High Performance Propellant Fragment Impact Testing: Small-scale and Full-scale

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SEPT 2016

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Background

- Full-scale rocket motor assets are expensive to test. The development of predictive tools to help predict/understand the response of propellants (non-ideal explosives) would lower overall cost and provide useful IM tools.

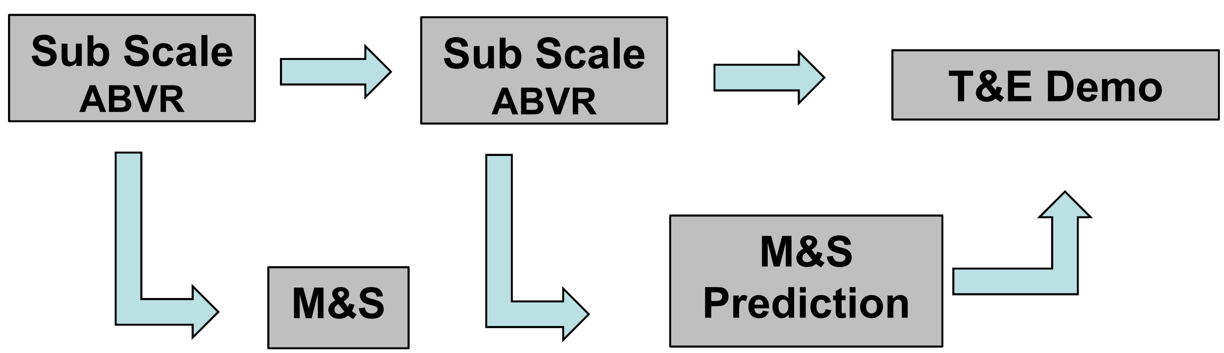
- Goal: Predictive capabilities for IM threats on energetics in representative systems

Technical Approach Outline

ABVR (Army Burn to Violent Reaction)- Sub scale fragment impact tests representing full scale; data provided for M&S; component tests performed for material characterization and model calibration

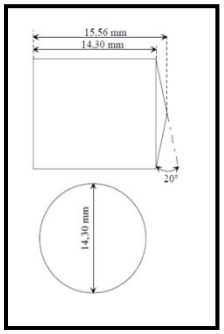
M&S- Modeling and simulation iterations to design a full scale fragment impact prediction tool; Integrated analog T&E Demo pre-test predictions

Test and Evaluation (T&E) Analog Demo– Full scale fragment impact test with analog rocket motor; Integrated analog T&E Demo test materials & test article fabricated, test range configured and test executed

