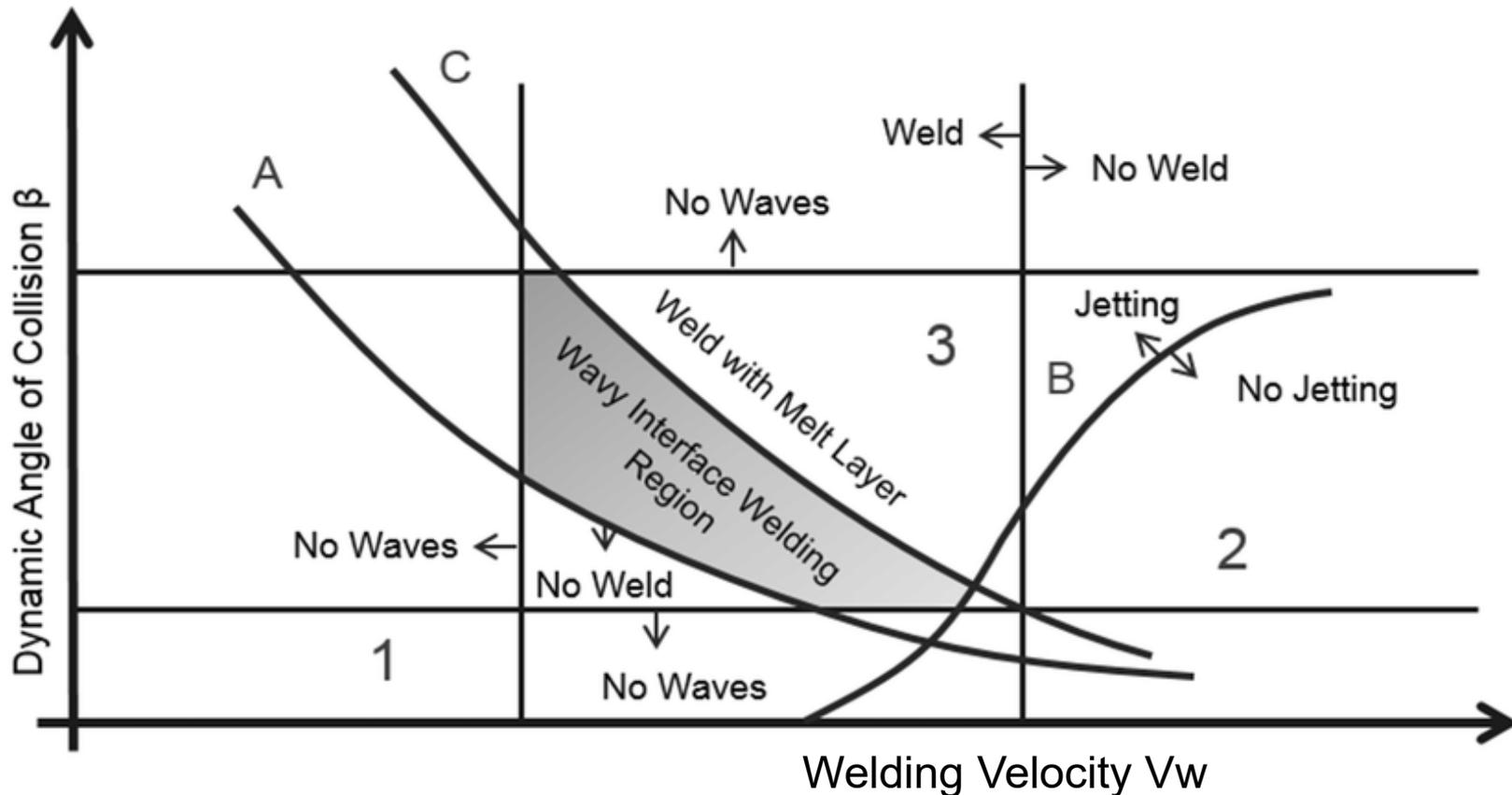
Lu, Y., Huang, J. Y., Wang, C., Sun, S., & Lou, J. (2010). Cold welding of ultrathin gold nanowires. *Nature nanotechnology*, 5(3), 218.



Vivek, A., et al (2014), JMPT



The Impact Welding Window



Rebensdorf, Anatoli & Böhm, Stefan. (2016). Increase of the Reproducibility of Joints Welded with Magnetic Pulse Technology Using Graded Surface Topographies. 10.17877/DE290R-16979.

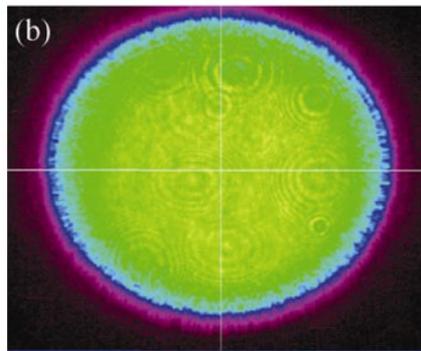


Augmented Laser Impact Welding

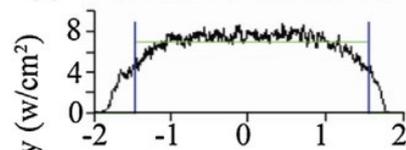


Our Laser:

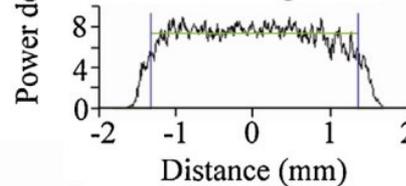
- Nominal 3J output
- Pulse Width of 8ns
- Power: 375MW



(c) Horizontal line Profile



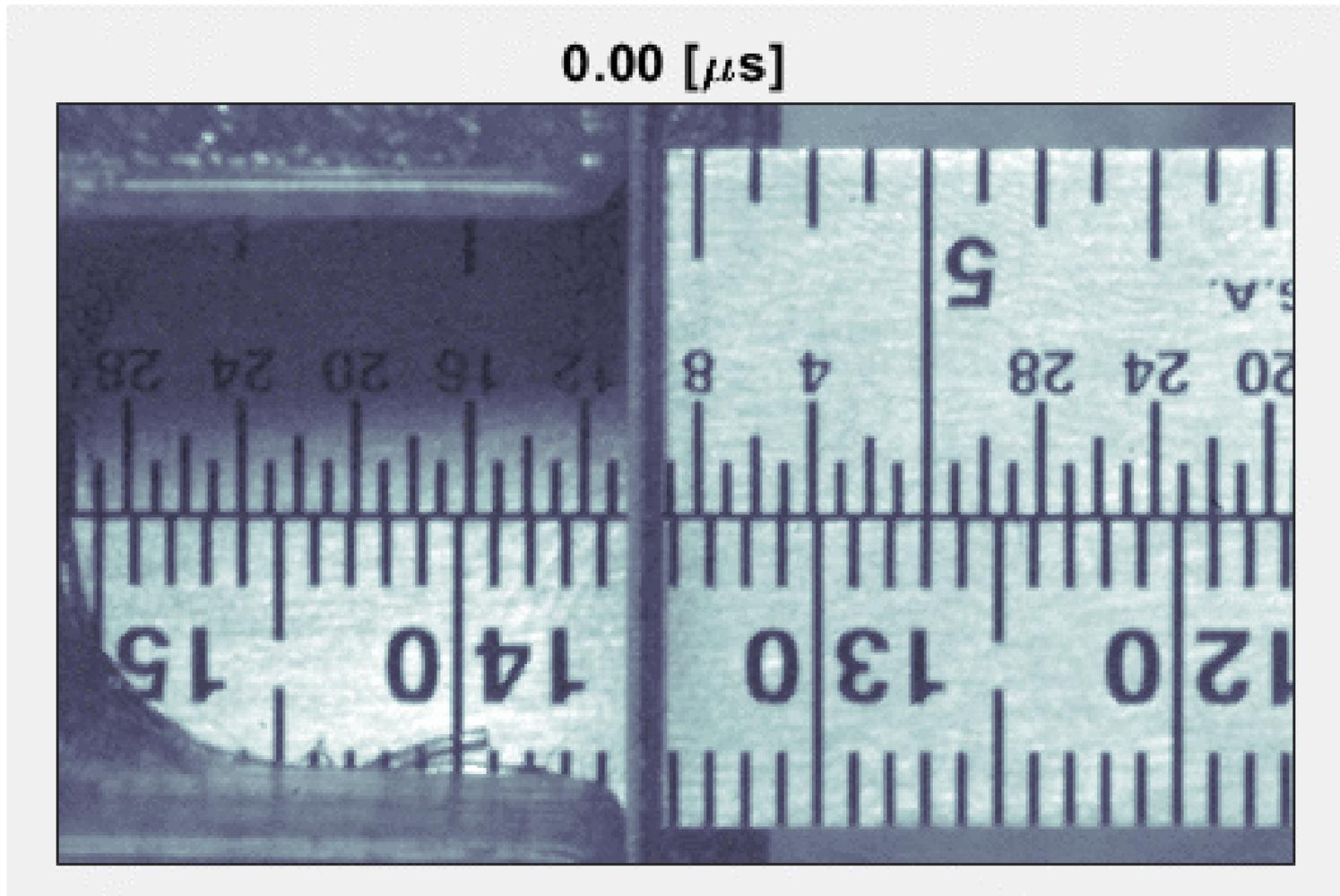
Vertical line profile



Wang, H., Taber, G., Liu, D., Hansen, S., Chowdhury, E., Terry, S., Lippold, J. C., & Daehn, G. S. (2015). Laser impact welding: Design of apparatus and parametric optimization. *Journal of Manufacturing Processes*, 19, 118–124. <https://doi-org.proxy.lib.ohio-state.edu/10.1016/j.jmapro.2015.05.007>



Video of a Laser Impulse



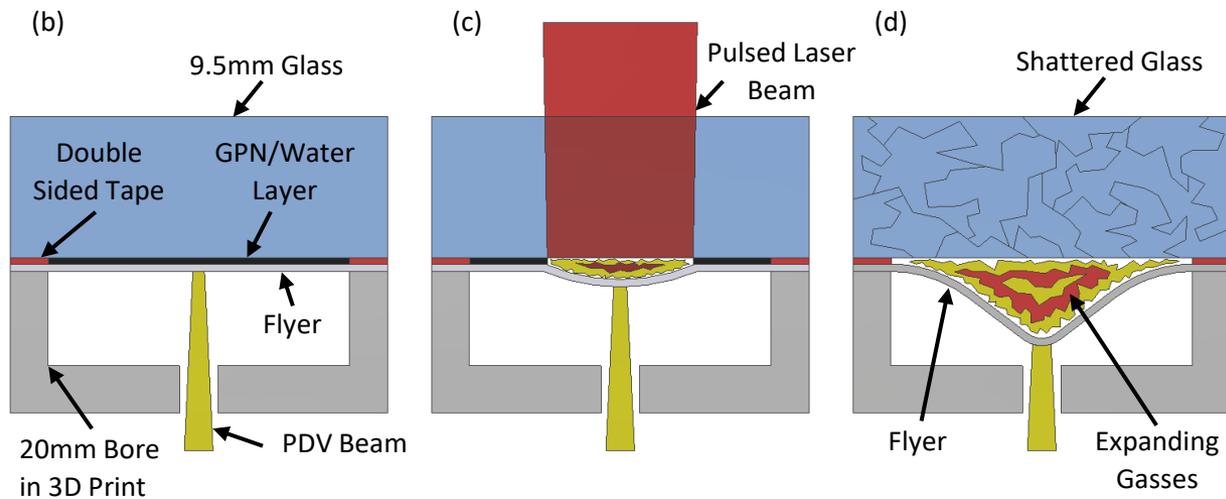
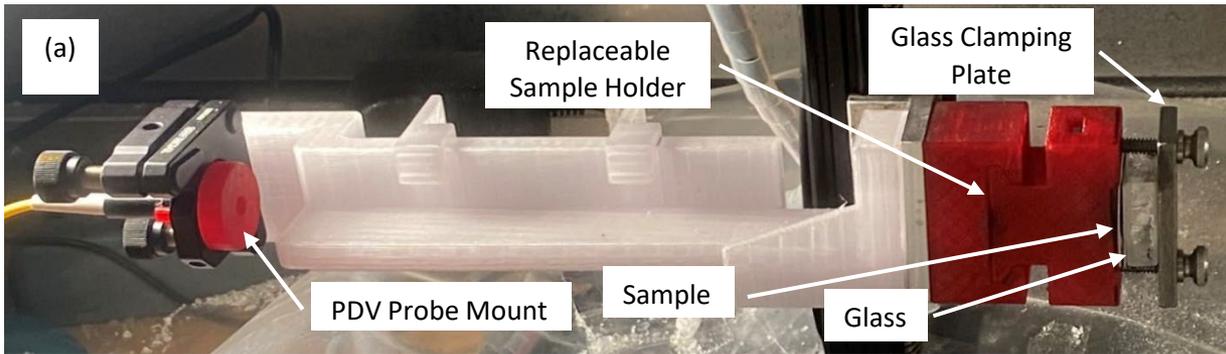
Camera work by Dr. Jeremy Seidt of OSU



