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Use of Multiplexed Photonic Doppler Velocimetry (MPDV) in Measuring Plastic Deformation of Plates under Hypervelocity Condition

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Outline

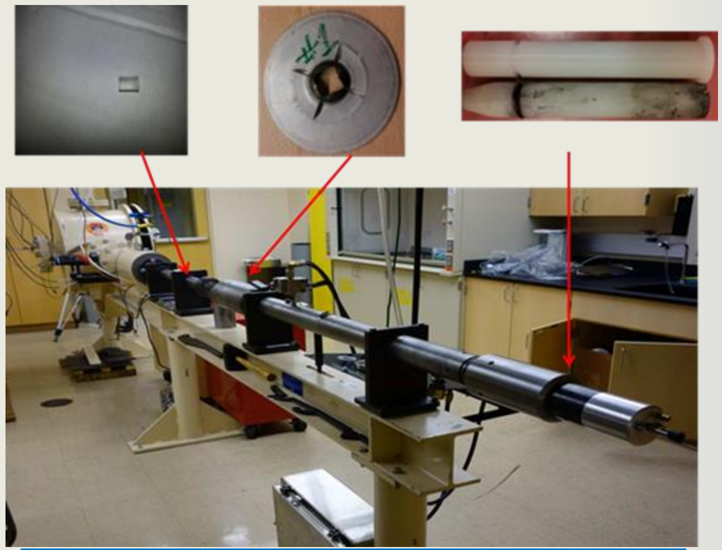
- Objective
- Experimental Setup
- Results & Discussion
- Computational Simulation
- Simulation Comparison
- Conclusion
- Future Work

Objective

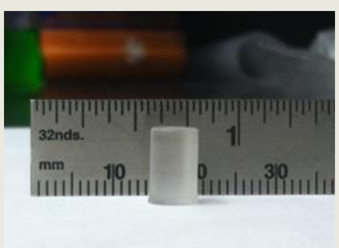
- Metallic plates experience extreme pressure and high strain rate during hypervelocity impact which results in severe localized deformation.
- Experiments under hypervelocity conditions often require sophisticated diagnostic system to comprehend the dynamic response of materials.
- The capability of Multiplexed Photonic Doppler Velocimetry (MPDV) in such experiments needs to be explored.
- Due to the complexity and expensiveness of such experiments, it is beneficial to develop predictive computational models which can predict deformation behavior accurately in such conditions.

Experimental: Two-stage Light Gas Gun

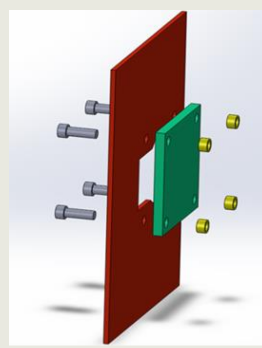
- A two-stage light gas gun is used to launch a cylindrical projectile into a target plate at a velocity range of 4.5-6 km/s.
- The gun uses either Hydrogen or Helium
  - Projectile: Lexan (5.6 mm diameter)
  - Target: A36 steel plate (152.4 × 152.4 × 12.7 mm)
- The target is bolted on a mounting plate during the experiment.
- Laser intervalometer system is used to measure projectile velocity.