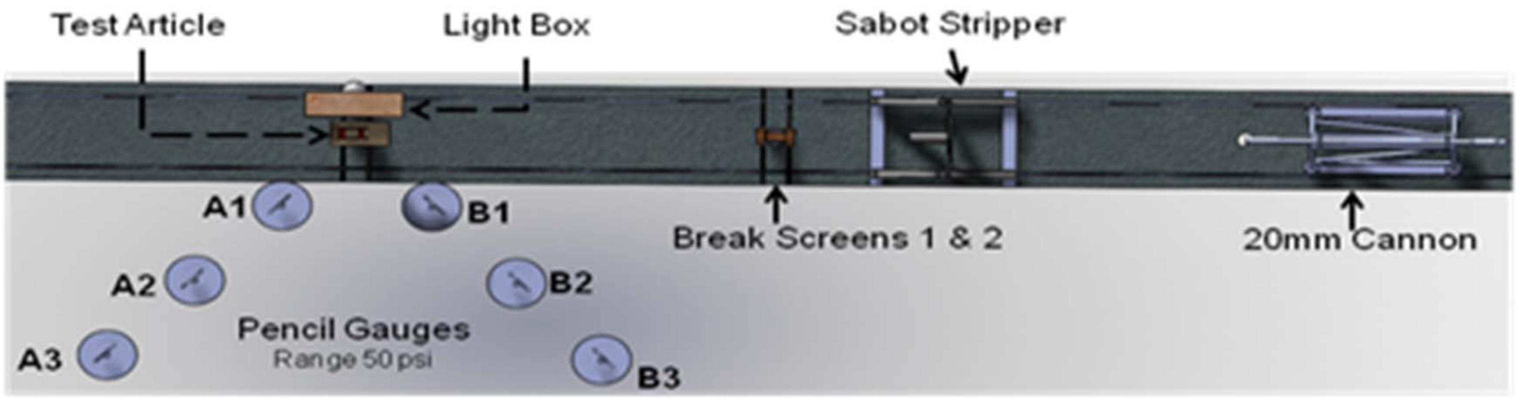


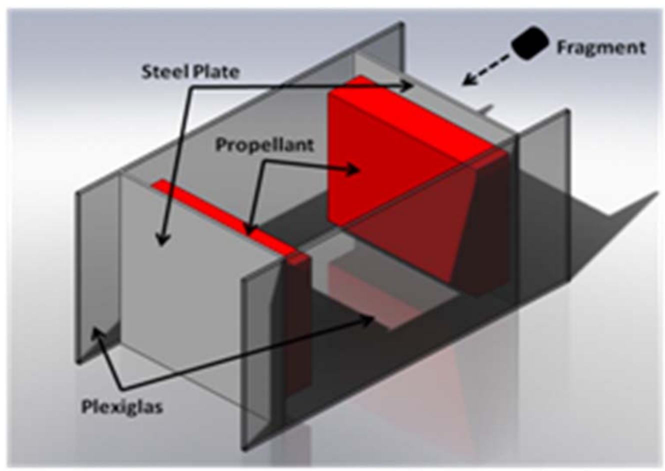
ABVR Test Method

- **High Performance Propellant (HPP)-Ammonium Perchlorate (AP) and aluminum powder bonded by hydroxyl-terminated butadiene**