THE OHIO STATE UNIVERSITY
COLLEGE OF ENGINEERING



Augmented Laser Impact

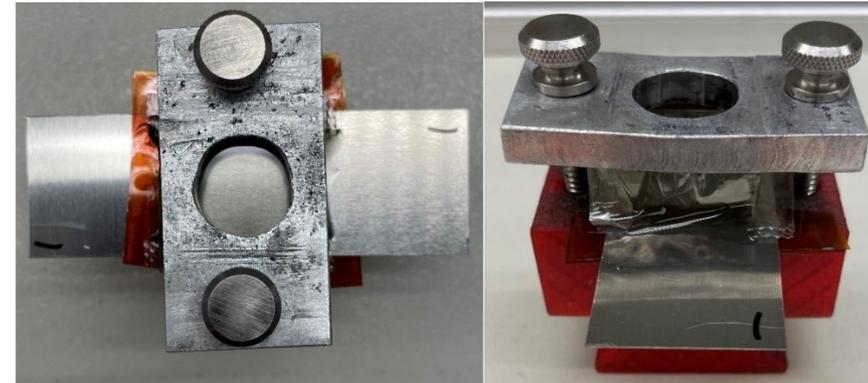


Experimental setup for collection of PDV data.

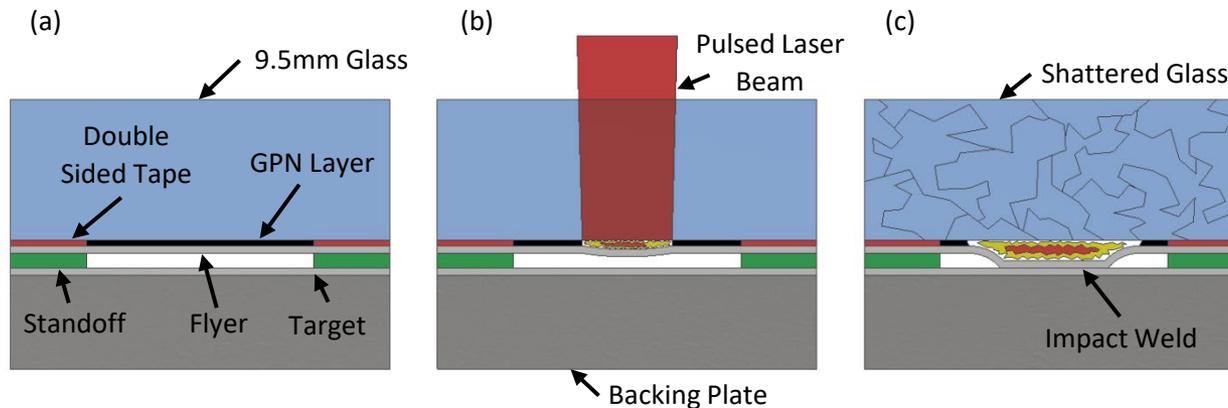


Impact Welding by Augmented Laser Impact

- Impact welds are made with a GPN thickness of 0.37mm and a laser spot size of 6mm and a standoff gap of 1mm



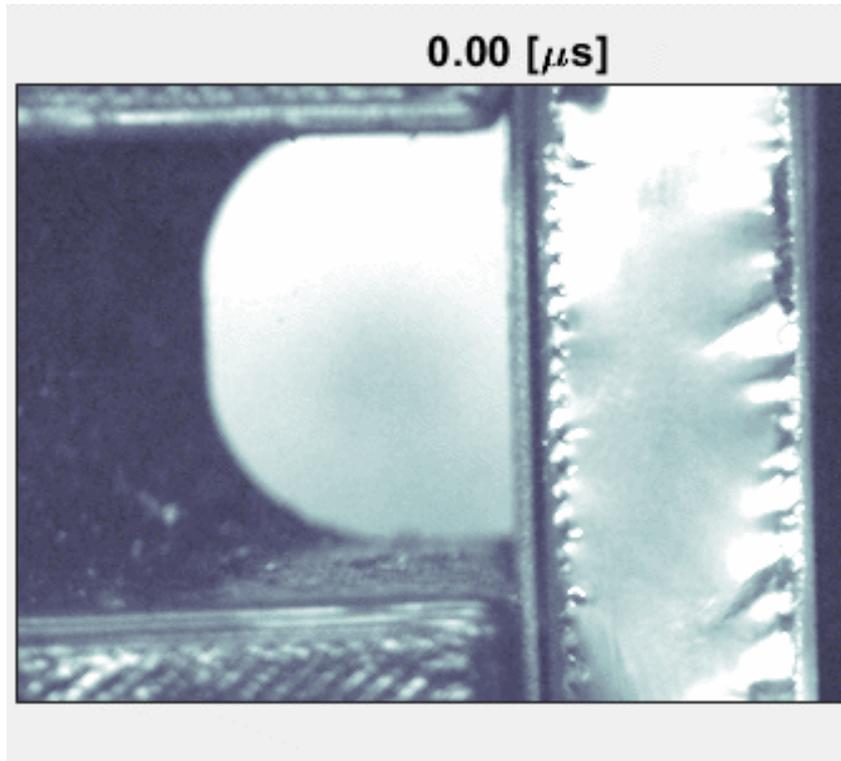
Welding experimental setup.



Schematic overview of the welding process.

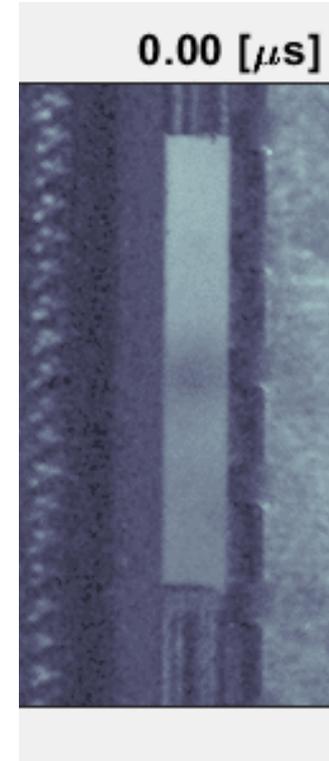


Augmented Laser Impact



Camera work by Dr. Jeremy Seidt of OSU

Free Flyer Propelled by
Augmented Laser Impact



Flyer Impact
With Target



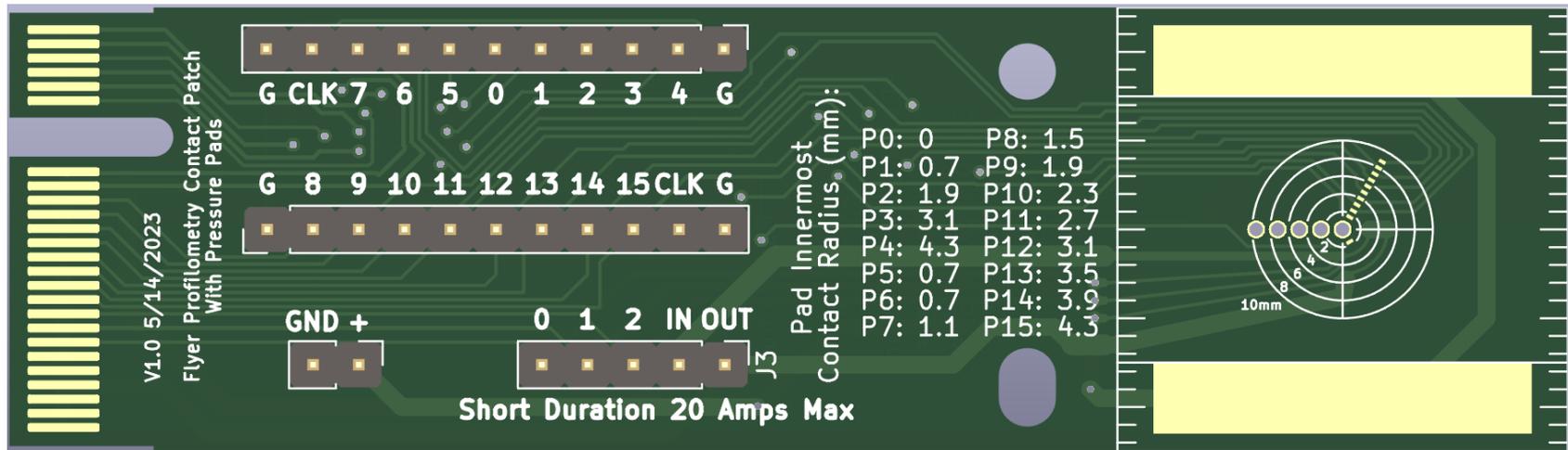
Multiply Welded Sheets by Augmented Laser Impact Welding (ALIW)



In Situ Data Collection with Custom Circuit Boards

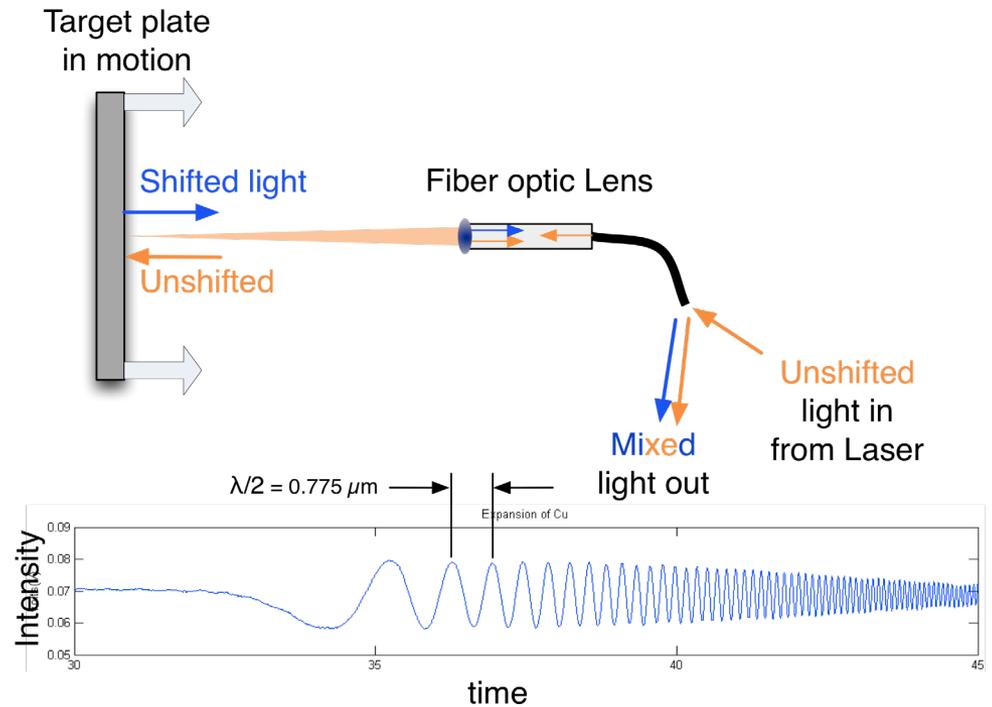
Aspirations:

- Collection of flyer shape evolution
- Measurement of welding velocity
- Estimation of impact angles



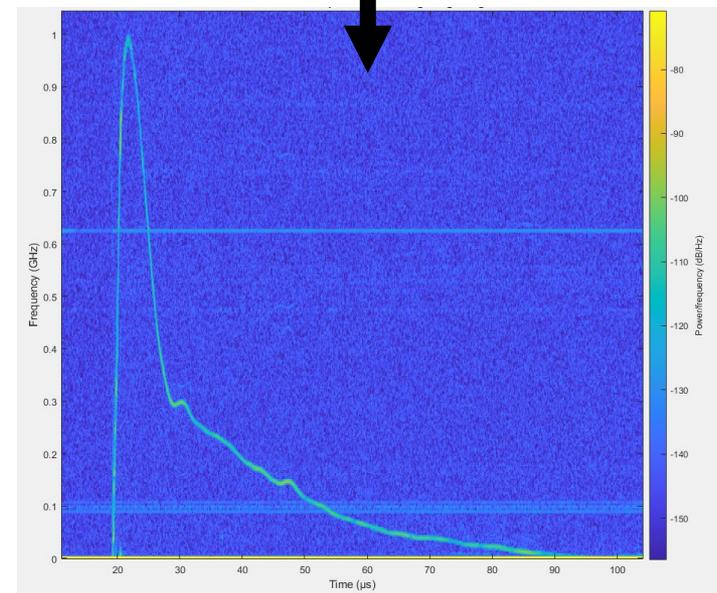
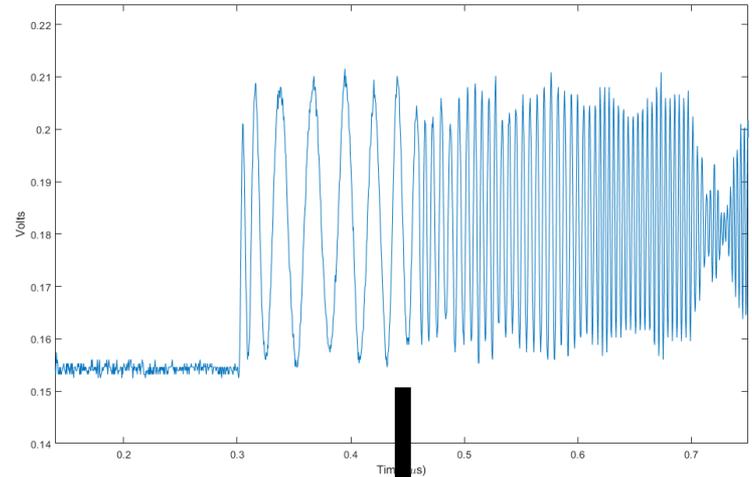
Photon Doppler Velocimetry

- For measuring flyer velocity
- Velocity is 775 times the frequency in GHz
- 1 GHz = 775 m/s
- Typical laser power is 125mW



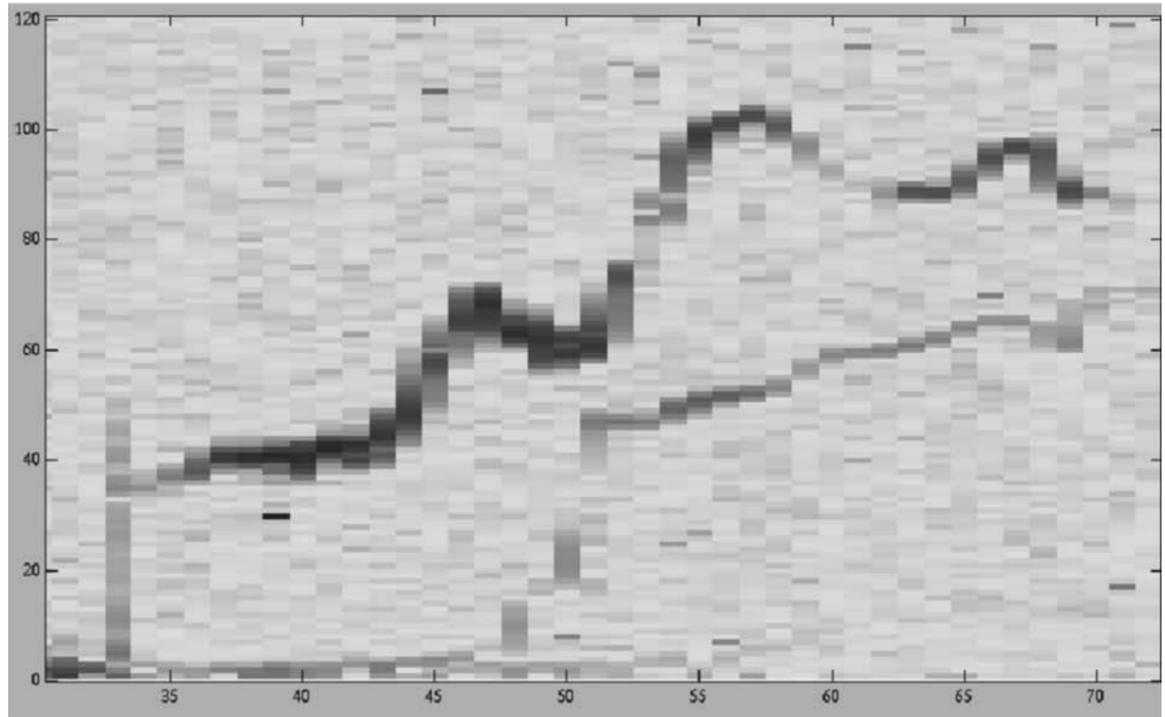
Photon Doppler Velocimetry

- PDV waveforms are fed into a moving window Fourier transform to make a spectrogram
- The PDV signal appears in the spectrogram as a higher intensity line compared to the background frequencies (which are near zero)
- Velocity is 775 times the frequency in GHz



Multiple Signals In Spectrogram

- More than one signal can be present in the spectrogram
- If two or more moving reflectors are present in the beam then two PDV signals will be present in the spectrogram

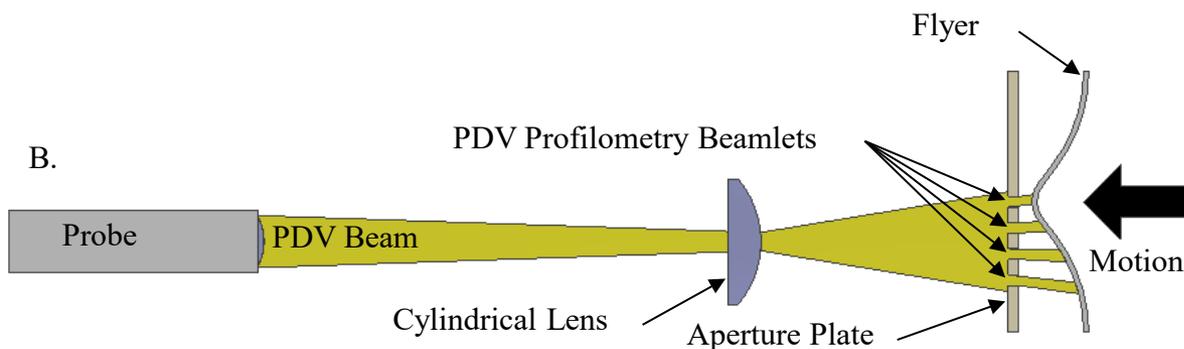
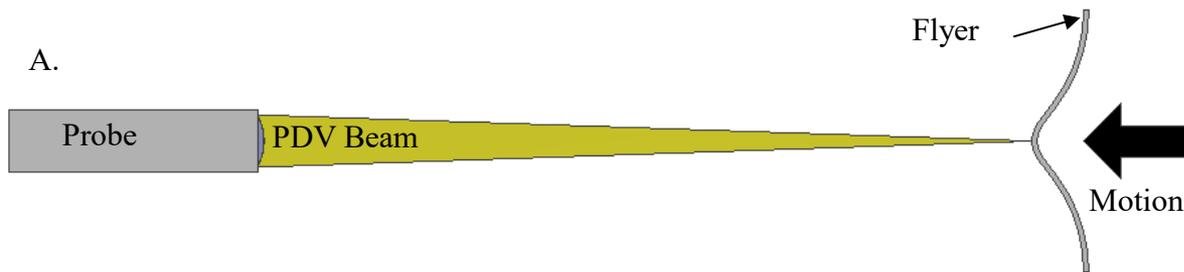


O. T. Strand, D. R. Goosman, C. Martinez and T. L. Whitworth, "Compact system for high-speed velocimetry using heterodyne techniques," *Review of Scientific Instruments*, vol. 77, no. 8, 2006

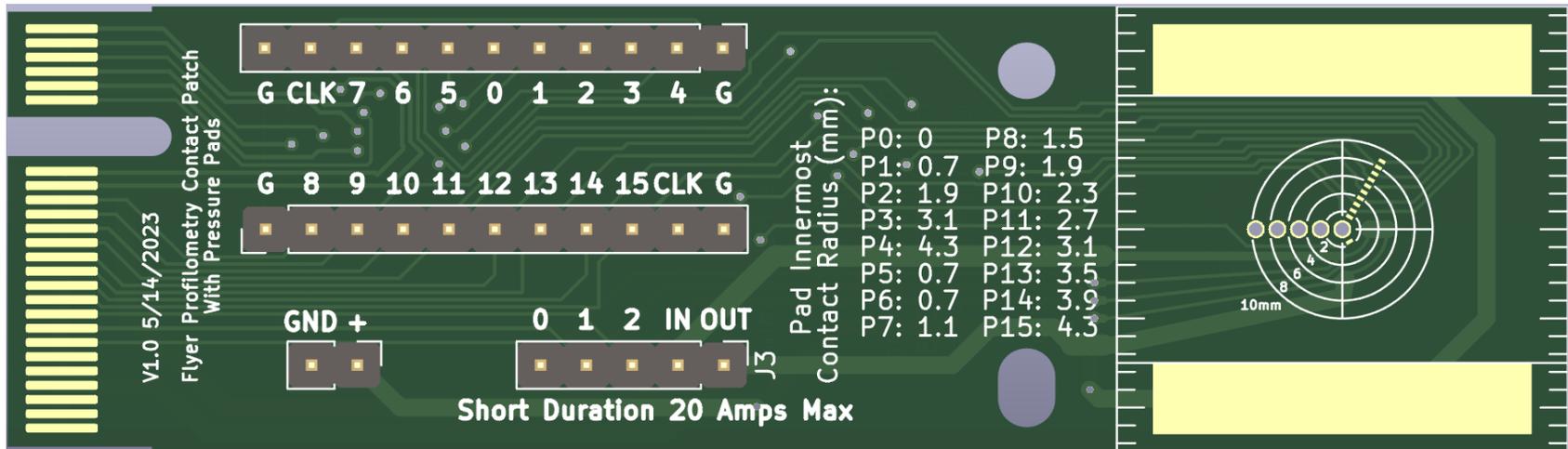
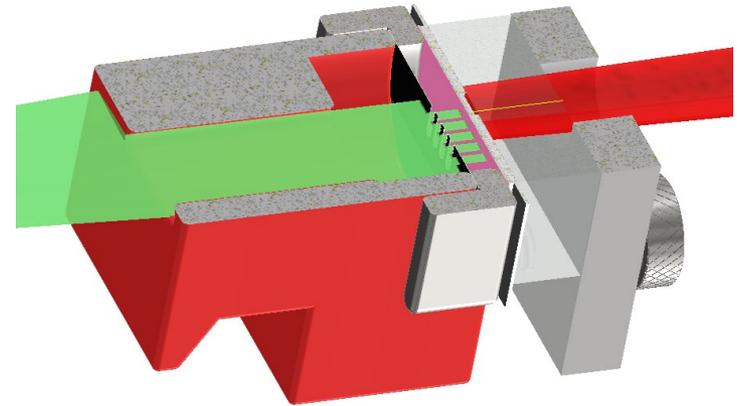