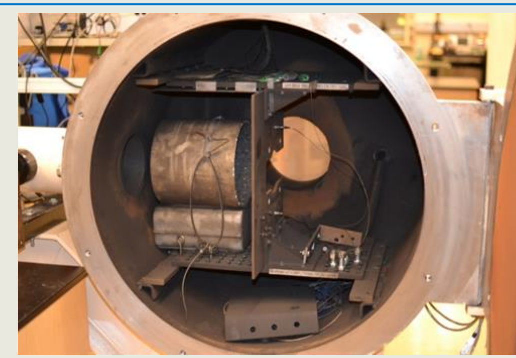
UNLV two-stage light gas gun



Lexan projectile



Target mounting plate



Target chamber assembly

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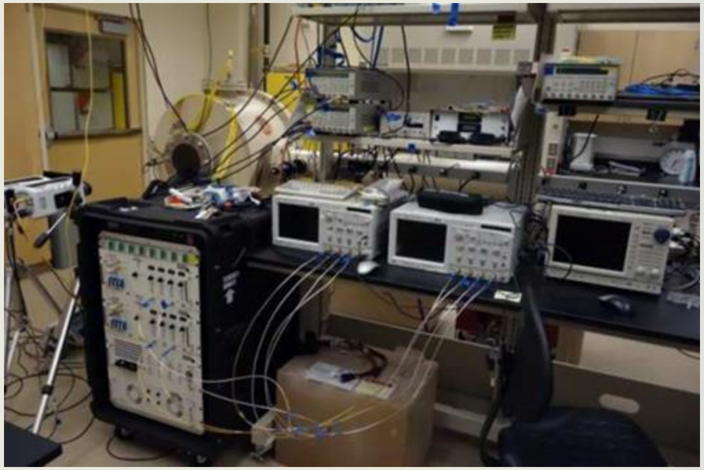
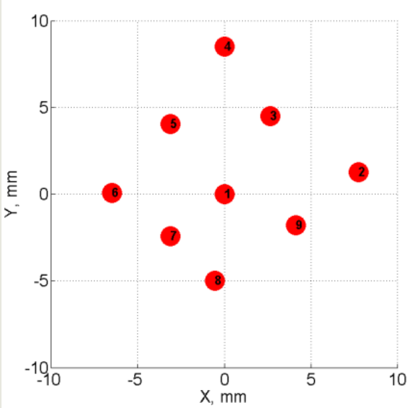
Experimental: Multiplexed Photonic Doppler Velocimetry

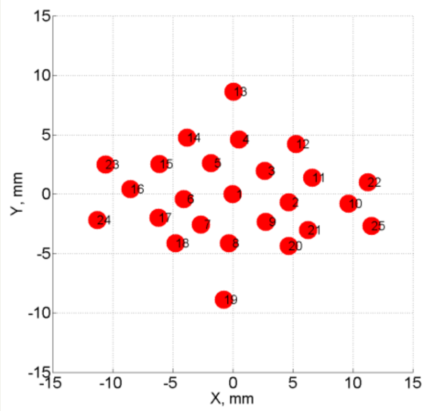
- Multiplexed Photonic Doppler Velocimetry (MPDV) system has been used as a diagnostic tool to collect the velocimetry data.
- PDV is a heterodyne interferometric technique which can record velocity data in terms of displacement using Doppler shift of reflected light frequency from moving surface.
- In case of MPDV system, data is collected from multiple points with multiple optical fiber probes.
- So far, 9-probe and 25-probe arrangement has been used for MPDV system in gas gun experiments.



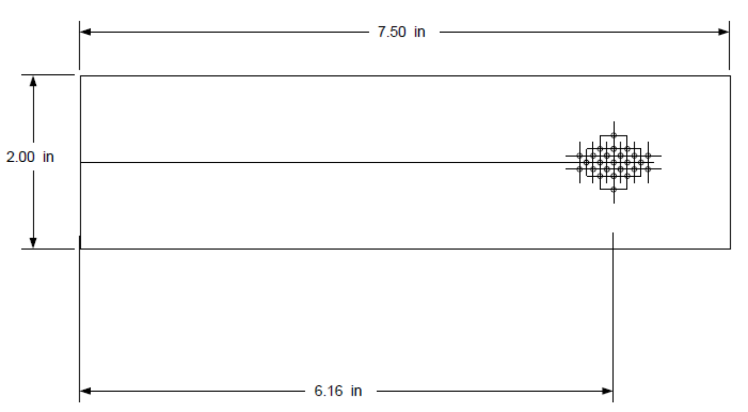
Typical MPDV system assembly in gas gun experiment