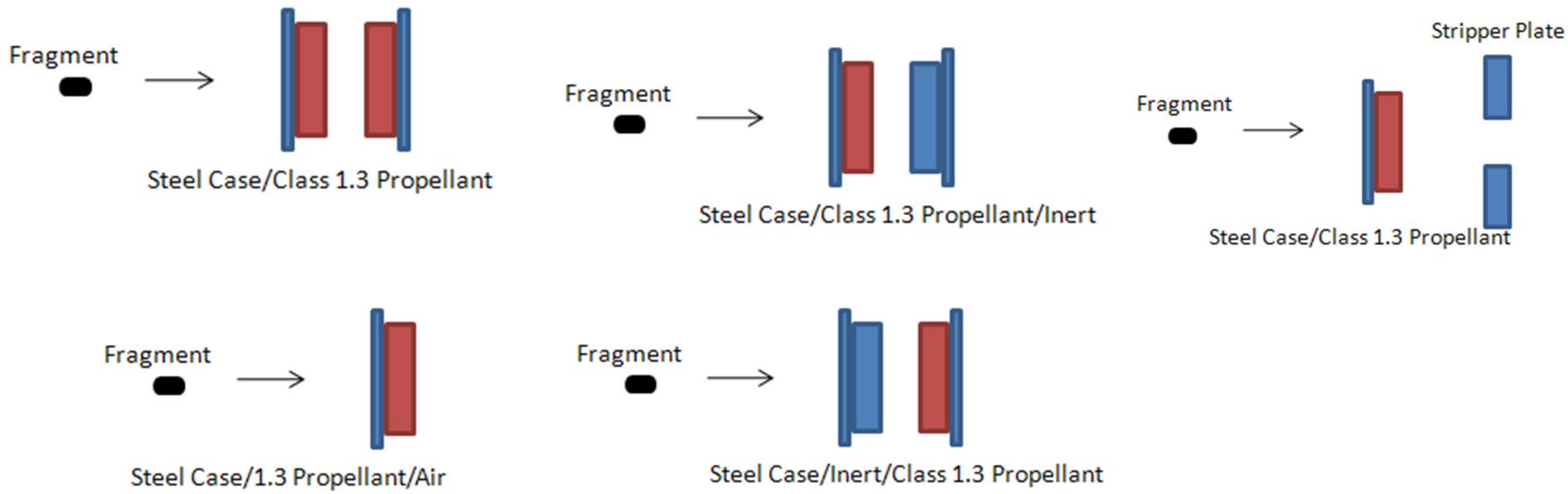
Fragment

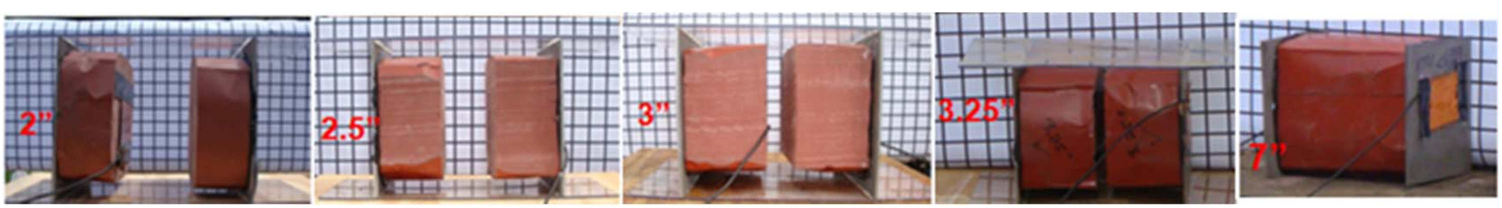




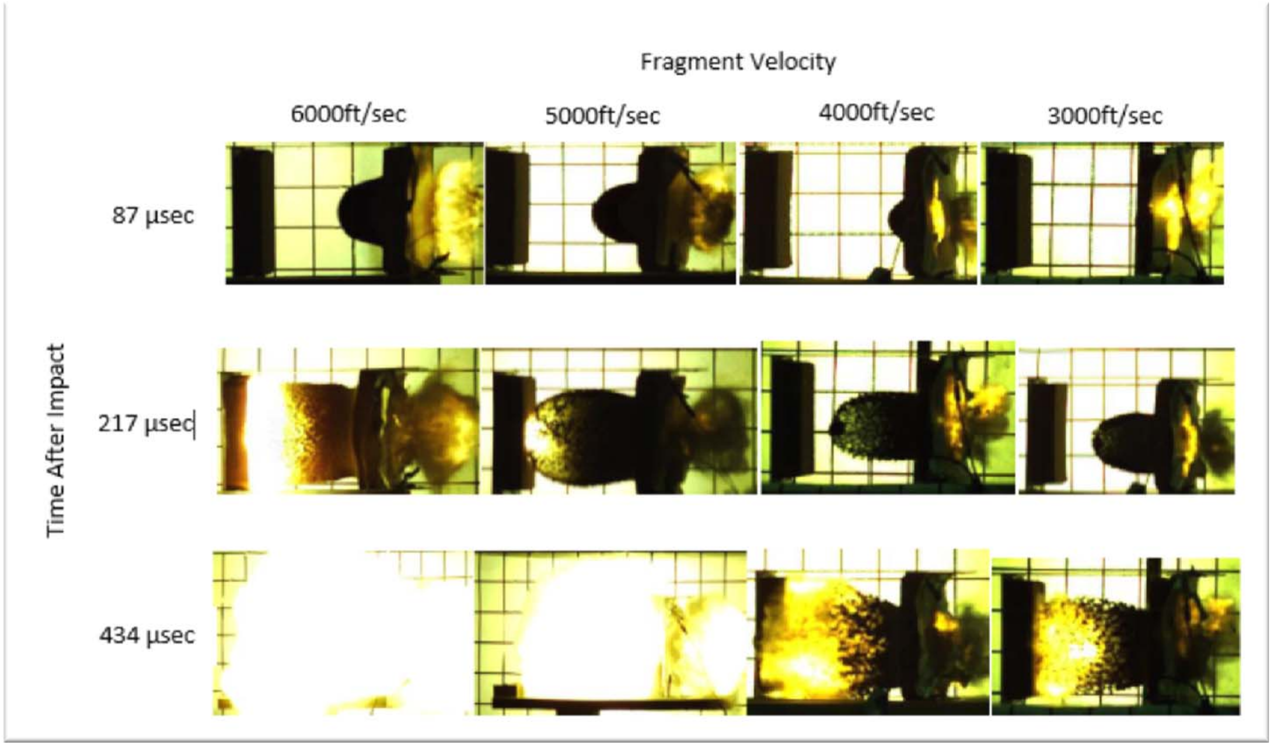
Standard Configuration

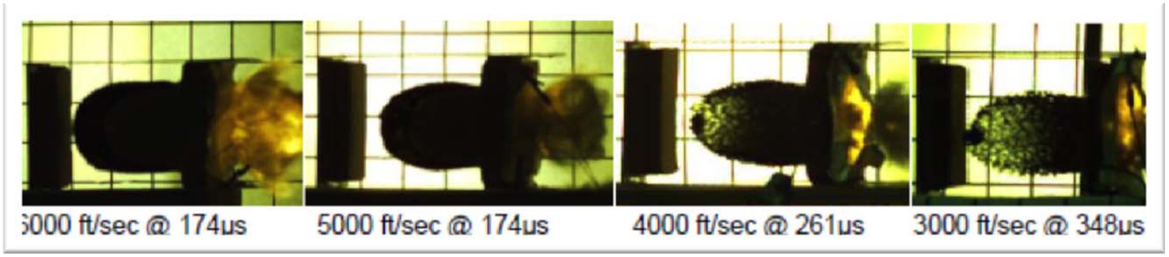
ABVR TESTING SEVEN SERIES



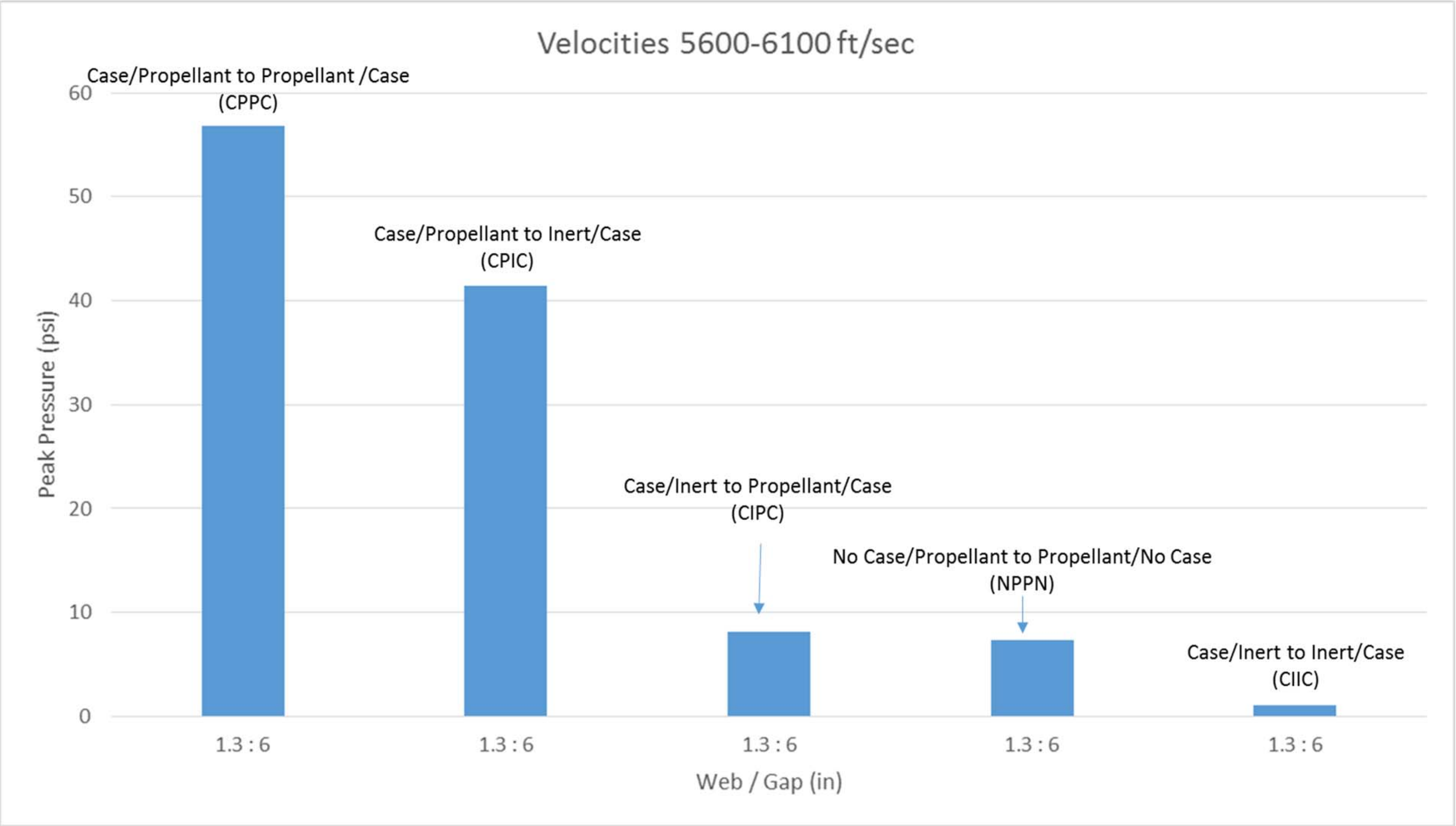


ABVR Results





ABVR Results



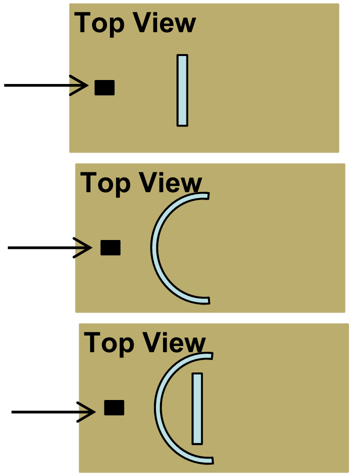
ABVR Tests
Preparations for Analog T&E

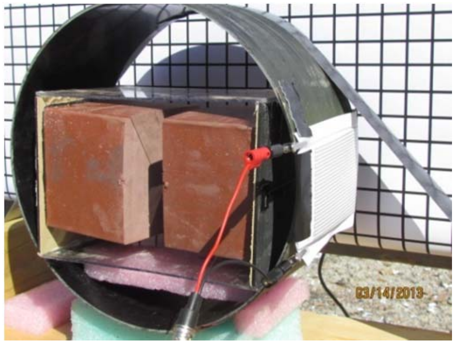
•**Test articles represent the dimensions and materials used for T&E Demonstration.**

-4 ABVR Tests
- **Composite panels**
- **3.65" thick HPP propellant slabs**
- **1.5" Air Gap**
- **Fragment Impact Velocity (4000 to 6000ft/sec)**

-4 Inert Impact Tests
- **Composite Panel (Bare)**
- **Composite Panel with Insulation**
- **Canister and Composite Panel (Bare) Canister**
- **Fragment Impact Velocity 6000ft/sec**