PDV Profilometry

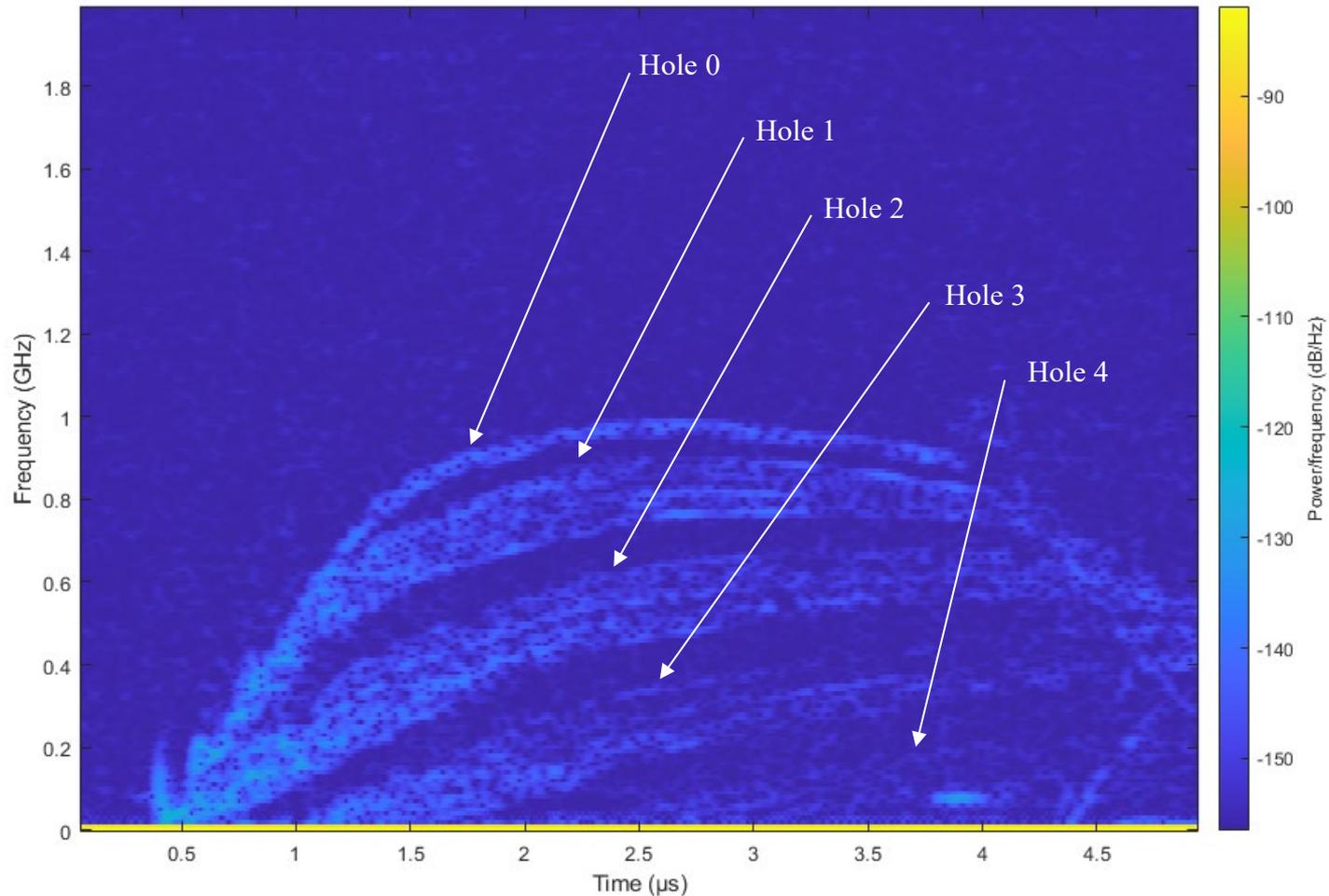
- Cylindrical Lens to spread beam
- Aperture Plate to create beamlets
- Each beamlet will produce a PDV signal



PDV Profilometry Beam Profile

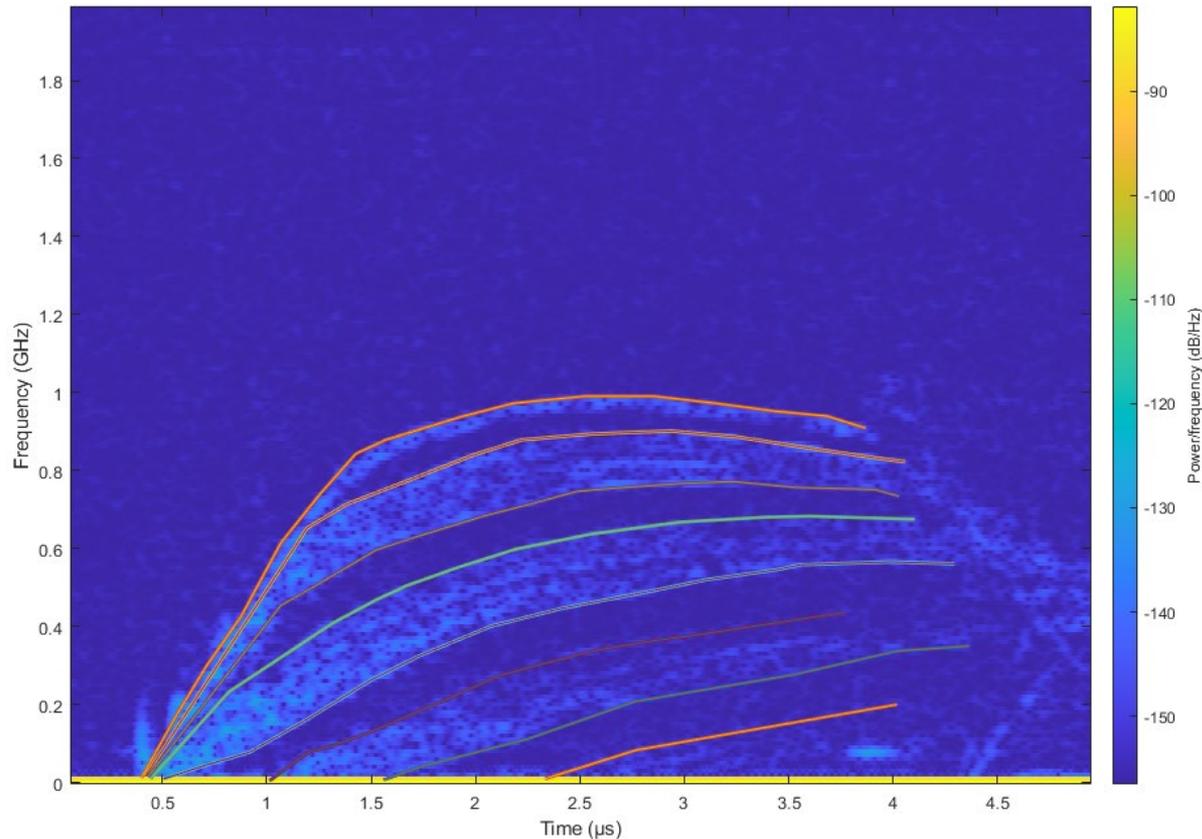


The PDV Profilometry Spectrogram

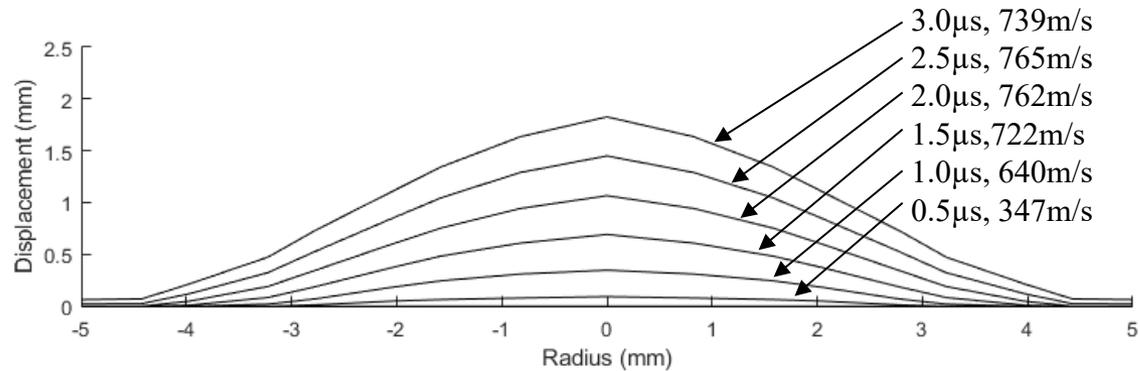
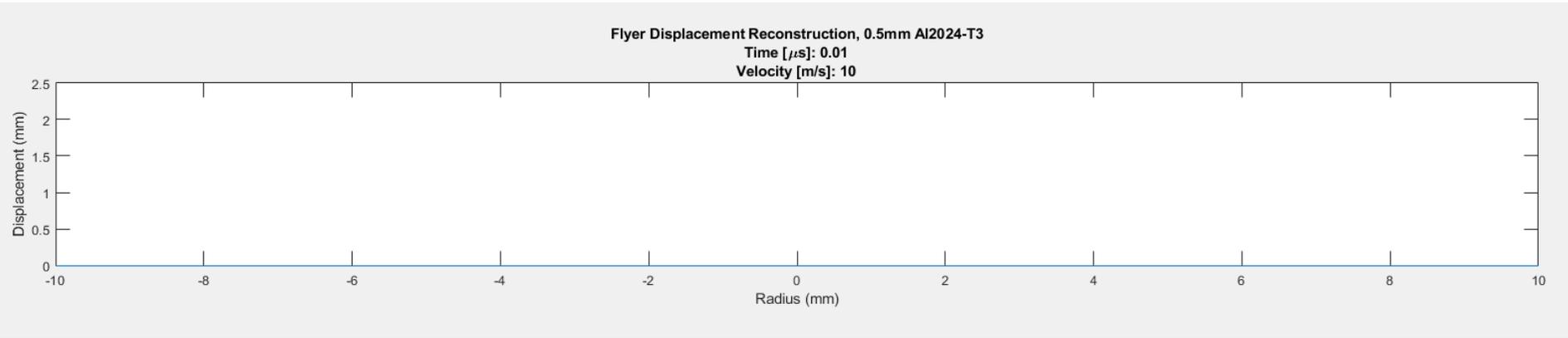