Typical 9-probe pattern



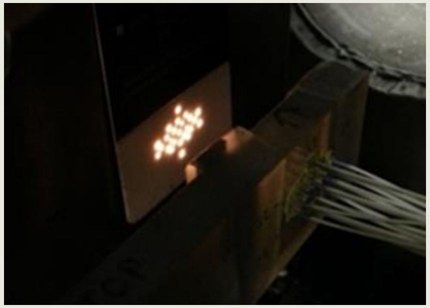
Typical 25-probe pattern



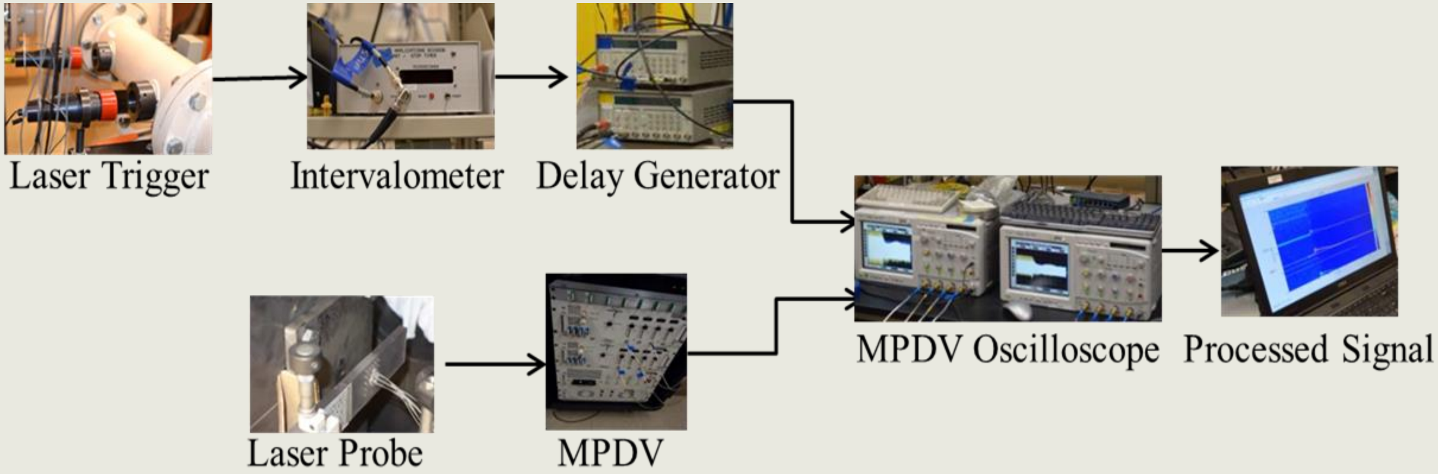
Schematic of MPDV probe pattern in holder

Experimental: Multiplexed Photonic Doppler Velocimetry

Typical 9-probe MPDV arrangement



Typical 25-probe MPDV arrangement



Overview of data acquisition by MPDV system in typical gas gun experiment

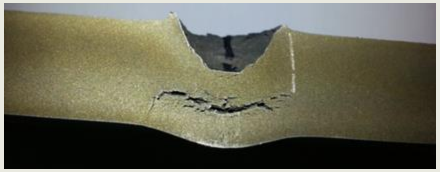
Results & Discussion

- A small crater with a bulge on the back side of the target plate is created as a result of impact.
- **Spall failure**
  - Spalling happens close to the rear side of the target.
  - Shock wave reaches a free surface end and reflects back resulting a tensile pressure in material.
  - The material fails when the tensile pressure is above the material strength.
- **Physical measurements** of crater and bulge are taken typically after every experiment.

Front Side

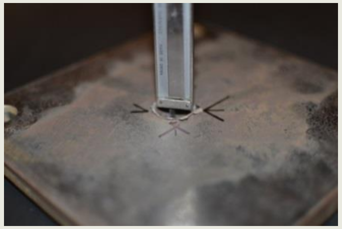
Back Side

Typical target plate after experiment



Spalling of target plate (sectioned)