•**Supply data to modelers for T&E demonstration predictions**

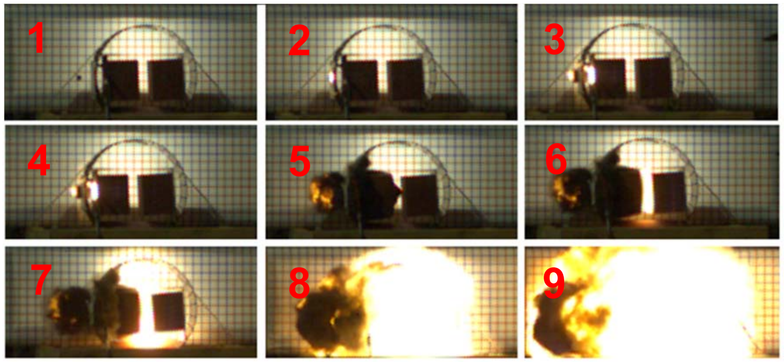




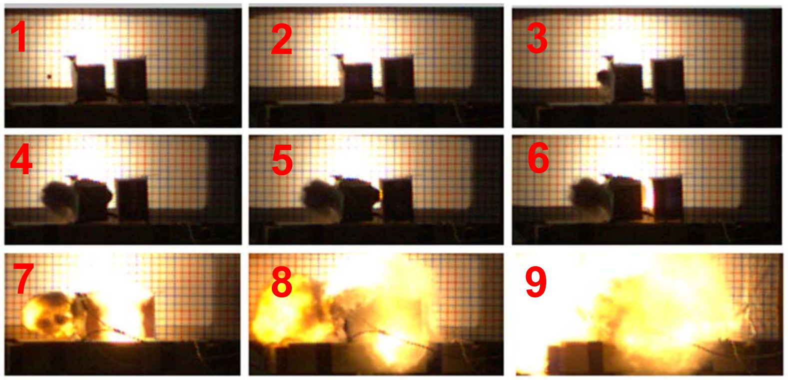
ABVR Tests
Preparations for Analog T&E

- **Reduction in velocity due to canister, case, and insulation material was significantly more than anticipated (see chart, 5-15% reduction).**
- **Increasing impact velocity increased pressure reading; with the exception of the added canister**

Test Number	Canister	Composite Panel	Insulation	Test Article	Initial Impact Velocity, ft/sec	Velocity Reduction, %	Reaction Type	Peak Pressure, psi
1	X				6211	7	None	N/A
2		X			6374	5	None	N/A
3		X	X		6250	8	None	N/A
4	X	X			6179	15	None	N/A
5	X			X	6237	N/A	Burn	11
6				X	6217	N/A	Burn	26
7				X	5177	N/A	Burn	15
8				X	3993	N/A	Burn	4.5