The PDV Profilometry Spectrogram

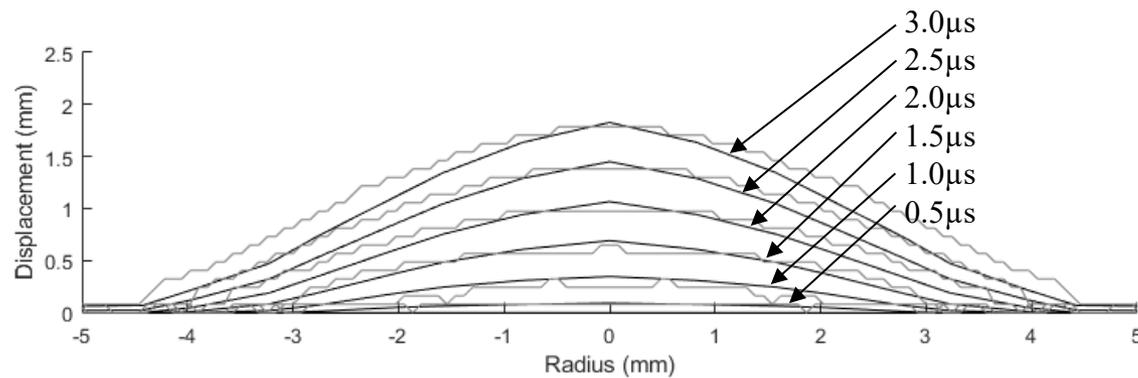
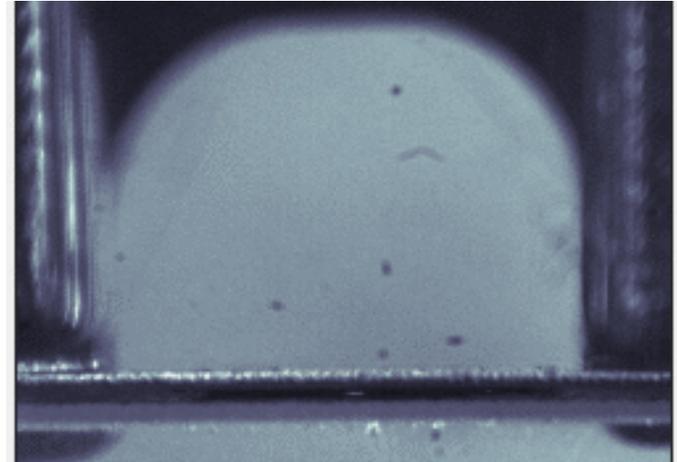
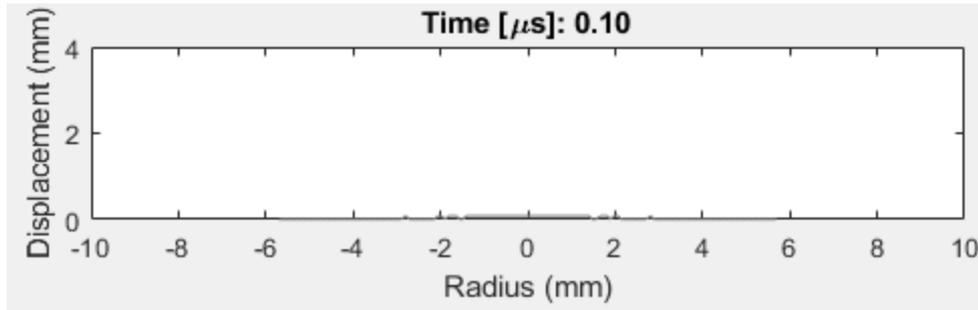
- The top and bottom of each trace are digitized. The top and bottom of each trace represent a different location on the flyer surface!



Profilometry Velocity Vs Time

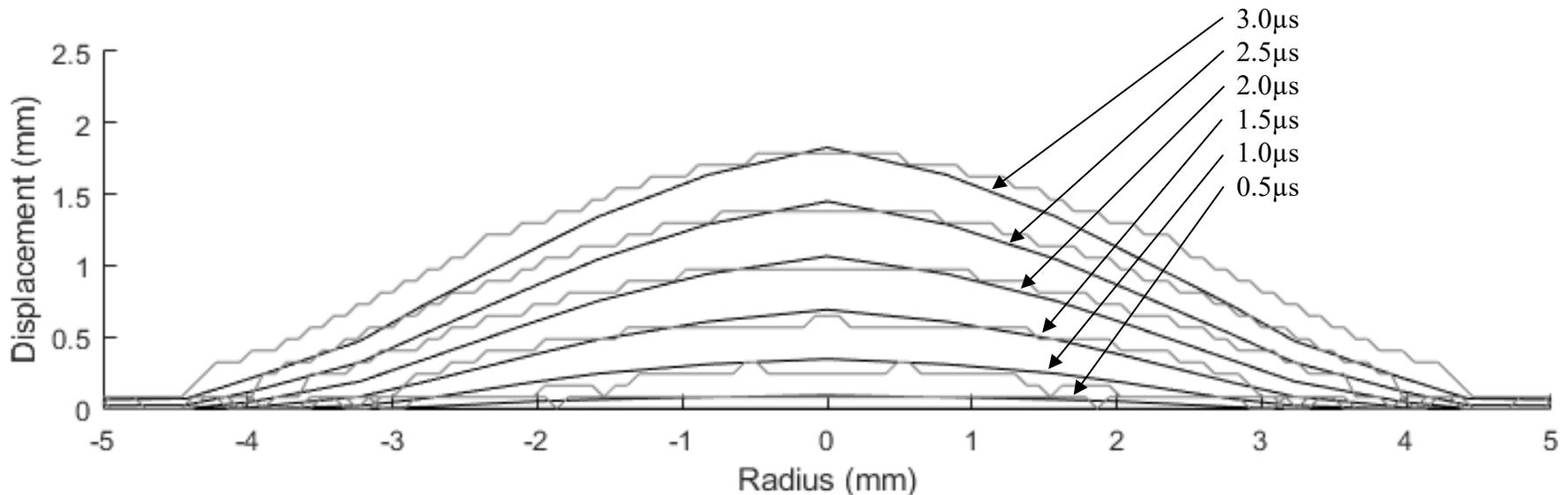


Profilometry Validation



Profilometry Validation

- Profilometry data compares well with high-speed camera data
- Some deviations are present at the flyer periphery



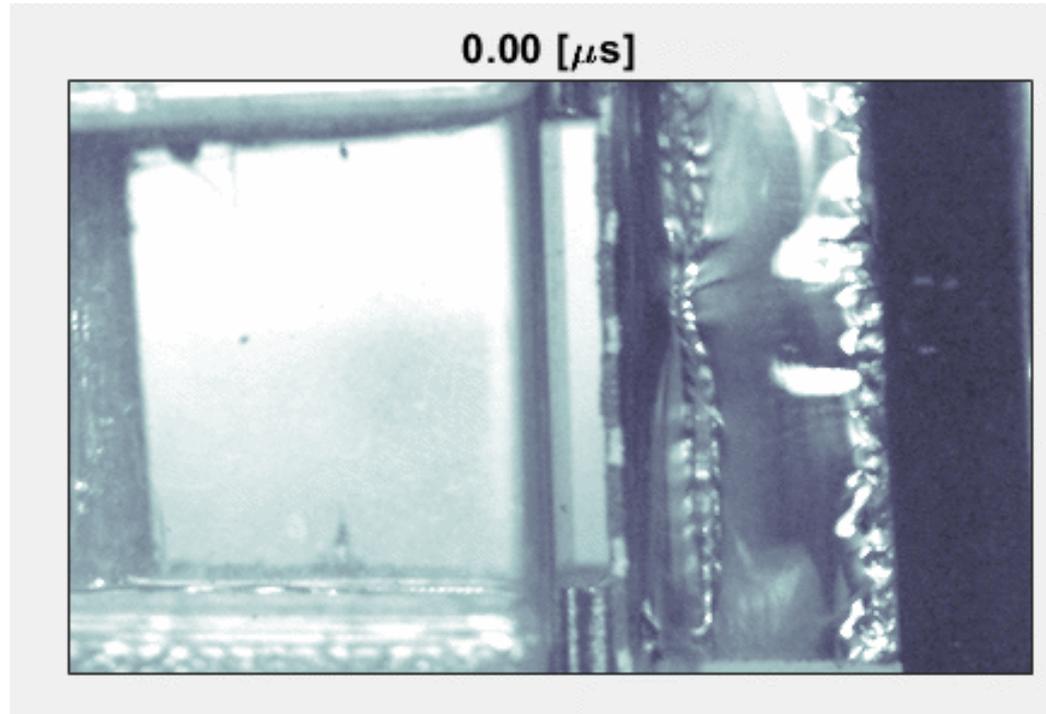
PDV Profilometry Conclusions

- Lots of potential for flyer evolution reconstruction
- Can be used for VFA as well
- Planar flyers should have a single thin trace (omitting sine errors due to spread of beam)
- Errors are likely due to fuzzy edges of profilometry spectrogram traces
- Mostly useful for flyer acceleration where the center accelerates faster than the other areas



Questions?