Impact crater diameter measurement



Depth of penetration measurement

Bulge measurement

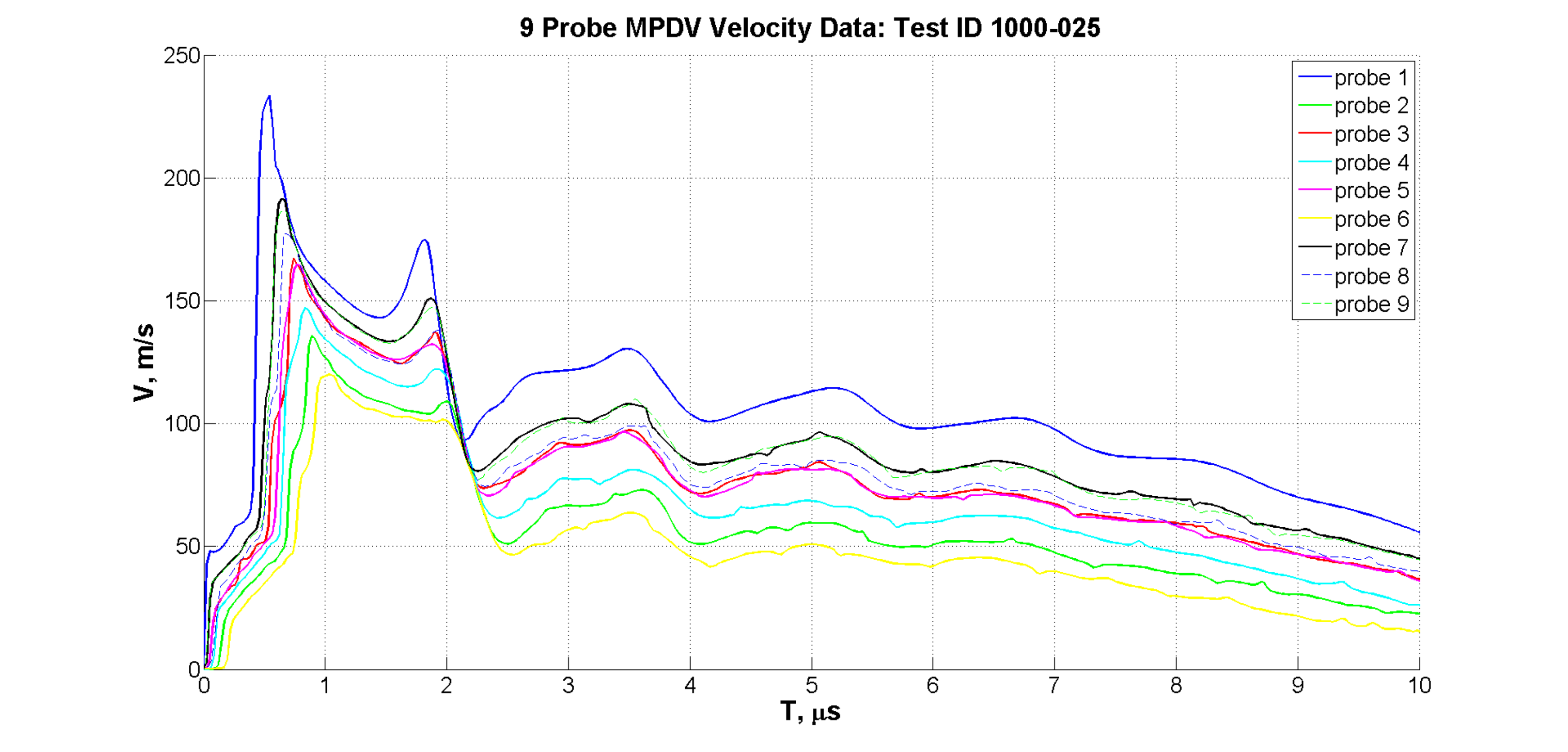
Results & Discussion

Test ID	MPDV system details	Impact Velocity, km/s	Target after impact		
			Crater Diameter, mm	Penetration, mm	Bulge, mm
1000-024	9 probe	5.708	17.17	7.71	3.13
1000-025		4.763	15.37	6.50	1.42
1000-026	25 probe	4.823	15.14	6.51	1.48
1000-027		5.088	16.90	7.00	2.33
1000-028		5.157	15.90	6.50	1.67

- Damage trends seem reasonable: Higher impact velocity results in larger crater and bulge. (Although some minor discrepancies in damage dimensions still exist!)
- All the values listed above are an average of typical physical measurements of crater and the bulge on the back side.