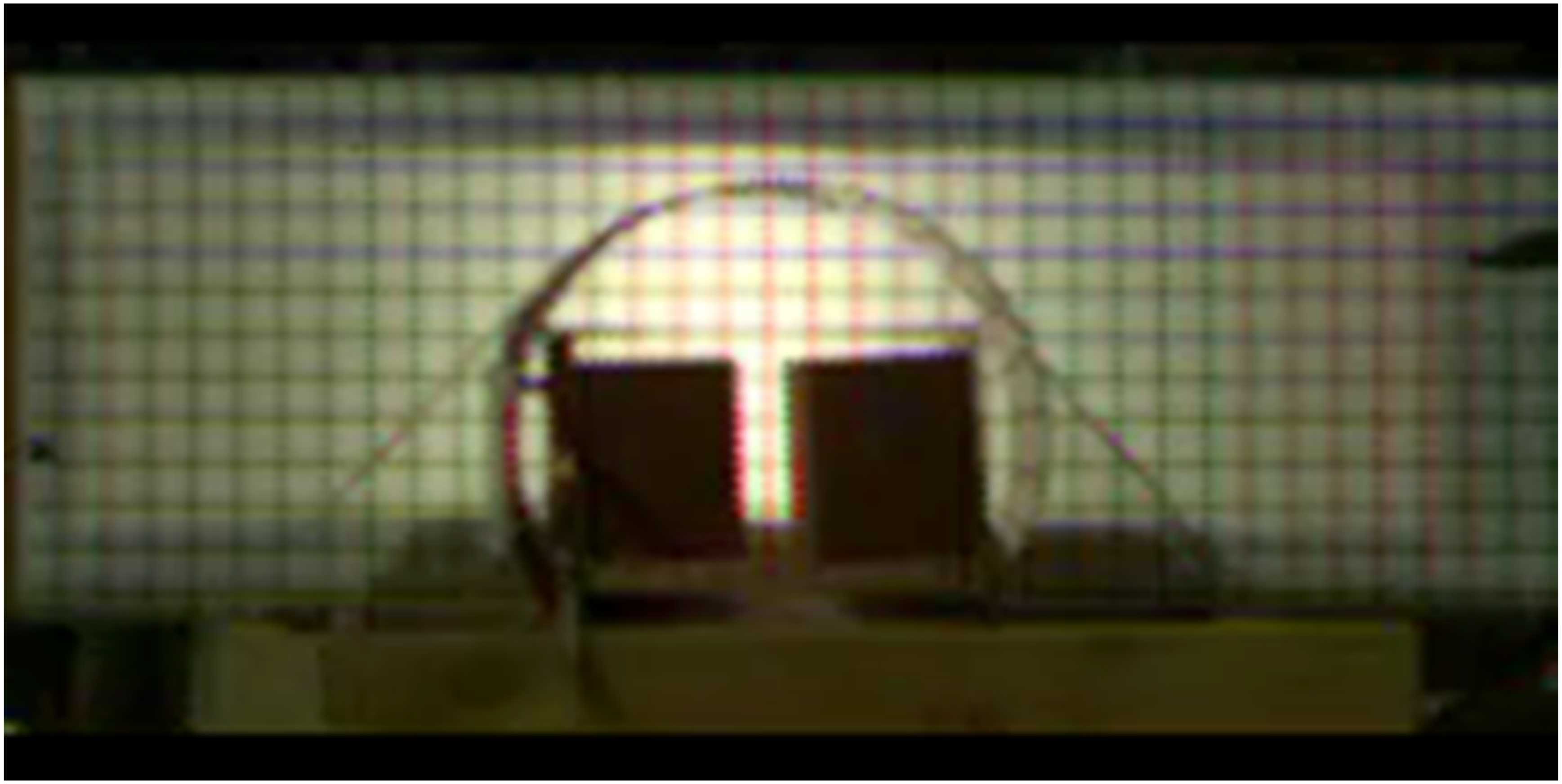


Test 5



Test 6

ABVR Video

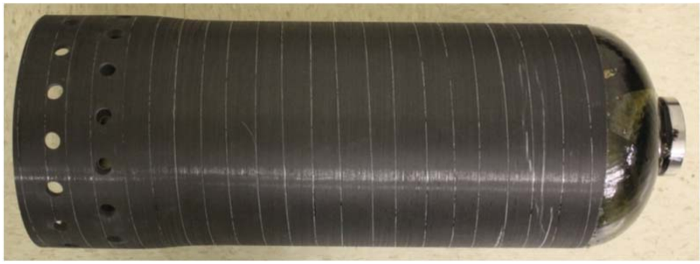


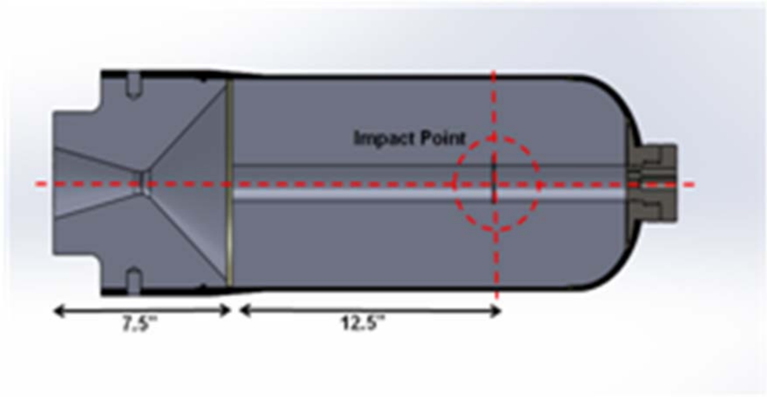
M & S Methods

- ALE3D multi-physics code with the PERMS reaction/burn model
  - Arbitrary Lagrangian Eulerian Three Dimensional (ALE3D) code
  - Propellant Energetic Response to Mechanical Stimuli (PERMS) material model with Equivalent Plastic Strain (EPS)-enhanced burning parameters to explore reactivity
  - Used ABVR test results to calibrate the models for Demo tests
  - Performed sensitivity studies on model parameters due to uncertainties in the HPP fragmentation response and its central role in capturing reaction violence
- CTH shock hydro-code with two propellant models
  - Initial model was Coupled Damage and Reaction with Kinetics (CDAR-K) but was not well suited to HPP material
  - Propellant Model (PMOD) was used effectively starting in 2012
  - PMOD parameters calibrated from ABVR results for Demo tests
- Material models for reactive & inert constituents were used extensively in both codes
  - ABVR-related experiments helped team to better understand physics

IM Analog Demo Rocket Motor Test Plan

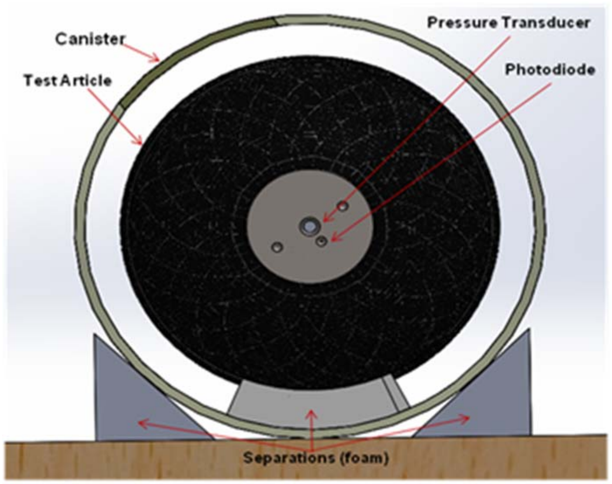
Test Number	Planned Impact Velocity, ft/sec	Bore Dimension, in	Configuration	Test Description
1	8300	2	No Canister	Baseline
2	8300	4	No Canister	Bore Variation
3	8300	2	Canister	Canister Influence