- Thanks to Dr. Jeremy Seidt of OUS for offering access to the high-speed camera

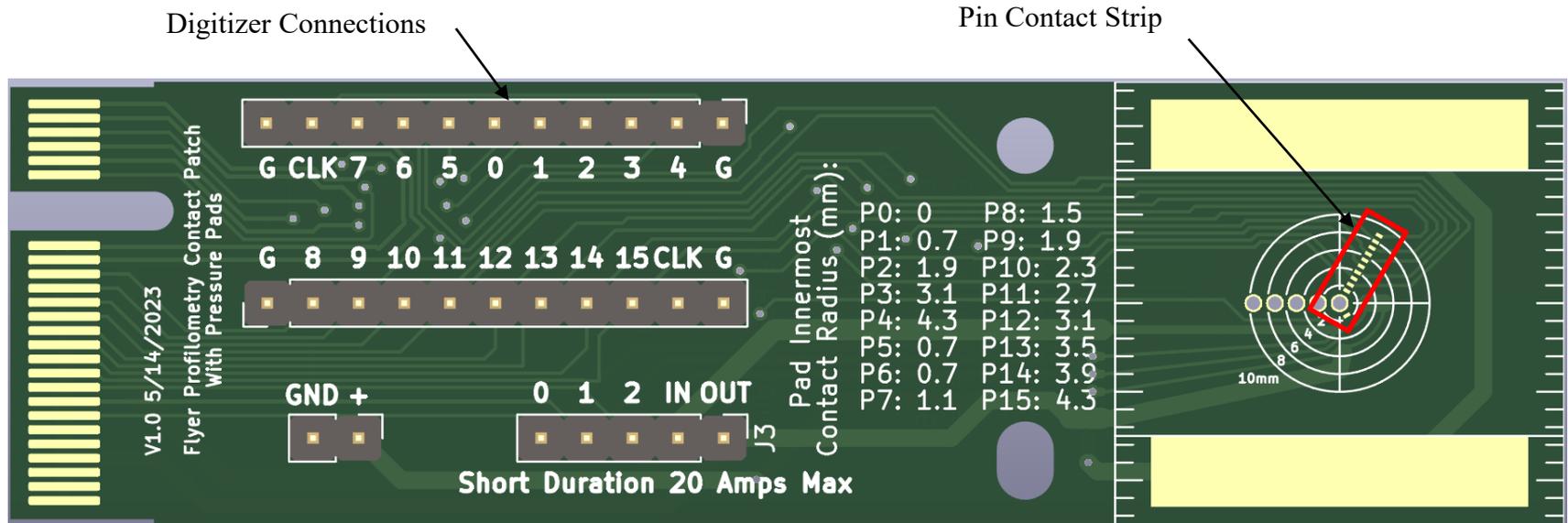


Acrylic Cube Impacted by Flyer at 760m/s

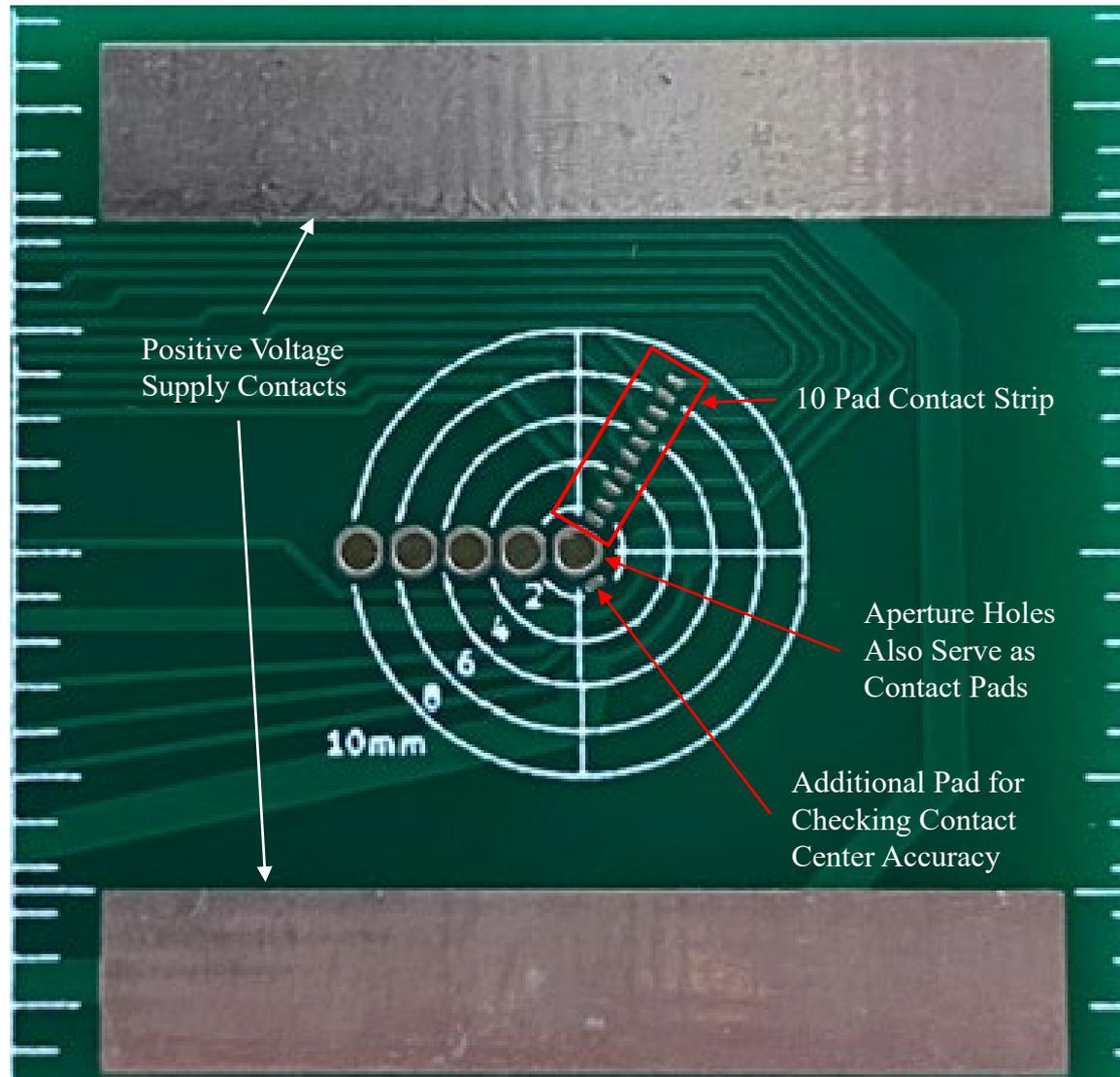


Welding Velocity Measurement

- A series of contact pads are included on the circuit board
- May be used with a digital logic analyzer
- Contact indicates flyer contact arrival time