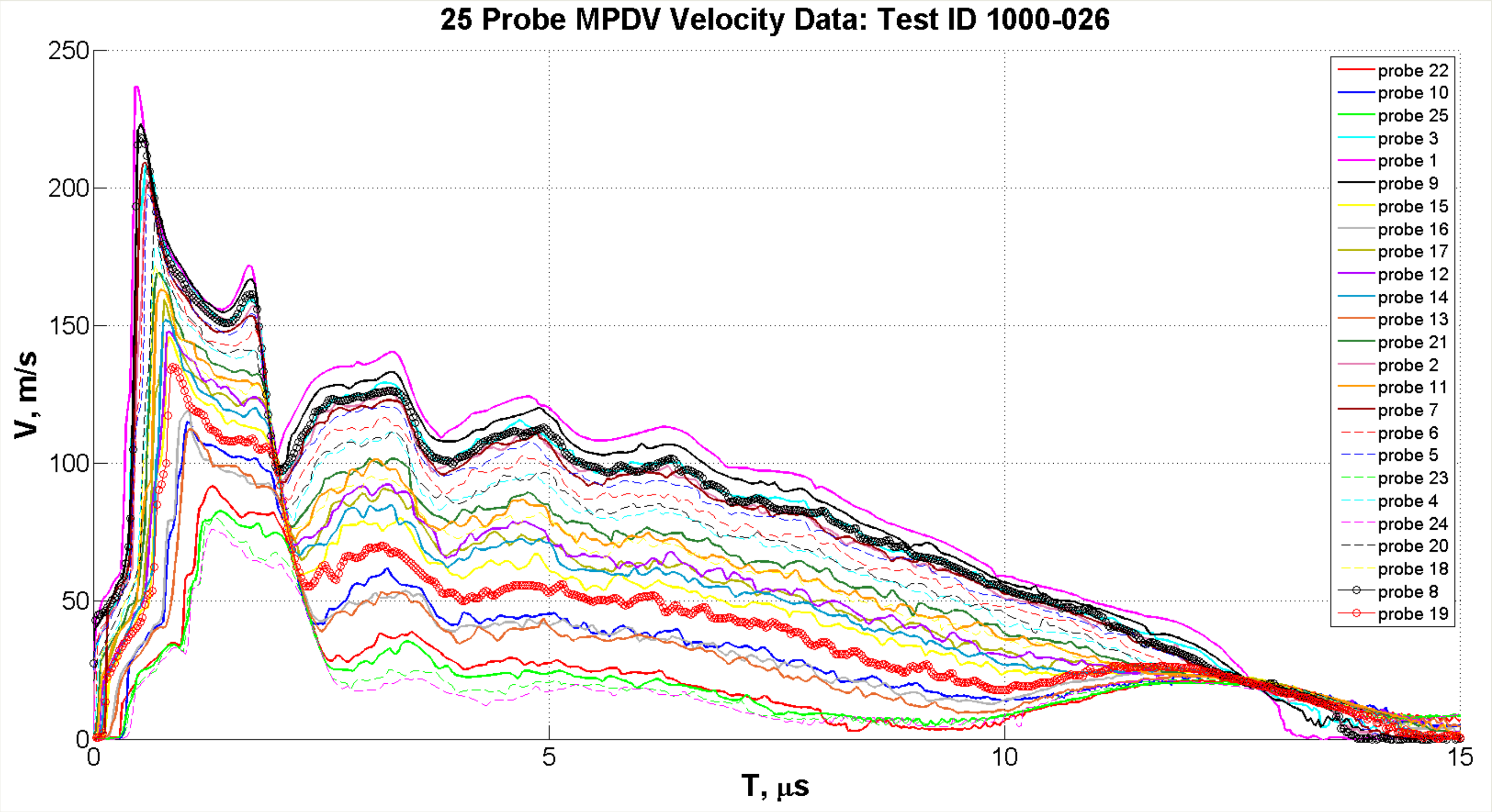
Results & Discussion

- **Free surface velocity** are measured by MPDV systems.
- Probe locations and velocity signal arrival time are very important for MPDV system.



Typical 9-probe MPDV data

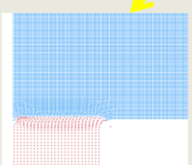
Results & Discussion



Typical 25-probe MPDV data

Computational Simulation

- Two finite element methods are used to simulate the impact phenomena computationally:
  - Lagrangian based Smooth Particle Hydrodynamics (SPH) in LS-DYNA
  - Eulerian baed Hydrocode in CTH
- 2D axi-symmetric models are developed.
- Both models have no boundary conditions.
- Extensive parametric study has been performed in both models.
- For LS-DYNA model, a general SPH particle spacing of 0.05 mm is chosen.
- For CTH, a zone size of 0.03 x 0.03 mm is chosen finally.