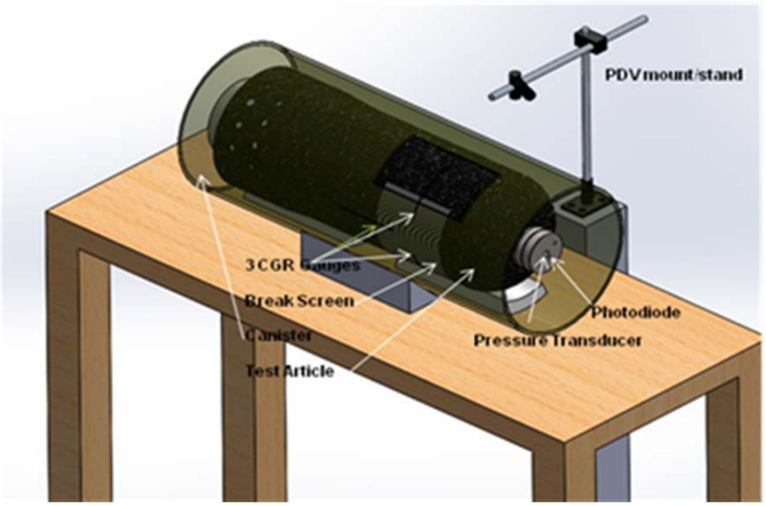




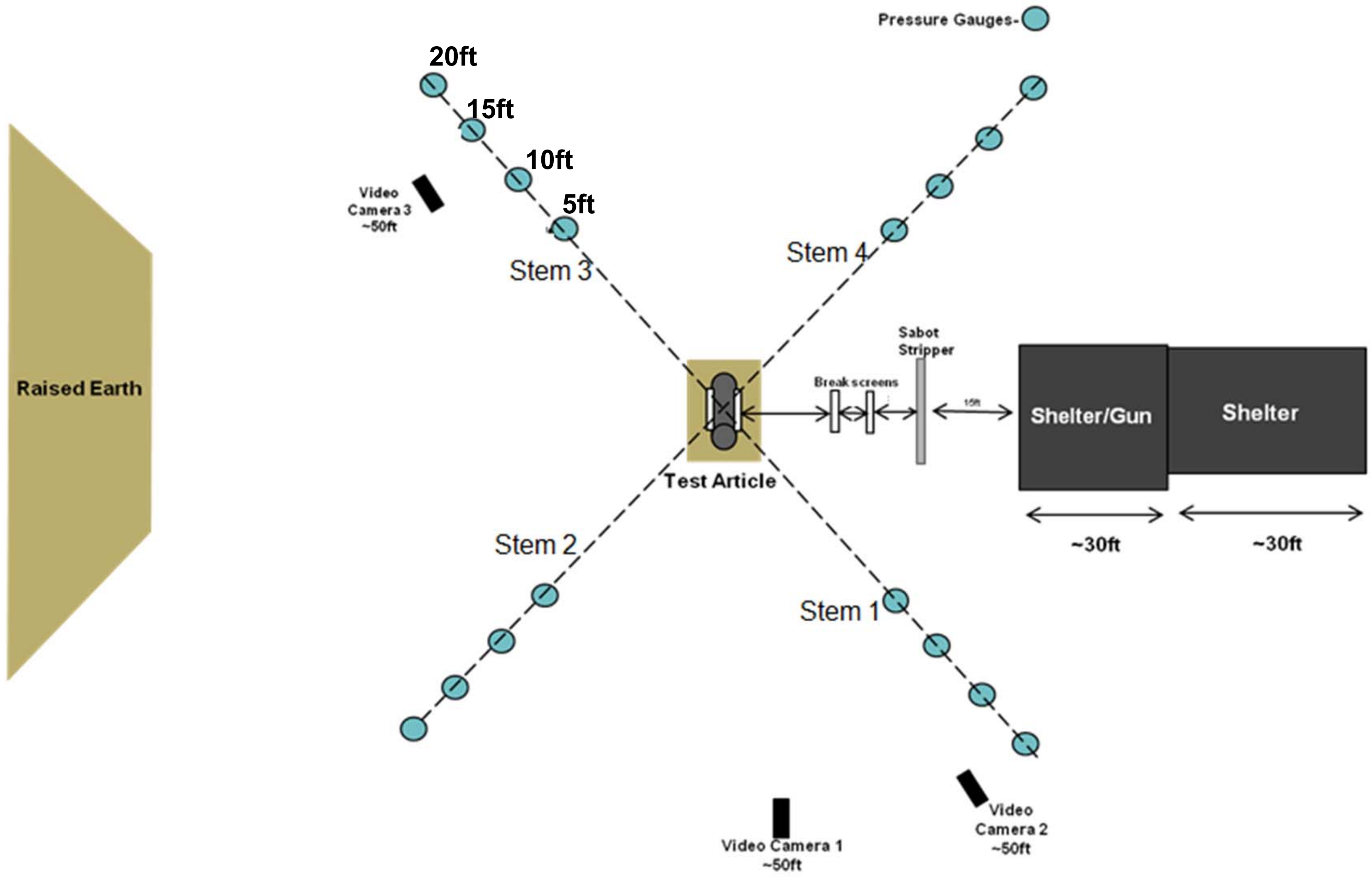
IM Analog Demo Rocket Motor Test Diagnostics