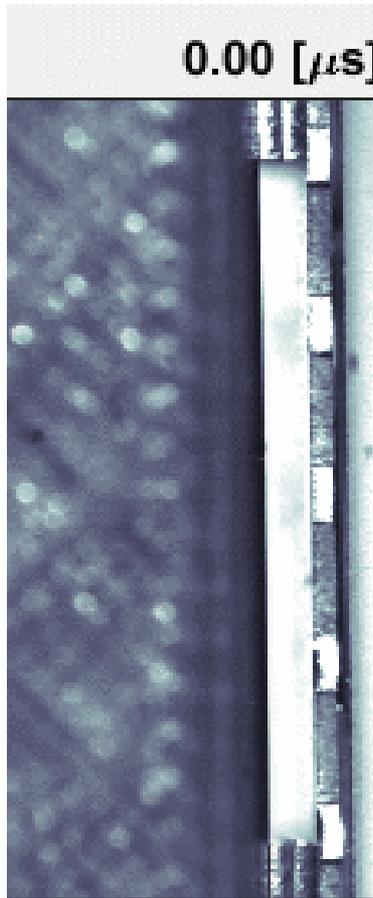


Pin Contact Patch Close Up

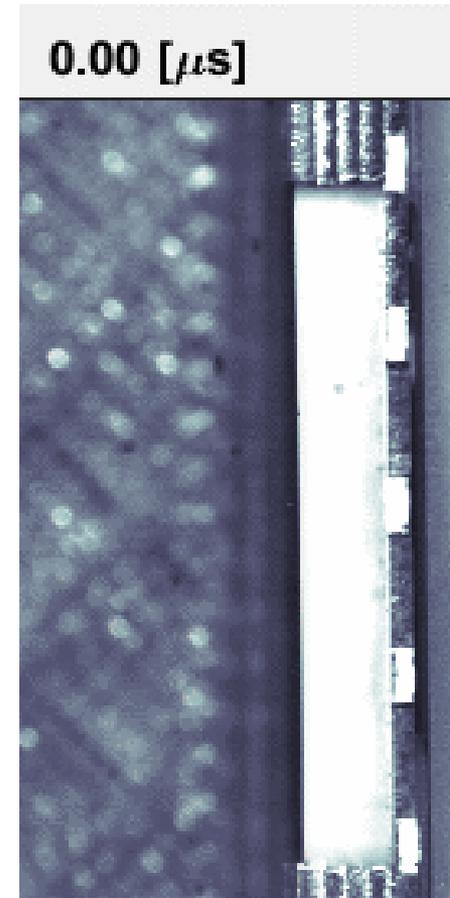


High Speed Camera Weld Velocity

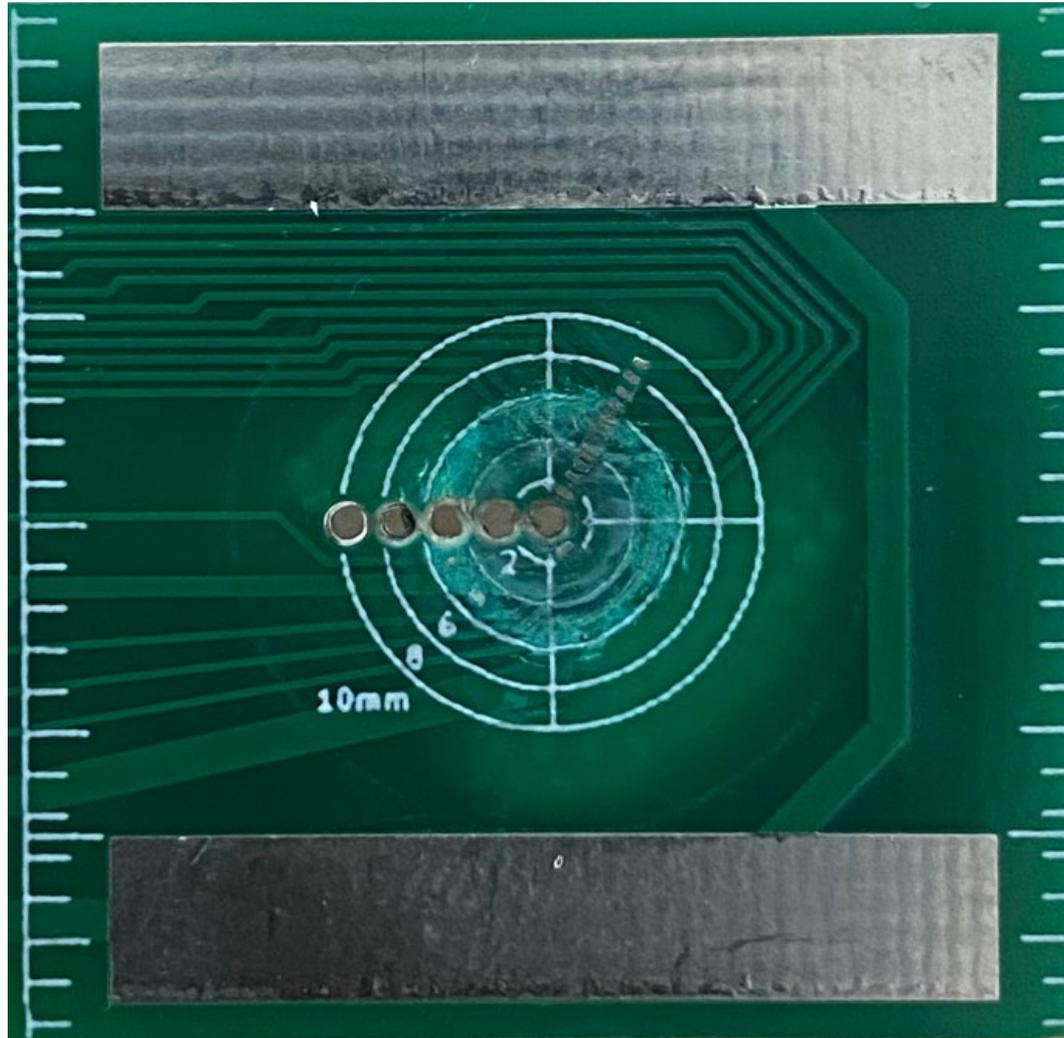
1mm Standoff



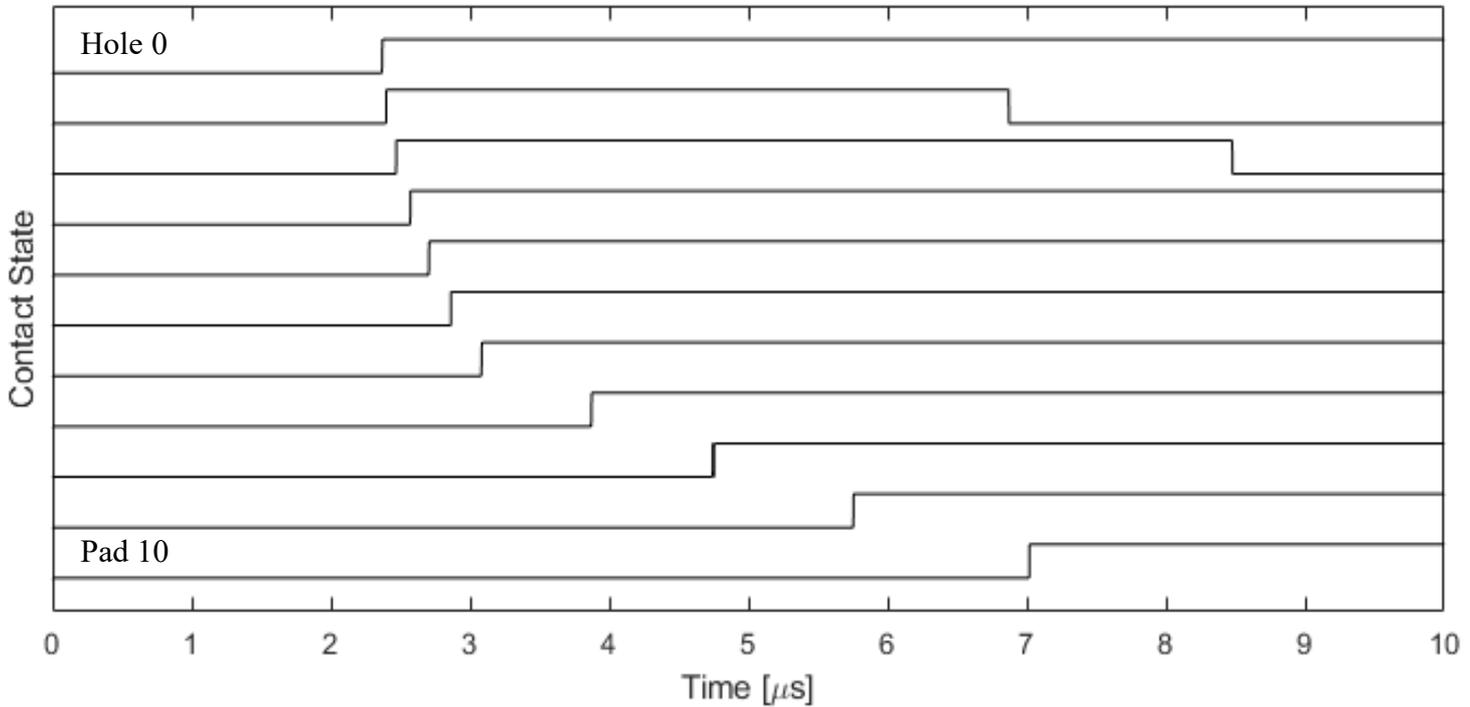
2mm Standoff



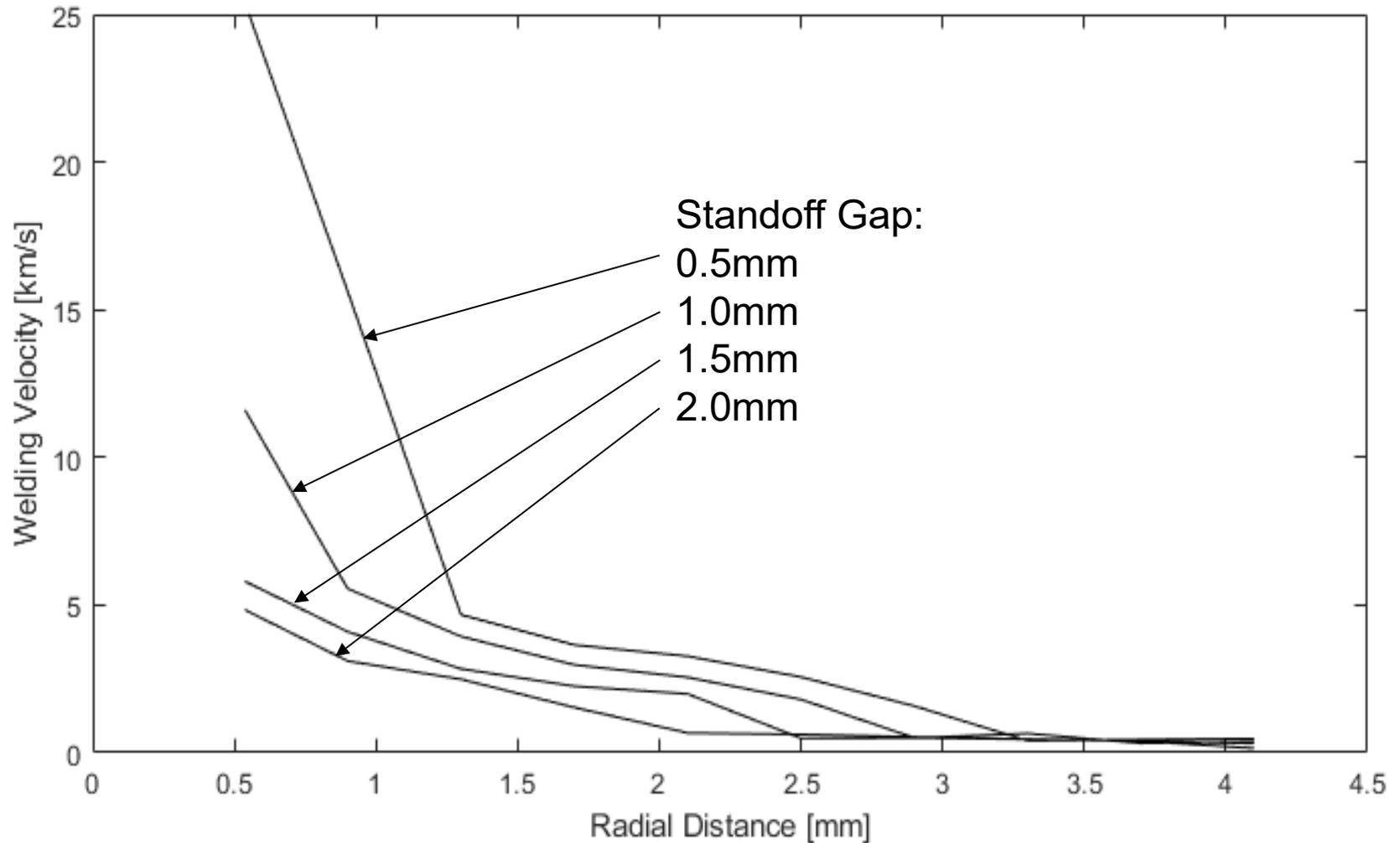
Pin Contact Patch After the Shot



Pin Contact Patch After the Shot

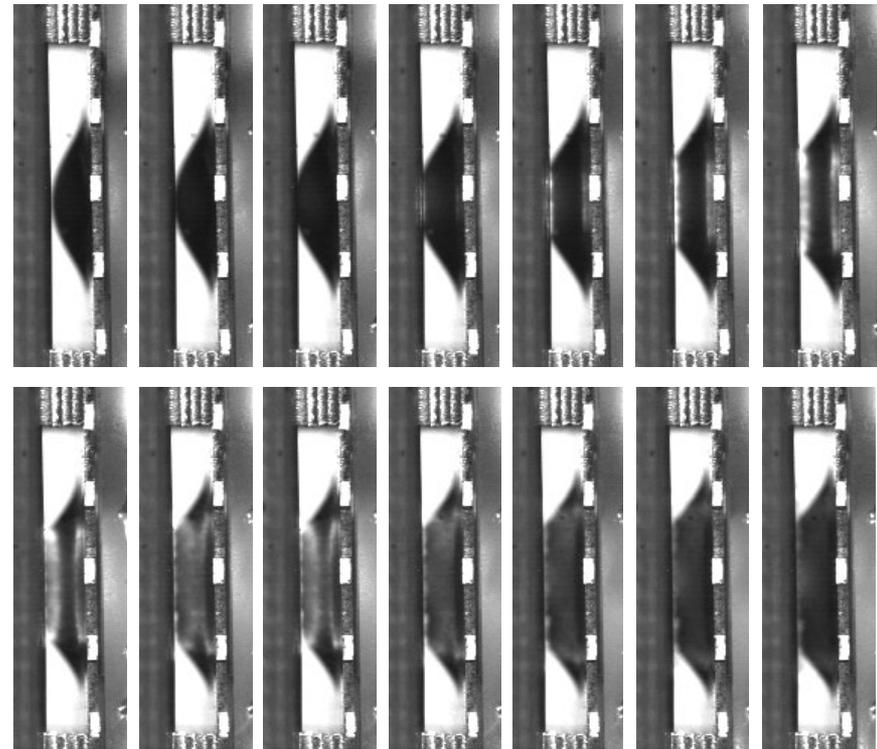
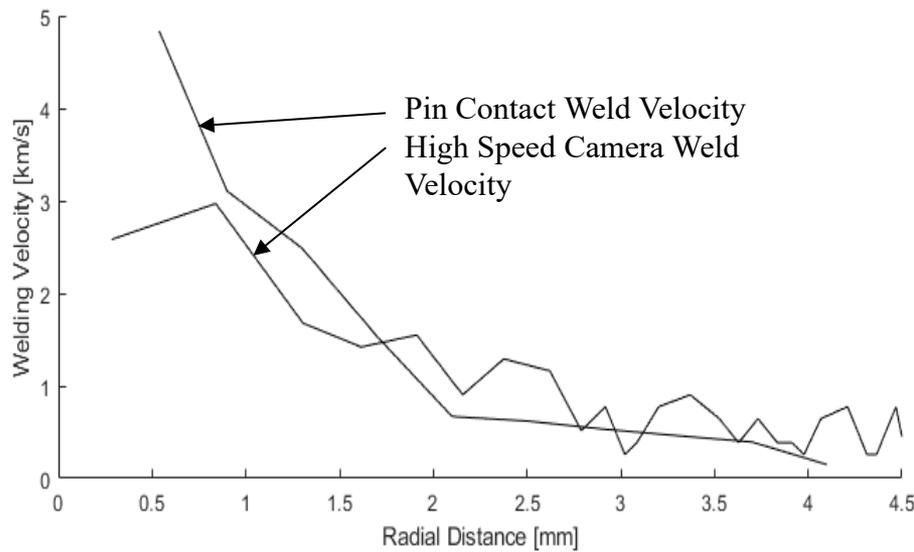