LS-DYNA SPH Model

CTH Model (zoomed in)

Computational Simulation: Material Model

- Both LS-DYNA and CTH models use Johnson-Cook material model for both Lexan projectiles and A36 steel target plates.

- Parameters of Johnson-Cook material model are taken from the available literatures.

Material	A, MPa	B, MPa	C	M	N	T_{melt},°K
Lexan (Littlewood)	75.8	68.9	0	1.85	1.004	533
A36 Steel (Seidt)	286.1	500.1	0.022	0.917	0.2282	1811

Littlewood, D.J., Simulation of dynamic fracture using peridynamics, finite element modeling, and contact: *ASME 2010 International Mechanical Engineering Congress & Exposition*, Vancouver, British Columbia, Canada, November 12-18, 2010.

Seidt, J.D. et al., High strain rate, high temperature constitutive and failure models for EOD impact scenarios: *Proceedings of the 2007 SEM Annual Conference and Exposition on Experimental and Applied Mechanics*, Springfield, MA, June, 2007.

Computational Simulation: Equation of State

- Both LS-DYNA and CTH models use Grüneisen equation of state for both Lexan and A36 steel.
- EOS parameters are also taken from the available literatures.

Material	ρ, kg/m^3	C_0 , m/s	S_1	ϒ
Lexan (Steinberg)	1190	1933	1.42	0.61
A36 Steel (Seidt)	7890	4569	1.49	2.17

Steinberg, D. J., *Equation of State and Strength Properties of Selected Materials*, UCMRL−MA−106439; Lawrence Livermore National Laboratory: Livermore, CA, 1996.

Seidt, J.D. et al., High strain rate, high temperature constitutive and failure models for EOD impact scenarios: *Proceedings of the 2007 SEM Annual Conference and Exposition on Experimental and Applied Mechanics*, Springfield, MA, June, 2007.

Computational Simulation: Spall Parameter

- In both LS-DYNA and CTH, spall failure is defined as a pressure cut-off (i.e. P_{min}) value in Johnson-Cook material model.
- Spall happens in both models if tensile stress exceeds a certain P_{min} value.
- P_{min} value is also taken from literature.

Lexan: P_{min} = - 160 MPa (Steinberg)

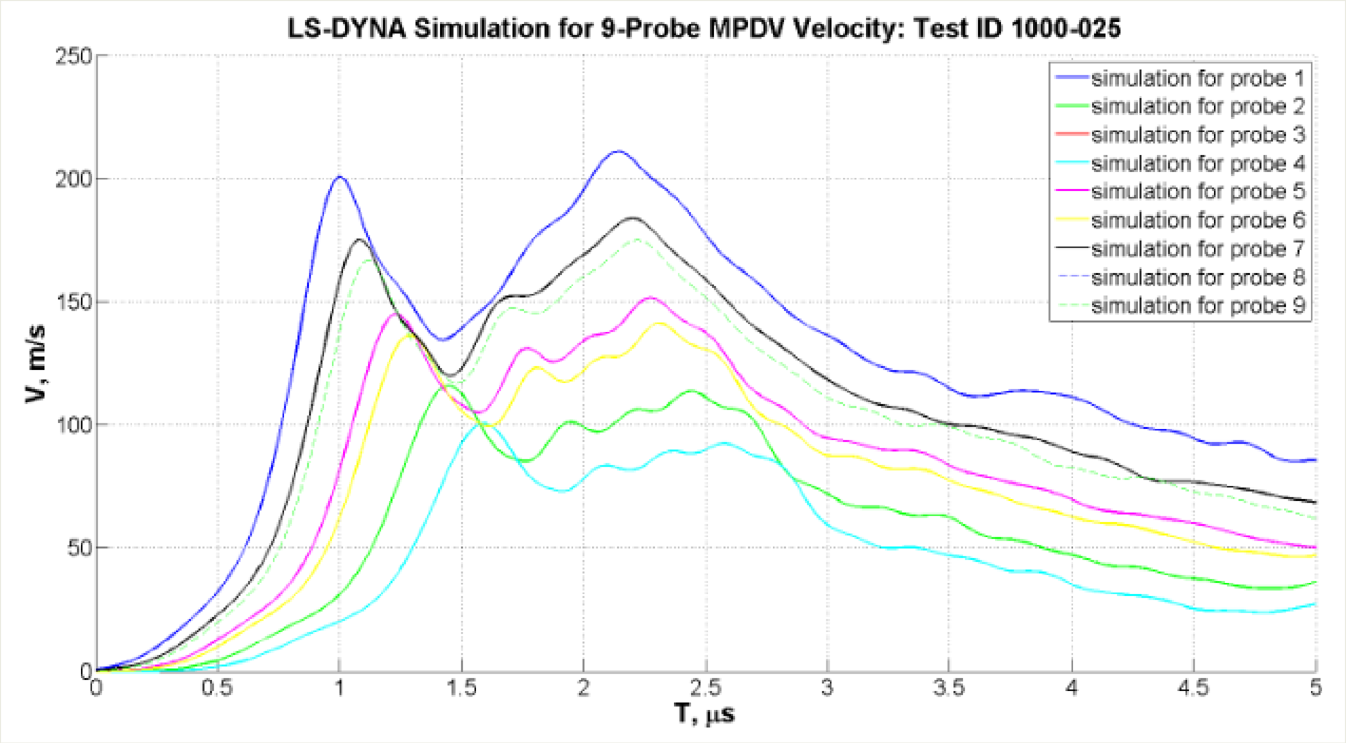
A36 steel: P_{min} = - 700 MPa (Zurek)