- **In-Bore Pressure Transducer**
- **Open Air Over-Pressure (OP) Gauges**
- **Breakscreens (6) near and on Test Article**
  - **Measure Fragment Velocity, V_o**
  - **Time, T_o, for Fragment Impact on Test Article**
  - **Time, T_f, for (potential) Fragment Exit**
- **Standard Video (3 views)**
- **High Speed Video (3 views)**
- **Still Photography**
- **Photodiode**
- **Photonic Doppler Velocimetry (PDV)**





HPP IM T&E Demonstration Test Setup



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IM Analog Motor Demo Video

IM Analog Demo Rocket Motor Test Data

Test	Velocity (ft/s)	Max.@5ft OP, (psi)	In-Bore Pressure, psi	Reaction Type
1	7989	12	>10K	IV
2	8399	20	>10K	IV
3	8279	11	8400	IV

Test Number	Description	Distance, ft	Location, degree
1	Aft End of Motor	22	220
1	Dome and Case Material	35	60
1	Propellant and Case Material	95	50
1	Firebrand	249	225
1	Forward Closure	300	20
2	Aft End of Motor	33	170
2	Firebrand	230	215
2	Case Material	2	225
3	Motor and Canister (minus Forward End Cap)	N/A	N/A

Test Data to Post-test M & S Results Comparison

	Case Velocity (PDV 90º probe) (ft/s)	Photodiode (time to 1st light) (µsec)	Max. OP, Stem 4 (psi)	In-bore pressure (psi)	Penetration through Test Article
Test 1					
Test data	43	No Data	12 at 5ft 5 at 10ft	>10K	No
CTH	140	N/A	16 at 5ft	40K	No
ALE3D	590	110	N/A	25K	No
Test 2					
Test data	No Data	No Data	20 at 5ft 9 at 10ft	>10K	Unknown
CTH	100	N/A	32 at 5ft	13.5K	Yes
ALE3D	295	102	N/A	13.6K	Yes
Test 3					
Test data	7.5	213	11 at 5ft 5 at 10ft	8400	Unknown
CTH	75	260	N/A	6700	No
ALE3D	280	165	N/A	6000	No

Conclusions

- ABVR tests provided useful velocity, pressure, and visual data to make pre-test prediction simulations for the analog demonstration rocket motor IM tests

- ABVR tests provided velocity reduction information
  - Canister reduced fragment speed by approx. 7% (from ABVR)
  - Composite with insulation reduced fragment speed by approx. 8% (from ABVR)

- Pre-test predictive simulations of the analog demonstration rocket motor tests suggested bore size would influence the violence of the reaction
  - Bore size did influence violence of the reaction
  - As anticipated, data confirmed a more violent reaction for the larger bore diameter

- Pre-test prediction modeling was important to the analog demo RM design and the test matrix

Conclusions Continued

- Canister appeared to mitigate the reaction of the motor to fragment impact
- Placement of over pressure gauges closer to target was important to provide meaningful data as suggested by simulations
- 10K in-bore pressure gauge was not rated high enough for actual pressures
- Placement and type of break screens is critical to accurate time and velocity measurements
- Refined post-test ALE3D and CTH model simulations provided values that were improvements compared to the original predictions
  - Gaps in the test data and needed improvements in the M&S technology
  - Further experimental work and modeling enhancements are needed to continue to evolve predictive capabilities

Acknowledgments

- **Lawrence Livermore –H. Keo Springer, Lara Leininger, and Tony Whitworth**
- **Los Alamos -Thomas Mason and Paul Butler**
- **Sandia - Eric Harstad, Ken Chavez, and Michael Kaneshige**
- **AMRDEC Energetic function- Britteny Hamilton, Larry Pledger, Wayne Steelman and Glenn Hamer**
- **AMRDEC Aerospace Materials function-Cheryl Steele and Robert Esslinger**
- **AMRDEC Missile Sustainment- Justin Grissim**
- **AMRDEC Propulsion Technology- Joey Reed, Bill Delaney and Brian Curtis**
- **RTC- Jerry Webb and Justin Merritt**
- **Project guidance, support, and funding- Jose Gonzalez, William Ruppert, Stuart Blashill, Jamie Neidert, and Steve Collignon**