Pin Contact Patch After the Shot



Verification of Contact Data

- Contact data was verified using the 2mm standoff gap high speed footage

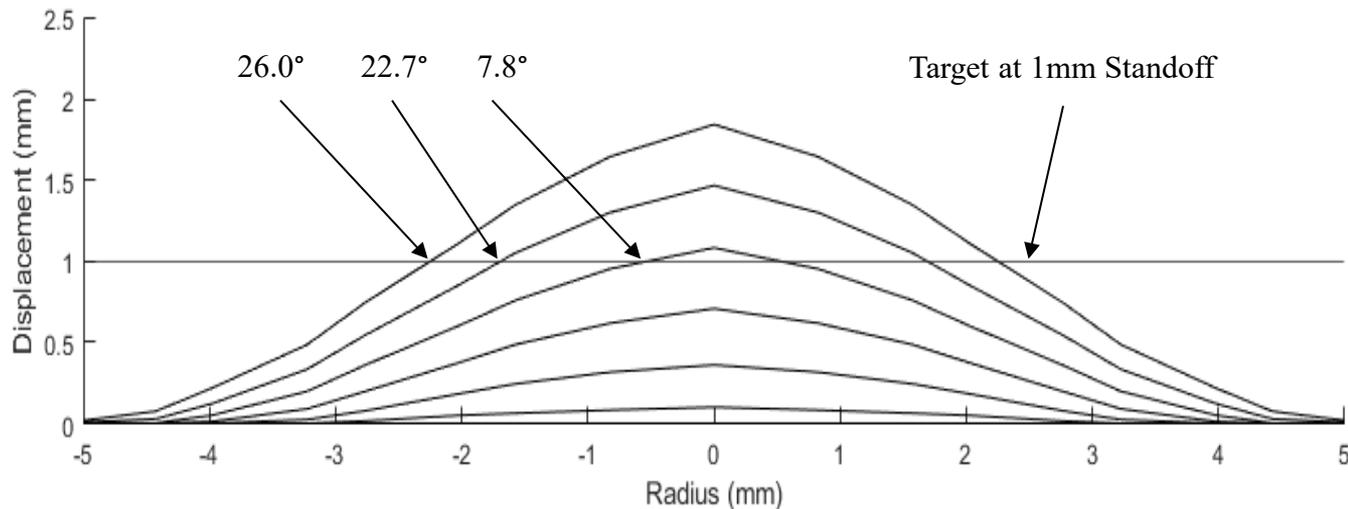


200ns between images
2mm standoff gap



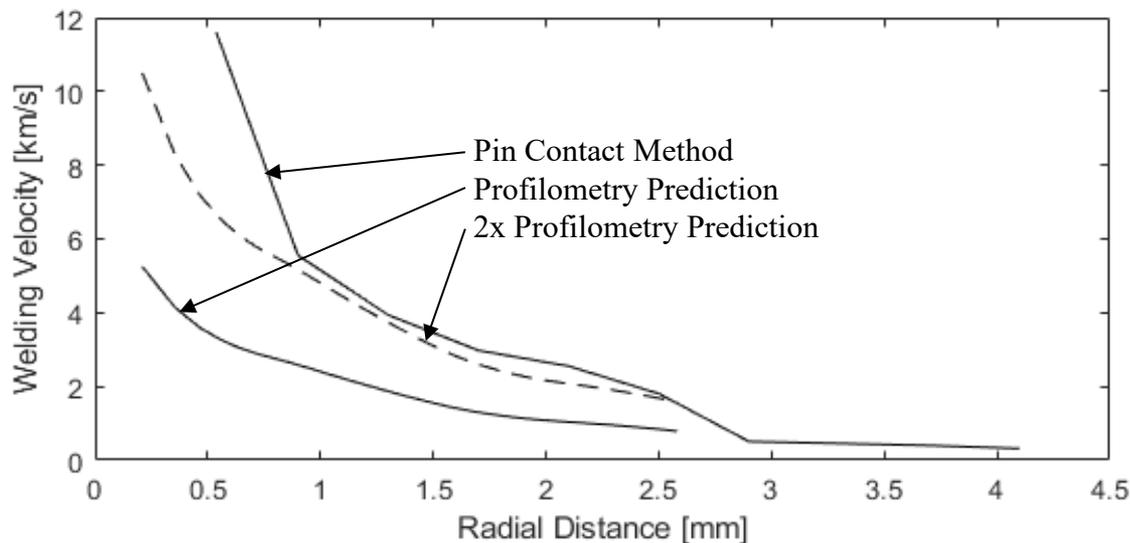
Impact Angle Reconstruction

- Profilometry data may be used to estimate impact angles at a given standoff distance
- Weld velocity can be estimated by this technique as well



Impact Angle Reconstruction

- Weld velocities predicted by PDV Profilometry data are much lower than those measured pin contact
- The weld velocity estimates were found to be $\frac{1}{2}$ the measured weld velocities

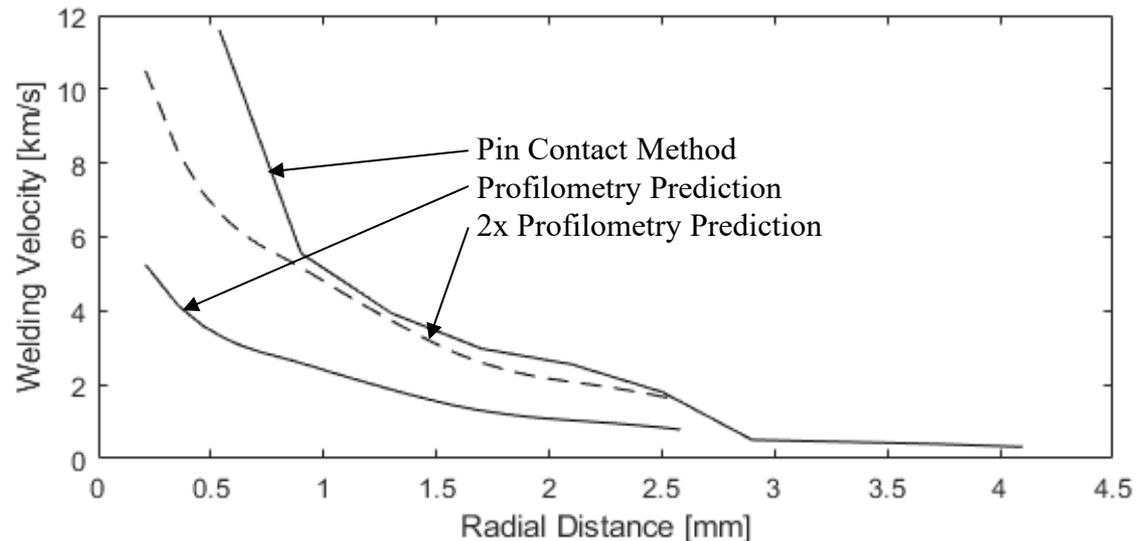


Upper and Lower Angle Estimates

- Weld Velocity and impact angle are related by the following equation:

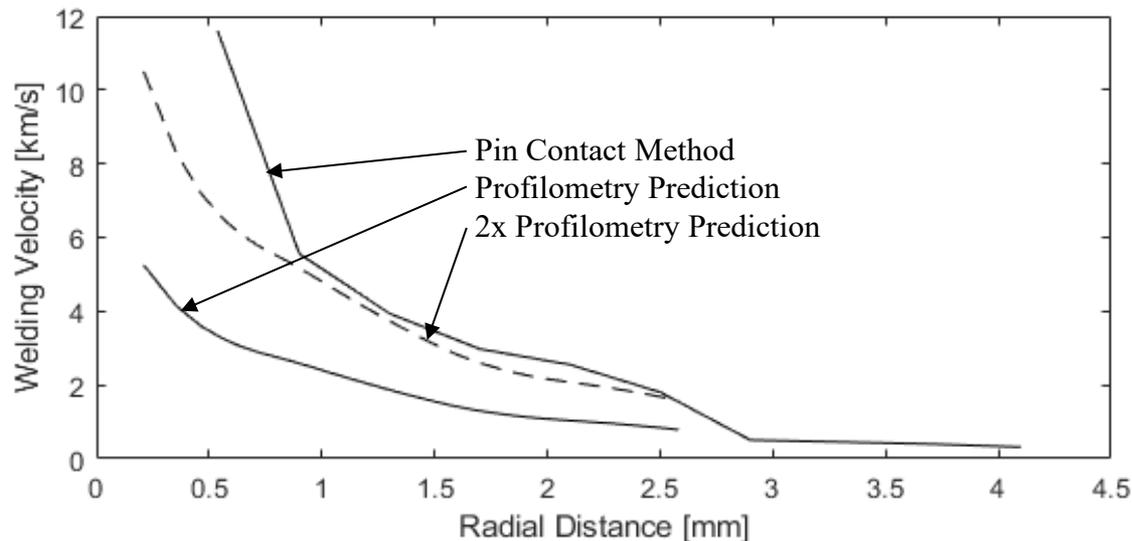
- V_w - weld velocity
- V_f - Flyer normal velocity
- β - Impact angle

$$V_w = \frac{V_f}{2\sin(\beta/2)}$$



Upper and Lower Angle Estimates

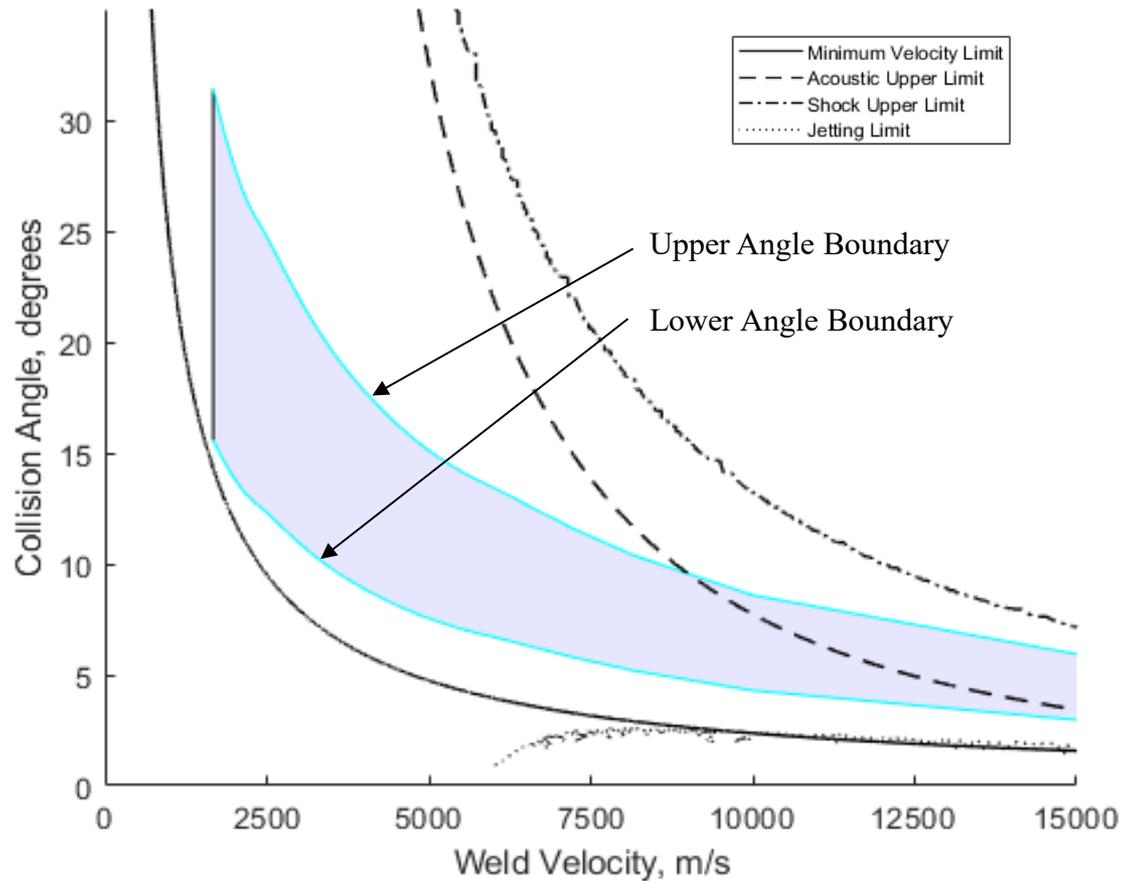
- Upper angle limit: V_w is 2x the profilometry velocity
- Lower angle limit: β is $\frac{1}{2}x$ the profilometry estimated angle



$$V_w = \frac{V_f}{2\sin(\beta/2)}$$



Estimates on Welding Window



Estimates on Welding Window