Steinberg, D. J. *'Equation of State and Strength Properties of Selected Materials';* UCMRL−MA−106439; Lawrence Livermore National Laboratory: Livermore, CA, 1996.

Zurek, A. K., et al., Experimental Study of A36 Steel Spall Fracture. *Journal De Physique IV*, 110, pp. 863–867, 2003.

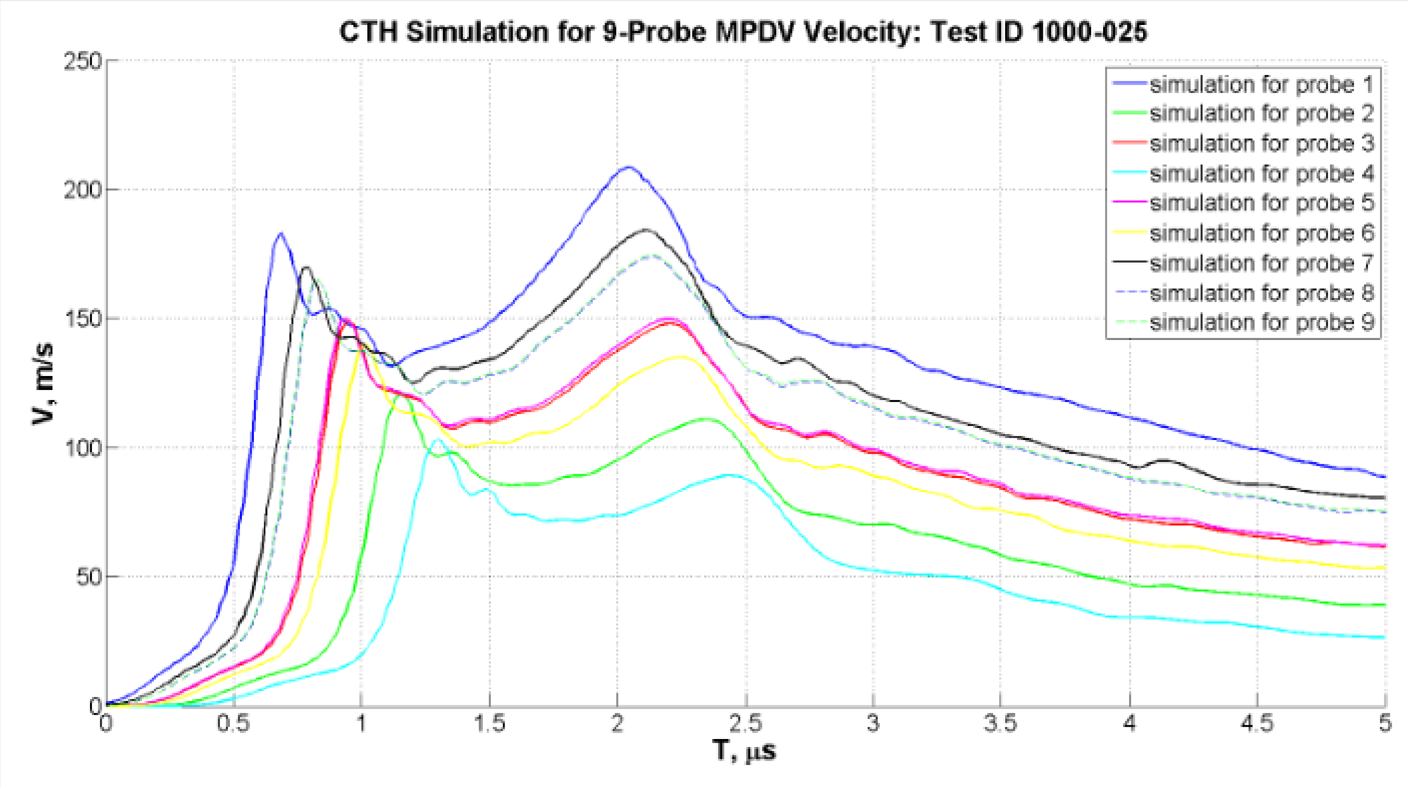
Simulation Comparison: Free Surface Velocity

- Both LS-DYNA and CTH simulations have reasonably capture the free surface velocity profiles.
- Further refinement of the simulation models are still in progress.



Typical free surface velocity from LS-DYNA simulation

Simulation Comparison: Free Surface Velocity



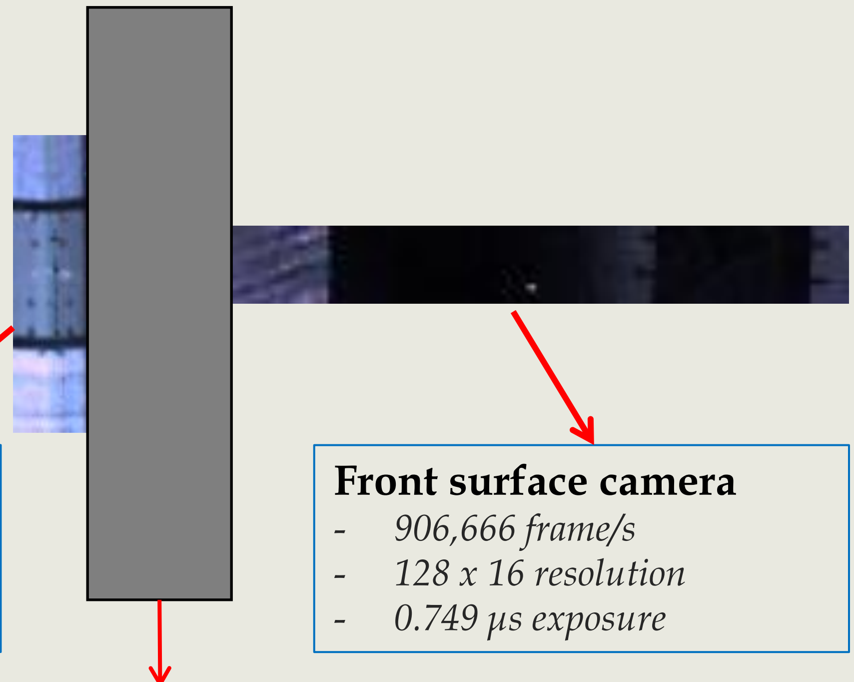
Typical free surface velocity from CTH simulation

Conclusion

- MPDV system can capture the free surface velocity from the back of target plate in high velocity impact experiments and provide better understanding of plastic deformation.
- Simulation models developed in LS-DYNA SPH solver and CTH hydrocode can reasonably simulate the experiments.
- Additional experiments and refinement of the simulation models, including the use of more accurate material models and simulation parameters are needed to further refine the simulation results.

Future Work

- Designing better probe array for MPDV systems to acquire more interesting results.
- High speed camera to capture Video data and correlate to MPDV data.
- Investigation of phase transition in A36 steel by Electron Back Scattered Microscopy (EBSD).



Back surface camera

- *680,000 frame/s*
- *32 x 128 resolution*
- *1.09 μs exposure*

Front surface camera

- *906,666 frame/s*
- *128 x 16 resolution*
- *0.749 μs exposure*

Target

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Thank You!

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